ENG.20080221.0008

BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA: QA

2. Page 1

3. System	4. Document Identifier
Monitored Geologic Repository	060-PSA-CR00-00100-000-00A

5. Title

Canister Receipt and Closure Facility Event Sequence Development Analysis

6. Group

Preclosure Safety Analyses

7. Document Status Designation

☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments

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9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial Issue	314	G-89	Jeffrey Marr [signature] 02/21/2008	Geoffrey Kaiser [signature] for G. Kaiser 2/21/08	Michael Frank [signature] 2/21/08	Mark Wisenburg [signature] 2/21/08

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ACRONYMS AND ABBREVIATIONS

Acronyms

BSC	Bechtel SAIC Company, LLC
CFR	Code of Federal Regulations
CRCF	Canister Receipt and Closure Facility
CTM	canister transfer machine
CTT	cask transfer trolley
DOE	U.S. Department of Energy
DPC	dual-purpose canister
DSTD	DOE standardized canister
ESD	event sequence diagram
GROA	geologic repository operations area
HAZOP	hazard and operability
HEPA	high-efficiency particulate air
HLW	high-level radioactive waste
HVAC	heating, ventilation, and air conditioning
MAP	mobile access platform
MCO	multicanister overpack
MLD	master logic diagram
PCSA	preclosure safety analysis
PFD	process flow diagram
PRA	probabilistic risk assessment
RHS	remote handling system
SNF	spent nuclear fuel
SPM	site prime mover
SSC	structure, system, or component
SSCs	structures, systems, and components
TAD	transportation, aging, and disposal
TEV	transport and emplacement vehicle
TTC	a transportation cask that is upended using a tilt frame
TWF	typical waste handling facility

ACRONYMS AND ABBREVIATIONS (Continued)

WHF	Wet Handling Facility
WPTT	waste package transfer trolley
YMP	Yucca Mountain Project

Abbreviations

ft	feet
in.	inch

1. PURPOSE

This document, along with its companion document entitled *Canister Receipt and Closure 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 (Code of Federal Regulations) Part 63 (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 (Ref. 2.3.2) and 10 CFR 63.112 (Ref. 2.3.2), and to be responsive to the acceptance criteria articulated in the *Yucca Mountain Review Plan* (Ref. 2.2.88). The PCSA, however, limits the use of PRA technology to identification and development of event sequences that might lead to direct exposure of workers or onsite members of the public, radiological releases that may affect the public or workers (onsite and offsite), and criticality.

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

“Event sequence” is defined in 10 CFR 63.2 :(Ref. 2.3.2) as follows:

> Event sequence means a series of actions and/or occurrences within the natural and engineered components of a geologic repository operations area that could potentially lead to exposure of individuals to radiation. An event sequence includes one or more initiating events and associated combinations of repository system component failures, including those produced by the action or inaction of operating personnel.
>
> Those event sequences that are expected to occur one or more times before permanent closure of the GROA 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 is 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 (Ref. 2.3.1), 71 (Ref. 2.3.3) and 72 (Ref. 2.3.4)) and associated quality assurance (QA) programs. As a result of compliance to such regulations, the SSCs are deemed to pose no undue risk to health and safety. Although the analyses do not address quantitative probabilities, it is clear that very conservative design criteria and QA result in unlikely exposures to radiation.

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

Other boundary conditions used in the PCSA include:

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

- No other simultaneous initiating events. It is standard 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 span is small and, (b) each initiating event will cause 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 SSC corresponds to that required to make the initiating or pivotal event occur.

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

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

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

This analysis includes: a process flow diagram (PFD), a master logic diagram (MLD), a hazard and operability (HAZOP) evaluation, event sequence diagrams (ESDs), and event trees. Initiating events considered in this analysis include internal events (i.e., events that are initiated within the CRCF) as well as external events (i.e., events that are initiated from outside the CRCF). 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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2.3 DESIGN CONSTRAINTS

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2.4 DESIGN OUTPUTS

This calculation is used as input to the following analysis:

2.4.1 BSC 2007. *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis*. 060-PSA-CR00-00200-000-00A. Las Vegas, Nevada: Bechtel SAIC Company.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

None used.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

None used.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This analysis is prepared in accordance with the procedures *Calculations and Analyses* (Ref. 2.1.1) and *Preclosure Safety Analysis Process* (Ref. 2.1.4). Therefore, the approved version is designated as "QA: QA." This analysis addresses the applicable criteria in Section 7 of the *Project Design Criteria Document* (Ref. 2.2.71)

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

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

- *CRCF & IHF WP Shield Ring Lift Beam Mechanical Equipment Envelope* (Ref. 2.2.23)
- *CRCF, RF, WHF & IHF Impact Limiter Lifting Device Mechanical Equipment Envelope* (Ref. 2.2.37)
- *CRCF, RF, WHF & IHF Personnel Barrier Lifting Device Mechanical Equipment Envelope* (Ref. 2.2.38)
- *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.76)
- *CRCF 1 Cask Preparation Platform Mechanical Equipment Envelope Sheet 1 of 2* (Ref. 2.2.24)
- *CRCF 1 Cask Preparation Platform Mechanical Equipment Envelope Sheet 2* (Ref. 2.2.25)
- *CRCF, RF and WHF Mobile Access Platform Mechanical Equipment Envelope Sheet 1 of 2* (Ref. 2.2.35)
- *CRCF, RF and WHF Mobile Access Platform Mechanical Equipment Envelope Sheet 2* (Ref. 2.2.36)
- *Nuclear Facilities Rail Cask Lid Adapter Mechanical Equipment Envelope* (Ref. 2.2.69)
- *Nuclear Facilities Truck Cask Lid Adapter Mechanical Equipment Envelope* (Ref. 2.2.70).

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. 2.2.80) and *Component Design Description: Welding and Inspection System* (Ref. 2.2.91). This information is presented to give the reader a basic understanding of the processes involved. The supplier documents cited provide suitable descriptive information on waste package closure equipment that has been designed specifically for repository use.

4.2 USE OF SOFTWARE

Visio Professional 2003 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. 2.2.89 and Ref. 2.2.90), 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:

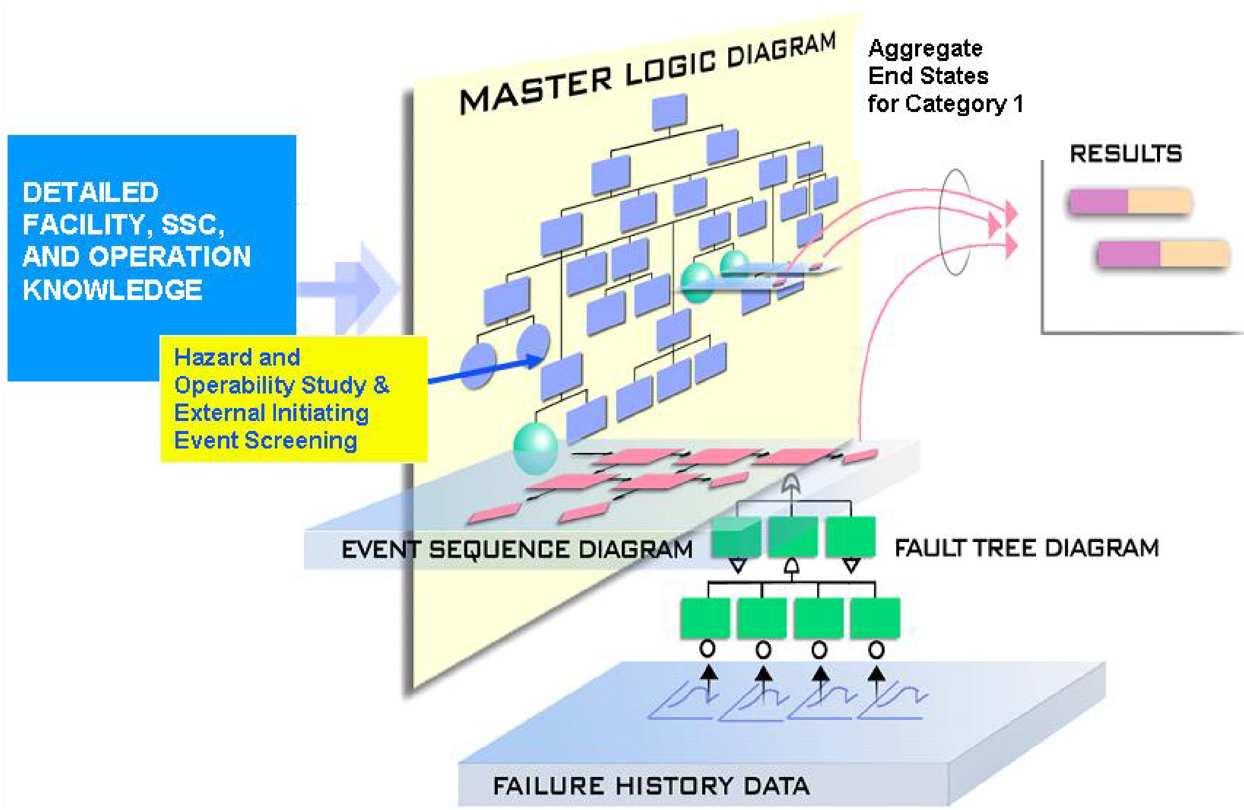
- Microsoft Windows 2000 Professional
- Windows XP
- Windows XP running inside a VMware virtual machine with VMware Player.

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 CRCF. Specific features of the CRCF and its operations are not discussed until Section 6, where the methods described here are applied to the CRCF. The PCSA uses the technology of PRA as described in references such as American Society of Mechanical Engineers *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications* (Ref. 2.2.3). The PRA answers three questions:

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

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



Source: Modified from (Ref. 2.2.92)

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

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

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

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

The estimation of event sequence frequencies follows the development of event sequences, and answers the question "How likely is it?" The PCSA uses ***failure history*** records (for example, *Nonelectronic Parts Reliability Data* (Ref. 2.2.82) and *Nuclear Computerized Library for Assessing Reactor Reliability* (Ref. 2.2.83)), structural reliability analysis, thermal stress analysis, and engineering and scientific knowledge about the design as the basis for estimation of probabilities and frequencies. These sources coupled with the techniques of probability and statistics, for example, *Handbook of Parameter Estimation for Probabilistic Risk Assessment*. NUREG/CR-6823 (Ref. 2.2.4) are used to estimate frequencies of initiating events and event sequences, and the conditional probabilities of pivotal events.

Pivotal events are characterized by *conditional probabilities* because their values rely on the conditions set by previous events in an event sequence. For example, the failure of electrical/electronic equipment depends on the temperature at which it operates. Therefore, if a previous event in a scenario is a failure of a cooling system, then the probability of the electronic equipment failure would depend on the operation or not of the cooling system. The frequency of occurrence of an event sequence is the product of the frequency of its initiating event and conditional probabilities of pivotal events. The 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.

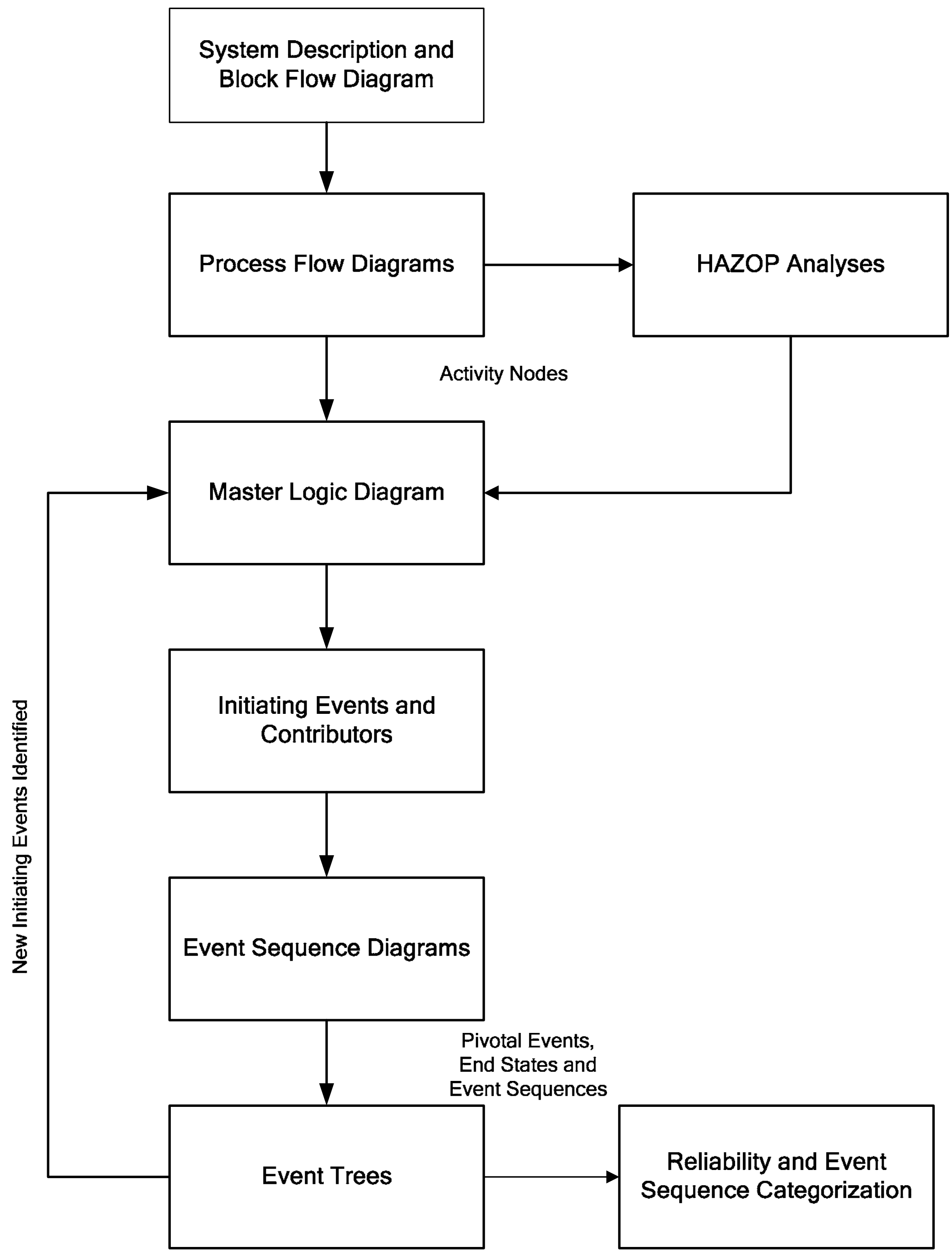
As required by the performance objectives for the geologic repository operations area through permanent closure in 10 CFR 63.111 (Ref. 2.3.2), each event sequence is categorized based on its frequency. Therefore, the focus of this analysis is to:

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

4.3.1 Initiating Event Development

The identification of initiating events is accomplished through a series of logically related activities that begin 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 a MLD. The MLD as a tool for initiating event development is

[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).

described in the *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants* (Ref. 2.2.87), Section 3.4.2.2.

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

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

- *Fires in or at Industrial Chemical, Hazardous Chemical and Plastic Manufacturing Facilities, 1988-1997 Unallocated Annual Averages and Narratives*. (Ref. 2.2.1)
- *Probabilistic Risk Assessment (PRA) of Bolted Storage Casks, Updated Quantification and Analysis Report* (Ref. 2.2.78).
- *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants*. (Ref. 2.2.79)
- *Canister Storage Building Design Basis Accident Analysis Documentation*. (Ref. 2.2.81)
- *Safety Analysis Report, Idaho Spent Fuel Facility*. (Ref. 2.2.84)
- *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002.* (Ref. 2.2.85)
- *Control of Heavy Loads at Nuclear Power Plants.* (Ref. 2.2.86).

The MLD is cross-checked to the HAZOP evaluation, which is performed on the facility processes and operations, and based on nodes, that is, specifically defined portions of the handling operation, established in the PFD. Although the repository is in some ways to be the first of its kind, the operations are based on established technologies: transportation cask movement by truck and rail, crane transfers of casks and canisters, rail-based trolleys, air-based conveyances, robotic welding, pool operations, etc. The team assembled for the HAZOP evaluation (and available on call when questions came up) has experience with such technologies and is well equipped to perform a HAZOP evaluation. As has already been noted, the MLD is modified to include any initiators and contributors that are identified in the HAZOP evaluation, 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 listing of risk-dominant initiating events.

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

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

4.3.1.1 Process Flow Diagram

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

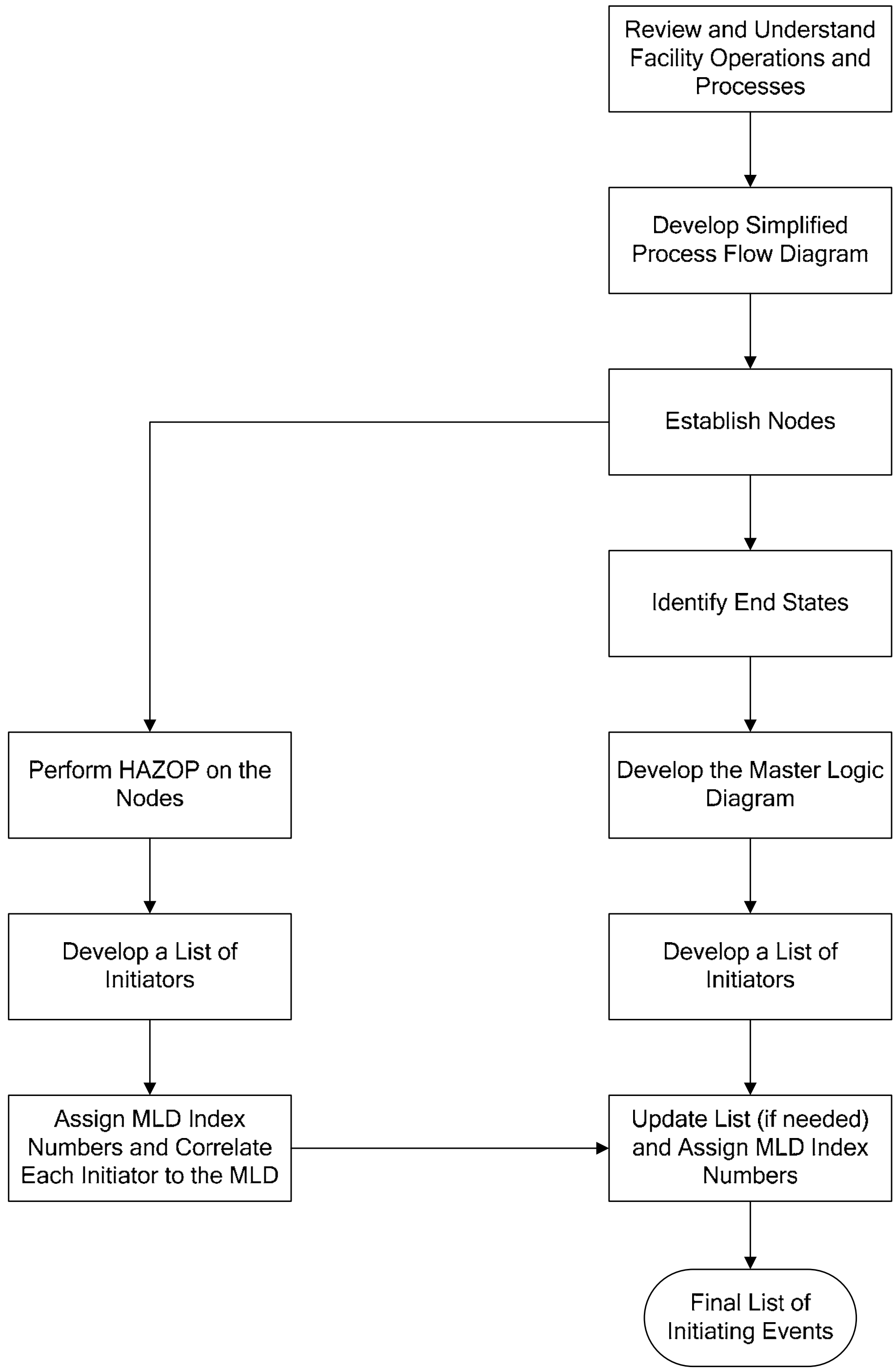


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Figure 3. Initiating Event Identification

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*. NUREG/CR-2300 (Ref. 2.2.87), 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 a MLD, the initiating events are shown at the next-to-lowest level. The lowest level provides contributors to the initiating event.

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

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

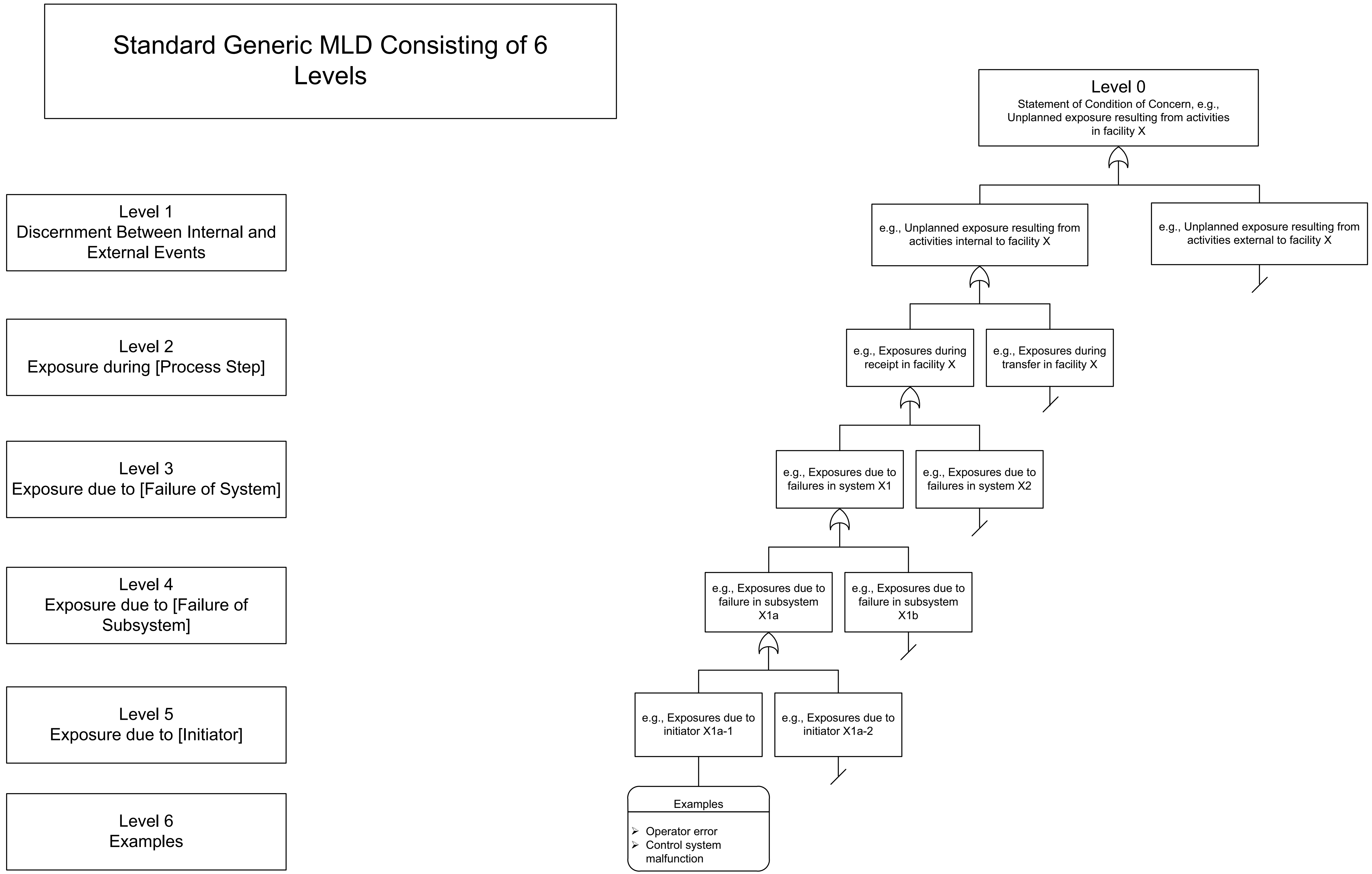
- Level 0: The entry point into the MLD is an expression of the undesired condition for a given facility. Level 0 is the top event of the MLD. In the MLD framework shown in Figure 4, the top event is expressed as "Unplanned exposure of individuals to radiation or radioactive materials due to operations in the facility." This top event includes direct exposure to radiation sources, or exposure as a 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) failures for the operational areas identified in Level 2.

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



Source: Original

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

The HAZOP evaluation process focuses on identifying potential initiators that are depicted in the lower levels of the MLD. Initiating events are assigned a specific MLD index number (e.g., TWF-202) in the HAZOP evaluation table. The MLD index number correlates the initiator associated with the HAZOP evaluation with a corresponding initiator on the MLD. This correlation is illustrated in Section 4.3.4.2, Figure 9 and Table 6.

As discussed in Section 4.3.1, the HAZOP evaluation is conducted to supplement the MLD results. The HAZOP evaluation is a "bottom-up" analysis used to supplement the "top-down" approach of the MLD (Ref. 2.2.2 103763). 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 Cask 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 (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 evaluation process ensures that potential hazards are considered in the evaluation through a formalized application of "guidewords" that represent a set of potential deviations from normal (i.e., intended) operations. The HAZOP evaluation is performed by a multidisciplinary team that is well-versed in the design, operations, safety and reliability issues, as well as human factors and human reliability. An experienced team leader leads, stimulates, and focuses the analysis to ensure that the HAZOP evaluation is conducted efficiently and productively.

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

This PCSA follows the HAZOP evaluation 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. 2.2.88, Section 2.1.1.3.5), lists the American Institute of Chemical Engineers guidelines as a principal reference for performing a HAZOP evaluation. Consistent with the MLD, this HAZOP evaluation is focused on potential radiological hazards for the preclosure period that could lead to event sequences.

Table 2. Common Hazard and Operability Evaluation 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 evaluation team. Steps may be manual, automatic, or software-implemented actions. The deviations applied to each process step are different than deviations that may be defined for a continuous process.
INTENTION	Defines how the plant or process node is expected to operate in the absence of deviations at the study nodes. This can take a number of forms and can either be descriptive or diagrammatic (e.g., flow sheets, line diagrams, piping and instrumentation diagrams).
GUIDEWORDS	Simple words that are used to qualify or describe the intention in order to guide and stimulate the brainstorming process and so discover deviations. The guidewords shown in Table 1 are the ones most often used in a HAZOP evaluation. However, the list may be made more application-specific to guide the team more quickly to the areas where prior operations or experience have identified problems. Each guideword is applied to the process variables at the point in the plant (study node) which is being examined.
PROCESS PARAMETER	Physical or chemical property associated with the process. This includes general terms like mixing, concentration and specific items such as temperature, pressure, flow, and phase for processes, or general terms like lift, relocate, and specific terms like lift height and speed of movement for handling of containers.
DEVIATIONS	Departures from the intention that are discovered by systematically applying the guidewords to process parameters (e.g., "more pressure," “too high lift height”). This provides a list of potential deviations for the team to consider for each node. Teams may supplement the list of deviations with ad hoc items.
CAUSES	Reasons why deviations might occur. Once a deviation has been shown to have a credible cause, it can be treated as a meaningful deviation. These causes can be hardware failures, human failure events, an unanticipated process state (e.g., change of composition, or introduction of an over-weight or over-sized container into the handling facility), external disruptions (e.g., loss of power), etc.
CONSEQUENCES	Results of the deviations should they occur (e.g., release of radioactive or toxic materials, exposure to radiation). Normally, the team assumes that active protection systems or safeguards fail to work. Consequences that are unrelated to the study objective are not considered. Minor consequences, relative to the study objective, are dropped.
SAFEGUARDS	Engineering or administrative controls that are used to prevent the causes or mitigate the consequences of deviations (e.g., alarms, interlocks, procedures). Safeguards are not credited when defining consequences of a deviation, but are addressed in evaluating the need for actions or recommendations.
ACTIONS (or Recommendations, Comments)	Suggestions for design or procedural changes (i.e., to provide new or additional safeguards) or areas for further study (e.g., analyses of reliability of active or passive systems credited as safeguards, human reliability analysis, or radiological consequence analyses).

NOTE: HAZOP = hazard and operability.

Source: Modified from (Ref. 2.2.2, Table 6.1.3)

The HAZOP evaluation applies seven guidewords that, in principal, cover possible deviations that can occur in a given node of a given process. Table 1 lists the seven guidewords that are crafted to ensure that potential deviations are addressed in a systematic process. In practice, the application of the guidewords requires knowledge and imagination of the HAZOP evaluation team to ensure that the 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 evaluation team may note and record the design or operational procedure that may be used to prevent or mitigate the consequences of an event. This information may be used, if needed, later in the event sequence analysis.

Table 3. Examples of Deviations for a Chemical Process

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

Source: (Ref. 2.2.2, p. 132)

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

After the HAZOP evaluation 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 are added to the MLD to encompass all deviations not previously included in the MLD. To protect the independence of the HAZOP evaluation, initiating events appearing in the MLD that were not identified as part of the HAZOP evaluation, are not included in the HAZOP evaluation worksheets.

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 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 *Canister Receipt and Closure 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 *Canister Receipt and Closure 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 *Canister Receipt and Closure 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. 2.2.87), Section 3.4.3.2. To construct an ESD, the analyst, begins with the initiating events that were identified by the MLD and HAZOP evaluation and then, in effect, answers the question “What can happen next?” until an end state is reached. ESDs are designed to logically depict the progression of event sequences from the initiating event up to and including the end state. ESDs identify the key safety functions necessary to reach an end state after the initiating event, as well as the associated structure, system, or component responses. Although operator actions are not shown explicitly on the ESDs in this analysis, human failure events are implicit in some of the initiating events and pivotal events. An ESD is structured as a decision tree in which pivotal events are queried with two possible results: a yes/success (desired) outcome and a no/failure (undesired) outcome. The structure allows for a straightforward transposition of ESDs into event trees. In this PCSA, ESDs and the associated event trees consider human, mechanical, electrical, electronic, controller, structural, thermal and naturally occurring events. However, as noted in Section 1, event sequences for external events (including seismic events) are not developed in this analysis. External events and any associated event sequences are evaluated and documented separately.

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

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

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

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

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

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

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

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

2. Direct Exposure, Degraded Shielding–Applies to event sequences where an SSC providing shielding is not breached, but 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 dual-purpose canister (DPC) or transportation, aging, and disposal (TAD) canister inside maintaining its containment function. In another example, this end state applies to shield doors inadvertently opened. 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 confinement, through the pool of the WHF or through an unfiltered path, to the environment. Excludes nuclear reactivity increases.

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

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

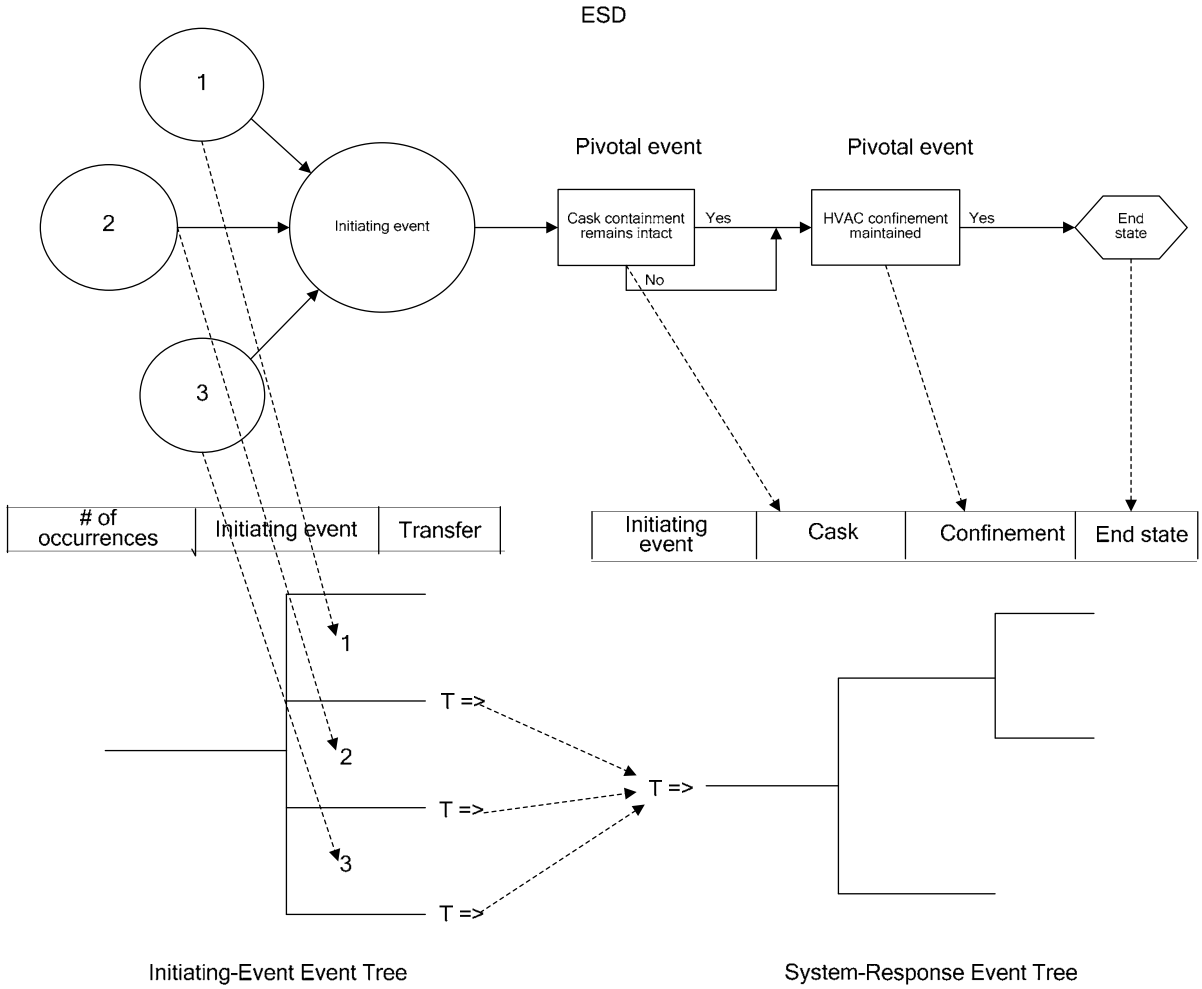
8. Important to Criticality–This end state refers to a situation in which there has been no radionuclide release and (unless the associated event sequence is beyond Category 2) a criticality investigation is indicated.

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

As has already been noted, the criticality parameter of moderation must be included in the event sequence analysis in order to complement the separate deterministic criticality analysis. The reason that the event sequence development includes only moderation is explained in Section 1. Under normal conditions, sealed canisters containing dry waste are received in sealed transportation casks. 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. 2.2.87), Section 3.4.4.2. As shown in Figure 5, an event tree is a logic diagram that delineates the event sequences of an ESD.



Source: Original

Figure 5. Event Sequence Diagram–Event Tree Relationship

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

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

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

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

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

4.3.2.3 Internal Fire and Flooding Event Analysis

Fire and flooding initiating events identified in the MLDs are analyzed in the *Canister Receipt and Closure Facility Reliability and Event Sequence Categorization Analysis* (Ref. 2.4.1).

4.3.3 External Events

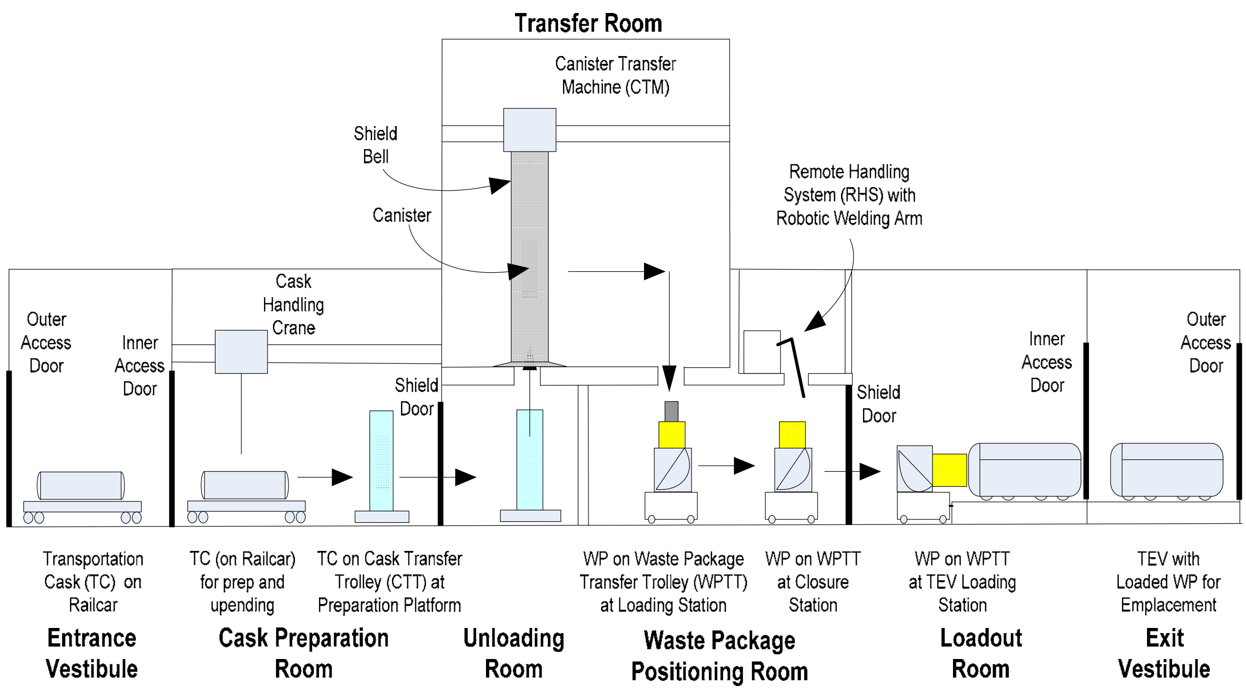
Non-seismic external initiating events are discussed further in the *External Events Hazards Screening Analysis* (Ref. 2.2.5).

4.3.4 Example Facility Analysis

By the use of an examplar, typical facility, this section illustrates the overall event sequence development approach. It is particularly useful for understanding the relationships among the PFD, MLD, HAZOP evaluation, ESDs and event trees. This example portrays a 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 CRCF. CRCF specific features, initiating events, and event sequences are presented beginning in Section 6. This TWF receives, repackages, and exports waste forms for emplacement, employing equipment and processes that are representative of an actual facility. This example describes the facility, shows a generic PFD and a generalized MLD, provides a sample HAZOP evaluation, and describes development of an ESD and event tree for waste transfer activities of the facility using the canister transfer machine (CTM). The analysis presented here focuses on a particular operation: the transfer of a waste form using a CTM. The objective of this example is to demonstrate how event sequences are developed employing the methodologies identified above. A generic description of the TWF operations is provided below.

Typical Waste-Handling Facility Overview

A simplified schematic of the operations of the example facility, TWF, is shown in Figure 6. Note that the example facility is not the same as the CRCF and it has a fictitious mission, design features, and operations that differ from those of the CRCF. 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 Canister 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 Canister 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 Waste Package Loadout Room where it is rotated into horizontal orientation and loaded into a TEV for removal from the facility and emplacement into the repository.

4.3.4.1 Process Flow Diagram Development

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

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

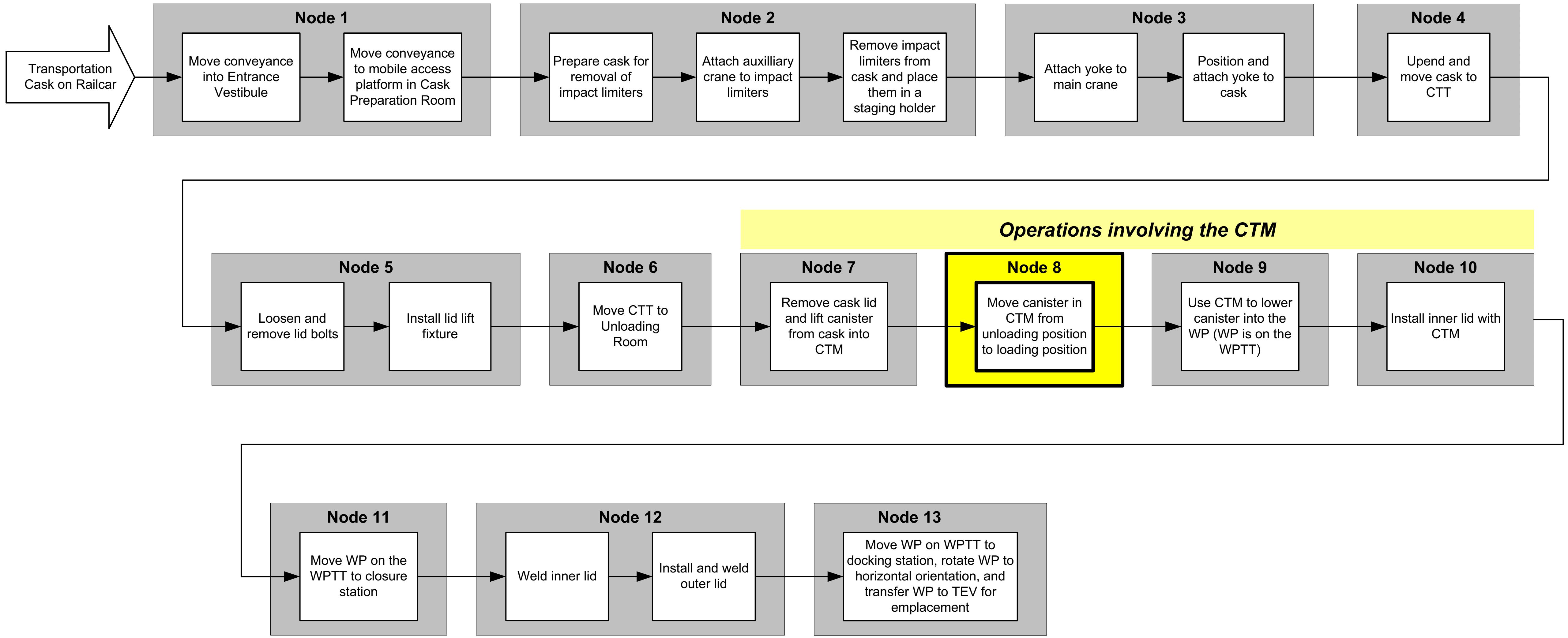
4.3.4.2 Master Logic Diagram Development

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

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 Cask Unloading Room shield door (closed).

Table 4. Process Node Descriptions (Continued)

<table>
<tr><th>Node No.</th><th>Description</th></tr>
<tr><td>3</td><td>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
• Cask Unloading Room shield door (closed).</td></tr>
<tr><td>4</td><td>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
• Cask Unloading Room shield door (closed).</td></tr>
<tr><td>5</td><td>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)
• Cask Unloading Room shield door (closed).</td></tr>
</table>

Table 4. Process Node Descriptions (Continued)

Node No.	Description
6	The Cask 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 Cask 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 Cask Unloading Room is cleared of personnel and the Cask 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 Canister 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, Canister 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 Canister 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 Canister 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 Canister 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 Canister Transfer Room.) Loading operations identified as Node 9 on the PFD are essentially the reverse of the Node 7 unloading operations. The CTM (aligned above the loading port) lowers the shield skirt to close the gap between the bottom of the shield bell and the floor of the Canister Transfer Room. The loading port shield gate is opened, the shield gate on the bottom of the shield bell is opened, and the CTM lowers the canister through the loading port. The canister is lowered into the waste package, and the grapple is released and withdrawn. The CTM then retrieves the waste package inner lid and places it in the waste package (refer to Node 10 description).

Table 4. Process Node Descriptions (Continued)

Node No.	Description
7,9 Cont'd	Equipment involved in Node 7,9 operations: • Cask 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 Canister 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 Canister 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 Canister 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 Canister 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 Canister 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 Waste Package Loadout Room. The Waste Package 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 Waste Package 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.

Table 4. Process Node Descriptions (Continued)

Node No.	Description
13 Cont'd	The waste package is now secured in the TEV, and the TEV exits the facility. With both the Waste Package Positioning Room shield door and the Exit Vestibule outer access door closed, the Exit Vestibule inner access door is opened. The loaded TEV transports the waste package out of the facility to the Exit Vestibule, which is the interface point between the facility and the outside. The Exit Vestibule inner access door is closed, completing the facility's canister transfer operation. The Exit Vestibule outer access door is opened, and the TEV takes the waste package to the repository for emplacement. 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 Cask 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 Cask Unloading Room (i.e., the floor of the Canister 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)

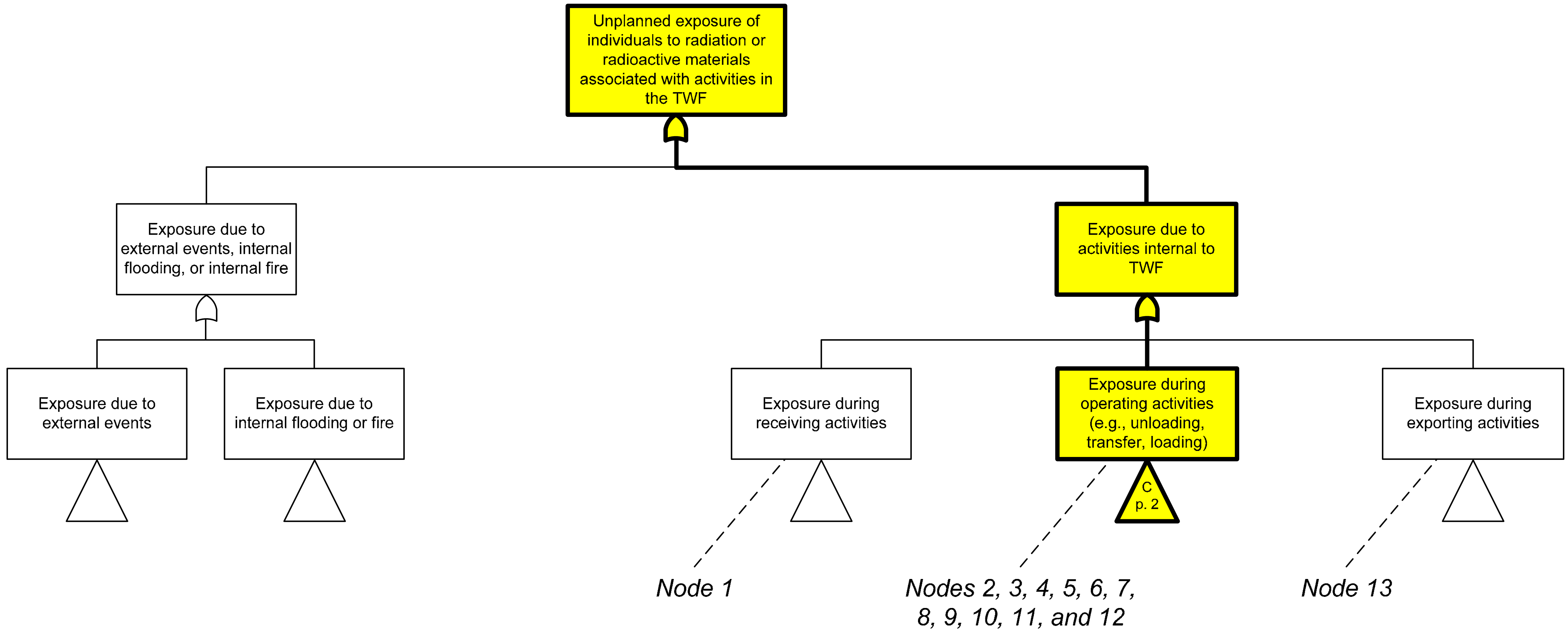
Equipment Type	Description
Cask Transfer Trolley	The CTT is used to transfer transportation casks between the Cask Preparation Room and the Cask Unloading Room. The CTT is a metal frame platform that, when in operation, floats on a thin film of air above the floor surface. The frame and restraining brackets 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. × 15 ft × 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 Canister 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 Canister 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 Canister 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 Canister 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 Canister 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 Canister 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 Waste Package 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 Waste Package 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 Waste Package 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 Waste Package 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 Cask 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.

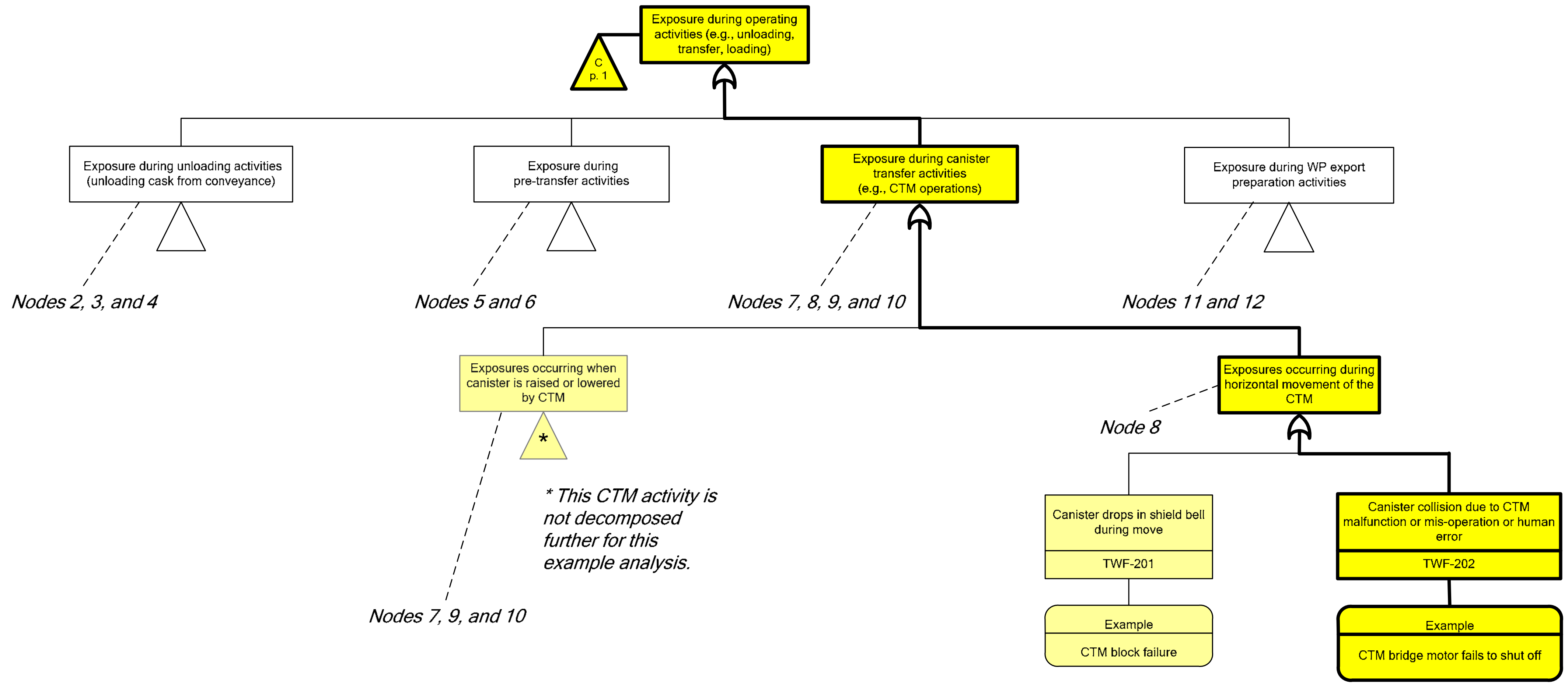
- Nodes 7, 8, 9, and 10 are essentially canister transfer activities relying heavily on the CTM, and are evaluated as such. Events for these activities tend to involve impacting the cask or canister with objects, shearing of the canister, dropping the canister, dropping objects onto the canister, and 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; TWF = typical waste-handling facility; WP = waste package.

Source: Original

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

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

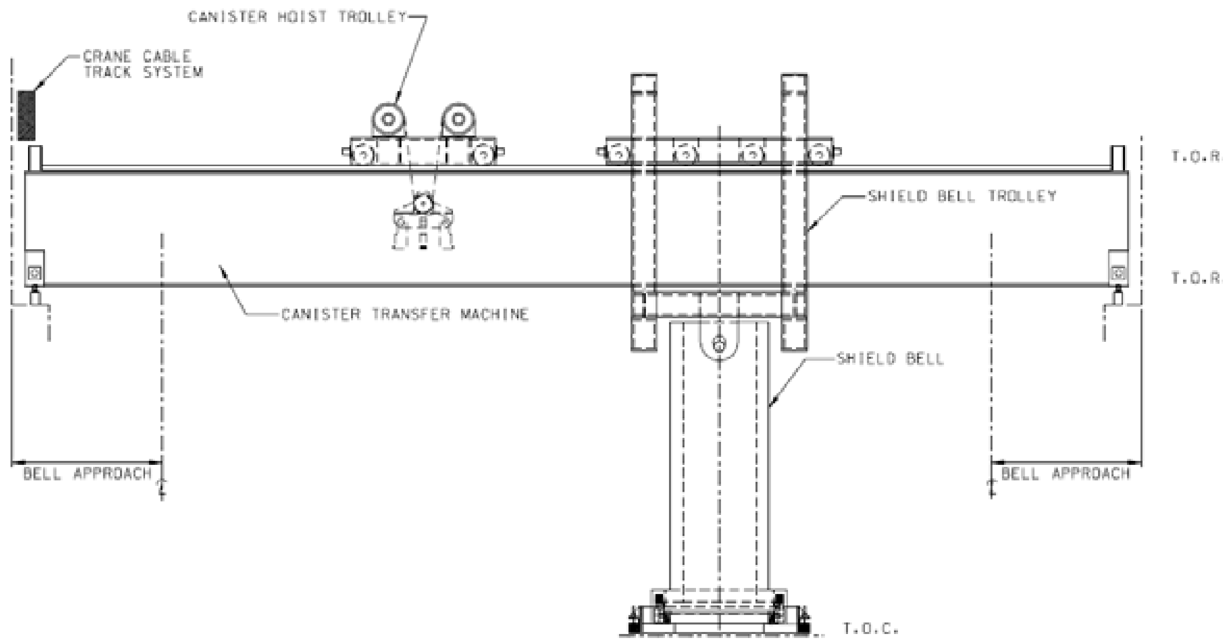
Each set of initiating events and contributors in the MLD is similarly developed and examined. The level at which initiating events are identified is the highest level for which the same system response event tree applies. Lower levels provide failure events associated with the initiating event. The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

4.3.4.3 HAZOP Evaluation Development

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

To demonstrate this process for the example facility, TWF, activities involved in the horizontal movement of the CTM are examined (shown on the MLD as “Exposures occurring during horizontal movement of the CTM” (Figure 9). As discussed previously, horizontal movement of the CTM is identified as Node 8 in the PFD and is evaluated discretely from vertical canister movement. The HAZOP evaluation results for Node 8 appear as contributors in Figure 9. Speed and direction are the primary parameters of concern for horizontal CTM operations. Deviations from normal operational movement (e.g., movement that is too fast, too slow, wrong direction, gets stuck, two-blocking, or grapple malfunction) are considered, and postulated causes (e.g., human or mechanical failure), consequences (e.g., 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: (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 evaluation 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 add additional time while the load is suspended 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 evaluation also presents several deviations that are specific to the CTM and for which no standard HAZOP evaluation guidewords exist. One example of a “Miscellaneous” parameter/deviation is “two-blocking” (Node Item Number 8.11).

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

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

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

Source: Original

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

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

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

MLD Index #	Contributor/ Deviation	Event Cause	Consequence	Originally Included in MLD	Added to MLD from HAZOP Evaluation
TWF-201	Two-blocking of crane	Human or mechanical failure	Potential canister drop leading to 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
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

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

MLD Index #	Contributor/ Deviation	Event Cause	Consequence	Originally Included in MLD	Added to MLD from HAZOP Evaluation
TWF-202	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

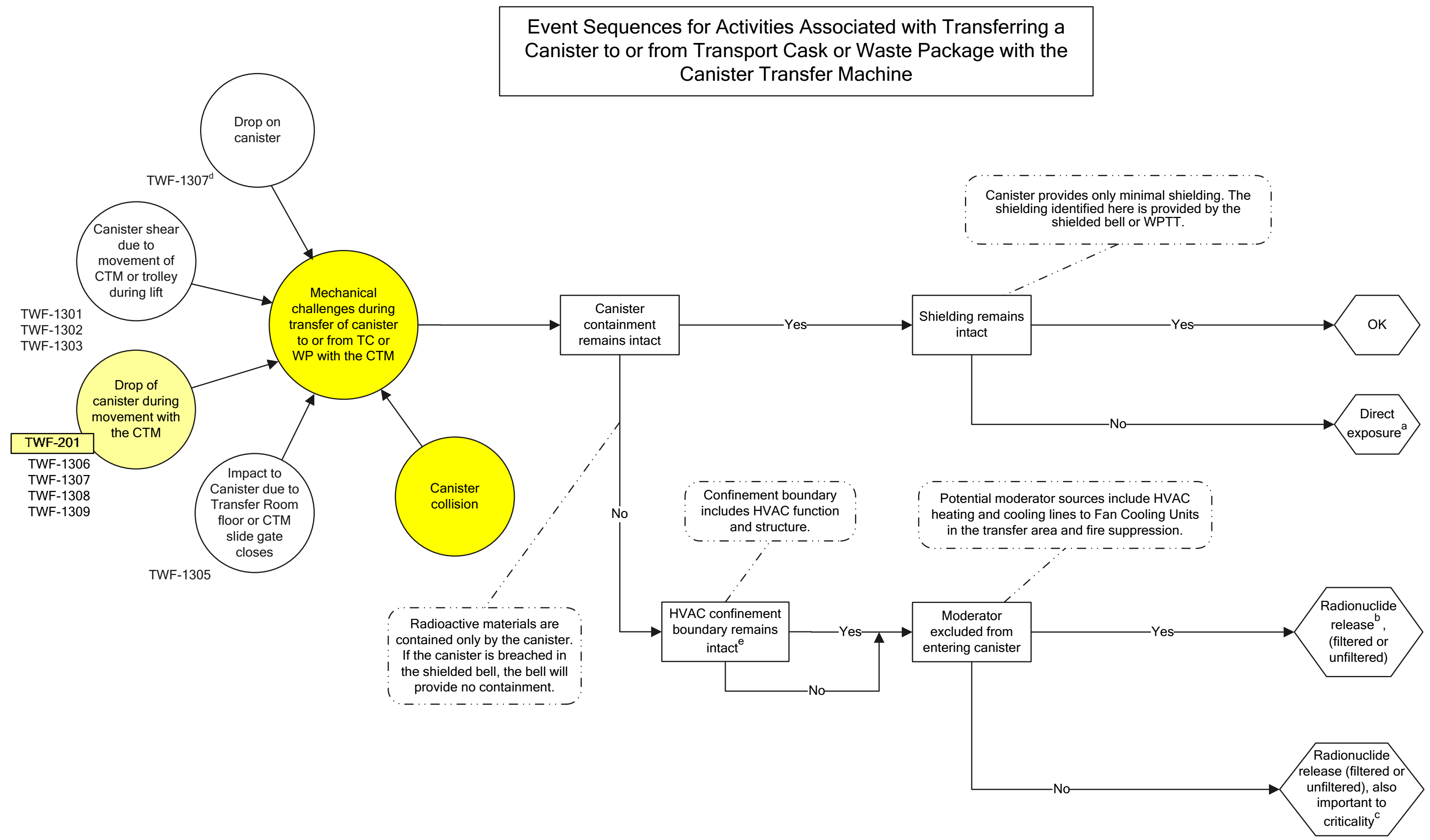
NOTE: CTM = canister transfer machine; HAZOP = hazard and operability; MLD = master logic diagram; N = no; TWF = typical waste-handling facility; Y = yes.

Source: Original

4.3.4.4 Event Sequence Diagram Development

After the HAZOP evaluation and MLD results are correlated and the MLD is developed, 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 ESD. Based on this grouping ESD development can begin.

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



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

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

"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.

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

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

[d] Potential for fire analyzed in fire ESDs.

[e] Canister striking structures results in a drop.

For sequence involving two containers, failure path of pivot event "one canister breached" represents the breach of two canisters.

CTM = canister transfer machine; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; MLD = master logic diagram, TC = transportation cask; TWF = typical waste-handling facility, WP = waste package; WPTT = waste package transfer trolley.

Source: Original

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

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

Following the flow of the ESD to the right, one can see that the small bubbles point to a central, large bubble. The large bubble represents the aggregated initiating event. Each small bubble on an ESD can be considered a subset of the large bubble. Because each small bubble represents an initiating event with a unique frequency, the large bubble is an aggregated initiating event. As is discussed in the *Canister Receipt and Closure 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 could be compromised even if the canister remains intact and, therefore, determines that the state of the shielding after the insult is the next pivotal event. Either success or failure for the shielding results in an end state as follows. If the shielding remains intact, the end state is "OK." If the shielding does not remain intact, the identified end state is "Direct Exposure."

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

- **Canister Containment**. First opportunity for exposure (radiological release) in normal operating conditions.
- **Shielding**. If the canister successfully contains the radiological material, failure of the shielding presents the next opportunity for exposure (via direct shine to workers).
- **HVAC Confinement**. If the canister containment fails, the success of the HVAC system filters exposure to radionuclides; alternatively, failure leads to unfiltered exposure.
- **Moderator Ingress**. If a condition arises in which a moderator (e.g., water from fire suppression system) is present but is successfully isolated from the waste form by, for example, the canister's containment barrier or if moderator is not present, then a release that is also important to criticality is avoided. If moderator is present and able to contact the waste form, a potential for criticality exists. Note that failure to prevent moderator ingress does not imply an inevitable criticality event, but rather indicates that further analysis must be done to show either that the event sequence will not result in criticality or that the event sequence is beyond Category 2.

4.3.4.5 Event Tree Development

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

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

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

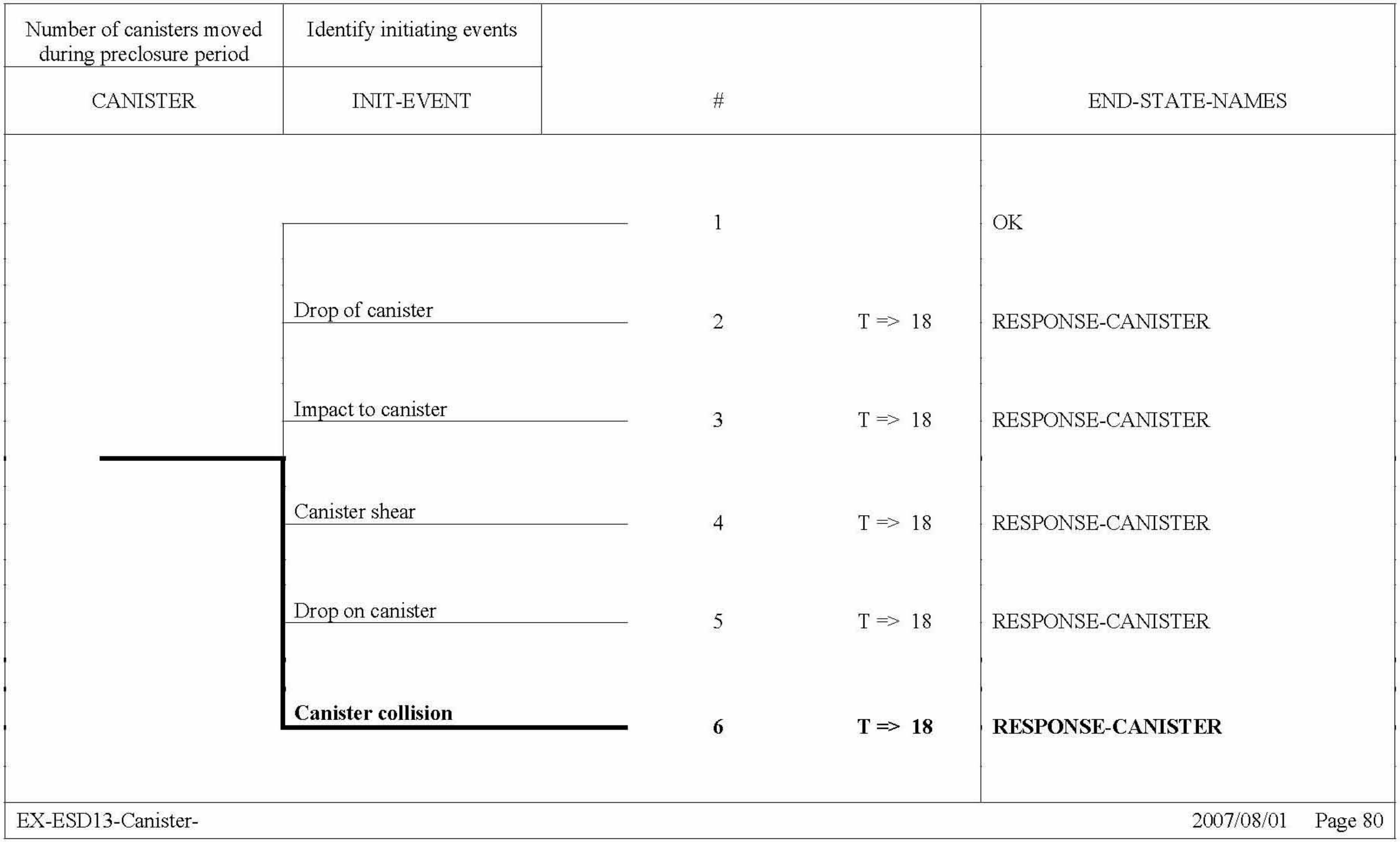
Table 8. Initiating Event Descriptions for Event Sequence Diagram for Typical Waste-Handling Facility

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

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

Source: Original

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

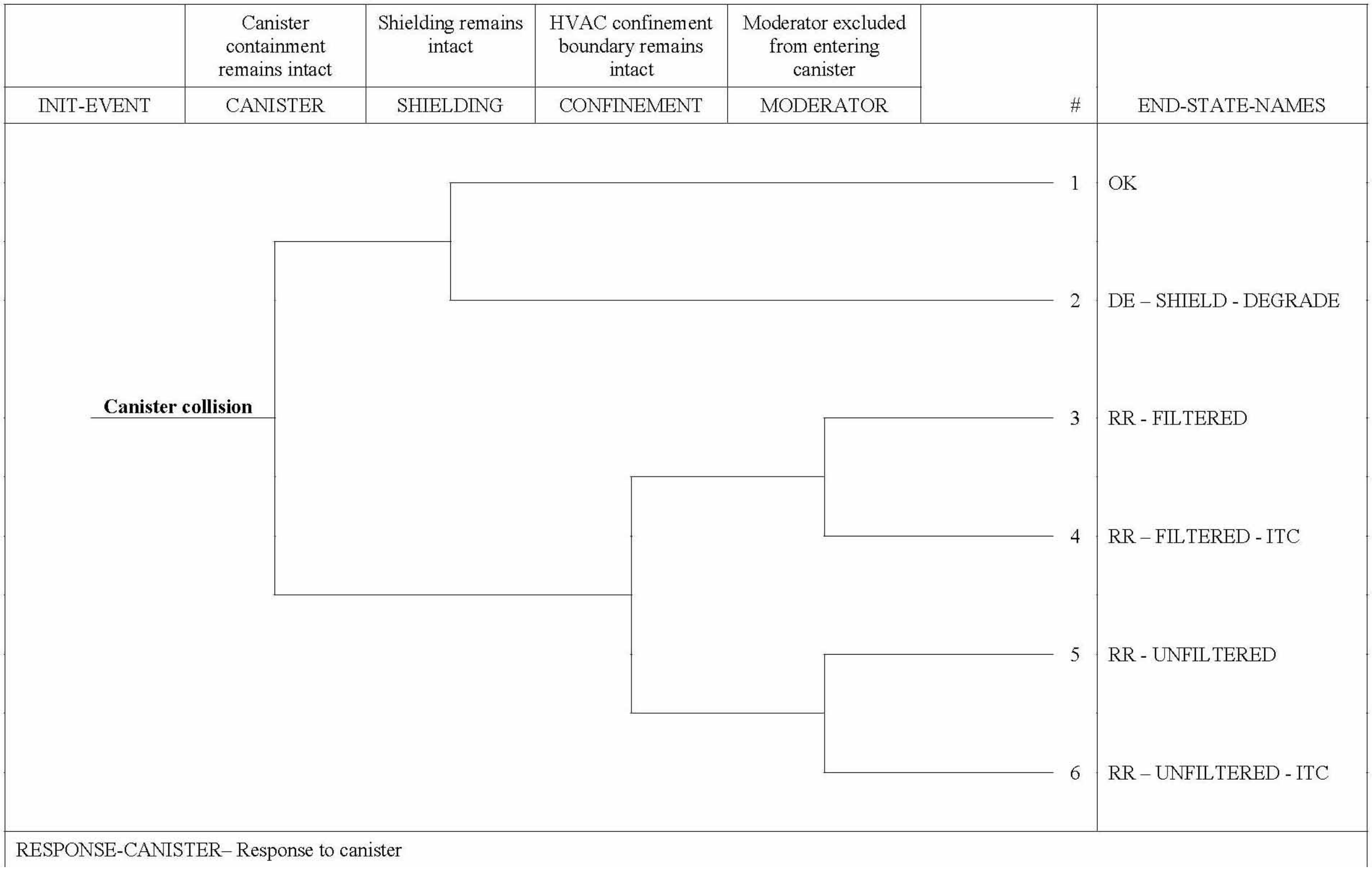


NOTE: INIT = initiating.

Figure G-1 provides additional explanation of the SAPHIRE event tree format.

Source: Original

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



NOTE: DE = direct exposure; DEGRADE = degraded; HVAC = heating, ventilation, and air conditioning; INIT = initiating; ITC = important to criticality; RAD = radiation; RR = radiation release; SHIELD = shielding.

Source: Original

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

5. LIST OF ATTACHMENTS

		Number of Pages
Attachment A.	Canister Receipt and Closure Facility Layout and Equipment Summary	14
Attachment B.	Canister Receipt and Closure Facility Operational Summary	9
Attachment C.	Canister Receipt and Closure Facility Location Within the GROA	2
Attachment D.	Canister Receipt and Closure Facility Master Logic Diagram	20
Attachment E.	Canister Receipt and Closure Facility Hazard and Operability Evaluation	29
Attachment F.	Canister Receipt and Closure Facility Event Sequence Diagrams	21
Attachment G.	Canister Receipt and Closure Facility Event Trees	89

6. BODY OF CALCULATION

6.1 INITIATING EVENT ANALYSIS

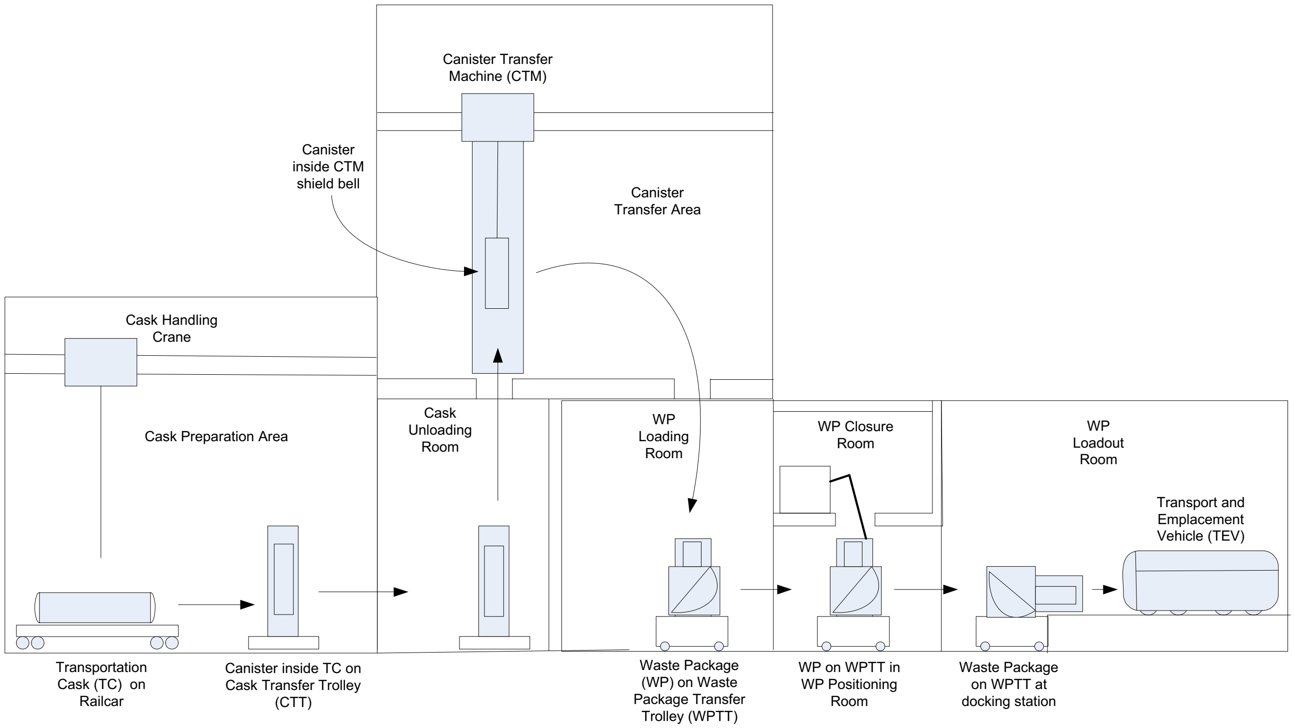
6.1.1 Introduction

Initiating events are identified for the YMP using MLDs that are verified with a HAZOP evaluation as described in Section 4. Each phase of the operations within the CRCF is analyzed to ensure that a comprehensive list of initiators is 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. 2.2.5), include natural phenomena such as tornado, earthquakes, flooding, lightning, etc., and activities external to the GROA such as aircraft crash, nearby industrial facilities, etc. or (b) internal events, which include events that could occur randomly within the facility, such as mechanical or electromechanical equipment failure (e.g., crane failure), human failure events associated with the operations of the systems or components (e.g., collision with a structure due to human failure), and fires or flooding events. These initiating events are depicted in the MLD.

6.1.2 Overview of Canister Receipt and Closure Facility and Its Operations

Consistent with the methodology discussed in Sections 4.3.1.1 and 4.3.4.1, this section contains a brief overview of the CRCF and its operations. The overview provides the basis for the identification of initiating events and the development of event sequences. Operational details are presented at a level that is intended to be sufficient in most cases for development of the MLD, the HAZOP evaluation, and the ESDs. Attachments A and B provide supplemental details that may be needed to understand some of the potential initiating events and the subsequent event sequences. The location of the CRCF within the GROA is shown in Attachment C.

The CRCF provides handling capability for a portion of the DOE managed waste stream. The waste stream for the CRCF includes dual-purpose canisters, DOE standardized canisters (DSTD) and multicanister overpacks, (MCOs), HLW canisters, and TAD canisters. As illustrated in Figure 14, canisters received in transportation casks by the CRCF are transferred into waste packages, which are welded closed and carried out of the CRCF by the transport and emplacement vehicle (TEV) for emplacement in the repository. The primary mode of receipt of waste into the CRCF is rail service. In addition, the CRCF is designed to receive trucks, each of which carries a transportation cask loaded with a single HLW canister. TAD canisters can also be received in aging overpacks delivered by the site transporter.



NOTE: This simplified conceptual depiction is not to scale.

Figure 14. Schematic Diagram of CRCF Mechanical Handling Operations

For the purposes of this analysis, CRCF operations are defined to include operations spanning the receipt of transportation casks and aging overpacks on a conveyance (i.e., railcar, truck trailer, or site transporter) into the Cask Preparation Room of the CRCF through the loading of waste packages into the TEV for emplacement, or to be placed into an aging overpack for movement to the aging pad (Ref. 2.2.10).

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

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

The operational summary continues with Section 6.1.2.1, and is organized according to the nodes, which are indicated in the PFD (Figure 15). The summary is based primarily on the Level 3 mechanical handling block flow diagram for the CRCF. 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 CRCF and other references have also been used, and are cited as needed for information that is not found in the block flow diagram.

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

6.1.2.1 Node 1: Receive a Loaded Transportation Cask or Aging Overpack

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 CRCF. (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 CRCF.) The overhead door to the CRCF Cask Preparation Room is opened and the conveyance is parked and secured in the Cask Preparation Room ((Ref. 2.2.11) and (Ref. 2.2.75)). If personnel barriers are present on the transportation cask after the cask is received into the CRCF, they are removed at this point using the cask handling crane.

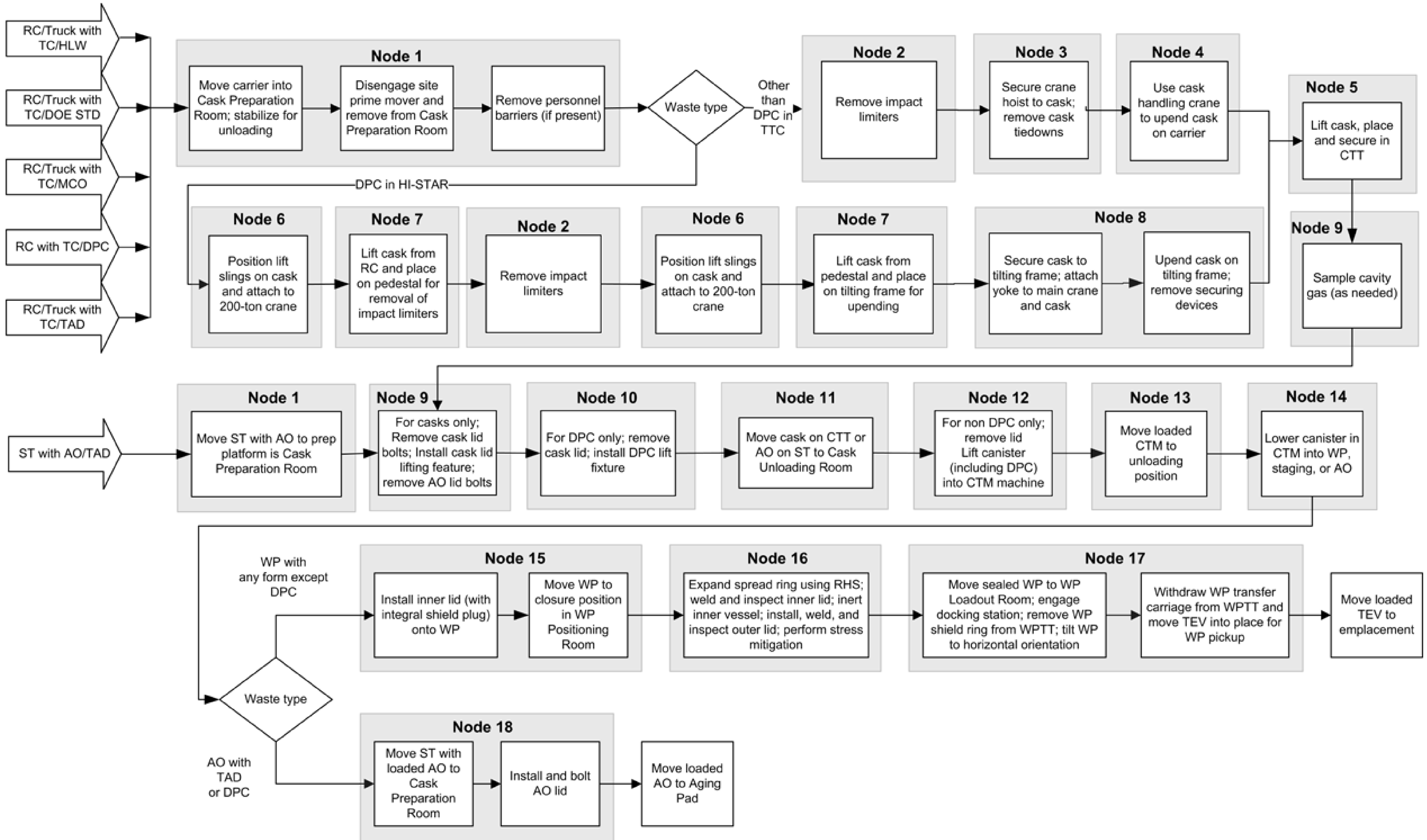
A loaded aging overpack on a site transporter is moved from the aging pad to the CRCF. The crew opens the overhead door and directs the conveyance into the CRCF Cask Preparation Room. At this point the crew verifies that the waste form received matches the pre-job plan. The aging overpack could be collocated in the preparation room with a cask.

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 2* (Ref. 2.2.51) and in the *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 6* (Ref. 2.2.55).

6.1.2.2 Node 2: Remove Impact Limiters from Transportation Cask

Some cask-handling steps are different depending on whether or not they are transportation casks which are upended using a tilt frame (TTC). For casks other than TTCs, 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. 2.2.75) and (Ref. 2.2.11). The MAP allows personnel access to the transportation cask. The corresponding process for TTCs is described in Section 6.1.2.6.

The MAP is a rail-mounted structure that bridges over the cask lying on the carrier (Ref. 2.2.35) *and* (Ref. 2.2.36). 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.



NOTE: CTT = cask transfer trolley; CTM = canister transfer machine; HLW = high-level radioactive waste; RC = railcar; TEV = transport and emplacement vehicle; TTC = transportation casks which are upended using a tilt frame; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure 15. CRCF Process Flow Diagram

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 3* (Ref. 2.2.52) and *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 4* Ref. 2.2.53).

6.1.2.3 Node 3: Prepare to Hoist Transportation Cask

The applicable yoke or lifting device is attached to the cask handling crane (Ref. 2.2.44). Cask clamps and tie-downs, which secure the cask to the carrier, are removed using the cask handling crane. Operators use the mobile access platform in the performance of these operational steps.

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 3* (Ref. 2.2.52) and *Mechanical Handling System Block Flow Diagram - Level 3 Sheet 4* (Ref. 2.2.53).

6.1.2.4 Node 4: Upend Transportation Cask on Its Conveyance

The cask handling crane is used to upend the cask while it is on the carrier (Ref. 2.2.75).

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 3* (Ref. 2.2.52).

6.1.2.5 Node 5: Move Transportation Cask to Cask Transfer Trolley

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. The CTT is an air-based carrier that floats on an air film (Ref. 2.2.11 and Ref. 2.2.72). 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 cask from the crane.

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 3* (Ref. 2.2.52)

6.1.2.6 Nodes 6-8: Cask Upending and Removal from Conveyance (Cask Contains DPC)

For a TTC containing a DPC, the crane operator uses the cask handling crane and a sling to move the cask with impact limiters from the conveyance to the cask stand. The impact limiters are removed and stored. The transportation cask is moved onto and secured to the cask tilting frame. The cask is lifted a small distance to verify the crane is bearing the weight and that all attachments were made properly. The cask is fully uprighted and then it is released from the cask tilting frame.

These nodes are described further in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 4* (Ref. 2.2.53).

6.1.2.7 Nodes 9 and 10: Prepare Transportation Cask or Aging Overpack for Removal of Lid

The lid bolts of the cask or aging overpack are removed. For casks, a lid-lift feature (lid adapter) is installed. The lid is left in place until it is later removed by the CTM (Nodes 12-14). Cask cavity gas sampling may be conducted as a prerequisite to removal of cask lid bolts (Ref. 2.2.75). For DPCs, the lid is removed and a DPC lift fixture is installed.

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 3* (Ref. 2.2.52) and in the *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 6* (Ref. 2.2.55).

6.1.2.8 Node 11: Move Loaded Cask Transfer Trolley or Site Transporter to Cask Unloading Room

The CTT for a transportation cask, or site transporter for an aging overpack, is used to move the loaded transportation cask or aging overpack from the Cask Preparation Room to the Cask Unloading Room (Ref. 2.2.75). Opening and closing the applicable shield door is required in this node. The CTT is an air lifted vertical enclosure, powered by an electric motor driver vehicle. An operator will guide the CTT into the Cask Unloading Room.

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 3* (Ref. 2.2.52), the *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 6* (and Ref. 2.2.55).

6.1.2.9 Nodes 12-14: Transfer Canister with Canister Transfer Machine

For a cask containing a DPC, the cask lid has been removed. For the other casks and aging overpack, the cask lid is still in place, though its bolts have been removed. In both cases, the CTM is moved into position over the cask and the CTM slide gate and the cask port slide gate are opened (Ref. 2.2.75); (Ref. 2.2.6); (Ref. 2.2.15) and(Ref. 2.2.31). For waste containers other than a DPC, the CTM is used to remove the cask/aging overpack lid. Also, for casks not containing a DPC, the appropriate exchangeable grapple must be attached to the CTM grapple (Ref. 2.2.19); (Ref. 2.2.30); and (Ref. 2.2.26). 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 Room (Ref. 2.2.6) and (Ref. 2.2.15). The CTM is mounted on a pair of rails on top of bridge girders. The primary function of the CTM is to transfer the canister from a transportation cask to a waste package. The process for assembly and placement of an empty waste package under the waste package port can be found in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 5*, (Ref. 2.2.54). The CTM has an integrated trolley mechanism with a shield compartment (or bell) capable of retaining a canister in place, while moving from port to port. The shield-bell trolley consists of a shield bell with an integrated structural frame and trolley mechanism. A sliding shield gate is provided at the bottom of the bell. The trolley mechanism is able to move along the span of the bridge girders to position the shield bell over the floor openings.

The horizontal movement of the CTM carries the canister from a position over the cask port to a position above the waste package port, the other Cask Unloading Room, or above a storage location. Positioned below the waste package port is an empty waste package in the WPTT or below the other Cask Unloading Room is an empty aging overpack on a site transporter (Ref. 2.2.75) The WPTT is a rail-based conveyance that is designed to carry the waste package in vertical orientation from the waste package port to the Waste Package Positioning Room for closure, and then on to the WPTT docking station, where it tilts the waste package to a horizontal orientation (Ref. 2.2.75); (Ref. 2.2.49); (Ref. 2.2.48); (Ref. 2.2.11); and (Ref. 2.2.15).

Once the CTM is in position over the waste package port, the CTM slide gate and the waste package port or cask port slide gate are opened (Ref. 2.2.75). Next, the canister is lowered into the waste package or aging overpack, and the waste package port or cask port slide gate and the CTM slide gate are closed. For HLW waste packages, which are designed to hold five HLW canisters, the steps involved in this process are repeated until the waste package is full (Ref. 2.2.8) and (Ref. 2.2.7). The unloaded transportation cask or aging overpack are removed from the facility as described in *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 7* (Ref. 2.2.56 55201), (Ref. 2.2.57 184783), and (Ref. 2.2.58 55203).

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 10* (Ref. 2.2.59); *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 11* (Ref. 2.2.60); *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 12* (Ref. 2.2.61); *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 13* (Ref. 2.2.62); *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 14* and (Ref. 2.2.63).

6.1.2.10 Node 15: Install Inner Lid and Move Waste Package to Waste Package Positioning Room

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

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 11* (Ref. 2.2.60) and the *CRCF-1 Mechanical Handling System Block Flow Diagram - Level 3 Sheet 15* (Ref. 2.2.64).

6.1.2.11 Node 16: Close Waste Package

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

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

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 15* (Ref. 2.2.64).

6.1.2.12 Node 17: Move Waste Package to Transport and Emplacement Vehicle

The sealed waste package is moved from the Waste Package Positioning Room to the Waste Package Loadout Room by the WPTT (Ref. 2.2.75). Opening and closing the applicable shield door is required in this node. The WPTT continues to the docking station where it is locked in place. The waste package handling crane is used to remove the waste package shield ring from the top of the waste package in the WPTT (Ref. 2.2.14) and (Ref. 2.2.15). The TEV is moved into position to receive the waste package (Ref. 2.2.11) and (Ref. 2.2.15). The WPTT tilts the waste package down to horizontal orientation. The waste package transfer carriage is engaged by a mechanism in the docking station and pulled into place for pickup by the TEV (Ref. 2.2.75); *CRCF-1 and* (Ref. 2.2.50).

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 16* (Ref. 2.2.65).

6.1.2.13 Node 18: Close and Export Loaded Aging Overpack

The aging overpack is closed and exported in reverse fashion to the process used to receive, prepare, and move the aging overpack into the Cask Unloading Room. The site transporter moves the aging overpack from the Cask Unloading Room into the Cask Preparation Room. The aging overpack lid bolts are installed, and the aging overpack is moved on the site transporter from the Cask Preparation Room to the outside, via the Entrance Vestibule.

This node is described in the *CRCF-1 Mechanical Handling System Block Flow Diagram – Level 3 Sheet 7* (Ref. 2.2.56).

6.1.3 Identification of Initiating Events

The identification of initiating events is completed by constructing the MLD and supplementing it with a HAZOP evaluation. The methodologies for the MLD and HAZOP evaluation are described in Sections 4.3.1.1 and 4.3.1.2, respectively. The MLD diagram and HAZOP evaluation deviations for the CRCF are provided in Attachments D and E, respectively.

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

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

Table 9. List of External Initiating Events

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

Source: Original

Table 10. List of Internal Initiating Events

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
CRC-101	Not used	N/A	N/A	N/A
CRC-102	Not used	N/A	N/A	N/A
CRC-103	Exposure due to RC derailment leading to a cask drop	D-1	E-2	F-1
CRC-104	Exposure due to RC collision leading to impact	D-1	E-2	F-1, F-7
CRC-105	Exposure due to TT failure leading to rollover or load drop	D-1		F-1
CRC-106	Exposure due to TT collision leading to an impact	D-1		F-1, F-7
CRC-107	Exposure due to ST failure leading to rollover or load drop	D-1	E-20	F-2
CRC-108	Exposure due to ST collision leading to an impact	D-1	E-20	F-2, F-7
CRC-I301[a]	Exposure due to internal flooding caused by piping & valve failure	D-3		
CRC-I302[a]	Internal flooding caused by actuation of fire protection system	D-3		
CRC-I303	Fire affects TC on RC/TT in Cask Preparation Room (diesel)	D-3	E-2, E-20	F-20
CRC-I304	Fire affects TC on RC/TT in Cask Preparation Room (no diesel)	D-3	E-3, E-5, E-4, E-9	F-20
CRC-I305	Fire affects TC on CTT or AO on ST in Cask Preparation Room	D-3		F-20

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
CRC-I306	Fire affects TC or AO in Cask Unloading Room	D-3		F-20
CRC-I307	Fire affects canister in Canister Transfer Room	D-3		F-20
CRC-I308	Not Used	N/A	N/A	N/A
CRC-I309	Fire affects WP in WP Positioning Room	D-3		F-20
CRC-I310	Fire affects WP in WP Loadout Room	D-3		F-20
CRC-I311	Fire affects TC (diesel)	D-3		F-20
CRC-I312	Fire affects TC (no diesel)	D-3		F-20
CRC-I313	Fire affects canister in CTM	D-3		F-20
CRC-I314	Fire affects canister in WP	D-3		F-20
CRC-I315 [b]	Exposure due to excessive temperature (excluding internal fire event)	D-3	E-15	
CRC-401	CTM crane drops object onto DPC prior to attachment of grapple	D-4		F-9
CRC-402	Auxiliary hook drops load onto TC	D-4	E-3	F-3
CRC-403	Unplanned conveyance movement while crane is attached to TC or conveyance fixtures leading to an impact.	D-4		F-3
CRC-404	Cask handling crane malfunction causes cask conveyance to tipover	D-4	E-3	F-3
CRC-405	Impact from MAP operations	D-4	E-3	F-3
CRC-501	Cask handling crane malfunction causes TC drop	D-5	E-4, E-5	F-3
CRC-502	Cask handling crane causes unplanned conveyance movement	D-5	E-4	F-3
CRC-503	Unplanned conveyance movement while crane is attached to TC or conveyance fixtures	D-5		F-3
CRC-504	Cask handling crane drops object on TC	D-5	E-4	F-3
CRC-505	Unplanned conveyance movement prior to cask clearing pedestals	D-5		F-3
CRC-506	Cask handling crane drops cask	D-5	E-6, E-10	F-3
CRC-507	Cask handling crane drops object on cask	D-5		F-3
CRC-508	Cask collides with object while being moved by cask handling crane	D-5	E-6	F-3
CRC-509	Impact from platform operations	D-5	E-4	F-3
CRC-510	Cask tips and drops after placed onto CTT	D-5	E-10	F-3
CRC-601	Auxiliary hook drops load on cask	D-6		F-3
CRC-602	Cask handling crane malfunction causes cask stand to roll over	D-6		F-3
CRC-701	Unplanned conveyance movement prior to clearing pedestals leads to side impact of cask	D-7		F-3
CRC-702	Cask handling crane drops TC	D-7	E-7	F-3

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
CRC-703	Cask handling crane drops object on cask	D-7	E-7	F-3
CRC-704	TC collides with object during movement by cask handling crane leads to a cask drop	D-7	E-7	F-3
CRC-705	Impact due to platform operations	D-7	E-7	F-3
CRC-801	Cask handling crane drops cask	D-8	E-8	F-3
CRC-802	Cask handling crane drops object on cask	D-8		F-3
CRC-803	Cask collides with object while being moved by cask handling crane leading to side impact	D-8	E-8	F-3
CRC-901	Cask tilting frame failure causes cask drop	D-9	E-10	F-3
CRC-902	Cask handling crane malfunction leads to cask drop	D-9	E-9	F-3
CRC-903	Cask handling crane drops heavy load onto cask	D-9		F-3
CRC-1001	Cask handling crane drops cask	D-10	E-10	F-3
CRC-1002	Cask handling crane drops object on cask	D-10		F-3
CRC-1003	Cask collides with object while being moved by cask handling crane	D-10	E-9	F-3
CRC-1004	Impact due to platform operations	D-10		F-3
CRC-1101	Operation of auxiliary crane hook leads to TC tip over	D-11		F-4, F-5
CRC-1102	Auxiliary crane hook drops object onto TC	D-11		F-4
CRC-1103	Cask preparation crane causes impact to side of cask	D-11		F-4, F-5
CRC-1104	Cask impact resulting from unplanned movement of CTT during installation of cask lid-lift fixture	D-11		F-4, F-5
CRC-1105	Failure to close cask preparation platform shield plates	D-11		F-17
CRC-1106	Inadvertent opening of cask preparation platform shield plates	D-11		F-17
CRC-1201	Heavy load dropped onto cask or canister	D-12	E-12	F-4
CRC-1202	Main hook interferes with auxiliary hook leads to cask tipover	D-12		F-4
CRC-1203	Lid bind during removal leads to cask tipover	D-12	E-12	F-4
CRC-1204	Auxiliary hook malfunction/misoperation catches and tips over CTT leading to cask impact	D-12		F-4
CRC-1205	Auxiliary hook malfunction/misoperation leads to side impact	D-12	E-12	F-4
CRC-1206	Failure to close cask preparation platform shield plates	D-12		F-17
CRC-1207	Collision between CTT and another moving vehicle, facility structures, or facility equipment leading to cask impact	D-12		F-4
CRC-1208	Spurious movement of CTT with crane attached to lid leading to cask damage	D-12		F-4

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
CRC-1209	Inadvertent opening of cask preparation platform shield plates	D-12		F-17
CRC-1301	Cask Unloading Room shield door closes against CTT or ST leading to cask impact	D-13	E-13	F-7
CRC-1302	Collision with facility structures or equipment during movement leading to cask impact	D-13	E-13	F-6, F-7
CRC-1303	ST/CTT or cask catches crane hook or rigging during movement leading to cask impact	D-13		F-6
CRC-1401	CTM drops object onto cask or canister	D-14	E-14	F-9
CRC-1402	Lid binds during removal leading to dropped cask	D-14	E-14	F-4, F-9
CRC-1501	Temporary loss of shielding while the canister is lifted from the cask into the CTM shield bell or lowered from the CTM shield bell into a canister	D-15	E-14, E-16	F-18
CRC-1502	Canister drops from CTM shield bell during move	D-15		F-9
CRC-1503	Canister collision due to CTM malfunction leading to an impact	D-15	E-15	F-8, F-9
CRC-1601	WPTT moves while loading leading to an impact	D-16	E-16, E-17	F-9
CRC-1602	CTT moves during cask unloading leading to an impact	D-16	E-14	F-9
CRC-1603	Spurious movement of CTM bridge or trolley leading to an impact	D-16		F-9
CRC-1604	Canister strikes port edge, CTM slide gate or wall leading to canister drop	D-16	E-16	F-9
CRC-1605	Side impact to canister during lift	D-16	E-14,E-16	F-9
CRC-1606	CTM wire rope is cut leading to canister drop	D-16		F-9
CRC-1607	CTM failure or misoperation leading to canister impact or drop	D-16	E-14, E-16	F-9
CRC-1608	Not used	N/A	N/A	N/A
CRC-1609	Canister drop in CTM shield bell (with CTM slide gate closed) due to CTM malfunction	D-16	E-14, E-16	F-9
CRC-1610	ST moves while unloading leading to an impact	D-16		F-9
CRC-1701	CTM crane drops inner lid onto canister during placement	D-17	E-17, E-18	F-9
CRC-1702	RHS drops object (e.g., outer lid) on canister during placement	D-17	E-18	F-11
CRC-1703	Welding damages canister leading to radiation release	D-17		F-11
CRC-1704	WPTT impacts shield door	D-17	E-17, E-19	F-7, F-13
CRC-1705	WPTT derails leading to drop	D-17	E-17, E-19	F-10 ,F-13
CRC-1706	Collision between WPTT and facility structures or equipment	D-17	E-17, E-19	F-10, F-13
CRC-1707	Premature tilt-down of WPTT	D-17		F-10, F-13

Table 10. List of Internal Initiating Events (Continued)

Identifier	General Event Description	MLD Figure #	HAZOP Table #	ESD Figure #
CRC-1708	Direct exposure due to improper assembly of WP in WPTT leading to lack of shielding	D-17	E-17	F-19
CRC-1801	Dropped lid onto loaded AO in Cask Unloading Room	D-18		F-9
CRC-1802	Inadvertent crane movement when lid is partially attached to AO leading to tipover	D-18		F-12
CRC-1803	Crane movement when rigging is low enough to catch AO or ST leading to impact	D-18		F-12, F-14
CRC-1804	Main hook interferes with auxiliary hook causing ST to tipover	D-18		F-12
CRC-1805	Main hook malfunction/misoperation catches ST leading to tipover	D-18		F-12
CRC-1806	Collision between ST and another moving vehicle (e.g., ST, etc.) leading to an impact	D-18		F-14
CRC-1807	Not used	N/A	N/A	N/A
CRC-1808	Exposure due to collision involving the ST and another vehicle, facility structures, or equipment leading to an impact	D-18		F-14
CRC-1809	Not used	N/A	N/A	N/A
CRC-1810	Exposure from damaged AO/canister due to collision with Cask Unloading Room shield door and structure	D-18		F-7
CRC-1901	Exposure due to dropped AO or ST rollover	D-19	E-20	F-16
CRC-1902	Exposure resulting from WP handling crane dropping an object	D-19	E-19	F-15
CRC-1903	Exposure from crane interference with TEV or WPTT leading to tipover	D-19	E-19	F-15
CRC-1904	Exposure due to WPTT malfunction leading to impact	D-19	E-19	F-15
CRC-1905	Exposure due to WP transfer carriage malfunction leading to impact	D-19	E-19	F-15
CRC-1906	TEV collision leading to impact	D-19		F-15
CRC-1907	Untimely opening of shield door or personnel door to WP Loadout Room leading to loss of shielding (shine)	D-19		F-19
CRC-1908	Exposure due to collision involving the ST and another vehicle, facility structures, or equipment	D-19	E-20	F-7, F-16

NOTE: [a]These events are analyzed in a separate document ((Ref. 2.2.5).

[b]This event is analyzed in a separate document ((Ref. 2.2.74)

AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; ESD = event sequence diagram; MAP = mobile access platform; MLD = master logic diagram; RC = railcar; RHS = remote handling system; ST = site transporter; TC = transportation cask; TEV = transport and emplacement vehicle; TT = truck trailer; WP = waste package; WPTT waste package transfer trolley.

Source: Original

6.2 DEVELOPMENT OF INTERNAL EVENT SEQUENCES

6.2.1 Introduction

The ESD technique, as described in Section 4.3.2.1, is used to develop event sequences associated with initiating events identified in the MLD. The resulting ESDs are presented in Attachment F (Figures F-1 through F-20). Sections 6.2.2 through 6.2.21 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 logic
- A summary description of each event sequence embodied in the ESD.

6.2.2 CRC-ESD-01: Receipt of Transportation Cask into Cask Preparation Room

6.2.2.1 Overall Description

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

- Transportation cask containing DOE (SNF) composed of either five DSTDs, nine DSTDs, or four MCOs received on a railcar or truck trailer

- Transportation cask containing five high-level radioactive waste (HLW) canisters received on a railcar or truck trailer

- Transportation cask containing one DPC received on a railcar

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

6.2.2.2 Initiating Events

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

1. Railcar derailment
2. Railcar/Truck trailer collision
3. Truck trailer rollover.

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

6.2.2.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the transportation cask remains intact (given that the impact limiters are still in place). Determining whether or not the containment boundary of the transportation cask remains intact, 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 transportation cask shielding remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a “slumping effect” as the result of an impact. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is “OK.” Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs, depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied loss of shielding caused by cask breach. Otherwise, the containment boundaries of both the cask and the canister have been breached and a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement to ventilate the Cask Preparation Room and the potential for moderator intrusion.

First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as a vestibule or vestibule annex. This boundary, exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered. The remaining pivotal event provides further delineation of the event sequences by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the “Radionuclide release” end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as, “also important to criticality”). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, “also important to criticality” means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates seven event sequences. The ESD in Figure F-1 shows five 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 seven event sequences as follows:

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

6.2.3 CRC-ESD-02: Receipt of Aging Overpack into Cask Preparation Room

6.2.3.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the aging overpack that occurs in the Cask Preparation Room (Figure F-2, Sections 6.1.2.1, Node 1). This ESD applies to the following waste forms:

- Aging overpack containing a TAD canister received by site transporter.

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. Site transporter collision
2. Site transporter rollover or aging overpack drop.

The groups are summarized by a generic initiating event, which is represented by the big bubble in the ESD. The big bubble represents a structural challenge to the aging overpack that occurs in the Cask Preparation Room during receipt of aging overpacks.

6.2.3.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the canister remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the aging overpack shielding remains intact, as posed by the next pivotal event. Loss of shielding in an aging overpack could occur from an impact, but only if the aging overpack is cracked open such that a direct pathway is formed. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is "OK." Otherwise, the event sequence terminates in a direct exposure to radiation. If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as a vestibule or vestibule annex. This boundary, exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed flow paths within the facility ensure any release exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, then the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates six event sequences. The ESD in Figure F-2 shows four 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 six event sequences as follows:

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

2. Canister containment remains intact, but loss of aging overpack shielding 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.

6.2.4 CRC-ESD-03: Removal of Impact Limiters, Upending and Transfer of Transportation Cask to CTT

6.2.4.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the transportation cask that occurs in the Cask Preparation Room during removal of impact limiters, upending and transfer of the cask to the CTT (Figure F-3 and Sections 6.1.2.2, Node 2; 6.1.2.3, Node 3; 6.1.2.4, Node 4; 6.1.2.5, Node 5; and, 6.1.2.6, Nodes 6-8). This ESD applies to the following waste forms:

- Transportation cask containing a DOE SNF composed of either five DSTDs, nine DSTDs, or four MCOs

- Transportation cask containing five HLW canisters

- Transportation cask containing one DPC

- Transportation cask containing one TAD canister.

6.2.4.2 Initiating Events

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

1. Transportation cask dropped at operational height
2. Transportation cask dropped above operational height
3. Transportation cask tip over
4. Transportation cask impact from collision
5. Heavy load dropped on transportation cask
6. Unplanned carrier movement causes impact to transportation cask.

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

6.2.4.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the transportation cask remains intact (given that the impact limiters have been removed). Determining whether or not the containment boundary of the transportation cask remains intact 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 transportation cask shielding remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a "slumping effect" as the result of an impact. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is "OK." Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied loss of shielding caused by cask breach. Otherwise, the containment boundaries of both the cask and the canister have been breached and a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary, exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure any release is exhausts through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered. The remaining pivotal event provides further delineation of the event sequences by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the, "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates seven event sequences. The ESD in Figure F-3 shows five 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 seven event sequences as follows:

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

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

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

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

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

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

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

6.2.5 CRC-ESD-04: Cask Preparation Activities Associated with Unbolting and Lid Adapter Installation

6.2.5.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the transportation cask that occurs in the Cask Preparation Room during cask preparation activities involving the cask handling crane (Figure F-4 and Section 6.1.2.7, Nodes 9 and 10). This ESD applies to the following waste forms:

- Transportation cask containing DOE SNF composed of either five DSTDs, nine DSTDs, or four MCOs
- Transportation cask containing five HLW canisters
- Transportation cask containing one DPC
- Transportation cask containing one TAD canister.

6.2.5.2 Initiating Events

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

1. Transportation cask dropped
2. Side impact to transportation cask
3. Heavy load dropped on transportation cask
4. Activities resulting in transportation cask tip over.

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

This ESD considers activities that occur before the transportation cask lid bolts are removed. CRC-ESD-06 in Section 6.2.7 considers activities that occur after the lid bolts have been removed rendering the transportation cask less effective as a containment boundary.

6.2.5.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the transportation cask remains intact (given that the impact limiters have been removed). If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the transportation cask shielding remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a "slumping effect" as the result of an impact. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is “OK.” Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the transportation cask does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the canister containment remains intact, radionuclide release is avoided, but a direct exposure occurs due to an implied loss of shielding caused by cask breach. Otherwise, the containment boundaries of both the cask and the canister have been breached and a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion.

First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered. The remaining pivotal event provides further delineation of the event sequences by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the, “Radionuclide release” end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as also important to criticality”).

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates seven event sequences. The ESD in Figure F-4 shows five 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 seven event sequences.

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

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

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

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

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

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

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

6.2.6 CRC-ESD-05: Aging Overpack Preparation Activities (i.e. lid bolt removal, lid removal, or installation of lid-lift fixture (if required))

6.2.6.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to an aging overpack during preparation activities in the Cask Preparation Room (Figure F-5 and Section 6.1.2.7 Nodes 9 and10). This ESD applies to the following waste forms:

- Aging overpack containing a TAD canister

6.2.6.2 Initiating Events

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

1. Impact to aging overpack
2. Activities resulting in aging overpack tipover.

The groups are summarized by an aggregate initiating event, the big bubble in the ESD. The big bubble represents a structural challenge involving the Cask Preparation Room crane while preparing the aging overpack for removal of the canister.

6.2.6.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the canister containment remains in place. Determining whether or not the containment boundary 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 may occur depending on the outcome of the next pivotal event, that is, whether the aging overpack shielding remains intact. Loss of shielding in aging overpacks could occur from an impact, but only if the aging overpack is cracked open such that a direct pathway is formed. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is "OK". Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis will take into account the filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered.

The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator 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.

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

1. Canister containment remains intact and aging overpack shielding remains intact (no radiation exposure)

2. Canister containment remains intact and aging overpack shielding fails resulting in a 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 is maintained, and moderator intrusion is not prevented resulting in a filtered radionuclide release, also important to criticality

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

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

6.2.7 CRC-ESD-06: Transfer of a Cask on CTT or Aging Overpack on Site Transporter from the Cask Preparation Room to Cask Unloading Room

6.2.7.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to a loaded CTT that occurs during a transfer from the Cask Preparation Room to the Cask Unloading Room (Figure F-6 and Section 6.1.2.8, Node 11). This ESD applies to the following waste forms:

- Transportation cask containing either five DSTDs, nine DSTDs, or four MCOs on a CTT
- Transportation cask containing five HLW canisters on a CTT
- Transportation cask containing one DPC on a CTT
- Transportation cask containing one TAD canister on a CTT
- Aging overpack containing one TAD canister on a site transporter.

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. CTT/Site transporter or cask/aging overpack catches crane hook or rigging resulting in impact to cask
2. Site transporter or CTT impact collision with another vehicle, facility structures, or equipment (except shield door).

The groups are summarized by an aggregate initiating event, the big bubble in the ESD. The big bubble represents a structural challenge during movement of a loaded CTT or aging overpack from the Cask Preparation Room to the Cask Unloading Room.

6.2.7.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the canister remains intact. The transportation cask containment boundary is no longer applicable because the cask lid bolts have been removed. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that, the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the cask or aging overpack shielding remains intact, as posed by the next pivotal event. For a cask, slumping of the shield wall could occur from the structural challenge. Loss of shielding in an aging overpack could occur from an impact, but only if the aging overpack is cracked open such that a direct pathway is formed. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is "OK." Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, then the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates six event sequences. The ESD in Figure F-6 shows four 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 six event sequences as follows:

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

2. Canister containment remains intact, but loss of cask or aging overpack 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.

6.2.8 CRC-ESD-07: Event Sequences Associated with Collision of CTT, Site Transporter, or WPTT with CRCF Shield Door

6.2.8.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the cask on the CTT, an aging overpack on the site transporter, or a waste package on the WPTT. The structural challenge also occurs during receipt of a cask or aging overpack, the transfer of a cask or aging overpack from the Cask Preparation Room to the Cask Unloading Room, the transfer of an aging overpack from the Cask Unloading Room to the Cask Preparation Room; or it happens during export of a waste package or aging overpack (Figure F-7 and Section 6.1.2.2, Node 1, Section 6.1.2.8, Node 11, Section 6.1.2.12, Node 17, and 6.1.2.13, Node 18). This ESD applies to the following waste forms:

- Transportation cask containing either five DSTDs, nine DSTDs, or four MCOs on a CTT
- Transportation cask containing five HLW canisters received on a CTT
- Transportation cask containing one DPC received on a CTT
- Transportation cask containing one TAD canister received on a CTT
- An aging overpack containing one TAD canister on the site transporter.
- Waste package containing one DSTD and four or five HLW canister
- Waste package containing two MCOs and two HLW canisters
- Waste package containing one TAD canister.

6.2.8.2 Initiating Events

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

6.2.8.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the shield door remains on its tracks and does not fall onto the CTT or site transporter. Determining whether or not the door remains on track may be probabilistic in that the event involves uncertainties in both the load imposed on the shield door and the strength of the shield door anchoring design. If the shield door comes off its track and falls onto the CTT or site transporter, the impact to the waste form could be large. However, even if the shield door remains on its track, impact to the CTT or site transporter and the waste form could still exist due to the shield door interaction with the CTT or site transporter (and waste form). In either case, whether the canister containment boundary remains intact is questioned to determine if there is a release of radioactive materials. Whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the transportation cask or aging overpack shielding remains intact, as posed by the next pivotal event. Degradation of shielding in lead-shielded casks could occur due to a "slumping effect" as the result of an impact. Loss of shielding in aging overpacks could occur from an impact, but only if the aging overpack is cracked open such that a direct pathway is formed. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is "OK". Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the canister does not remain intact (i.e., for a negative answer to the question posed by the second pivotal event), a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans, and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates twelve event sequences. The ESD in Figure F-7 shows four 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). This would make six end states, except that, they are all further categorized depending upon whether the door remains on its tracks. The result is twelve event sequences as follows:

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

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

3. Shield door remains on its track, canister containment remains intact, but degradation of cask or aging overpack shielding causes direct exposure

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

5. Shield door remains on its track, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a filtered radionuclide release

6. Shield door falls off its track and crashes on CTT, canister containment fails, HVAC confinement is maintained, and moderator intrusion is prevented resulting in a filtered radionuclide release

7. Shield door remains on its track, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an unfiltered radionuclide release

8. Shield door falls off its track and crashes on CTT, canister containment fails, HVAC confinement fails, and moderator intrusion is prevented resulting in an unfiltered radionuclide release

9. Shield door remains on its track, canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a filtered radionuclide release, also important to criticality

10. Shield door falls off its track and crashes on CTT, canister containment fails, HVAC confinement is maintained, and moderator intrusion is not prevented resulting in a filtered radionuclide release, also important to criticality

11. Shield door remains on its track, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an unfiltered radionuclide release, also important to criticality

12. Shield door falls off its track and crashes on CTT, canister containment fails, HVAC confinement fails, and moderator intrusion is not prevented resulting in an unfiltered radionuclide release, also important to criticality.

6.2.9 CRC-ESD-08: Collision of two CTMs Loaded with Canisters

6.2.9.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to two canisters that occurs from a collision between two CTMs during the transfer of the canisters to or from staging, a transportation cask, a waste package, or aging overpack with the CTMs (Figure F-8 and Section 6.1.2.9 Nodes 12-14). This ESD applies to the following waste forms:

- DSTDs
- MCOs
- HLW canisters
- DPCs
- TAD canisters.

6.2.9.2 Initiating Events

The individual initiating event that was identified in the MLD is indicated on the ESD as a collision between two CTMs loaded with canisters. This initiating event is represented by the big bubble on the ESD.

6.2.9.3 System Response

After the structural challenge occurs, the first pivotal event asks whether containment of both canisters remain intact. If the containment boundaries of both remain intact, no radioactive release occurs. However, there remains the question whether or not the shielding remains intact, as posed by the next pivotal event. Shielding is provided by the CTM shield bell. If the bell could be distorted (i.e., thinning of the shield bell wall), a degraded condition could occur. 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 either one or both of the canisters does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), a radionuclide release is inevitable. Determining whether or not the containment boundary of one or both canisters 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 one of the canister's containment boundaries remains intact, radionuclide release is avoided from that canister. Otherwise, the containment boundaries of both canisters have been breached. In the interest of simplicity, if canister containment failure occurs, both canisters are modeled as being breached.

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. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release 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.

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

1. Both canister containment boundaries remain intact and CTM shield bell shielding remain intact (no radiation exposure)

2. Both canister containment boundaries remain intact, but loss of CTM shield bell shielding causes direct exposure

3. Both canister containment boundaries fail, HVAC confinement is maintained, and moderator intrusion is prevented, resulting in a filtered radionuclide release

4. Both canister containment boundaries fail, HVAC confinement fails, and moderator intrusion is prevented, resulting in an unfiltered radionuclide release

5. Both canister containment boundaries fail, HVAC confinement is maintained, and moderator intrusion is not prevented, resulting in a filtered radionuclide release, also important to criticality

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

6.2.10 CRC-ESD-09: Transfer of a Canister to or from Staging, Transportation Cask, Waste Package, or Aging Overpack with CTM

6.2.10.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the canister that occurs during a transfer of a single canister with the CTM. This includes event sequences that arise during lifting canisters into the CTM, moving the loaded CTM to the waste package port, and lowering the canister into a waste package (Figure F-9 and Sections 6.1.2.9, Nodes 12-14). This ESD applies to the following waste forms:

- DSTDs (for transfers from a transportation cask to staging, from a transportation cask to a waste package, or from staging to a waste package)

- MCOs (for transfers from a transportation cask to a waste package)

- HLW canisters (for transfers from a transportation cask to staging, from a transportation cask to a waste package, or from staging to a waste package)

- DPCs (for transfers from a transportation cask to an aging overpack)

- TAD canisters (for transfers from a transportation cask to an aging overpack, from a transportation cask to a waste package, or from an aging overpack to a waste package).

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

1. Dropped object on canister (for example a waste package inner lid dropped on the canister).

2. Canister impact due to movement of CTM, CTT, WPTT or site transporter during lift. This initiating event group corresponds to a structural challenge to the canister caused, for example, by a spurious horizontal movement of the CTT from which the canister is being extracted, one that occurs before the canister is completely lifted inside the shield bell of the CTM.

3. Canister dropped inside CTM during horizontal movement caused, for example, by the mechanical failure of lifting components)

4. Canister dropped at operational height (caused, for example, by improperly attached grapples)

5. Canister dropped above operational height (caused, for example, by a two-blocking event, i.e., a lift by the CTM to its mechanical limits that result in a cutting of the hoist wire ropes)

6. Impact to transportation cask or aging overpack associated with lid removal (caused by the CTM attempting to lift the cask or aging overpack lid while it is not completely unbolted; conceivably, this could cause binding of the lid and partial lifting of the cask or aging overpack, until it is dropped because the lifting capability of the CTM or the mechanical capabilities of the bolts are exceeded).

7. Collision or impact to canister (for example, by the shield bell of the CTM as a result of an abrupt stop).

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

6.2.10.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the canister remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the CTM shielding remains intact, as posed by the next pivotal event. The CTM shielding consists of the shield doors, slide gates, shield bell, and shield skirt. Damage to one or more of these components could result in a direct exposure to an individual. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is "OK." Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the canister does not remain intact (i.e., a breach has occurred), 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. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, then the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that a canister breach is a necessary prior condition to a subsequent moderator intrusion inside the canister. In addition, note that "also important to criticality" means that event sequences tagged as such that are found to be Category 1 or Category 2 in the subsequent categorization analysis must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates six event sequences. The ESD in Figure F-9 shows four 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 six event sequences as follows:

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

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

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

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

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

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

6.2.11 CRC-ESD-10: Waste Package Transfer to Closing Position in Waste Package Positioning Room below Waste Package Closure Room

6.2.11.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the canister or canisters inside the waste package that occurs during the waste package transfer to the closing position in the Waste Package Positioning Room below the Waste Package Closure Room (Figure F-10 and Section 6.1.2.10, Node 15). This ESD applies to the following waste forms:

- Waste package containing one DSTD and four or five HLW canisters
- Waste package containing two MCOs and two HLW canisters
- Waste package containing one TAD canister.

6.2.11.2 Initiating Events

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

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

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

6.2.11.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the canister remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that, the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the waste package shielding (i.e., waste package lid, shield ring, and WPTT shielding) remains in place, as posed by the next pivotal event. Determining whether or not the waste package shielding is in place may be probabilistic in that, the event involves uncertainties in the shock impacting the waste package lid and the potential for dislodging or damaging waste package shielding. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is “OK.”. Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, then the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates six event sequences. The ESD in Figure F-10 shows four 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 six event sequences as follows:

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

2. Canister containment remains intact, but loss of waste package 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.

6.2.12 CRC-ESD-11:Event Sequences Associated with Assembly and Closure of the Waste Package

6.2.12.1 Overall Description

This ESD delineates the event sequences that arise after mishaps during assembly and closure of the waste package that occurs in the Waste Package Positioning Room (Figure F-11). This includes event sequences that arise during the closure of the waste package (Section 6.1.2.11, Node 16). This ESD applies to the following waste forms:

- Waste package containing one DSTD and four or five HLW canisters
- Waste package containing two MCOs and two HLW canisters
- Waste package containing one TAD canister.

6.2.12.2 Initiating Events

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

1. Welding damages the canister(s)

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

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

6.2.12.3 System Response

After the structural challenge occurs, the first pivotal event asks whether the containment boundary of the canister remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that, the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the waste package shielding (i.e., waste package lid, shield ring, and WPTT shielding) remains in place, as posed by the next pivotal event. Determining whether or not the waste package shielding is in place may be probabilistic in that, the event involves uncertainties in the shock impacting the waste package lid and the potential for dislodging or damaging waste package shielding. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is “OK.”. Otherwise, the event sequence terminates in a direct exposure to radiation.

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed flow, paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, then the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates six event sequences. The ESD in Figure F-11 shows four 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 six event sequences as follows:

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

2. Canister containment remains intact, but loss of waste package 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.

6.2.13 CRC-ESD-12: Assembly and Closure of Aging Overpack

6.2.13.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the aging overpack that occurs during assembly and closure (Figure F-12 and Section 6.1.2.13 Node 18). This ESD applies to the following waste forms:

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

6.2.13.2 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. Aging overpack impact
2. Crane mishap results in aging overpack tipover.

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

6.2.13.3 System Response

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

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, then the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates six event sequences. The ESD in Figure F-12 shows four 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 six event sequences as follows:

1. Canister containment and shielding remain intact (no radiation exposure).
2. Canister containment remains intact, but loss of aging overpack shielding 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.

6.2.14 CRC-ESD-13: Transfer of the Waste Package from the Waste Package Closure Room to the WPTT Docking Station

6.2.14.1 Overall Description

This ESD delineates the event sequences that arise after a structural challenge to the waste package that occurs during the transfer of the waste package from the Waste Package Closure

Room to the WPTT Docking Station (Figure F-13 and Section 6.1.2.12, Node 17). This ESD applies to the following waste forms:

- Waste package containing one DSTD and four or five HLW canisters
- Waste package containing two MCOs and two HLW canisters
- Waste package containing one TAD canister.

6.2.14.2 Initiating Events

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

1. WPTT collision
2. WPTT premature tilt-down
3. WPTT derailment.

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

6.2.14.3 System Response

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

If the containment boundary of the waste package does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that, the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the canister remains intact, radionuclide release is avoided, but a direct exposure occurs due to a loss of shielding caused by the waste package breach and the implied failure of the waste package to remain within the WPTT shields. Otherwise, the containment boundaries of both the waste package and the canister have been breached and a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the

HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates seven event sequences. The ESD in Figure F-13 shows five 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 seven event sequences as follows:

1. Waste package and WPTT containment and shielding remain intact (no radiation exposure)

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

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

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

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

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

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

6.2.15 CRC-ESD-14: Transfer of Aging Overpack from Cask Unloading Room to Cask Preparation Room

6.2.15.1 Overall Description

This ESD delineates the event sequences arising after a structural challenge to the aging overpack that occurs in the Cask Preparation Room during transfer from the Cask Unloading Room (Figure F-14 and Sections 6.1.2.13 Node 18). This ESD applies to the following waste forms:

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

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. Site transporter or aging overpack catches crane hook or rigging resulting in impact to aging overpack

2. Site transporter impact collision with another vehicle, facility structures, or equipment (except shield door).

The groups are summarized by an aggregate initiating event, the big bubble in the ESD. The big bubble represents a structural challenge during movement of a loaded site transporter from the Cask Unloading Room to the Cask Preparation Room.

6.2.15.3 System Response

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

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, then the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates six event sequences. The ESD in Figure F-14 shows four 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 six event sequences as follows:

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

2. Canister containment remains intact, but loss of aging overpack shielding 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.

6.2.16 CRC-ESD-15: Exporting of Waste Package from CRCF

6.2.16.1 Overall Description

This ESD delineates the event sequences arising after a structural challenge to the waste package that occurs during the export of a waste package from the CRCF. This includes event sequences that could occur from the introduction of the TEV into the WPTT, to removal of the waste package from the CRCF (Figure F-15 and Section 6.1.2.12, Node 17). This ESD applies to the following waste forms:

- Waste package containing one DSTD and four or five HLW canisters
- Waste package containing two MCOs and two HLW canisters
- Waste package containing one TAD canister.

6.2.16.2 Initiating Events

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

1. TEV collision with waste package
2. Impact due to object dropped on waste package
3. Waste package handling crane interference with TEV or WPTT
4. Impact due to malfunction of the WPTT or the waste package transfer carriage.

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

6.2.16.3 System Response

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

If the containment boundary of the waste package does not remain intact (i.e., for a negative answer to the question posed by the first pivotal event), whether or not a radionuclide release occurs depends on whether or not the canister containment boundary remains intact. Determining whether or not the containment boundary of the canister remains intact may be probabilistic in that, the event involves uncertainties in both the load imposed on the canister and the strength of the canister. If the canister remains intact, radionuclide release is avoided, but a direct exposure occurs due to a loss of shielding caused by the waste package breach and the implied failure of the waste package to remain within the WPTT shields. Otherwise, the containment boundaries of both the waste package and the canister have been breached and a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble); the ESD delineates seven event sequences. The ESD in Figure F-15 shows five 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 seven event sequences as follows:

1. Waste package and WPTT containment and shielding remain intact (no radiation exposure)

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

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

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

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

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

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

6.2.17 CRC-ESD-16: Exporting of Aging Overpack from CRCF

6.2.17.1 Overall Description

This ESD delineates the event sequences arising after a structural challenge to the aging overpack occurs while exporting from the CRCF (Figure F-16 and Sections 6.1.2.12, Node 18). This ESD applies to the following waste forms:

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

6.2.17.2 Initiating Events

The individual initiating events 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. Aging overpack dropped or site transporter rollover

2. Collision involving the site transporter and another vehicle, facility structures, or facility equipment.

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

6.2.17.3 System Response

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

If the containment boundary of the canister does not remain intact, a radionuclide release is inevitable. The subsequent pivotal events provide further characterization of each potential event sequence regarding the availability of HVAC confinement and the potential for moderator intrusion. First, a pivotal event asks whether HVAC confinement is maintained. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. If HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, then the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator (for example, from inadvertent fire suppression system actuation or leakage of water from HVAC chillers) enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates six event sequences. The ESD in Figure F-16 shows four 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 six event sequences as follows:

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

2. Canister containment remains intact, but loss of aging overpack shielding 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.

6.2.18 CRC-ESD-17: Direct Exposure During Cask Preparation Activities

6.2.18.1 Overall Description

This ESD delineates direct-exposure event sequences during cask preparation activities that are not addressed in other ESDs (Figure F-17 and Section 6.1.2.6 Node 10) that would lead to direct exposure. This ESD applies to the following waste forms:

- All CRCF waste forms.

6.2.18.2 Initiating Events

The initiating event identified in the MLD is presented on the ESD as temporary loss of shielding associated with the cask preparation activities. This initiating event represents the big bubble on the ESD (Figure F-17). This ESD applies to the following waste forms:

- All CRCF waste forms.

6.2.18.3 System Response

No pivotal events were identified for this ESD.

6.2.19 CRC-ESD-18: Direct Exposure During CTM Activities

6.2.19.1 Overall Description

This ESD delineates direct-exposure event sequences during CTM activities that are not addressed in other ESDs (Figure F-18). This ESD applies to the following waste forms:

- All CRCF waste forms.

6.2.19.2 Initiating Events

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

6.2.19.3 System Response

No pivotal events were identified for this ESD.

6.2.20 CRC-ESD-19: Direct Exposure During Closure and Exporting Loaded Waste Package

6.2.20.1 Overall Description

This ESD delineates direct-exposure event sequences during exporting loaded waste packages that are not addressed in other ESDs (Figure F-19). This initiating event represents the big bubble on the ESD. This ESD applies to the following waste forms:

- All CRCF waste forms.

6.2.20.2 Initiating Events

The individual initiating events 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. Direct exposure during closure
2. Direct exposure during exporting

6.2.20.3 System Response

No pivotal events were identified for this ESD.

6.2.21 CRC-ESD-20: Events Sequences for Fires Occurring in the Canister Receipt and Closure Facility

6.2.21.1 Overall Description

This ESD delineates the event sequences that occur when a fire threatens waste forms in the CRCF. 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-20). There are no specific node associations between this event sequence and the PFD because fire event sequences might occur in any location. However, the initiating events associated with each waste form are specific to the handling and processing of the waste form throughout the facility.

This ESD applies to the following waste forms:

- All waste forms

6.2.21.2 Initiating Events

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

1. Localized fire threatens a waste package in the Waste Package Loadout Room

2. Localized fire threatens a transportation cask or aging overpack in the Cask Unloading Room

3. Localized fire threatens a waste package in the Waste Package Positioning Room

4. Localized fire threatens a transportation cask or aging overpack in the Cask Preparation Room

5. Localized fire threatens a canister in the CTM

6. Large fire threatens waste forms anywhere in the CRCF.

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

6.2.21.3 System Response

After a localized or large fire occurs and the waste form is 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, canister in a waste package, bare canister), the thermal analysis may consider the configuration of that waste form. For example, even though the pivotal event only specifically addresses the failure of the canister, if a canister is in a transportation cask, the ability of the cask to resist thermal failure and protect the canister contained within may be considered in the analysis. The same method may be used to determine a thermal failure of a canister that is contained within a waste package. If the containment boundary remains intact, no radioactive release occurs. However, there remains the question whether or not the cask, aging overpack, CTM bell, or WPTT shielding remains intact, as posed by the next pivotal event. Loss of shielding could occur from the thermal challenge such that a direct pathway is formed. If the shielding remains intact, there is no exposure of personnel to radiation and the end state is “OK.” Otherwise, the event sequence terminates in a direct exposure to radiation.

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. This boundary consists of the external concrete walls of the facility along with the HVAC ducting, exhaust fans and filter plenums exclusive of any areas designated as vestibules or vestibule annexes. This boundary exists only when the confinement doors between the main body of the facility and any designated vestibule areas are closed. When these doors are closed, flow paths within the facility ensure that any release is exhausted through the HEPA filters. The question posed by this pivotal event implies maintenance of the confinement boundary for a mission time sufficient to stop the release. An impediment to the ability of the HVAC system to maintain confinement in this instance is, the damage that the excessive particulates and hot gases could inflict on the HEPA filters and other components of the HVAC system. If (despite the difficulties inherent in the case of a fire severe enough to cause a radionuclide release) HVAC confinement is maintained over the mission time, the release is considered a filtered release and the consequence analysis may take into account the filter efficiency. If HVAC confinement is not maintained, the release is considered unfiltered. The remaining pivotal event provides further delineation by asking whether moderator is prevented from entering the breached canister. In the case of a fire, the analysis of this pivotal event is subject to the expectation that fire-suppression water would be in abundant supply. In the affirmative case, that is, the absence of moderator intrusion, the filtered or unfiltered release is represented by the "Radionuclide release" end state. In the negative case, that is, if moderator enters the breached canister, the corresponding event sequences terminate in either a filtered or an unfiltered radionuclide release that must be further evaluated with respect to criticality (which is indicated as "also important to criticality"). Moderator intrusion is selected for this pivotal event rather than a more general event asking about criticality because the design intention is to deny moderator to the canister internals, in the dry handling facilities, as the means of criticality prevention. Note that, "also important to criticality" means that event sequences tagged as such, that are found to be Category 1 or Category 2 in the subsequent categorization analysis, must be demonstrated to be subcritical. Demonstration of subcriticality is not required for event sequences that are beyond Category 2.

In summary, for each waste form and each initiating event group (little bubble), the ESD delineates five event sequences. The ESD in Figure F-20 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 as follows:

1. Canister containment remains intact (no radiation exposure)

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

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

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

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

6.3 EVENT TREES

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

7. RESULTS AND CONCLUSIONS

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

- An MLD for the CRCF (Attachment D) that identifies potential initiating events for event sequences
- A set of ESDs for the CRCF (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
CANISTER RECEIPT AND CLOSURE 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 have little dependence on the dimensions, weights, and weight capacities given, they may change without affecting the results.

A2 FACILITY OVERVIEW

The CRCF is physically separated from other buildings to isolate it from interactions with other facility structures during a seismic event. The CRCF is a multilevel concrete and steel structure with a 92,000 ft^2 footprint. The two lower levels of the facility contain the operating areas and equipment used in the waste handling process, while the third level houses a 15-ton maintenance crane. The overall dimensions of the CRCF are approximately 400 ft wide by 421 ft long and 100 ft high. The exterior main walls of the CRCF superstructure are typically 4 ft thick reinforced concrete. Some interior concrete walls and the concrete walls of some support areas are nominally 1 to 2 ft thick. The CRCF second level processing areas floor elevations are 32 ft above grade. The second level floors are of a concrete slab design ranging in thickness from 18 in. to 4 ft over the processing cells. The roof slab over the Canister Transfer Room at elevation 100 ft and the Cask Preparation Room at elevation 72 ft is 18 in. concrete cast on a 3 in. metal deck supported by steel trusses and beams. The roof slab over the loadout areas at elevation 64 ft is 33 in. and cast over the same type of steel support structures used at the other roof elevations.

The CRCF is founded on natural alluvium. The location of the facility was selected to avoid the main trace of quaternary faults with a potential for significant displacement. The 6 ft thick reinforced concrete mat foundation includes steel reinforcing bars placed horizontally in each direction, on the top and bottom surfaces to resist applied moments and forces. Also, vertical reinforcing steel bars are provided in areas of the mat foundation where the concrete shear capacity is less than the demand shear forces. The mat foundation and steel reinforcing bar configurations are consistent with nuclear industry practices for the design and construction of reinforced concrete structures and foundations. *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11) provides CRCF structural footprint information.

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. Explanations of 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:

- *Canister Receipt and Closure Facility 1 General Arrangement Legend and General Notes* (Ref. 2.2.12)
- *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11)
- *Canister Receipt and Closure Facility 1 General Arrangement Second Floor Plan* (Ref. 2.2.14)
- *Canister Receipt and Closure Facility 1 General Arrangement Third Floor Plan* (Ref. 2.2.18)
- *Canister Receipt and Closure Facility 1 General Arrangement Roof Plan* (Ref. 2.2.13)
- *Canister Receipt and Closure Facility 1 General Arrangement Sections A and B* (Ref. 2.2.15)
- *Canister Receipt and Closure Facility 1 General Arrangement Sections C and D* (Ref. 2.2.16)
- *Canister Receipt and Closure Facility 1 General Arrangement Sections E and F* (Ref. 2.2.17).

A3.1 TRANSPORTATION CASK (ENTRANCE) VESTIBULE ANNEX

The Transportation Cask Vestibule Annex (Room 1036A) provides an extension of the Transportation Cask Vestibule (Room 1036). The annex and vestibule located on the southeast side of the facility has direct rail access to handle either National Transportation shipping casks or aging overpacks brought in by railcar or truck trailer. The 56 ft by approximately 40 ft annex room and 34 ft × 70 ft vestibule are necessary to accommodate the length of the railcar and transportation cask and cask transfer trailer for entry into the Cask Preparation Room. Together, the annex and cask vestibule form a staging area for transportation casks and provides an environmental separation or buffer between the Cask Preparation Room and the outside environment.

The annex contains two access doors: one from the outside and one granting access to/from the Personnel Vestibule (Room 1036B). The Transportation Cask Vestibule/Annex inner and outer overhead doors are interlocked preventing both doors from being opened at the same time. The vestibule/annex plays an important role in maintaining confinement inside the facility. Both contain HVAC equipment to control the differential air pressure necessary for confinement. The annex is outside the main facility structure and is constructed of insulated metal wall and roof panels on steel framing. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11).

A3.2 SITE TRANSPORTER (ENTRANCE) VESTIBULE

The Site Transporter Vestibule (Room 1027) provides a parking area for the site transporter containing an aging overpack or transportation cask prior to entry into the Cask Preparation Room. It also provides an environmental separation between the outside environment and the Cask Preparation Room. Room 1027 is centrally located on the east side of the CRCF.

The Site Transporter Vestibule has an inner and an outer overhead door. The inner door serves as a confinement boundary for important to safety (ITS) HVAC. The vestibule has no confinement function. Room 1027 is a non-confinement area and contains recirculation fan equipment. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11).

A3.3 CASK PREPARATION ROOM AND CASK PREPARATION PLATFORM

The Cask Preparation Room (Room 1026) prepares the transportation cask and aging overpack for canister transfer and prepares empty casks and aging overpacks exiting the facility. Room 1026 is adjacent to the entrance vestibules for the site transporter and transportation cask, ground level Cask Unloading Rooms, second level Canister Transfer Room, HVAC Rooms, Ground Floor Support Area, the Operations Room, and Gas Sample Room. The room is approximately 85 ft × 90 ft in floor dimensions and 70 ft high. The room is classified as a C2 contamination area. The walls are 4 ft thick reinforced concrete. The roof is an 18-in. concrete slab on a 3-in. metal deck supported by steel trusses. Because of the C2 contamination zoning of Room 1026, the area is maintained under negative pressure with respect to the outdoors and adjacent vestibules by cascaded airflow. The airflow is exhausted by means of exhaust fans located in the HVAC Rooms through high-efficiency particulate air (HEPA) filters. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11).

The Cask Preparation Room houses the following equipment:

- **Cask handling bridge crane**: The cask handling bridge crane is located in the Cask Preparation Room and has a dimensional envelope of approximately 65 ft × 89 ft × 60.3 ft clearance envelope elevation. The crane houses two trolleys on a single overhead gantry bridge; one trolley is rated for 200 tons and the other is rated for 20 tons. 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 bridge crane is used for heavy load lifts in the preparation area. The main function is the placement of a transportation cask from a cask conveyance into a CTT. The auxiliary trolley on the cask handling crane is rated at 20 tons. It is used to move impact limiters and other equipment and lighter loads as required in the Cask Preparation Room. Mechanical equipment envelope details are provided in *Canister Receipt and Closure Facility Cask Handling Crane Mechanical Equipment Envelope* (Ref. 2.2.20). Control system design details are provided in *CRCF, RF and IHF Cask Handling Crane Process and Instrumentation Diagram Sheet 1 of 4* (Ref. 2.2.43); *CRCF, RF and IHF Cask Handling Crane Process and Instrumentation Diagram Sheet 2* (Ref. 2.2.32); and *CRCF, RF and IHF Cask Handling Crane Process and Instrumentation Diagram Sheet 3* (Ref. 2.2.33).

- **Cask handling yoke**: The cask handling yoke is used to transfer casks between the truck or rail conveyances and the CTT. The yoke has two adjustable lifting arms that accommodate various cask diameters and connect to the cask trunnions. The main function is to engage the cask lifting trunnions from the horizontal/vertical orientation and rotate the cask to the vertical/horizontal orientation. The cask handling yoke couples to the 200-ton crane hook and has a dimensional envelope of approximately 2 ft- 4 in. × 15 ft × 13 ft-6 in. weighing 7.5 tons. When not in use, the cask handling yoke rests in the cask handling yoke stand. Mechanical equipment envelope details are provided in *CRCF, RF, WHF and IHF Cask Handling Yoke Mechanical Equipment Envelope* (Ref. 2.2.44).

- **Cask tilting frame**: The cask tilting frame is used to upend transportation casks (TTCs) that do not have provisions for righting them on the conveyance. These casks are transferred from the conveyance to the cask tilting frame, while still horizontal. The cask tilting frame is then used to orient the cask vertically. The cask tilting frame dimensional envelope is 18 ft × 9.4 ft × 9.6 ft with a 34 ft maximum clearance for tilting. The estimated weight of the frame is 6 tons. Mechanical equipment envelope details are provided in *CRCF, RF and WHF Cask Tilting Frame Mechanical Equipment Envelope* (Ref. 2.2.34).

- **Cask transfer trolley**: The CTT is used to transfer transportation casks and aging overpacks between the Cask Preparation Room and the Cask Unloading Rooms. The CTT is an air-based machine floating on a thin film of air above the floor surface. It operates by electric and pneumatic control and air modules. An automatic, programmable, logic based system, controls the air pressure and lift height of the trolley platform. Sensors on the CTT provide control system inputs on the floating height and rate of rise and lowering speed of the CTT platform. The maximum lift height of the trolley from the floor is approximately one inch. Mechanical equipment envelope details are provided in *Cask Transfer Trolley MEE* (Ref. 2.2.72). Control system design details are provided in *CRCF, RF, WHF, and IHF Cask Transfer Trolley Process and Instrumentation Diagram* (Ref. 2.2.46).

- **Cask preparation platform**: The cask preparation platform provides personnel and tool access to the top of a transportation cask while the cask is restrained in the CTT. The platform consists of two sections that are anchored to the floor and separated from each other to allow the CTT to locate between them. Each platform section has an articulating subsection that travels from vertical to horizontal in orientation, surrounding the top of the cask, providing safe access to the cask top by facility operators for sampling, bolt removal, and lift fixture installation. One side of the platform has a stairway with landings, while the other side is equipped with a caged ladder for access. Ref. 2.2.24), (Ref. 2.2.25).

- **Mobile access platform**: The mobile access platform provides personnel access to tools for transportation casks while on the conveyance for cask preparation for removal from the railcar or truck. The steel mobile access platform provides four working levels for personnel to access the CTT. The platform is split down the center to allow passage of the CTT to the Cask Transfer Room. The top two levels of the mobile access platform 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 mobile access platform is 27 ft × 16 ft × 29 ft. Mechanical equipment envelope details are provided in Ref. 2.2.35) and Ref. 2.2.36).

- **Shield doors**: The Cask Unloading Room shield door protects the Cask Preparation Room from radiation when a canister is lifted out of a cask or aging overpack. The Cask Unloading Room shield door provides equipment and personnel access to the Cask Unloading Room. The Cask Unloading Room shield door is a single slide open type door made of 16 in. thick steel plate and weighing approximately 268 tons. The door is operated by an electric motor turning a screw that interacts with a door mounted bracket. The door overlaps the aperture on the top, bottom, and both sides to provide shielding. Mechanical equipment envelope details are provided in *Nuclear Facilities Equipment Shield Door-Type 1 Mechanical Equipment Envelope* (Ref. 2.2.67). 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. 2.2.66).

- **Cask stand**: The cask stand is a structural steel frame used to support the horizontal cask while the impact limiters are removed. The cask stand is pre-staged in the Cask Preparation Room as required.

- **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 × 17 ft 6in. × 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 CRCF. The transporter is powered by a CRCF electrical system inside the facility. Site transporter mechanical equipment envelope details are provided in *Site Transporter Mechanical Equipment Envelope* (Ref. 2.2.9).

- **Common tools**: An array of common hand tools is available for removing/replacing bolts and attaching lid adapters.

A3.4 GAS SAMPLING ROOM

The Gas Sampling Room (Room 1034) is adjacent to the Cask Preparation Room and houses gas sampling equipment comprised of a vacuum pump, helium piping, and devices that analyze gases for radionuclide concentrations. The gas sampling equipment draws gas samples from inside the transportation cask and analyzes it before the cask is opened. The vacuum pump discharges the sample to the HVAC filtration equipment and helium is used to purge recirculation piping from the transportation cask after sampling. This task is accomplished prior to unbolting and removing the lid in preparation for waste canister unloading. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11)

A3.5 CASK UNLOADING ROOMS

Two side-by-side Cask Unloading Rooms (Rooms 1023 and 1024) located north and south between the Cask Preparation Room and Waste Package Positioning Rooms, provide space for two CTMs to remove waste canisters from casks and place them in waste packages. The rooms are approximately 32 ft square by 28 ft in height. The walls are made of a 4ft thick reinforced concrete design. There are equipment/shield doors in the east wall and a port slide gate in the roof of each room. The port slide gate, when open, allows the CTM to remove the canister from the cask and lift it into the Canister Transfer Room (Room 2004) on the second level. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11)

Equipment used in the Cask Unloading Room includes:

- **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 slide shield gates made of 9-in. thick steel, with a 1.5-in. thick cover plate, mounted on heavy duty bearing blocks and single edged v-slide. The gates are driven at an operating speed of approximately 2 in. per second by an electric motor and linear actuator for each gate. The port in the concrete floor is 84 in. in diameter. The concrete floor cover plate is flush and level to allow proper contact of the retractable shield skirt for the CTM. The gate provides sufficient shielding to allow operators on the deck when loaded casks are located in the Cask Transfer Room. Platform mechanical equipment envelope details are provided in *CRCF, IHF, RF, & WHF * Port Slide Gate Mechanical Equipment Envelope* (Ref. 2.2.31)

- **Cask transfer machine**: The shielded CTM, located in the Canister Transfer Room, is mounted on a pair of bridge girders that run on rails supported by the walls. The capacity of the CTM is 70 tons. The primary function of the CTM is to transfer canisters between ports, accessing packaging and staging locations located in the floor of the Canister Transfer Room. The CTM is a rail crane with a shielded enclosure called the "shielded bell." It is attached to and suspended from the crane trolley. A shield gate and a shield skirt are located at the bottom of the bell. The shield gate opens to allow a canister to be lifted into or out of the bell. It then closes to provide shielding for the lower portion of the bell and to limit the height over which a canister might fall, should it drop from the hoist. The shielded skirt is raised when the CTM is moved and is lowered to shield the gap between the shielded bell and the floor when a canister is being raised or lowered. The port and bell slide gates are interlocked so they can not open until the shield skirt is lowered into position. The crane hook travels vertically along the main axis of the shielded bell. Mechanical equipment envelope details are provided in *CRCF, IHF, RF, and WHF Canister Transfer Machine Mechanical Equipment Envelope* (Ref. 2.2.6). Control system design details are provided in *CRCF, RF, WHF and IHF Canister Transfer Machine Process and Instrumentation Diagram Sheet 1 of 4* (Ref. 2.2.39); *CRCF, RF, WHF, and IHF Canister Transfer Machine Process and Instrumentation Diagram Sheet 2* (Ref. 2.2.40); *CRCF, RF, WHF and IHF Canister Transfer Machine Process and Instrumentation Diagram Sheet 3* (Ref. 2.2.41)); and *CRCF, RF, WHF and IHF Canister Transfer Machine Process and Instrumentation Diagram Sheet 4* (Ref. 2.2.42).

- **Cask transfer trolley**: The CTT is used to transfer transportation casks and aging overpacks between the Cask Preparation Room and the Cask Unloading Rooms. The CTT is an air-based machine floating on a thin film of air above the floor surface. It operates by electric and pneumatic control and air modules. An automatic, programmable, logic-based control system, controls the air pressure and lift height of the trolley platform. Sensors on the CTT provide control system inputs on the floating height and rate of rise and lowering speed of the CTT platform. The maximum lift height of the trolley from the floor is approximately one inch. Mechanical equipment envelope details are provided in *Cask Transfer Trolley MEE* (Ref. 2.2.72). Control system design details are provided in *CRCF, RF, WHF, and IHF Cask Transfer Trolley Process and Instrumentation Diagram* (Ref. 2.2.46)

- **Shield doors**: The Cask Unloading Room shield door protects the Cask Preparation Room from radiation when a canister is lifted out of a cask or aging overpack. The Cask Unloading Room shield door provides equipment and personnel access to the Cask Unloading Room. The Cask Unloading Room shield door is a single slide open type door made of 16 in. thick steel plate and weighing approximately 268 tons. The door is operated by an electric motor turning a screw that interacts with a door mounted bracket. The door overlaps the aperture on the top, bottom, and both sides to provide shielding. Mechanical equipment envelope details are provided in *Nuclear Facilities Equipment Shield Door-Type 1 Mechanical Equipment Envelope* (Ref. 2.2.67) 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. 2.2.66)

A3.6 CANISTER TRANSFER ROOM

The Canister Transfer Room (Room 2004) is located at 32 ft in elevation, on the second floor, above the Cask Unloading Room. It houses two CTMs and corresponding specialized lifting equipment called grapples for handling the canisters. The CTMs traverse the room on a rail system at an elevation of 59 ft, 11 in. The CTMs are used to transfer canisters from the Cask Unloading Rooms to Waste Package Positioning Rooms and Canister Staging Areas located on the first floor. The Canister Transfer Room contains a 15-ton bridge crane used for operations and maintenance support. The 15-ton crane traverses a rail system above the CTMs located at an elevation of 80 ft 6 in. The primary uses for the 15-ton crane are to remove the lids from casks that contain waste canisters that are not equipped with a top shield on the canister, and to support the CTM maintenance activities. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Second Floor Plan* (Ref. 2.2.14)

The primary equipment components used within the Canister Transfer Room operations are as follows:

- **Canister transfer machine**: The shielded CTM, located in the Canister Transfer Room, is mounted on a pair of bridge girders that run on rails supported by the walls. The capacity of the CTM is 70 tons. The primary function of the CTM is to transfer canisters between ports, accessing packaging and staging locations located in the floor of the Canister Transfer Room. The CTM is a rail crane with a shielded enclosure called the "shielded bell." It is attached to and suspended from the crane trolley. A shield gate and a shield skirt are located at the bottom of the bell. The shield gate opens to allow a canister to be lifted into or out of the bell. It then closes to provide shielding for the lower portion of the bell and to limit the height over which a canister might fall, should it drop from the hoist. The shielded skirt is raised when the CTM is moved and is lowered to shield the gap between the shielded bell and the floor when a canister is being raised or lowered. The port and bell slide gates are interlocked so they can not open until the shield skirt is lowered into position. The crane hook travels vertically along the main axis of the shielded bell. Mechanical equipment envelope details are provided in *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope*

*Elevation & Detail–Sheet 2*Ref. 2.2.48) Control system design details are provided in Ref. 2.2.39), Ref. 2.2.40); Ref. 2.2.41); and Ref. 2.2.42)

- **CTM maintenance crane**: The CTM maintenance crane is a standard commercial overhead bridge crane rated for 15 tons. It is located in the Canister Transfer Room above the CTM. Mechanical equipment envelope details are provided in *Canister Receipt and Closure Facility CTM Maintenance Crane Mechanical Equipment Envelope* (Ref. 2.2.21) Control system design details are provided in *CRCF, RF, WHF, and IHF CTM Maintenance Crane Process and Instrumentation Diagram* (Ref. 2.2.47)

- **Canister grapples**: There are various grapples that are used to couple the different types of canisters to the CTM for lifting and transfer. The grapples configurations utilize three equally spaced jaws to clamp onto a canister for lifting. Grapple actuation mechanisms vary with the grapple type as well as the lifting capacities and estimated weight. Grapples are mechanically or electrically interlocked so that CTM lifting can not occur until the grapples are securely affixed to the load. Mechanical equipment envelope details are provided *in Canister Receipt and Closure Facility 18" SNF Canister Grapple Mechanical Equipment Envelope* (Ref. 2.2.19); *CRCF and IHF DWPF/INL Canister Grapple Mechanical Equipment Envelope* (Ref. 2.2.26); *CRCF and IHF WVDP/Hanford HLW Canister Grapple Mechanical Equipment Envelope* (Ref. 2.2.30*); CRCF, RF, WHF and IHF CTM Canister Grapple Process and Instrumentation Diagram* (Ref. 2.2.45).

- **Cask transfer trolley**: The CTT is used to transfer transportation casks and aging overpacks between the Cask Preparation Room and the Cask Unloading Rooms. The CTT is an air-based machine floating on a thin film of air above the floor surface. It operates by electric and pneumatic control and air modules. An automatic, programmable, logic-based control system, controls the air pressure and lift height of the trolley platform. Sensors on the CTT provide control system inputs on the floating height and rate of rise and lowering speed of the CTT platform. The maximum lift height of the trolley from the floor is approximately one inch. Mechanical equipment envelope details are provided in *Cask Transfer Trolley MEE* (Ref. 2.2.72) Control system design details are provided in *CRCF, RF, WHF, and IHF Cask Transfer Trolley Process and Instrumentation Diagram* (Ref. 2.2.46)

- **Cask port slide gate**: The cask port slide gates provide shielding to allow operators on the deck when canisters are located in the loading, unloading, or staging areas below the Canister Transfer Room floor. These gates are located in the operating deck, flush with the concrete floor, above each of these access ports (As described in Section A3.5)

- **Common tools**: An array of common hand tools is available for removing/replacing bolts and attaching lid adapters.

A3.7 WASTE PACKAGE POSITIONING ROOM

The Waste Package Positioning Rooms (Rooms 1018 and 1019) are located on the first floor below the Canister Transfer Room and the Waste Package Closure Room. The WPTT positions the waste package for loading below the access port in the floor of the Canister Transfer Room. The CTM is used to place a canister into the WPTT. The WPTT moves the waste package from beneath the waste package port in this room to beneath the Waste Package Closure Room where welding equipment in the Waste Package Closure Room accesses the top of the waste package, through welding ports in the floor, to weld the waste package inner and outer lids in place. After welding and cooling, the WPTT traverses to the west end of the Waste Package Positioning Room, where doors open accessing the Waste Package Loadout Room. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11)

The primary equipment in the Waste Package Positioning Room is the following:

- **Positioning room shield door**: The Waste Package Positioning Room shield doors are located at the west end of the positioning rooms between the Waste Package Positioning Rooms and the Waste Package Loadout Room. The doors prevent exposure to radiation from an exposed waste package. The shield door dimensions are approximately 47 ft × 26 ft 5 in. in height × 3 ft 3 in. The doors have an estimated weight of 245 tons. Mechanical equipment envelope details are provided in *Nuclear Facilities Equipment Shield Door-Type 4 Mechanical Equipment Envelope* (Ref. 2.2.68)

- **Waste package transfer trolley**: The WPTT is a motorized, rail mounted trolley that carries the waste package in a shielded enclosure from under the waste package port (Waste Package Positioning Room) into the Waste Package Closure Room for welding, and then to the TEV docking station in the Waste Package Loadout Room. The WPTT shielded enclosure can be rotated between vertical and horizontal orientations for loading and unloading. A waste package is loaded with a canister and closed in the vertical position. The WPTT mates with the docking station and rotates the shielded enclosure into the horizontal position for transferring the waste package into the TEV. Mechanical equipment envelope details are provided in *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Plan & Elevations Sh 1 of 2* (Ref. 2.2.49) and *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Elevation & Detail - Sheet 2* (Ref. 2.2.48) Trolley control design is provided in *CRCF and IHF WP Transfer Trolley Process & Instrumentation Diagram* (Ref. 2.2.29)

- **Waste package port slide gate**: Port slide gates provide shielding to allow operators to be on the deck of the Canister Transfer Room when canisters are located in the loading, unloading, or staging areas below the Canister Transfer Room floor. These gates are located in the operating deck, flush with the concrete floor, above each of these access ports (As described in Section A3.5)

A3.8 WASTE PACKAGE CLOSURE ROOM

The Waste Package Closure Room (Room 2007) is located on the second floor of the CRCF above the Waste Package Positioning Room. It contains the automated welding equipment used to close, seal, weld, and weld test waste packages. The NDE system verifies the integrity of the welds when they are completed. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Second Floor Plan* (Ref. 2.2.14)

The primary equipment components used within the Canister Transfer Room operations are as follows:

- **Remote handling system (RHS)**: The RHS is used in the Waste Package Closure Room to perform the various activities associated with sealing and testing of a waste package. The RHS consists of an overhead bridge, trolley, telescoping vertical mast, and a rotator actuator with a tool plate on the end. (Ref. 2.2.80)

- **Robotic arm 1 and 2**: The robotic arms are equipped with quick release features to change connectors to various end effectors for the lid welding and inspection process. The arms are mounted on a carriage assembly that traverses a concentric circular track around the floor aperture. The arms reach through the floor opening, to perform work on the top of the waste package held by the WPTT.

- **Bumpy bar code reader**: The bumpy bar code reader is used to read bumpy bar codes on the waste package. The reader verifies that the correct components are matched before the final assembly procedures are performed.

- **Burnishing tool**: The burnishing tool is an end effector attachment for the robotic arm. It is used to remove tensile stresses caused by the welding process of the closure weld. The burnishing tool is a roller ball assembly that basically peens the closure weld as the rollers run over the weld, applying pressure. The net effect induces a layer of compressive stress at the weld surface.

- **Machine vision camera**: The machine vision camera attached to the RHS is used to determine the location of the waste package during the closure process.

- **Purge port tool**: The purge port tool connects to a port in the center of the waste package inner lid after the initial welding process is complete. The purge port tool removes the port plug from the inner lid, purges and pressurizes the waste package with helium for the spread ring leak test. The tool remains on the lid for the duration of the leak test and inserts the port plug upon verification of successful leak testing.

- **Spread ring expander tool**: The spreader ring expander tool is used by the RHS during the process of sealing a loaded waste package. The tool applies pressure to the ring, expanding the ring before it is welded in place. After the ring is tacked and welded to the inner vessel, the spread ring expander tool holds the ring in place, and then is removed.

- **Spread ring leak test tool**: The spread ring leak test tool is used by the RHS in the Waste Package Closure Room in tandem with the purge port tool during leak tests. The tool is a circular gasket steel plate that fits over the installed spreader ring. The tool has a hole in its center to accommodate the purge port tool. The plate's gasket surface seals against the spread ring. The space between the spread ring and leak test tool is evacuated while the purge port tool pressurizes the waste package. The system monitors any helium escaping from the waste package through the spread ring.

- **Ultrasonic current testing/eddy current testing (UT/ET) end effectors 1 and 2**: The UT/ET end effectors are used to perform NDEs on the waste package closure process welds. The end effectors are attached to the robotic arms to perform the tests.

- **Weld end effectors 1 and 2**: The weld end effectors are attached to the robotic arms using quick-change connectors. The weld end effector welds the lid to the rest of the waste package. It incorporates a weld seam-tracking sensor that scans the weld joint ahead of the welding torch. Three dimensional measurements of the weld joint and weld surface are capable using this sensor. The weld end effector also incorporates a weld vision camera system capable of providing images of the welding process.

A3.9 WASTE PACKAGE LOADOUT ROOM

The Waste Package Loadout Room (Room 1015) is located on the west side of the CRCF between the Waste Package Positioning Rooms and the Waste Package Loadout Exit Vestibule. The Waste Package Loadout Room is approximately 90 ft wide by 100 ft long. The walls of this room form a part of the CRCF concrete superstructure and are 4 ft thick. The Waste Package Loadout Room is used for moving loaded waste packages out of the facility and receiving empty waste packages and pallets from the warehouse and placing them on the WPTT for subsequent use in cask unloading and transfer operations. Shield doors are located at the interfaces to both the Waste Package Positioning Rooms and the Waste Package Loadout Exit Vestibule. There is an elevated viewing gallery at the east end of the room that provides windows for monitoring activities in the Waste Package Closure and Waste Package Loadout Rooms. Room location is provided in *Canister Receipt and Closure Facility 1 General Arrangement Ground Floor Plan* (Ref. 2.2.11)

The primary equipment components used within the Waste Package Loadout Room operations are as follows:

- **Waste package handling crane**: The waste package handling crane is located in the Waste Package Loadout Room and has a dimensional envelope of approximately 78 ft × 89 ft × 49.5 ft clearance envelope elevation. The crane houses two trolleys on a single overhead gantry bridge: one rated for 100 tons and the other rated for 20 tons. The estimated weight of the bridge is 65 tons, the main trolley is 24 tons, and the block is 5 tons. The crane 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 waste package handling crane is used for lifting empty waste packages, waste package emplacement pallets and hardware associated with the WPTT. The auxiliary trolley on the waste package handling crane is rated at 20 tons. Mechanical equipment envelope details are provided in *Canister Receipt and Closure Facility WP Handling Crane Mechanical Equipment Envelope* (Ref. 2.2.22) Control system design details are provided in *CRCF and IHF Waste Package Handling Crane Process and Instrumentation Diagram* (Ref. 2.2.27)

- **Waste Package Loadout Room personnel shield doors**: The Waste Package Loadout Room personnel shield doors are located between the Waste Package Loadout Room and the Waste Package Loadout Exit Vestibule to protect personnel from radiation.

- **Waste package pallet yoke**: The waste package handling bridge crane lifts and moves empty waste packages and pallet assemblies in the Waste Package Loadout Room using the waste package pallet yoke. The yoke reaches around the waste package in the horizontal orientation, engaging the lifting features of the waste package pallet. The waste package and pallet assemblies are moved between the transporter vehicle and the WPTT carriage assembly. Mechanical equipment envelope details are provided in *CRCF and IHF WP Pallet Yoke Mechanical Equipment Envelope* (Ref. 2.2.28).

- **Waste package pedestals**: The WPTT transports waste packages of varying lengths. The top of each type of waste package is positioned at a set height. To accommodate the various waste packages and maintain the top set height requirement, waste package pedestals are used within the WPTT shielded enclosure. The pedestals are loaded into the WPTT shielded enclosure by use of the waste package handling bridge crane while the shielded enclosure is in the vertical position.

- **Waste package shield ring beam**: The waste package shield ring beam is used to install and remove the waste package shield rings from the WPTT while the WPTT shield ring enclosure is in the vertical orientation. The beam is used in conjunction with the waste package handling bridge crane and engages the four waste package ring shield trunnions for shield removal and installation. The shield ring protects workers from radiological exposure owing to shine from between the waste package and the inside of the Waste Package Transfer Trolley when the waste package is in the vertical position.

- **Waste package shield ring stand**: The waste package shield ring stand is a floor mounted structural frame used to hold and store the waste package shield ring while not being used.

- **Waste package transfer trolley**: The WPTT is a motorized, rail mounted trolley that carries the waste package in a shielded enclosure from under the waste package port (Waste Package Positioning Room) into the Waste Package Closure Room for welding and then to the TEV docking station in the Waste Package Loadout Room. The WPTT shielded enclosure can be rotated between vertical and horizontal orientations for loading and unloading. A waste package is loaded with a canister and closed in the vertical position. The WPTT mates with the docking station and rotates the shielded enclosure into the horizontal position for transferring the waste package into the TEV. Mechanical equipment envelope details are provided in *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Plan & Elevations Sh 1 of 2* (Ref. 2.2.49) and *CRCF-1 and IHF WP Transfer Trolley Mechanical Equipment Envelope Elevation &*

Detail - Sheet 2 (Ref. 2.2.48) Trolley control design is provided in *CRCF and IHF WP Transfer Trolley Process & Instrumentation Diagram* (Ref. 2.2.29)

- **Waste package transfer carriage**: The waste package transfer carriage assembly is used in conjunction with the WPTT and the waste package transfer docking station to move loaded waste packages out of the WPTT and into a TEV and to move unloaded waste package and pallets into the WPTT.

- **Waste package transfer carriage docking station**: The waste package transfer carriage docking station provides an elevated surface for the waste package transfer carriage to transverse from the WPTT shielded enclosure to the TEV.

A3.10 WASTE PACKAGE LOADOUT EXIT VESTIBULE

The Waste Package Loadout Exit Vestibule (Room 1014) provides TEV access to the CRCF, and an environmental separation between the outside environment and the Waste Package Loadout Room. Room 1014 is centrally located on the west side of the CRCF. The vestibule contains access doors at the north and south ends of the room, respectively, leading to the outside. The Waste Package Loadout Exit Vestibule has two sets of inner shield doors and outer overhead doors, interlocked to prevent both doors from being opened at the same time. Room 1014 is a non-confinement area. Room location is provided in *Canister Receipt and Facility 1 General Arrangement Ground Floor* Plan (Ref. 2.2.11)

ATTACHMENT B
CANISTER RECEIPT AND CLOSURE FACILITY OPERATIONAL SUMMARY

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.

B1 INTRODUCTION

A summary of CRCF 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 CRCF from receipt of waste forms in either a transportation cask or aging overpack, to export of canisters in waste packages or aging overpacks. These operations are presented according to the nodes of the CRCF PFD, Figure 15. The major pieces of mechanical handling equipment, including overhead bridge cranes, CTTs, CTMs, and associated lifting fixtures and devices are described in Attachment A.

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

B3 NODE 1: RECEIPT OF LOADED CASK OR AGING OVERPACK IN CASK PREPARATION ROOM

Pre-Job Plan

Before the cask/aging overpack and conveyance reach the CRCF, a certified crew member is notified of the type of cask/conveyance to expect and how to process it. According to this information, the crew member determines the appropriate procedures and equipment to use to process this cask/conveyance type. The crew member also communicates this information to all the crew members involved in the processing of this cask/conveyance. The person in charge must also fill out a pre-lift safety checklist.

Move Carrier into Cask Preparation Room

- The crew is at the entrance of the CRCF to facilitate movement of the transportation cask/aging overpack into the CRCF. The transportation cask, whether on a railcar or truck, is conveyed to the CRCF by the SPM. The SPM runs on either rail or road. The aging overpack is conveyed to the CRCF by the site transporter.

- Once the railcar, truck trailer, or site transporter reaches the facility, the crew opens the overhead door and directs the conveyance into the CRCF Cask Preparation Room. At this point the crew verifies that the waste form received matches the pre-job plan.

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

Remove Site Prime Mover from Cask Preparation Room

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

Remove and Store Personnel Barrier (If Required)

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

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

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

For all waste forms received in transportation casks, with exception of DPCs in horizontal casks, the impact limiters are removed and stored using the cask handling 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 handling 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 handling crane, removes and stores the impact limiters as follows:

- Crane operator moves crane to impact limiter position.
- Crane operator aligns crane to impact limiter and crew attaches rigging.
- Crane operator removes the impact limiter.
- Crane operator moves impact limiter to position for lowering.
- Crane operator lowers impact limiter and disengages.
- Personnel install trunnions on the cask if required.

B5 NODES 3-5: CASK UPENDING AND REMOVAL FROM CONVEYANCE (EXCEPT CASKS CONTAINING DUAL PURPOSE CANISTERS)

- The cask is upended and placed vertically into the CTT. For this operation, the CTT with proper cask pedestal is pre-staged in the CRCF Cask Preparation Room.

Node 3: Prepare Cask for Upending

- 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. The bolts are counted and the crew supervisor checks off bolt removal on the checklist. To upend the cask, the crew uses the mobile access platform to attach the cask handling crane, with cask handling yoke, to the cask as follows:

- Crew attaches cask handling yoke to cask handling crane.

- Crane operator moves cask handling crane to transportation cask.

- Crane operator aligns crane to cask.

- Crane operator engages yoke arms on trunnions.

Node 4: Upend Transportation Cask on Conveyance

The crane operator upends the transportation cask using the cask handling crane with yoke. The crew then uses common tools and the mobile access platform to unbolt the constraints on the bottom half of the cask so the cask can be lifted. This step is verified.

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

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. There may be bumpers installed prior to closing the CTT door. Once the cask is secure in the CTT, the crew disengages the cask from the crane. This step is defined in training and must be signed off on the checklist prior to continuing with operations.

B6 NODES 6-8: CASK UPENDING AND REMOVAL FROM CONVEYANCE (CASK CONTAINS DUAL PURPOSE CANISTERS)

The cask containing a DPC is upended using a tilting frame. This operation employs lift slings to lift and move the cask.

Node 6: Position Lift Slings on Cask and Attach to 200-ton Crane

The crew positions the lift sling onto the cask. The sling is attached to the cask handling crane. This node occurs for both the lift from the railcar to the pedestal and the lift from the pedestal to the tilting frame.

Node 7: Lift and Move Cask

The crane operator uses the cask handling crane and a sling to move the cask with impact limiters from the conveyance to the cask stand. The impact limiters are removed (Node 2) and stored. If necessary, trunnions are installed onto the cask using common tools, standard rigging, the crane auxiliary hook, and the mobile platform. Next, the transportation cask is moved onto the cask tilting frame using the cask handling crane and a sling.

Node 8: Secure Cask to Cask Tilting Frame and Upright Cask

The cask is secured to the cask tilting frame using common tools and the cask handling platform. A yoke is attached to the cask handling crane and positioned so that the yoke arms are aligned with the trunnions. After the yoke arms are verified to engage, the cask is lifted a small distance to verify the crane is bearing the weight and that all attachments were made properly. The crane is then carefully moved to maintain a vertical line directly above the upper trunnions. Once the cask is fully upright, the cask is released from the cask tilting frame using common tools.

B7 NODES 9 AND 10: CASK AND AGING OVERPACK PREPARATION ACTIVITIES

Preparation of a transportation cask involves gas sampling (if required) and preparation for lid removal by the CTM (remove lid bolts and attach cask lid adapter).

Node 9: Gas Sampling and Equalization

To sample the cask, a crewmember must plug a hose into the quick-disconnect sampling port and then open the valve to start flow. Once connected, a crew member takes a sample reading of gas in the Gas Sampling Room. The crew member then verifies that the cask is safe for opening. After the sample is taken, the remainder of the gas is vented, the valve closed and the hose taken off.

Node 10: Lid Preparation

The crew uses common tools and the cask preparation platform to remove all of the transportation cask or aging overpack lid bolts. The bolts are counted and the crew supervisor checks off bolt removal on the checklist before the lid lift fixture is attached. For transportation casks, once the bolts are removed, the crane operator and crew use the cask preparation platform, common tools and the cask handling crane with standard rigging to retrieve and emplace the proper lid-lifting fixture. The following specific steps are involved in lid preparation:

- Crane operator selects and retrieves appropriate lid lift fixture with cask handling crane auxiliary hook. There are two lid lift fixtures available: one for a rail cask and the other for a truck cask.
- Crane operator moves lid lift fixture to cask and opens shield plate.
- Crane operator lowers lid lift fixture and disengages and closes shield plate.
- Crew members bolt lid lift fixture to cask lid. Using the cask preparation platform and common tools, crewmembers emplace and tighten the fixture bolts and verify (checklist) that all the bolts have been properly installed.

For DPCs, the lid is removed and a DPC lift fixture is installed. See Node 11 for disposition of the non-DPC cask lid.

B8 NODE 11: TRANSFER TRANSPORTATON CASK ON CASK TRANSFER TROLLEY OR AGING OVERPACK ON SITE TRANSPORTER FROM CASK PREPARATION ROOM TO CASK UNLOADING ROOM

Using the CTT or site transporter, the crew moves the transportation cask or aging overpack from the Cask Preparation Room to the Cask Unloading Room and positions the cask/aging overpack under the cask port. The steps here are the same for all waste forms. To do this, the crew moves the CTT or site transporter to the Cask Preparation Room door; they open the shield door, move the CTT or ST through the door into position under the cask port, disconnecting the site transporter power or CTT air hoses, and close the shield door.

B9 NODES 12-14: TRANSFER A CANISTER INTO A WASTE PACKAGE OR AGING OVERPACK WITH THE CANISTER TRANSFER MACHINE

Using the CTM, the crew moves a canister from a transportation cask or aging overpack and places it into a waste package, aging overpack, or storage location. CTM operations are performed remotely from a control room within the CRCF. Since the CRCF contains two CTMs, two CTM operations can occur simultaneously. The CRCF has the capability to place canisters into an aging overpack on the site transporter, to subsequently move to the aging pad and also has the capability to receive aging overpacks from the aging pad, RF, or WHF.

Node 12: Remove Cask Lid (Non-DPC Only) and Lift Canister Into CTM

Prior to transferring a canister, the lid of the cask/aging overpack must be removed from the cask/aging overpack as follows:

- Move CTM to port and lower shield skirt.
- Open CTM slide gate and cask port slide gate.
- Lift cask/aging overpack lid into CTM and close cask port slide gate.
- Bypass the slide gate interlock and lift the skirt in preparation of movement.
- Move CTM to transportation cask lid station.
- Lower lid to lid station, disengage grapple and re-engage bypass.

The canister is then lifted into the CTM as follows:

- Install appropriate canister grapple – The CTM operator moves the CTM to the CTM Maintenance Area where a crew member manually attaches the appropriate canister grapple.

- Move CTM to cask port and lower skirt.

- Open CTM slide gate and cask port slide gate.

- Lower hoist, engage grapple and lift canister into CTM.

Node 13: Move Canister to Unloading Position

Using the CTM, the crew moves a canister to the unloading position as follows:

- Close CTM slide gate and cask port slide gate.
- Lift shield skirt and move CTM to waste package port or to other cask port.

Node 14: Lower Canister into Waste Package, staging, or Aging Overpack

Using the CTM, the crew lowers a canister into the waste package, staging cell, or aging overpack as follows:

- Lower shield skirt and open CTM slide gate and waste package port or other cask port slide gate.

- Lower canister into waste package or aging overpack.

- Disengage CTM from canister.

- Close CTM slide gate and waste package port or cask port slide gate.

B10 NODE 15: MOVEMENT OF LOADED WASTE PACKAGE TRANSFER TROLLEY TO CLOSURE POSITION IN THE WASTE PACKAGE POSITIONING ROOM

The WPTT carries the loaded waste package to the closure position in the Waste Package Positioning Room.

Prepare Waste Package for Movement to Closure Position

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

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

Move Loaded Waste Package to Closure Position

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

B11 NODE 16: CLOSURE OF THE WASTE PACKAGE

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

Verify Canister and Waste Package

The following steps are performed remotely The operator uses the camera and bumpy bar code reader to read the bar code on the waste package to ensure it is the correct package. At this time, the operator puts the waste package serial number into the tracking chart. This step is verified by quality assurance.

Seal the Inner Lid

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

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

The RHS operator remotely retrieves the purge port tool and places it on top of the purge port. Once properly positioned, the crew initiates the tool to evacuate the inner vessel and backfills the vessel with helium. The crew then stops helium flow, closes the cap and performs leak detection.

Seal Waste Package

The crew retrieves the purge port cap, scans it with the bumpy bar code reader, documents the serial number, and places it onto the purge port. The crew then welds the cap in place while quality assurance visually inspects the process. Once welded, the crew dresses the weld.

Once the purge port cap is on, the crew proceeds to install the outer lid. The crew uses the camera and bumpy bar code reader to read and document the bar code on the waste package outer lid. This step is verified by quality assurance. Once the serial number of the outer lid is documented, the crew retrieves the lid, engages the lid grapple, moves the lid to the proper position and then disengages the grapple. The crew then welds the outer lid and tests the weld.

B12 NODE 17: EXPORT LOADED WASTE PACKAGE

Move Waste Package on WPTT from Positioning Room to Loadout Room

The waste package is moved from the Waste Package Positioning Room to the Waste Package Loadout Room. This step concludes with the waste package in the loadout area, ready to be placed in the TEV for export. This step is performed remotely. The operator opens the Waste Package Positioning Room shield door and moves the WPTT (on rails) to the docking station in the Waste Package Loadout Room. Once the WPTT has cleared the door, an operator closes the Waste Package Positioning Room shield door. When in the proper position by the docking station, the WPTT engages the docking station by moving an arm down. Engagement is automatic. The operator checks the indicator to ensure proper engagement before continuing.

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

At this point, the operator removes the shield ring from the waste package.

Rotate WPTT Horizontally and Load Waste Package into TEV

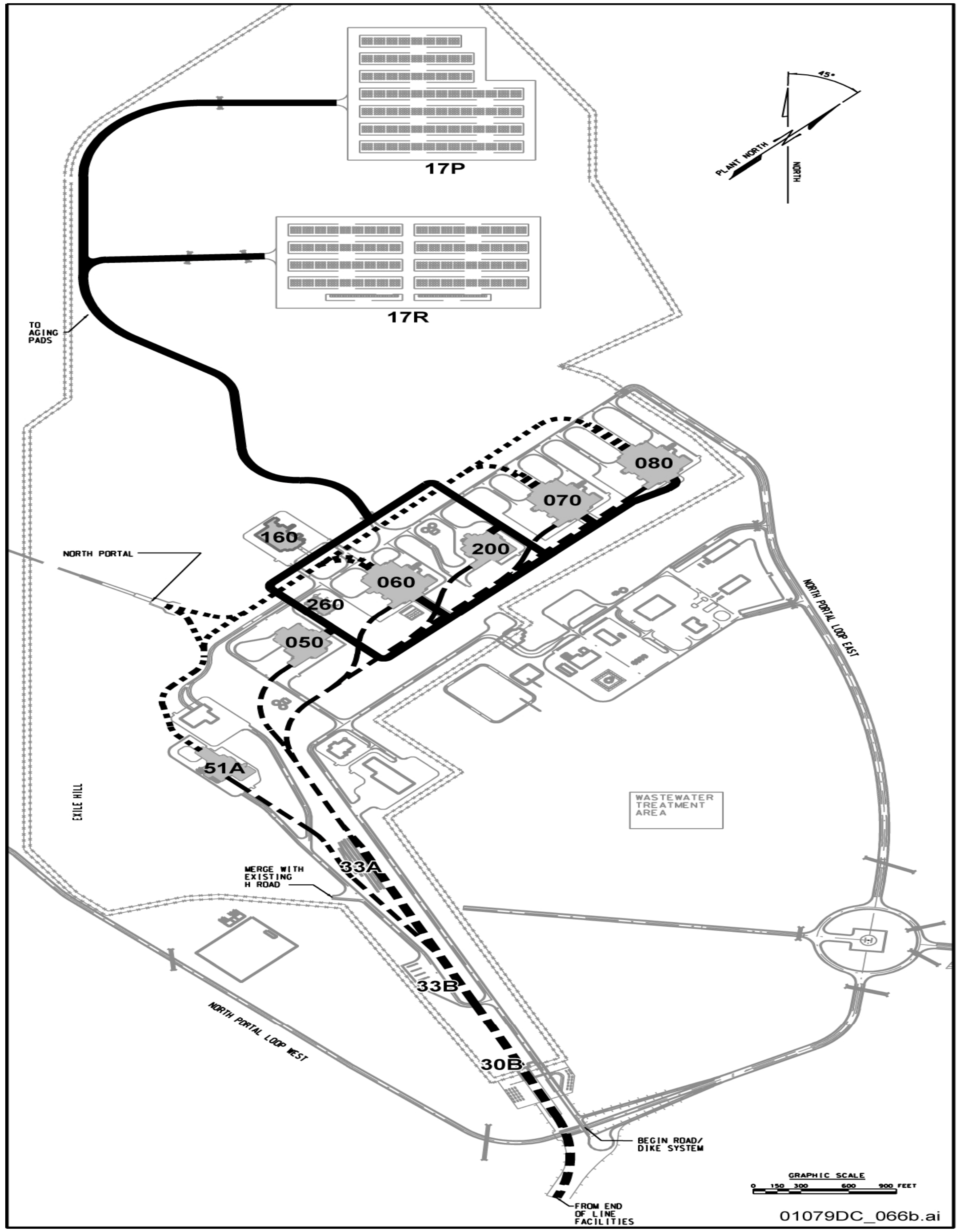
The following steps are performed remotely: The TEV is pre-staged in the Waste Package Loadout Room with its shield doors open, base plate extended and shielded enclosure lowered. The operator ensures that the loadout room is cleared of personnel and then signals the WPTT to tilt down the waste package. By tilting down the waste package, the screw drive of the docking station connects to the waste package transfer carriage. The waste package transfer carriage can then be pulled into the TEV. The waste package is then visually inspected via camera for defects while it is loaded into the TEV. Once the waste package has been moved completely into the shielded enclosure of the TEV, the operator signals the TEV to pick up the waste package by lifting the shielded enclosure. Once the shielded enclosure is lifted, the TEV base plate retracts and the shield door automatically closes and locks into the base plate. Once the TEV is fully loaded and secured, the operator signals the facility door to open, and the TEV to exit the facility.

B13 NODE 18: CLOSE AND EXPORT LOADED AGING OVERPACK

The aging overpack is closed and exported, in reverse fashion, to the process used to receive, prepare, and move the aging overpack into the Cask Unloading Room. The site transporter moves the aging overpack from the Cask Unloading Room into the Cask Preparation Room. The aging overpack lid bolts are installed using common tools and the cask preparation platform. The aging overpack is moved on the site transporter from the Cask Preparation Room to the outside via the Site Transporter Vestibule.

ATTACHMENT C
CANISTER RECEIPT AND CLOSURE FACILITY LOCATION WITHIN THE GROA

The CRCF is one of four waste-handling building types (Refs. 2.2.76) and (Ref. 2.2.77). Figure C-1 displays the location of the CRCF and other major facilities within the GROA. The CRCF specializes in receiving transportation casks (containing DPCs, DOE standard canisters, HLW, MCOs, or TAD canisters), removing the waste-bearing canister (or canisters) from the casks, transferring the waste into waste packages (or aging overpacks), closing the waste packages (or aging overpacks), and sending the waste packages underground (or aging overpacks to the aging pad). The CRCF also receives aging overpacks containing TAD canisters from the aging pad which are removed and transferred into waste packages for placement underground.



FACILITIES

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

TRANSPORTATION ROUTES

- APPROXIMATE TRANSPORTATION CASK CONVEYANCE ROUTES (dashed line)
- TEV TRANSPORTATION ROUTES (dotted line)
- APPROXIMATE SITE TRANSPORTER AND CASK TRANSFER TRAILER ROUTES (solid line)

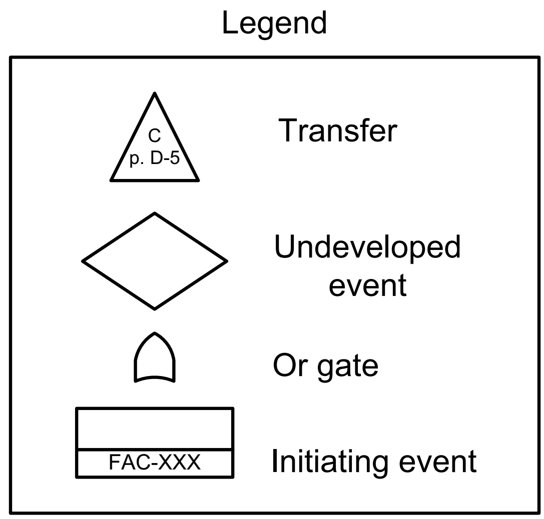
NOTES: TEV = transport and emplacement vehicle.

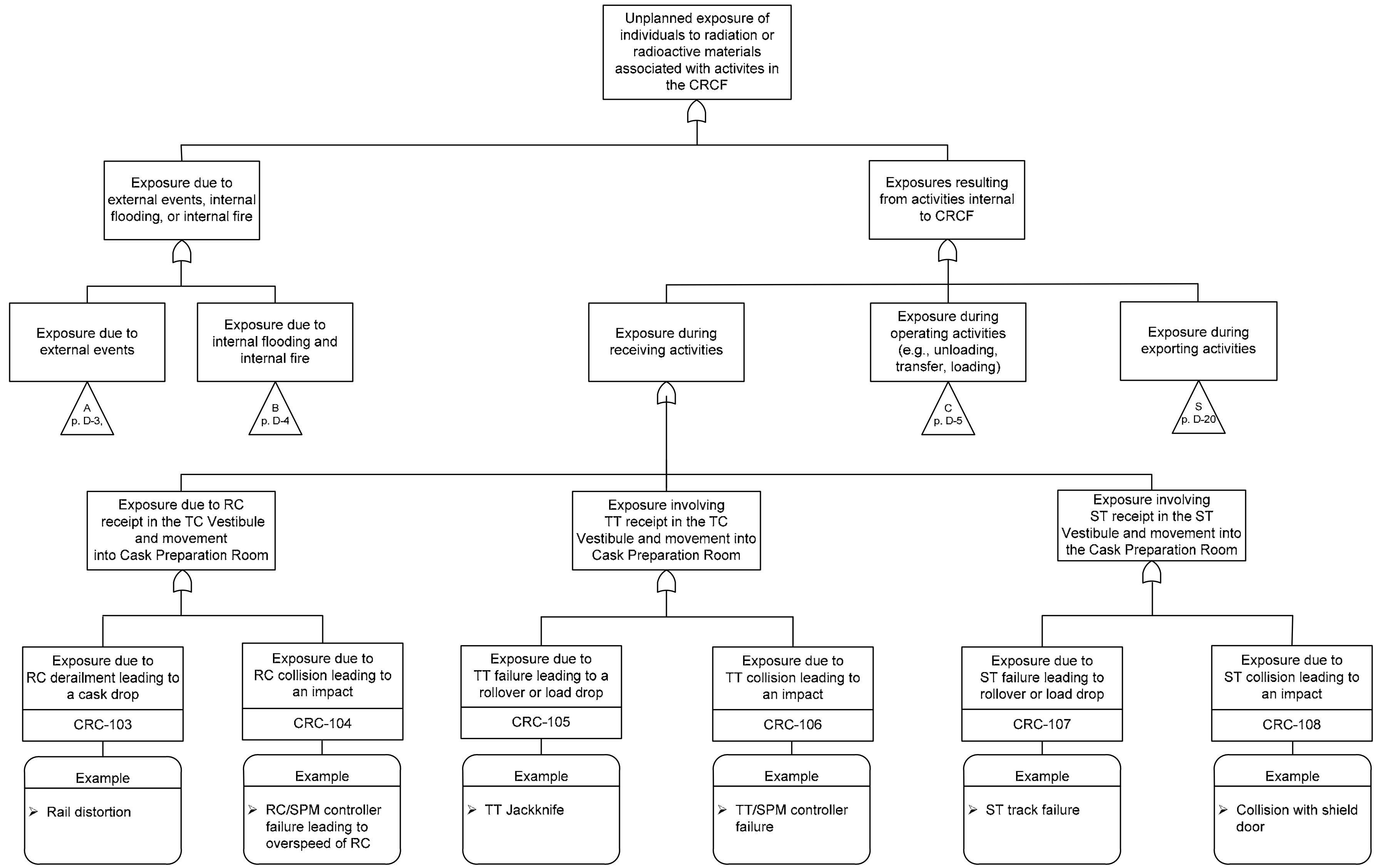
Source: Modified from (Ref. 2.2.76) and (Ref. 2.2.77).

Figure C-1 Geologic Repository Operations Area Overall Site Plan

ATTACHMENT D
CANISTER RECEIPT AND CLOSURE FACILITY MASTER LOGIC DIAGRAMS

A MLD describing internal hazards including internal fires and floods, and external hazards for the CRCF is presented in Figures D-1 to D-19.

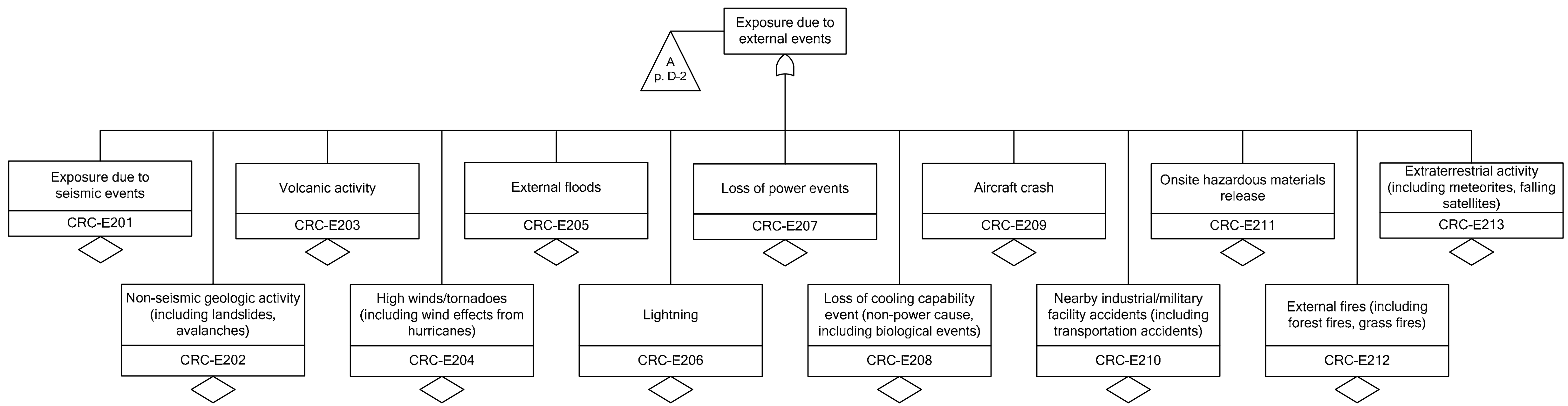




NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CRCF = Canister Receipt and Closure Facility; RC = railcar; SPM = site prime mover; ST = site transporter; TC = transportation cask; TT = truck trailer.

Source: Original

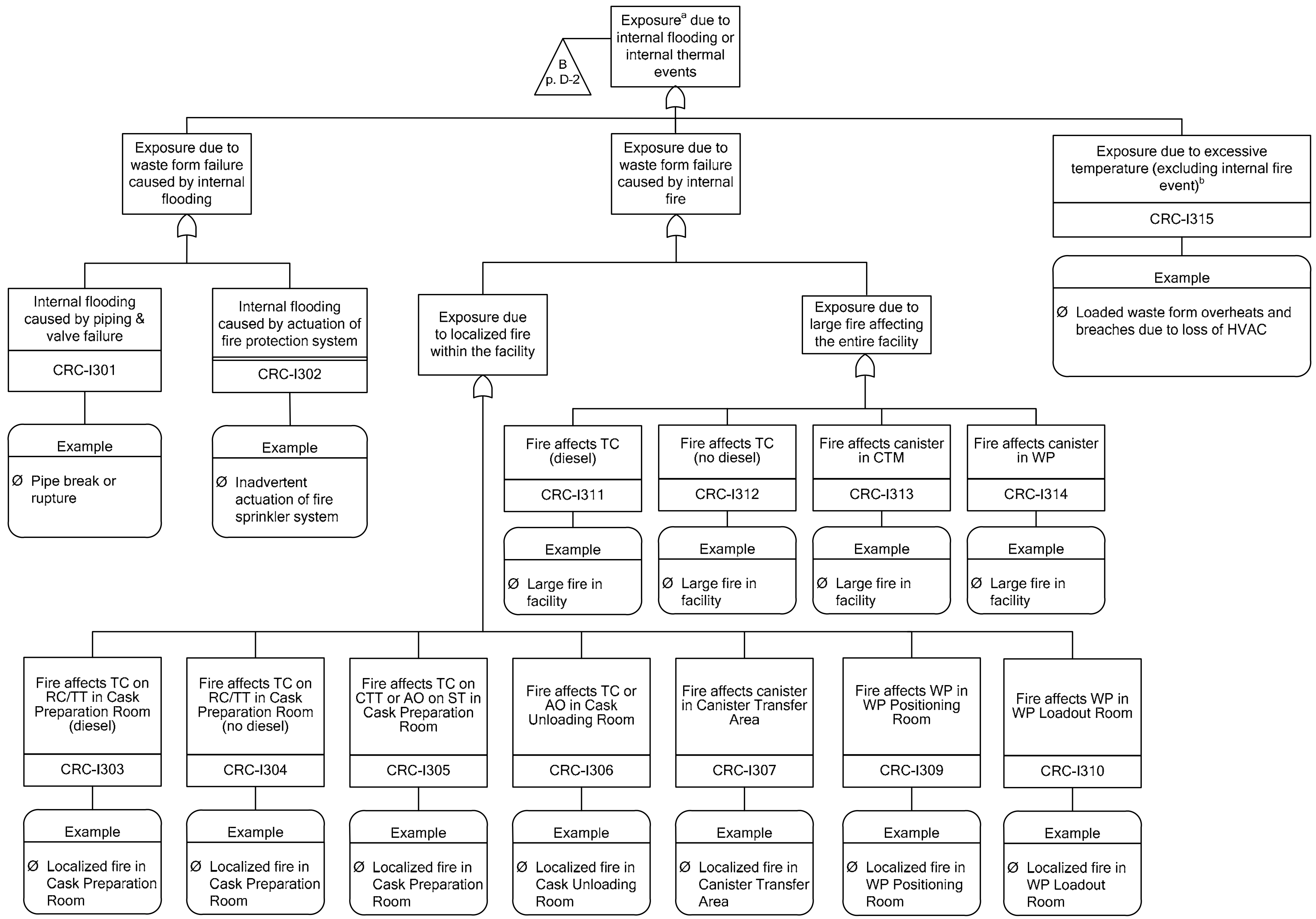
Figure D-1. Unplanned Exposure of Individuals to Radiation or Radioactive Materials Associated with Activities in the CRCF



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

Source: Original

Figure D-2. Exposure Due to External Events



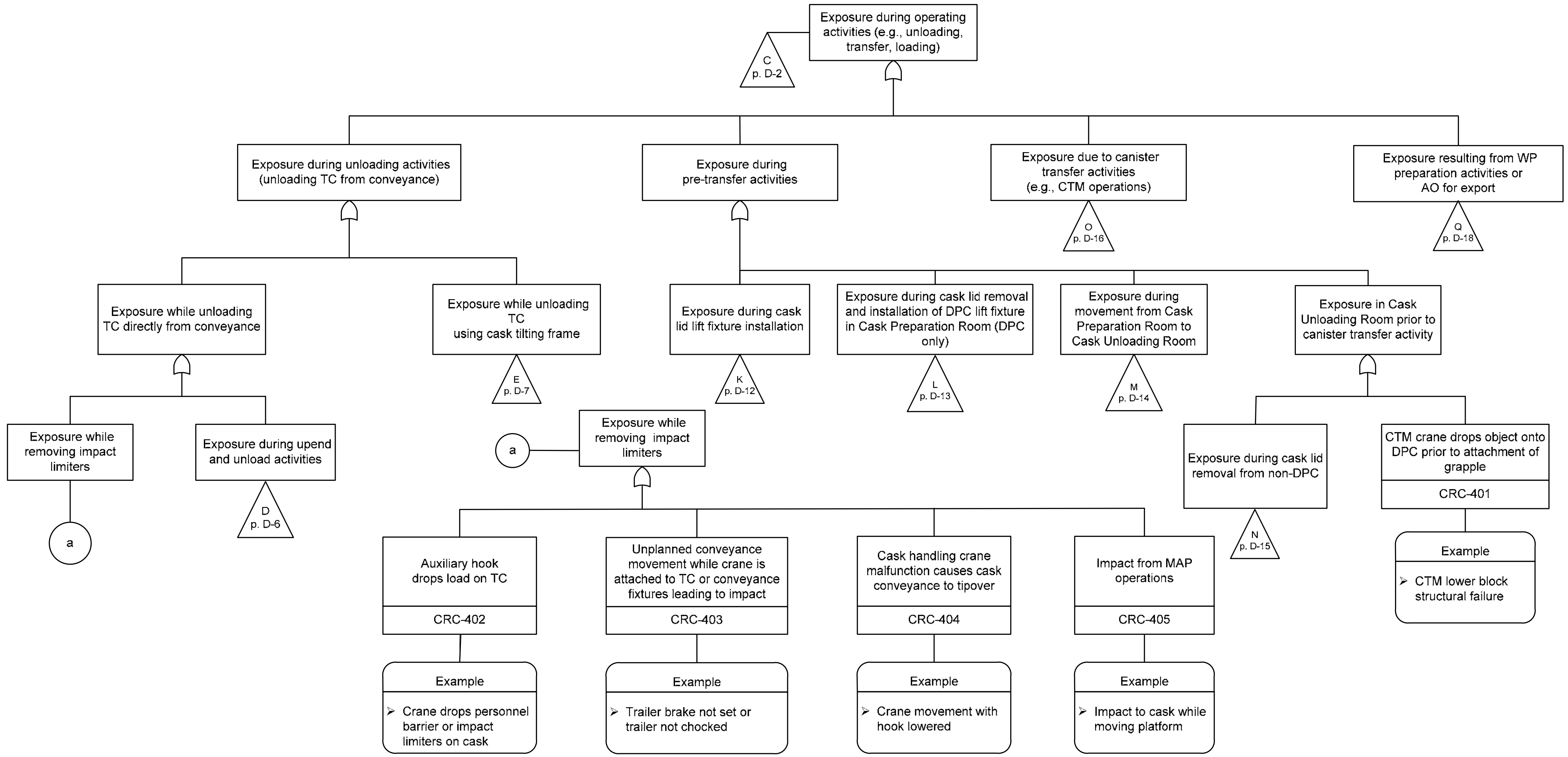
NOTE: [a] Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."

Non-fire thermal event sequences have not been developed because canisters in the CRCF experiencing a loss of HVAC flow would not reach a high enough temperature to jeopardize the structural integrity of the canister. (Ref. 2.2.74)

[b] AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; HVAC = heating, ventilation, and air conditioning; RC = railcar; ST = site transporter; TC = transportation cask; TT = truck trailer; WP = waste package.

Source: Original

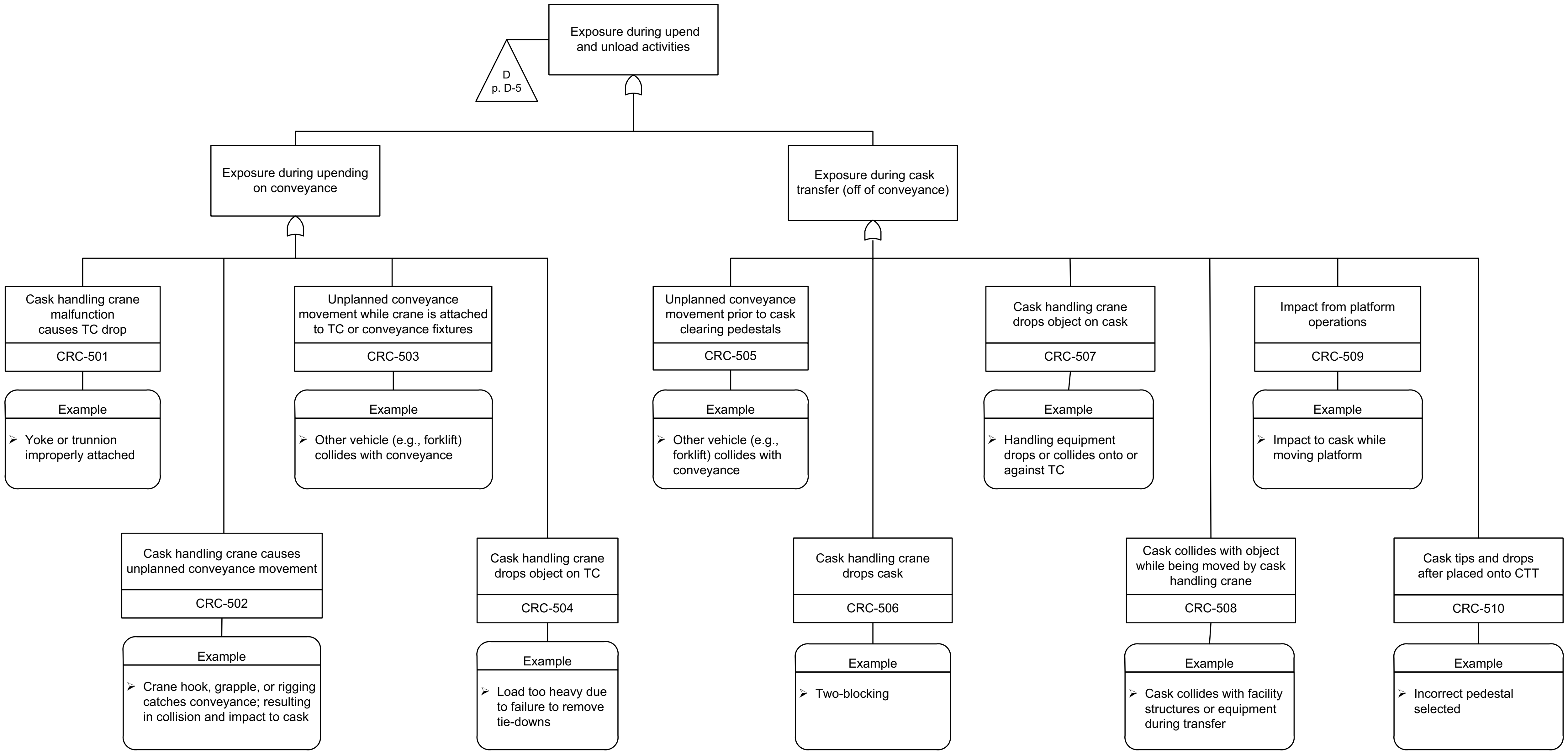
Figure D-3. Exposure Due to Internal Flooding or Internal Thermal Events



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
AO = aging overpack; CTM = canister transfer machine; DPC = dual-purpose canister; MAP = mobile access platform; TC = transportation cask.

Source: Original

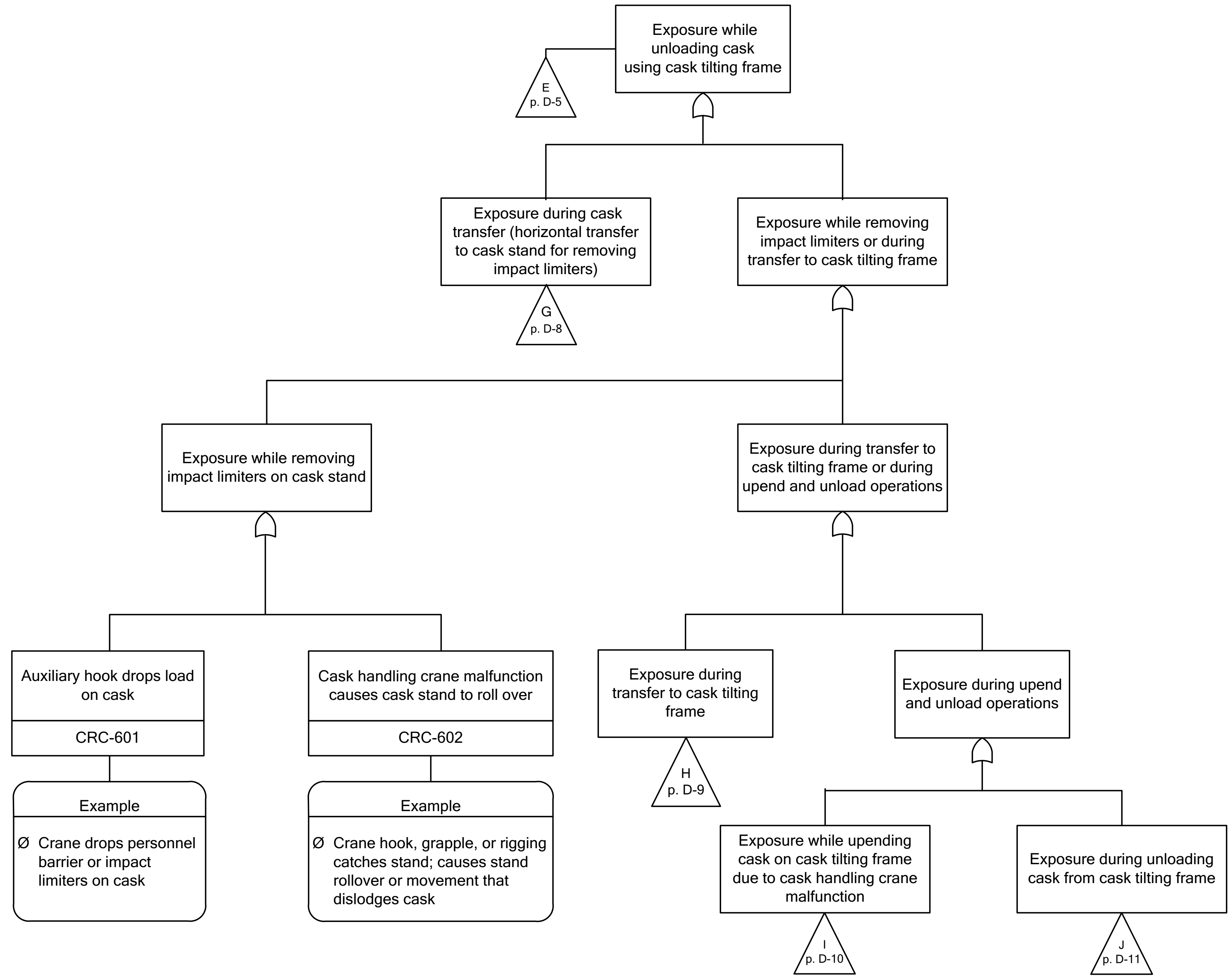
Figure D-4. Exposure During Operating Activities (e.g., unloading, transfer, loading)



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

Source: Original

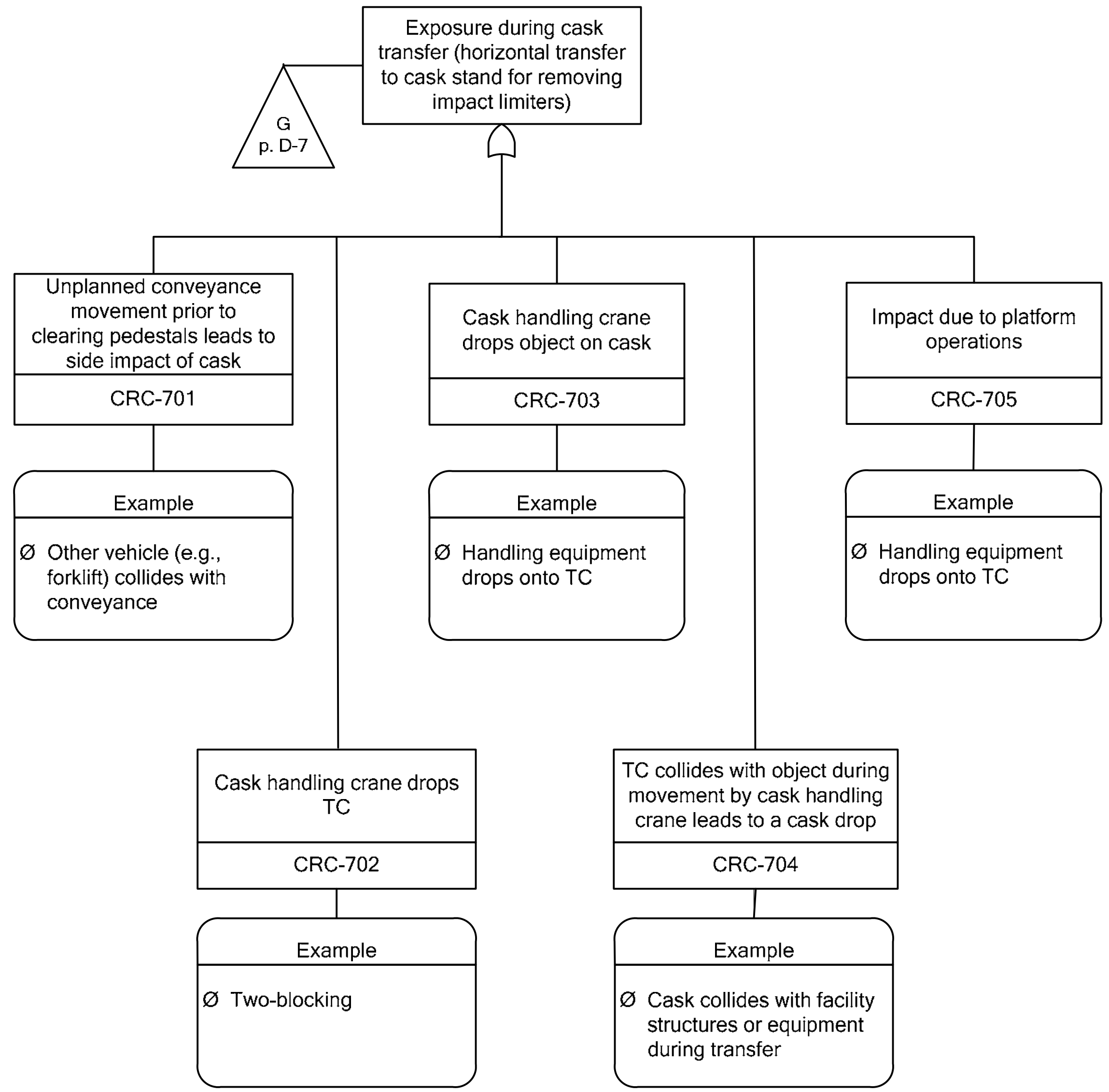
Figure D-5. Exposure During Upend and Unload Activities



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

Source: Original

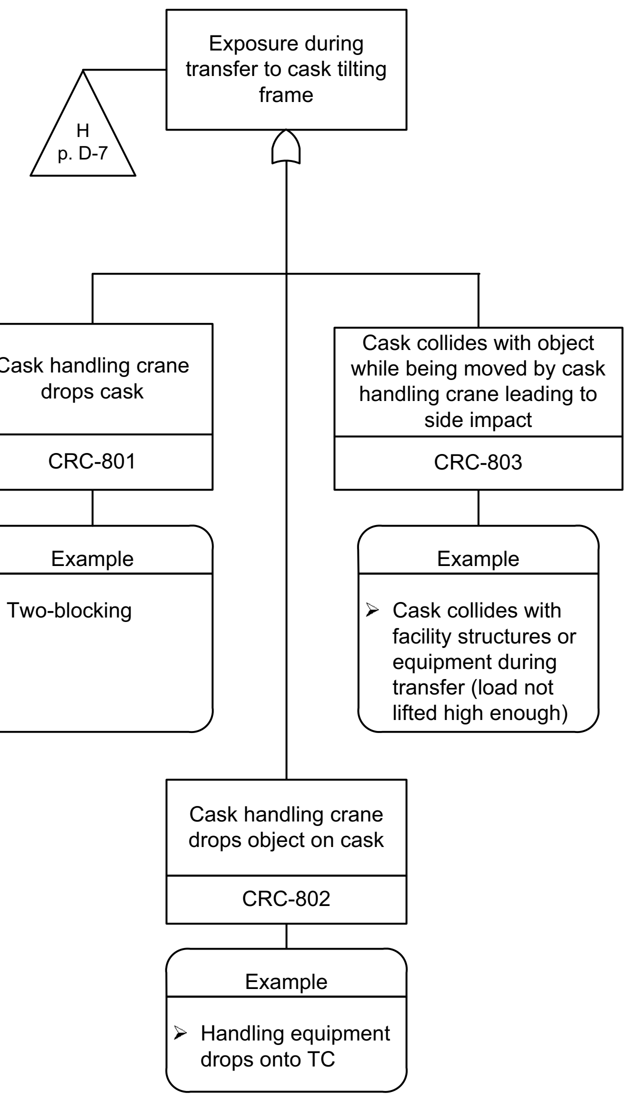
Figure D-6. Exposure While Unloading Cask Using Cask Tilting Frame



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

Source: Original

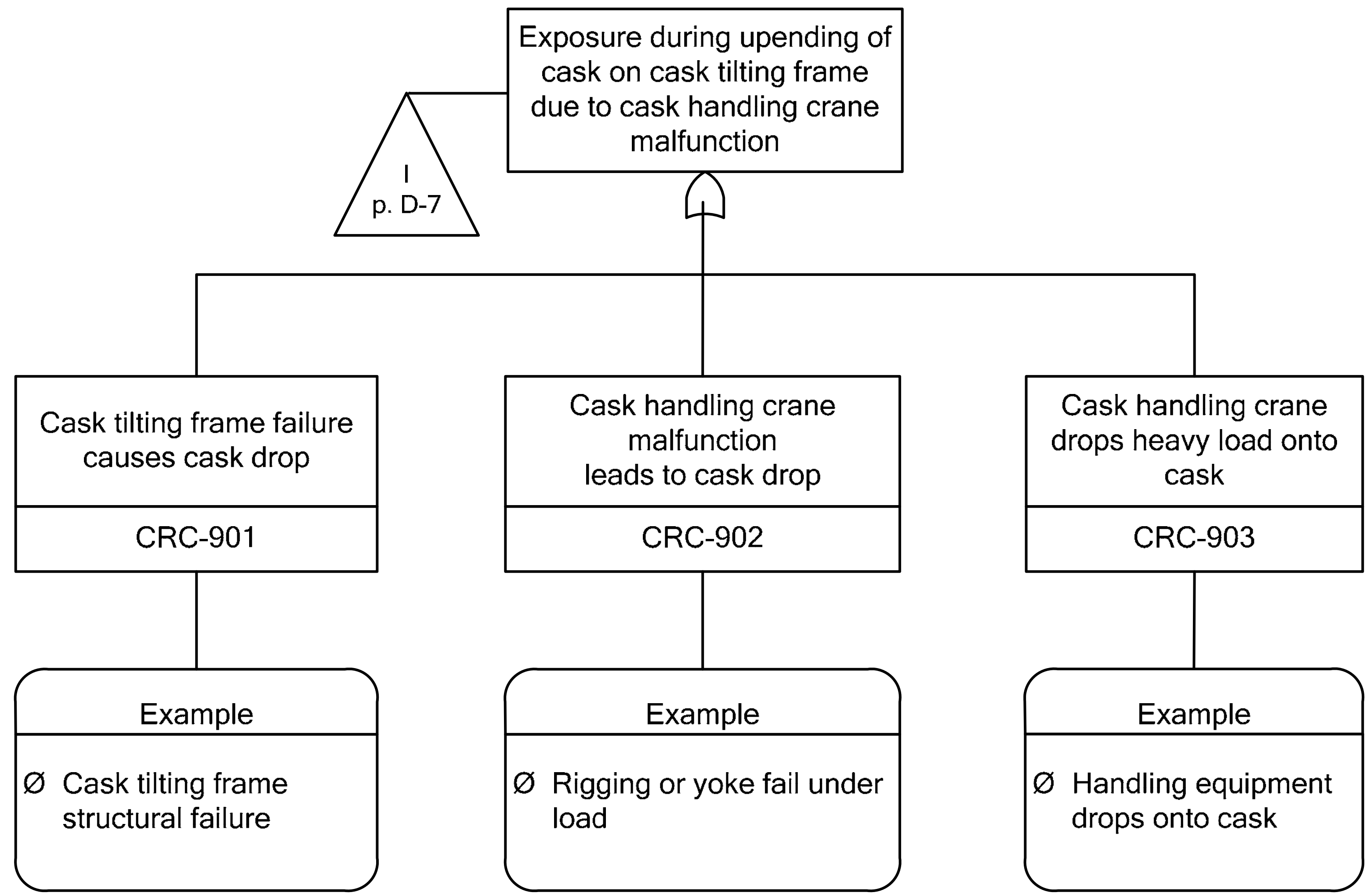
Figure D-7 Exposure During Cask Transfer (Horizontal Transfer to Cask Stand for Removing Impact Limiters)



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

Source: Original

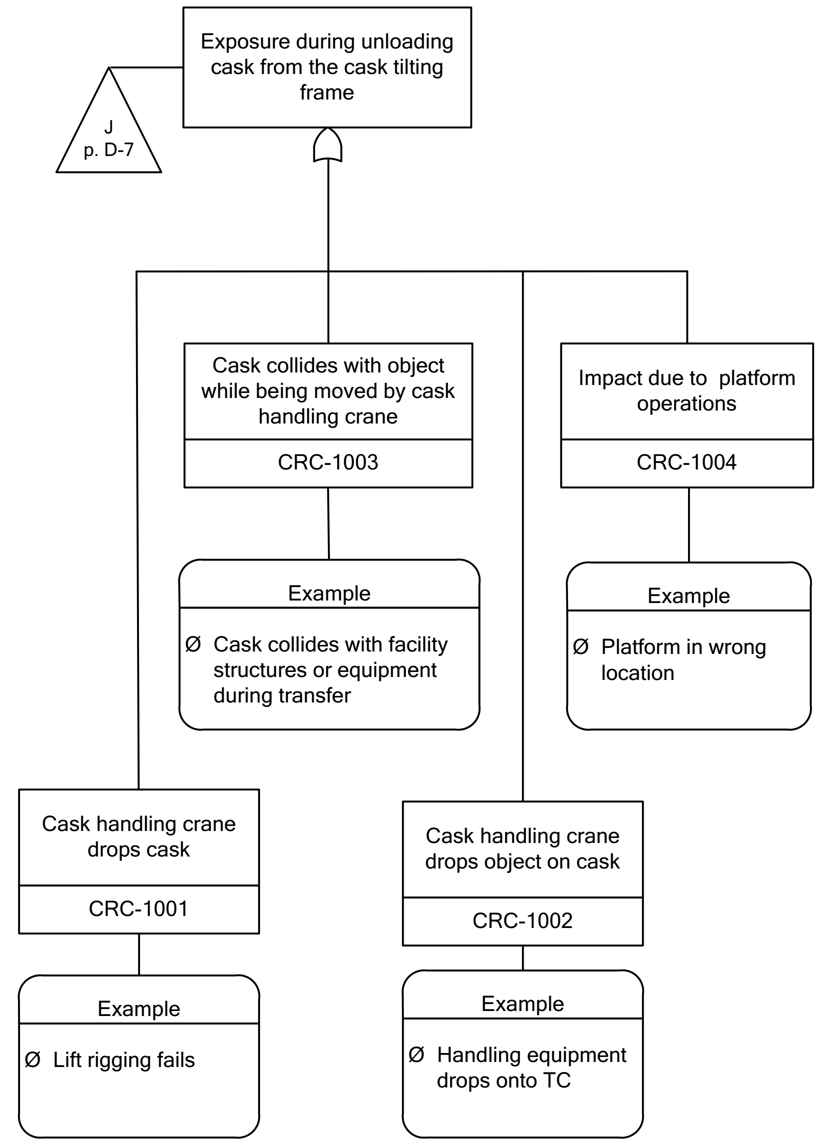
Figure D-8. Exposure During Transfer to Cask Tilting Frame



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

Source: Original

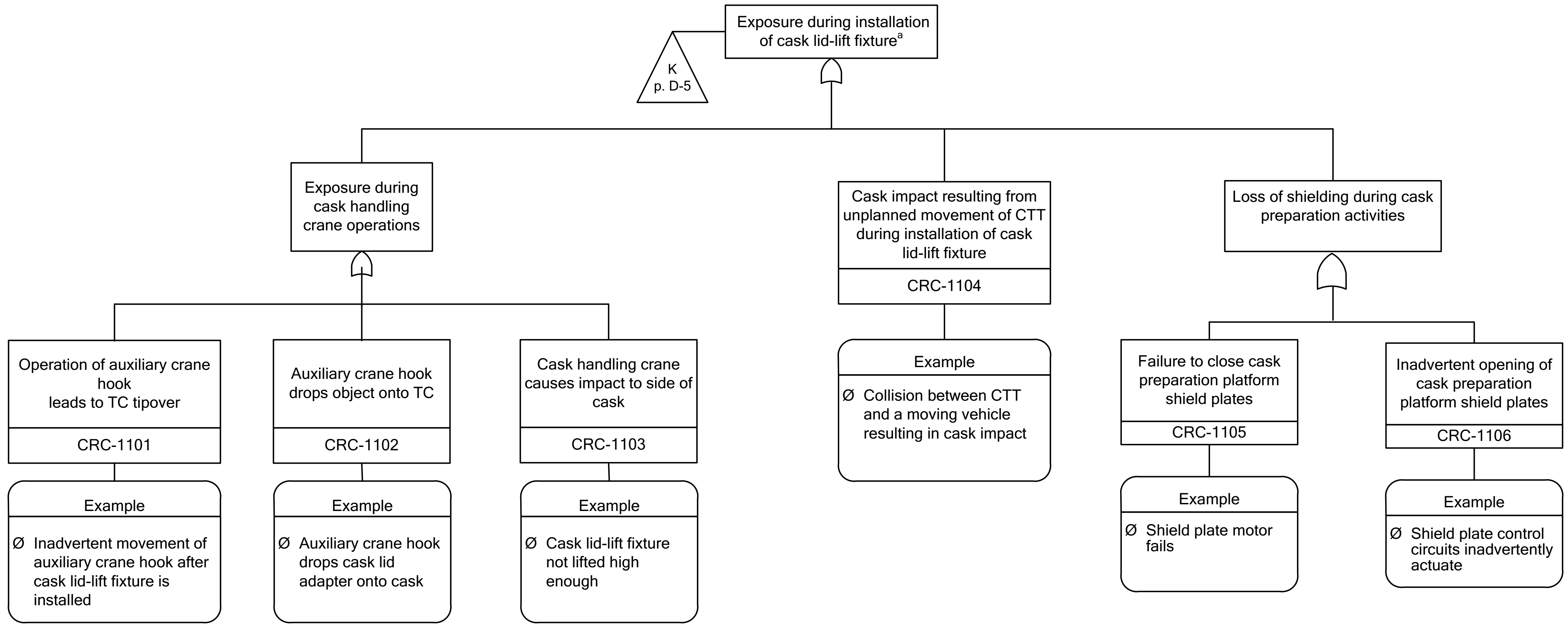
Figure D-9 Exposure During Upending of Cask on Cask Tilting Frame Due to Cask Handling Crane Malfunction



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

Source: Original

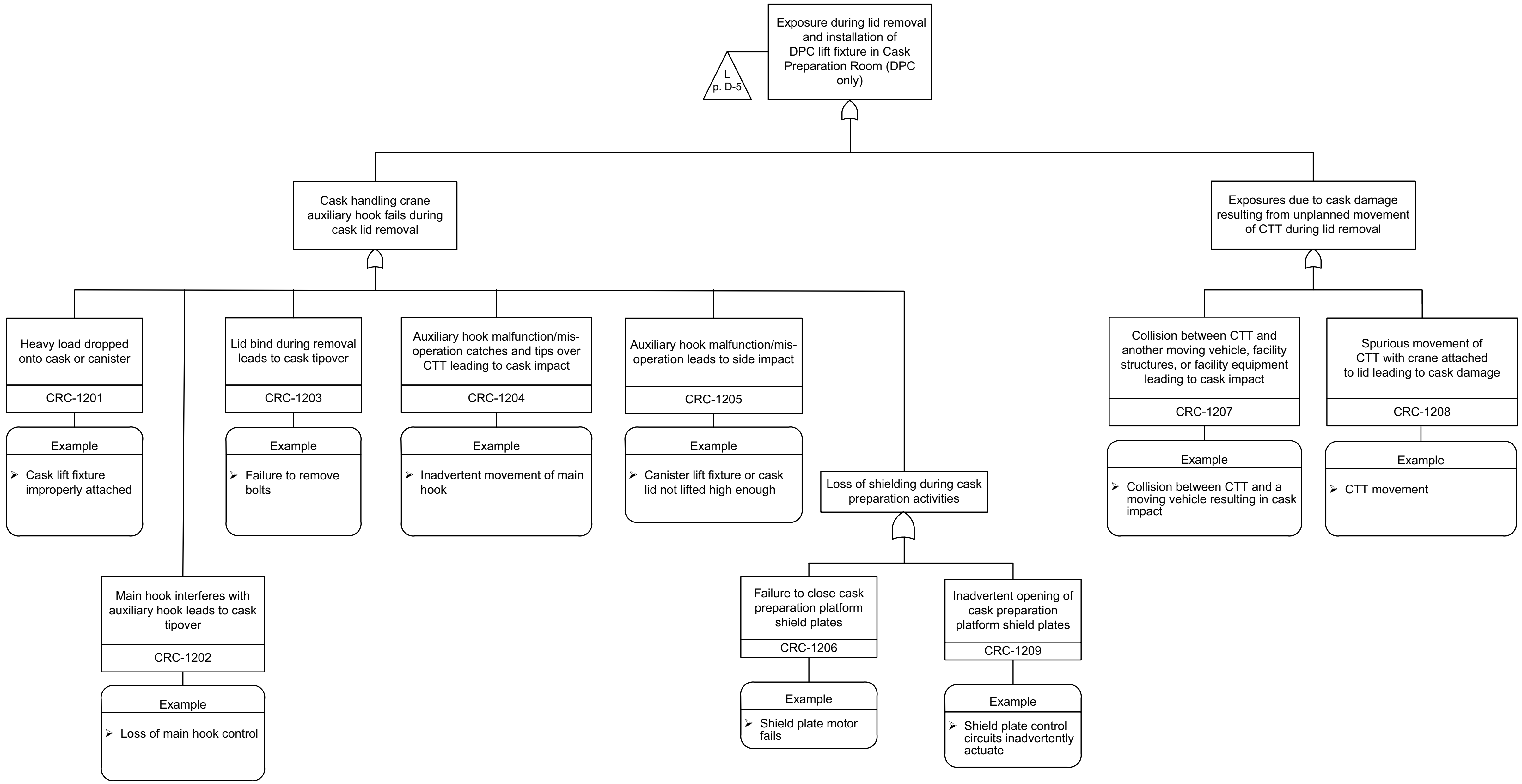
Figure D-10. Exposure During Unloading Cask from the Cask Tilting Frame



NOTE: [a] This event also applies to operations involving an aging overpack.
Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTT = cask transfer trolley; TC = transportation cask.

Source: Original

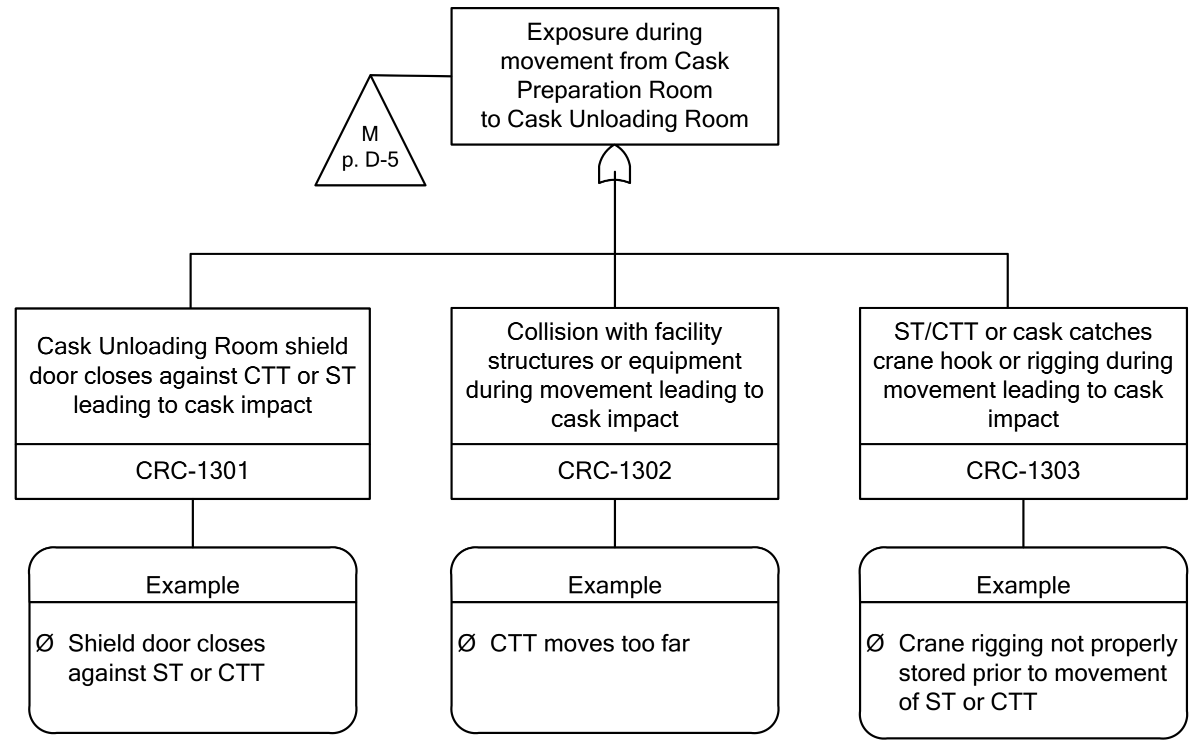
Figure D-11. Exposure During Installation of Cask Lid-Lift Fixture



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

Source: Original

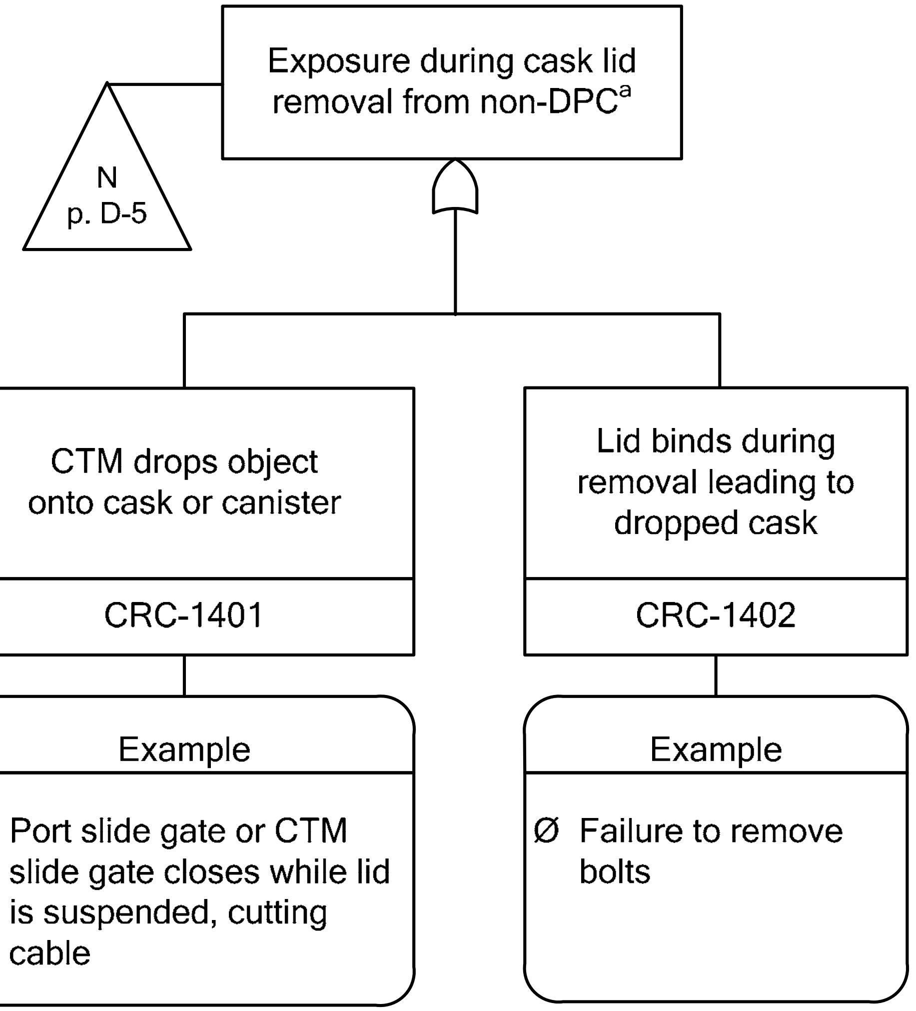
Figure D-12. Exposure During Lid Removal and Installation of DPC Lift Fixture in Cask Preparation Room (DPC only)



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTT = cask transfer trolley; ST = site transporter.

Source: Original

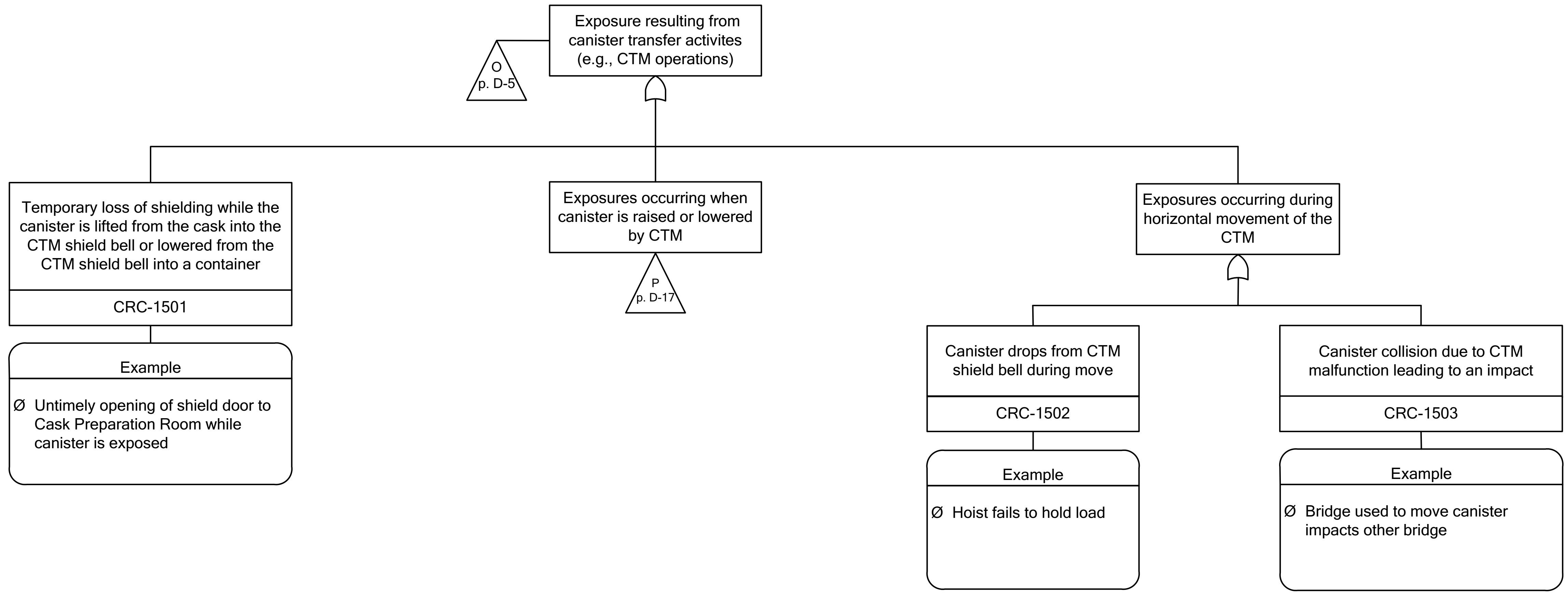
Figure D-13. Exposure During Movement from Cask Preparation Room to Cask Unloading Room



NOTE: [a] This event also applies to operations involving an aging overpack.
Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
CTM = canister transfer machine; DPC = dual-purpose canister.

Source: Original

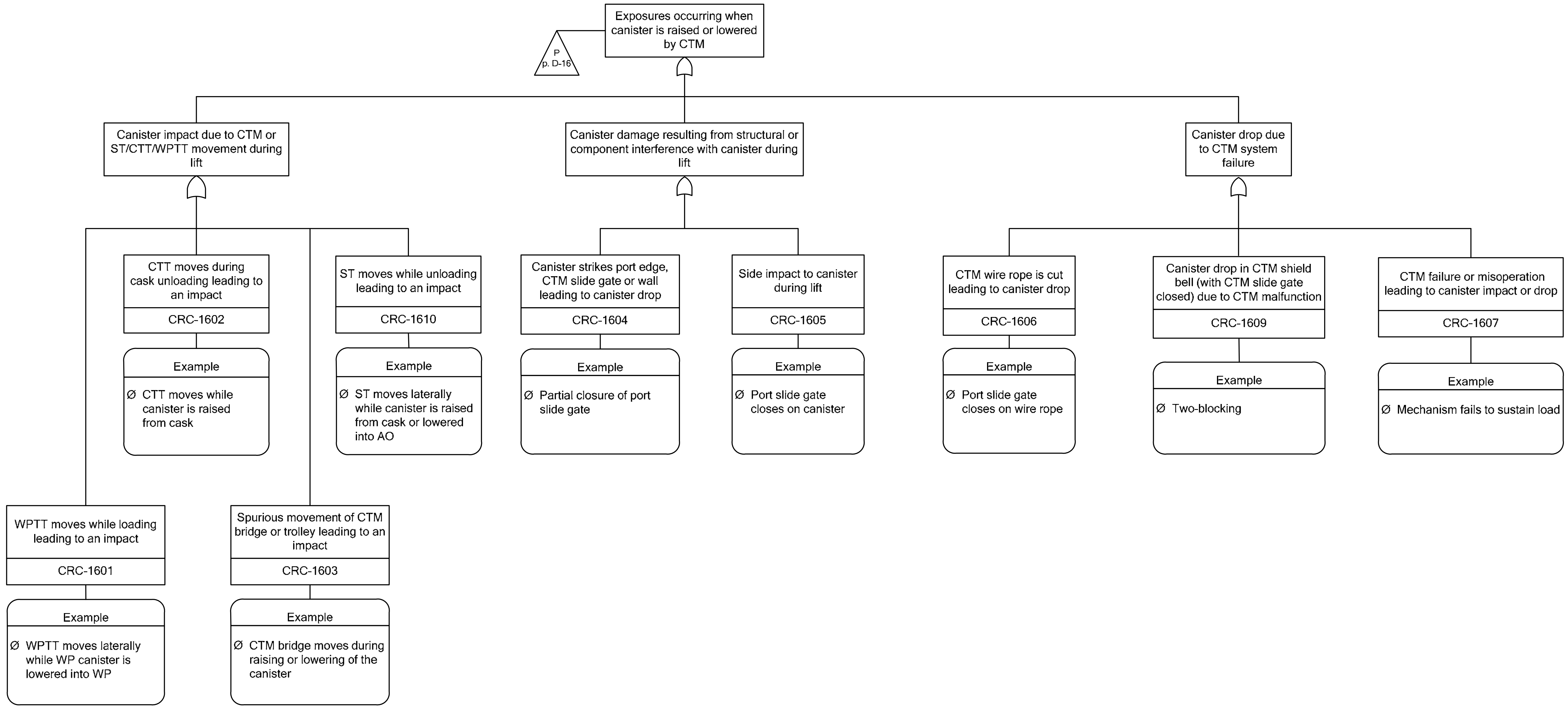
Figure D-14. Exposure During Cask Lid Removal from Non-DPC



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

Source: Original

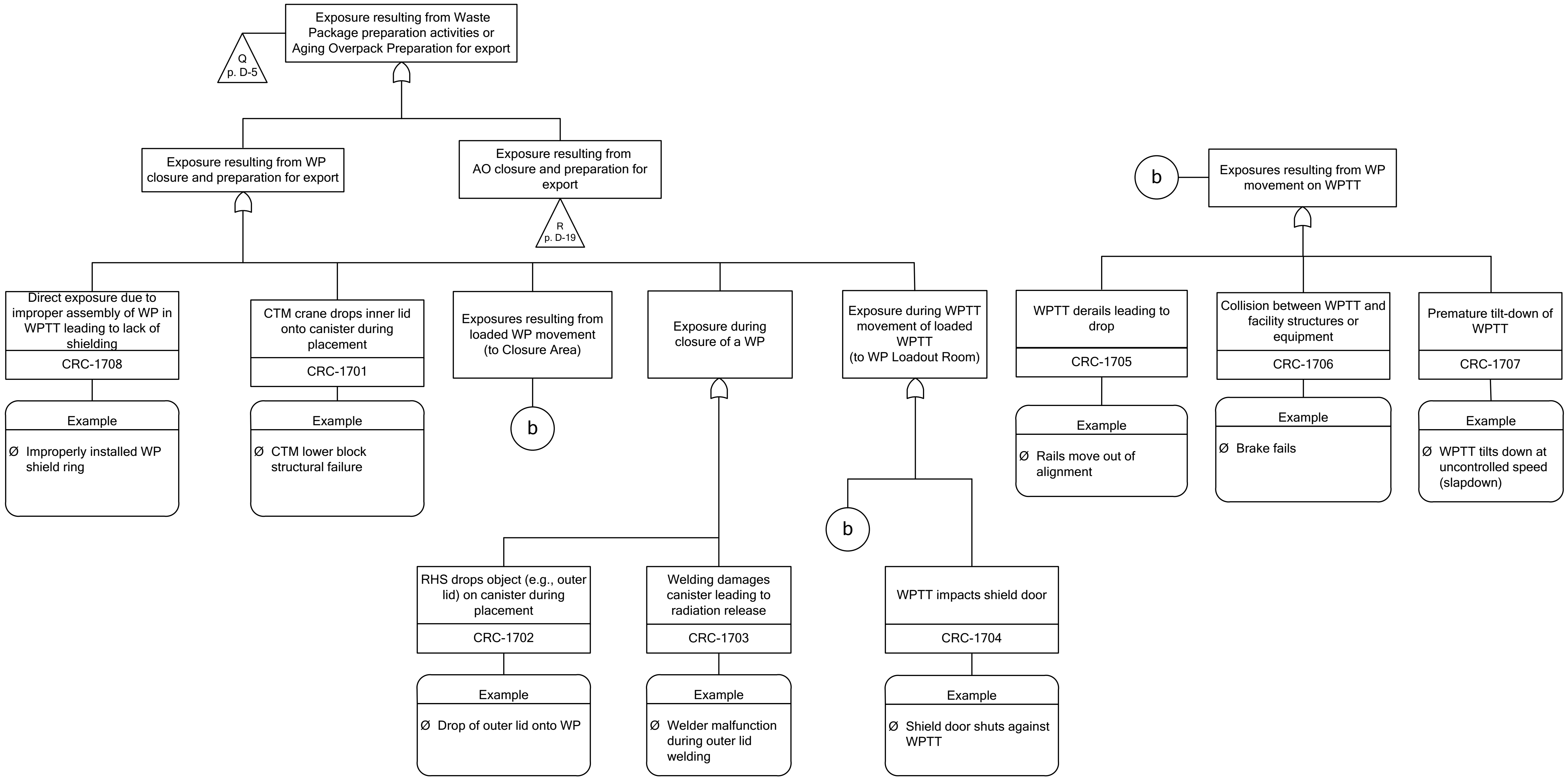
Figure D-15. Exposure Resulting from Canister Transfer Activities (e.g., CTM operations)



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

Source: Original

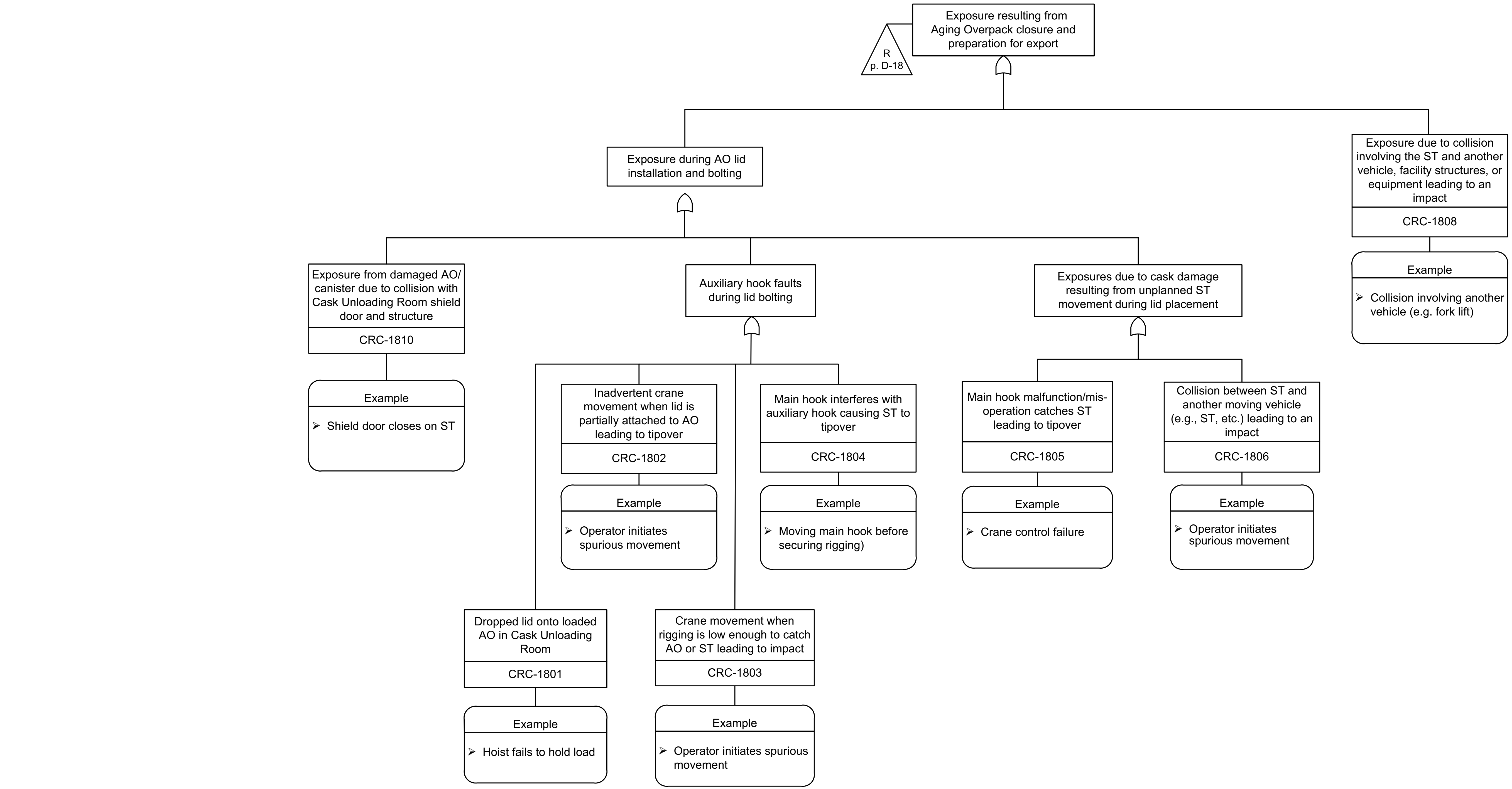
Figure D-16. Exposures Occurring When Canister is Raised or Lowered by CTM



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

Source: Original

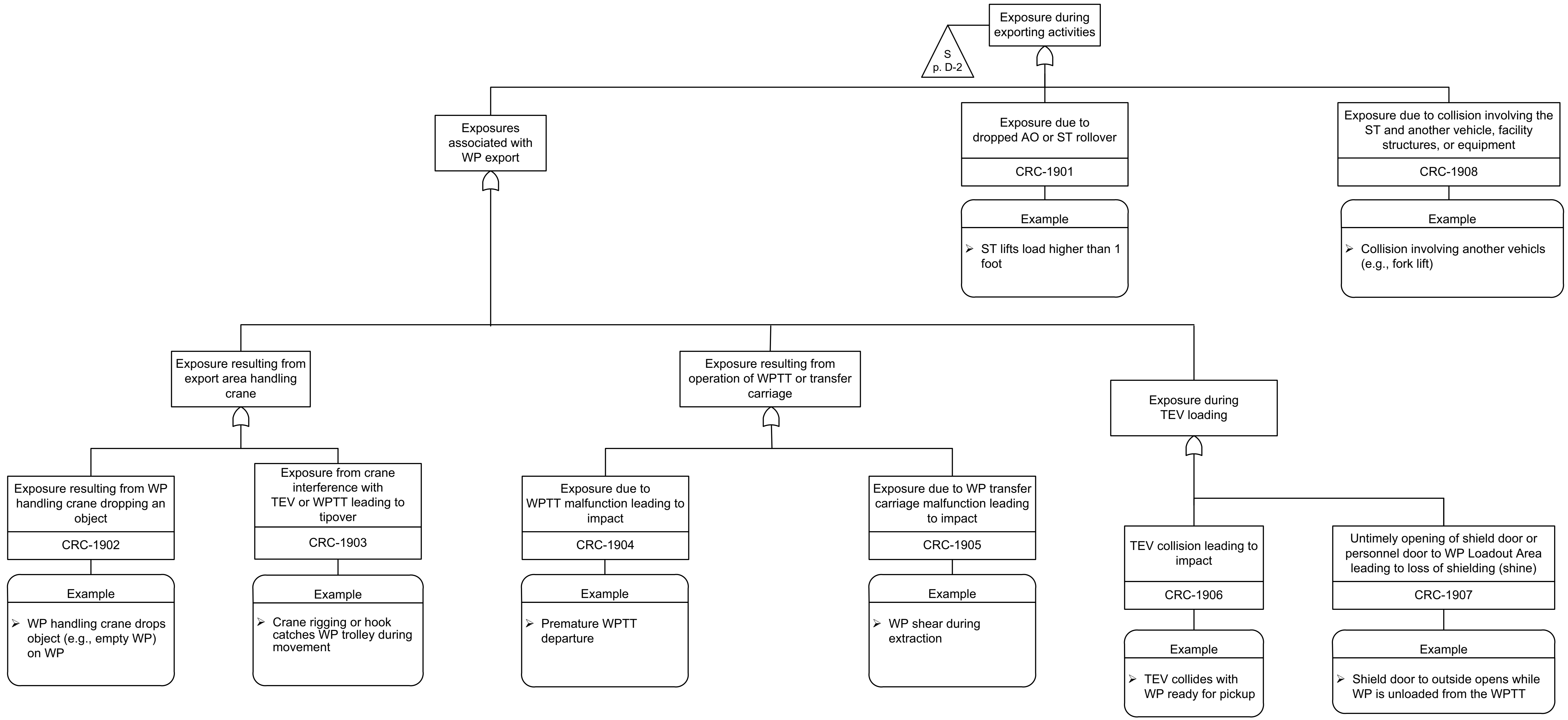
Figure D-17. Exposure Resulting From Waste Package Preparation Activities or Aging Overpack Preparation for Export



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

Source: Original

Figure D-18. Exposure Resulting from Aging Overpack Closure and Preparation for Export



NOTE: Unplanned exposure of individuals to radiation or radioactive materials is herein referred to as "exposure."
AO = aging overpack; ST = site transporter; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure D-19. Exposure During Exporting Activities

ATTACHMENT E
CANISTER RECEIPT AND CLOSURE FACILITY
HAZARD AND OPERABILITY EVALUATION

The results of a hazard and operability (HAZOP) evaluation for the CRCF are provided in this attachment. The HAZOP evaluation was conducted in accordance with the process described in Section 4.3.1.3. The HAZOP evaluations were conducted in a series of meetings that lasted from 4 to 8 hours for each facility. A list of attendees and bios of the team members is also provided in this attachment.

HAZOP EVALUATION MEETINGS

LIST OF SUBJECT MATTER EXPERT ATTENDEES AND BIOGRAPHIES

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

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

HAZOP Evaluation 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 Evaluation 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 Evaluation 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

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

HAZOP Evaluation Meetings		
Name	**Telephone Number**	**Organization**
Meeting Date: April 5, 2007		
Paul Amico	702-821-7911	SAIC
Erin Collins	702-821-7913	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Ernest Lindner	702-821-7713	BSC
Suzanne Loyd	702-821-7350	SAIC
Doug Orvis	702-821-7914	BSC
Mary Presley	505-272-7102	ARES
Clarence Smith	702-821-7126	BSC
Meeting Date: April 6, 2007		
Paul Amico	702-821-7911	SAIC
Norm Graves	702-821-7012	BSC
Daryl Keppler	505-272-7102	ARES
Phuoc Le	702-821-7468	SAIC
Dale Pendry	702-821-8380	BSC
Mary Presley	505-272-7102	ARES

Source: Original

Biographies of subject matter experts attending the HAZOP evaluation meetings:

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

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

Robert J. Garrett: Mr. Garrett is a safety analyst with over 17 years of experience in risk analysis and hazards analysis at DOE non-reactor nuclear facilities. He has participated in several HAZOP evaluations 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 evaluation sessions.

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

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

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

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

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

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

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

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

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

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

Table E-2. HAZOP Evaluation Worksheet for Node 1

Facility/Operation: CRCF					Process: Receipt and Transfer into Cask Preparation Room		
Node 1: Receive and Move TC (HLW/Commercial SNF) Railcar into Cask Preparation Room for Unloading					Process/Equipment: SPM, Railcar		
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of					Consequence Categories: Radioactive Release, Lack of Shielding, Criticality		
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
1.1	Speed	(More) SPM moves too fast	Driver drives SPM too fast	Potential loss of control or collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training	Creeping speed	CRC-104
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	CRC-104
1.3	Speed	(Less) SPM moves too slow	Mechanical failure of SPM	No internal event			
1.4	Speed	(No) SPM does not move	1 – Human failure 2 – Mechanical failure	No internal event		Always at least one-door boundary for HVAC if conveyance is stuck in doorway	
1.5	Direction	(Reverse) SPM backs up instead of going forward	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training	Potential loss of HVAC boundary if collision with door	CRC-104
1.6	Direction	(Other Than) SPM derailment	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training		CRC-103
1.7	Direction	(Other Than) SPM derailment	Rail distortion due to structural failure	Potential drop of TC leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training 3 – Rail design		CRC-103
1.8	Direction	(Other Than) SPM does not follow designated route and goes to wrong location or problem area	1 – Human failure 2 – Mechanical failure	Potential loss of control or collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training	Faulty track or switch indicator	CRC-104
1.9	Parking	(Other Than) Improper positioning and constraint of cask conveyance	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training 3 – Brakes, chocks, and rail stops	Collision caused by unconstrained cask conveyance	CRC-104
1.10	Temperature	(More) Exceeds 10 CFR 71 temperature design basis	Fire	1 –Radioactive release 2 – Potential criticality	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training 3 – Combustible materials control	1 – 10 CFR 71 temperature design basis 2 – Combustible material provided by SPM 3 – Entrance into facility to be controlled	CRC-I303
1.11	Temperature	(Less) Below 10 CFR 71 temperature design basis	Normal condition	No safety consequences			N/A
1.12	Shielding	(Less) Displacement of TC shielding	Impact or fire	Direct exposure	1 – TC remains in 10 CFR 71 configuration 2 – Procedures and training 3 – Combustible materials control	Includes reduction or complete loss of shielding	

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

HLW is received on a truck trailer and is handled in the same manner as casks on a railcar, therefore, casks on truck trailers are considered and addressed by the railcar discussion in the main body of Section 6.2.

CFR = Code of Federal Regulations; CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; Commercial SNF = commercial spent nuclear fuel; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning;
IHF = Initial Handling Facility; SPM = site prime mover; TC = transportation cask.

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

Table E-3. HAZOP Evaluation Worksheet for Node 2

Facility/Operation: CRCF							Process: TC Unloading
Node 2: Remove Impact Limiters from TC on Railcar							Process/Equipment: Railcar, Cask Handling Crane (Auxiliary Hook), Cask Access Platform
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
2.1	Load	(More) Load lifted too heavy for crane	Failure to remove restraining bolt on impact limiters	Potential drop of load onto TC leading to radioactive release	1 – TC design 2 – Procedures and training 3 – Crane design and below-the-hook devices	Cask handling crane auxiliary hook	CRC-402
2.2	Load	(Less) Load lifted too light	N/A	No safety consequences	N/A	N/A	N/A
2.3	Speed (Crane)	(More) Hook lowered too fast	1 – Human failure 2 – Mechanical failure	Potential drop of load onto TC leading to radioactive release	1 – TC design 2 – Procedures and training 3 – Crane design	N/A	CRC-402
2.4	Speed (Crane)	(Less) Hook lowered too slow	N/A	No safety consequences	N/A	N/A	N/A
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	N/A	CRC-404
2.6	Travel (Crane)	(More) Crane moves past desired position for activity	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
2.7	Travel (Crane)	(Less) Crane does not move into desired position for activity	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
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	N/A	CRC-404
2.9	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Potential fire scenario	CRC-I304
2.10	Maintenance	(No) Improper maintenance of crane	Human failure	N/A	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	N/A
2.11	Controls (PLC)	(Other Than)	N/A	N/A	N/A	Considered in event sequence development (event tree/FTA/HRA)	N/A
2.12	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	N/A	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	N/A
2.13	Alignment	(Other Than)	See 2.5 through 2.8 above	N/A	N/A	N/A	N/A
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	N/A	CRC-405

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

CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; TC = transportation cask.

Source: Original

Table E-4. HAZOP Evaluation Worksheet for Node 3

Facility/Operation: CRCF							Process: TC Unloading
Node 3: Attach Lift Yoke to TC on Railcar							Process/Equipment: Railcar, 200-ton Crane, Lift Yoke, Trunnions (as required)
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
3.1	Speed (Crane)	(More) Yoke lowered too fast	1 – Human failure 2 – Mechanical failure	Potential drop of load onto TC leading to radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	CRC-504
3.2	Speed (Crane)	(Less) Yoke lowered too slow	N/A	No safety consequences	N/A	N/A	N/A
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	CRC-502
3.4	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Potential fire scenario	CRC-I304
3.5	Maintenance	(No) Improper maintenance of crane	Human failure	N/A	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	N/A
3.6	Controls (PLC)	(Other Than)	N/A	N/A	N/A	Considered in event sequence development (Event tree/FTA/HRA)	N/A
3.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	N/A	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	N/A
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	N/A	CRC-509
3.9	Engagement (Yoke)	(More) Overtravel 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	N/A	CRC-501
3.10	Engagement (Yoke)	(Less) Undertravel 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	CRC-501
3.11	Engagement (Yoke)	(No) Failed to engage	N/A	No safety consequences	N/A	N/A	N/A
3.12	Yoke	(Other Than) Trunnion installed incorrectly	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Trunnion design	As required for certain casks	CRC-501

NOTE: Guidewords not used in this node: Reverse and As Well As.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; TC = transportation cask.

Source: Original

Table E-5. HAZOP Evaluation Worksheet for Node 4

Facility/Operation: CRCF							Process: TC Unloading
Node 4: Upend TC on Railcar							Process/Equipment: Railcar, 200-ton Crane
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
4.1	Load	(More) Load lifted too heavy for crane	Failure to remove tie-downs	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Crane design	1 – Cask handling crane main hook 2 – TC may mitigate event, depending on passive equipment failure analysis	CRC-501
4.2	Load	(Less) Load lifted too light	N/A	No safety consequences	N/A	N/A	N/A
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	CRC-501
4.4	Travel (Crane)	(Reverse) Travels in wrong direction	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	1 – TC may mitigate event, depending on passive equipment failure analysis 2 – Crane feature to prevent rapid rundown needs to be subjected to FTA	CRC-501
4.5	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Potential fire scenario	CRC-I304
4.6	Motor Motive Force	(Less or No) Loss of motive force allows rapid rundown	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	N/A	1 – TC may mitigate event depending on passive equipment failure analysis 2 – Crane feature to prevent rapid rundown needs to be subjected to FTA	CRC-501
4.7	Maintenance	(No) Improper maintenance of crane	Human failure		Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	N/A
4.8	Controls (PLC)	(Other Than)	N/A	N/A	N/A	Considered in event sequence development (event tree/FTA/HRA)	
4.9	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	N/A	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	
4.10	Alignment	(Other Than)	See 4.3 above	N/A	N/A	N/A	N/A
4.11	Pivot Point	(Other Than) Pivot point constraint fails	Cover brackets fail or are removed out of sequence	Potential radioactive release resulting from slap-down	1 – Transportation skid pedestal design 2 – Procedures and training		CRC-501

NOTE: Guidewords not used in this node: As Well As and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; TC = transportation cask.

Source: Original

Table E-6. HAZOP Evaluation Worksheet for Node 5

Facility/Operation: CRCF							Process: TC Unloading
Node 5: Transfer TC from Railcar to CTT (Air Pallet)							Process/Equipment: Railcar, 200-ton Crane, CTT
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
5.1	Lift	(More) Two-blocking	1 – Human failure 2 – Mechanical failure	Potential drop of TC 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	CRC-506
5.2	Lift	(Less) Not lifted high enough to clear other structures or equipment	1 – Human failure 2 – Mechanical failure	Potential collision of TC leading to radioactive release	Procedures and training	N/A	CRC-508
5.3	Lift	(No)	N/A	No safety consequences	N/A	N/A	N/A
5.4	Lift	(Reverse) Rapid rundown	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Crane design 2 – Procedures and training	TC may mitigate event, depending on passive equipment failure analysis	CRC-506
5.5	Speed (Crane)	(More) Crane moves faster than allowed by procedures	1 – Human failure 2 – Mechanical failure	Potential collision of TC leading to radioactive release	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	CRC-508
5.6	Speed (Crane)	(Less) Crane moves too slow	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	Procedures and training	Prolonged exposure time for sequence initiation	N/A
5.7	Speed (Crane)	(Other Than) Abrupt stop	1 – Human failure 2 – Mechanical failure	Potential collision with TC leading to radioactive release	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	CRC-508
5.8	Alignment (Trolley)	(No) Improper alignment	Human failure	N/A	N/A	Check for self-aligning features or electronic-aligning features	N/A
5.9	Miscellaneous	N/A	N/A	N/A	N/A	Check door design on CTT – hinged or need to fetch with crane	N/A
5.10	Miscellaneous	N/A	N/A	N/A	N/A	Verify mechanisms for securing cask to CTT	N/A

NOTE: Guidewords not used in this node: As Well As and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTT = cask transfer trolley; ft = feet; TC = transportation cask.

Source: Original

Table E-7. HAZOP Evaluation Worksheet for Node 6

Facility/Operation: CRCF							Process: TC Unloading
Node 6: Attach Slings to TC on Railcar							Process/Equipment: Railcar, 200-ton Crane, Lift Slings
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
6.1	Speed (Crane)	(More) Slings lowered too fast	1 – Human failure 2 – Mechanical failure	Potential drop of load onto TC leading to radioactive release	1 – Procedures and training 2 – Crane design	TC design may mitigate event, depending on passive equipment failure analysis	CRC-703
6.2	Speed (Crane)	(Less) Slings lowered too slow	N/A	No safety consequences	N/A	N/A	N/A
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	CRC-704
6.4	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Potential fire scenario	N/A
6.5	Maintenance	(No) Improper maintenance of crane	Human failure	N/A	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	N/A
6.6	Controls (PLC)	(Other Than)	N/A	N/A	N/A	Considered in event sequence development (event tree/FTA/HRA)	N/A
6.7	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	N/A	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	N/A
6.8	Mobile Access Platform Operations	(Other Than) Impact from operational activities	1 – Human failure 2 – Mechanical failure	Potential impact to TC leading to radioactive release	1 – TC design 2 – Procedures and training 3 – Platform and tool design	N/A	CRC-705
6.9	Engagement (Sling)	(More) Overtravel on sling 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	N/A	CRC-702
6.10	Engagement (Sling)	(Less) Undertravel on sling 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	CRC-702
6.11	Engagement (Sling)	(No) Failed to engage	N/A	No safety consequences	N/A	N/A	N/A
6.12	Sling	(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	CRC-702

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; TC = transportation cask.

Source: Original

Table E-8. HAZOP Evaluation Worksheet for Node 7

Facility/Operation: CRCF							Process: TC Unloading
Node 7: Transfer Horizontal TC from Railcar to Cask Stand for Removal of Impact Limiters							Process/Equipment: Railcar, 200-ton Crane, Cask Stand
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
7.1	Lift	(More) Two-blocking	1 – Human failure 2 – Mechanical failure	Potential drop of TC 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	CRC-801
7.2	Lift	(Less) Not lifted high enough to clear other structures or equipment	1 – Human failure 2 – Mechanical failure	Potential collision with TC leading to radioactive release	Procedures and training	N/A	CRC-803
7.3	Lift	(No)	N/A	No safety consequences	N/A	N/A	N/A
7.4	Lift	(Reverse) Rapid rundown	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	1 – Crane design 2 – Procedures and training	TC may mitigate event, depending on passive equipment failure analysis	CRC-801
7.5	Speed (Crane)	(More) Crane moves faster than allowed by procedures	1 – Human failure 2 – Mechanical failure	Potential collision with TC leading to radioactive release	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	CRC-803
7.6	Speed (Crane)	(Less) Crane moves too slow	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Prolonged exposure time for sequence initiation	N/A
7.7	Speed (Crane)	(Other Than) Abrupt stop	1 – Human failure 2 – Mechanical failure	Potential collision with TC leading to radioactive release	1 – Crane design 2 – Procedures and training	TC design may mitigate event, depending on passive equipment failure analysis	CRC-803

NOTE: Guidewords not used in this node: As Well As and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; ft = feet; TC = transportation cask.

Source: Original

Table E-9. HAZOP Evaluation Worksheet for Node 8

Facility/Operation: CRCF					Process: TC Unloading		
Node 8: Upend Horizontal TC on Cask Tilting Frame					Process/Equipment: 200-ton Crane, Cask Tilting Frame		
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of					Consequence Categories: Radioactive Release, Lack of Shielding, Criticality		
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
8.1	Load	(More) Load lifted too heavy for crane	Failure to remove tie-downs	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Crane design	1 – Cask handling crane main hook 2 – TC may mitigate event, depending on passive equipment failure analysis	CRC-902
8.2	Load	(Less) Load lifted too light	N/A	No safety consequences	N/A	N/A	N/A
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 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	CRC-902
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	CRC-1003
8.5	Motor	(More) Motor temperature too high	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Potential fire scenario	CRC-I304
8.6	Motor Motive Force	(Less or No) Loss of motive force allows rapid rundown	1 – Human failure 2 – Mechanical failure	Potential drop of TC leading to radioactive release	N/A	1 – TC may mitigate event, depending on passive equipment failure analysis 2 – Crane feature to prevent rapid rundown needs to be subjected to FTA	CRC-902
8.7	Maintenance	(No) Improper maintenance of crane	Human failure	N/A	Maintenance program	Considered in event sequence development (event tree/FTA/HRA)	N/A
8.8	Controls (PLC)	(Other Than)	N/A	N/A	N/A	Considered in event sequence development (event tree/FTA/HRA)	N/A
8.9	Vision/ Communication	(Other Than) Unclear communication	Poor operating environment	N/A	1 – Crane operator training program 2 – Human factor evaluation 3 – Industrial hygiene standards	Considered in HRA	N/A
8.10	Alignment	(Other Than)	See 8.3 above	N/A	N/A	N/A	N/A
8.11	Pivot Point	(Other Than) Pivot point constraint fails	Cover brackets fail or are removed out of sequence	Potential slap-down of TC leading to radioactive release	1 – Transportation skid pedestal design 2 – Procedures and training	Issue regarding whether pivot point is constrained is under review	N/A – No pivot point constraint

NOTE: Guidewords not used in this node: As Well As and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; FTA = fault-tree analysis; HRA = human-reliability analysis; PLC = programmable logic controller; TC = transportation cask.

Source: Original

Table E-10. HAZOP Evaluation Worksheet for Nodes 1-8

Facility/Operation: CRCF				Process: TC Receipt Step by Step			
Nodes 1-8: Receive TC on Railcar and Transfer to CTT				Process/Equipment: N/A			
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
N/A	N/A	Chooses wrong cask pedestal	Human failure	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Pedestal design	1 – Human factors 2 – Scheduling by campaigns may minimize occurrence	CRC-510
N/A	N/A	200-ton crane used instead of 20-ton crane to remove impact limiters	Human failure	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Hook design	N/A	CRC-506
N/A	N/A	Yoke selection not consistent with canister (use of naval yoke)	Human failure	No safety consequences	N/A	Prevented by design of naval device which would preclude connection to wrong type of cask	N/A
N/A	N/A	Cask not secured to cask-tilting frame prior to bringing upright	1 – Human failure 2 – Mechanical failure	Potential drop of or impact to TC leading to radioactive release	1 – Procedures and training 2 – Cask tilting frame design	N/A	CRC-901
N/A	N/A	Failure to release cask from cask-tilting frame after bringing upright	Human failure	Potential drop of or impact to TC leading to radioactive release	Procedures and training	N/A	CRC-1001

NOTE: No guidewords were used in this node.
Node Item Number = “N/A” as this is a step-by-step overview of Node 1 – Node 8.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTT = cask transfer trolley; TC = transportation cask.

Source: Original

Table E-11. HAZOP Evaluation Worksheet for Node 9

Facility/Operation: CRCF				Process: TC Preparation			
Node 9: Preparation Operations for TAD Canisters, DOE SNF, HLW				Process/Equipment: Preparation Station, Common Tools			
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
9.1	Sample Line Hookup	(Other Than) Improper hookup	Human failure	Potential release of materials in cask/canister annulus to environment	1 – Procedures and training 2 – Connection design	Sampling no longer part of the process	N/A
9.2	Sample Line Hookup	(Other Than) Line break	1 – Human failure 2 – Equipment failure	Potential release of materials in cask/canister annulus to environment	1 – Procedures and training 2 – Sample system design	Sampling no longer part of the process	N/A
9.3	Taking Sample	(Other Than) Incorrect or inadequate sample or false negative	1 – Human failure 2 – Equipment failure	Potential release of materials in cask/canister annulus to environment	1 – Procedures and training 2 – Sample system design	Sampling no longer part of the process	N/A
9.4	Loosen/Remove Bolts	(Other Than) Failure to remove	Human failure	No safety consequences	N/A	1 – Verify how and where bolts are removed 2 – Potential precursor to overloading CTM	N/A
9.5	Loosen/Remove Bolts	(Reverse) Tighten bolts instead of loosen	1 – Human failure 2 – Equipment failure	No safety consequences	N/A	Potential precursor to overloading CTM	N/A
9.6	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	1 – Check TC lid design 2 – Precursor to drop of lid back onto canister	N/A

NOTE: Guidewords not used in this node: No, More, Less, As Well As, and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; DOE = U.S. Department of Energy; HLW = high-level radioactive waste; SNF = spent nuclear fuel; TAD = transportation, aging, and disposal; TC = transportation cask.

Source: Original

Table E-12. HAZOP Evaluation Worksheet for Node 10

Facility/Operation: CRCF	Process: TC Preparation
Node 10: Preparation Operations for DPC	Process/Equipment: Preparation Station, Common Tools, Cask Shield Ring, Standard Rigging, Cask Handling Crane with Auxiliary Hook
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of	Consequence Categories: Radioactive Release, Lack of Shielding, Criticality

Node Item Number	Parameter	Deviation Considered	Postulated Cause	Consequence(s)	Potential Prevention/Mitigation Design of Operational Feature	Notes	MLD Index Number
10.1	Sample Line Hookup	(Other Than) Improper hookup	Human failure	Potential release of materials in cask/canister annulus to environment	1 – Procedures and training 2 – Connection design	Sampling no longer part of the process	
10.2	Sample Line Hookup	(Other Than) Line breaks	1 – Human failure 2 – Equipment failure	Potential release of materials in cask/canister annulus to environment	1 – Procedures and training 2 – Sample system design	Sampling no longer part of the process	
10.3	Taking Sample	(Other Than) Incorrect or inadequate sample or false negative	1 – Human failure 2 – Equipment failure	Potential release of materials in cask/canister annulus to environment	1 – Procedures and training 2 – Sample system design	Sampling no longer part of the process	
10.4	Loosen/Remove Lid Bolts	(Other Than) Failure to remove	Human failure	No safety consequences	N/A	1 – Sequence of bolt removal and installation of lift fixture may impact human failure probability associated with failure to remove bolts 2 – Precursor to cask drop if remaining bolts overloaded	N/A
10.5	Loosen/Remove Bolts	(Reverse) Tighten bolts instead of loosen	1 – Human failure 2 – Equipment failure	No safety consequences	N/A	Potential precursor to cask drop if remaining bolts overloaded	N/A
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	N/A
10.7	Remove TC Lid	(More) Attempting to lift more than the lid alone (see 11.7 and 11.8 above)	Human failure	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Crane design features	Model crane overload protection features and failure modes	CRC-1203
10.8	Remove TC Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential impact to TC leading to radioactive release	1 – Procedures and training 2 – Crane design features	N/A	CRC-1201
10.9	Remove TC Lid	(Less) Not lifting lid high enough to clear cask	Human failure	Potential tipover of TC leading to radioactive release	Procedures and training	N/A	CRC-1205
10.10	Remove TC Lid	(Other Than) Lift with fixture improperly attached (see 11.9 above)	Human failure	Potential impact to TC leading to radioactive release	Procedures and training	N/A	CRC-1201
10.11	Remove Inner Rings	(See 11.10 through 11.13 above)	Human failure	(See 11.10 through 11.13 above)	Procedures and training	Verify rings that must be removed	N/A
10.12	Install Shield Ring	(More) Lift too high	1 – Human failure 2 – Equipment failure	Potential impact to TC leading to radioactive release	Procedures and training	Shield ring installation no longer part of the process	
10.13	Install Shield Ring	(Less) Lift not high enough to clear cask	Human failure	Potential impact to TC leading to radioactive release	Procedures and training	Shield ring installation no longer part of the process	
10.14	Install Shield Ring	(No) No installation	Human failure	Direct exposure	Procedures and training	Shield ring installation no longer part of the process	
10.15	Install Shield Ring	(Other Than) Improperly installed	Human failure	Direct exposure	Procedures and training	Shield ring installation no longer part of the process	
10.16	Install Canister Lift Fixture	(More) Lift too high	1 – Human failure 2 – Equipment failure	Potential impact to TC leading to radioactive release	Procedures and training	Lifted by main crane	CRC-1201
10.17	Install Canister Lift Fixture	(Less) Lift not high enough to clear cask	Human failure	Potential impact to TC leading to radioactive release	Procedures and training	N/A	CRC-1205
10.18	Install Canister Lift Fixture	(Other Than) Improperly installed for movement to installation position	Human failure	Potential impact to TC leading to radioactive release	Procedures and training	N/A	CRC-1201

Table E-12. HAZOP Evaluation Worksheet for Node 10 (Continued)

Facility/Operation: CRCF				Process: TC Preparation			
Node 10: Preparation Operations for DPC				Process/Equipment: Preparation Station, Common Tools, Cask Shield Ring, Standard Rigging, Cask Handling Crane with Auxiliary Hook			
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
10.19	Install Canister Lift Fixture	(Other Than) Improperly installed	Human failure	No safety consequence	Procedures and training	Precursor to drop of canister during lift	N/A
10.20	Remove and Store Shield Ring	(More) Lift too high	1 – Human failure 2 – Equipment failure	Potential impact to TC leading to radioactive release	Procedures and training	Shield ring removal no longer part of the process	
10.21	Remove and Store Shield Ring	(Less) Lift not high enough to clear cask	Human failure	Potential impact to TC leading to radioactive release	Procedures and training	Shield ring removal no longer part of the process	
10.22	Remove and Store Shield Ring	(No) No removal	Human failure	No safety consequences	Procedures and training	Shield ring removal no longer part of the process	

NOTE: Guidewords not used in this node: As Well As and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; DPC = dual-purpose canister; TC = transportation cask.

Source: Original

Table E-13. HAZOP Evaluation Worksheet for Node 11

Facility/Operation: CRCF					Process: TC Preparation		
Node 11: Move to Unload Cell/Bay/Room					Process/Equipment: CTT		
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of					Consequence Categories: Radioactive Release, Lack of Shielding, Criticality		
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
11.1	CTT Lift	(More) Too much lift	No cause identified	N/A	N/A	N/A	N/A
11.2	CTT Lift	(Less) Not enough lift	1 – Lack of air pressure 2 – Cone malfunction	No safety consequences	N/A	N/A	N/A
11.3	CTT Lift	(Other Than) Uneven lift	Cone malfunction	No safety consequences	N/A	Unable to lift more than 5/16-in. over longest dimension	N/A
11.4	CTT Lift	(Other Than) Drop	Loss of air	No safety consequences	N/A	N/A	N/A
11.5	CTT Movement	(More) Moves too far	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design	Shield door open, collision with facility structure	CRC-1302
11.6	CTT Movement	(More) Moves too far	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design	Shield door closed, collision with shield door	CRC-1302
11.7	CTT Movement	(Less) Doesn't move enough	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
11.8	CTT Movement	(Reverse) Moves in opposite direction	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design	N/A	CRC-1302
11.9	CTT Movement	(Other Than) Sideways movement	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design	N/A	CRC-1302
11.10	Shield Door Movement	(Other Than) Spurious closure of shield door	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – Design of shield-door controls 3 – TC design	N/A	CRC-1301
11.11	Preparation Platform Position	(Other Than) Out of position leading to platform collision with CTT frame	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – CTT design 3 – TC design	N/A	CRC-1302

NOTE: Guidewords not used in this node: No, As Well As, and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTT = cask transfer trolley; in. = inch; TC = transportation cask.

Source: Original

Table E-14. HAZOP Evaluation Worksheet for Node 12

Facility/Operation: CRCF				Process: CTM Operation			
Node 12: Remove Canister from Cask using CTM				Process/Equipment: CTM			
Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
12.1	Shield Door Movement	(Other Than) Failure to close shield door	1 – Human failure 2 – Mechanical failure	Direct exposure	1 – Procedures and training 2 – Design of shield-door controls	Must be concurrent with canister removal	CRC-1501
12.2	Shield Door Movement	(Other Than) Spurious opening of shield door	1 – Human failure 2 – Mechanical failure	Direct exposure	1 – Procedures and training 2 – Design of shield door controls	Must be concurrent with canister removal	CRC-1501
12.3	Shield Door Movement	(Other Than) Failure to evacuate personnel prior to door closure	1 – Human failure 2 – Mechanical failure	Direct exposure	1 – Procedures and training 2 – Design of shield door controls	Must be concurrent with canister removal	CRC-1501
12.4	Port Slide Gate	(Other Than) Failure to open slide gate	1 – Human failure 2 – Mechanical failure	No safety consequences	1 – Procedures and training 2 – Design of slide gate controls	N/A	N/A
12.5	Port Slide Gate	(Other Than) Failure to close slide gate	1 – Human failure 2 – Mechanical failure	Potential direct exposure to personnel on second floor when CTM moved	1 – Procedures and training 2 – Design of slide gate controls	N/A	CRC-1501
12.6	Port Slide Gate	(Other Than) Opening of port slide gate	1 – Human failure 2 – Mechanical failure	Potential direct exposure to personnel on second floor when CTM moved	1 – Procedures and training 2 – Design of slide gate controls	N/A	CRC-1501
12.7	Port Slide Gate	(Other Than) Closure while lifting canister	1 – Human failure 2 – Mechanical failure	Potential release	1 – Procedures and training 2 – Design of slide gate controls	Examine closures on rope as well as canister	CRC-1605
12.8	CTM Slide Gate	(Other Than) Failure to open slide gate	1 – Human failure 2 – Mechanical failure	No safety consequences	1 – Procedures and training 2 – Design of slide gate controls	N/A	N/A
12.9	CTM Slide Gate	(Other Than) Failure to close slide gate	1 – Human failure 2 – Mechanical failure	Potential direct exposure to personnel on second floor when skirt lifted	1 – Procedures and training 2 – Design of slide gate controls	N/A	CRC-1501
12.10	CTM Slide Gate	(Other Than) Opening of CTM slide gate	1 – Human failure 2 – Mechanical failure	Potential direct exposure to personnel on second floor when skirt lifted	1 – Procedures and training 2 – Design of slide-gate controls	N/A	CRC-1501
12.11	CTM Slide Gate	(Other Than) Closure while lifting canister	1 – Human failure 2 – Mechanical failure	Potential release	1 – Procedures and training 2 – Design of slide-gate controls	Examine closures on rope as well as canister	CRC-1605
12.12	Lid Grapple Engagement	(Other Than) Improper attachment	1 – Human failure 2 – Equipment failure	No safety consequences	1 – Procedures and training 2 – Potentially precluded by design	Potential precursor to cask lid drop	N/A
12.13	Remove TC Lid	(More) Attempting to lift more than lid alone (see bolt removal parameters above)	Human failure	Potential drop of TC leading to radioactive release	1 – Procedures and training 2 – Crane design features	1 – Does not apply to DPC or naval canisters 2 – Model crane overload protection features and failure modes	CRC-1402

Table E-14. HAZOP Evaluation Worksheet for Node 12 (Continued)

Facility/Operation: CRCF				Process: CTM Operation			
Node 12: Remove Canister from Cask using CTM				Process/Equipment: CTM			
Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
12.14	Remove TC Lid	(More) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential impact to canister leading to radioactive release	1 – Procedures and training 2 – Crane design features	Does not apply to DPC or naval canisters	CRC-1401
12.15	Remove TC Lid	(Less) Not lifting lid high enough to clear cask	Human failure	Potential impact to canister leading to radioactive release	Procedures and training	Does not apply to DPC or naval canisters	CRC-1401
12.16	Remove TC Lid	(Other Than) Lift with grapple improperly attached (see 13.12 above)	Human failure	Potential impact to canister leading to radioactive release	Procedures and training	Does not apply to DPC or naval canisters	CRC-1401
12.17	Canister Grapple Engagement	(Other Than) Improper attachment	1 – Human failure 2 – Equipment failure	No safety consequences	1 – Procedures and training 2 – Potentially precluded by design	Potential precursor to canister drop	N/A
12.18	Lift	(More) Attempting to lift more than canister	Human failure	Potential drop of canister leading to radioactive release	1 – Procedures and training 2 – CTM design features	Model CTM overload protection features and failure modes	CRC-1607
12.19	Lift	(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	N/A	CRC-1607
12.20	Lift Canister	(Less) Not lifting canister high enough to clear floor	Human failure	Potential shear of canister leading to radioactive release	Procedures and training	N/A	CRC-1607
12.21	Lift Canister	(Other Than) Movement of carrier (CTT/ ST) during lift of canister	Human failure	Potential shear of canister leading to radioactive release	1 – Procedures and training 2 – CTT and ST design features	N/A	CRC-1602
12.22	Lift Canister	(Other Than) Miscellaneous mechanical failures	Mechanical failure	Potential drop of canister leading to radioactive release	CTM design features	Maintenance program	CRC-1609
12.23	Lift Canister	(Other Than) Lift with grapple improperly attached (see 13.17 above)	1 – Human failure 2 – Mechanical failure	Potential drop of canister leading to radioactive release	Procedures and training	N/A	CRC-1607

NOTE: Guidewords not used in this node: No, Reverse, As Well As, and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; CTT = cask transfer trolley; DPC = dual-purpose canister; ST = site transporter.

Source: Original

Table E-15. HAZOP Evaluation Worksheet for Node 13

Facility/Operation: CRCF				Process: CTM Operation			
Node 13: Move CTM Laterally				Process/Equipment: CTM			
Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
13.1	Speed (CTM)	(More) CTM moves faster than allowed by procedures	1 – Human failure 2 – Mechanical failure	Potential collision with canister leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	CRC-1503
13.2	Speed (CTM)	(No) CTM stuck in middle of room during move	1 – Human failure 2 – Mechanical failure	Potential radioactive release due to heat-up, etc.	N/A	Verify cooling requirements	CRC-I315
13.3	Speed (CTM)	(Less) CTM moves too slow	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
13.4	Speed (CTM)	(Other Than) Abrupt stop	1 – Human failure 2 – Mechanical failure	Potential collision with canister leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	CRC-1503
13.5	Direction (CTM)	(More) CTM moves too far	1 – Human failure 2 – Mechanical failure	Potential collision with canister leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	CRC-1503
13.6	Direction (CTM)	(Less) CTM does not move enough	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
13.7	Direction (CTM)	(Other Than) Moves in wrong direction	1 – Human failure 2 – Mechanical failure	Potential collision with canister leading to radioactive release	1 – CTM design 2 – Procedures and training	N/A	CRC-1503
13.8	Miscellaneous (CTM)	(Other Than) Moves over lid not properly stored	Human failure	Potential collision with canister leading to radioactive release	1 – Facility design 2 – Procedures and training	N/A	CRC-1503

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine.

Source: Original

Table E-16. HAZOP Evaluation Worksheet for Node 14

Facility/Operation: CRCF				Process: CTM Operation			
Node 14: Lower Canister from CTM to Receptacle				Process/Equipment: AO, WP, Staging Area			
Guidewords: No, More, Less, Reverse, Other Than, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
14.1	Shield Door Movement	(Other Than) Failure to close shield door	1 – Human failure 2 – Mechanical failure	Direct exposure	1 – Procedures and training 2 – Design of shield door controls	Must be concurrent with canister lowering	CRC-1501
14.2	Shield Door Movement	(Other Than) Spurious opening of shield door	1 – Human failure 2 – Mechanical failure	Direct exposure	1 – Procedures and training 2 – Design of shield door controls	Must be concurrent with canister lowering	CRC-1501
14.3	Shield Door Movement	(Other Than) Failure to evacuate personnel prior to door closure	1 – Human failure 2 – Mechanical failure	Direct exposure	1 – Procedures and training 2 – Design of shield door controls	Must be concurrent with canister lowering	CRC-1501
14.4	Port Slide Gate	(Other Than) Failure to open slide gate	1 – Human failure 2 – Mechanical failure	No safety consequences	1 – Procedures and training 2 – Design of slide gate controls	Verify with passive equipment failure analysis	N/A
14.5	Port Slide Gate	(Other Than) Failure to close slide gate	1 – Human failure 2 – Mechanical failure	Potential direct exposure to personnel on second floor when CTM moved	1 – Procedures and training 2 – Design of slide gate controls	After canister lowered into receptacle	CRC-1501
14.6	Port Slide Gate	(Other Than) Inadvertent opening of port slide gate	1 – Human failure 2 – Mechanical failure	Potential direct exposure to personnel on second floor when CTM moved	1 – Procedures and training 2 – Design of slide gate controls	After canister lowered into receptacle	CRC-1501
14.7	Port Slide Gate	(Other Than) Closure while lowering canister	1 – Human failure 2 – Mechanical failure	Potential release	1 – Procedures and training 2 – Design of slide gate controls	Examine closures on rope as well as canister	CRC-1605
14.8	CTM Slide Gate	(Other Than) Failure to open slide gate	1 – Human failure 2 – Mechanical failure	No safety consequences	1 – Procedures and training 2 – Design of slide gate controls	N/A	N/A
14.9	CTM Slide Gate	(Other Than) Failure to close slide gate	1 – Human failure 2 – Mechanical failure	Direct exposure	N/A	N/A	CRC-1501
14.10	CTM Slide Gate	(Other Than) Opening of CTM slide gate	1 – Human failure 2 – Mechanical failure	Potential direct exposure to personnel on second floor when skirt lifted	1 – Procedures and training 2 – Design of slide gate controls	N/A	CRC-1501
14.11	CTM Slide Gate	(Other Than) Closure while lowering canister	1 – Human failure 2 – Mechanical failure	Potential release	1 – Procedures and training 2 – Design of slide gate controls	Examine closures on rope as well as canister	CRC-1605
14.12	Lowering of Canister	(Less) Not lowering canister enough to clear bottom of second floor	Human failure	Potential shear of canister leading to radioactive release	Procedures and training	N/A	CRC-1603
14.13	Lowering of Canister	(Other Than) Movement of CTT, WPTT, or ST during lowering of canister	Human failure	Potential shear of canister leading to radioactive release	1 – Procedures and training 2 – CTT, WPTT, and ST design features	Includes inadvertent movement of WPTT rotating mechanism	CRC-1601
14.14	Lowering of Canister	(Other Than) Miscellaneous mechanical failures	Mechanical failure	Potential drop of canister leading to radioactive release	CTM design features	Maintenance program	CRC-1609
14.15	Lowering of Canister	(Other Than) Lowering canister without receptacle below	1 – Human failure 2 – Mechanical failure	Potential direct exposure	Procedures and training	N/A	CRC-1501
14.16	Lowering of Canister	(Other Than) Misalignment of CTM and port	1 – Human failure 2 – Mechanical failure	Potential drop of or impact to canister leading to radioactive release	Procedures and training	Potential of catching ledge and dropping into hole	CRC-1604

NOTE: Guidewords not used in this node: No, More, Reverse, As Well As, and Part Of.
AO = aging overpack; CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; CTT = cask transfer trolley; ST = site transporter; TC = transportation cask; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Table E-17. HAZOP Evaluation Worksheet for Node 15

Facility/Operation: CRCF							Process: WP Operation
Node 15: Install WP Inner Lid and Move to WP Closure Room							Process/Equipment: CTM, WP, WPTT
Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
15.1	WPTT Preparation	(Other Than) Improper positioning of empty WP in WPTT	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Precursor to WP loading mishaps	N/A
15.2	WPTT Preparation	(Other Than) Pedestal not loaded or improper pedestal loaded	Human failure	No safety consequences	N/A	Precursor to WP loading mishaps	N/A
15.3	WPTT Preparation	(Other Than) Improper alignment of WP to vertical axis when bringing upright	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Precursor to WP loading mishaps	N/A
15.4	WPTT Preparation	(Other Than) Shield ring not installed	Human failure	Direct exposure	N/A	Could cause overexposure of personnel in CRCF viewing gallery or CRCF Control Room and subject welding equipment to exposure greater than design	CRC-1708
15.5	WPTT Preparation	(Other Than) Wrong WP used for waste form to be loaded	Human failure	No safety consequences	N/A	Precursor to WP loading mishaps	N/A
15.6	WPTT Movement with Empty WP	(Other Than) Impact or derailment	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Precursor to WP loading mishaps	N/A
15.7	WPTT Movement with Empty WP	(Other Than) Misalignment of WP and port	1 – Human failure 2 – Mechanical failure (see precursors above for this node)	Potential drop of or impact to canister leading to radioactive release	Procedures and training	Potential of catching ledge and dropping into WP	CRC-1601
15.8	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 (WP requires multiple lids)	N/A
15.9	Install Lid	(Other Than) Install wrong lid or not installing lid	Human failure	Direct exposure	Procedures and training	N/A	CRC-1708
15.10	Install Lid	(Reverse) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential impact to canister leading to radioactive release	1 – Procedures and training 2 – Crane design features	N/A	CRC-1701
15.11	Install Lid	(Other Than) Lift with grapple improperly attached (see 16.8 above)	Human failure	Potential impact to canister leading to radioactive release	Procedures and training	N/A	CRC-1701
15.12	WPTT Movement with Loaded WP	(Other Than) Impact or derailment	1 – Human failure 2 – Mechanical failure	Potential drop of or impact to WP leading to radioactive release	1 – Procedures and training 2 – Maintenance	Impacts include premature tilting	CRC-1704 CRC-1705, CRC-1706

NOTE: Guidewords not used in this node: No, More, Less, As Well As, and Part Of.

CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Table E-18. HAZOP Evaluation Worksheet for Node 16

Facility/Operation: CRCF				Process: WP Operation			
Node 16: Close WP				Process/Equipment: Welding Machine, WP, WPTT, Crane, Inner and Outer Lids			
Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
16.1	WPTT Alignment	(Other Than) Greater than 1-in. deviation from expected position	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	Positioning monitored by camera	N/A
16.2	Lid Placement	N/A	N/A	N/A	N/A	N/A	N/A
16.3	Welding Process Temperature	(More) Greater than expected temperature	1 – Human failure 2 – Mechanical failure	No safety consequences	Weld machine design	Non-Q study states burn-through not possible	N/A
16.4	Welding Process Temperature	(Less) Less than expected temperature	1 – Human failure 2 – Mechanical failure	No safety consequences	Weld machine design	1 – Improper weld 2 – Potential weakening of WP boundary	N/A
16.5	Welding Process Material	(Other Than) Wrong welding material	Human failure	No safety consequences	Procedures and training	1 – Improper weld 2 – Potential weakening of WP boundary	N/A
16.6	Welding Process Material	(More) More than expected amount	1 – Human failure 2 – Mechanical failure	No safety consequences	Procedures and training	1 – Improper weld 2 – Potential weakening of WP boundary	N/A
16.7	Welding Process Material	(Less) Less than expected amount	1 – Human failure 2 – Mechanical failure	No safety consequences	Procedures and training	1 – Improper weld 2 – Potential weakening of WP boundary	N/A
16.8	Welding Process Debris	N/A	N/A	N/A	N/A	No debris from weld process utilized for WP closure	N/A
16.9	Welding Process Inerting Blanket	(No or Less) Loss of inerting blanket	1 – Human failure 2 – Mechanical failure	No safety consequences	Procedures and training	1 – Improper weld 2 – Potential weakening of WP boundary	N/A
16.10	Welding Process Inerting Blanket	(Other Than) Flammable gas substituted for inerting gas	Human failure	No safety consequences	Procedures and training	1 – Potential fire initiator 2 – Improper weld	N/A
16.11	Weld Cooling	(More) Too much cooling	1 – Human failure 2 – Mechanical failure	No safety consequences	Procedures and training	Check water supply for ultrasonic testing	N/A
16.12	Weld Cooling	(Less) Localized temperature exceeds limits	1 – Human failure 2 – Mechanical failure	No safety consequences	Procedures and training	N/A	N/A
16.13	Welding Process	See 16.1 through 16.5 in previous node	N/A	N/A	N/A	N/A	N/A
16.14	Install Outer Lid	(Other Than) Install wrong lid or no lid	Human failure	Potential direct exposure	Procedures and training	N/A	
16.15	Install Outer Lid	(Reverse) Attempting to lift lid too high (i.e., two-blocking)	Human failure	Potential drop of lid onto WP	1 – Procedures and training 2 – Crane design features	N/A	CRC-1701
16.16	Install Outer Lid	(Other Than) Lift with grapple improperly attached (see attach grapple engagement above)	Human failure	Potential impact to WP leading to radioactive release	Procedures and training	N/A	CRC-1702

NOTE: Guidewords not used in this node: As Well As and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; in. = inch; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Table E-19. HAZOP Evaluation Worksheet for Node 17

Facility/Operation: CRCF							Process: WP Operation
Node 17: Move to WP Load Out Room							Process/Equipment: WP, WPTT
Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of							Consequence Categories: Radioactive Release, Lack of Shielding, Criticality
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
17.1	WPTT Movement with Loaded WP	(Other Than) Impact or derailment	1 – Human failure 2 – Mechanical failure	Potential drop of or impact to WP leading to radioactive release	1 – Procedures and training 2 – Maintenance	N/A	CRC-1704 CRC-1705, CRC-1706
17.2	Shield Door Movement	(Other Than) Failure to open shield door	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – Design of shield door controls 3 – WP design	N/A	CRC-1704
17.3	Shield Door Movement	(Other Than) Closure on WPTT during transit	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – Design of shield door controls 3 – WP design	N/A	CRC-1704
17.4	WPTT Engagement	(Other Than) Fail to secure WPTT to docking station prior to shield ring removal or WP transfer	1 – Human failure 2 – Mechanical failure	Potential drop of or impact to WP leading to radioactive release	1 – Procedures and training 2 – WPTT/Docking Station design	Potential displacement of WPTT during tilt-down or shield ring removal	CRC-1904
17.5	Shield Ring Removal	(Other Than) Not removed	Human failure	No safety consequences	Procedures and training	Excess weight of shield accelerates tilt-down	N/A
17.6	Shield Ring Removal	(Other Than) Drops onto WP during removal	1 – Human failure 2 – Mechanical failure	Potential impact to WP leading to radioactive release	1 – Procedures and training 2 – Crane design	Includes installation of grapple	CRC-1902
17.7	Shield Ring Removal	(Other Than) Shield ring binds with WP during shield removal	1 – Human failure 2 – Mechanical failure	Potential drop of WP leading to radioactive release	1 – Procedures and training 2 – Crane design	Partial lift of WP with drop of WP	CRC-1903
17.8	Shield Ring Removal	(Less) Shield ring fails to clear WPTT or WP during shield removal	1 – Human failure 2 – Mechanical failure	Potential drop of or impact to WP leading to radioactive release	1 – Procedures and training 2 – Crane design	Tip over of WPTT	CRC-1903
17.9	Down-ending of WP in WPTT	(More) Rapid tilting rundown	1 – Human failure 2 – Mechanical failure	Potential impact to WP leading to radioactive release	1 – Procedures and training 2 – WPTT design	Potential ejection of WP and pallet	CRC-1904
17.10	Down-ending of WP in WPTT	(Less or No) Stuck in mid-travel during tilting	1 – Human failure 2 – Mechanical failure	Potential impact to WP leading to radioactive release	1 – Procedures and training 2 – WPTT design	N/A	CRC-1904
17.11	Extract WP and Pallet from WPTT	(Less or No) WP and pallet stuck in WPTT	1 – Human failure 2 – Mechanical failure	Potential impact to WP leading to radioactive release	1 – Procedures and training 2 – WPTT design	Interface point with TEV and Subsurface operations	CRC-1904
17.12	Extract WP and Pallet from WPTT	(More) WP and pallet extracted too rapidly from WPTT	1 – Human failure 2 – Mechanical failure	Potential collision leading to Radioactive Release	1 – Procedures and training 2 – WPTT design	1 – Interface point with TEV and Subsurface operations 2 – Potential collision if TEV not ready to receive	CRC-1905
17.13	Extract WP and Pallet from WPTT	(More) WP and pallet extracted before TEV doors open	1 – Human failure 2 – Mechanical failure	Potential collision leading to Radioactive Release	1 – Procedures and training 2 – WPTT/TEV design	1 – Interface point with TEV and Subsurface operations 2 – Potential collision if TEV not ready to receive	

NOTE: Guidewords not used in this node: Reverse, As Well As, and Part Of.
CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Table E-20. HAZOP Evaluation Worksheet for Node 18

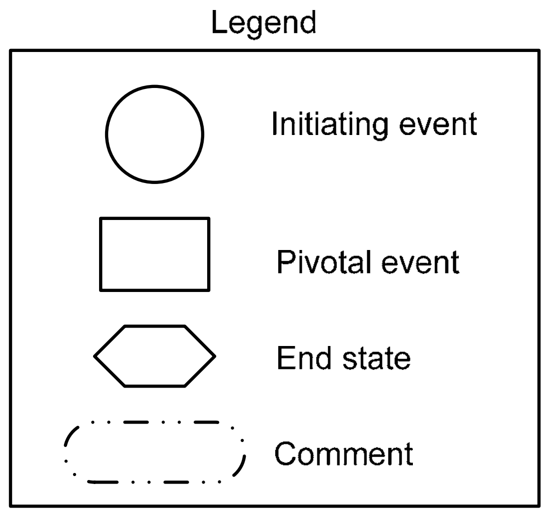
Facility/Operation: CRCF				Process: ST Operation			
Node 18: Move Loaded Receptacle/Carrier on ST into or out of RF, CRCF, WHF				Process Equipment: ST, AO			
Guidewords: No, More, Less, Other Than, Reverse, As Well As, Part Of				Consequence Categories: Radioactive Release, Lack of Shielding, Criticality			
Node Item Number	**Parameter**	**Deviation Considered**	**Postulated Cause**	**Consequence(s)**	**Potential Prevention/Mitigation Design of Operational Feature**	**Notes**	**MLD Index Number**
18.1	ST Movement	(More) Moves too far	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – ST design 3 – Receptacle/carrier design	Possible mitigation of event by receptacle/carrier depending on passive equipment failure analysis	CRC-108 CRC-1908
18.2	ST Movement	(Less) Doesn't move far enough	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	N/A	N/A
18.3	ST Movement	(Less) ST loses track or other breakdown	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – ST design 3 – Receptacle/carrier design	N/A	CRC-107 CRC-1908
18.4	ST Movement	(Reverse) Moves in wrong direction	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – ST design 3 – Receptacle/carrier design	N/A	CRC-1908
18.5	ST Movement	(Other Than) Steers off designated path	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – Procedures and training 2 – ST design 3 – Receptacle/carrier design	N/A	CRC-1908
18.6	ST	(Other Than) Fire	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	For PCSA Fire Analysis	CRC-I303
18.7	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	CRC-1901
18.8	Lift	(Less) ST does not lift required transport height	1 – Human failure 2 – Mechanical failure	Potential collision leading to radioactive release	1 – ST design 2 – Procedures and training	N/A	CRC-1908
18.9	Lift	(No) ST does not lift load	1 – Human failure 2 – Mechanical failure	No safety consequences	N/A	1 – No loss of shielding or radioactive release 2 – Expected damage to bottom plate only	N/A

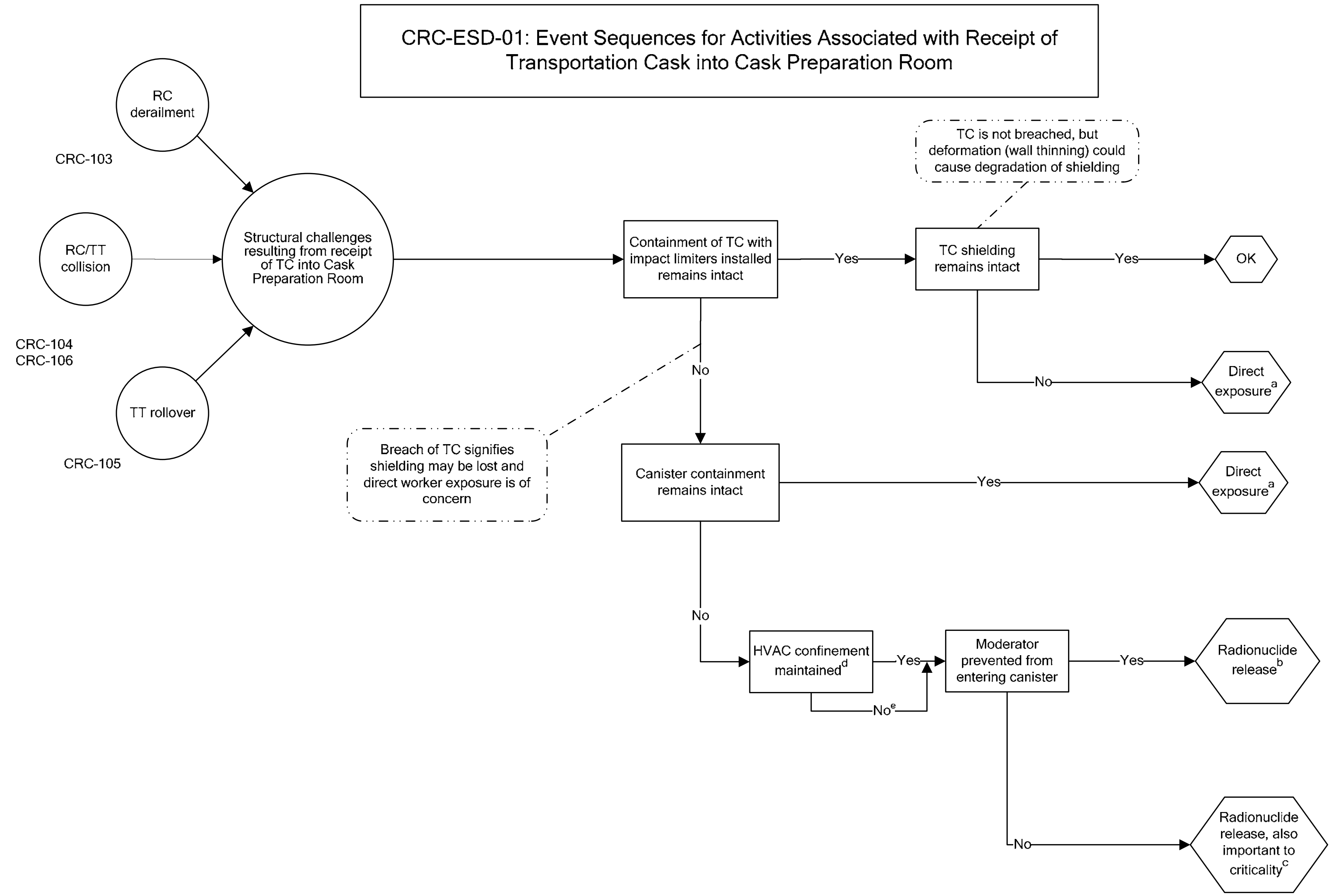
NOTE: Guidewords not used in this node: As Well As and Part Of.
AO = aging overpack; CRC = Canister Receipt Closure; CRCF = Canister Receipt and Closure Facility; ft =foot; PCSA = Preclosure Safety Analysis; RF = Receipt Facility; ST = site transporter; WHF = Wet Handling Facility.

Source: Original

ATTACHMENT F
CANISTER RECEIPT AND CLOSURE FACILITY EVENT SEQUENCE DIAGRAMS

Event sequence diagrams for the CRCF are presented in Figures F-1 to F-20.





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

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

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

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

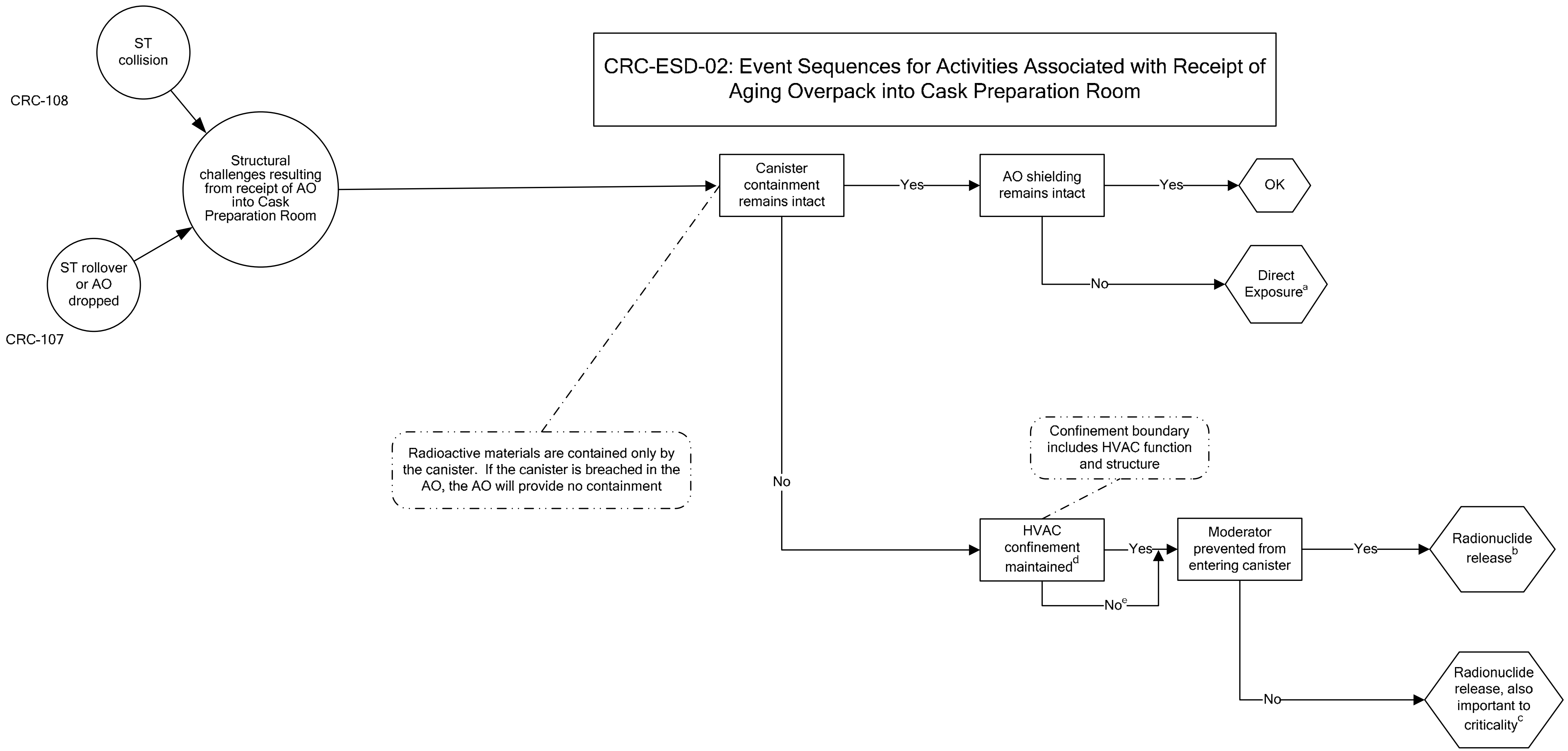
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to transportation casks with HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters.

DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; RC = railcar; TAD = transportation, aging, and disposal (canister); TC = transportation cask; TT = truck trailer.

Source: Original

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



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

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

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

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

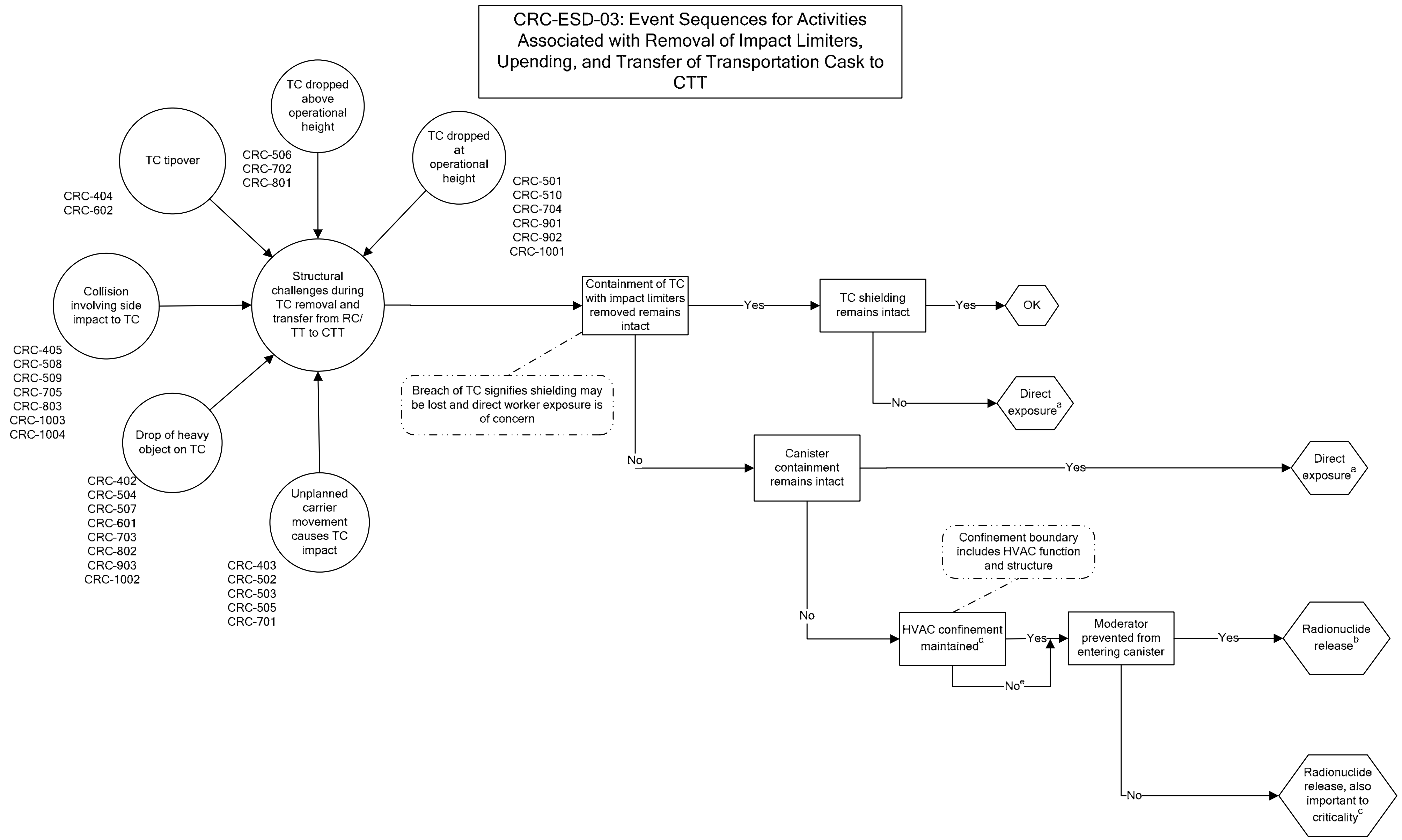
[c] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] This ESD applies to aging overpacks with TAD canisters.

[e] AO = aging overpack; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; ST = site transported; TAD = transportation, aging, and disposal (canister).

Source: Original

Figure F-2. CRC-ESD-02: Event Sequences for Activities Associated with Receipt of Aging Overpack into Cask Preparation Room



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

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

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

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

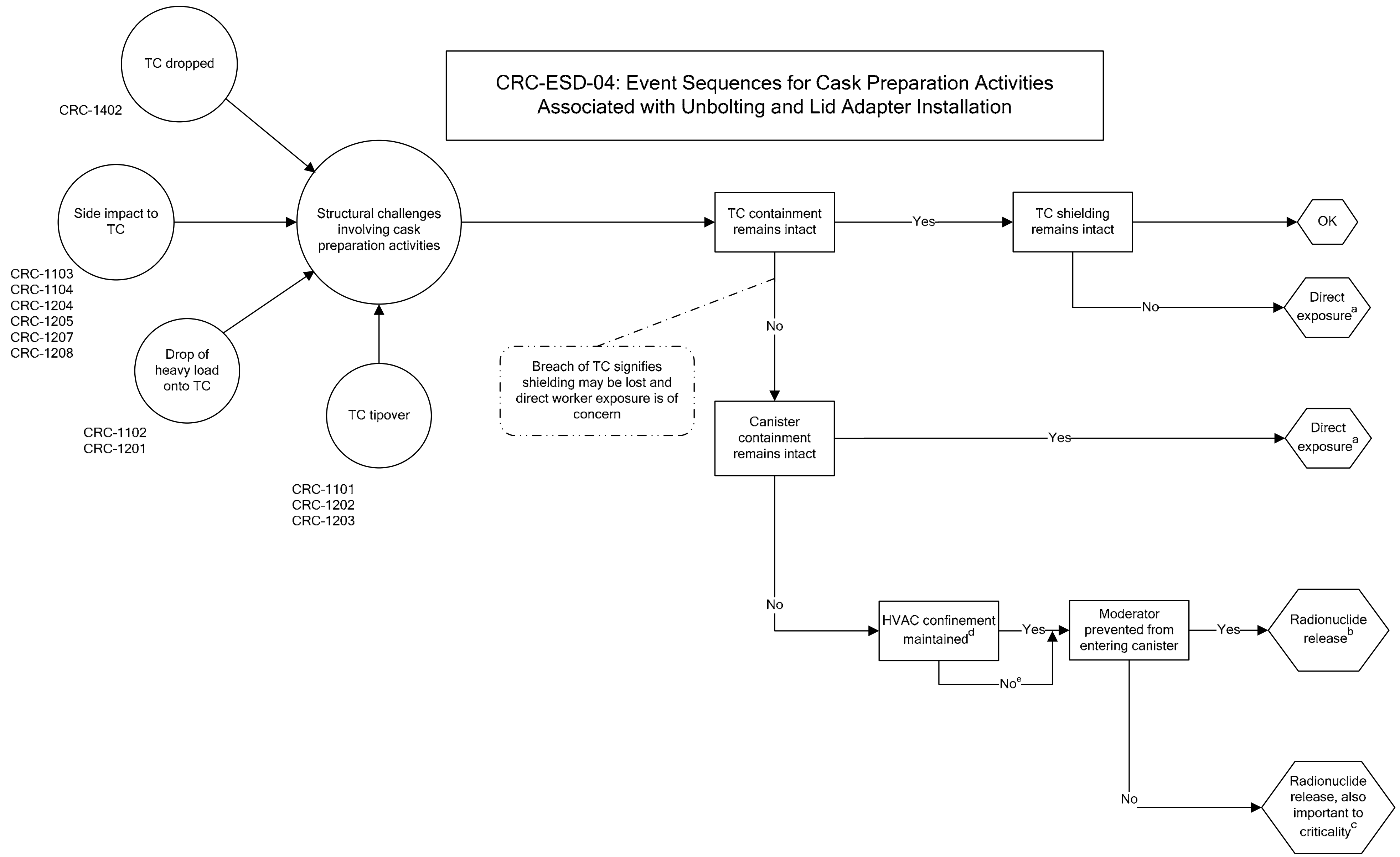
Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] This ESD applies to transportation casks with either HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters.

[e] CTT = cask transfer trolley; DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; RC = railcar; TAD = transportation, aging, and disposal (canister); TC = transportation cask; TT = truck trailer.

Source: Original

Figure F-3. CRC-ESD-03: Event Sequences for Activities Associated with Removal of Impact Limiters, Upending, and Transfer of Transportation Cask to CTT



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

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

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

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

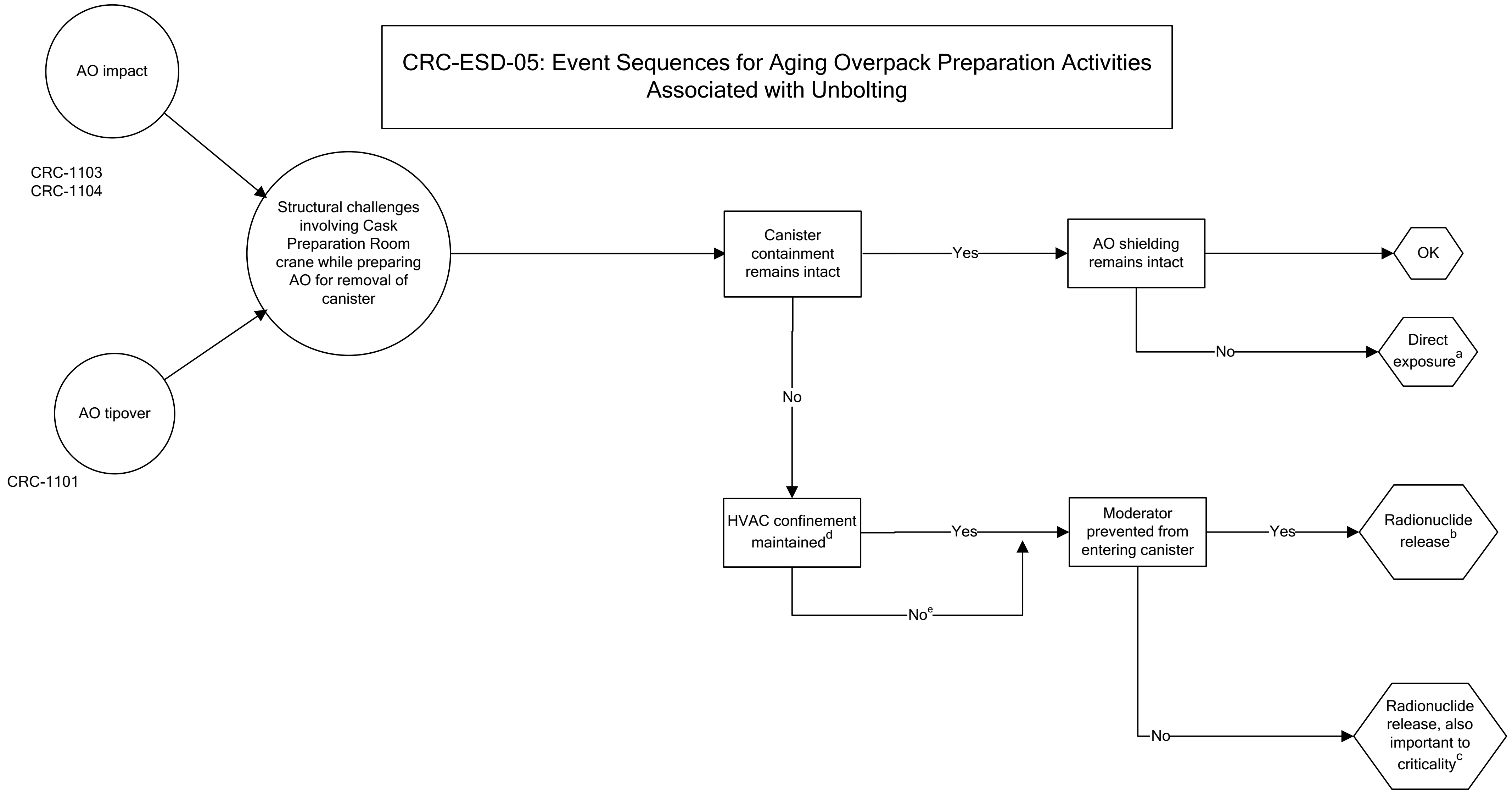
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to transportation casks with either HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters.

DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister); TC = transportation cask.

Source: Original

Figure F-4. CRC-ESD-04: Event Sequences for Cask Preparation Activities Associated with Unbolting and Lid Adapter Installation



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

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

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

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

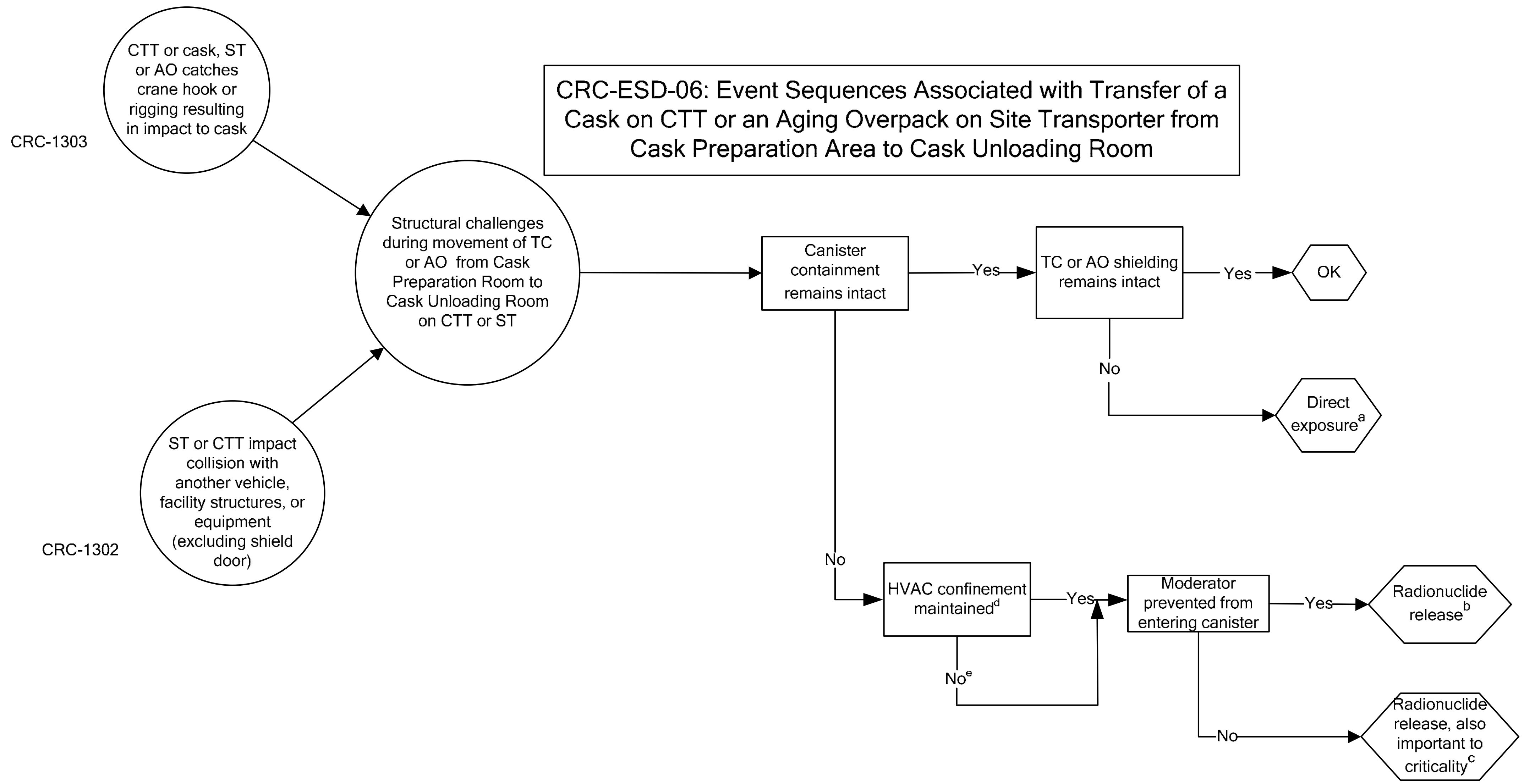
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to aging overpacks with TAD canisters.

AO = aging overpack; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TAD = transportation, aging, and disposal (canister).

Source: Original

Figure F-5. CRC-ESD-05: Event Sequences for Aging Overpack Preparation Activities Associated with Unbolting



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

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

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

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

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

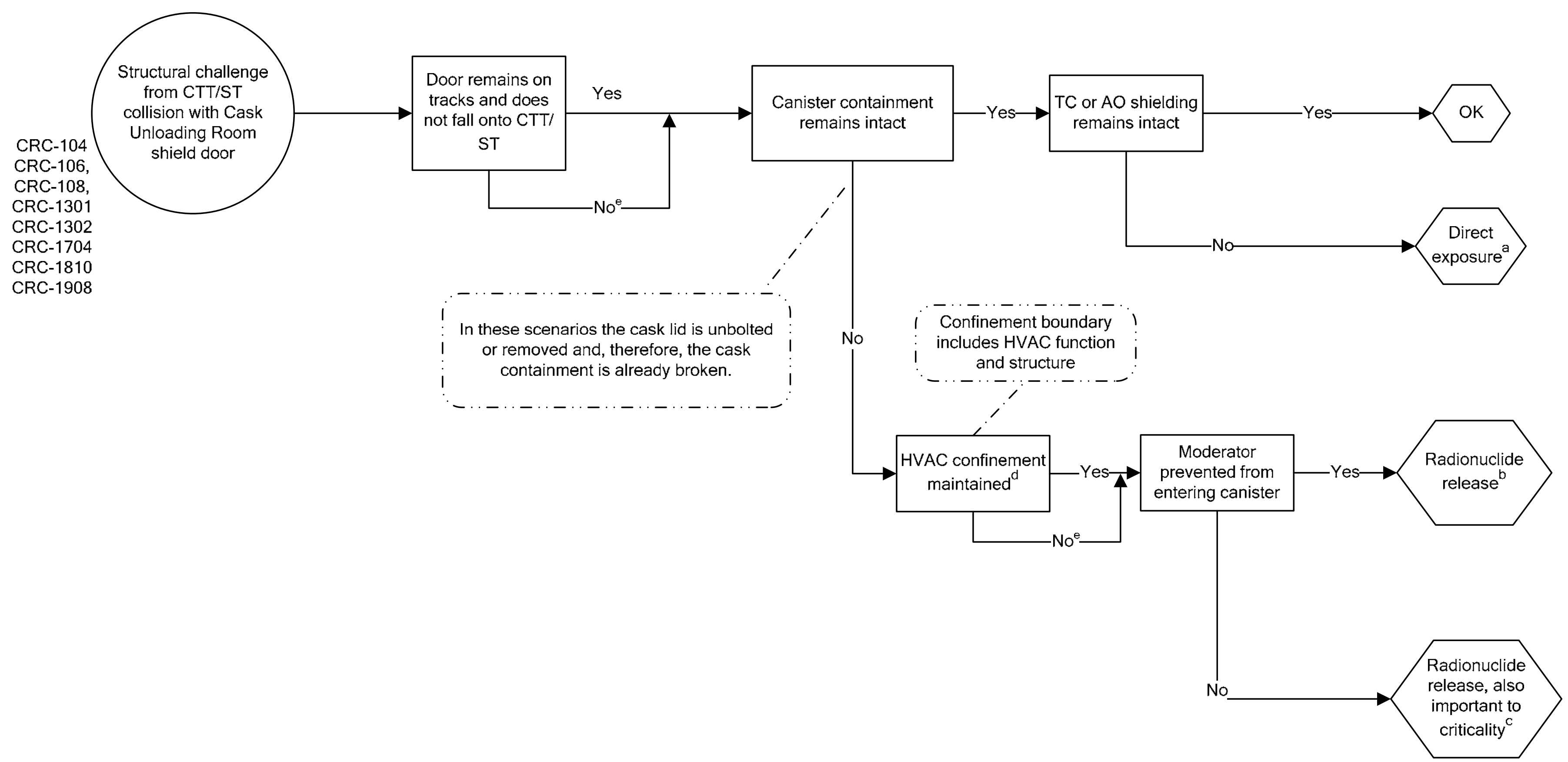
[d] This ESD applies to transportation casks with either HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters or to aging overpacks with TAD canisters

[e] AO = aging overpack; CTT = cask transfer trolley; DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; ST = site transporter; TAD = transportation, aging, and disposal (canister); TC = transportation cask.

Source: Original

Figure F-6. CRC-ESD-06: Event Sequences Associated with Transfer of a Cask on CTT or an Aging Overpack on Site Transporter from Cask Preparation Area to Cask Unloading Room

CRC-ESD-07: Event Sequences Associated with Collision of CTT, Site Transporter, or WPTT with CRCF Shield Door



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

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

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

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

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

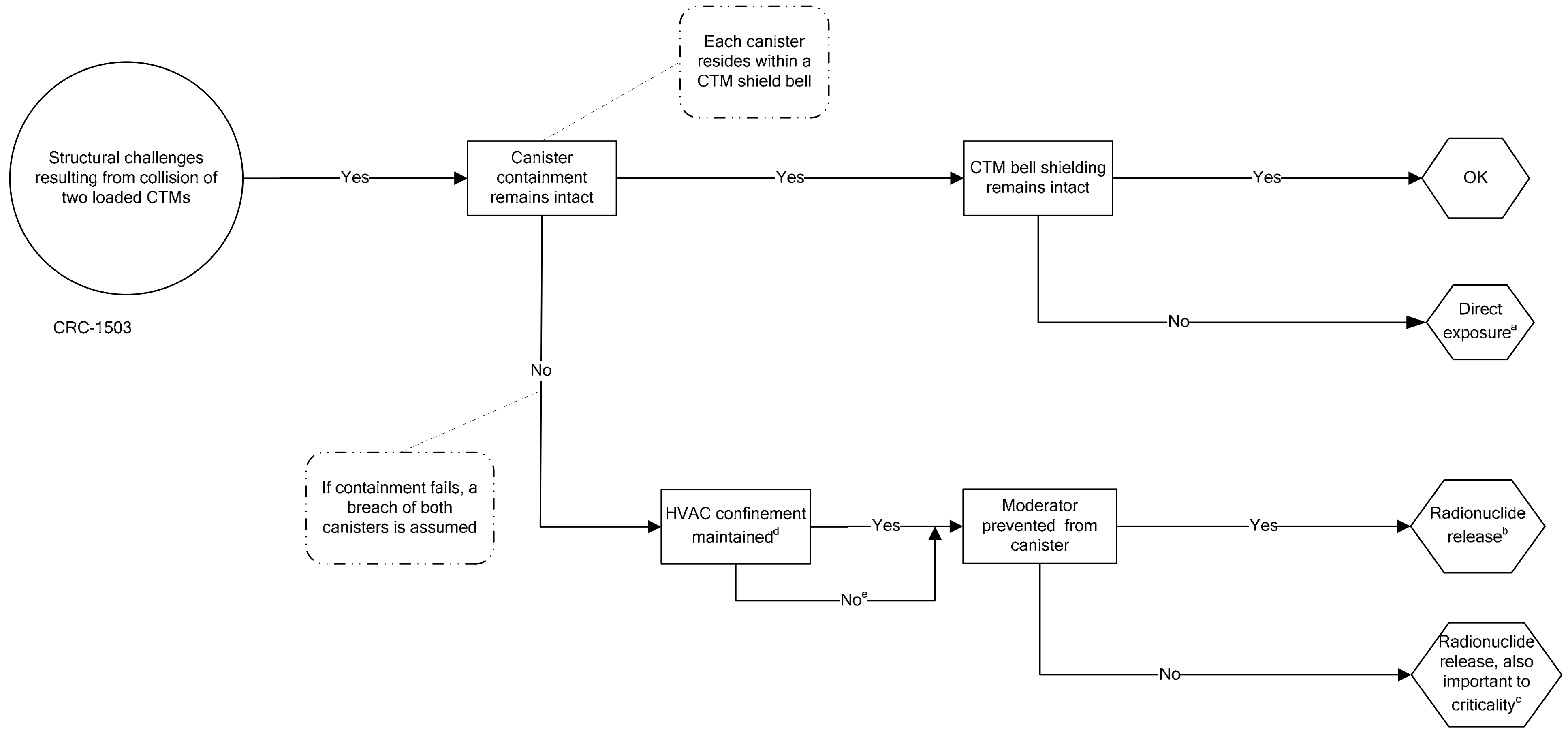
This ESD applies to transportation casks with either HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters, to aging overpacks with TAD canisters, or to WPs with HLW canisters and DOE standardized canisters, HLW canisters and MCOs, or TAD canisters.

AO = aging overpack; CTT = cask transfer trolley; DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; ST = site transporter; TAD = transportation, aging, and disposal (canister); TC = transportation cask.

Source: Original

Figure F-7. CRC-ESD-07: Event Sequences Associated with Collision of CTT or Site Transporter with Cask Unloading Room Shield Door

CRC-ESD-08: Event Sequences Associated with Collision of two CTMs Loaded with Canisters



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

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

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

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

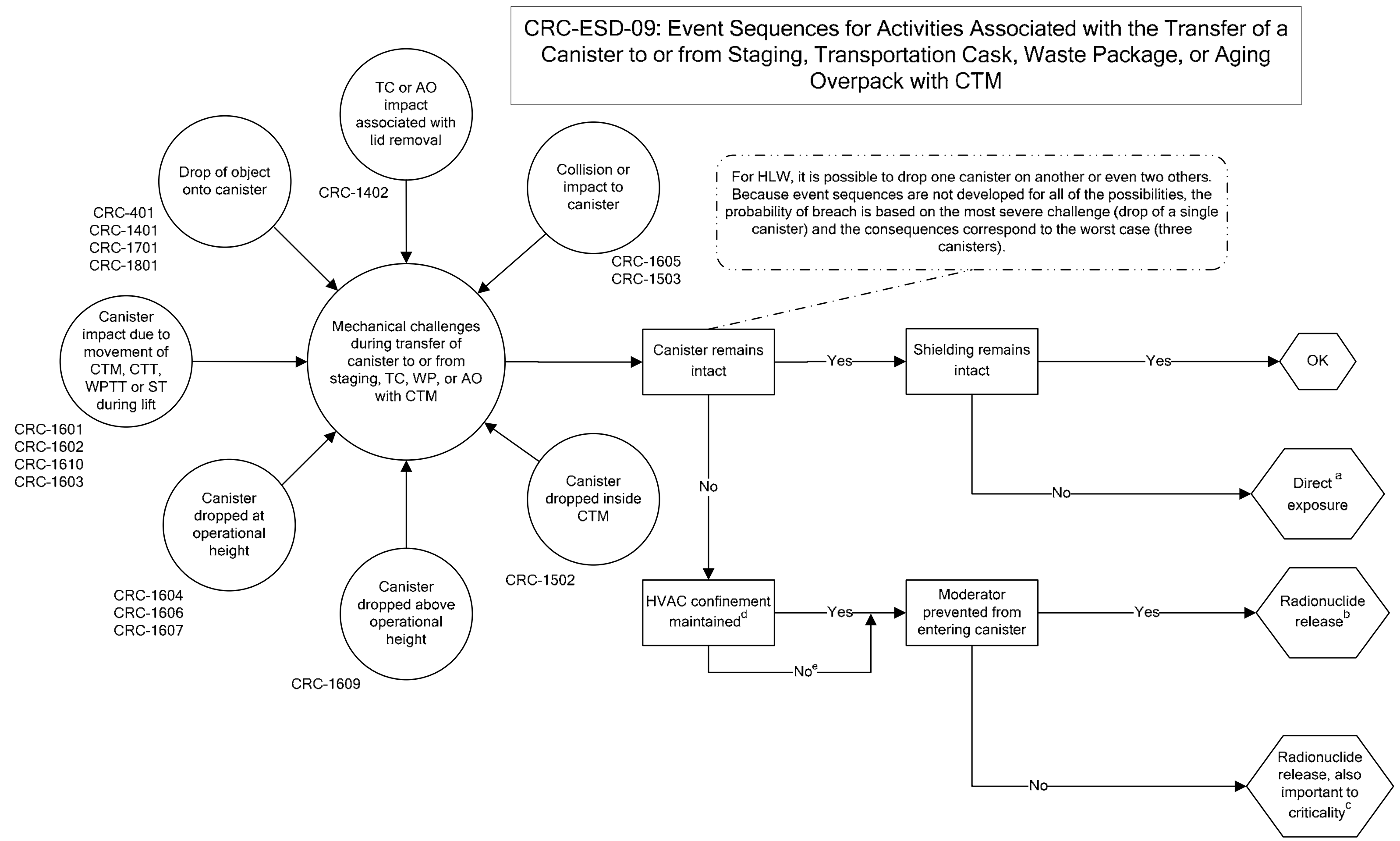
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters

CTM = canister transfer machine; DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister).

Source: Original

Figure F-8. CRC-ESD-08: Event Sequences Associated with Collision of Two CTMs Loaded with Canisters



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

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

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

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

[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.

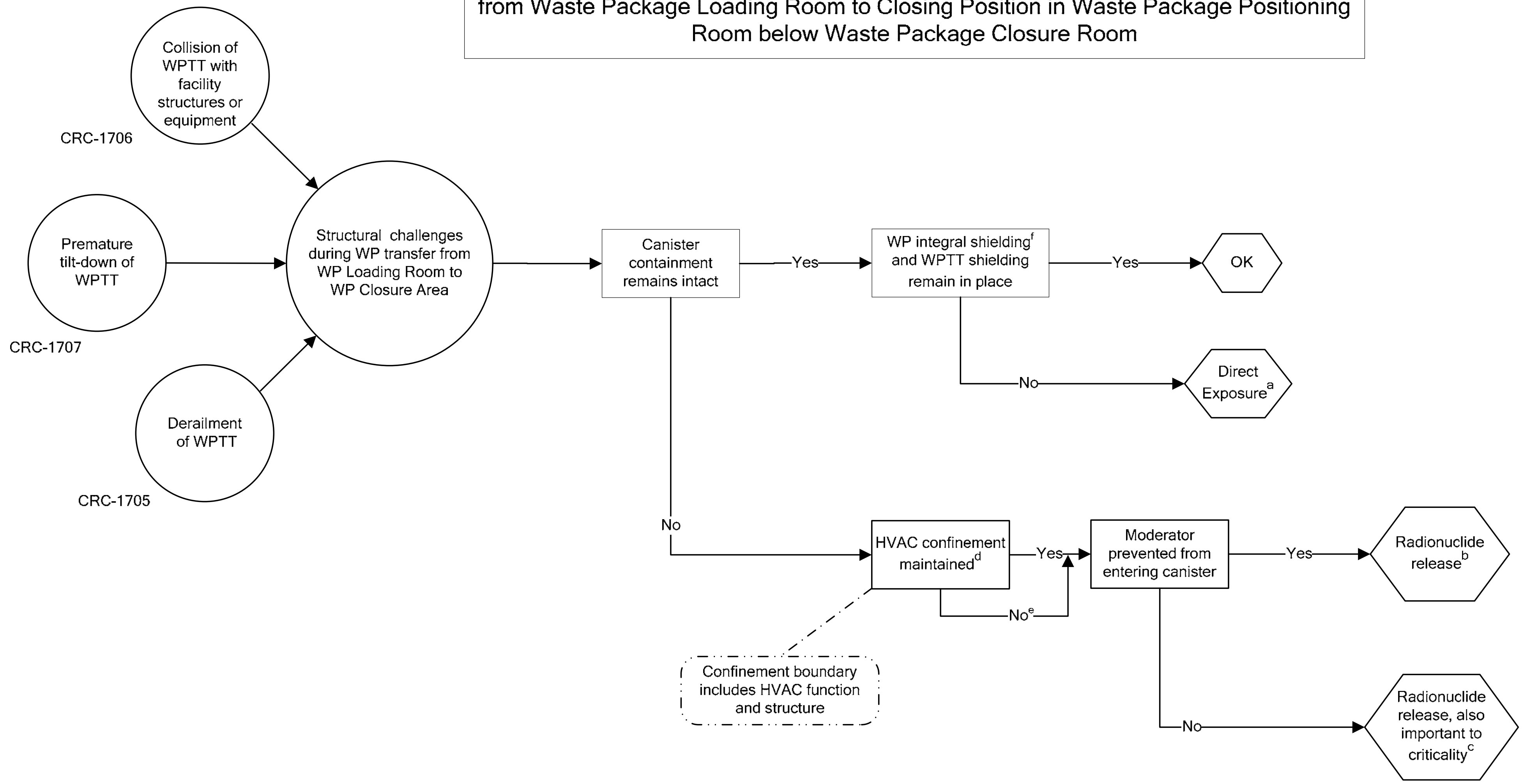
[d] This ESD applies to HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters.

[e] AO = aging overpack; CTM = canister transfer machine; CTT = cask transfer trolley; DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; ST = site transporter; TAD = transportation, aging, and disposal (canister); TC = transportation cask; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-9. CRC-ESD-09: Event Sequences for Activities Associated with the Transfer of a Canister to or from Staging, Transportation Cask, Waste Package, or Aging Overpack with CTM

CRC-ESD-10: Event Sequences for Activities Associated with Waste Package Transfer from Waste Package Loading Room to Closing Position in Waste Package Positioning Room below Waste Package Closure Room



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

[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.

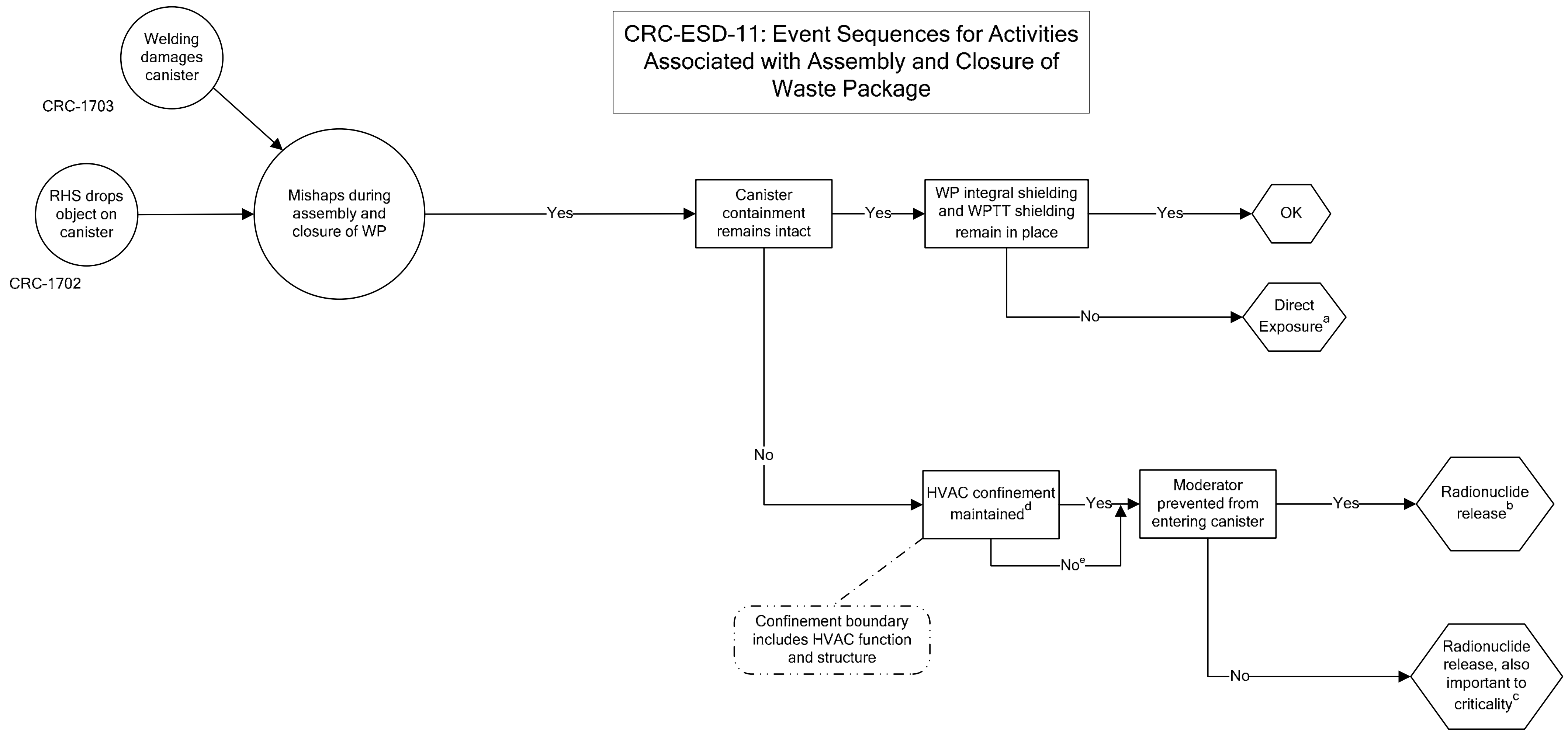
[f] Associated shielding includes WP lid and shield ring.

This ESD applies to WPs with HLW canisters and DOE standardized canisters, HLW canisters and MCOs, or TAD canisters

DOE = U.S. Department of Energy; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister); WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-10. CRC-ESD-10: Event Sequences for Activities Associated with Waste Package Transfer from Waste Package Loading Room to Closing Position in Waste Package Positioning Room below Waste Package Closure Room



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

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

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

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

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.

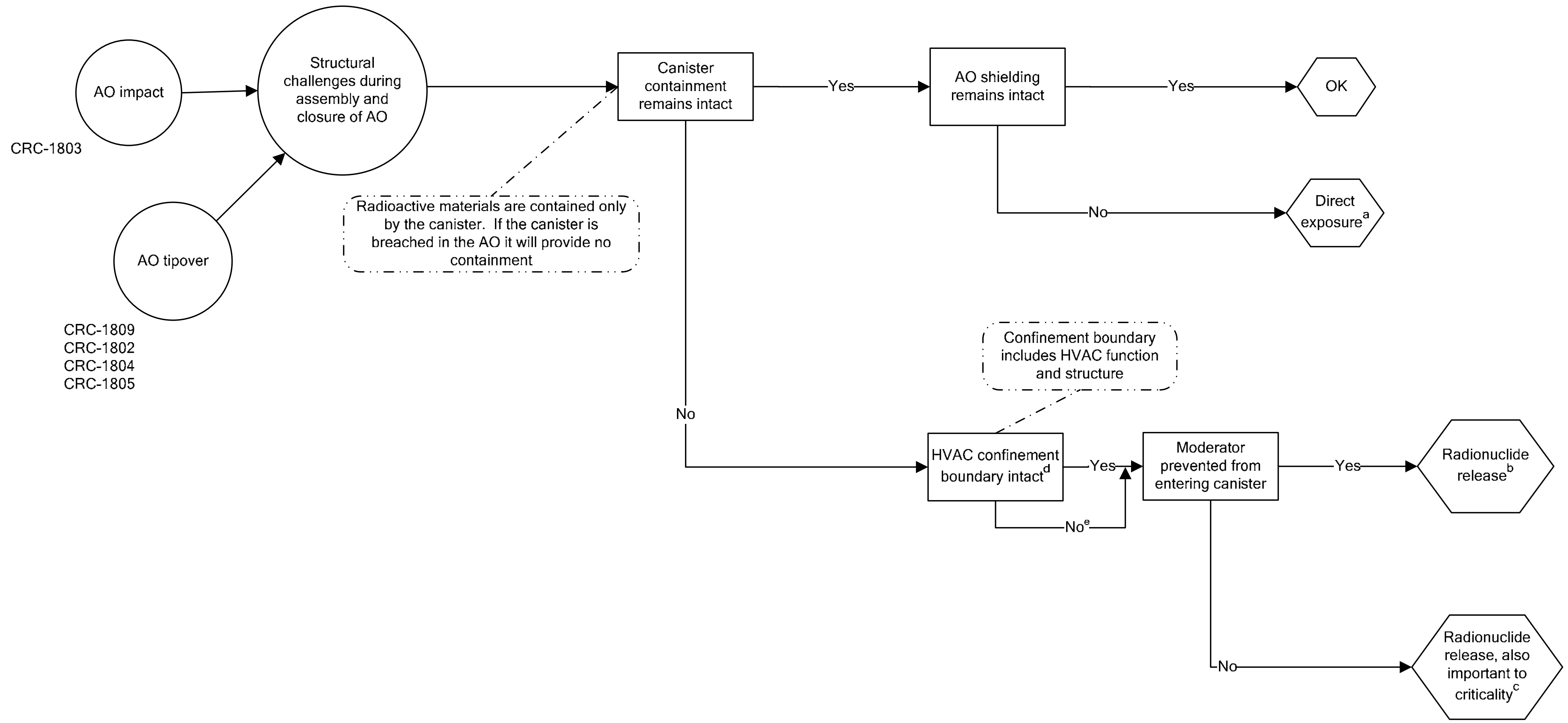
d This ESD applies to WPs with HLW canisters and DOE standardized canisters, HLW canisters and MCOs, or TAD canisters

e DOE = U.S. Department of Energy; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister); WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-11. CRC-ESD-11: Event Sequences for Activities Associated with Assembly and Closure of Waste Package

CRC-ESD-12: Event Sequences for Activities Associated with Assembly and Closure of Aging Overpack



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

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

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

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

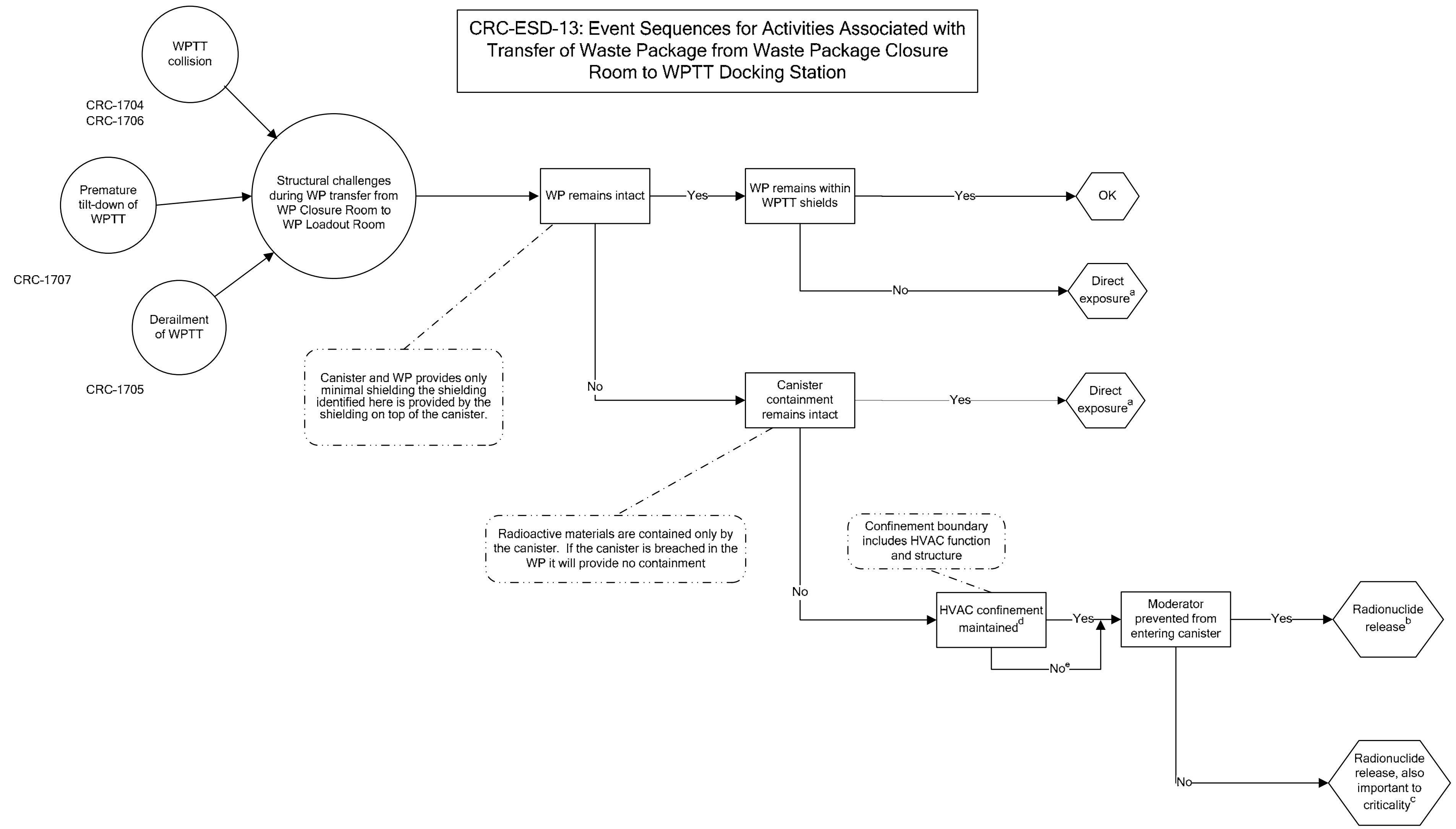
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to aging overpacks with DPCs or TAD canisters.

AO = aging overpack; DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TAD = transportation, aging, and disposal (canister).

Source: Original

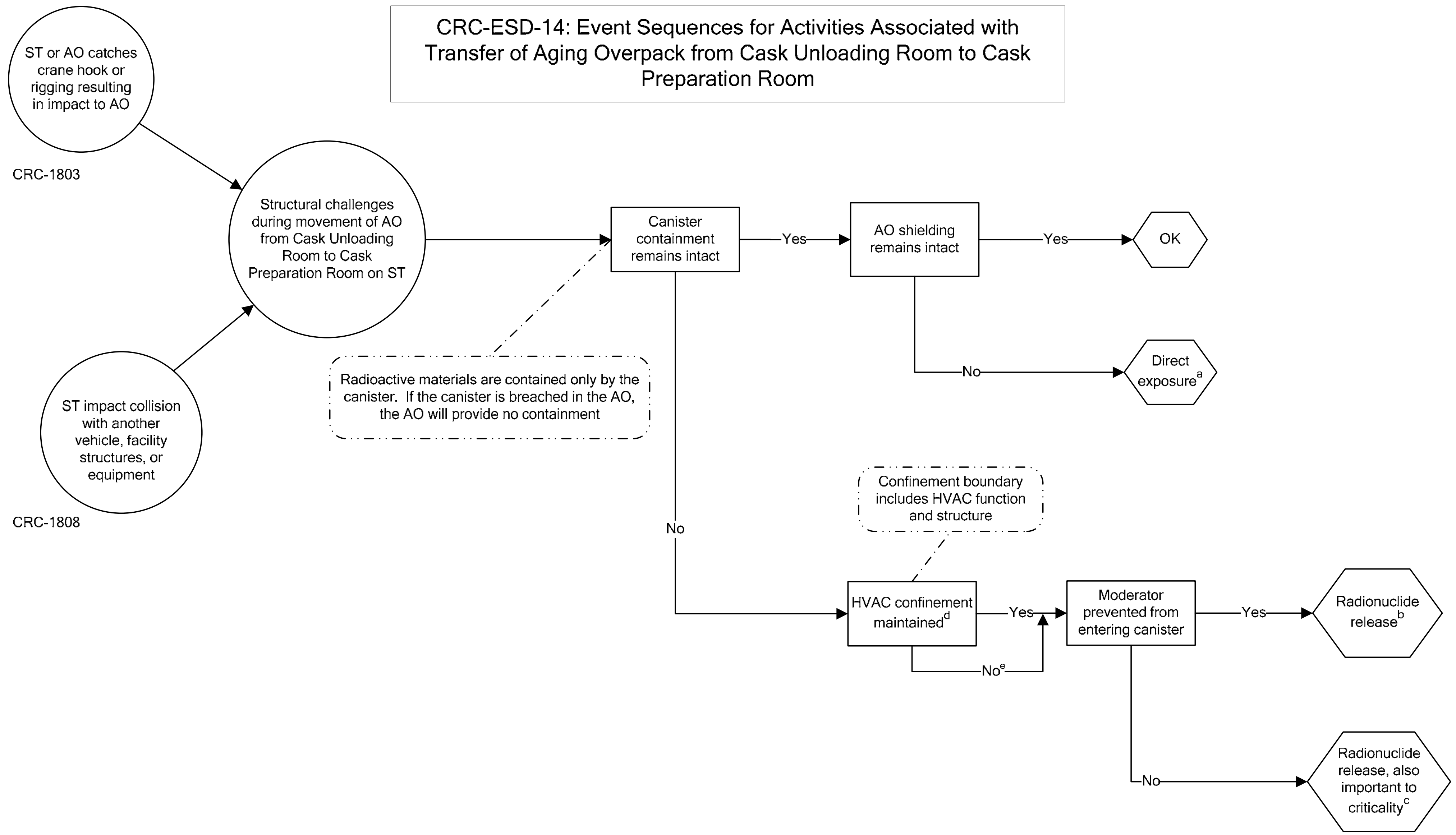
Figure F-12. CRC-ESD-12: Event Sequences for Activities Associated with Assembly and Closure of Aging Overpack



NOTE: [a] Direct exposure indicates the potential for a personnel exposure to direct or reflected radiation without a breach of a waste form container.
Radionuclide release describes a condition where radioactive material has been released from the container creating a potential inhalation or ingestion hazard, accompanied by the potential for immersion in a radioactive plume and direct exposure, as described above.
Radionuclide release, also important to criticality, involves radionuclide release as described above, accompanied by the potential for nuclear criticality, which may arise when liquid
[b] moderator is available to enter a breached container.
Successful operation of the HVAC system would mitigate a radionuclide release.
[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] This ESD applies to WPs with HLW canisters and DOE standardized canisters, HLW canisters and MCOs, or TAD canisters
[e] DOE = U.S. Department of Energy; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister); WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-13. CRC-ESD-13: Event Sequences for Activities Associated with Transfer of Waste Package from Waste Package Closure Room to WPTT Docking Station



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

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

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

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

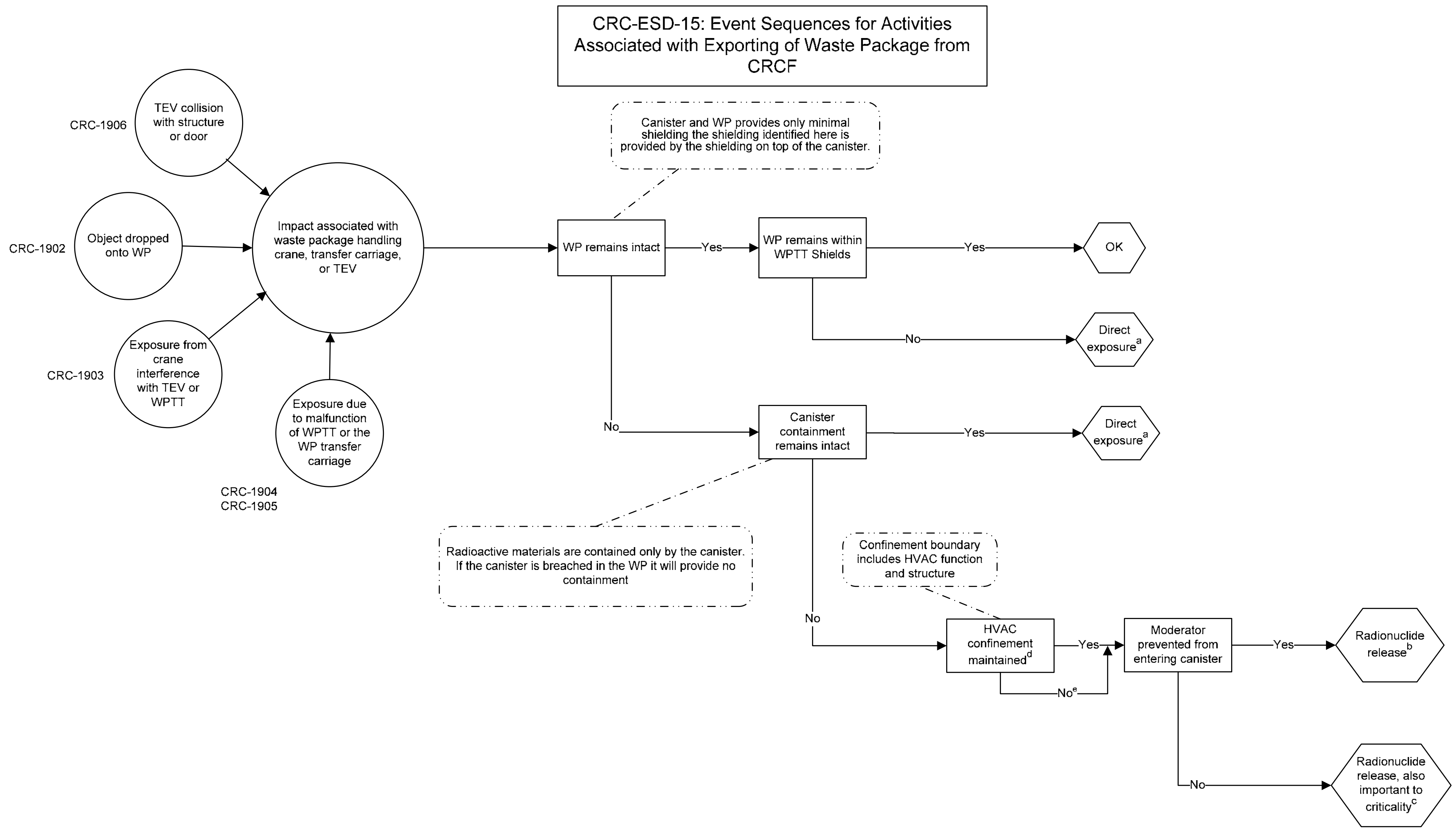
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to aging overpacks with DPCs or TAD canisters.

AO = aging overpack; DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; TAD = transportation, aging, and disposal (canister).

Source: Original

Figure F-14. CRC-ESD-14: Event Sequences for Activities Associated with Transfer of Aging Overpack from Cask Unloading Room to Cask Preparation Room



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

[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.

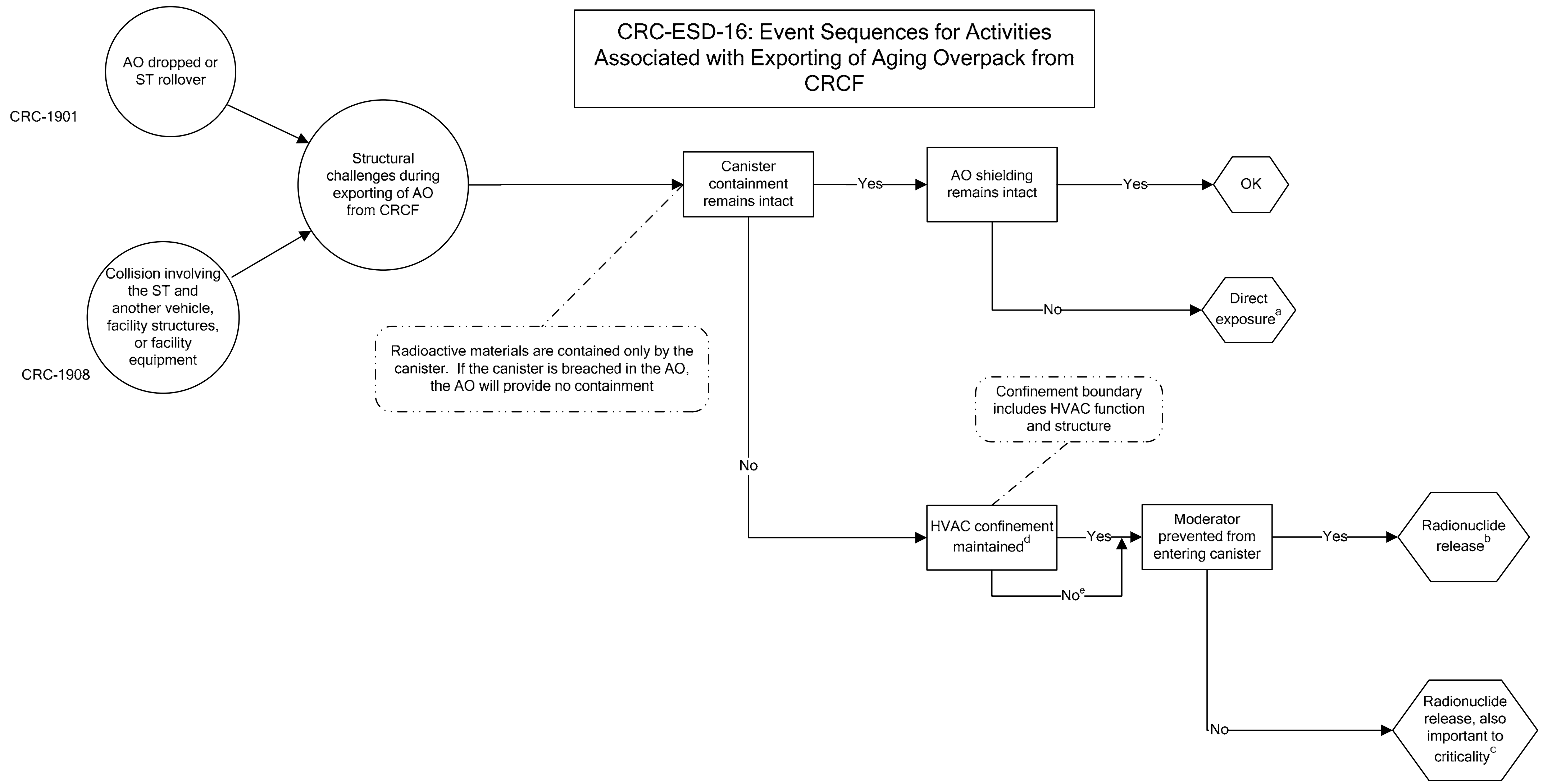
[e] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

This ESD applies to WPs with HLW canisters and DOE standardized canisters, HLW canisters and MCOs, or TAD canisters

CRCF = Canister Receipt and Closure Facility; DOE = U.S. Department of Energy; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air conditioning; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister); TEV = transport and emplacement vehicle; WP = waste package; WPTT = waste package transfer trolley.

Source: Original

Figure F-15. CRC-ESD-15: Event Sequences for Activities Associated with Exporting of Waste Package from CRCF



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

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

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

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

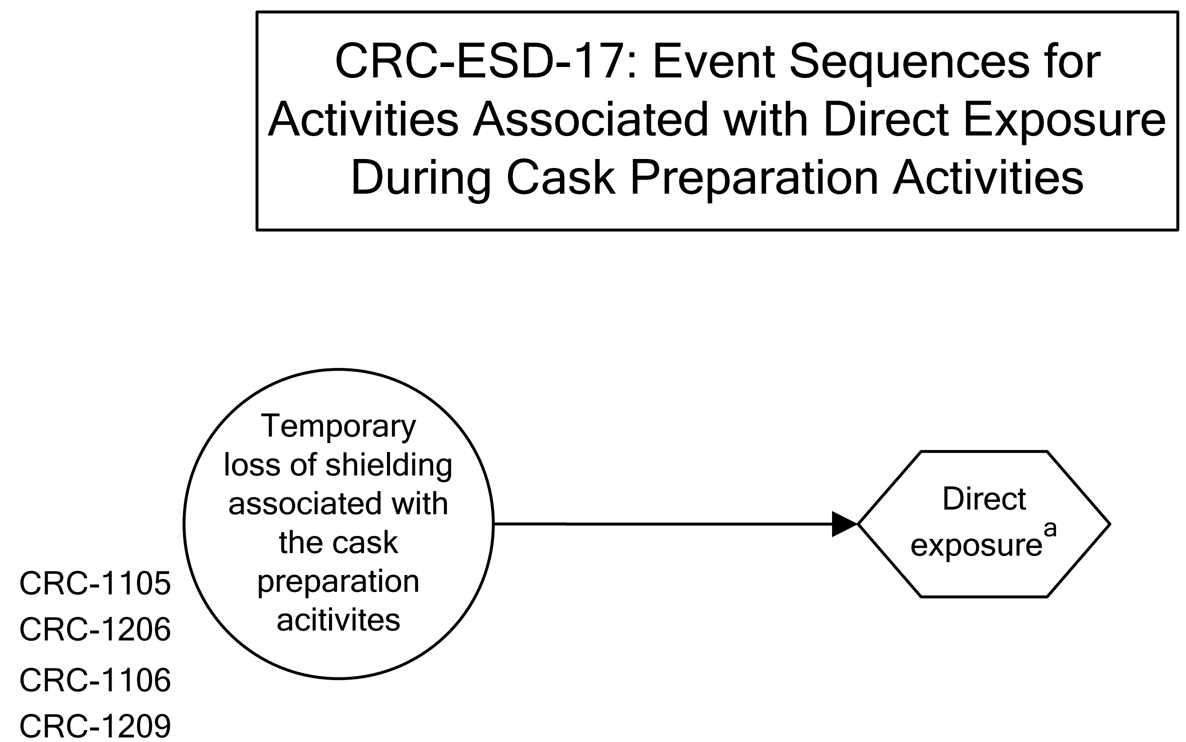
[c] Pivotal events for which both the yes and no paths merge are provided to simplify communication of the event sequences. The end state frequency and consequences for each path may be different.

[d] This ESD applies to aging overpacks with DPCs or TAD canisters.

[e] AO = aging overpack; CRCF = Canister Receipt and Closure Facility; DPC = dual-purpose canister; ESD = event sequence diagram; HVAC = heating, ventilation, and air conditioning; ST = site transporter; TAD = transportation, aging, and disposal (canister).

Source: Original

Figure F-16. CRC-ESD-16: Event Sequences for Activities Associated with Exporting of Aging Overpack from CRCF



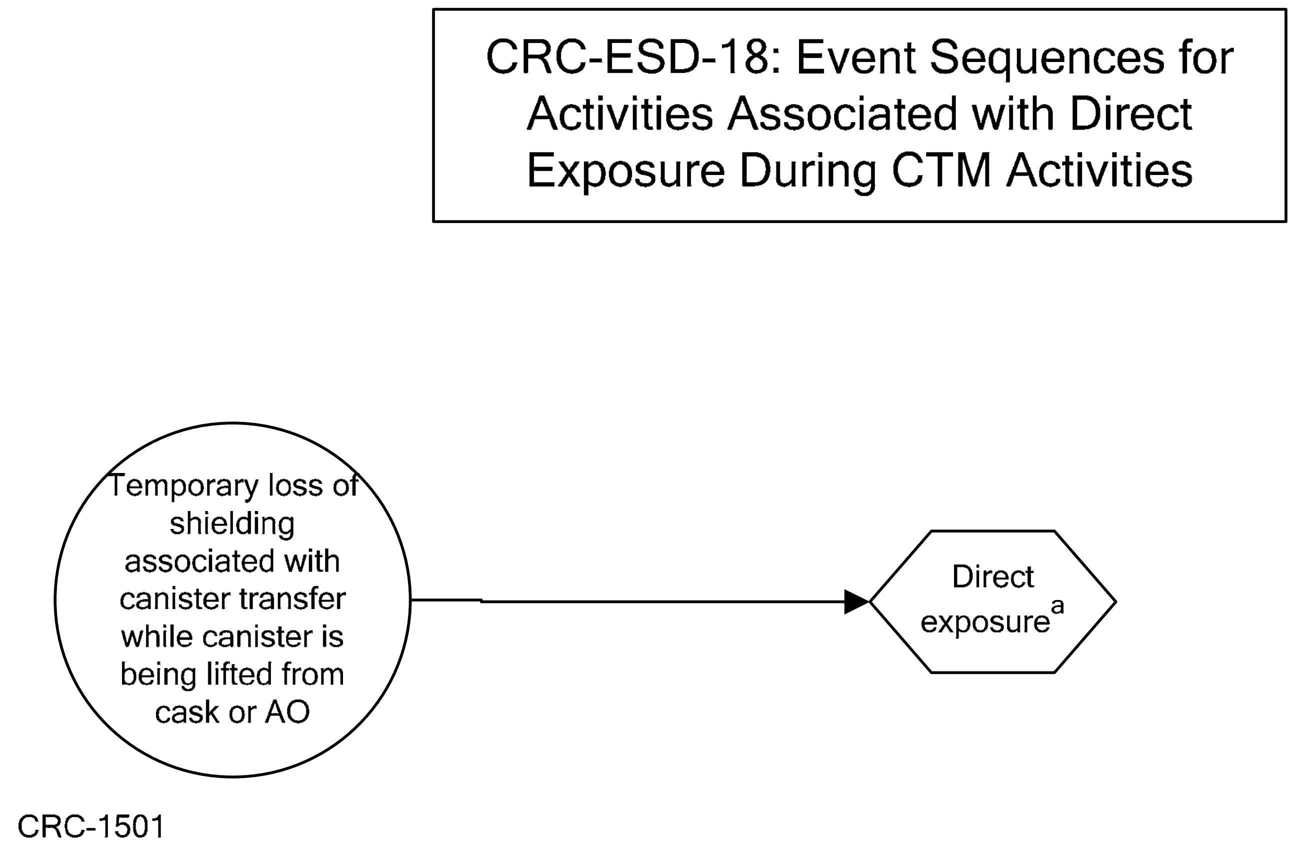
NOTE: [a] Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.

This ESD applies to transportation casks with either HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters or to aging overpacks with TAD canisters

AO = aging overpack; DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister); TC = transportation cask.

Source: Original

Figure F-17. CRC-ESD-17: Event Sequences for Activities Associated with Direct Exposure During Cask Preparation Activities



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

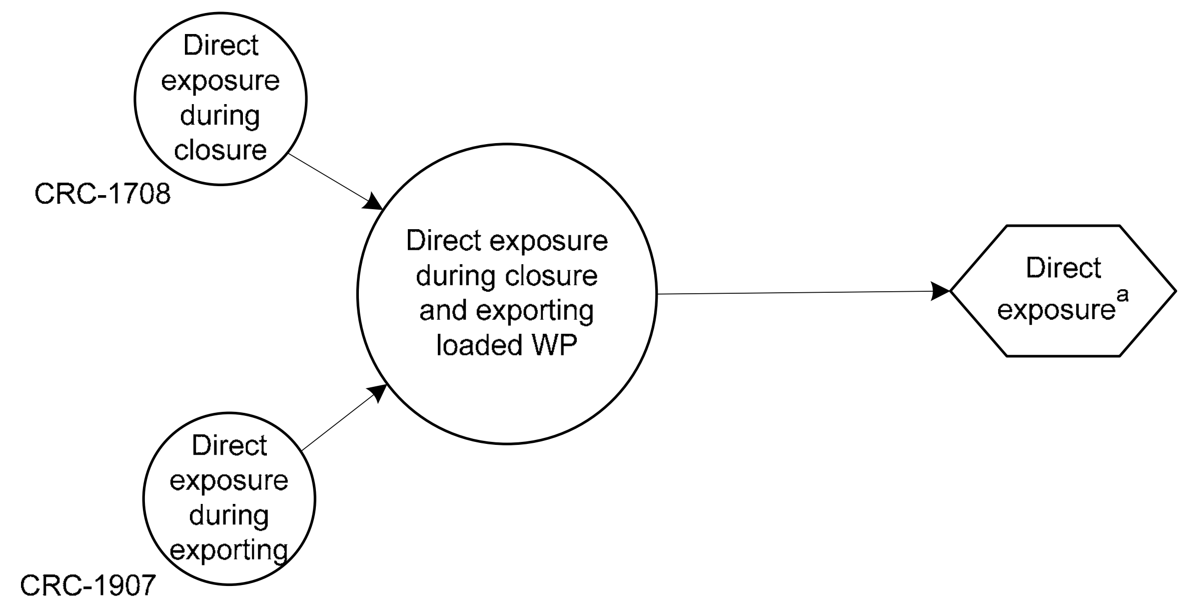
This ESD applies to HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters

AO = aging overpack; CTM = canister transfer machine; DOE = U.S. Department of Energy; ESD = event sequence diagram; HLW = high-level radioactive waste; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister).

Source: Original

Figure F-18. CRC-ESD-18: Event Sequences for Activities Associated with Direct Exposure During CTM Activities

CRC-ESD-19: Event Sequences for Activities Associated with Direct Exposure During Closure and Exporting Loaded Waste Package



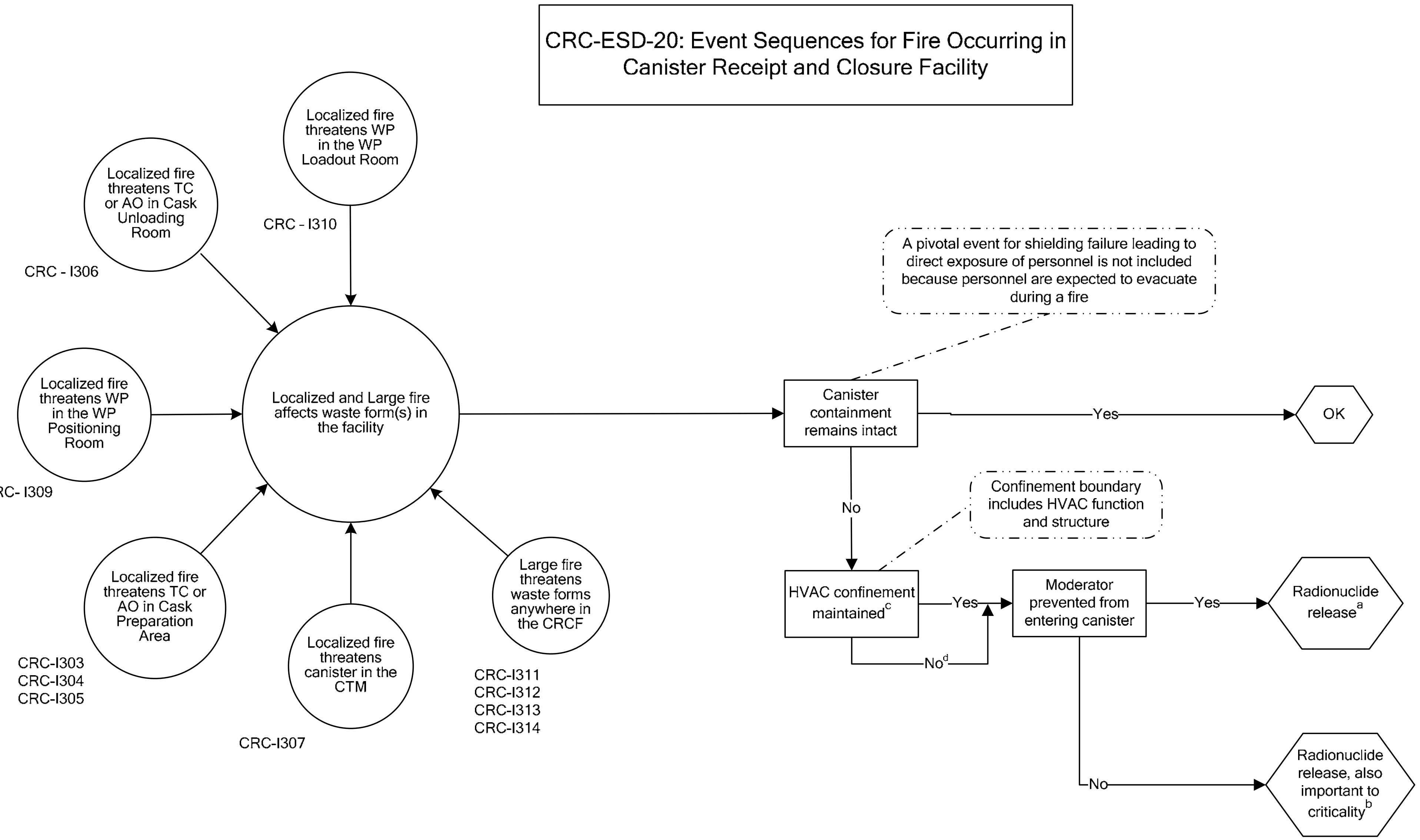
NOTE: [a] Direct exposure is that condition where individuals are directly exposed to the radiation beam streaming through areas where shielding has been compromised.

This ESD applies to WPs with HLW canisters and DOE standardized canisters, HLW canisters and MCOs, or TAD canisters

DOE = U.S. Department of Energy; ESD = event sequence diagram; HLW = high-level radioactive waste; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister); WP = waste package.

Source: Original

Figure F-19. CRC-ESD-19: Event Sequences for Activities Associated with Direct Exposure During Closure and Exporting Loaded Waste Package



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 immersion 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.

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

[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] This ESD applies to: 1) Transportation casks with either HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters;
2) Aging Overpacks with TAD canisters;

[d] 3) HLW canisters, DOE standardized canisters, MCOs, DPCs, or TAD canisters; and
4) WPs with HLW canisters & DOE standardized canisters, HLW canisters and MCOs, DPCs, or TAD canisters

AO = aging overpack; CRCF = canister receipt and closure facility; CTM = canister transfer machine; DOE = U.S. Department of Energy; DPC = dual-purpose canister; ESD = event sequence diagram; HLW = high-level radioactive waste; HVAC = heating, ventilation, and air-conditioning; MCO = multicanister overpack; TAD = transportation, aging, and disposal (canister); TC = transportation cask; WP = waste package.

Source: Original

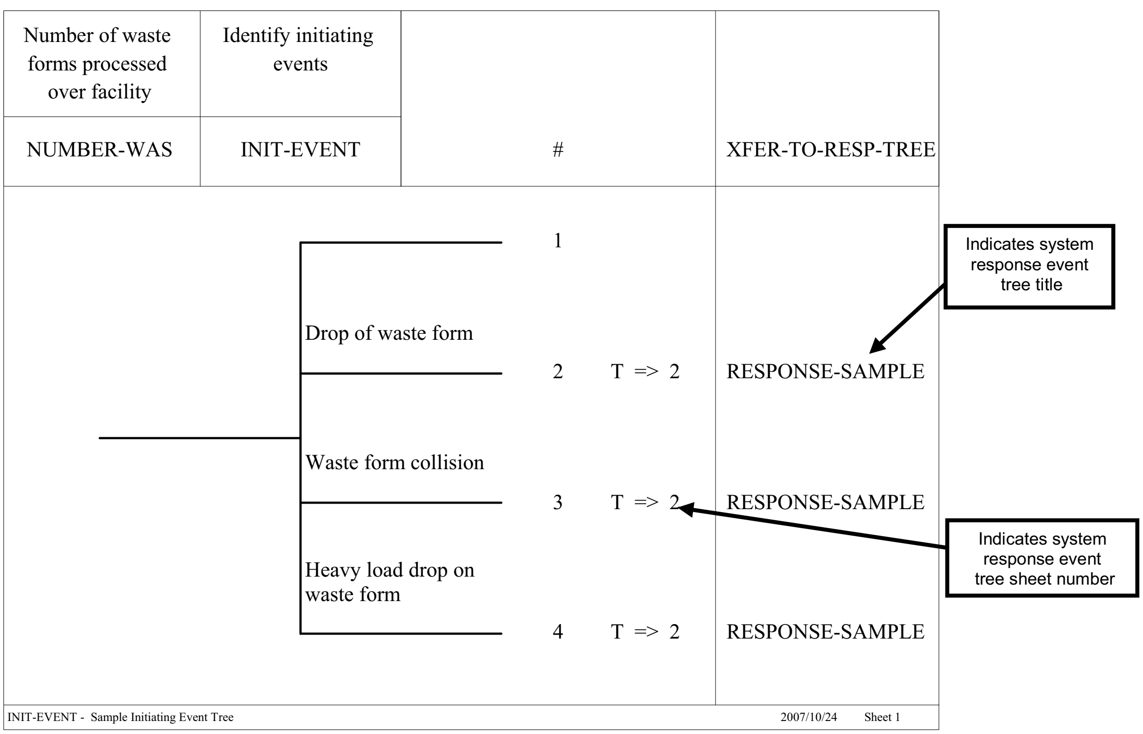
Figure F-20. CRC-ESD-20: Event Sequences for Fire Occurring in Canister Receipt and Closure Facility

ATTACHMENT G
CANISTER RECEIPT AND CLOSURE FACILITY EVENT TREES

G1 INTRODUCTION

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-86 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.



Source: Original

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
CRC-ESD-01	Event Sequences for Activities Associated with Receipt of TC in Transportation Cask Vestibule and Movement into Cask Preparation Room	CRCF-ESD01-DPC CRCF-ESD01-DSTD CRCF-ESD01-HLW CRCF-ESD01-MCO CRCF-ESD01-TAD	Figure G-2 Figure G-4 Figure G-5 Figure G-6 Figure G-7	RESPONSE-TCASK1	Figure G-3
CRC-ESD-02	Event Sequences for Activities Associated with Receipt of AO in Site Transporter Vestibule and Movement into Cask Preparation Room	CRCF-ESD02-TAD	Figure G-8	RESPONSE-GO1	Figure G-9
CRC-ESD-03	Event Sequences for Activities Associated with Removal of Impact Limiters, Upending and Transfer of TC to CTT	CRCF-ESD03-DPC CRCF-ESD03-DSTD CRCF-ESD03-HLW CRCF-ESD03-MCO CRCF-ESD03-TAD	Figure G-10 Figure G-11 Figure G-12 Figure G-13 Figure G-14	RESPONSE-TCASK1	Figure G-3
CRC-ESD-04	Event Sequences for Cask Preparation Activities Associated with Unbolting and Lid Adapter Installation	CRCF-ESD04-DPC CRCF-ESD04-DSTD CRCF-ESD04-HLW CRCF-ESD04-MCO CRCF-ESD04-TAD	Figure G-15 Figure G-16 Figure G-17 Figure G-18 Figure G-19	RESPONSE-TCASK1	Figure G-3
CRC-ESD-05	Event Sequences for AO Preparation Activities Associated with Unbolting and Lid Adapter Installation	CRCF-ESD05-TAD	Figure G-20	RESPONSE-CANISTER1	Figure G-21
CRC-ESD-06	Event Sequences Associated with Transfer of Cask on CTT or an AO on ST from Cask Preparation Room to Cask Unloading Room	CRCF-ESD06-DPC CRCF-ESD06-DSTD CRCF-ESD06-HLW CRCF-ESD06-MCO CRCF-ESD06-TAD	Figure G-22 Figure G-24 Figure G-25 Figure G-26 Figure G-27	RESPONSE-TCASK2	Figure G-23
CRC-ESD-07	Event Sequences Associated with Collision of CTT or ST with Cask Unloading Room Shield Door	CRCF-ESD07-DPC CRCF-ESD07-DSTD CRCF-ESD07-HLW CRCF-ESD07-MCO CRCF-ESD07-TAD CRCF-ESD07-WP-H&D CRCF-ESD07-WP-H&M CRCF-ESD07-WP-TAD	Figure G-28 Figure G-29 Figure G-30 Figure G-31 Figure G-32 Figure G-33 Figure G-34 Figure G-35	N/A	N/A
CRC-ESD-08	Event Sequences Associated with Collision of two CTMs Loaded with Canisters	CRCF-ESD08-DPC CRCF-ESD08-DSTD CRCF-ESD08-HLW CRCF-ESD08-MCO CRCF-ESD08-TAD	Figure G-36 Figure G-37 Figure G-38 Figure G-39 Figure G-40	RESPONSE-CANISTER1	Figure G-21

Table G-1. ESDs to Event Trees (Continued)

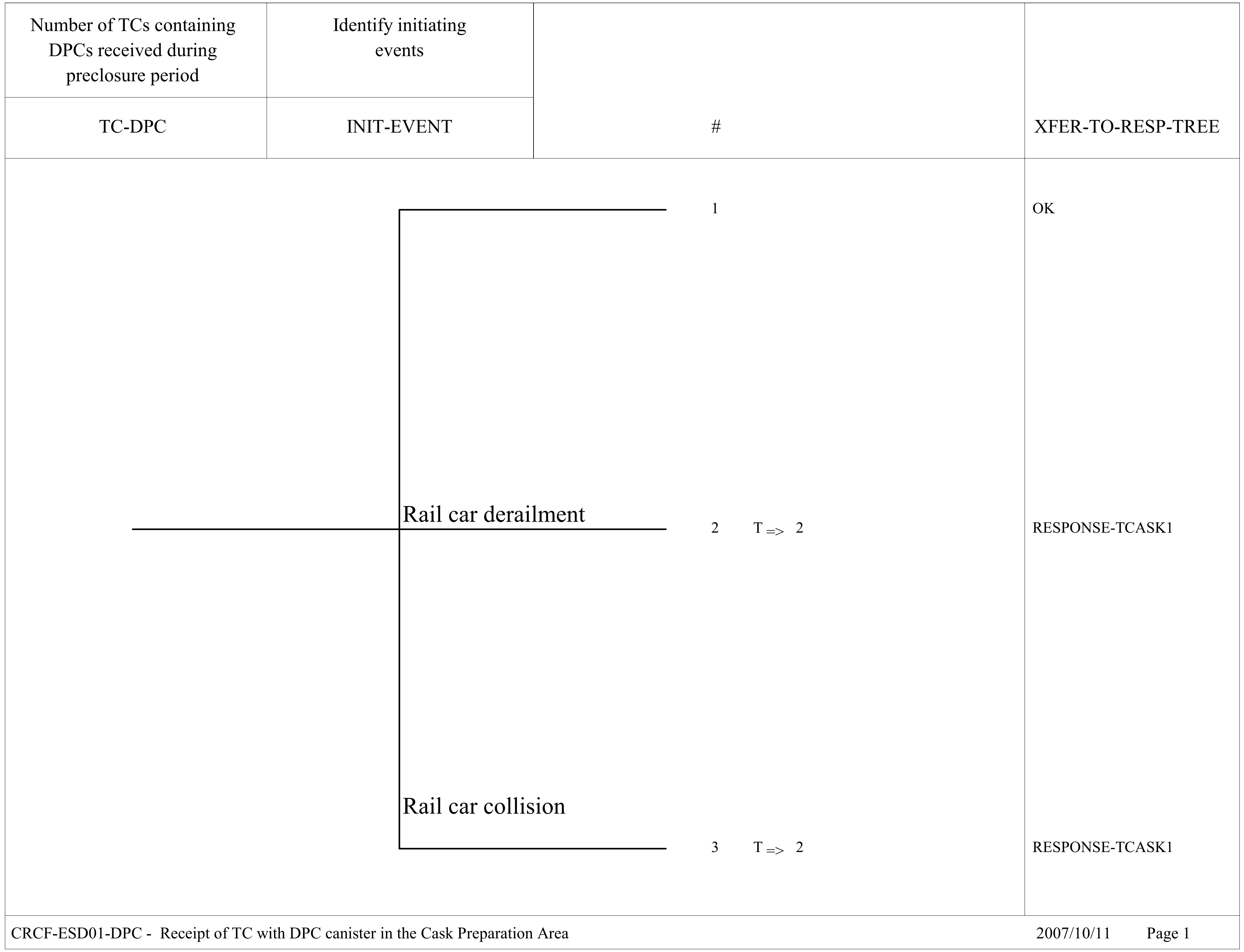
ESD#	ESD Title	IE Event Tree Name	IE Event Tree Location	Response Tree Name	Response Tree Location
CRC-ESD-09	Event Sequences for Activities Associated with Lifting and Lowering a Canister during Transfer to or from Staging, TC, WP, or AO with CTM	CRCF-ESD09-DPC CRCF-ESD09-DSTD CRCF-ESD09-HLW CRCF-ESD09-MCO CRCF-ESD09-TAD	Figure G-41 Figure G-42 Figure G-43 Figure G-44 Figure G-45	RESPONSE-CANISTER1	Figure G-21
CRC-ESD-10	Event Sequences for Activities Associated with WP Transfer from WP Loading Room to Closing Position in WP Positioning Room below WP Closure Room	CRCF-ESD10-WP-H&D CRCF-ESD10-WP-H&M CRCF-ESD10-WP-TAD	Figure G-46 Figure G-48 Figure G-49	RESPONSE-WP1	Figure G-47
CRC-ESD-11	Event Sequences for Activities Associated with Assembly and Closure of WP	CRCF-ESD11-WP-H&D CRCF-ESD11-WP-H&M CRCF-ESD11-WP-TAD	Figure G-50 Figure G-51 Figure G-52	RESPONSE-WP1	Figure G-47
CRC-ESD-12	Event Sequences for Activities Associated with Assembly and Closure of AO	CRCF-ESD12-DPC CRCF-ESD12-TAD	Figure G-53 Figure G-54	RESPONSE-AO1	Figure G-9
CRC-ESD-13	Event Sequences for Activities Associated with Transfer of WP from WP Closure Room to WPTT Docking Station	CRCF-ESD13-WP-H&D CRCF-ESD13-WP-H&M CRCF-ESD13-WP-TAD	Figure G-55 Figure G-57 Figure G-58	RESPONSE-WP2	Figure G-56
CRC-ESD-14	Event Sequences for Activities Associated with Transfer of AO from Cask Unloading Room to Cask Preparation Room	CRCF-ESD14-DPC CRCF-ESD14-TAD	Figure G-59 Figure G-60	RESPONSE-AO1	Figure G-9
CRC-ESD-15	Event Sequences for Activities Associated with Exporting of WP from CRCF	CRCF-ESD15-WP-H&D CRCF-ESD15-WP-H&M CRCF-ESD15-WP-TAD	Figure G-61 Figure G-62 Figure G-63	RESPONSE-WP2	Figure G-56
CRC-ESD-16	Event Sequences for Activities Associated with Exporting of AO from CRCF	CRCF-ESD16-DPC CRCF-ESD16-TAD	Figure G-64 Figure G-65	RESPONSE-AO1	Figure G-9
CRC-ESD-17	Event Sequences for Activities Associated with Direct Exposure During Cask Preparation Activities	CRCF-ESD17-DPC CRCF-ESD17-DSTD CRCF-ESD17-HLW CRCF-ESD17-MCO CRCF-ESD17-TAD	Figure G-66 Figure G-67 Figure G-68 Figure G-69 Figure G-70	N/A	N/A

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
CRC-ESD-18	Event Sequences for Activities Associated with Direct Exposure During CTM Activities	CRCF-ESD18-DPC CRCF-ESD18-DSTD CRCF-ESD18-HLW CRCF-ESD18-MCO CRCF-ESD18-TAD	Figure G-71 Figure G-72 Figure G-73 Figure G-7 Figure G-75	N/A	N/A
CRC-ESD-19	Event Sequences for Activities Associated with Direct Exposure During Closure and Exporting Loaded WP	CRCF-ESD19-WP H&D CRCF-ESD19- WP H&M CRCF-ESD19-WP-TAD	Figure G-76 Figure G-77 Figure G-78	N/A	N/A
CRC-ESD-20	Event Sequences for Fire Occurring in Canister Receipt and Closure Facility	CRCF-ESD20-DPC CRCF-ESD20-DSTD CRCF-ESD20-HLW CRCF-ESD20-MCO CRCF-ESD20-TAD CRCF-ESD20-WP-H&D CRCF-ESD20-WP-H&M	Figure G-79 Figure G-81 Figure G-82 Figure G-83 Figure G-84 Figure G-85 Figure G-86	RESPONSE-FIRE	Figure G-80

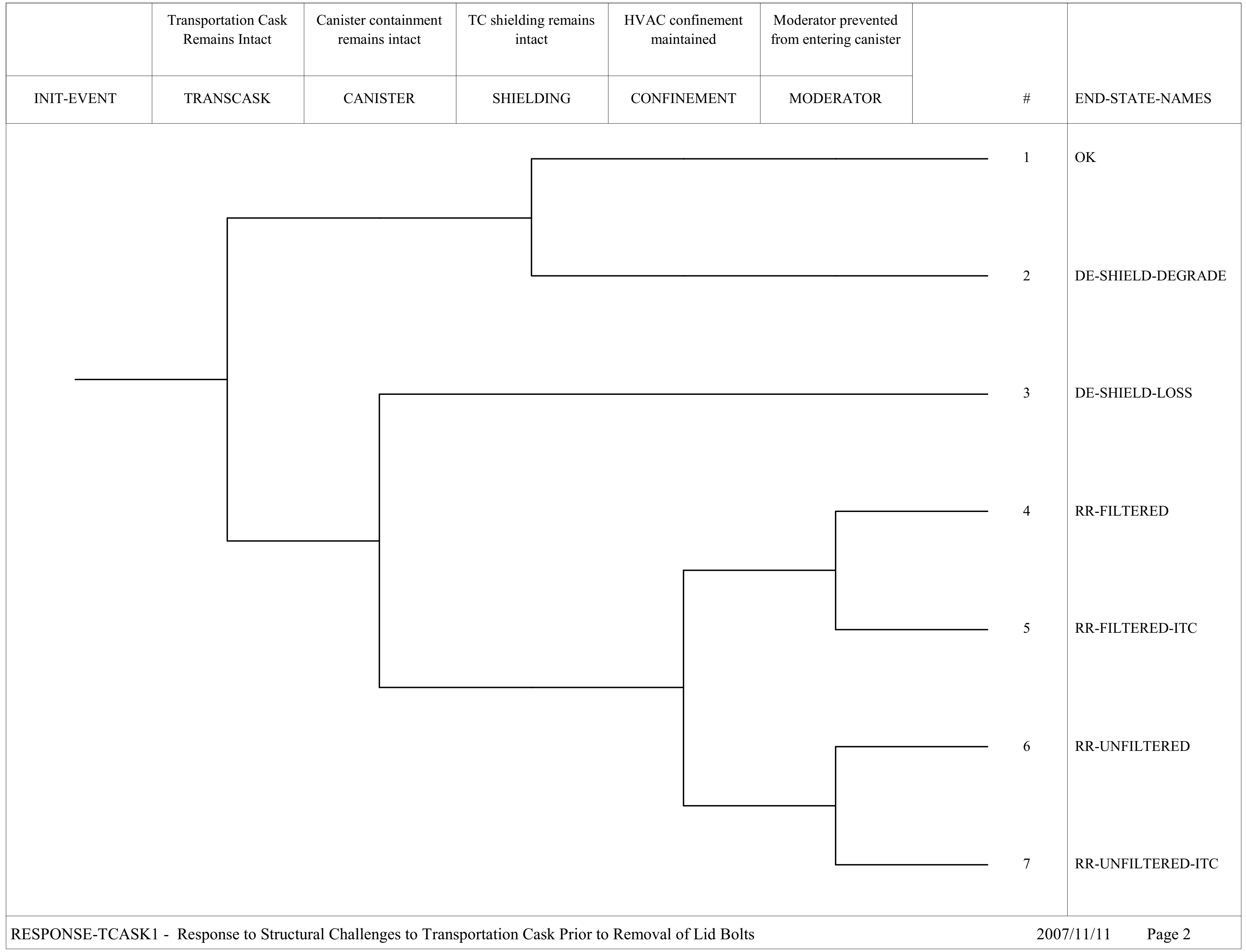
NOTE: AO = aging overpack; CRCF = Canister Receipt and Closure Facility; CTM = canister transfer machine; CTT = cask transfer trolley; N/A = not applicable; ST = site transporter; TC = transportation cask; WP = waste package; WPTT = waste package transfer trolley.

Source: Original



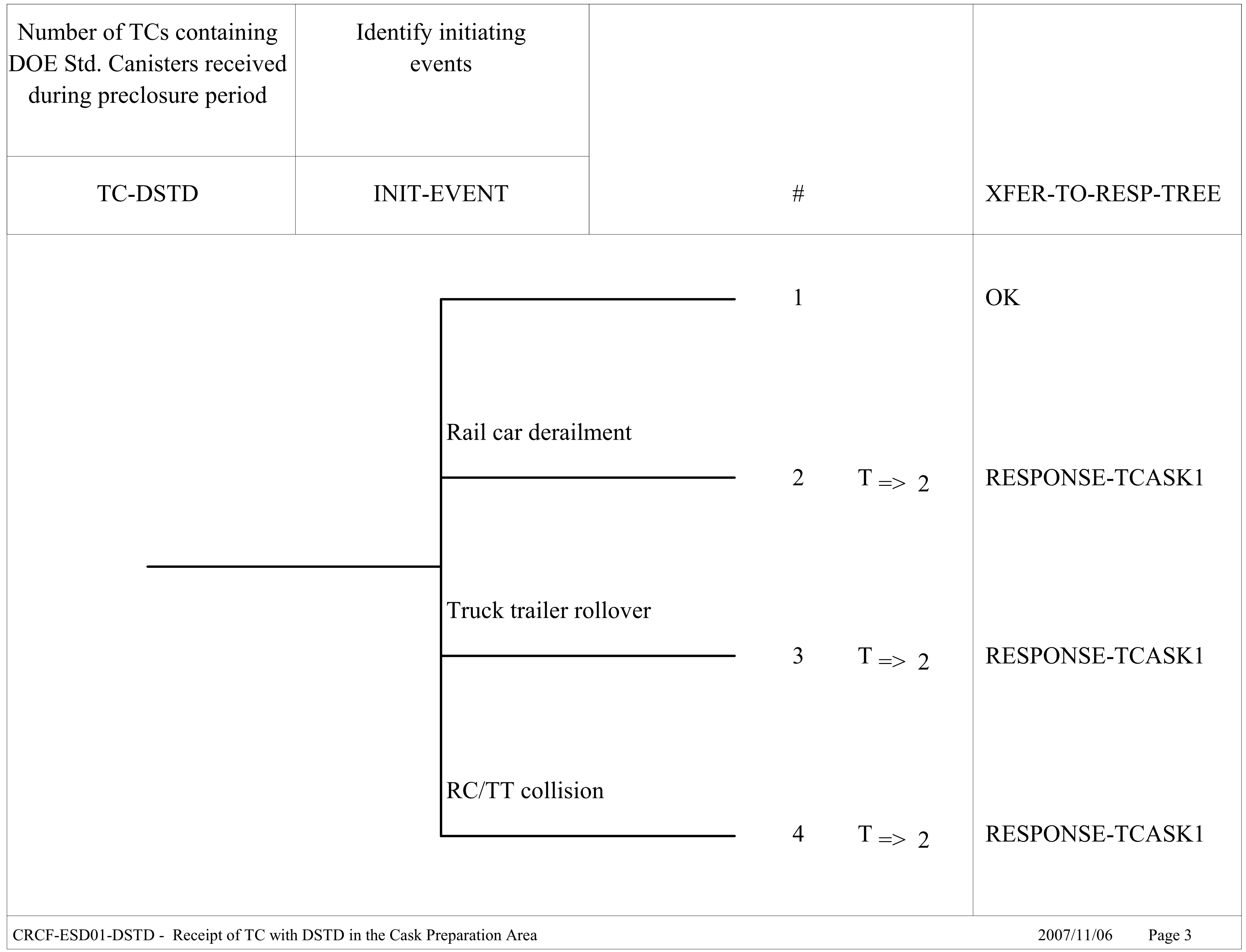
Source: Original

Figure G-2. Event Tree CRCF-ESD01-DPC – Receipt of Transportation Cask with DPC Canister in the Cask Preparation Area



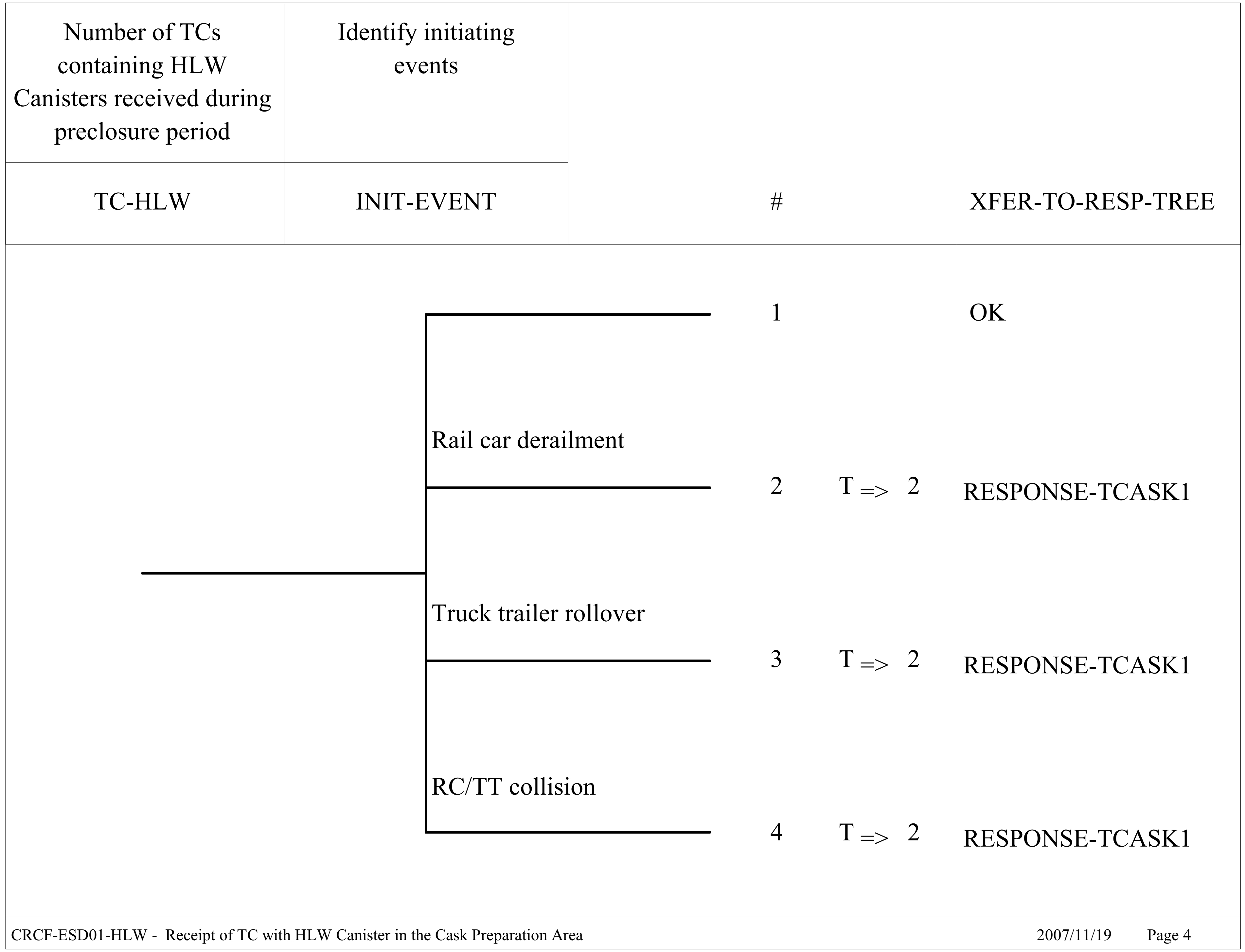
Source: Original

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



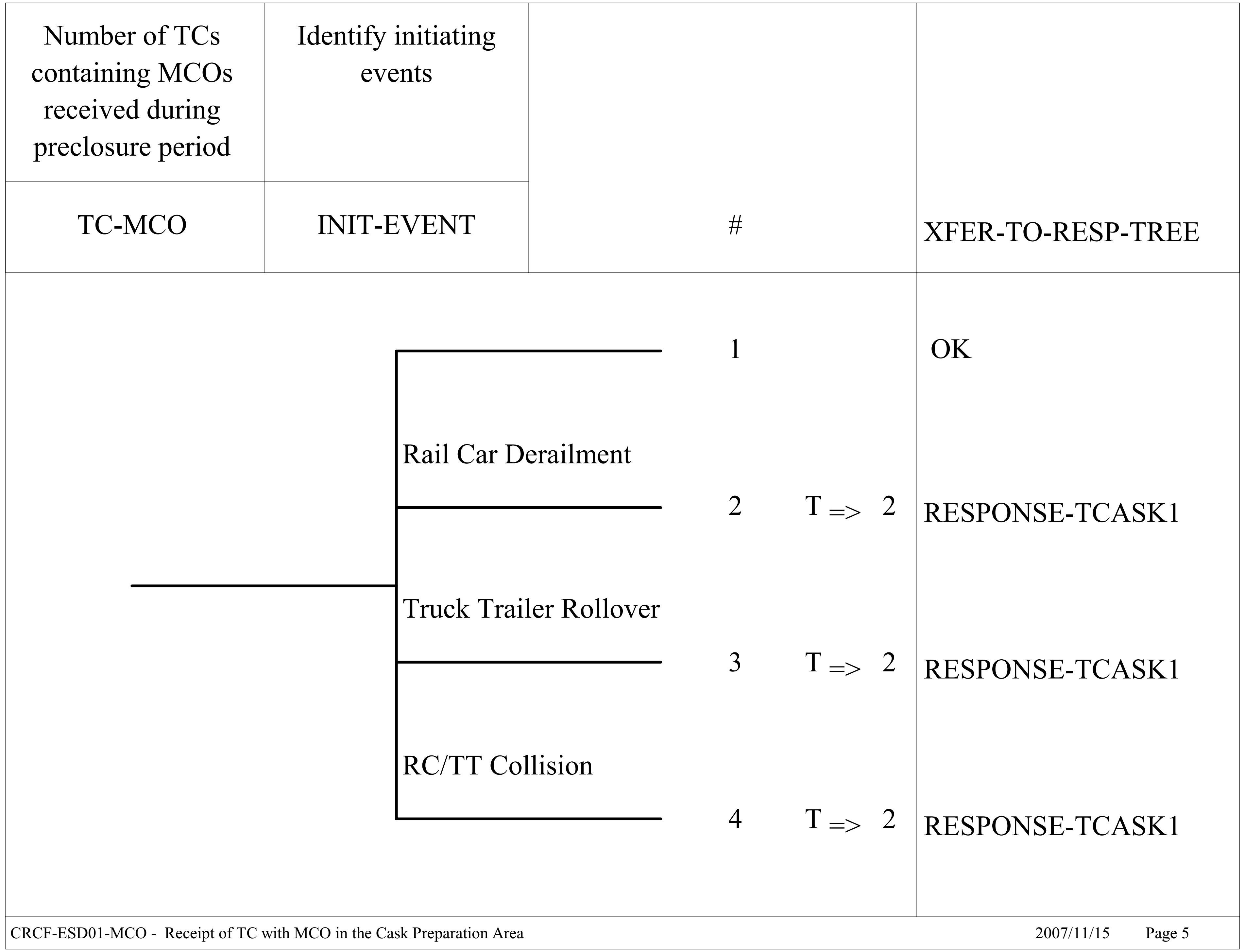
Source: Original

Figure G-4. Event Tree CRCF-ESD01-DSTD – Receipt of Transportation Cask with DSTD in the Cask Preparation Area



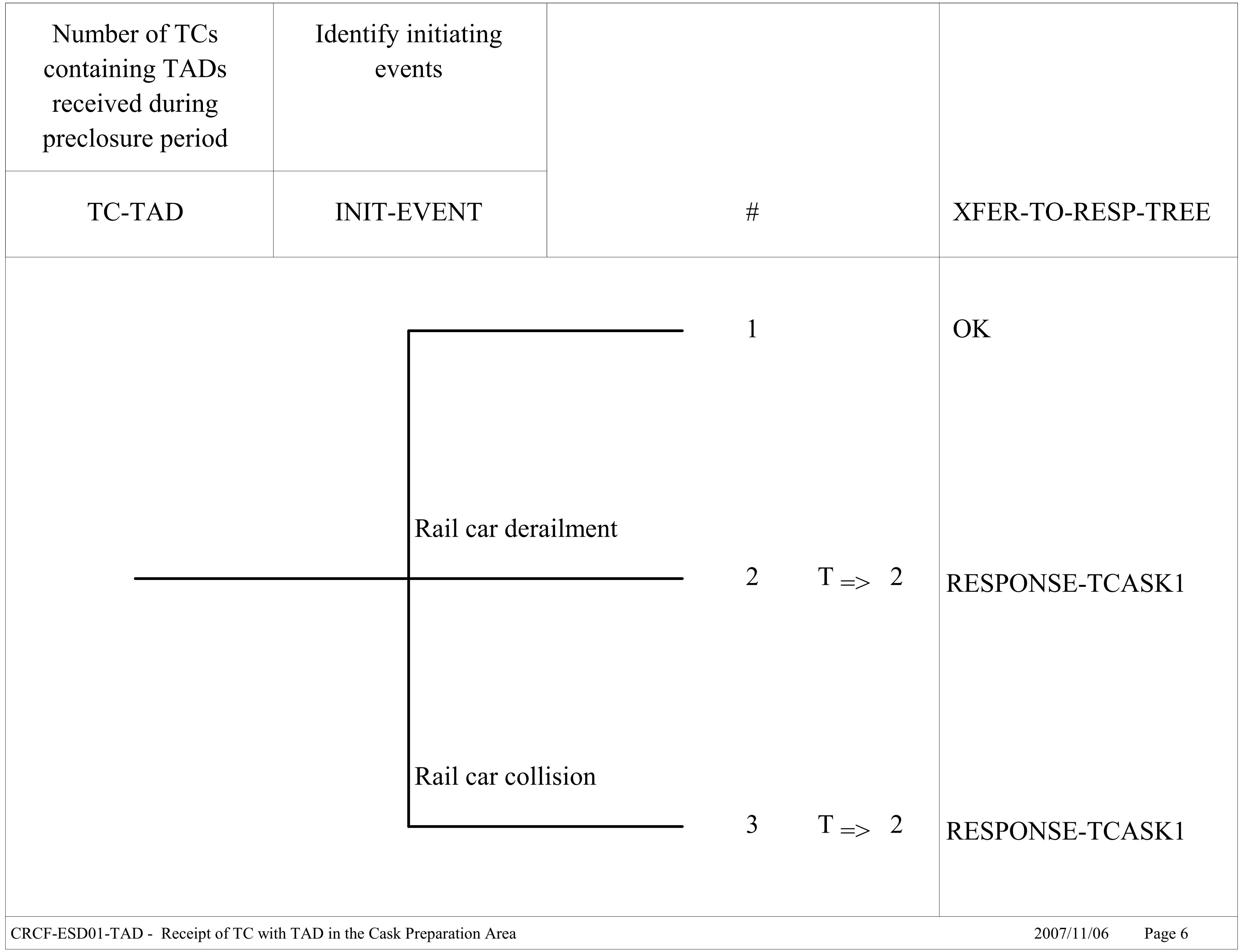
Source: Original

Figure G-5. Event Tree CRCF-ESD01-HLW - Receipt of Transportation Cask with HLW Canister in the Cask Preparation Area



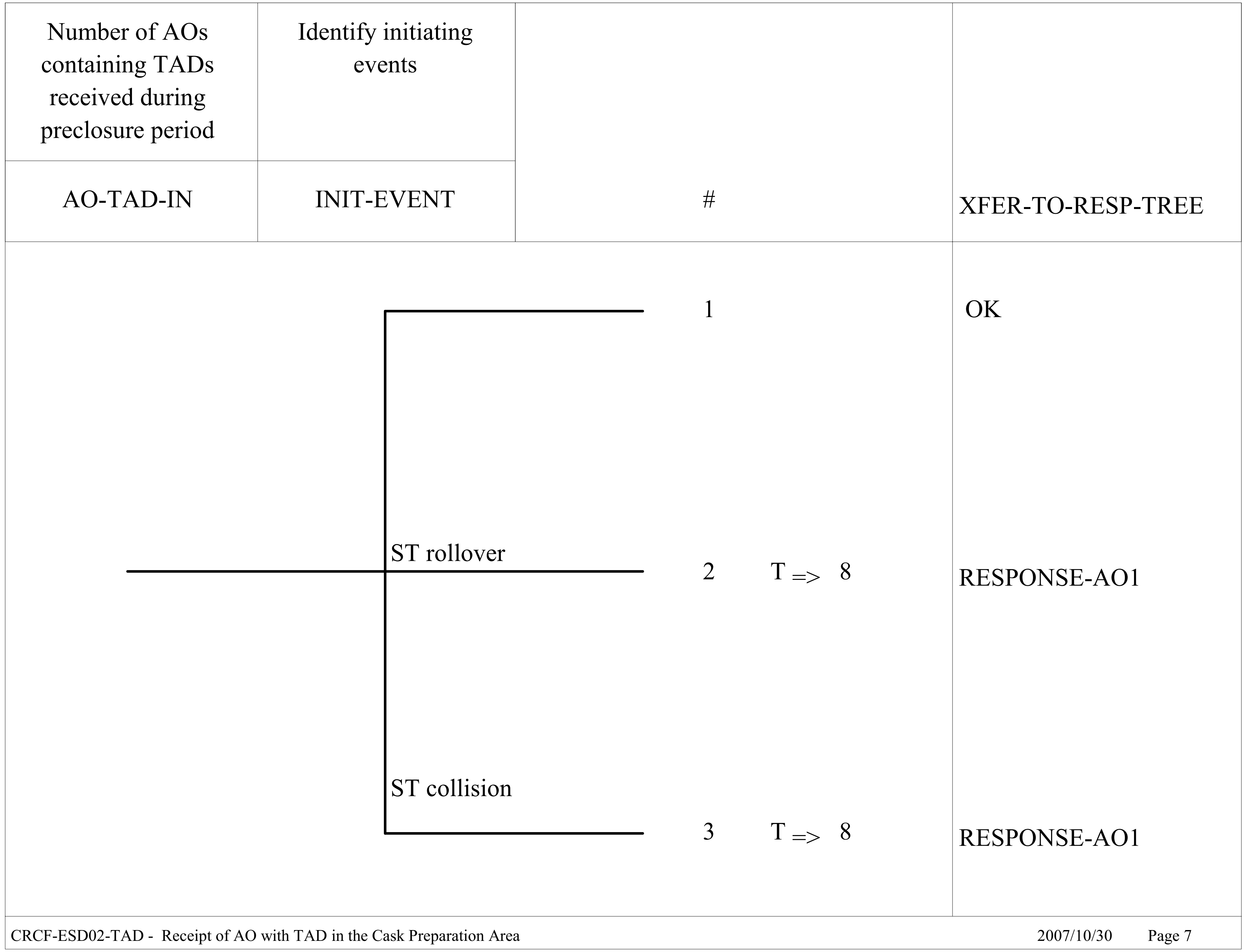
Source: Original

Figure G-6. Event Tree CRCF-ESD01-MCO - Receipt of Transportation Cask with MCO in the Cask Preparation Area



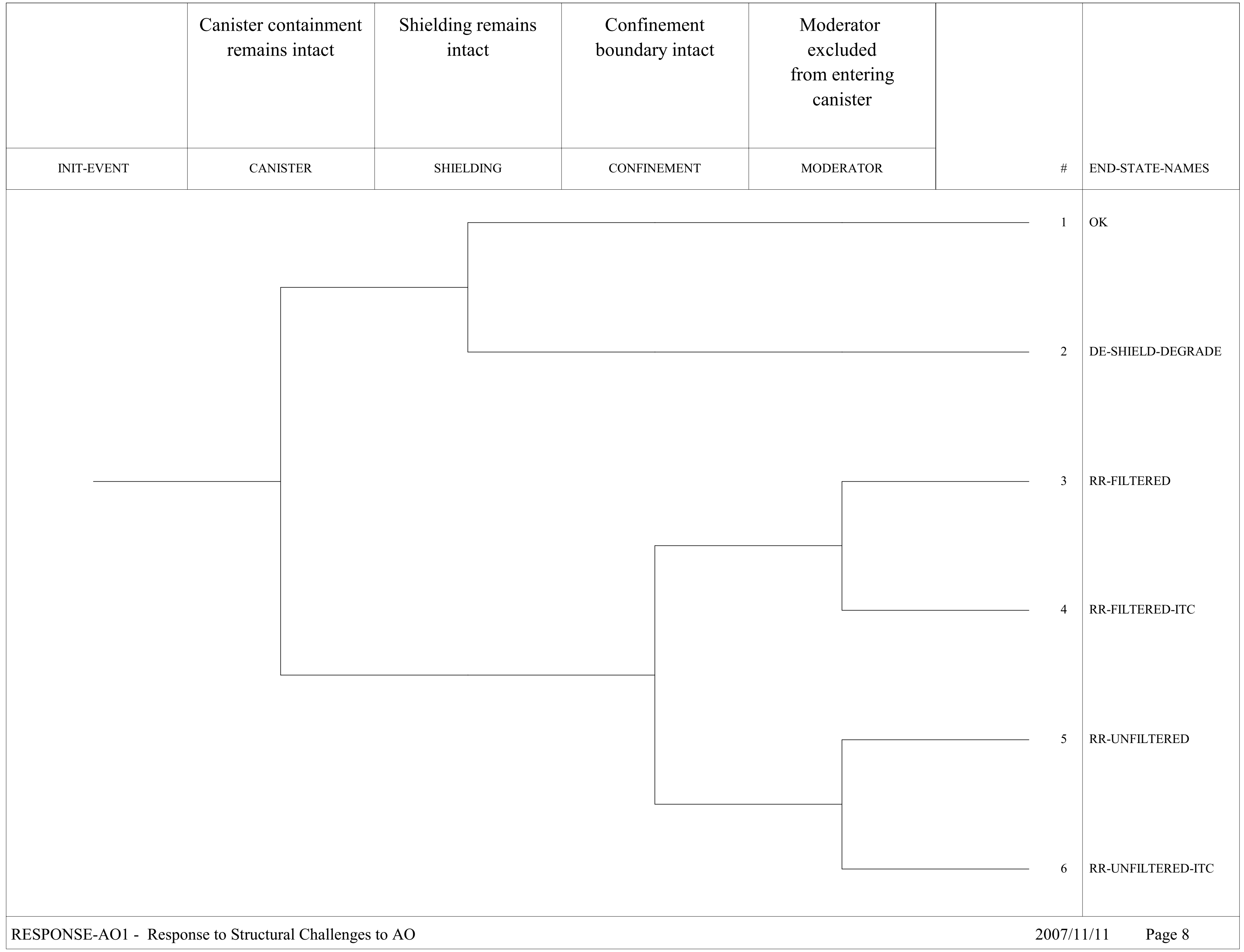
Source: Original

Figure G-7. Event Tree CRCF-ESD01-TAD – Receipt of Transportation Cask with TAD Canister in the Cask Preparation Area



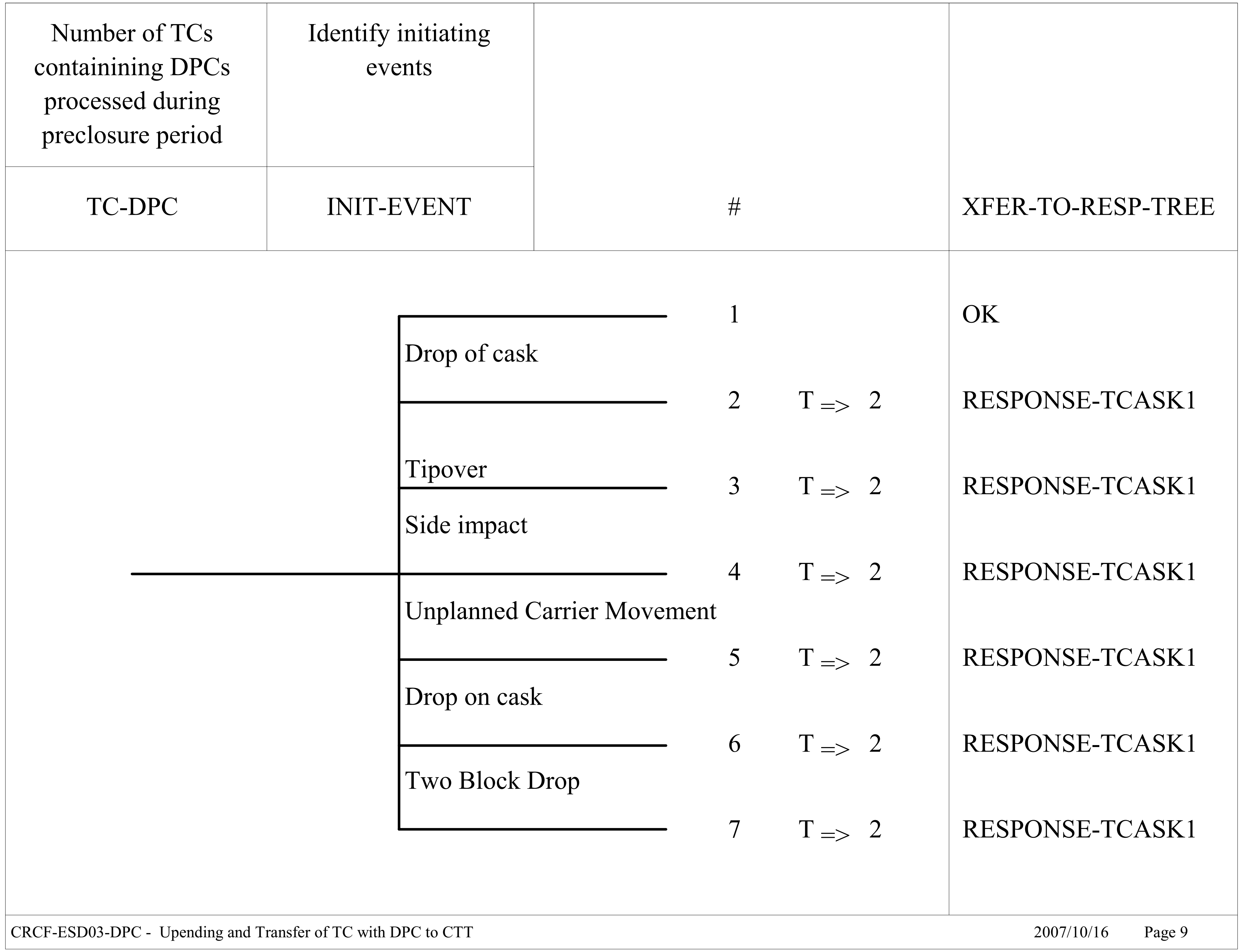
Source: Original

Figure G-8. Event Tree CRCF-ESD02-TAD – Receipt of Aging Overpack with TAD Canister in the Cask Preparation Area



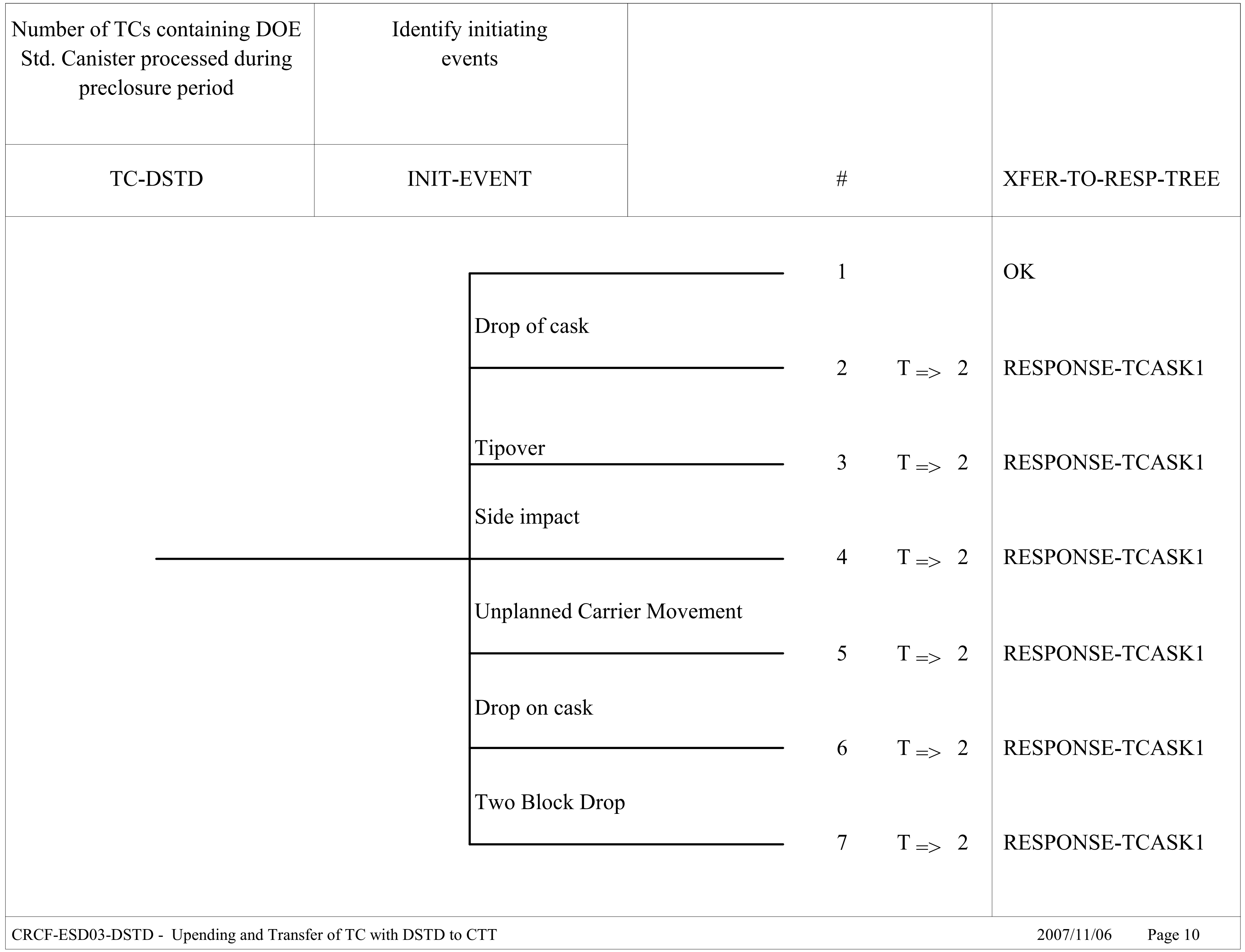
Source: Original

Figure G-9. Event Tree RESPONSE-AO1 – Response to Structural Challenges to Aging Overpack



Source: Original

Figure G-10. Event Tree CRCF-ESD03-DPC – Upending and Transfer of Transportation Cask with DPC to CTT



Source: Original

Figure G-11. Event Tree CRCF-ESD03-DSTD – Upending and Transfer of Transportation Cask with DSTD to CTT

Number of TCs containinig HLW Canisters processed during preclosure period	Identify initiating events			
TC-HLW	INIT-EVENT	#		XFER-TO-RESP-TREE
		1		OK
	Drop of cask	2	T => 2	RESPONSE-TCASK1
	Tipover	3	T => 2	RESPONSE-TCASK1
	Side impact	4	T => 2	RESPONSE-TCASK1
	Unplanned Carrier Movement	5	T => 2	RESPONSE-TCASK1
	Drop on cask	6	T => 2	RESPONSE-TCASK1
	Two Block Drop	7	T => 2	RESPONSE-TCASK1

CRCF-ESD03-HLW - Upending and Transfer of TC with HLW Canister to the CTT 2007/10/16 Page 11

Source: Original

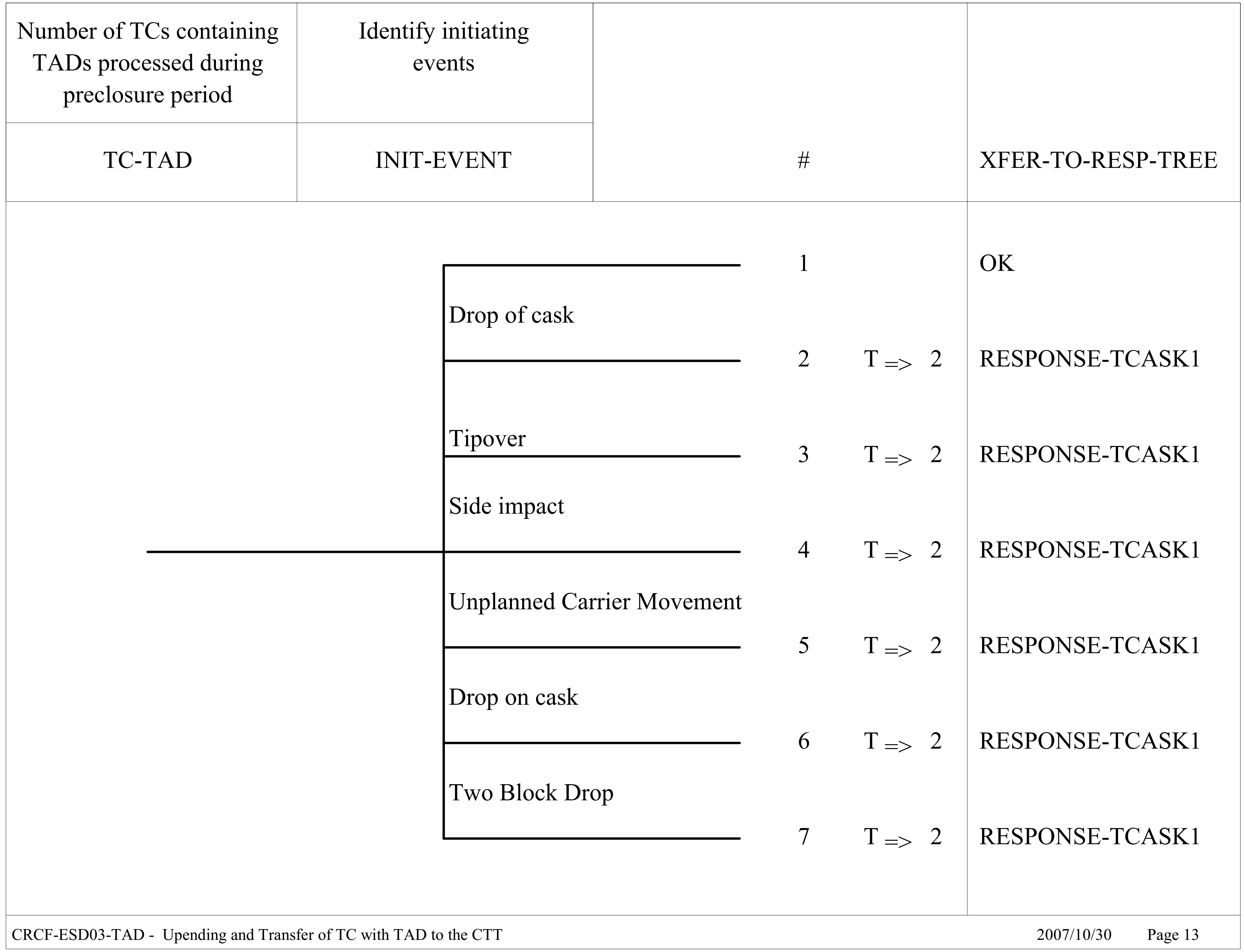
Figure G-12. Event Tree CRCF-ESD03-HLW – Upending and Transfer of Transportation Cask with HLW Canister to the CTT

Number of TCs containing MCOs processed during preclosure period	Identify initiating event			
TC-MCO	INIT-EVENT	#		XFER-TO-RESP-TREES
		1		OK
	Drop of Cask	2	T => 2	RESPONSE-TCASK1
	Tipover	3	T => 2	RESPONSE-TCASK1
	Side Impact	4	T => 2	RESPONSE-TCASK1
	Unplanned CarrierMovement	5	T => 2	RESPONSE-TCASK1
	Drop On Cask	6	T => 2	RESPONSE-TCASK1
	Two Block Drop	7	T => 2	RESPONSE-TCASK1

CRCF-ESD03-MCO - Upending and Transfer of TC with MCO to CTT 2008/02/20 Page 12

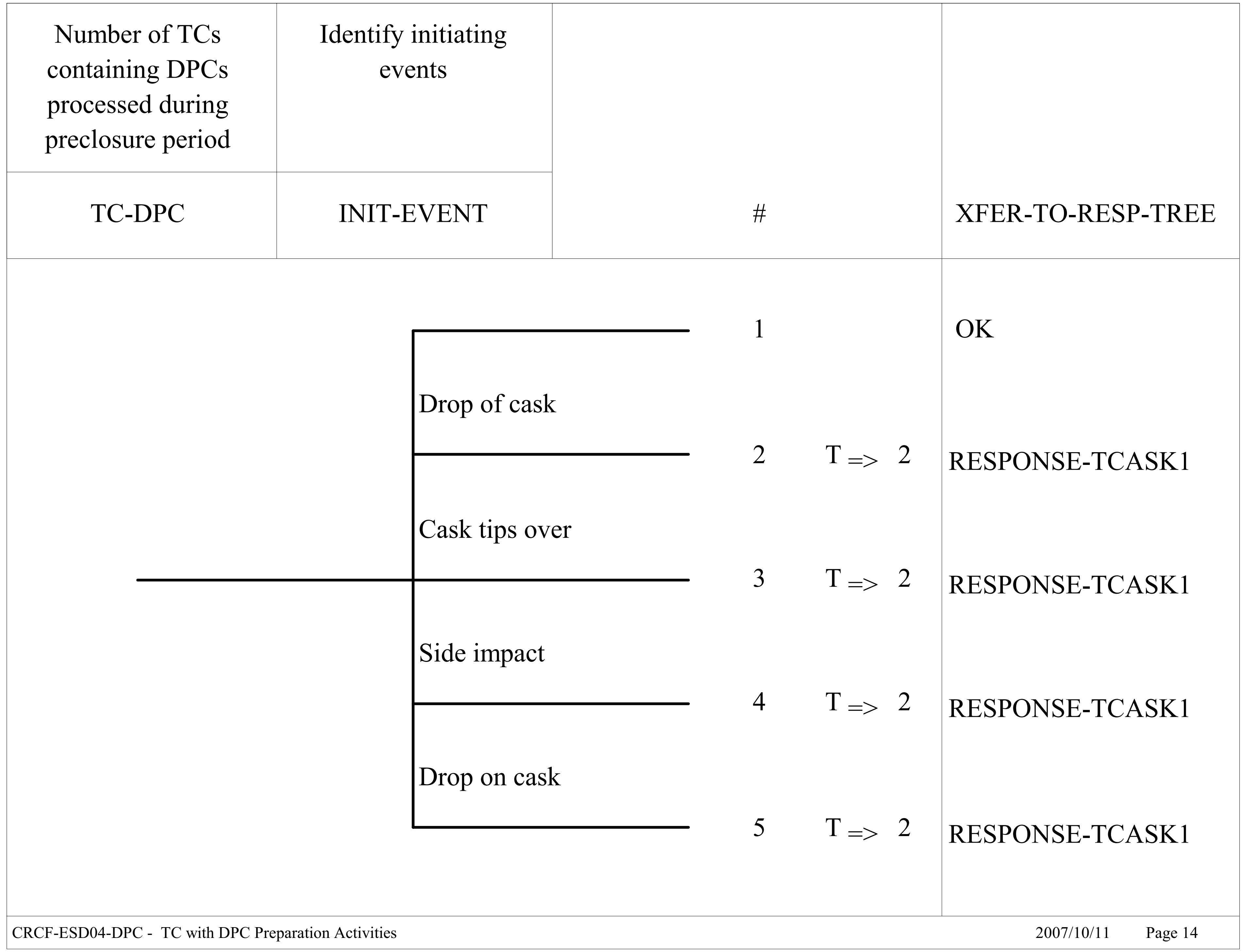
Source: Original

Figure G-13. Event Tree CRCF-ESD03-MCO – Upending and Transfer of Transportation Cask with MCO to the CTT



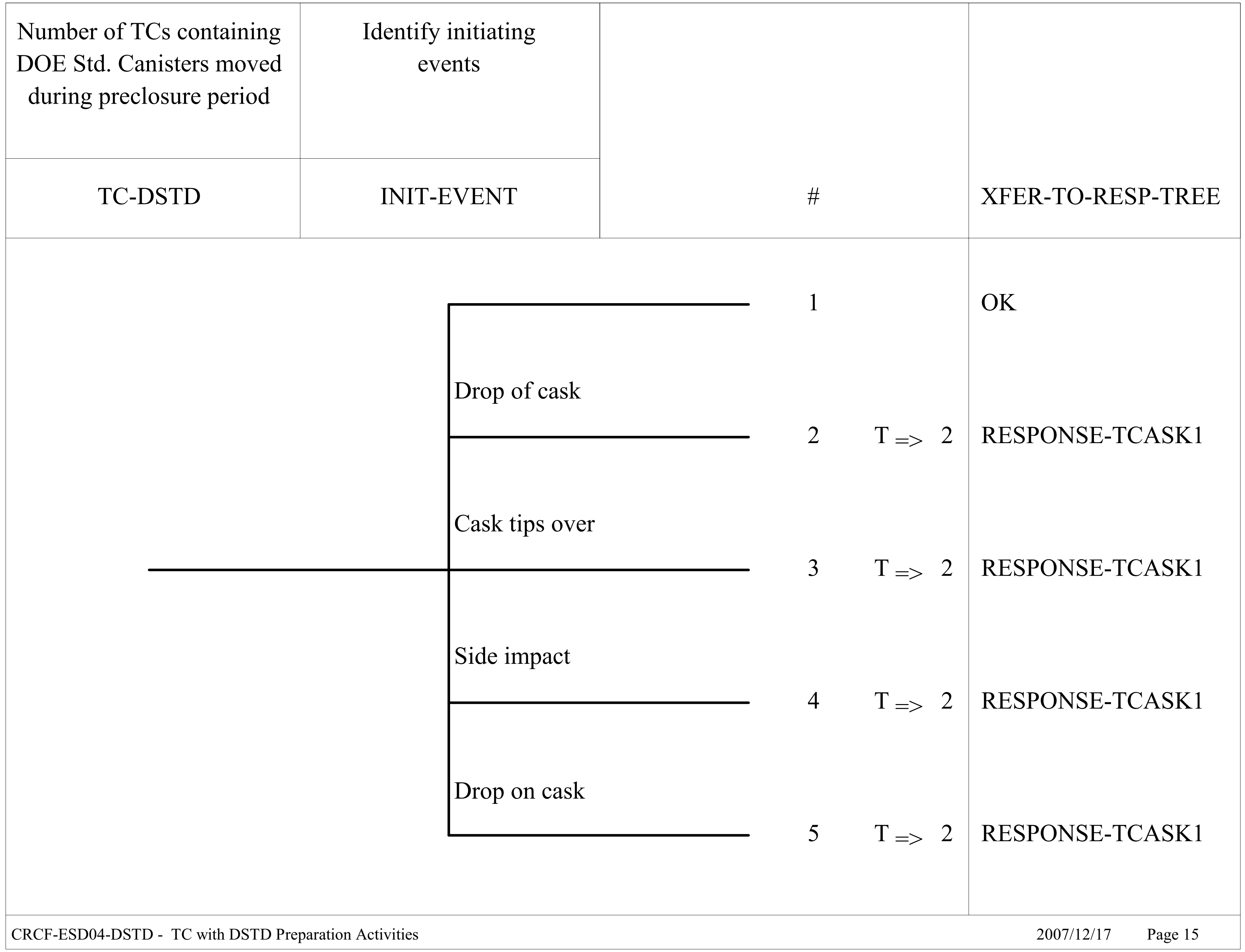
Source: Original

Figure G-14. Event Tree CRCF-ESD03-TAD – Upending and Transfer of Transportation Cask with TAD Canister to the CTT



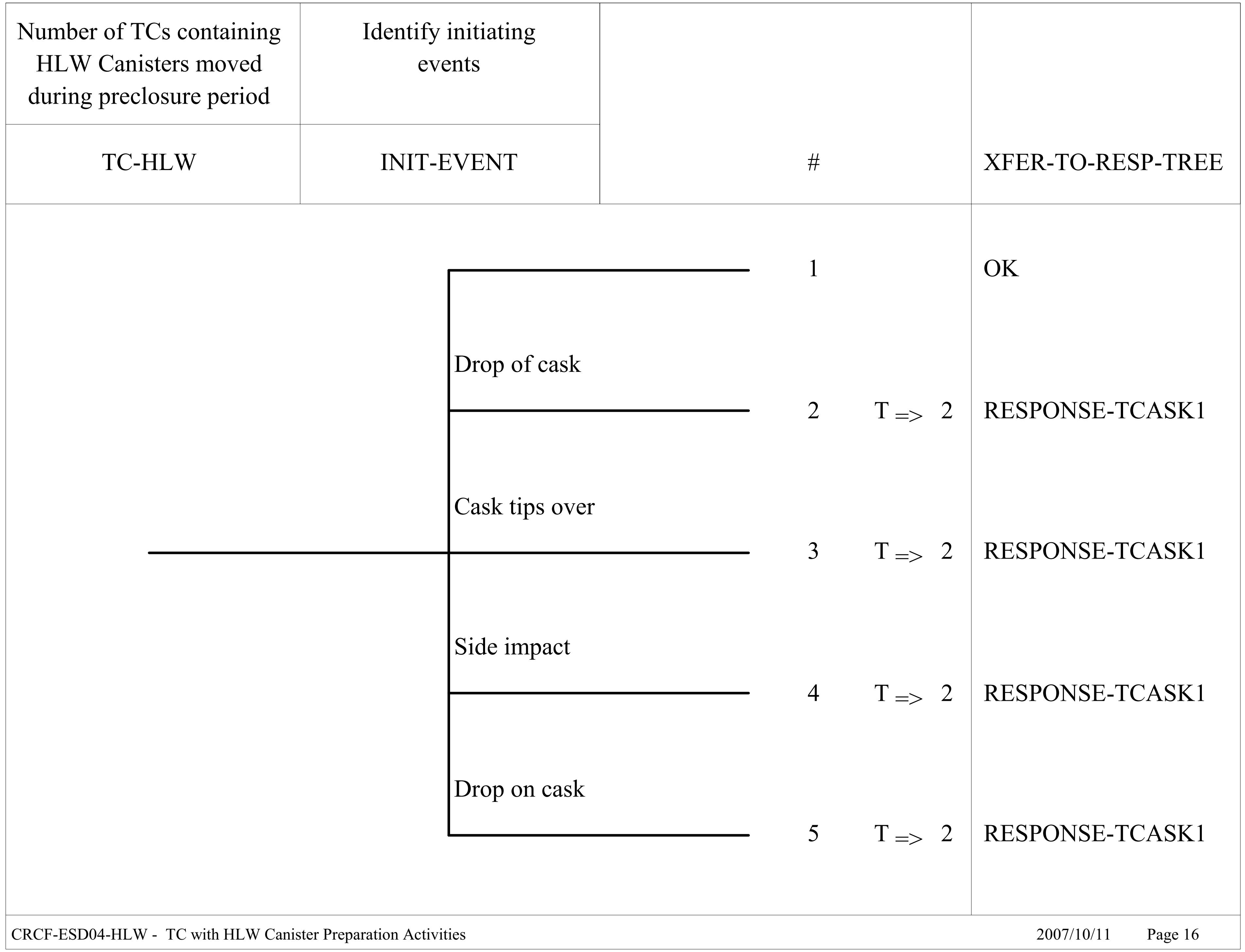
Source: Original

Figure G-15. Event Tree CRCF-ESD04-DPC – Transportation Cask with DPC Preparation Activities



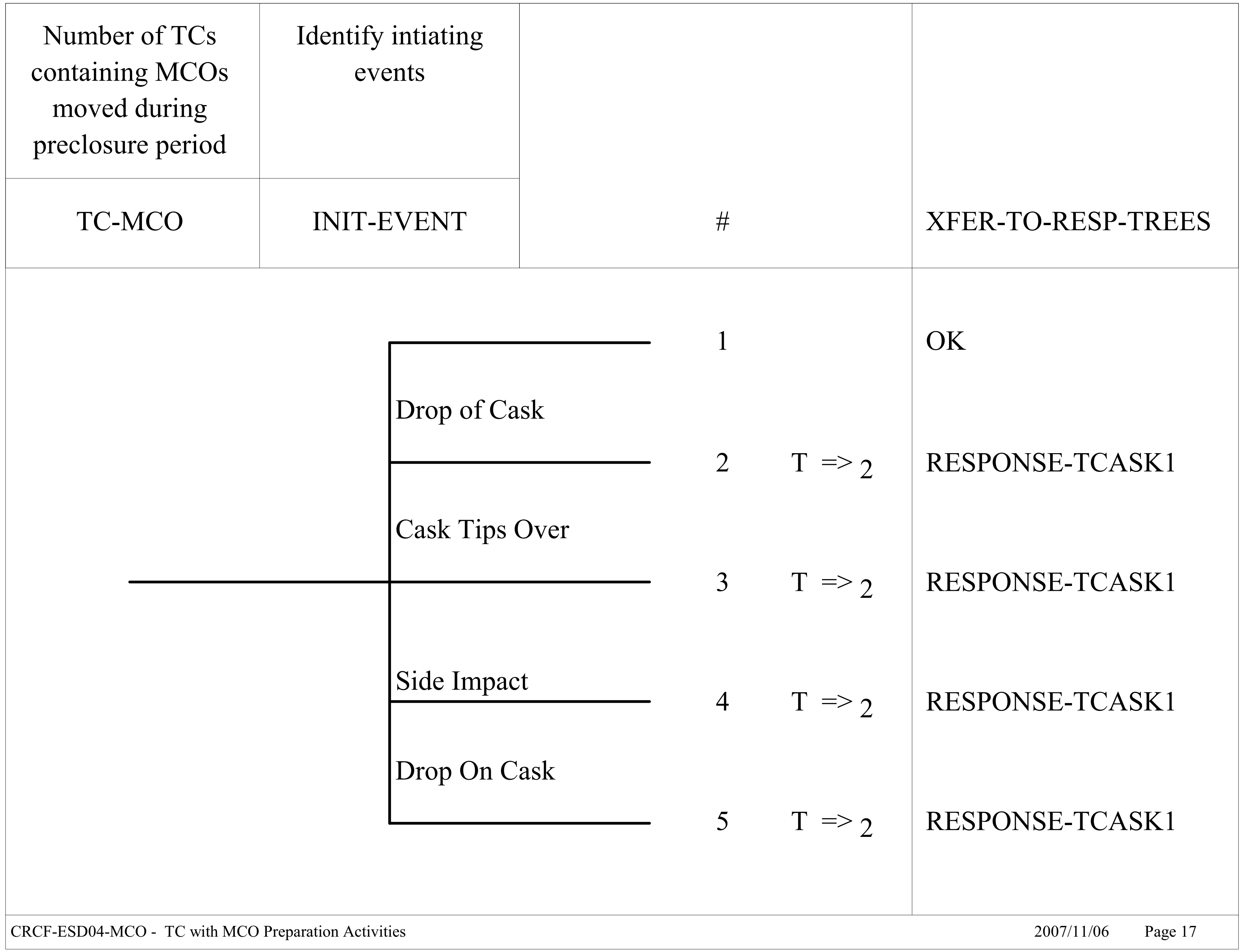
Source: Original

Figure G-16. Event Tree CRCF-ESD04-DSTD – Transportation Cask with DSTD Preparation Activities



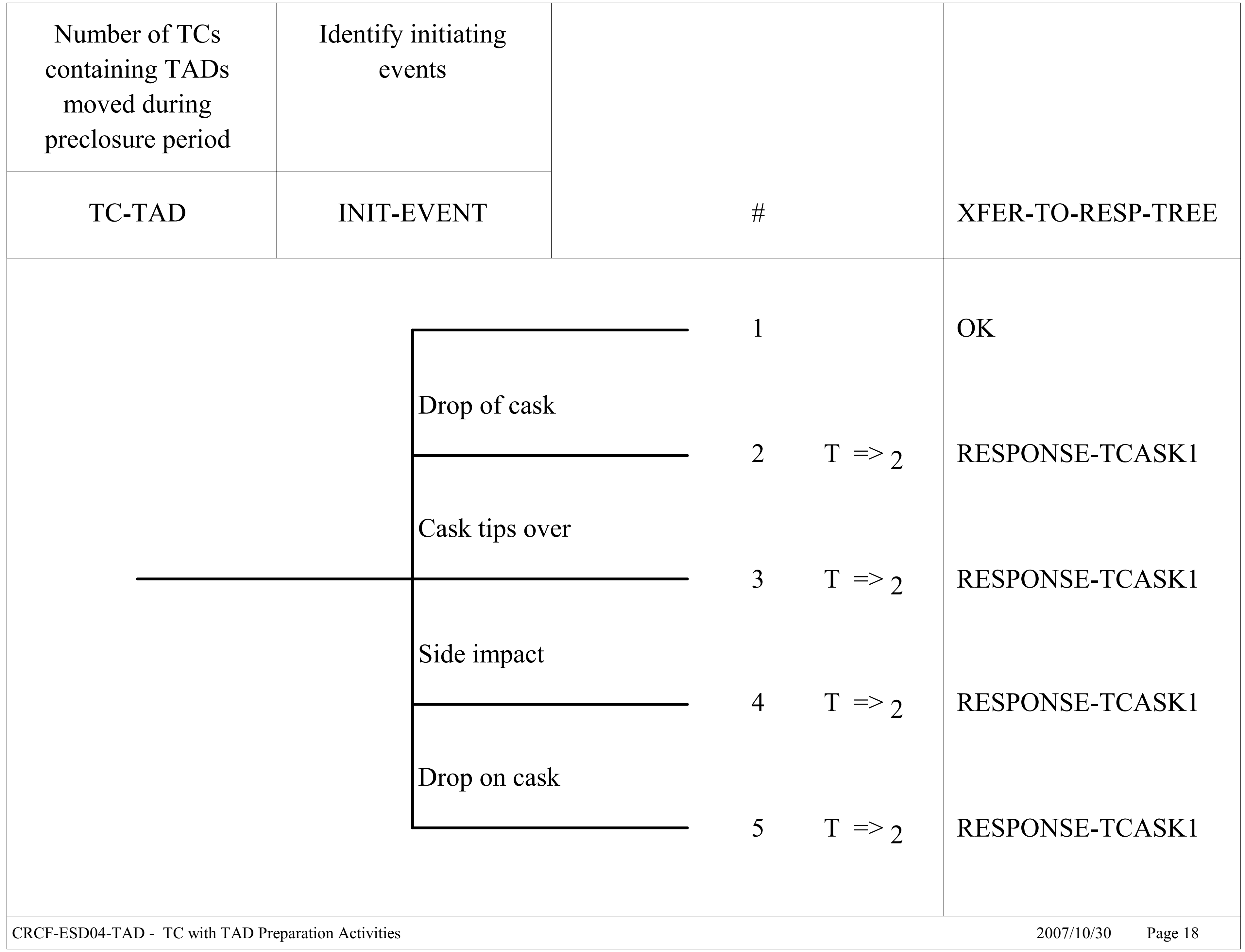
Source: Original

Figure G-17. Event Tree CRCF-ESD04-HLW – Transportation Cask with HLW Canister Preparation Activities



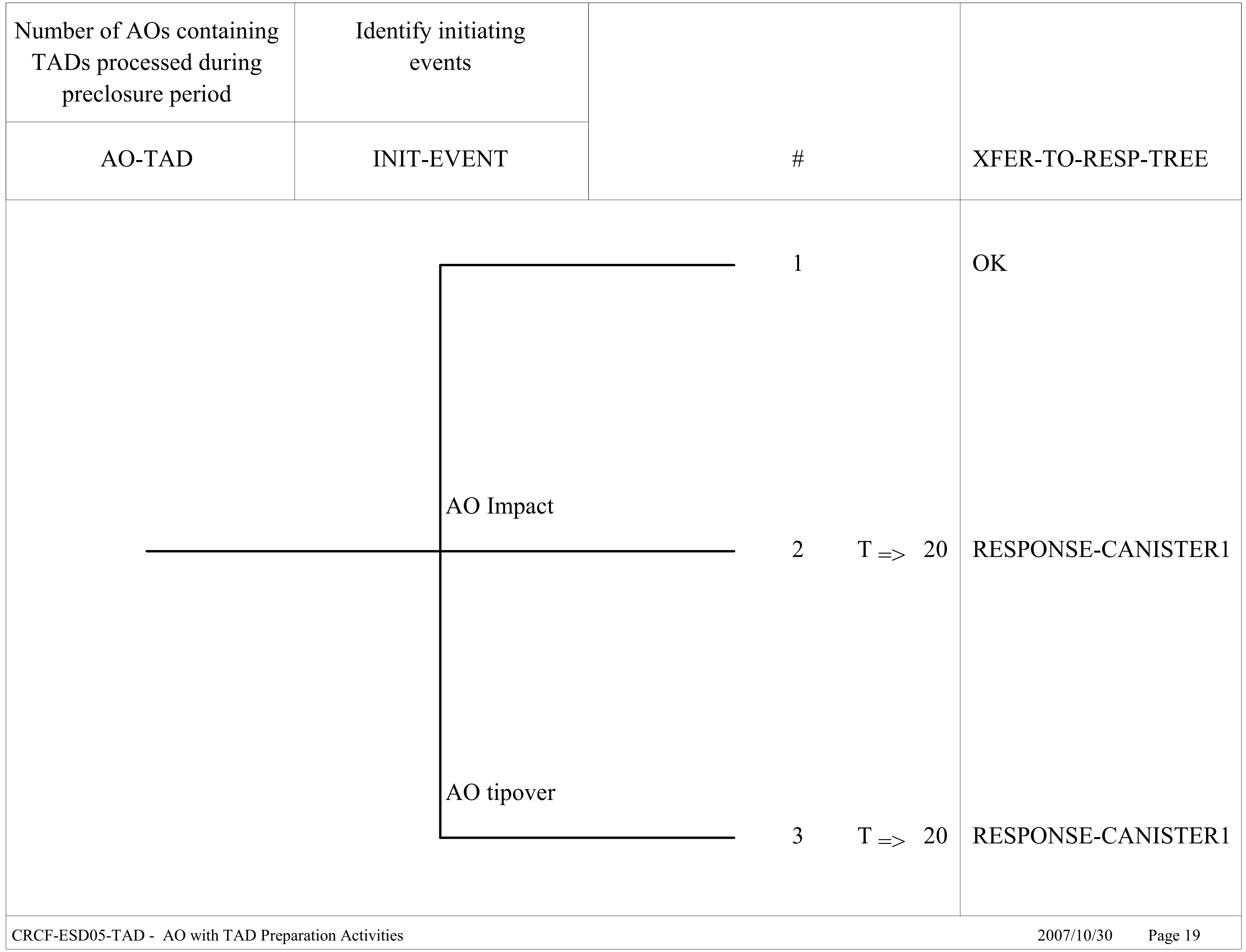
Source: Original

Figure G-18. Event Tree CRCF-ESD04-MCO – Transportation Cask with MCO Preparation Activities



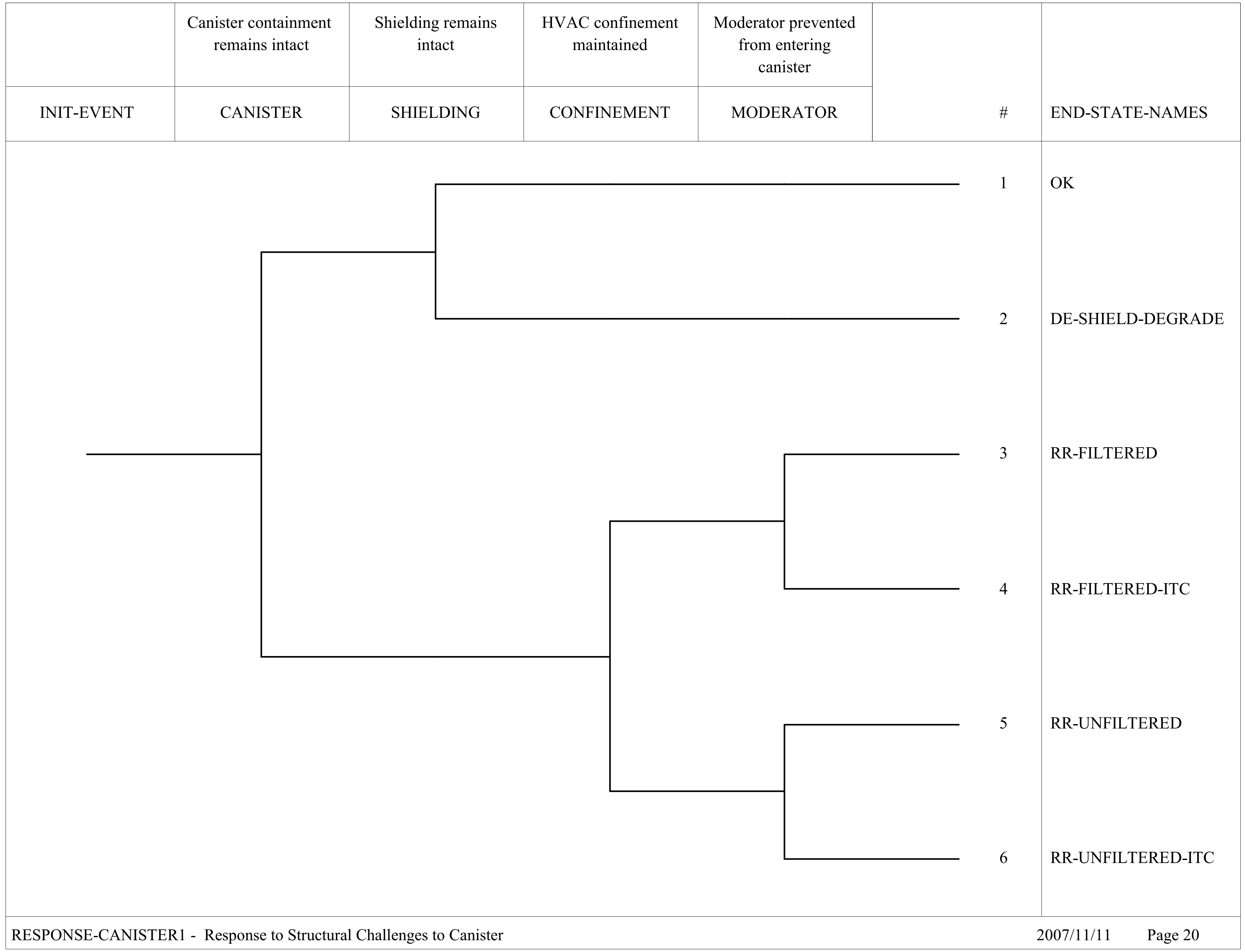
Source: Original

Figure G-19. Event Tree CRCF-ESD04-TAD – Transportation Cask with TAD Canister Preparation Activities



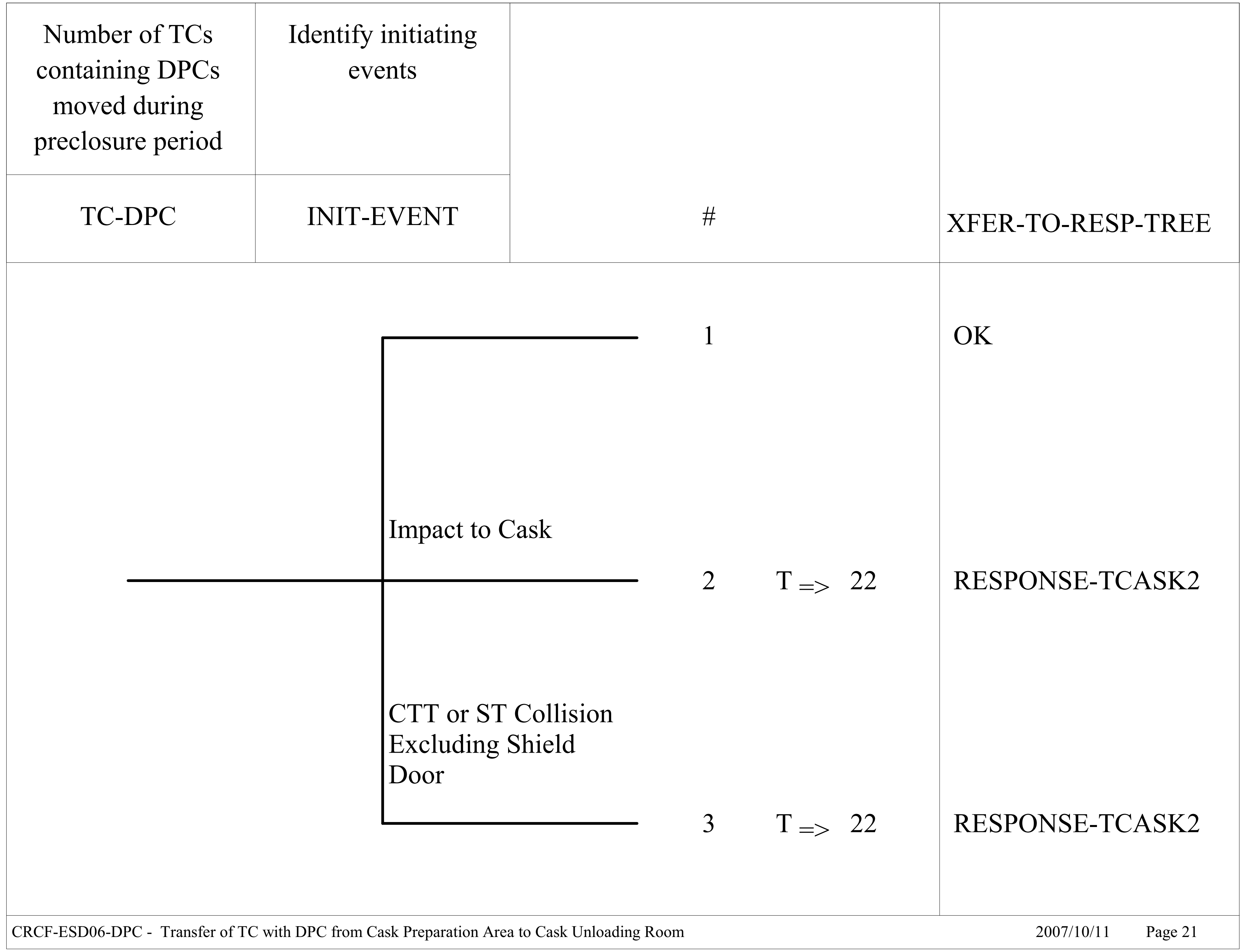
Source: Original

Figure G-20. Event Tree CRCF-ESD05-TAD – Aging Overpack with TAD Canister Preparation Activities



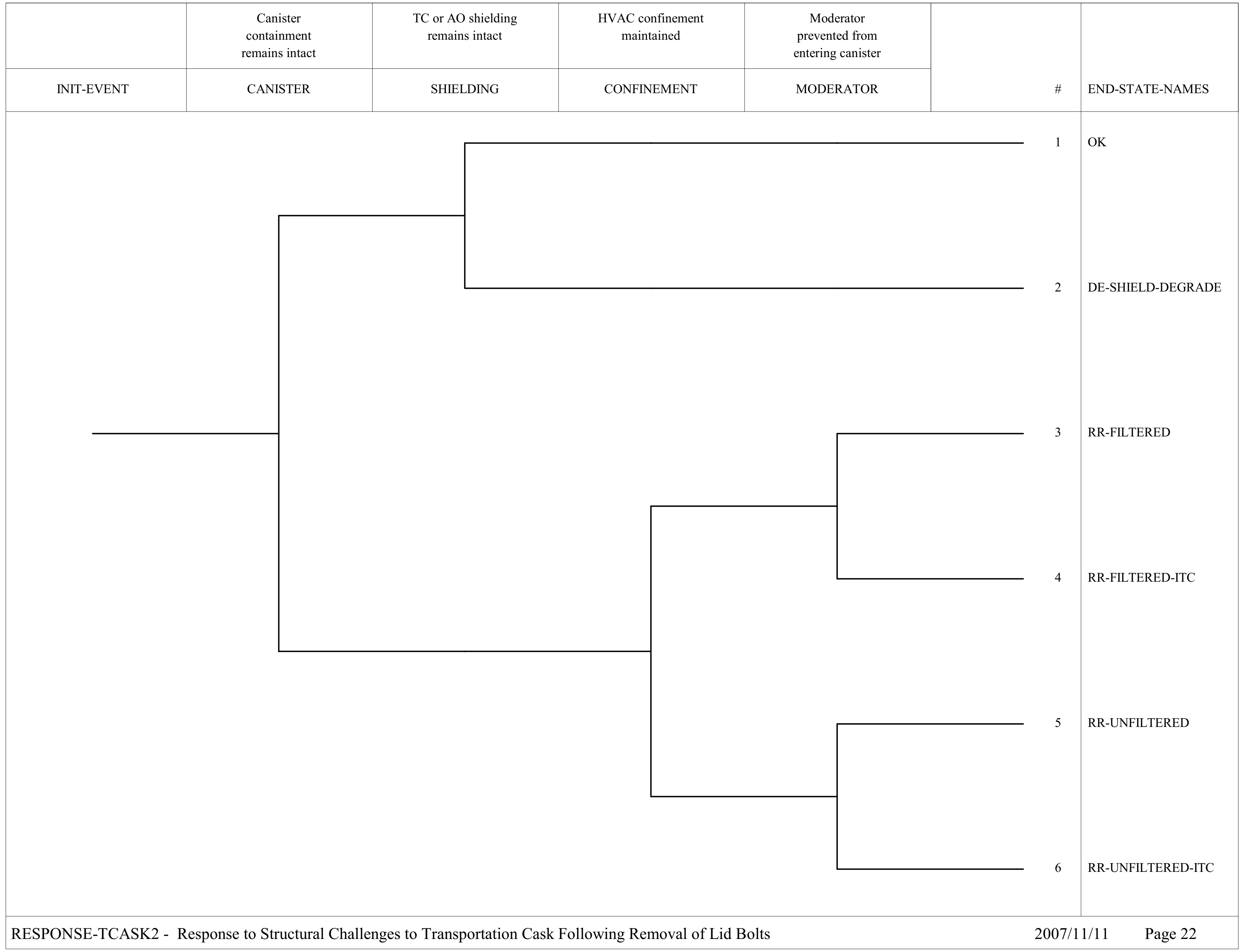
Source: Original

Figure G-21. Event Tree RESPONSE-CANISTER1 – Response to Structural Challenges to Canister



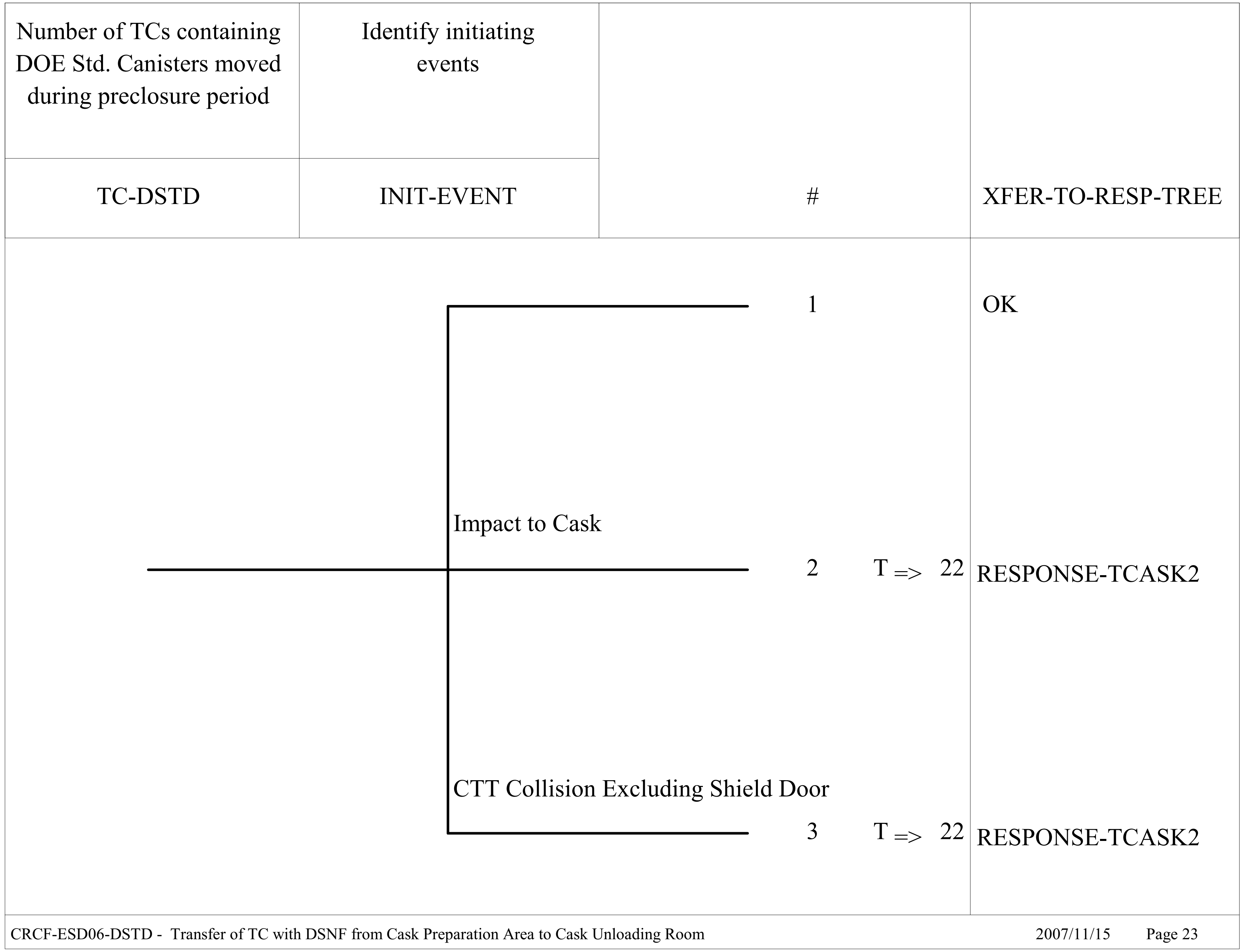
Source: Original

Figure G-22. Event Tree CRCF-ESD06-DPC – Transfer of Transportation Cask with DPC from Cask Preparation Area to Cask Unloading Room



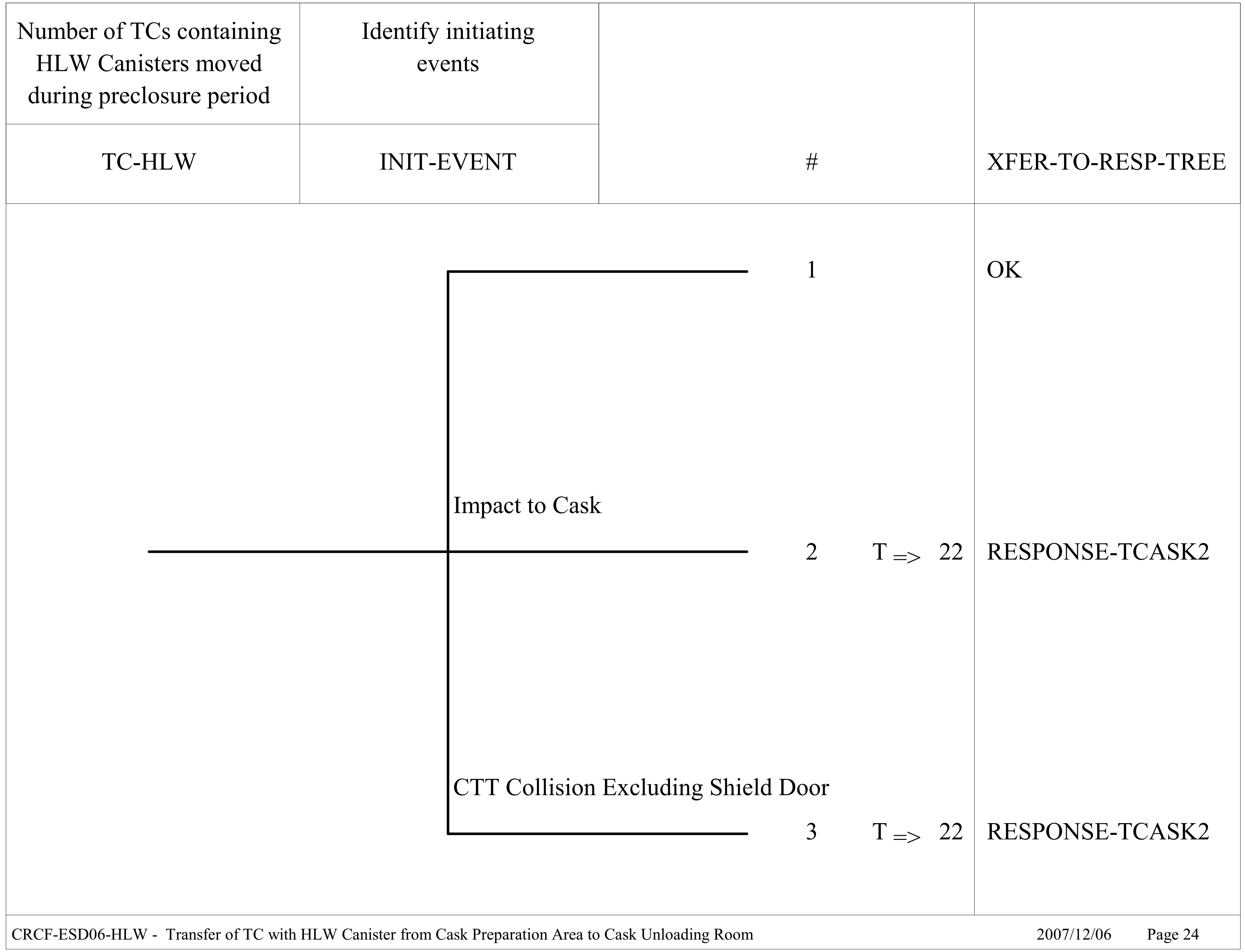
Source: Original

Figure G-23. Event Tree RESPONSE-TCASK2 – Response to Structural Challenges to Transportation Cask Following Removal of Lid Bolts



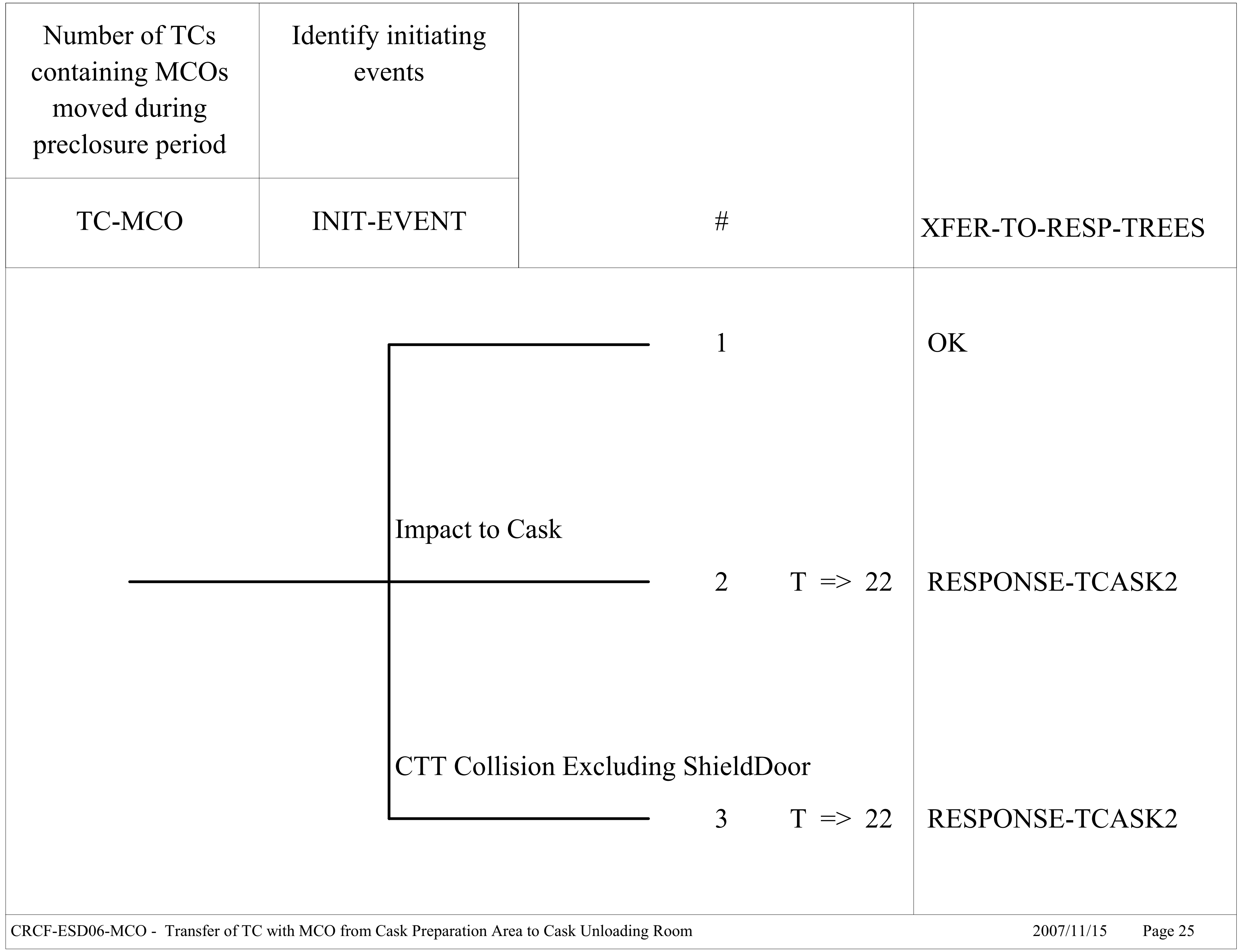
Source: Original

Figure G-24. Event Tree CRCF-ESD06-DSTD – Transfer of Transportation Cask with DSTD from Cask Preparation Area to Cask Unloading Room



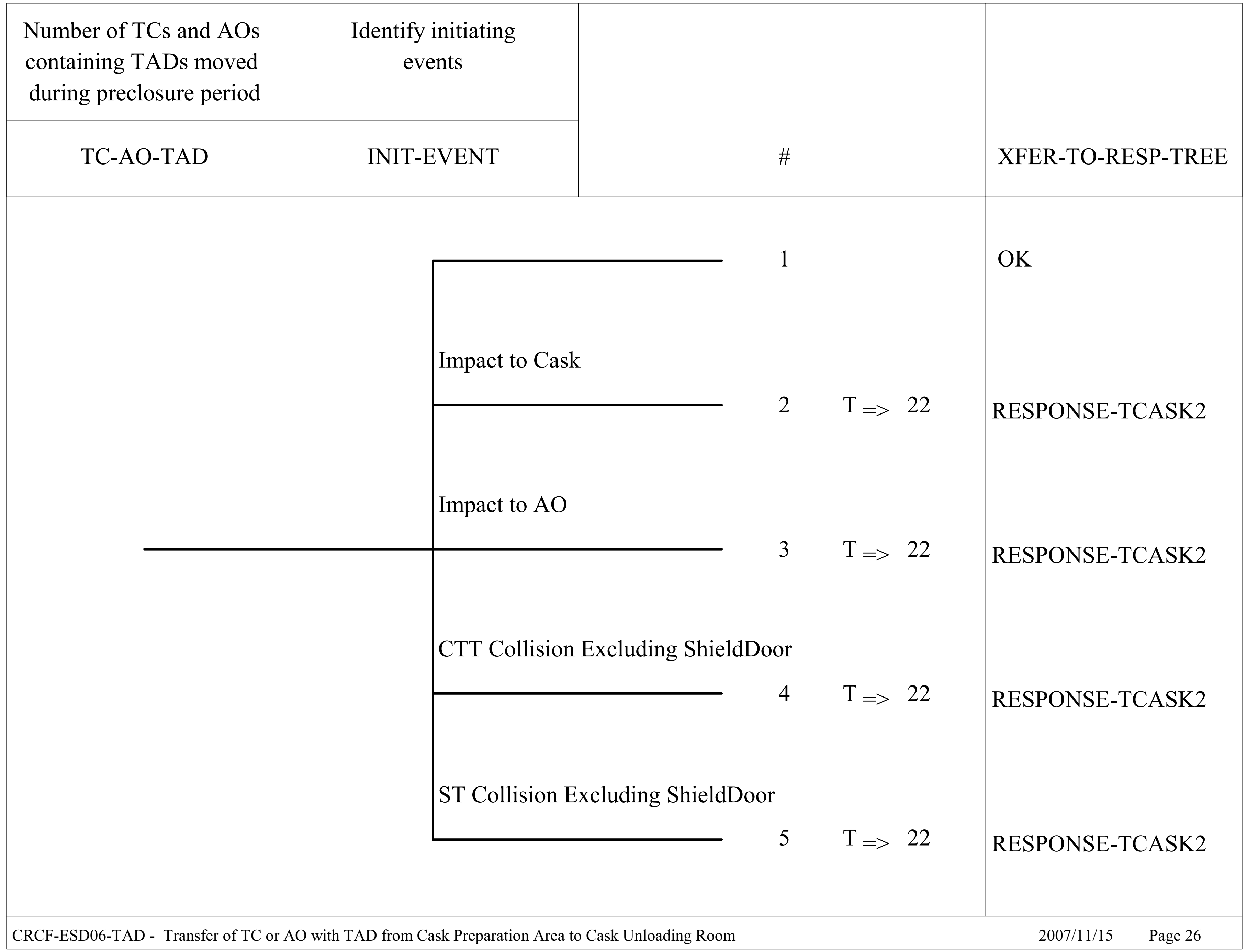
Source: Original

Figure G-25. Event Tree CRCF-ESD06-HLW – Transfer of Transportation Cask with HLW Canister from Cask Preparation Area to Cask Unloading Room



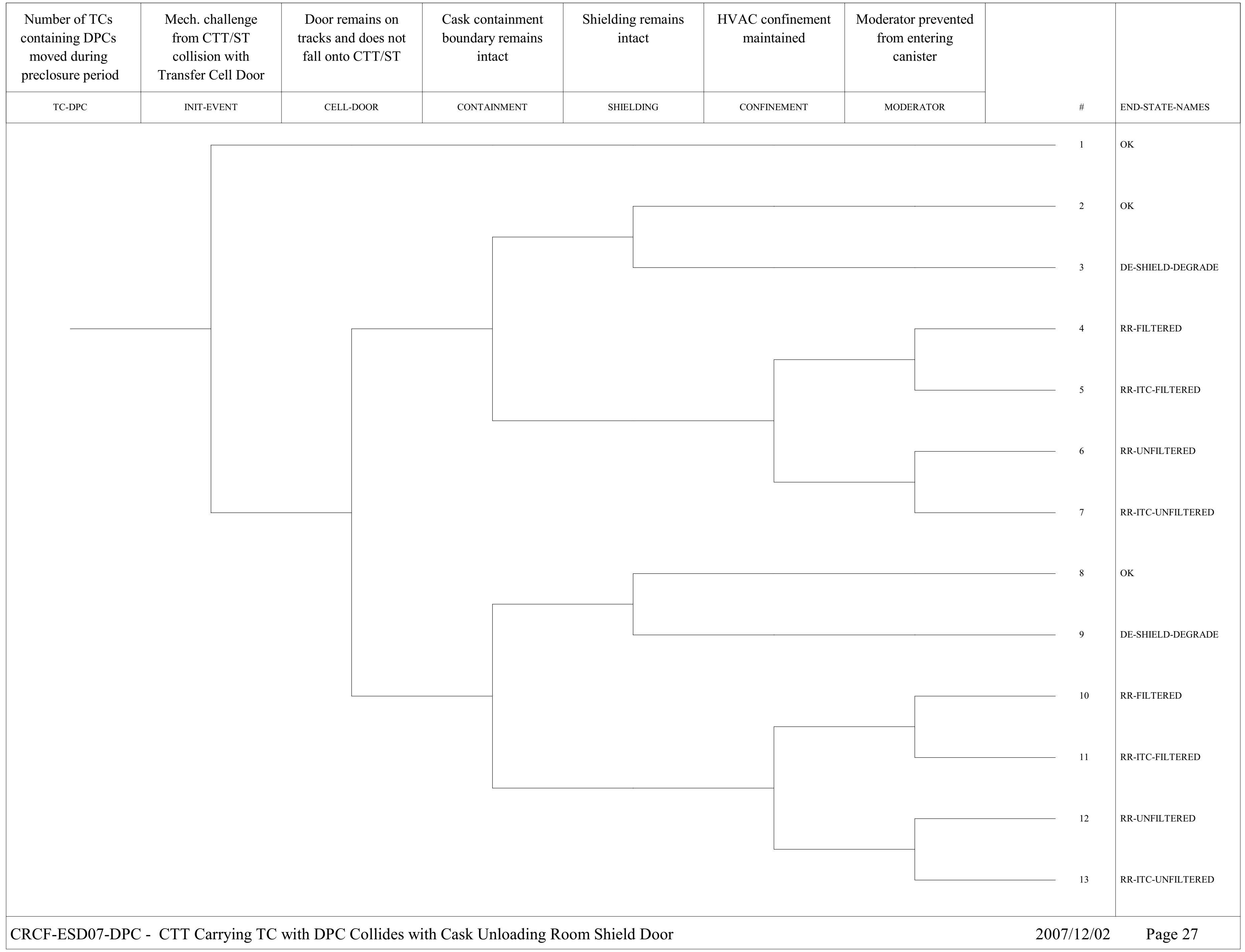
Source: Original

Figure G-26. Event Tree CRCF-ESD06-MCO – Transfer of Transportation Cask with MCO from Cask Preparation Area to Cask Unloading Room



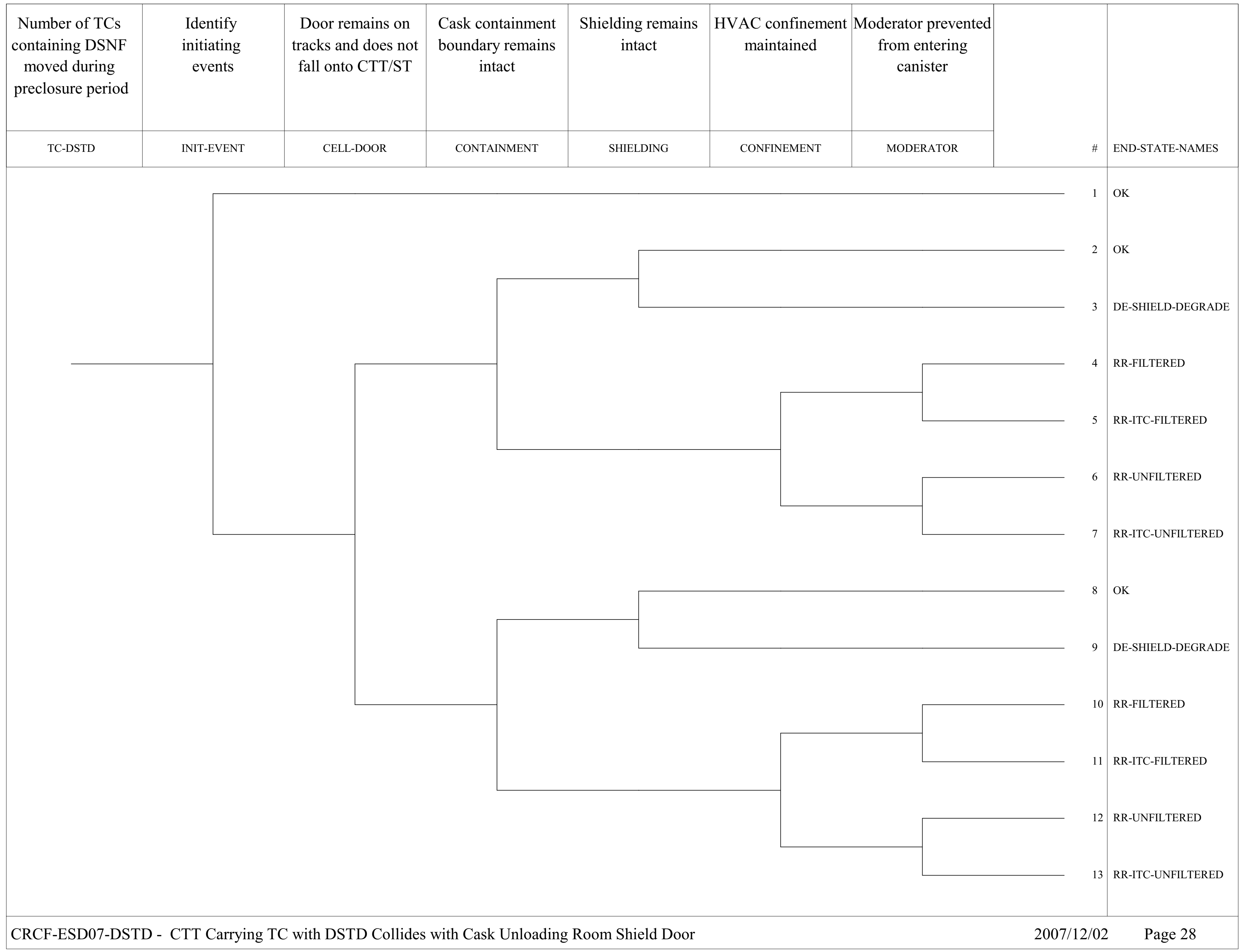
Source: Original

Figure G-27. Event Tree CRCF-ESD06-TAD – Transfer of Transportation Cask or Aging Overpack with TAD Canister from Cask Preparation Area to Cask Unloading Room



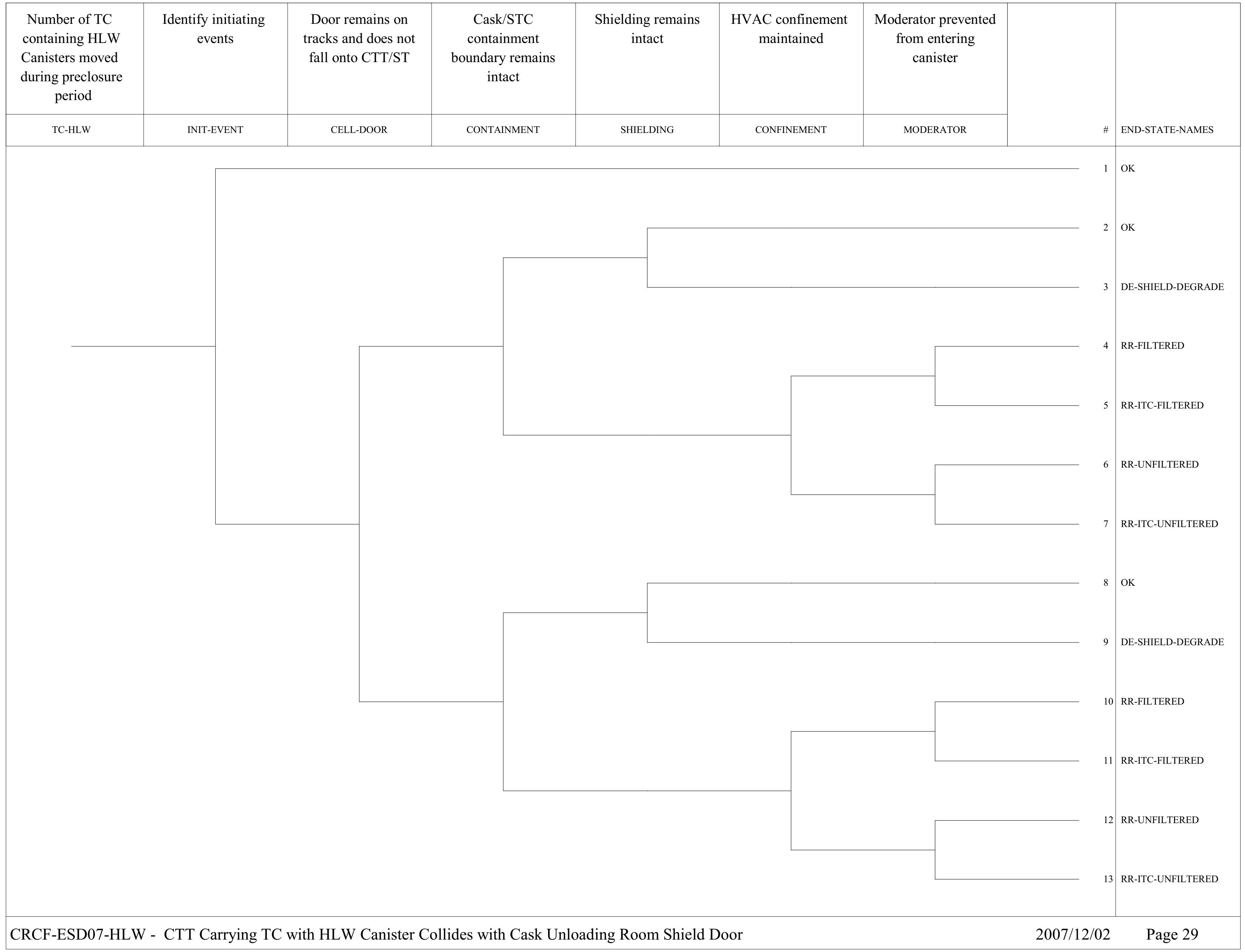
Source: Original

Figure G-28. Event Tree CRCF-ESD07-DPC – CTT Carrying Transportation Cask with DPC Collides with Cask Unloading Room Shield Door



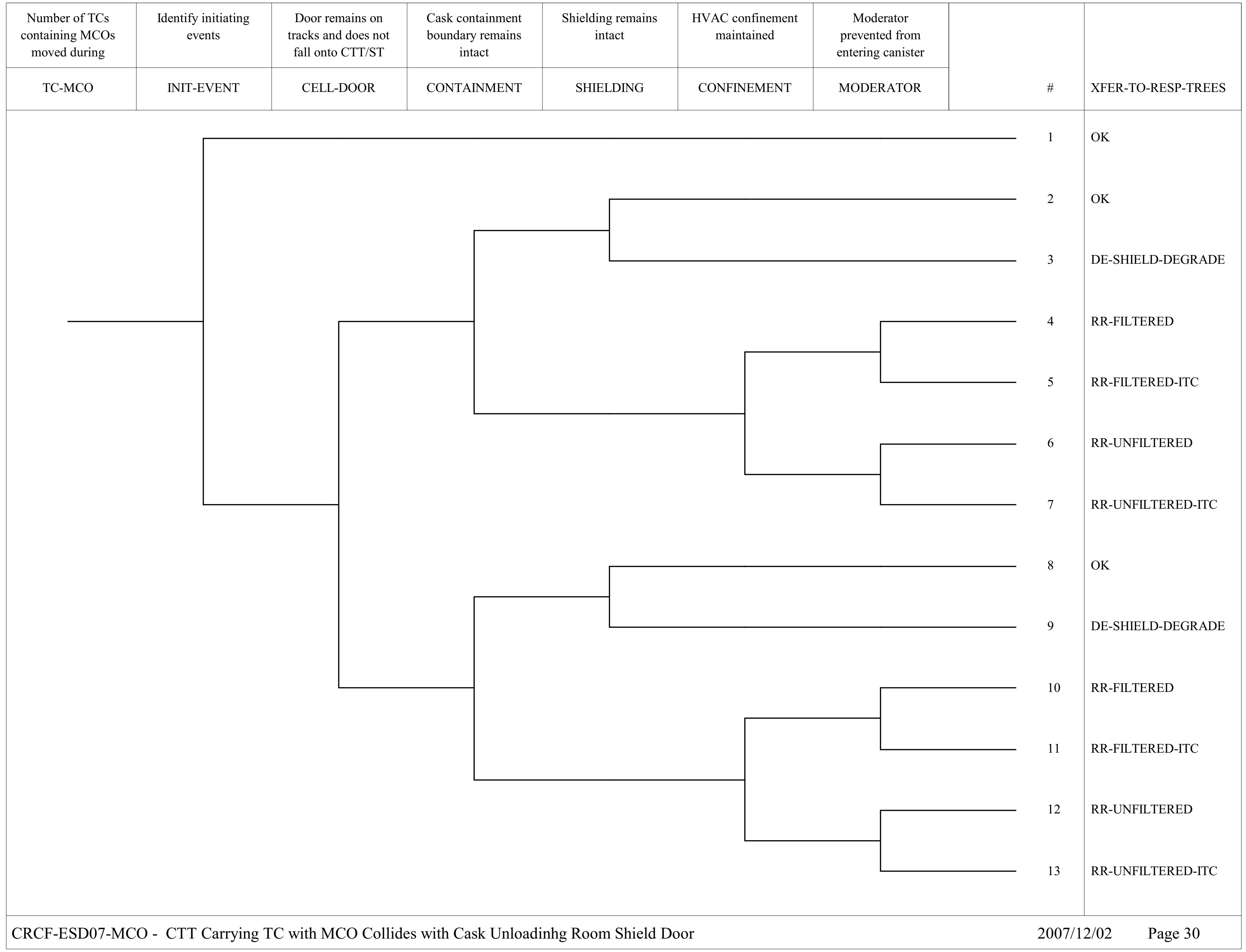
Source: Original

Figure G-29. Event Tree CRCF-ESD07-DSTD – CTT Carrying Transportation Cask with DSTD Collides with Cask Unloading Room Shield Door



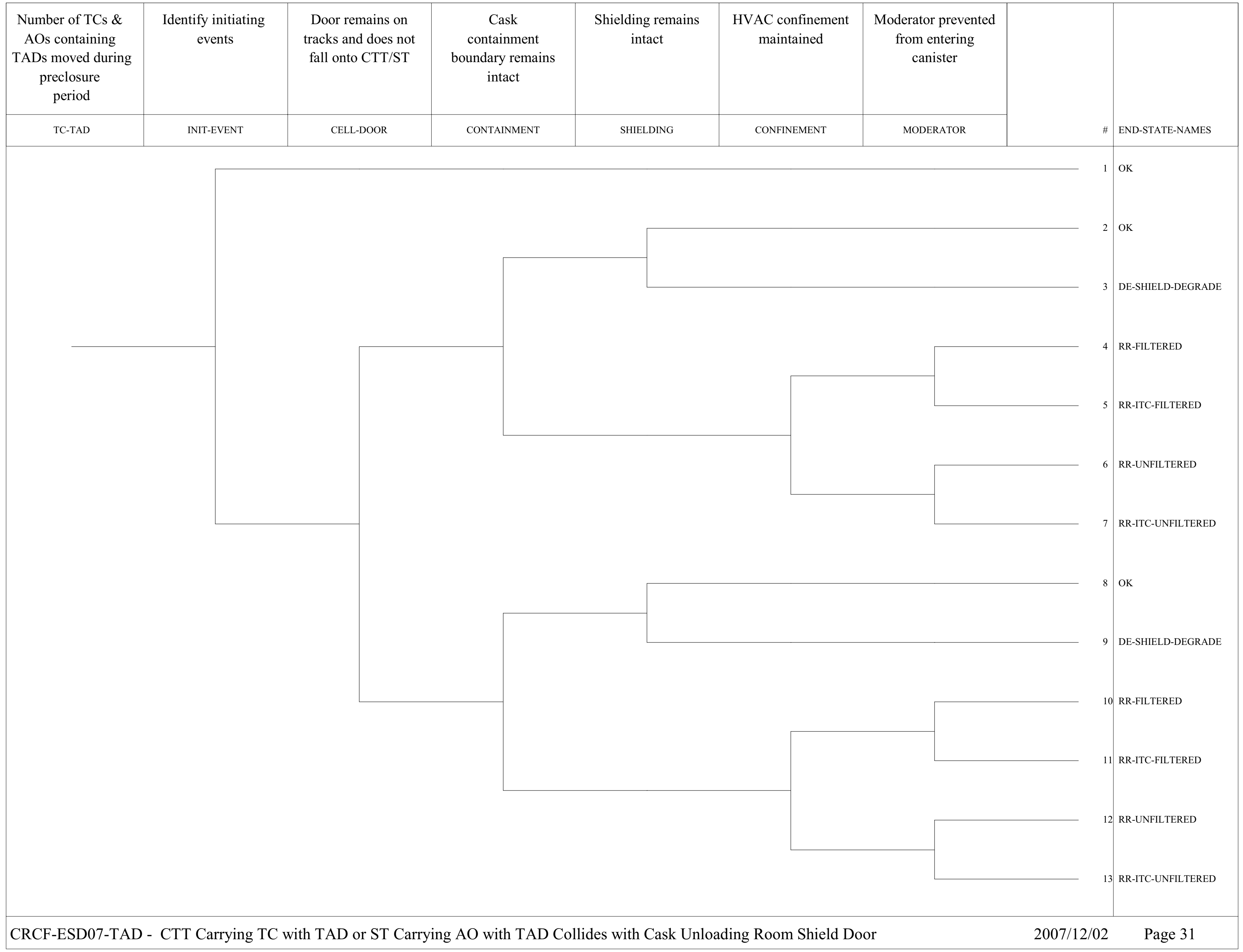
Source: Original

Figure G-30. Event Tree CRCF-ESD07-HLW – CTT Carrying Transportation Cask with HLW Canister Collides with Cask Unloading Room Shield Door



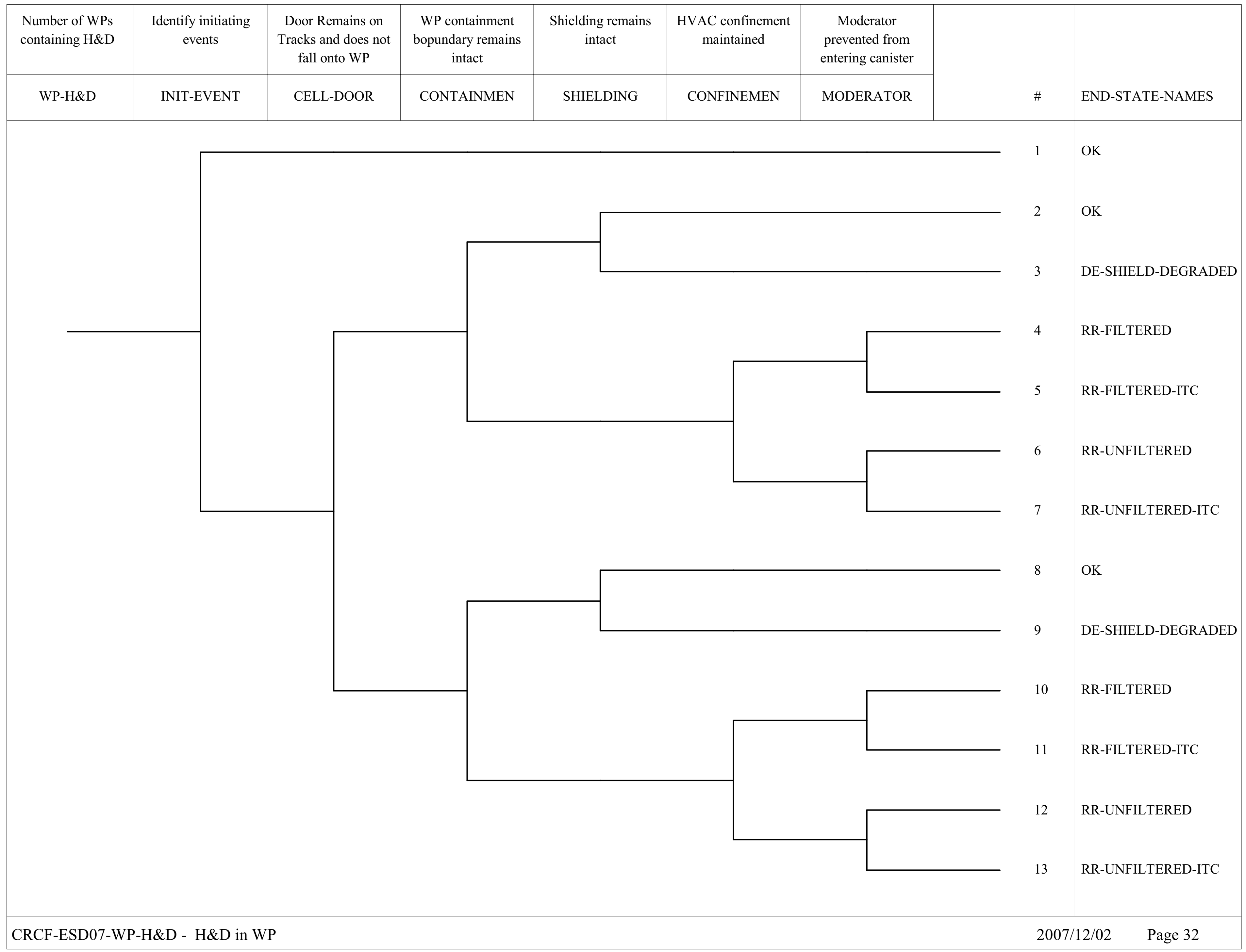
Source: Original

Figure G-31. Event Tree CRCF-ESD07-MCO – CTT Carrying Transportation Cask with MCO Collides with Cask Unloading Room Shield Door



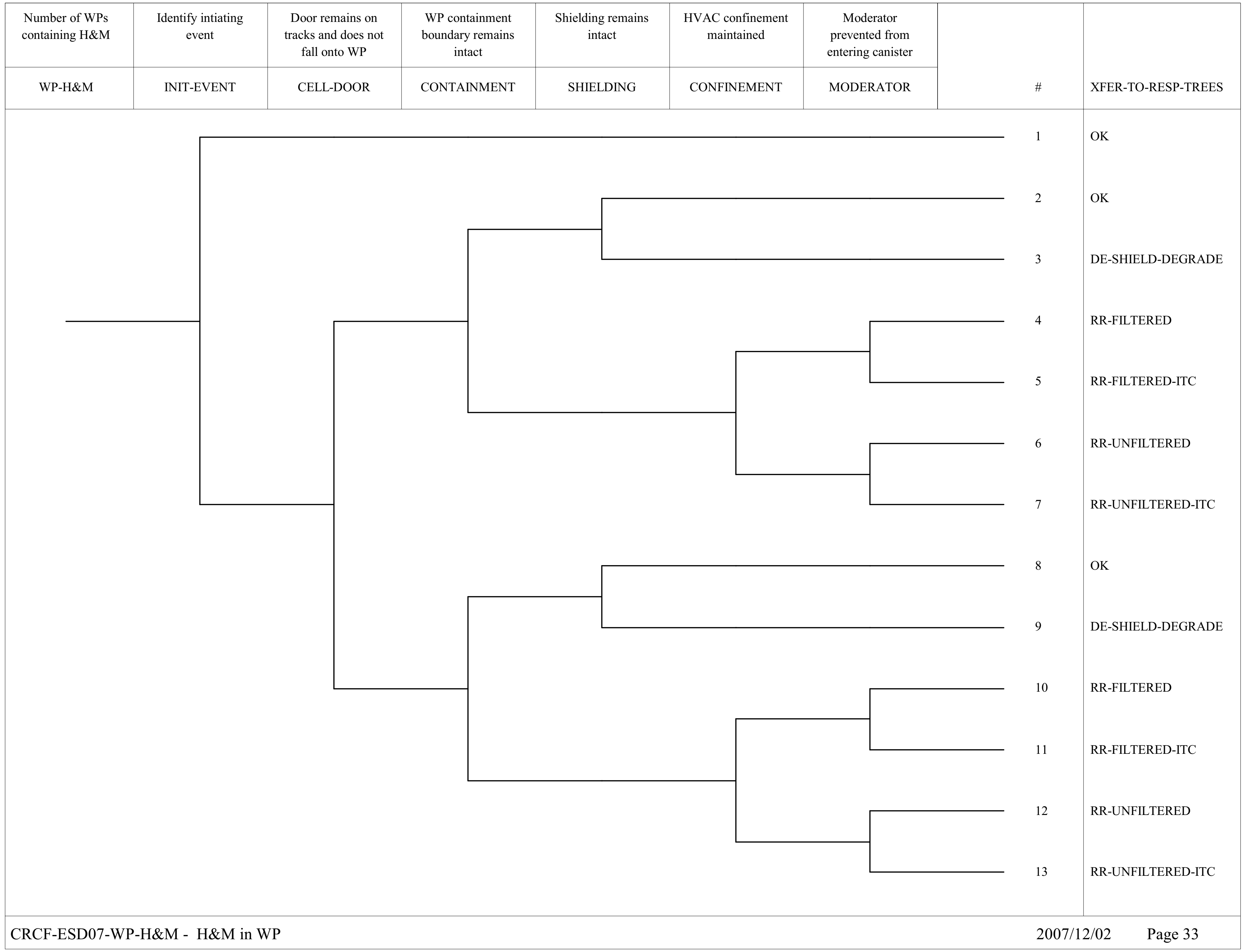
Source: Original

Figure G-32. Event Tree CRCF-ESD07-TAD – CTT Carrying Transportation Cask with TAD Canister or Site Transporter Carrying Aging Overpack with TAD Canister Collides with Cask Unloading Room Shield Door



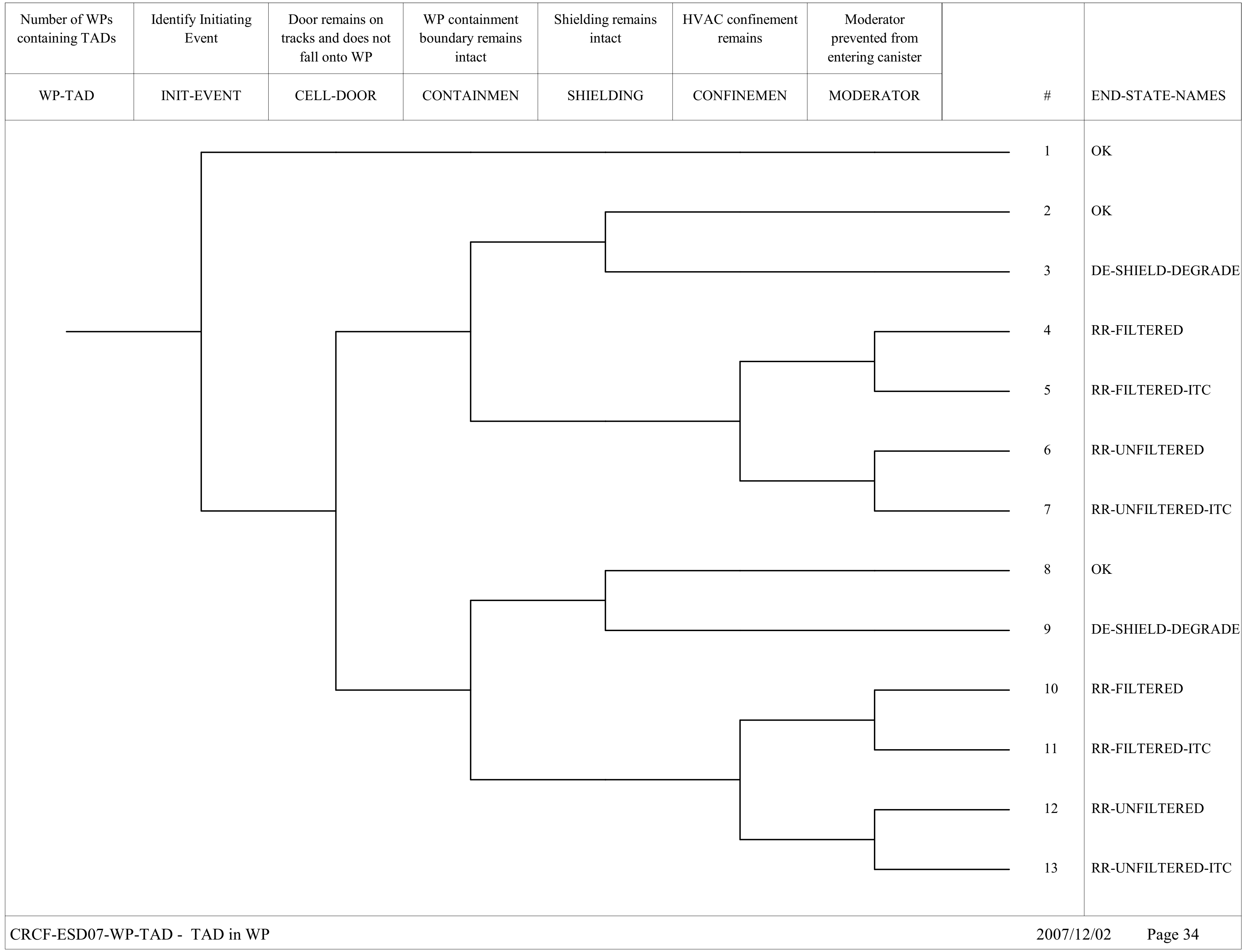
Source: Original

Figure G-33. Event Tree CRCF-ESD07-WP-H&D – H&D in Waste Package



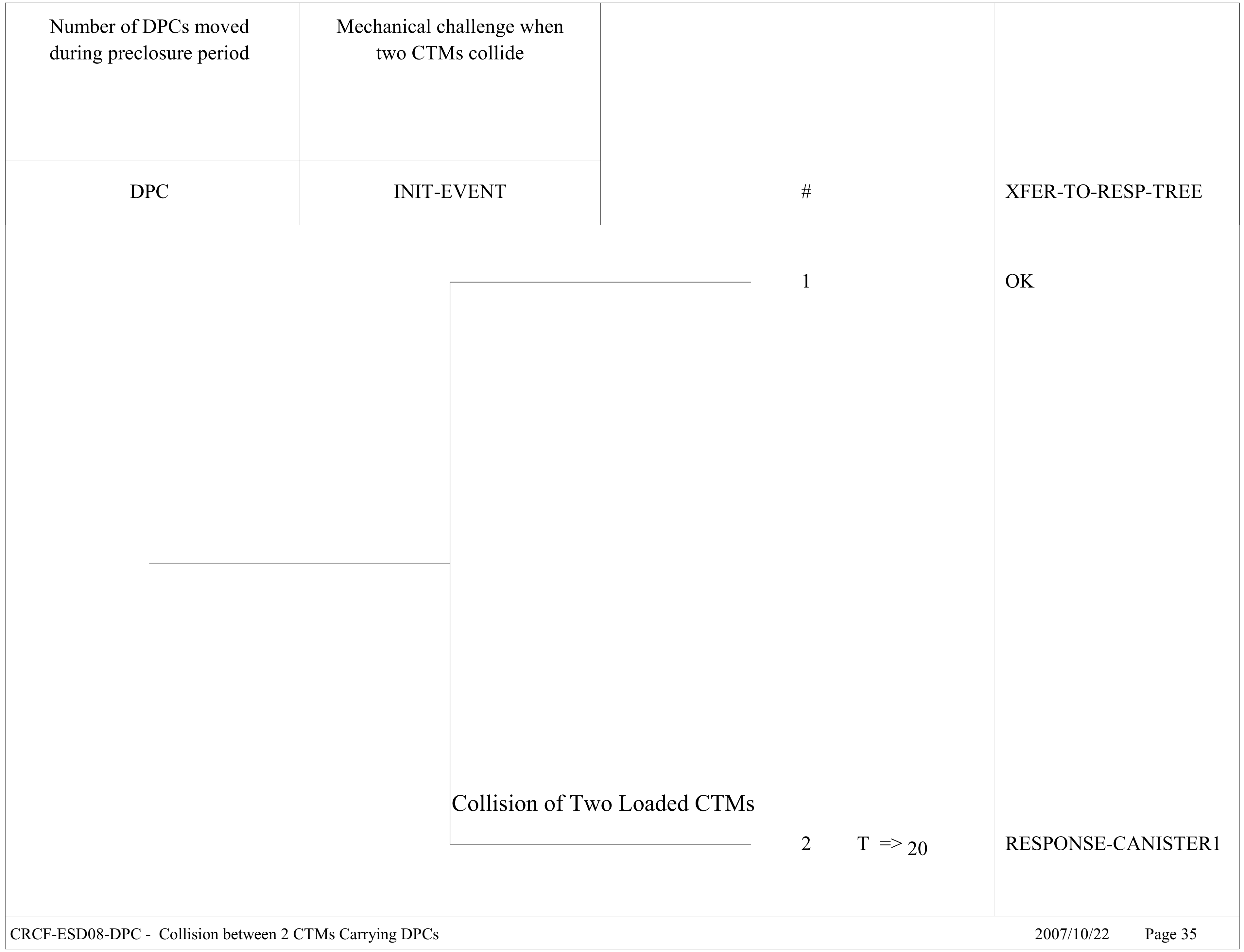
Source: Original

Figure G-34. Event Tree CRCF-ESD07-WP-H&M – H&M in Waste Package



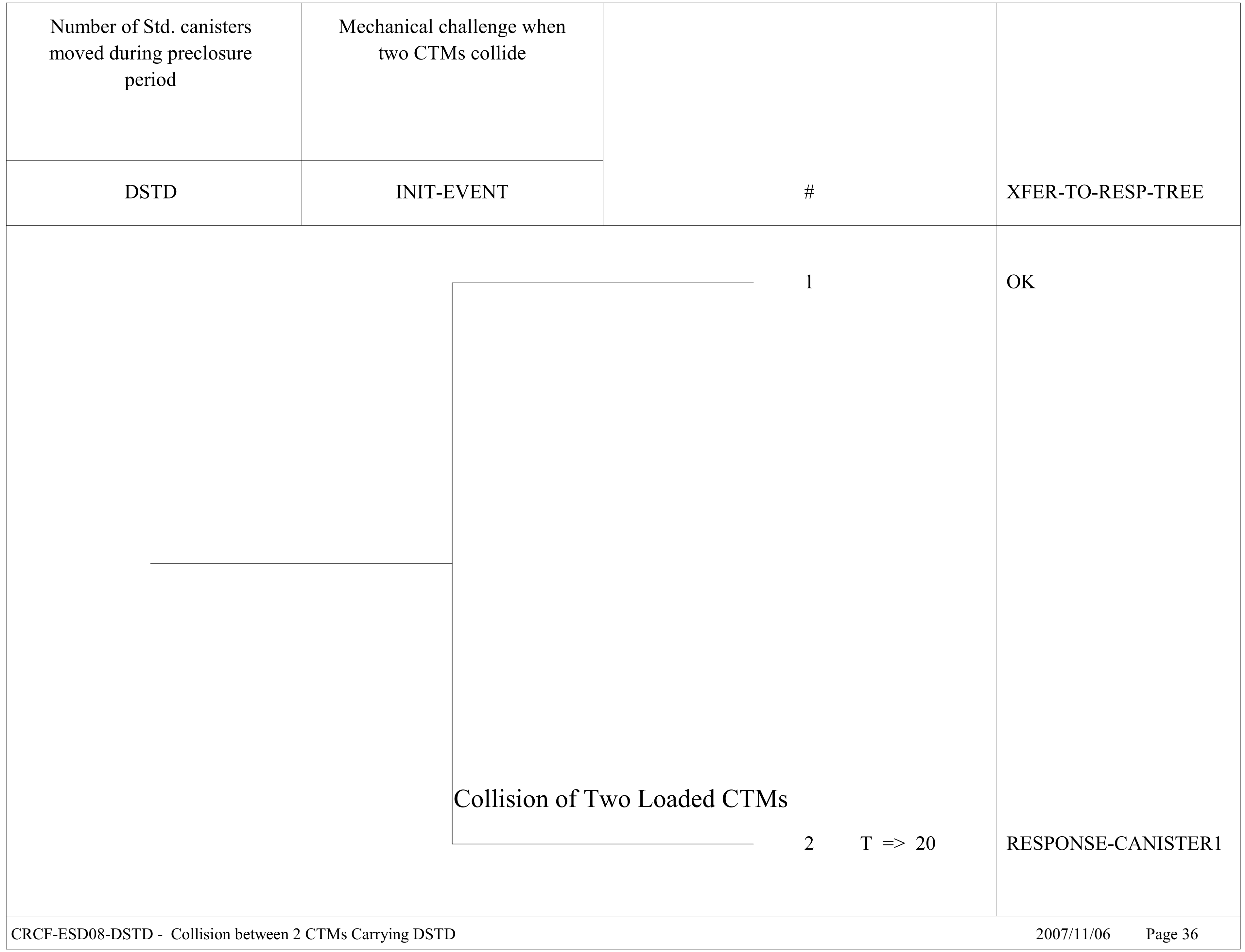
Source: Original

Figure G-35. Event Tree CRCF-ESDWP-TAD – TAD Canister in Waste Package



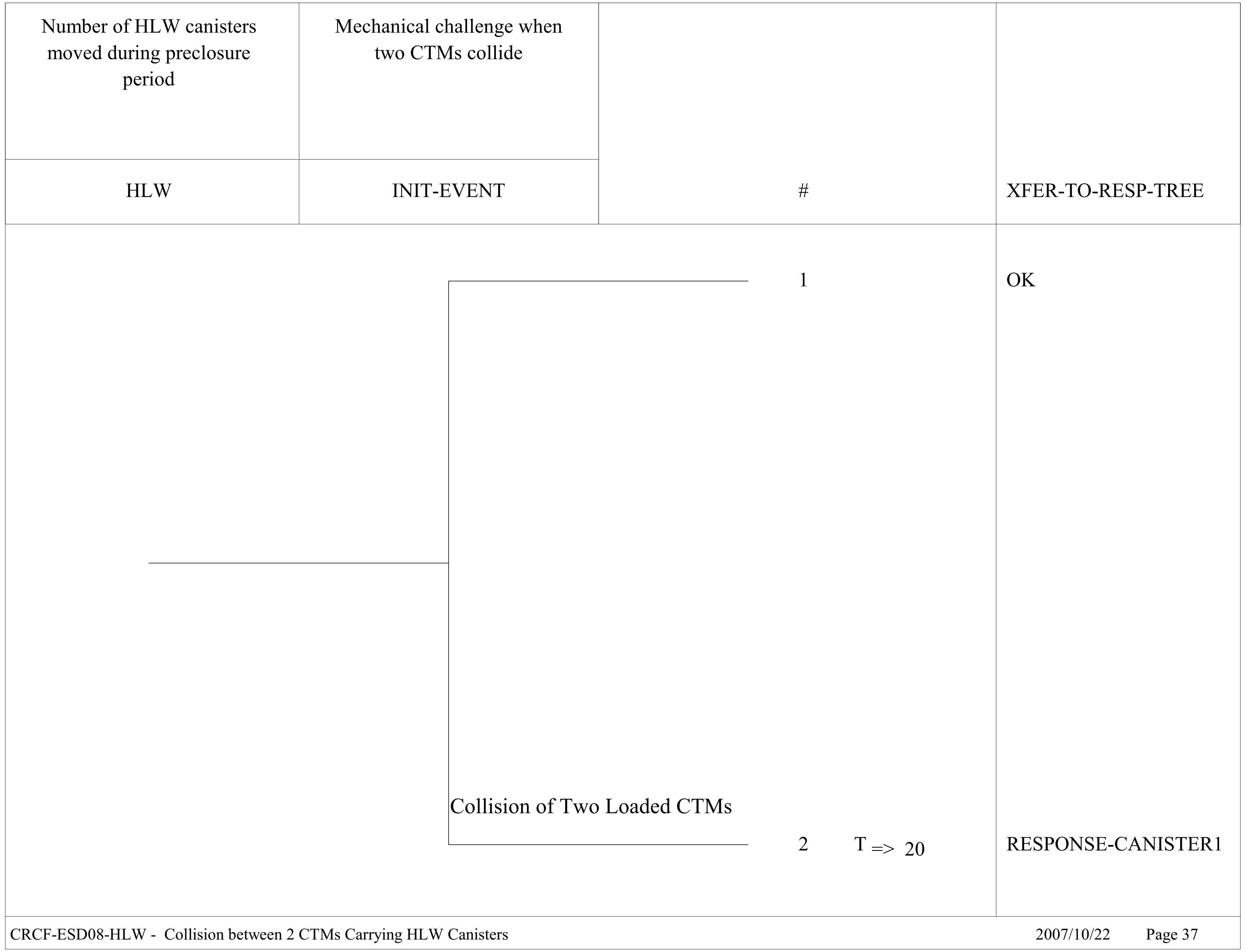
Source: Original

Figure G-36. Event Tree CRCF-ESD08-DPC – Collision between 2 CTMs Carrying DPCs



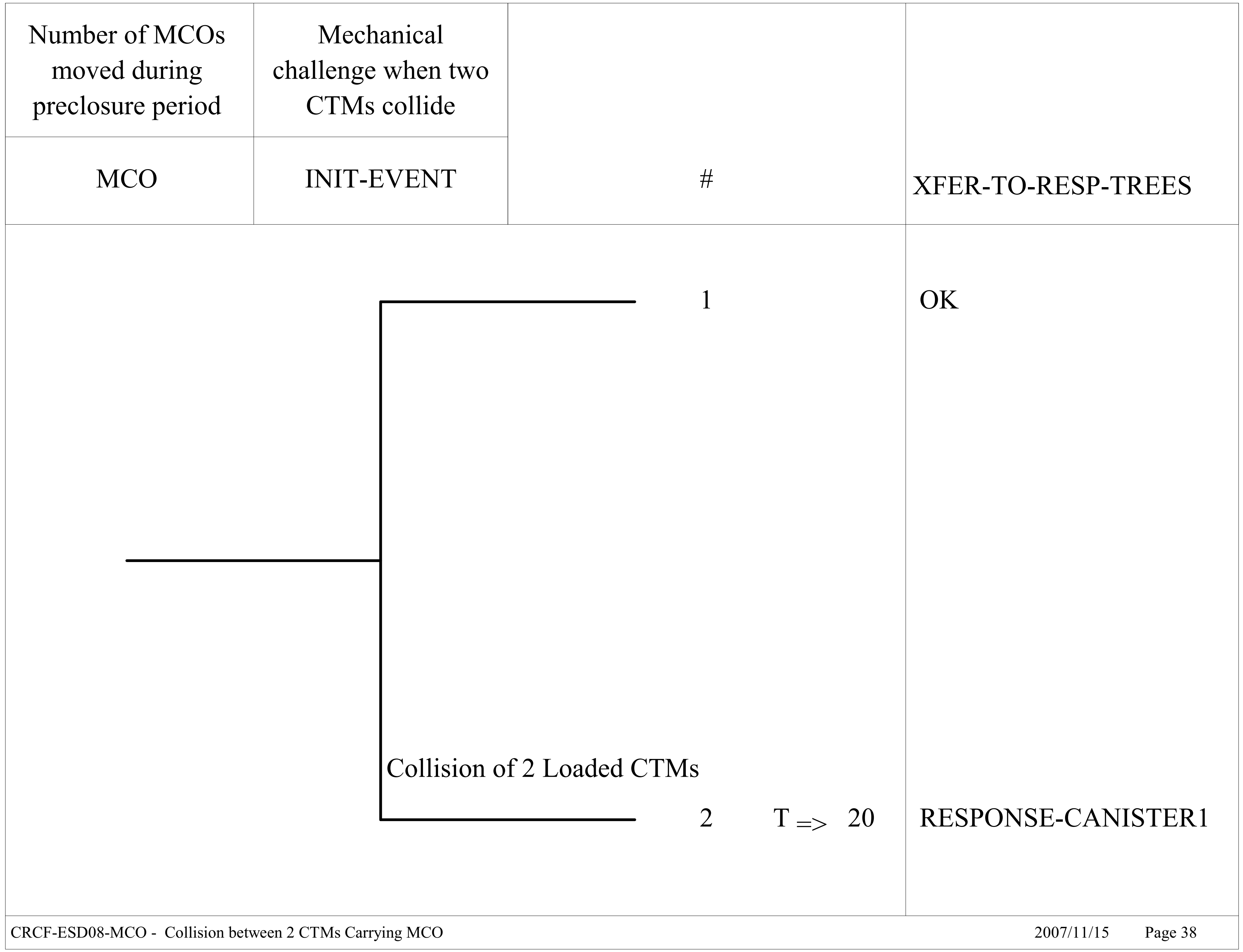
Source: Original

Figure G-37. Event Tree CRCF-ESD08-DSTD – Collision between 2 CTMs Carrying DSTD



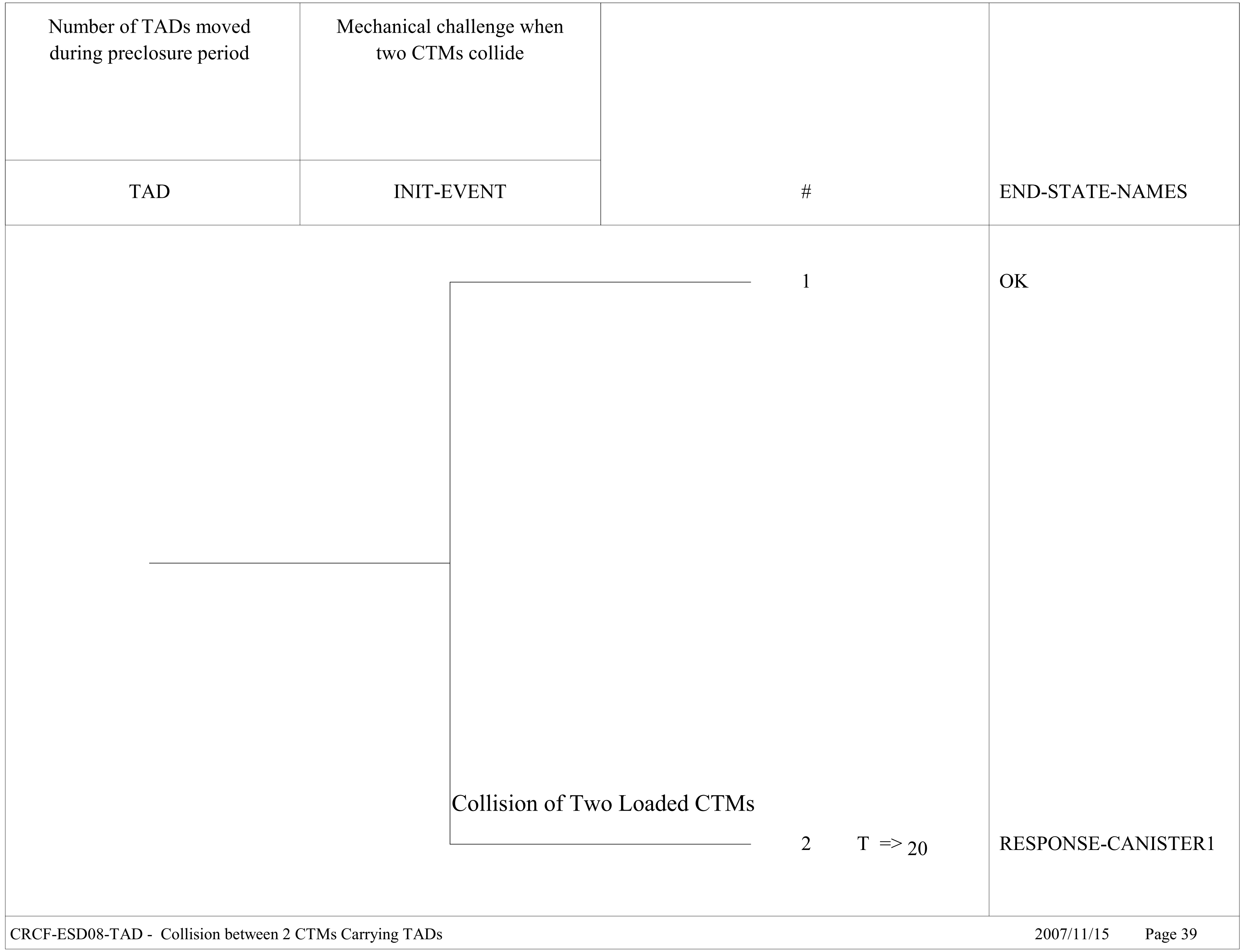
Source: Original

Figure G-38 Event Tree CRCF-ESD08-HLW – Collision between 2 CTMs Carrying HLW Canister



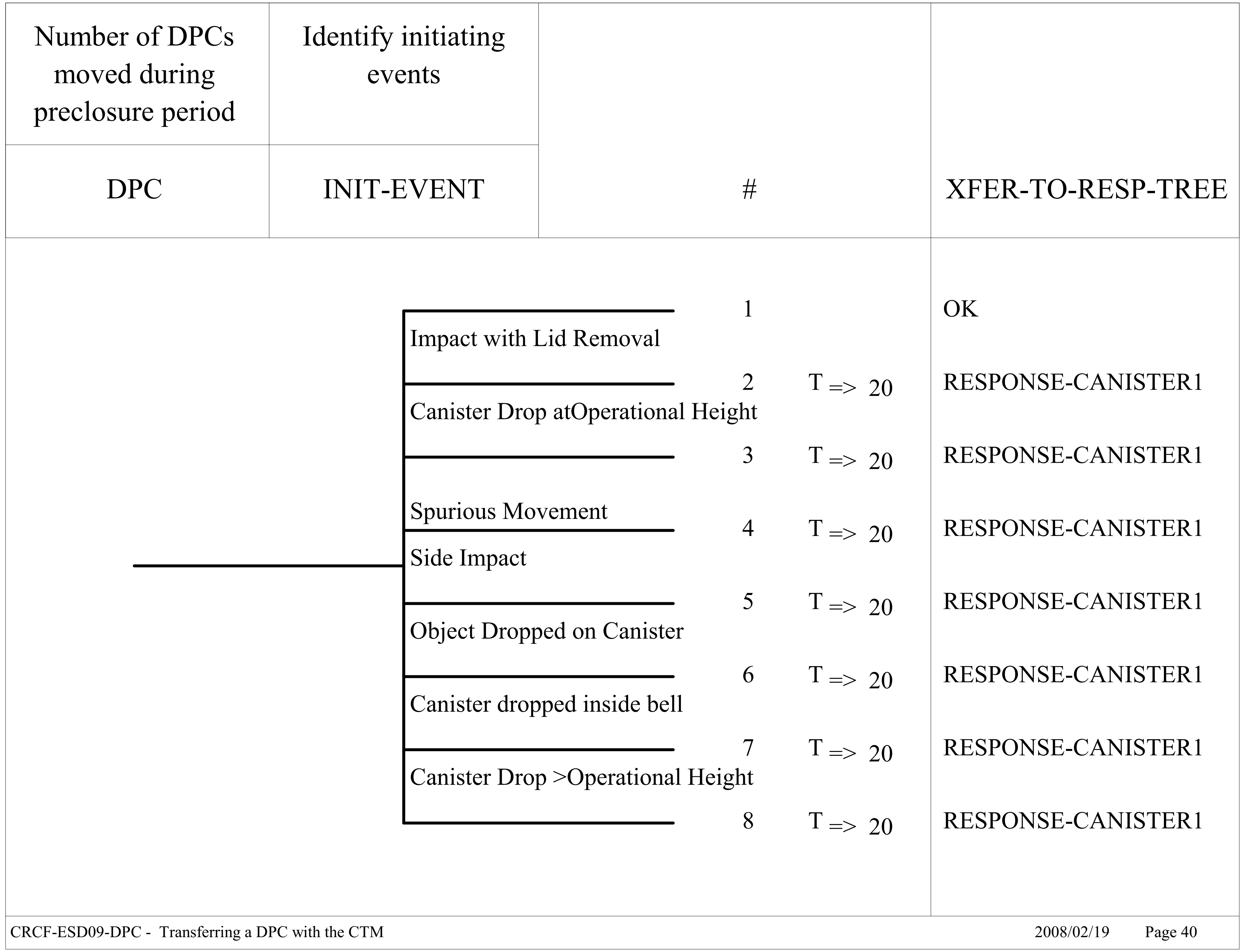
Source: Original

Figure G-39. Event Tree CRCF-ESD08-MCO – Collision between 2 CTMs Carrying MCO



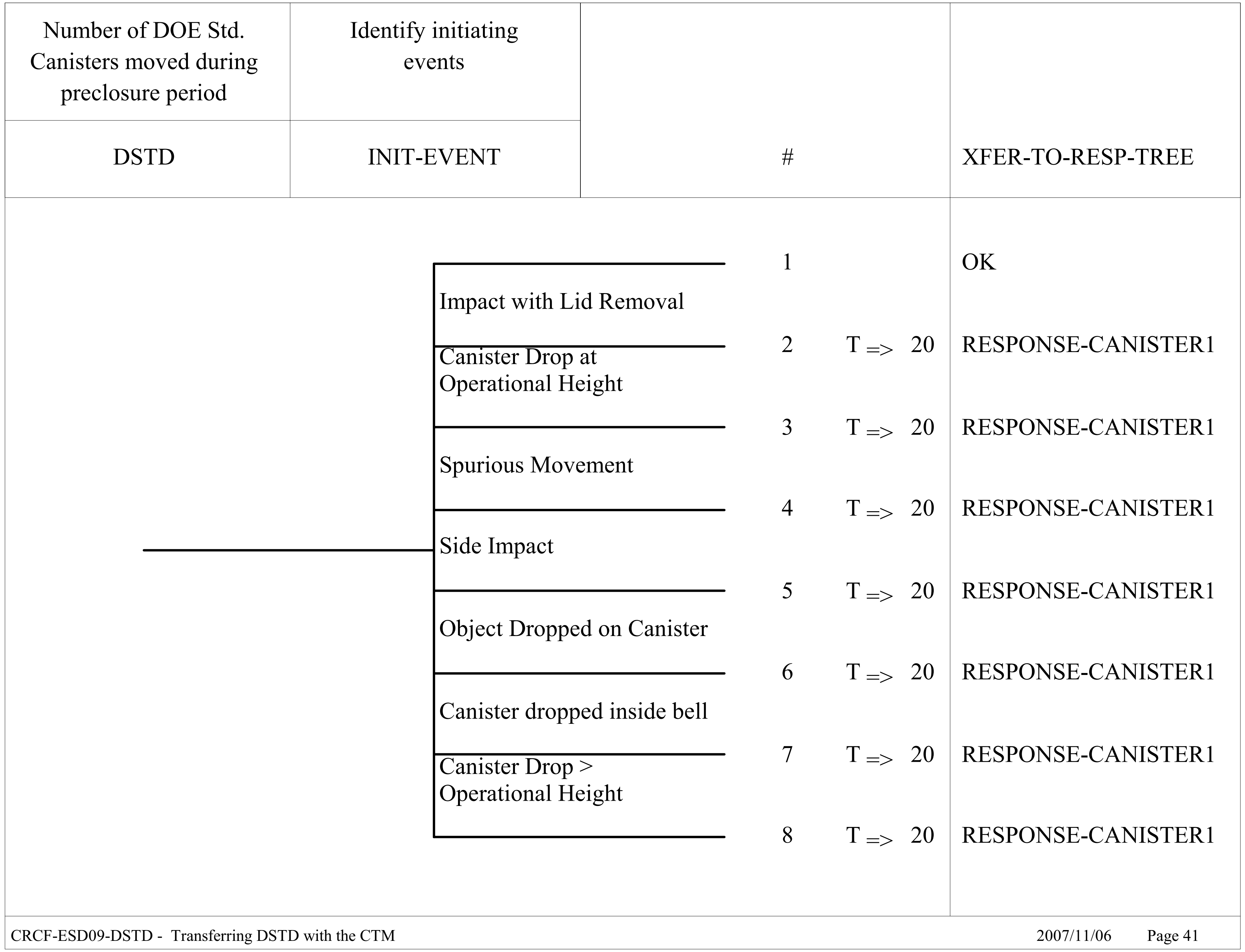
Source: Original

Figure G-40. Event Tree CRCF-ESD08-TAD – Collision between 2 CTMs Carrying TAD Canisters



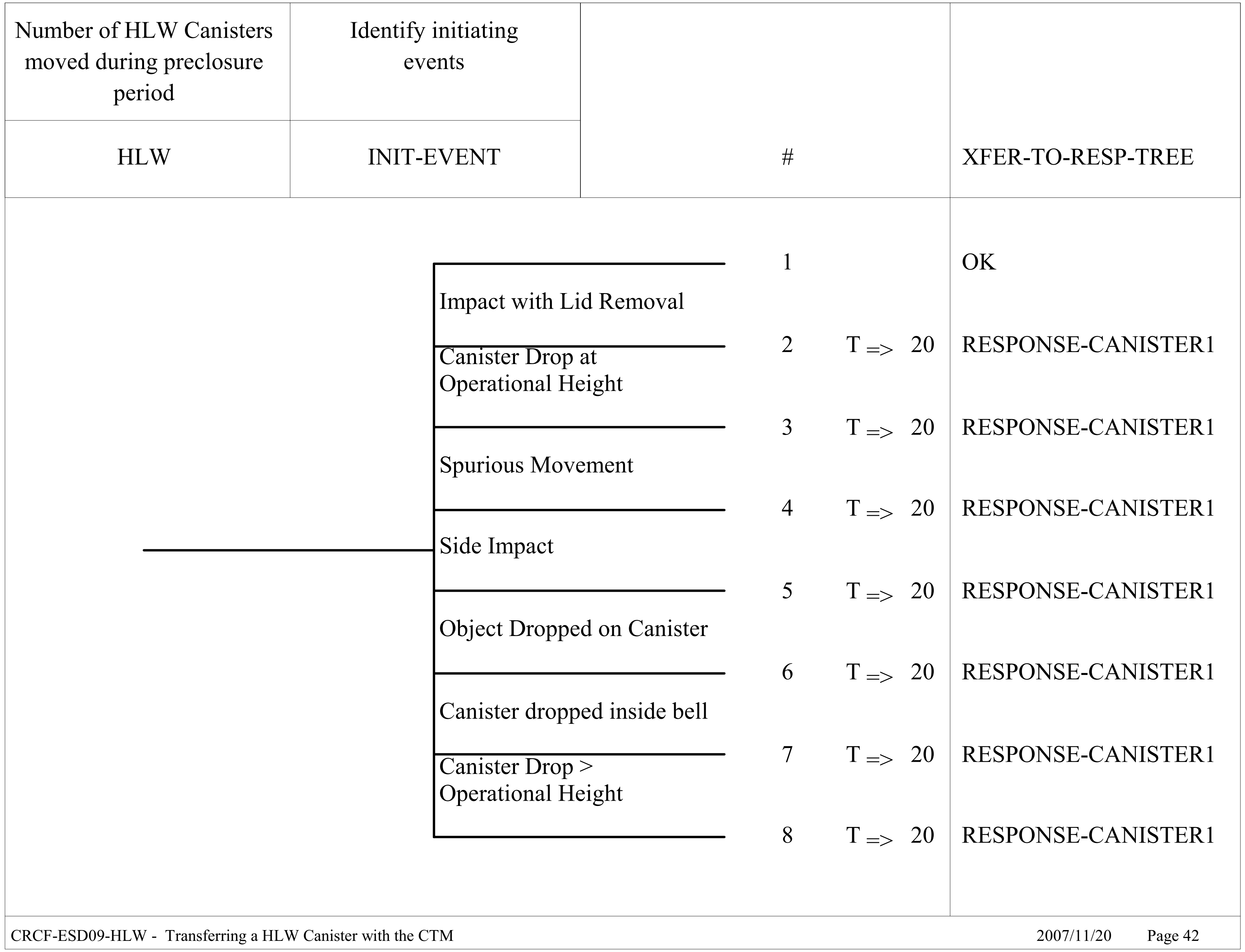
Source: Original

Figure G-41. Event Tree CRCF-ESD09-DPC – Transferring a DPC with the CTM



Source: Original

Figure G-42. Event Tree CRCF-ESD09-DSTD – Transferring DSTD with the CTM



Source: Original

Figure G-43. Event Tree CRCF-ESD09-HLW – Transferring a HLW Canister with the CTM

Number of MCOs moved during preclosure period	Identify initiating events			
MCO	INIT-EVENT	#		XFER-TO-RESP-TREES
		1		OK
	Impact with Lid Removal	2	T => 20	RESPONSE-CANISTER1
	Canister drop at operational height	3	T => 20	RESPONSE-CANISTER1
	Spurious Movement	4	T => 20	RESPONSE-CANISTER1
	Side Impact	5	T => 20	RESPONSE-CANISTER1
	Object Dropped On Canister	6	T => 20	RESPONSE-CANISTER1
	Canister dropped inside bell	7	T => 20	RESPONSE-CANISTER1
	Canister drop > operational height	8	T => 20	RESPONSE-CANISTER1

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Source: Original

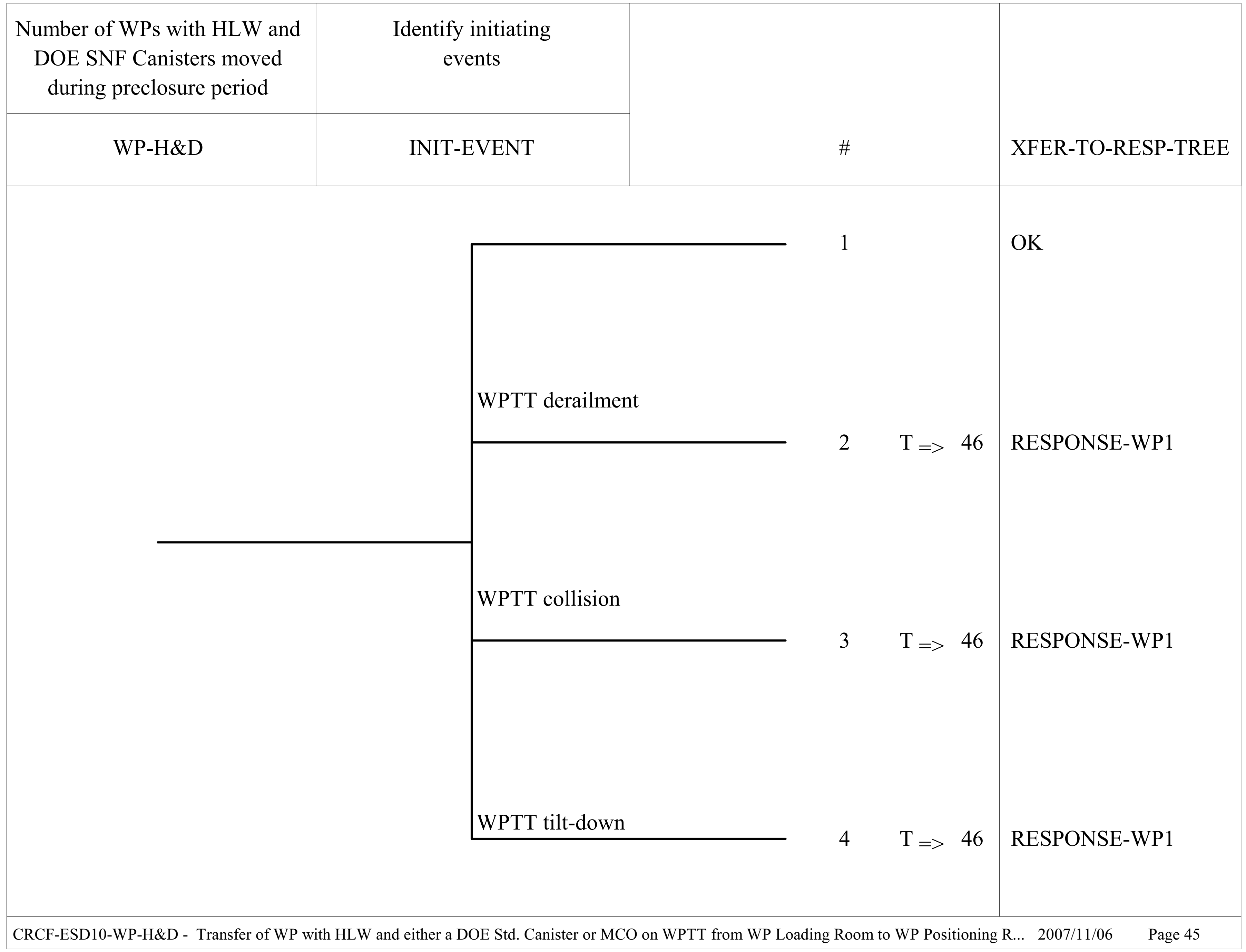
Figure G-44. Event Tree CRCF-ESD09-MCO – Transferring MCO with the CTM

Number of TADs moved during preclosure period	Identify initiating events			
TAD	INIT-EVENT	#		XFER-TO-RESP-TREE
	Impact with Lid Removal	1		OK
	Canister Drop at Operational Height	2	T => 20	RESPONSE-CANISTER1
	Spurious Movement	3	T => 20	RESPONSE-CANISTER1
	Side Impact	4	T => 20	RESPONSE-CANISTER1
	Object Dropped on Canister	5	T => 20	RESPONSE-CANISTER1
	Canister dropped inside bell	6	T => 20	RESPONSE-CANISTER1
	Canister Drop > Operational Height	7	T => 20	RESPONSE-CANISTER1
		8	T => 20	RESPONSE-CANISTER1

CRCF-ESD09-TAD - Transferring a TAD with the CTM 2007/10/30 Page 44

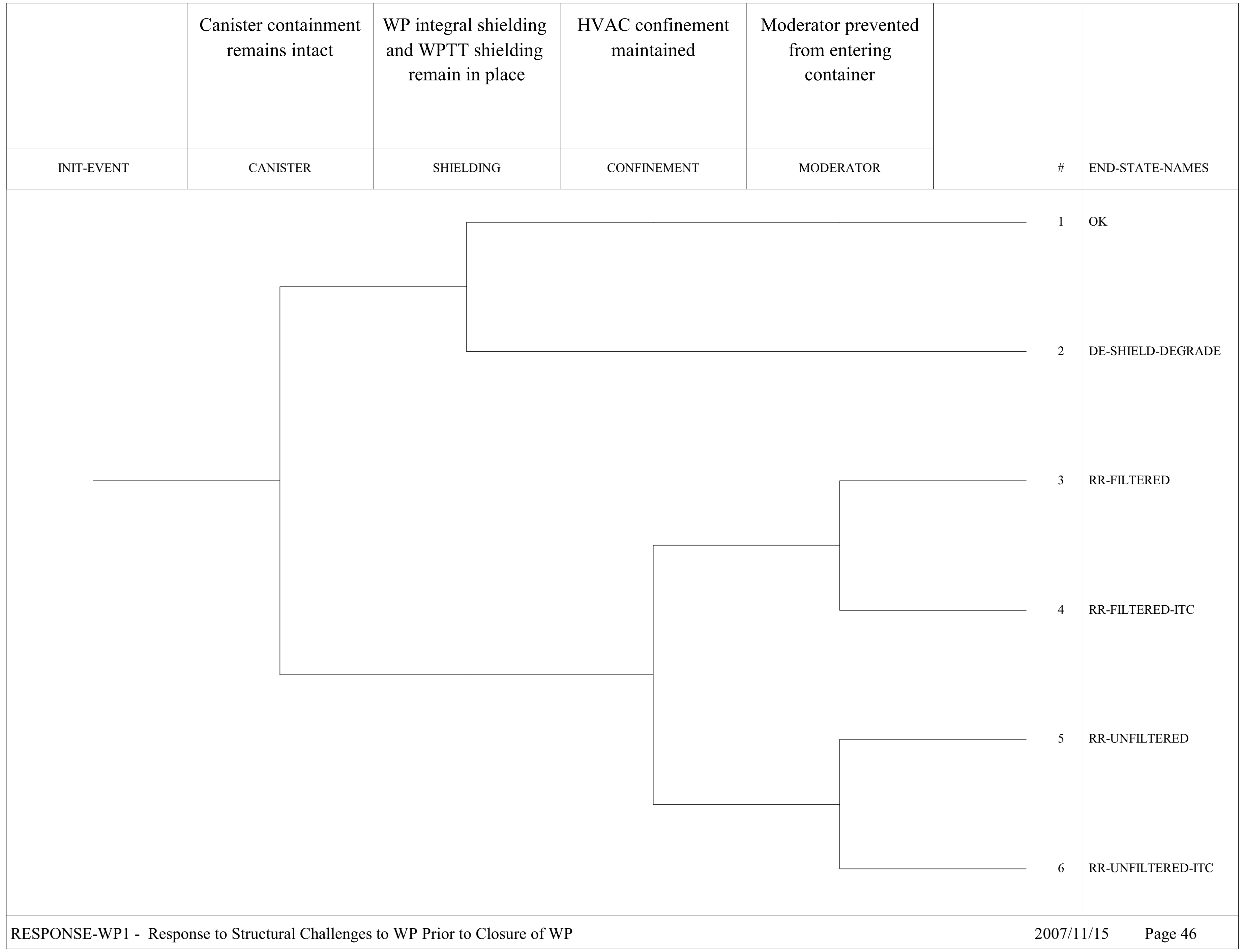
Source: Original

Figure G-45. Event Tree CRCF-ESD09-TAD – Transferring a TAD Canister with the CTM



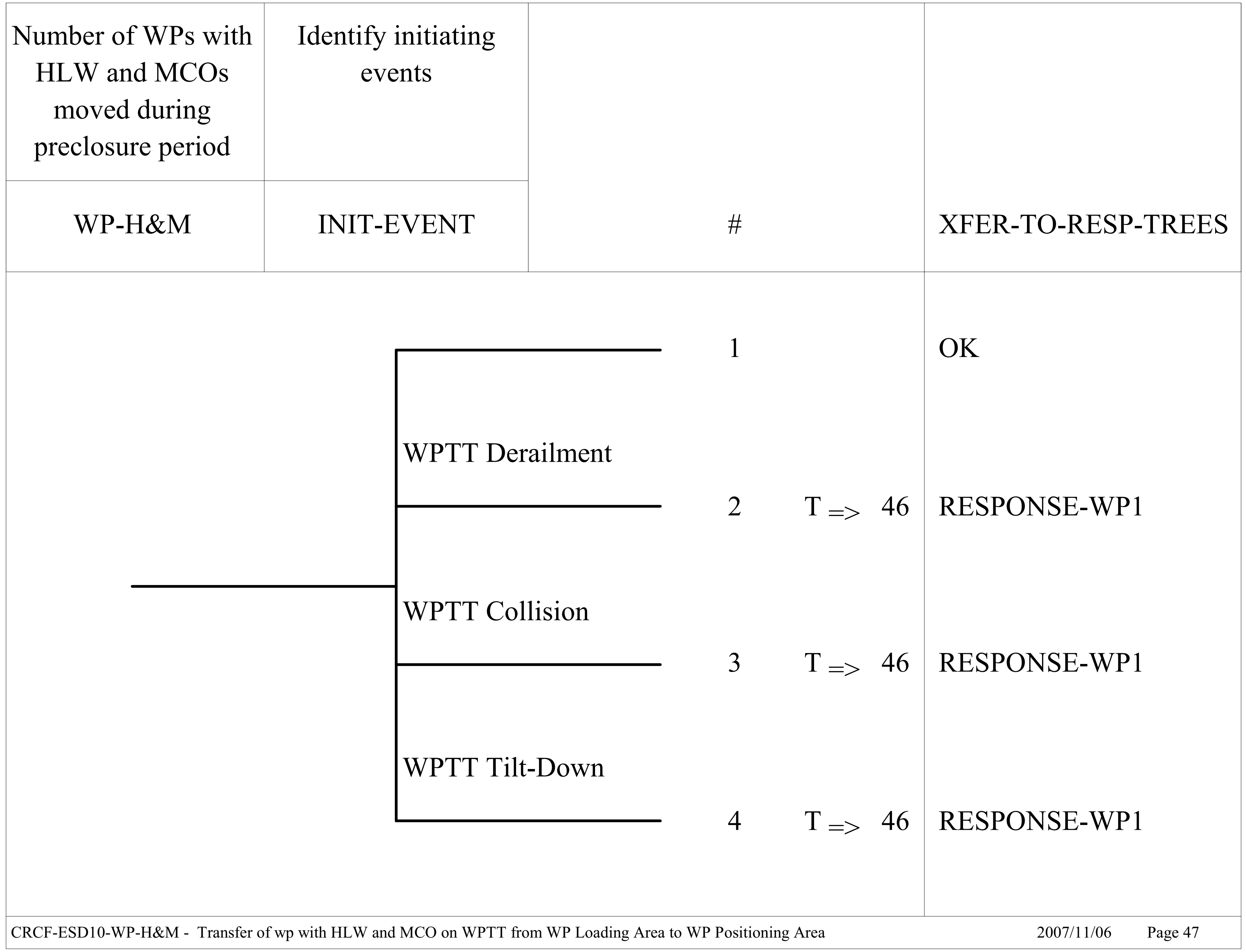
Source: Original

Figure G-46. Event Tree CRCF-ESD10-WP-H&D – Transfer of Waste Package with HLW and either a DOE Std. Canister or MCO on WPTT from Waste Package Loading Room to Waste Package Positioning Room



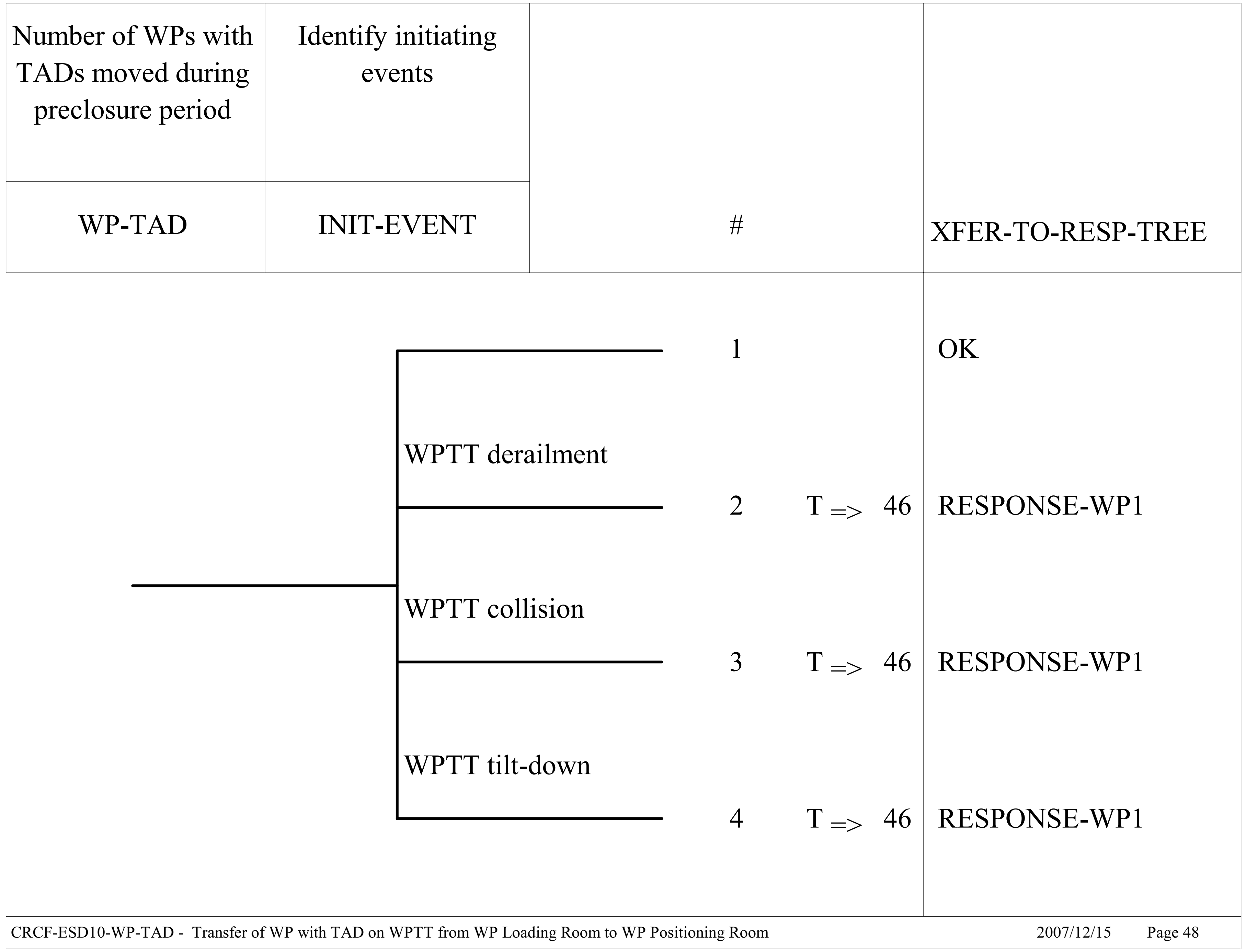
Source: Original

Figure G-47. Event Tree RESPONSE-WP1 – Response to Structural Challenges to Waste Package Prior to Closure of Waste Package



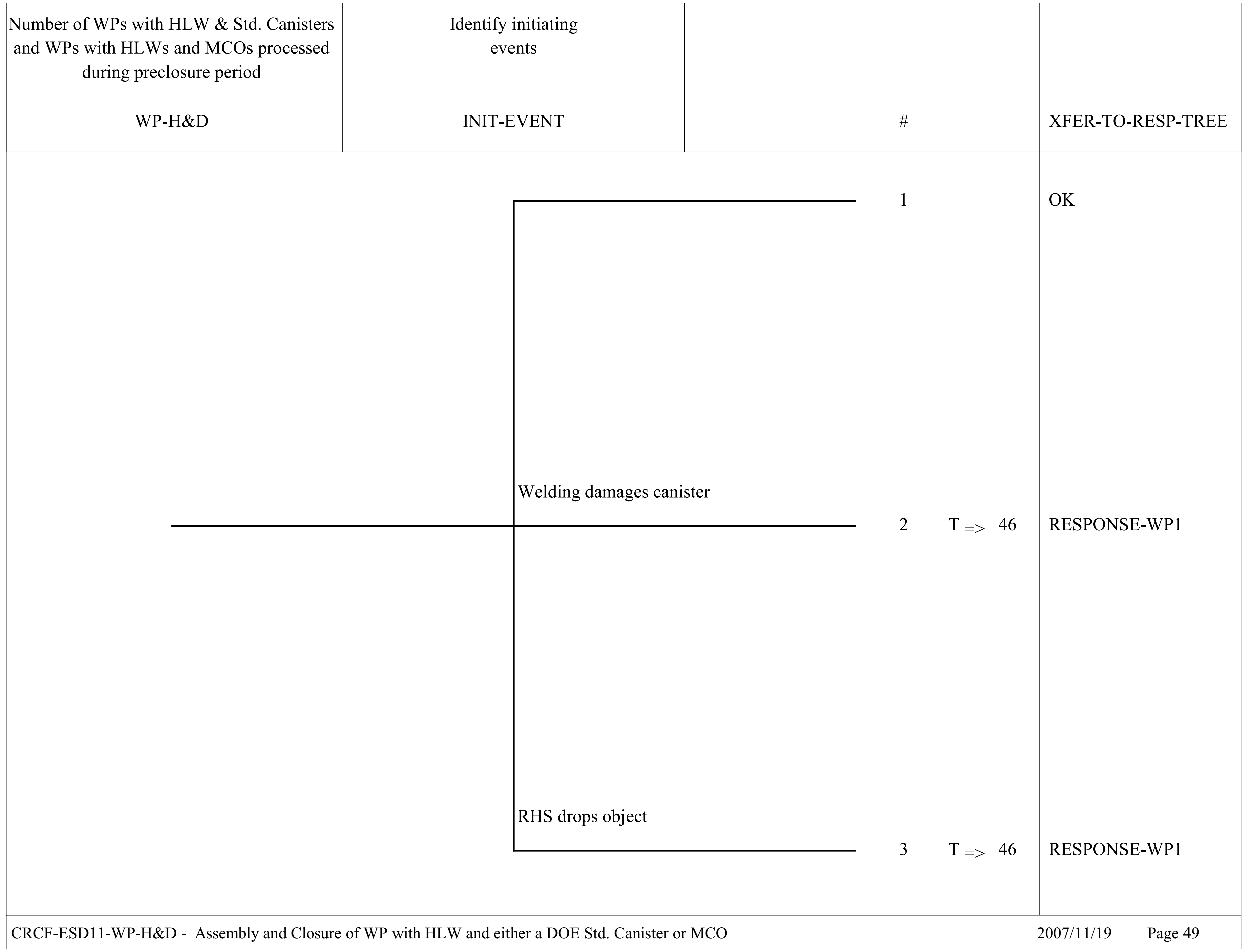
Source: Original

Figure G-48. Event Tree CRCF-ESD10-WP-H&M – Transfer of Waste Package with HLW and MCO on WPTT from Waste Package Loading Area to Waste Package Positioning Area



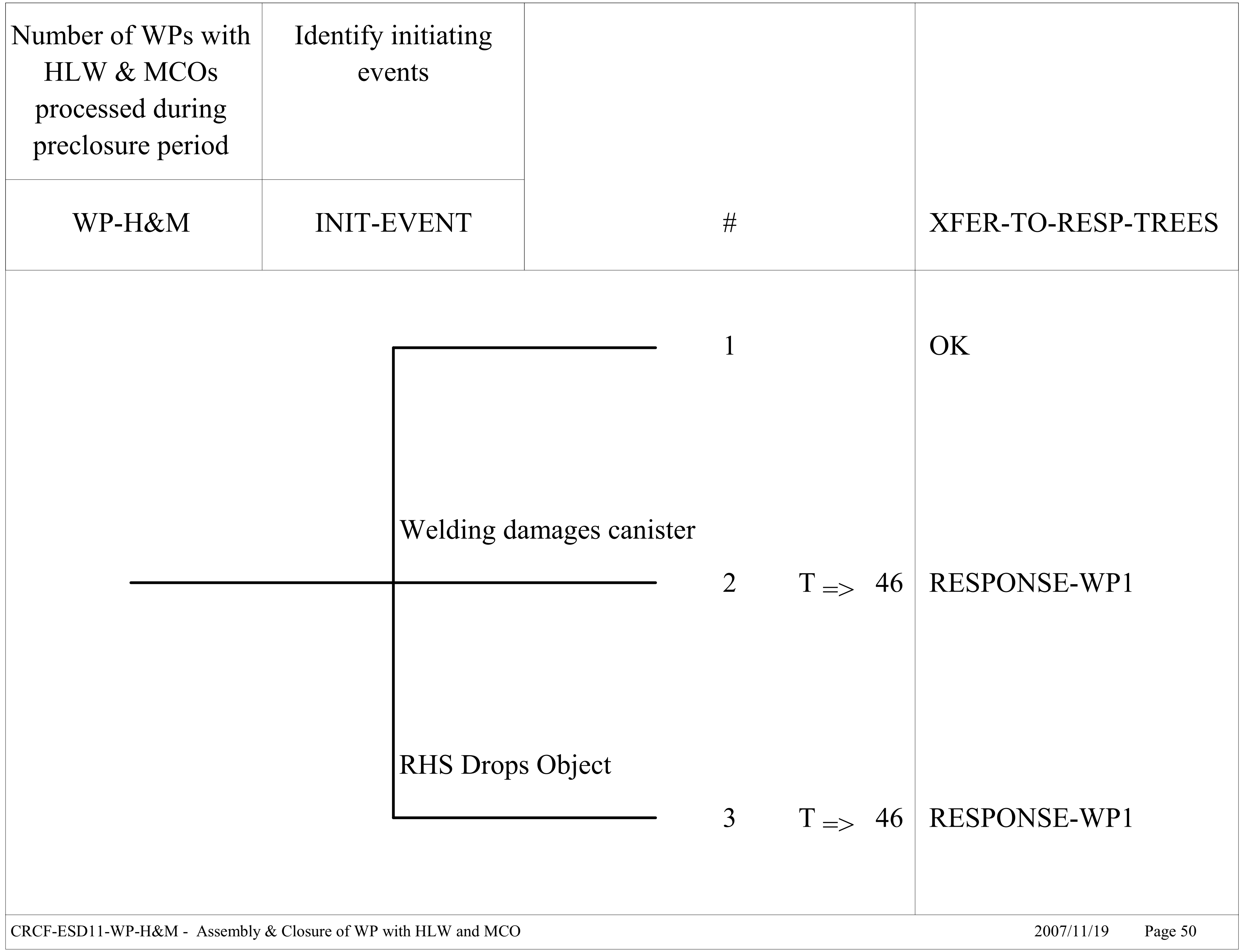
Source: Original

Figure G-49. Event Tree CRCF-ESD10-WP-TAD – Transfer of Waste Package with TAD Canister on WPTT from Waste Package Loading Room to Waste Package Positioning Room



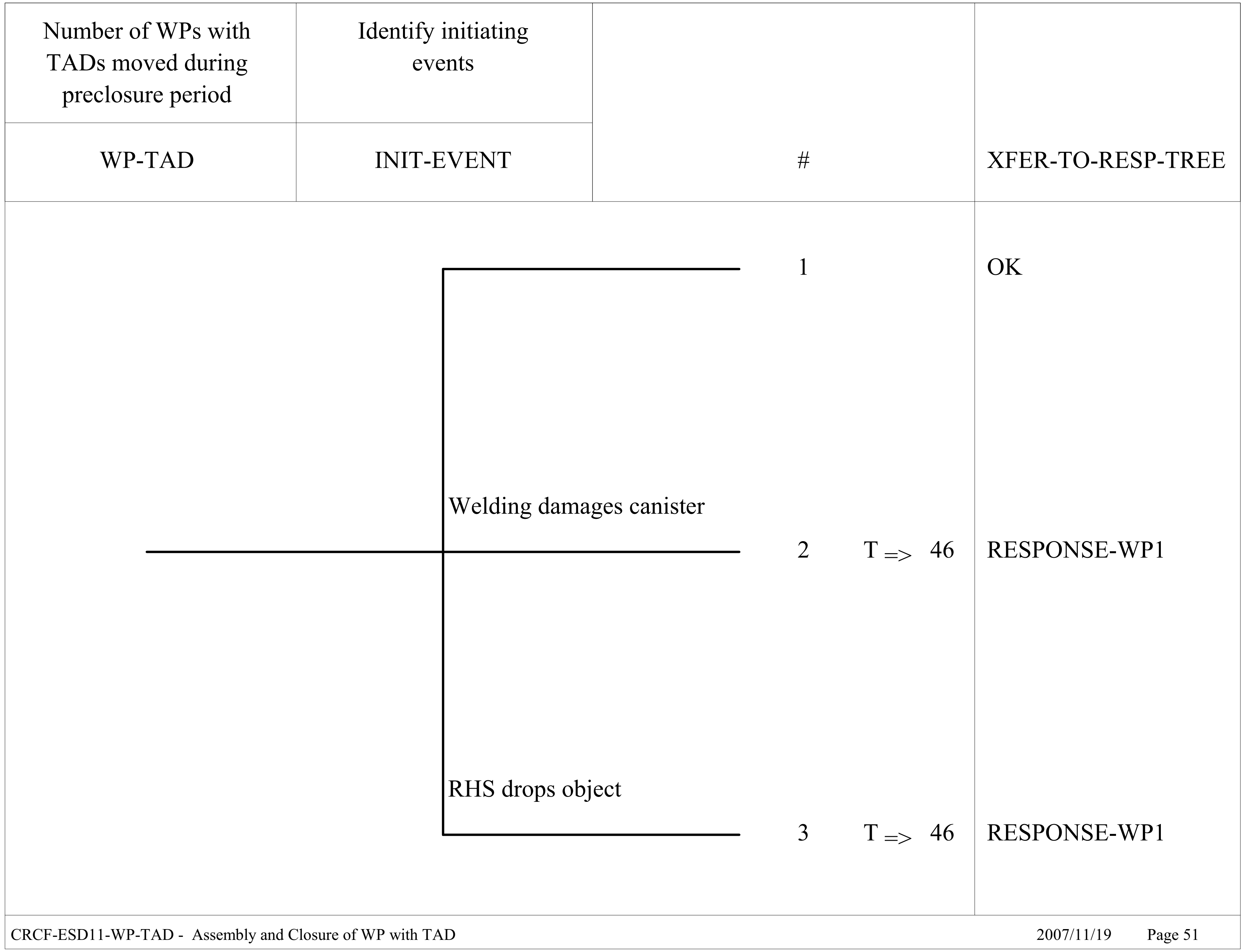
Source: Original

Figure G-50. Event Tree CRCF-ESD11-WP-H&D – Assembly and Closure of Waste Package with HLW and either a DOE Std. Canister or MCO



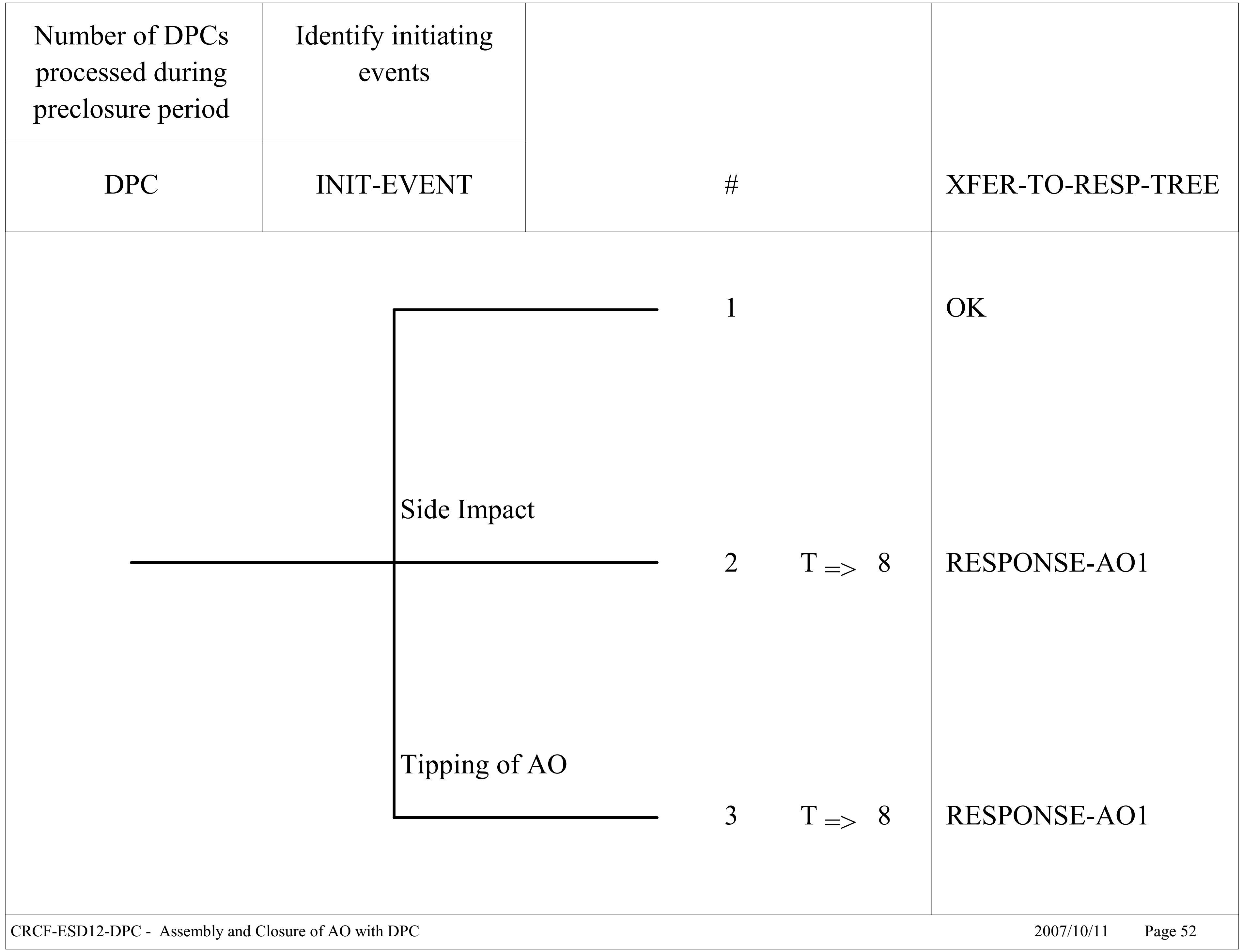
Source: Original

Figure G-51. Event Tree CRCF-ESD11-WP-H&M – Assembly and Closure of Waste Package with HLW and MCO



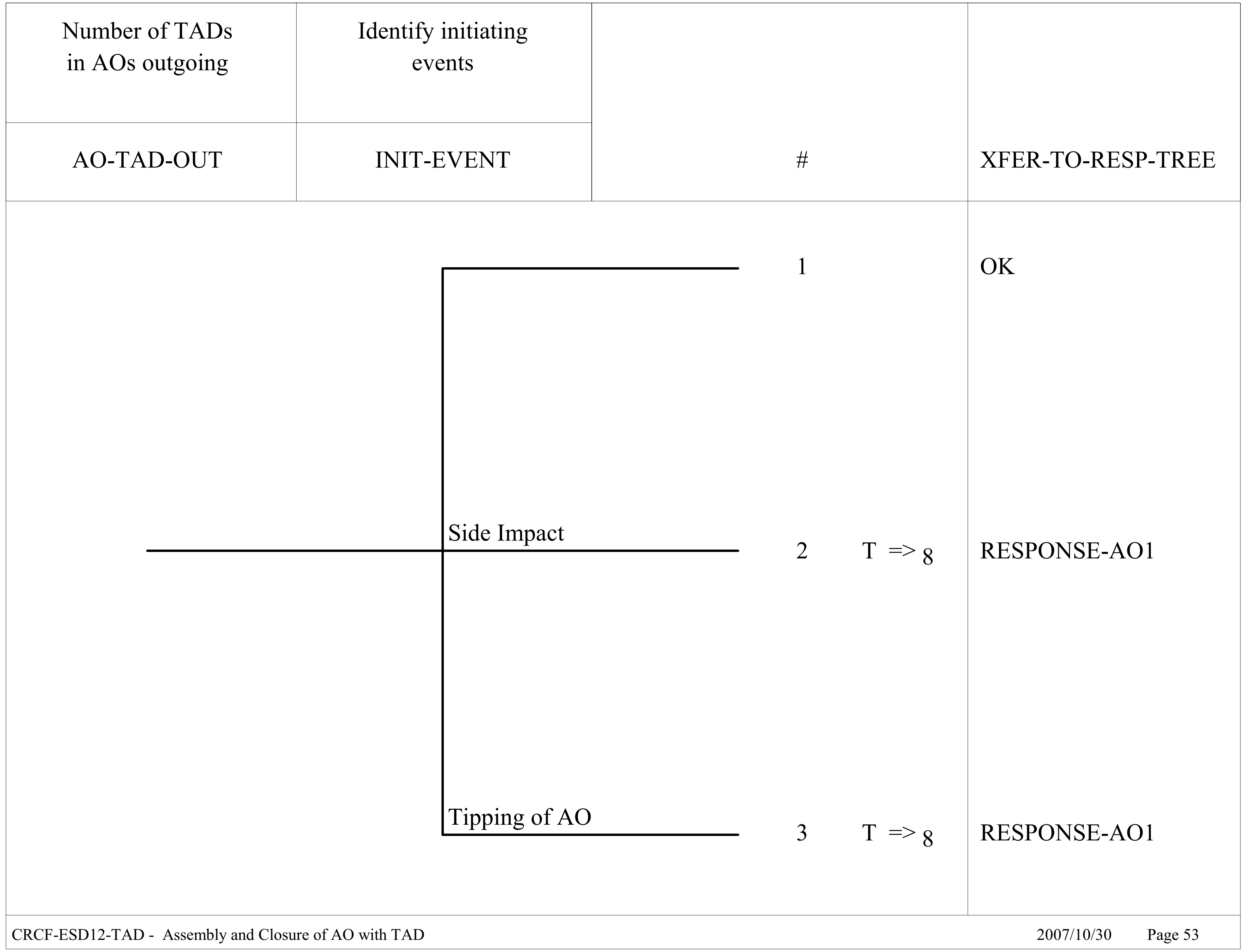
Source: Original

Figure G-52. Event Tree CRCF-ESD11-WP-TAD – Assembly and Closure of Waste Package with TAD Canister



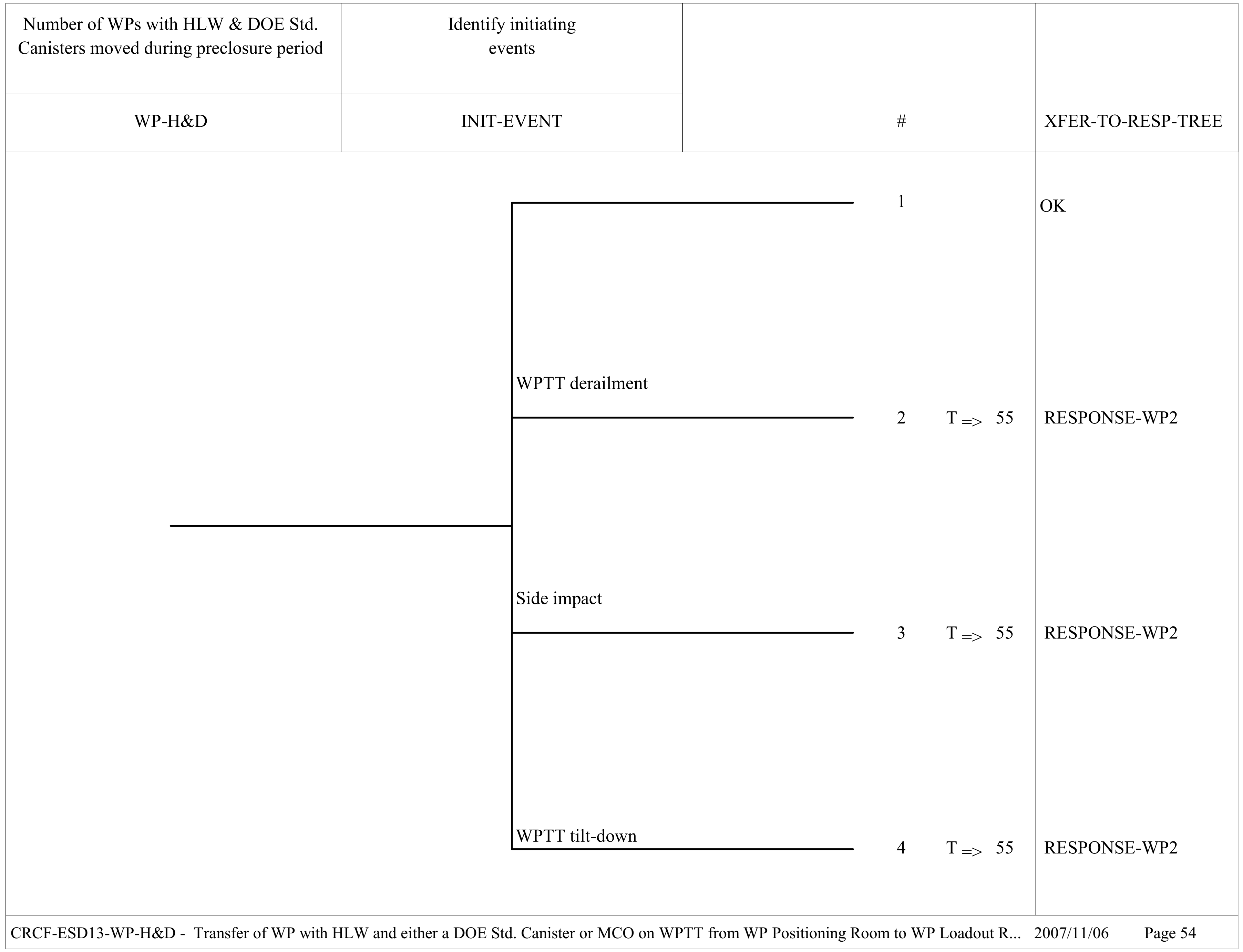
Source: Original

Figure G-53. Event Tree CRCF-ESD12-DPC – Assembly and Closure of Aging Overpack with DPC



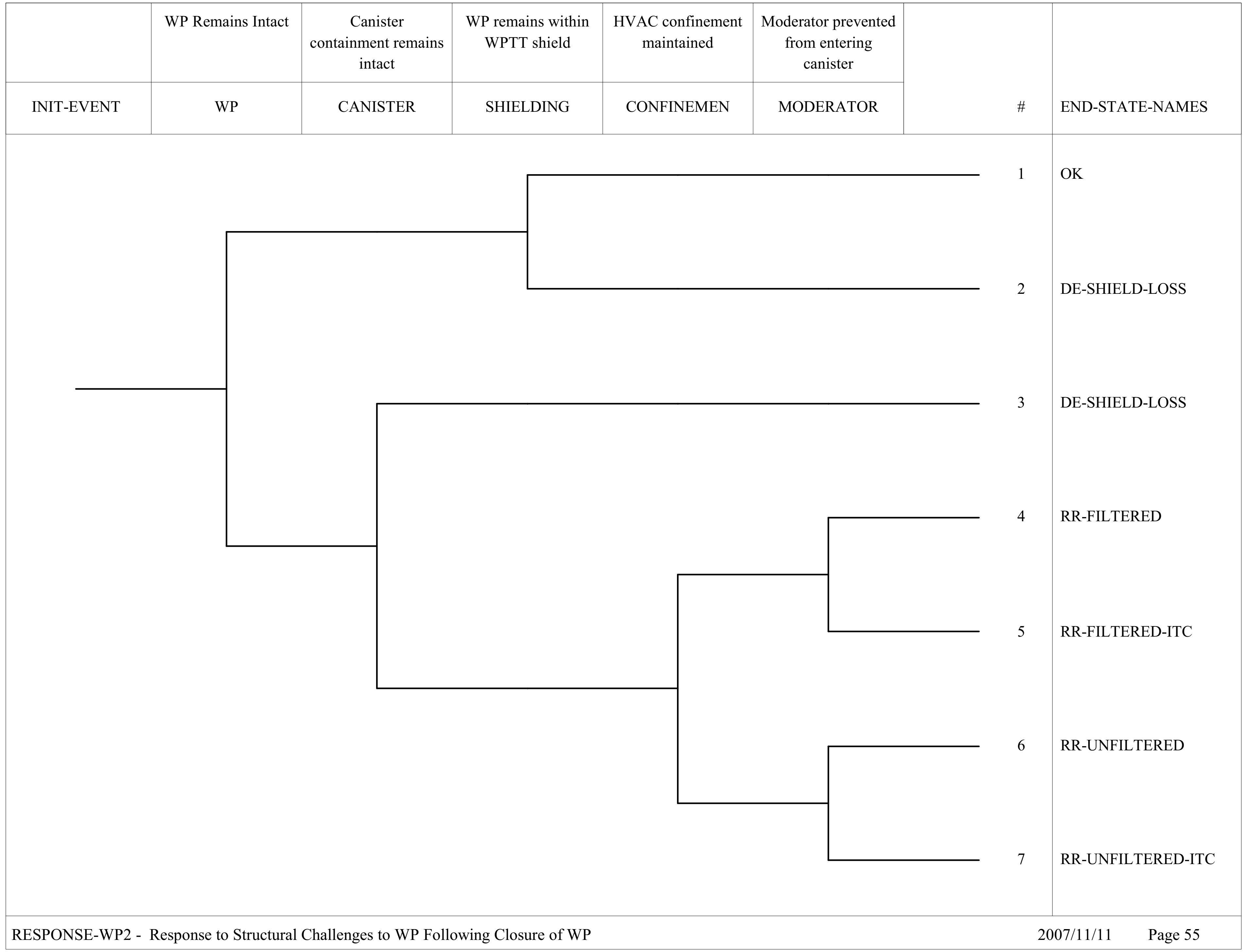
Source: Original

Figure G-54. Event Tree CRCF-ESD12-TAD – Assembly and Closure of Aging Overpack with TAD Canister



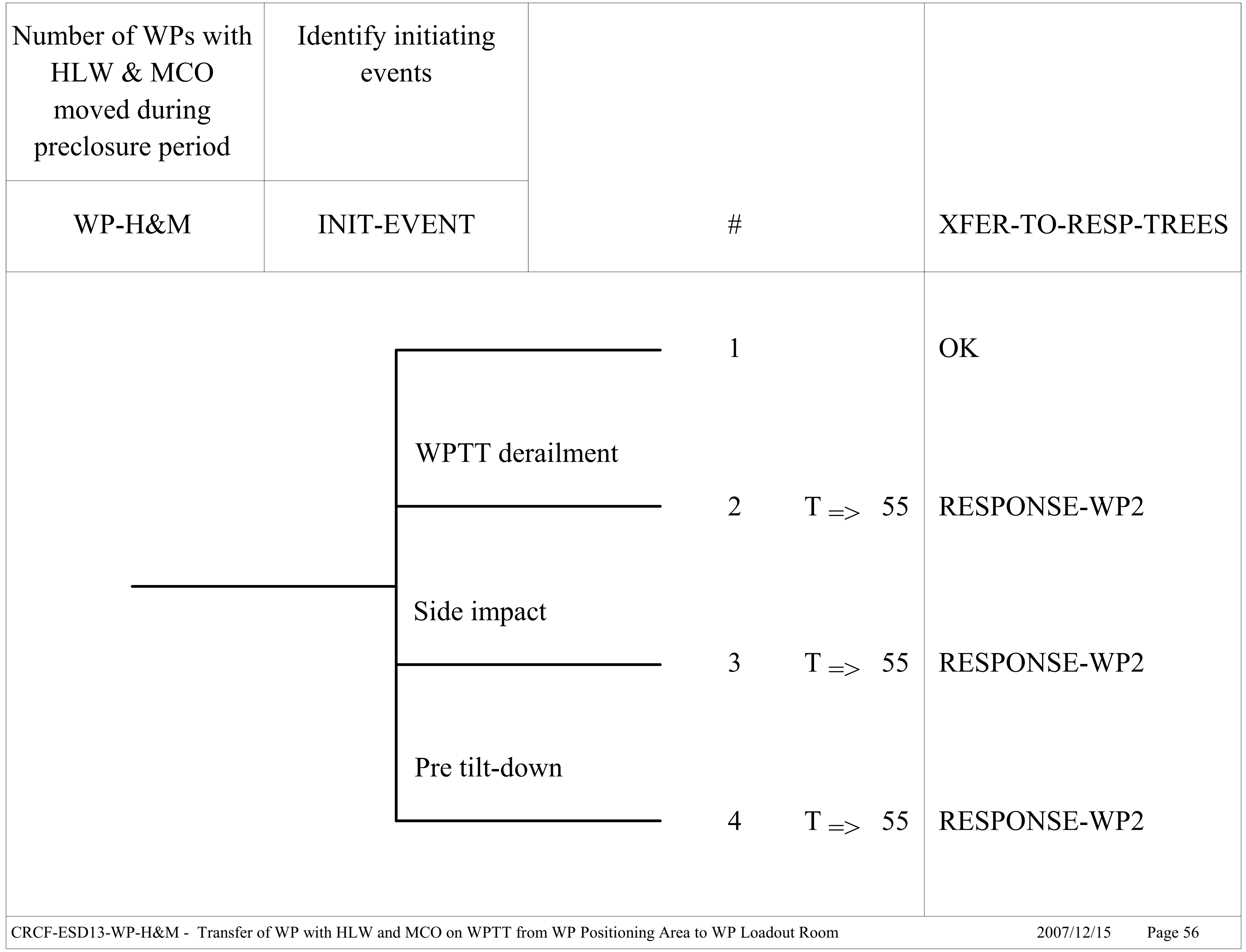
Source: Original

Figure G-55. Event Tree CRCF-ESD13-WP-H&D – Transfer of Waste Package with HLW and either a DOE Std. Canister or MCO on WPTT from Waste Package Positioning Room to Waste Package Loadout Room



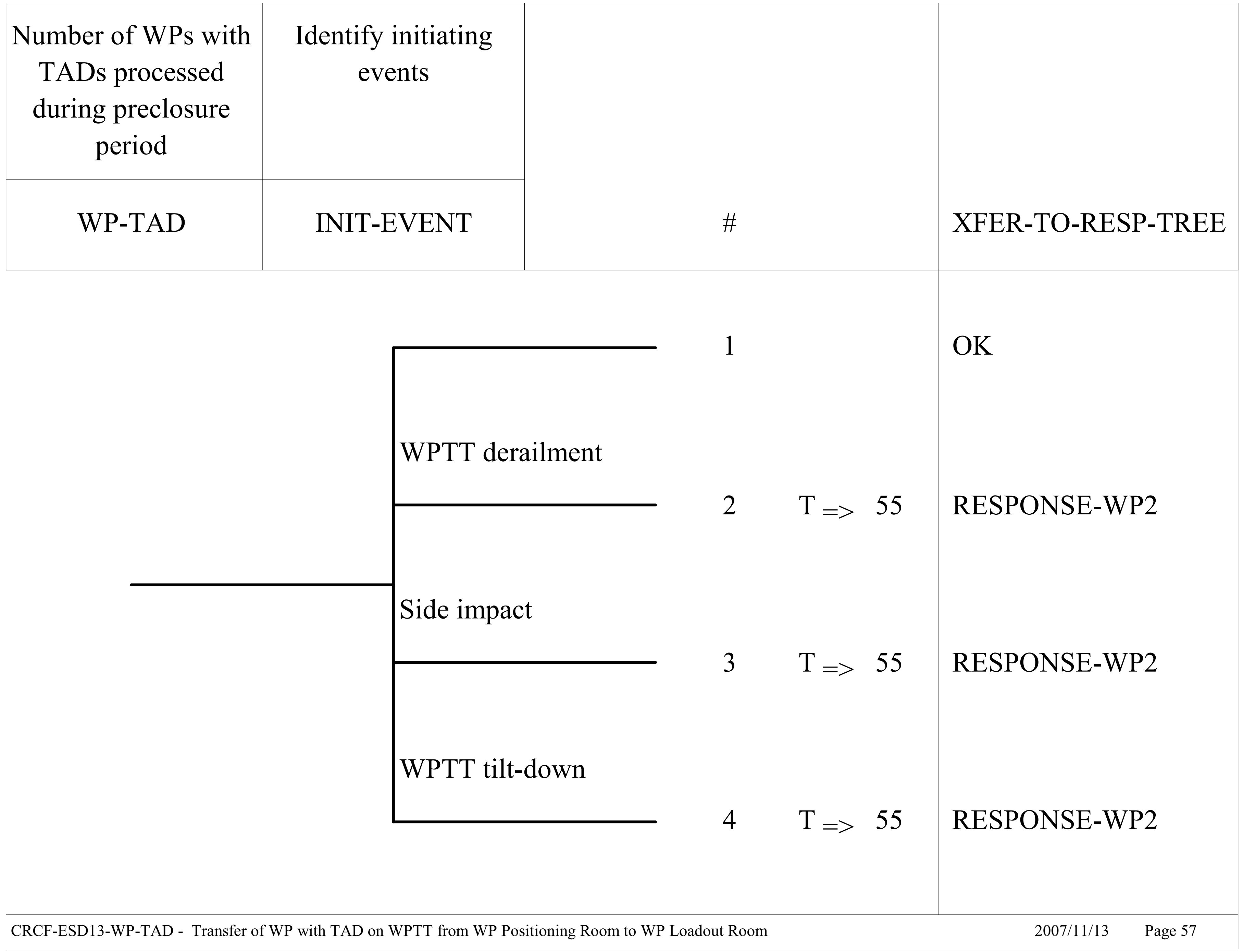
Source: Original

Figure G-56. Event Tree RESPONSE-WP2 – Response to Structural Challenge to Waste Package Following Closure of Waste Package



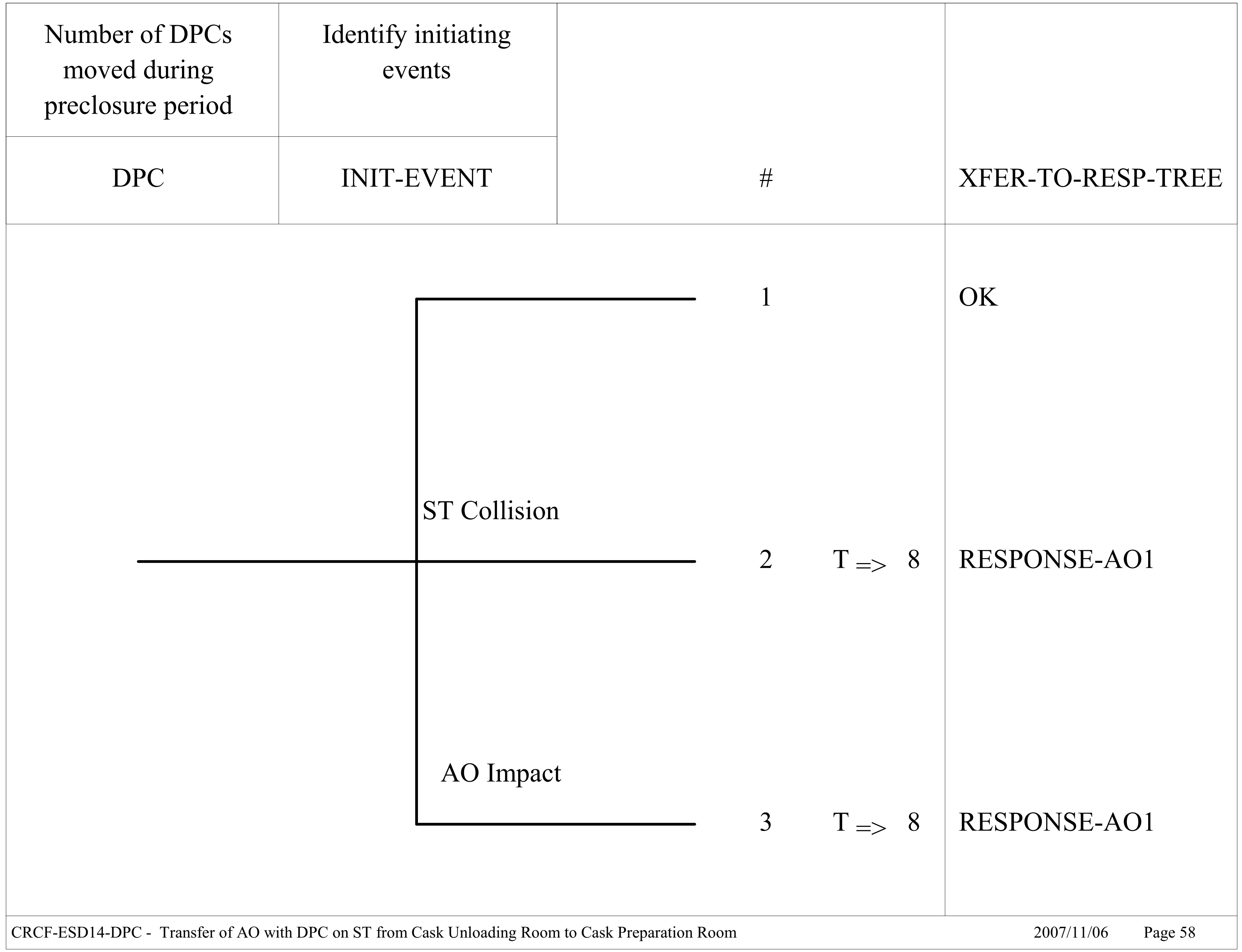
Source: Original

Figure G-57. Event Tree CRCF-ESD13-WP-H&M – Transfer of Waste Package with HLW and MCO on WPTT from Waste Package Positioning Area to Waste Package Loadout Room



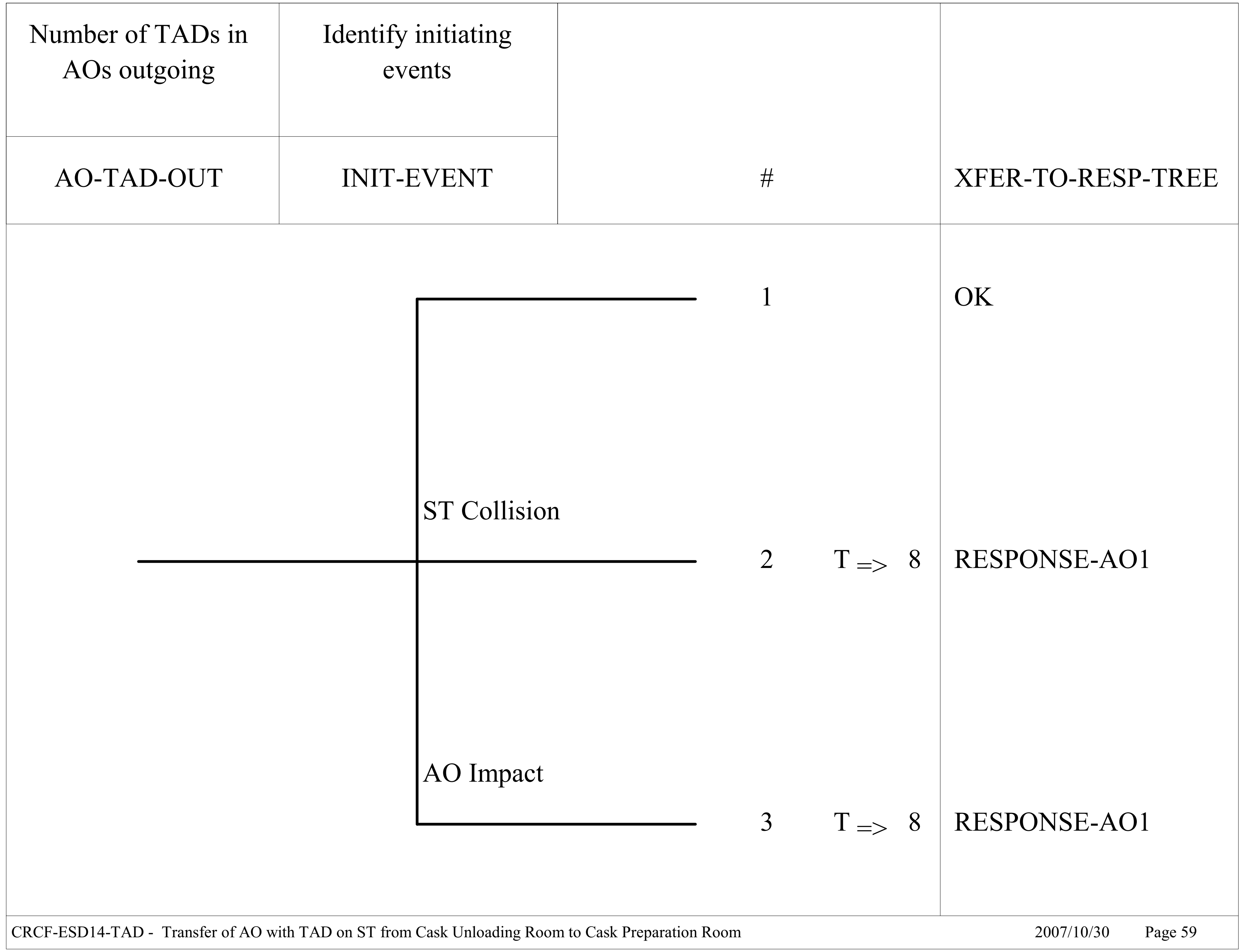
Source: Original

Figure G-58. Event Tree CRCF-ESD13-WP-TAD – Transfer of Waste Package with TAD Canister on WPTT from Waste Package Positioning Room to Waste Package Loadout Room



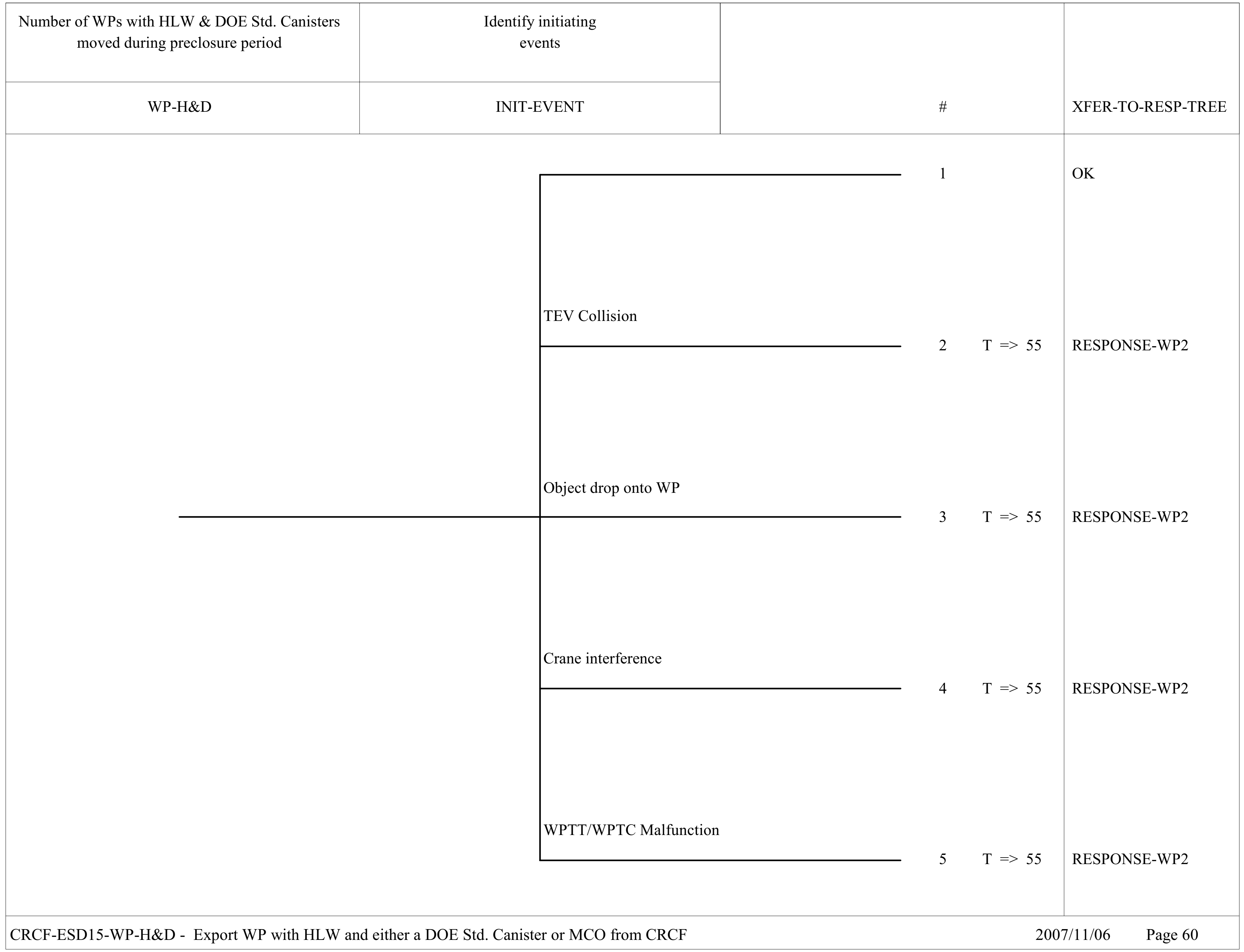
Source: Original

Figure G-59. Event Tree CRCF-ESD14-DPC – Transfer of Aging Overpack with DPC on Site Transporter from Cask Unloading Room to Cask Preparation Room



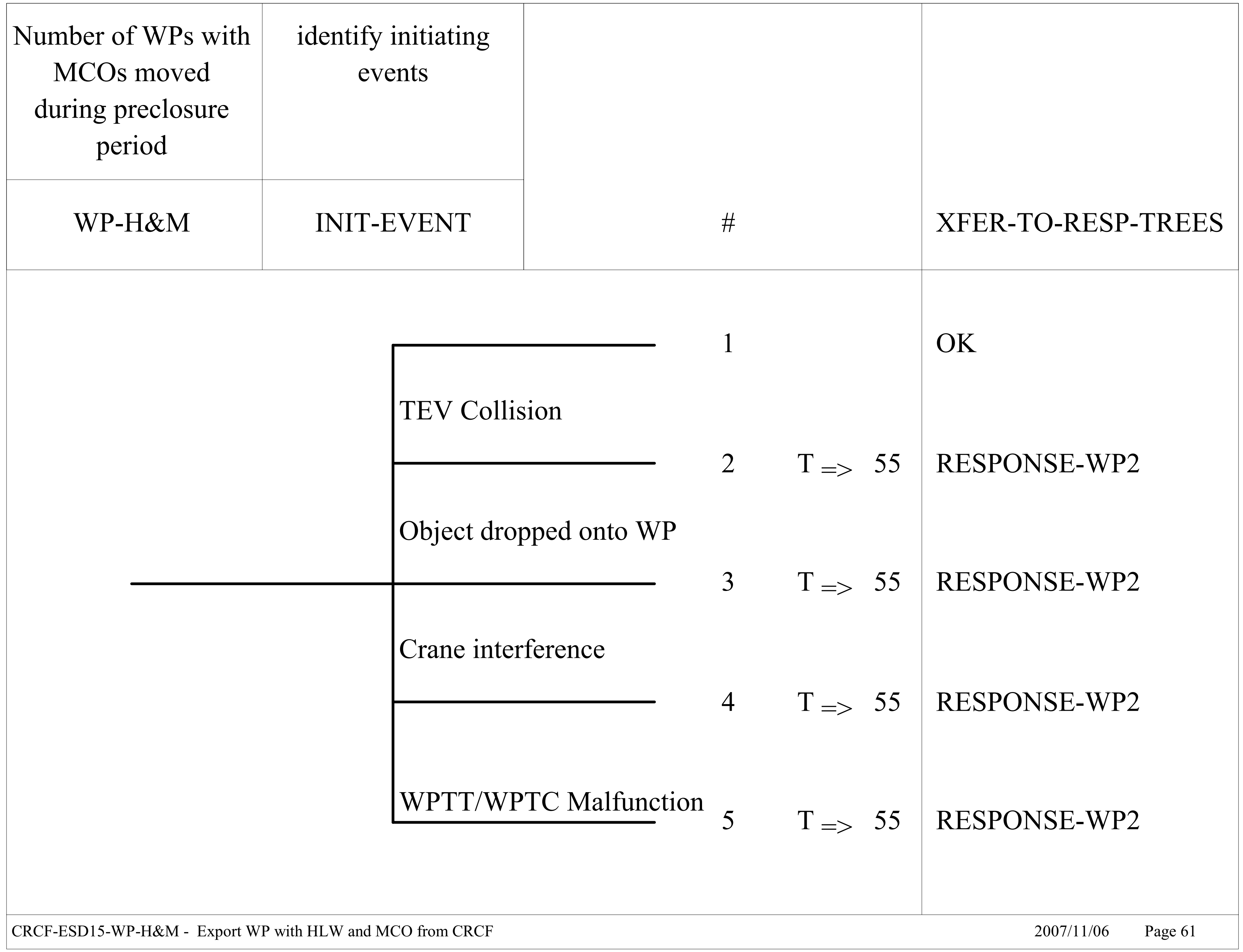
Source: Original

Figure G-60. Event Tree CRCF-ESD14-TAD – Transfer of Aging Overpack with TAD Canister on Site Transporter from Cask Unloading Room to Cask Preparation Room



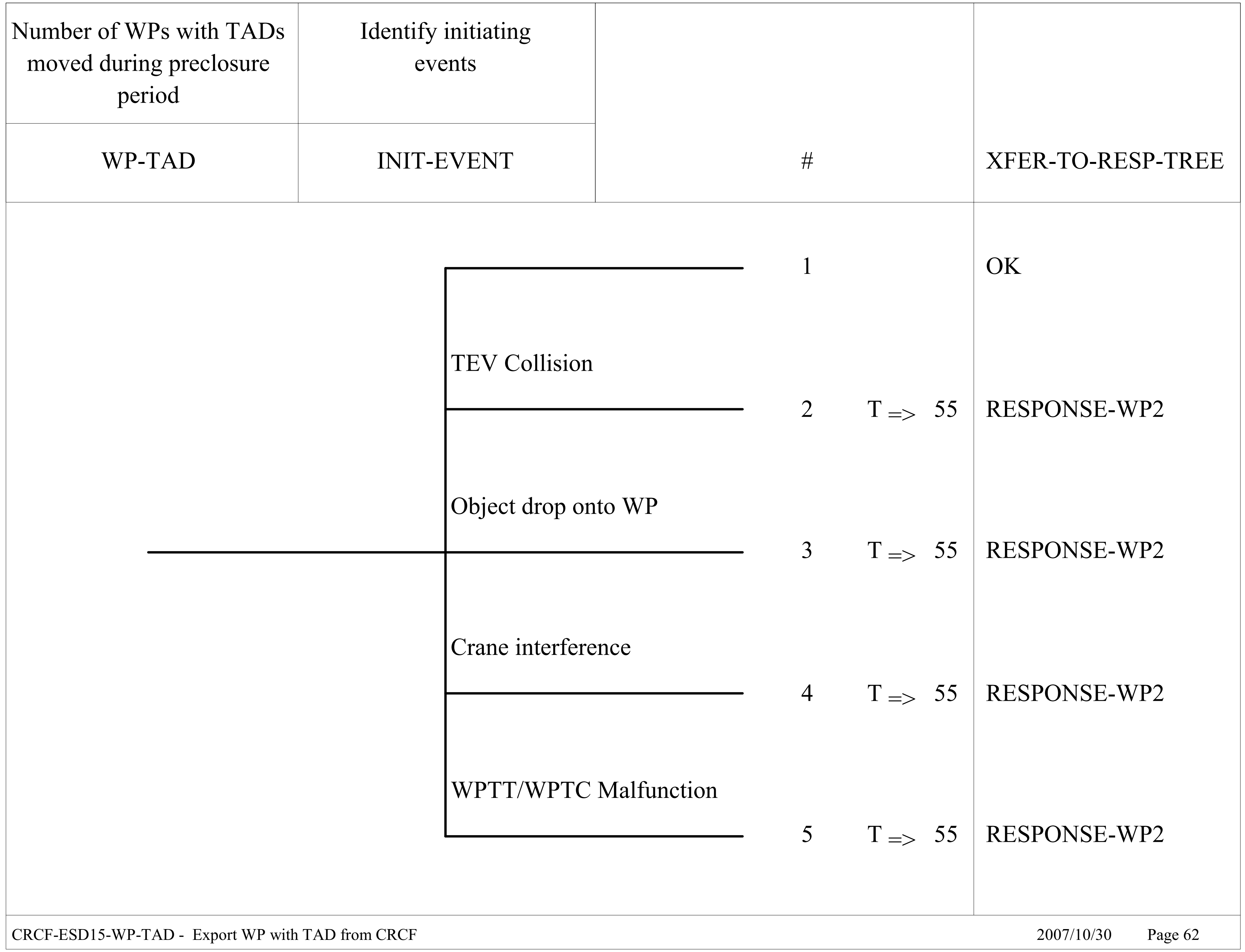
Source: Original

Figure G-61. Event Tree CRCF-ESD15-WP-H&D – Export Waste Package with HLW and either a DOE Std. Canister or MCO from CRCF



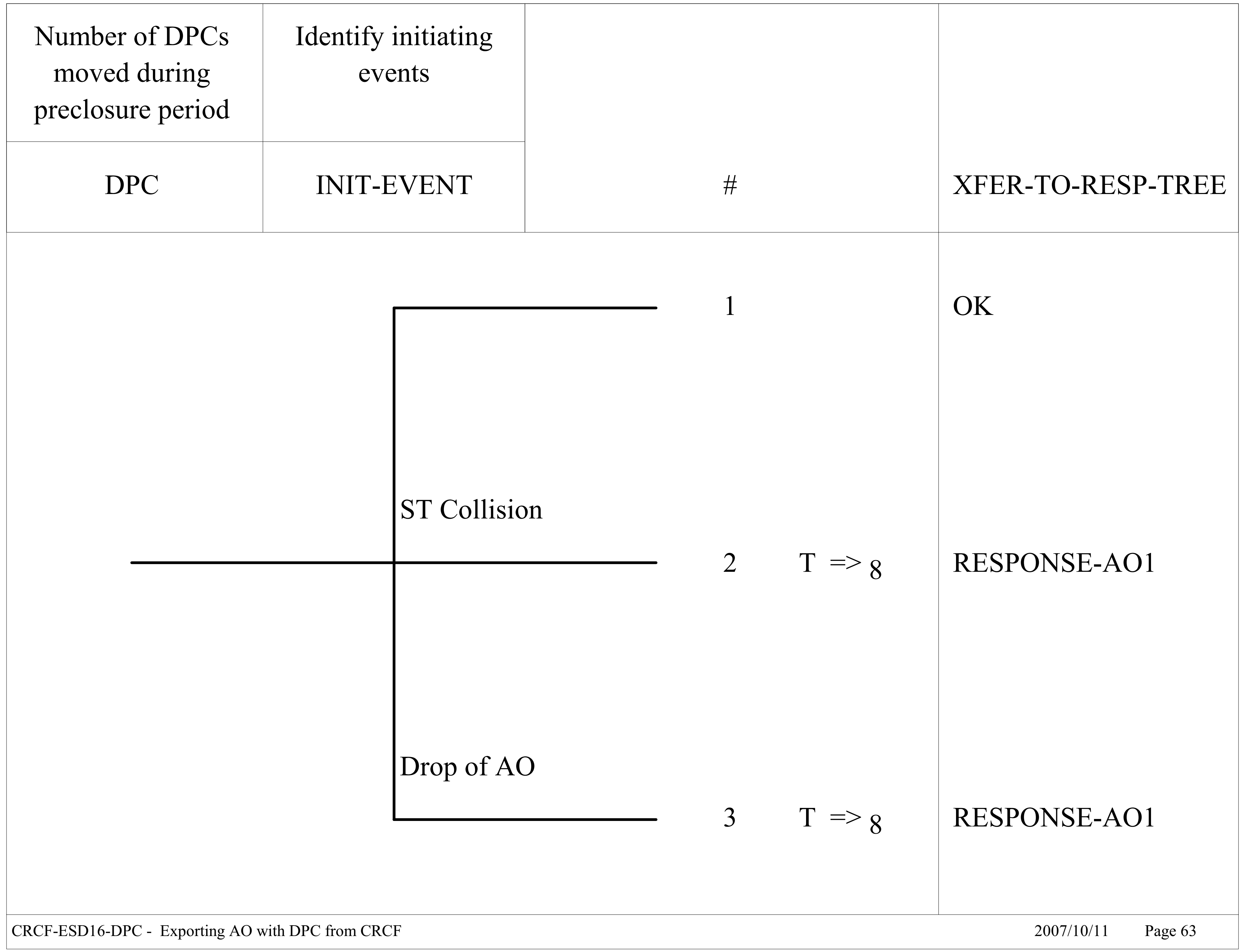
Source: Original

Figure G-62. Event Tree CRCF-ESD15-WP-H&M – Export Waste Package with HLW and MCO from CRCF



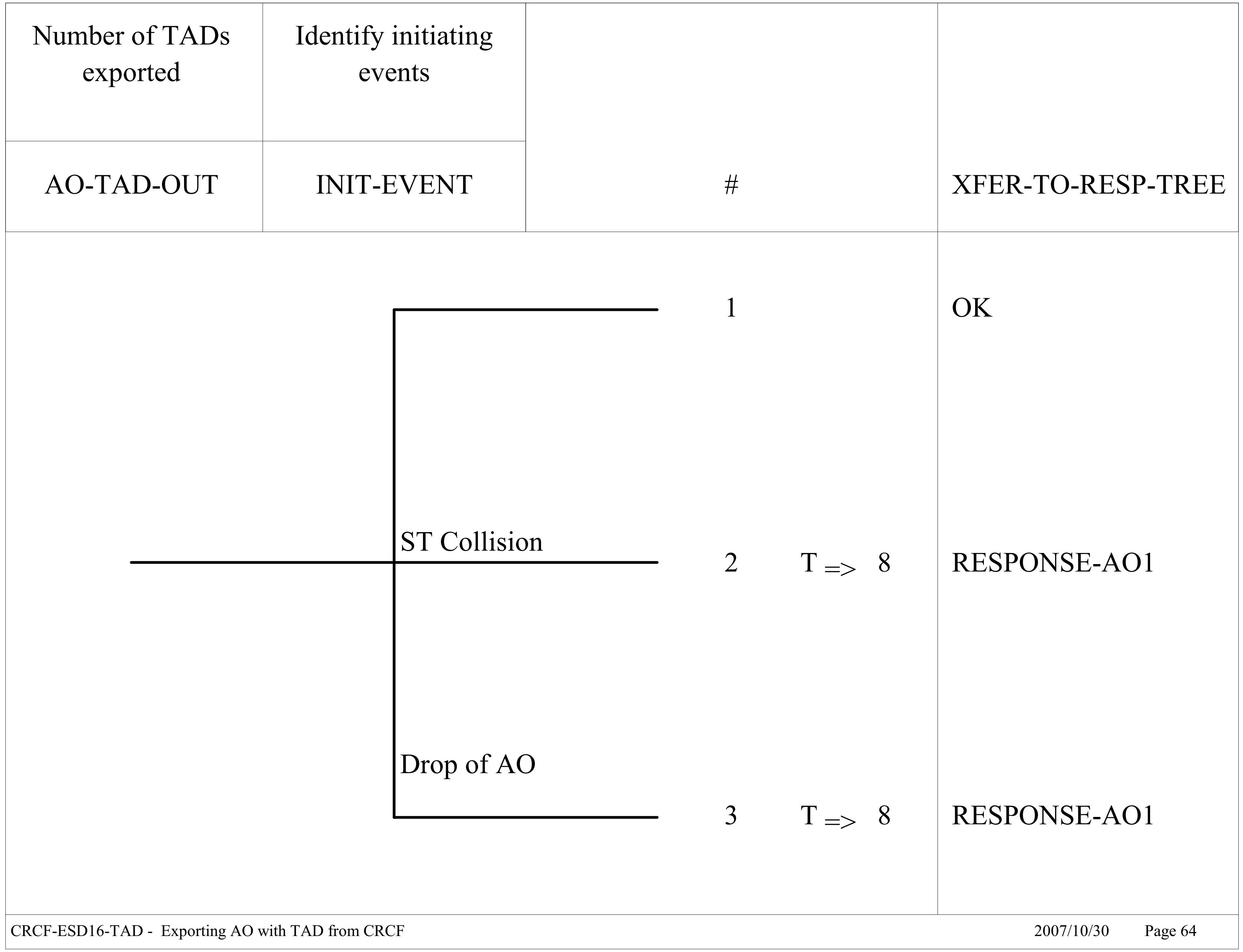
Source: Original

Figure G-63. Event Tree CRCF-ESD15-WP-TAD – Export Waste Package with TAD Canister from CRCF



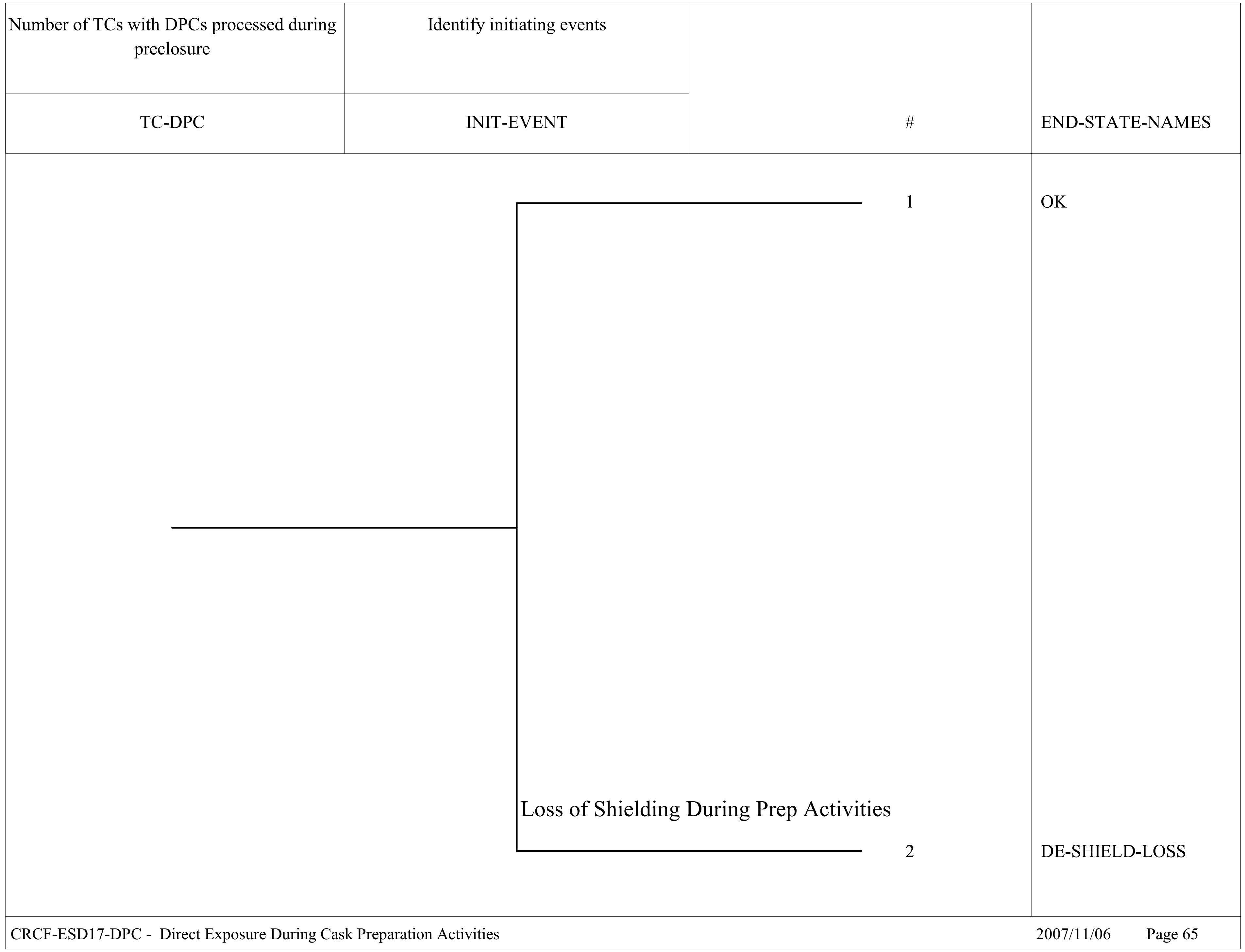
Source: Original

Figure G-64. Event Tree CRCF-ESD16-DPC – Exporting Aging Overpack with DPC from CRCF



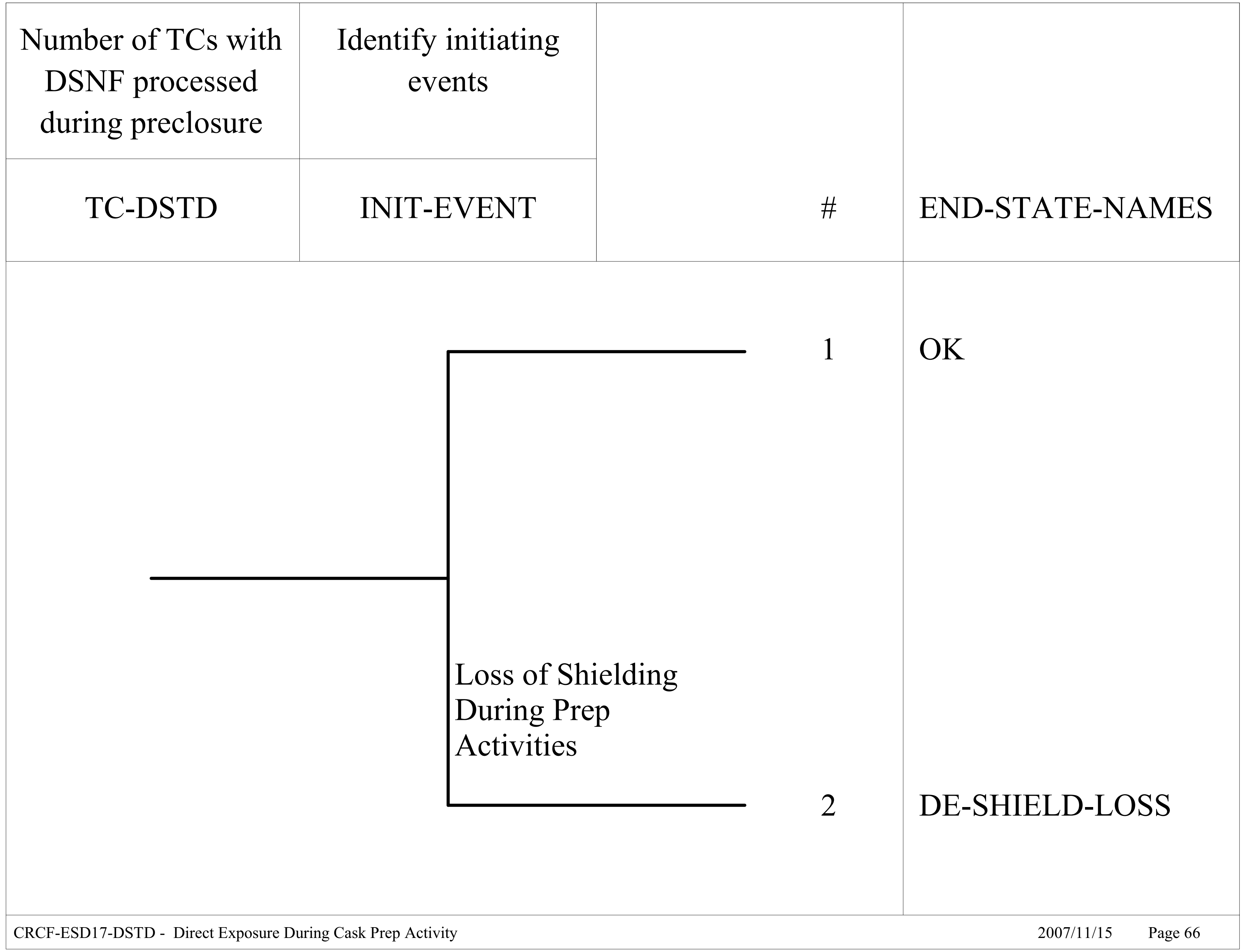
Source: Original

Figure G-65. Event Tree CRCF-ESD16-TAD – Exporting Aging Overpack with TAD Canister from CRCF



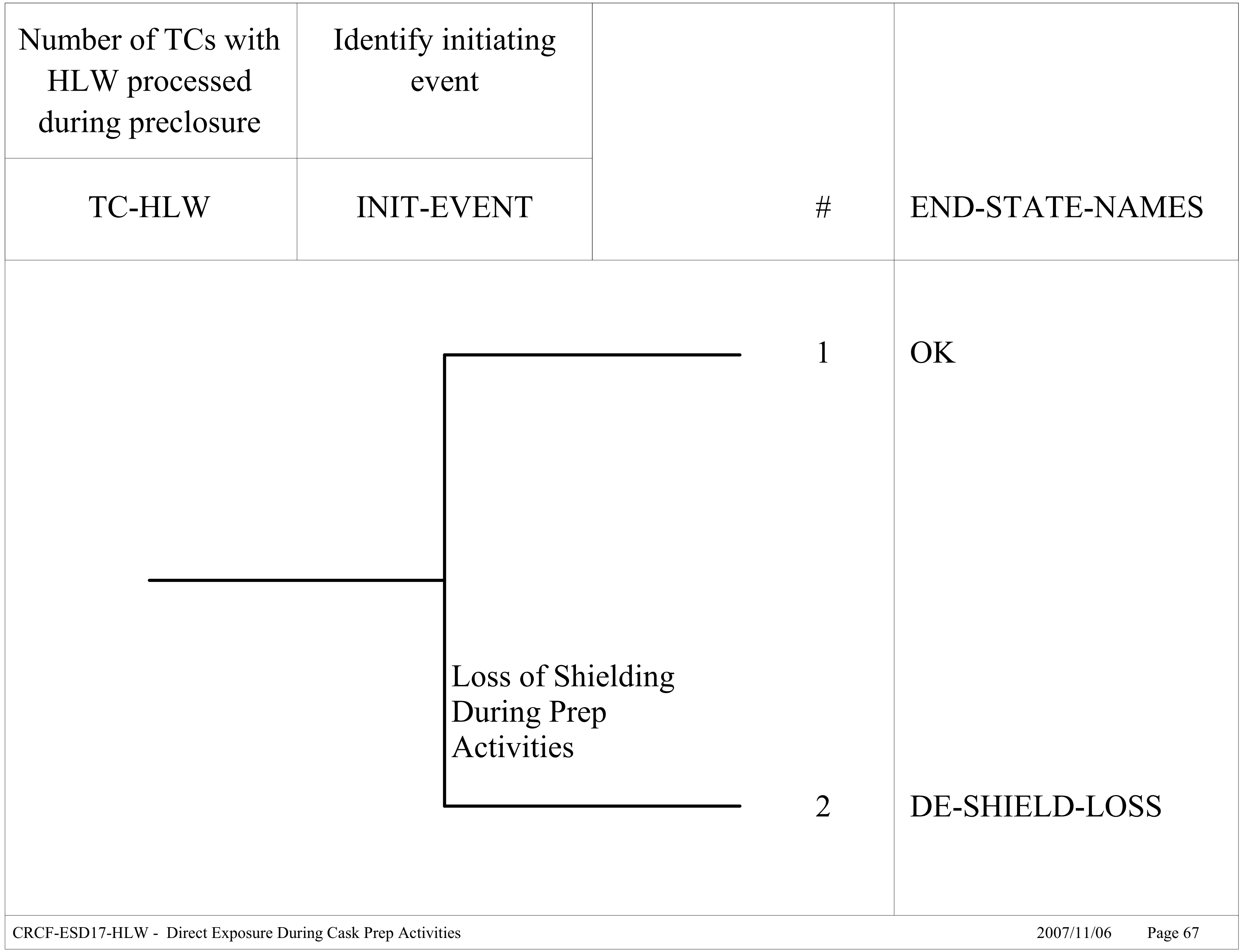
Source: Original

Figure G-66. Event Tree CRCF-ESD17-DPC – Direct Exposure During Cask Preparation Activities



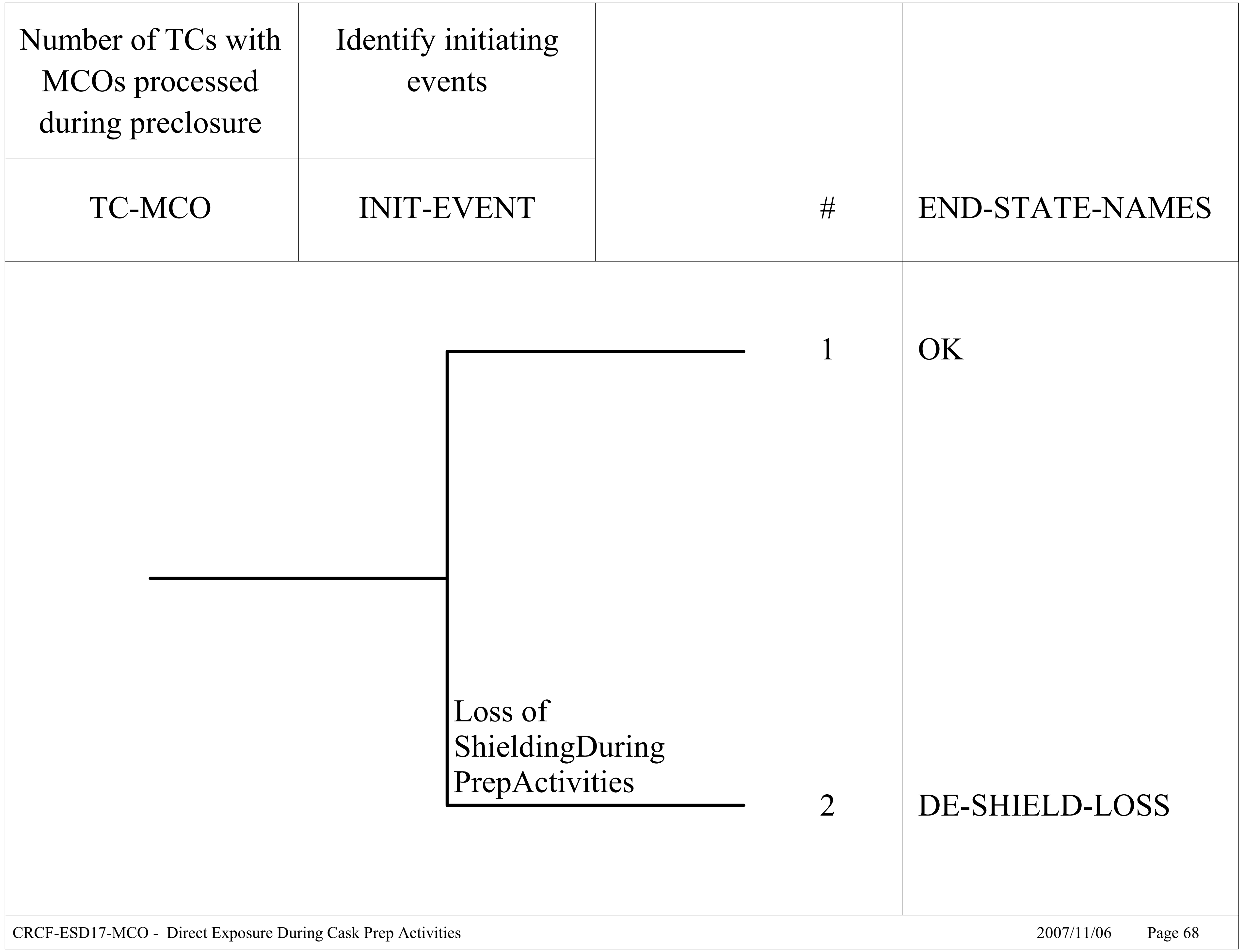
Source: Original

Figure G-67. Event Tree CRCF-ESD17-DSTD – Direct Exposure During Cask Preparation Activities



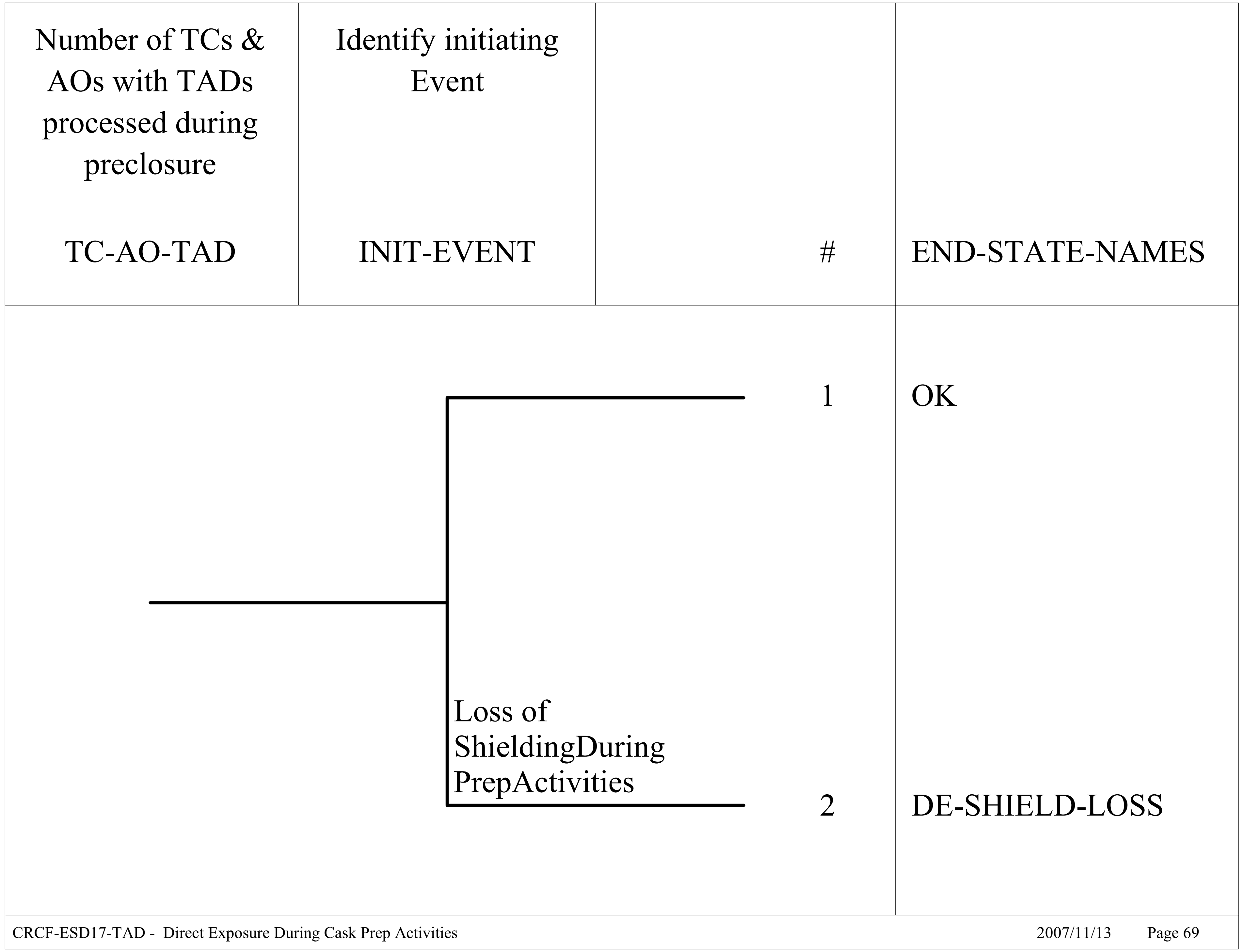
Source: Original

Figure G-68. Event Tree CRCF-ESD17-HLW – Direct Exposure During Cask Preparation Activities



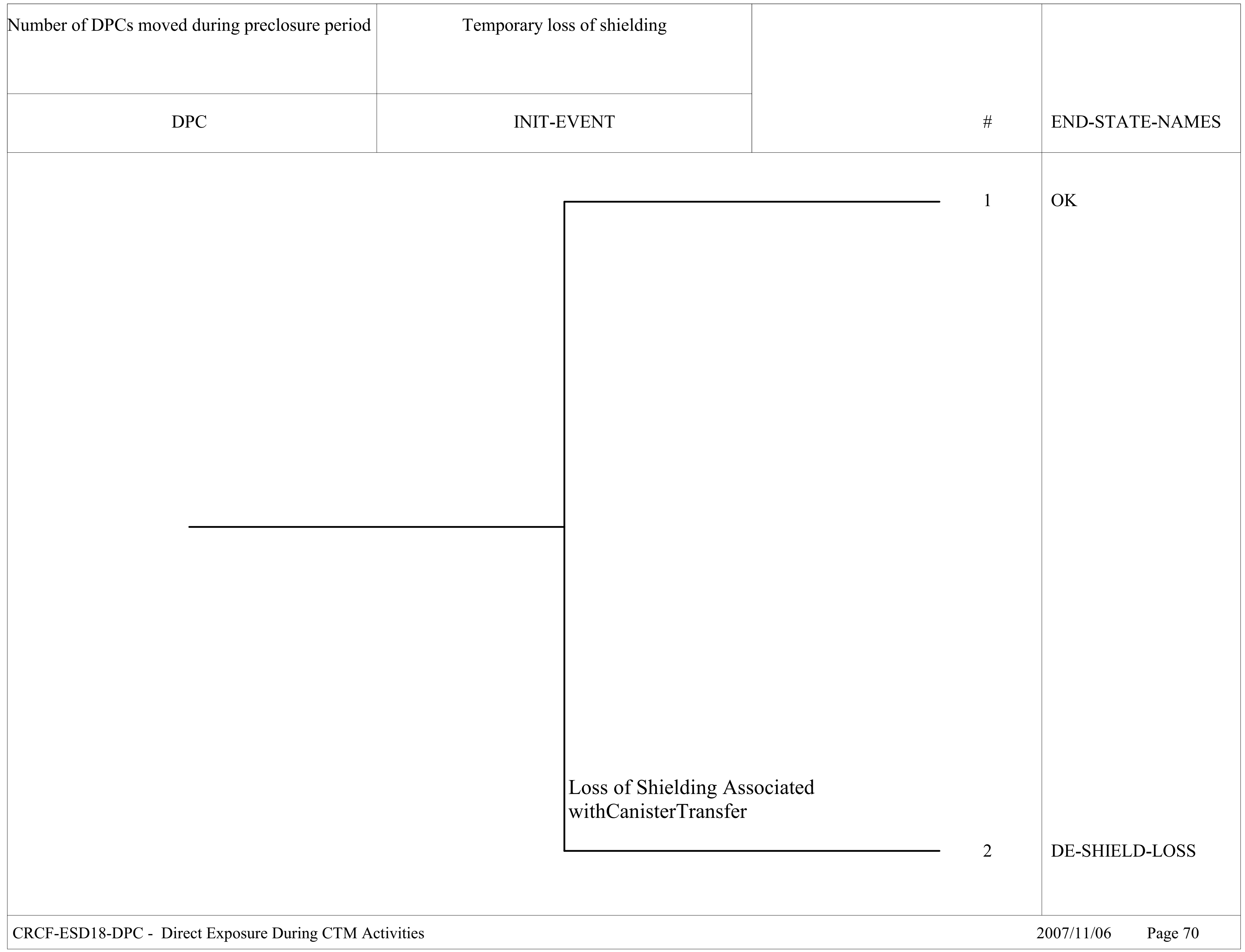
Source: Original

Figure G-69. Event Tree CRCF-ESD17-MCO – Direct Exposure During Cask Preparation Activities



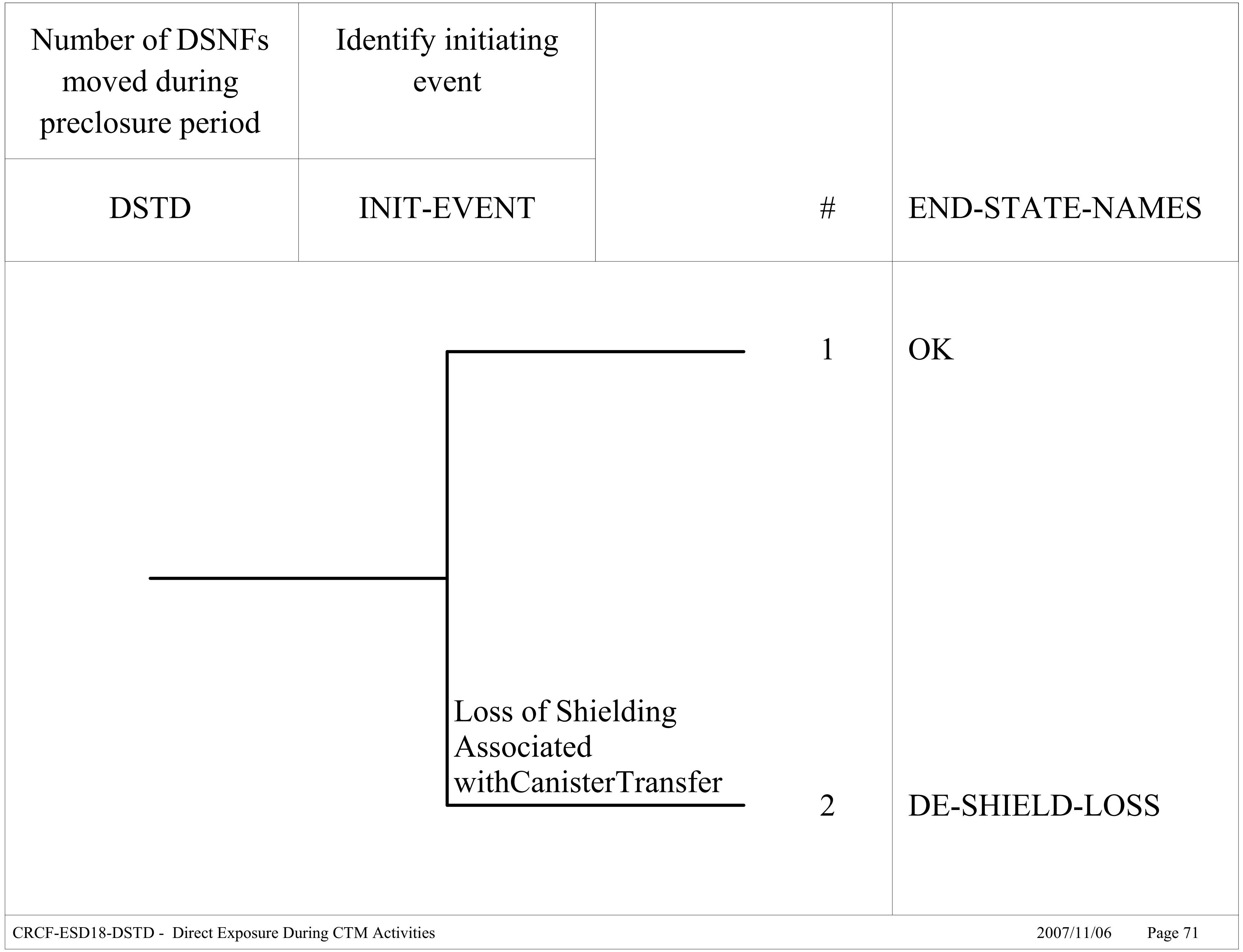
Source: Original

Figure G-70. Event Tree CRCF-ESD17-TAD – Direct Exposure During Cask Preparation Activities



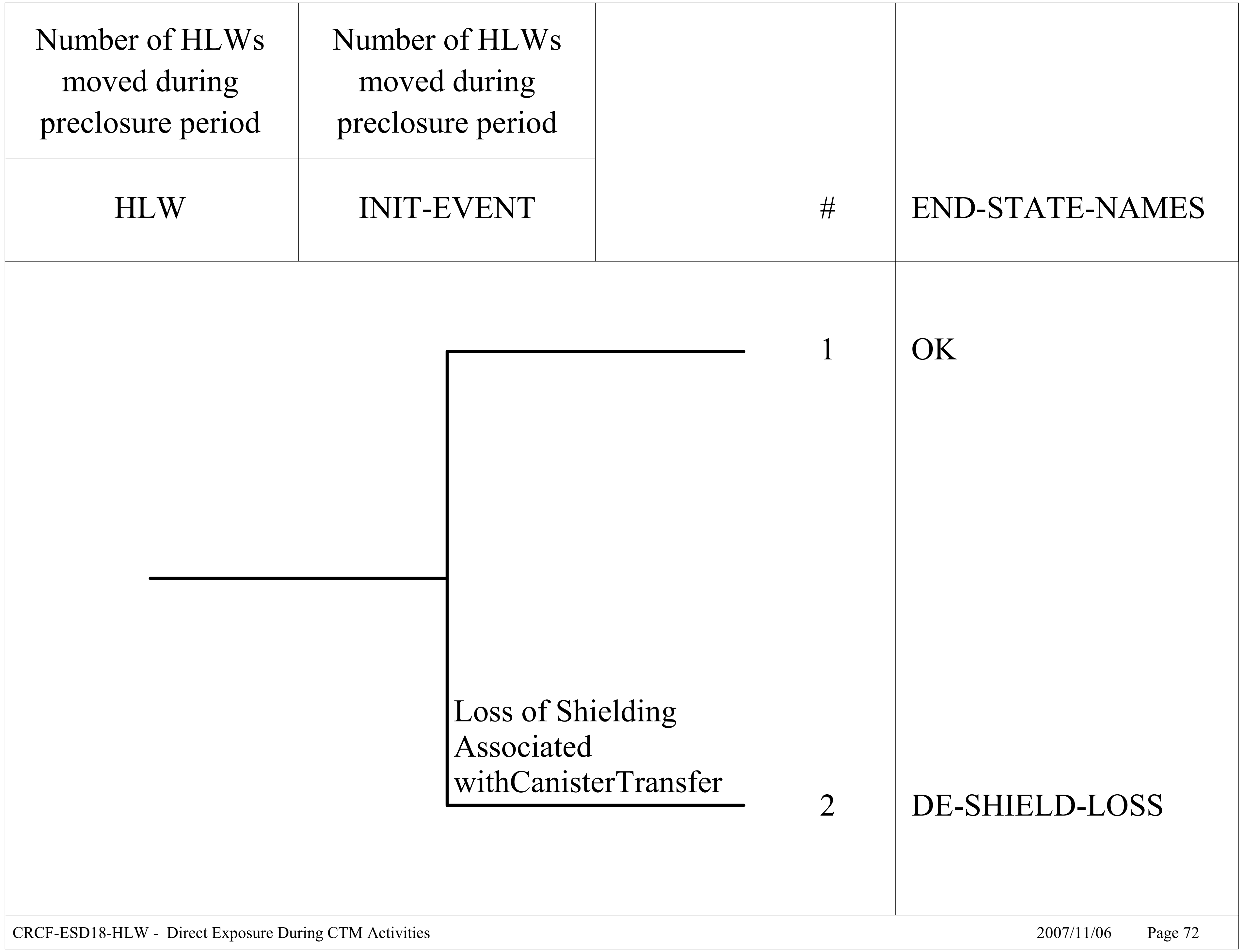
Source: Original

Figure G-71. Event Tree CRCF-ESD18-DPC – Direct Exposure During CTM Activities



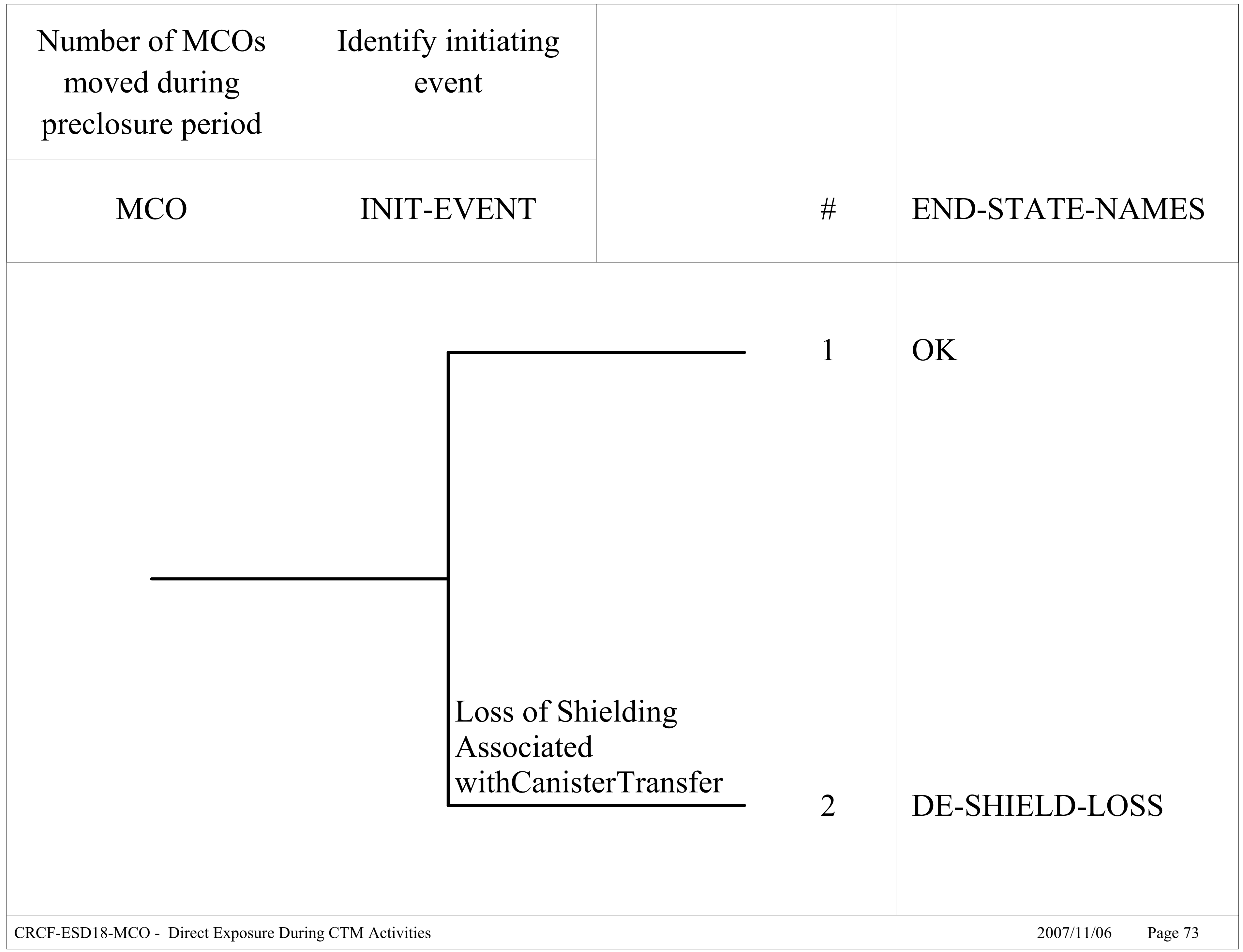
Source: Original

Figure G-72. Event Tree CRCF-ESD18-DSTD – Direct Exposure During CTM Activities



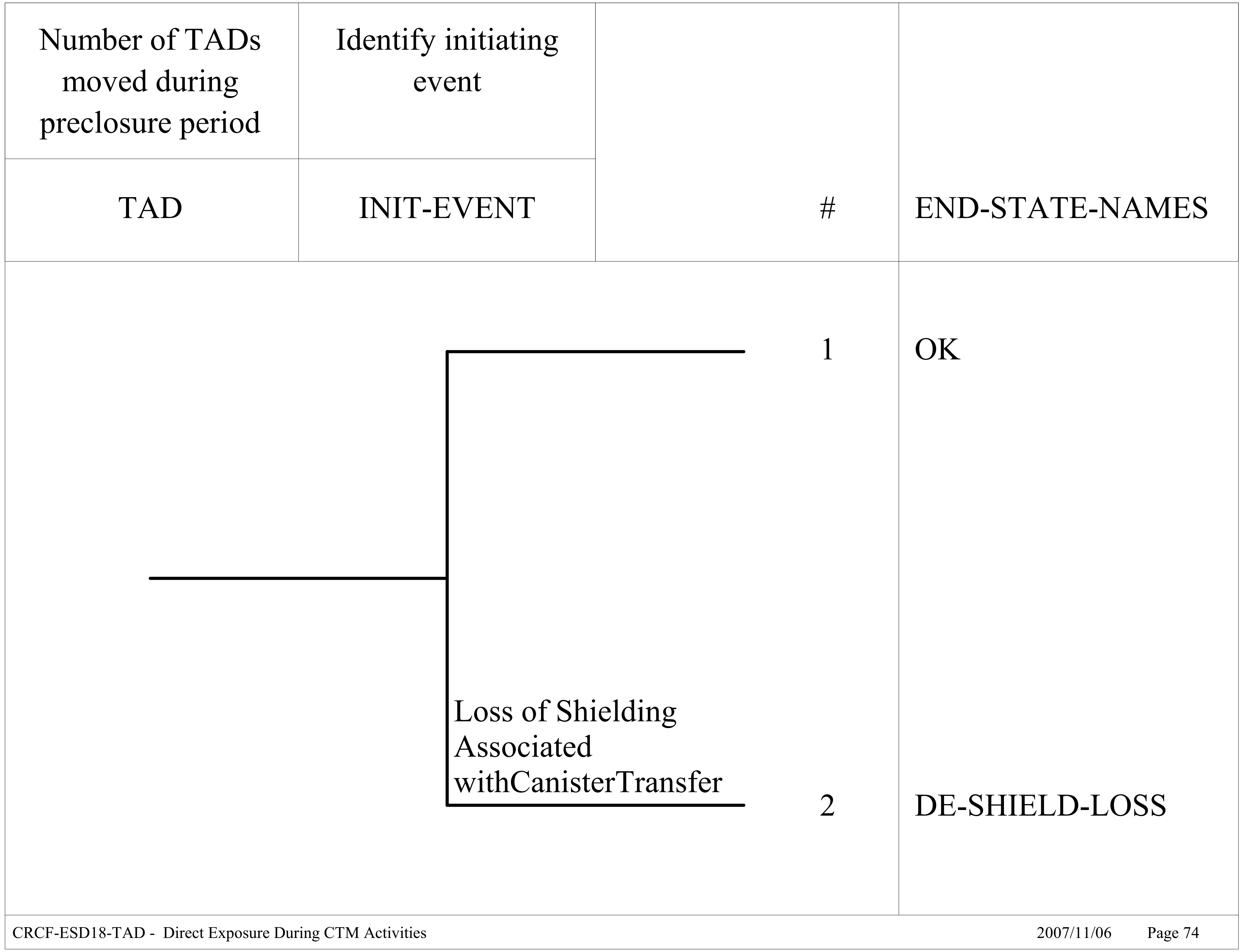
Source: Original

Figure G-73. Event Tree CRCF-ESD18-HLW – Direct Exposure During CTM Activities



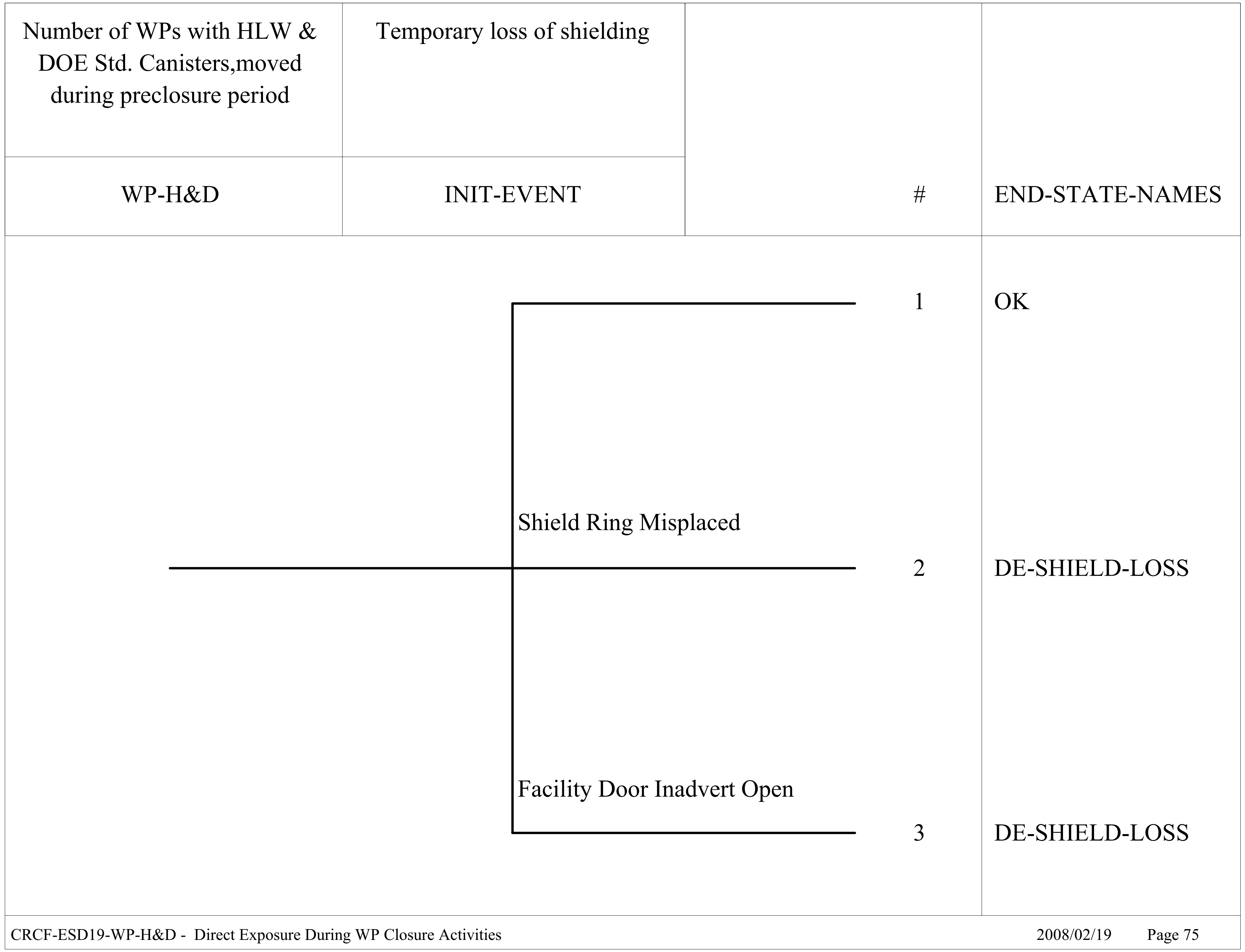
Source: Original

Figure G-74. Event Tree CRCF-ESD18-MCO – Direct Exposure During CTM Activities



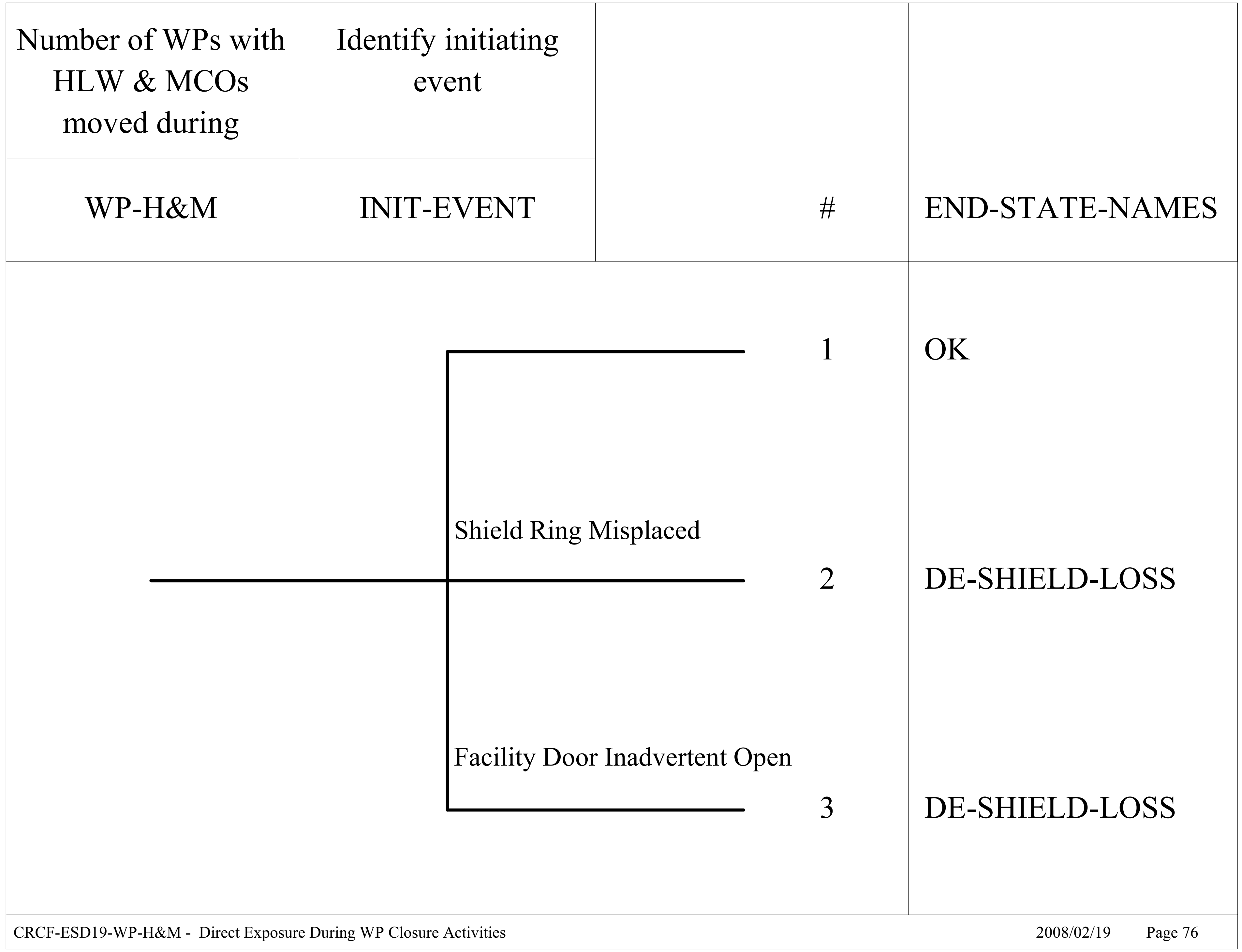
Source: Original

Figure G-75. Event Tree CRCF-ESD18-TAD – Direct Exposure During CTM Activities



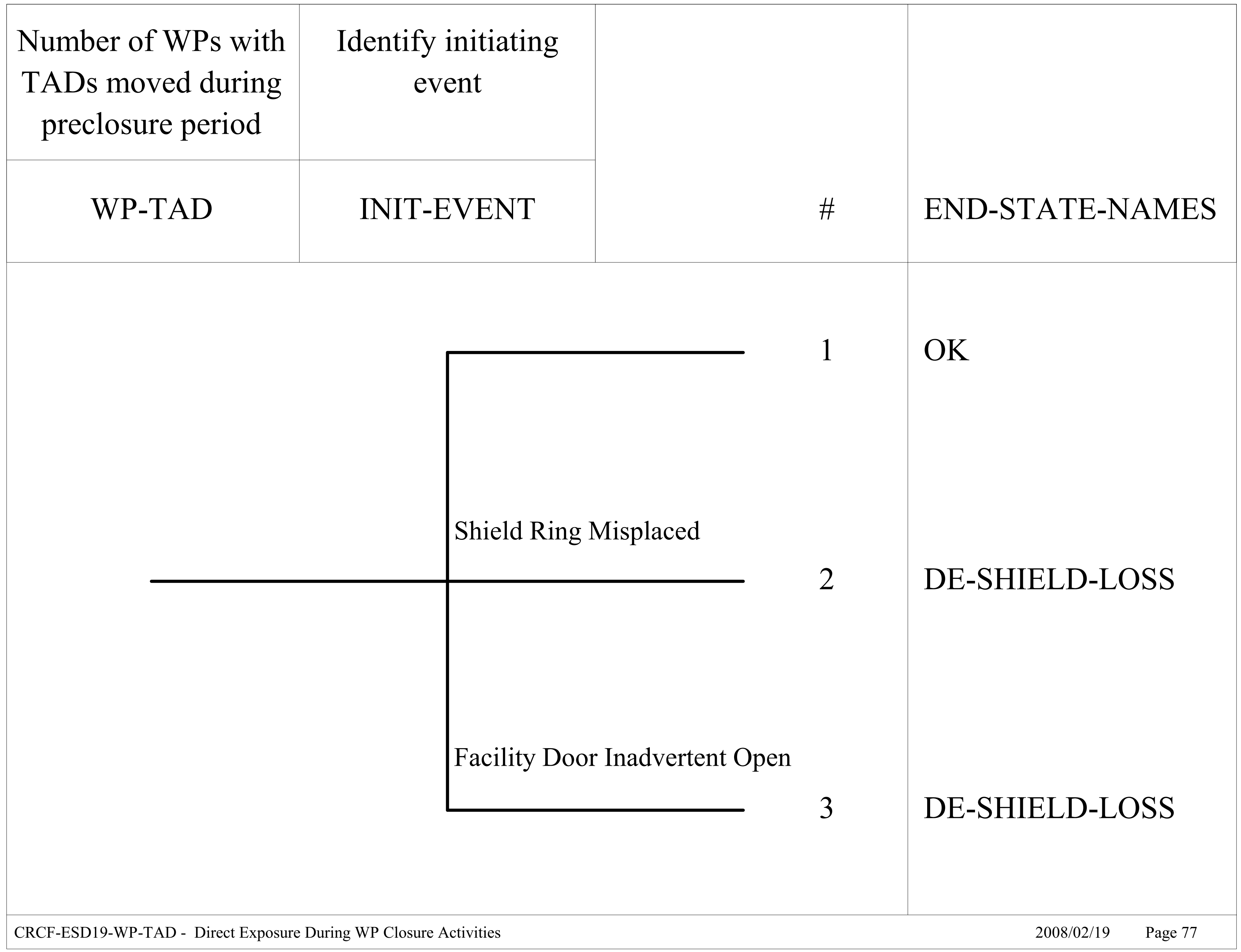
Source: Original

Figure G-76. Event Tree CRCF-ESD19-WP-H&D – Direct Exposure During Waste Package Closure Activities



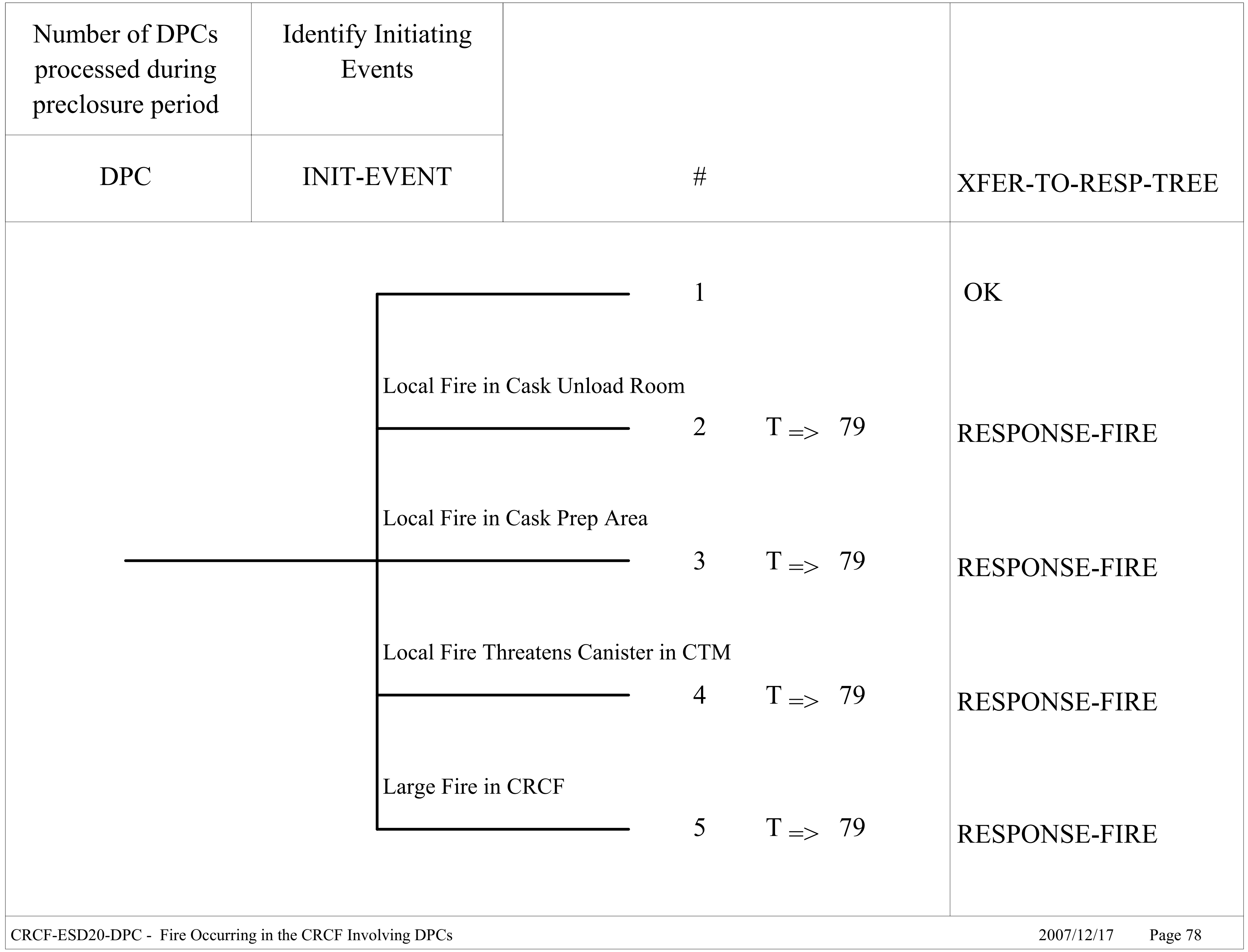
Source: Original

Figure G-77. Event Tree CRCF-ESD19-WP-H&M – Direct Exposure During Waste Package Closure Activities



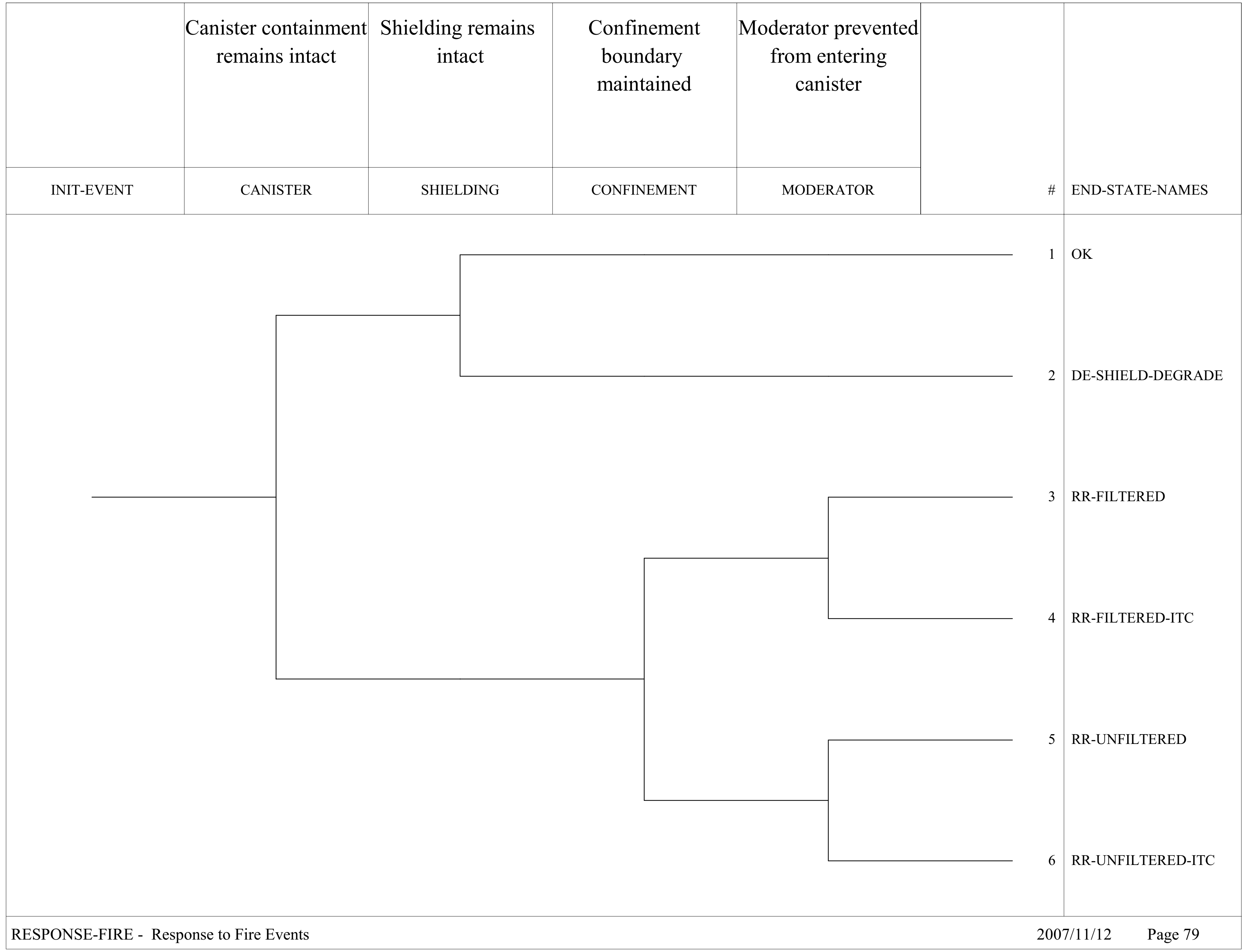
Source: Original

Figure G-78. Event Tree CRCF-ESD19 WP TAD – Direct Exposure During Waste Package Closure Activities



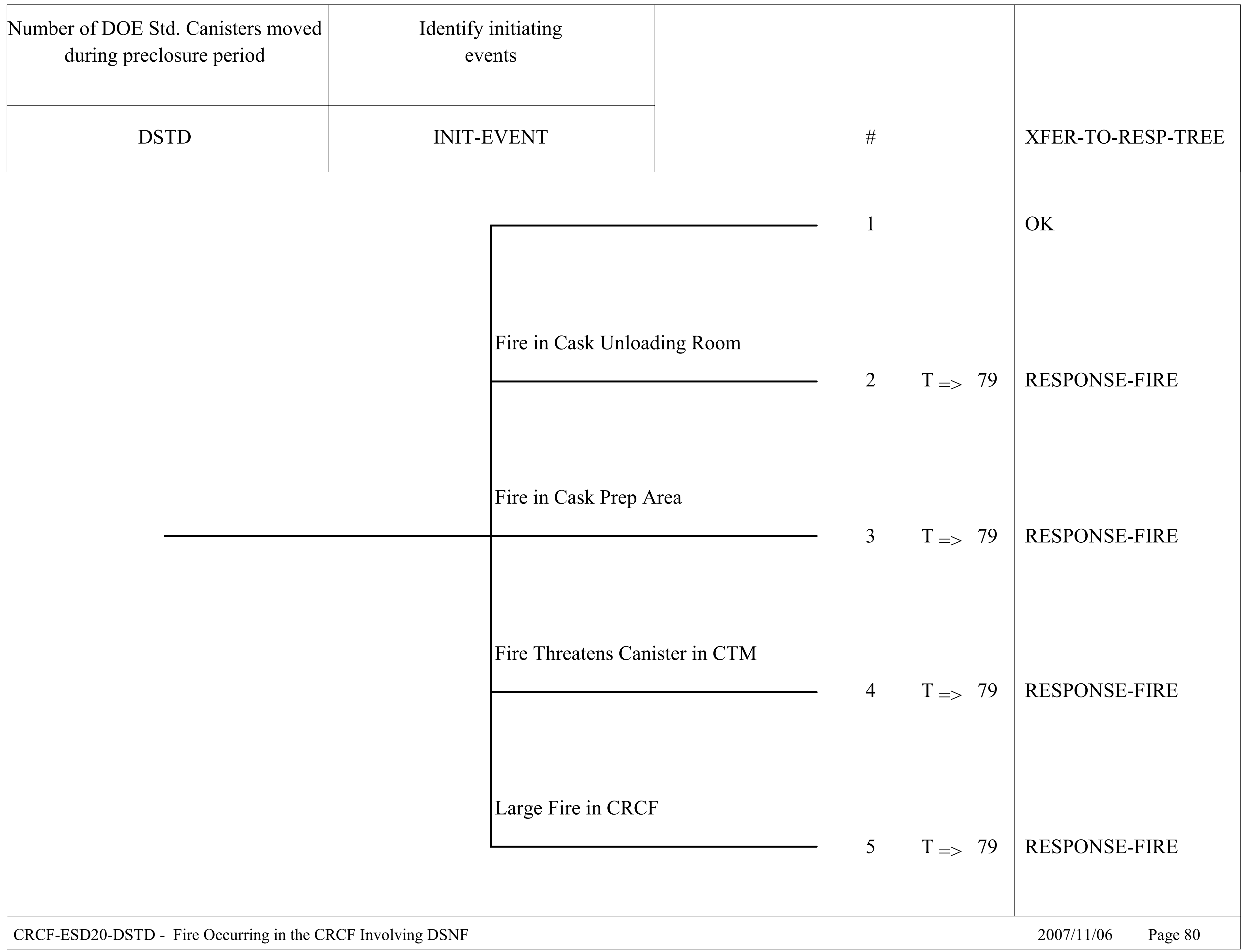
Source: Original

Figure G-79. Event Tree CRCF-ESD20-DPC – Fire Occurring in the CRCF Involving DPCs



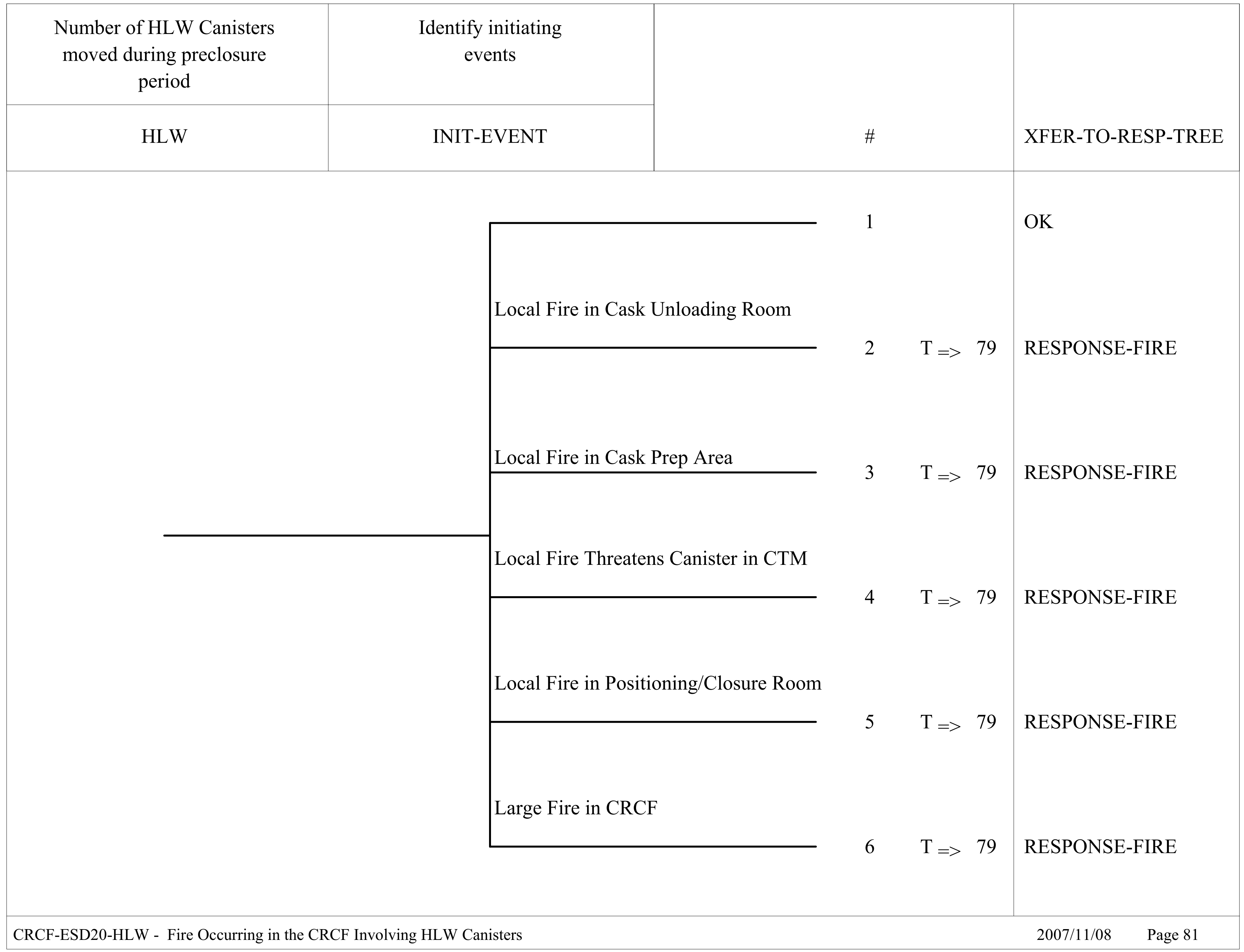
Source: Original

Figure G-80. Event Tree RESPONSE-FIRE – Response to Fire Events



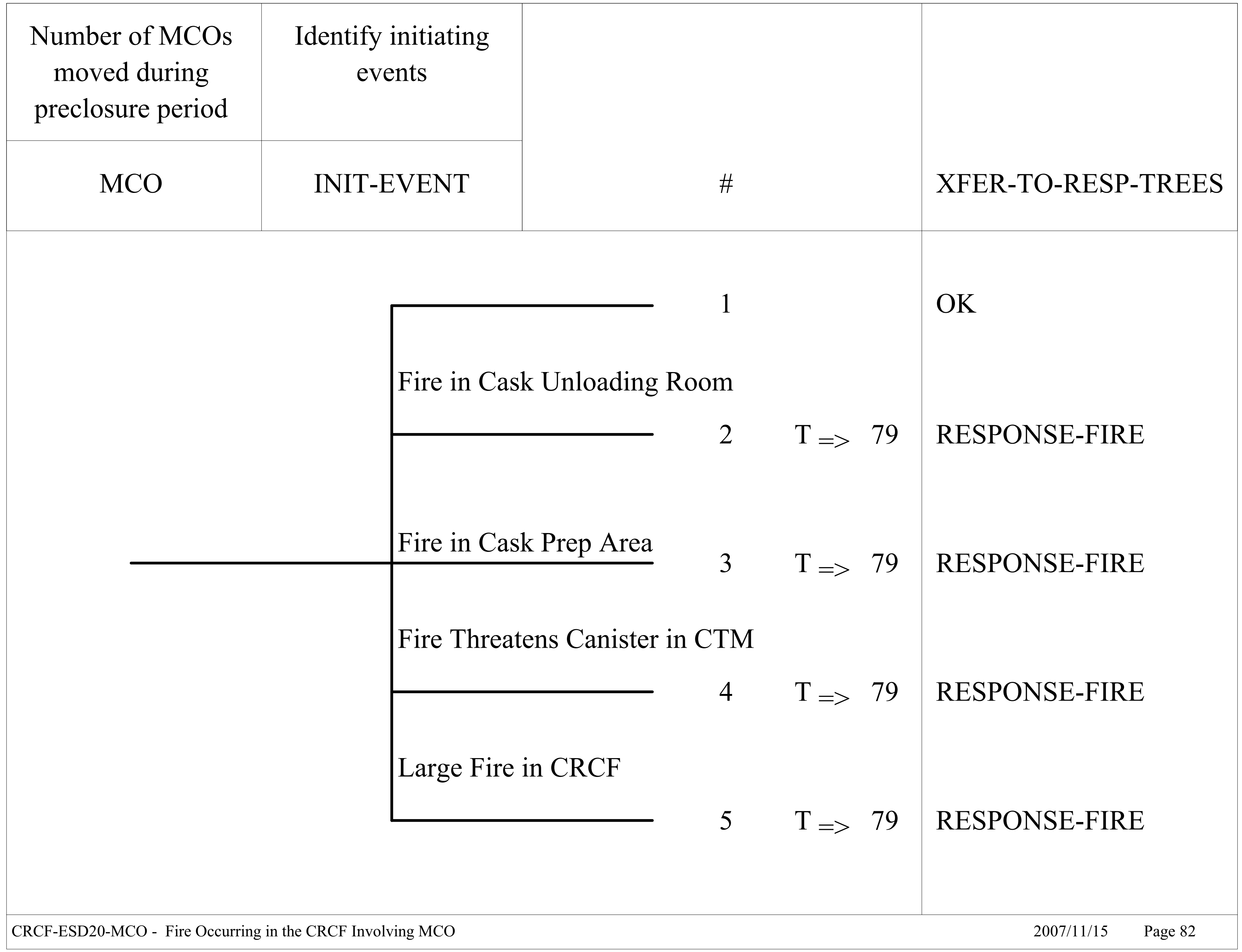
Source: Original

Figure G-81. Event Tree CRCF-ESD20-DSTD – Fire Occurring in the CRCF Involving DSTD



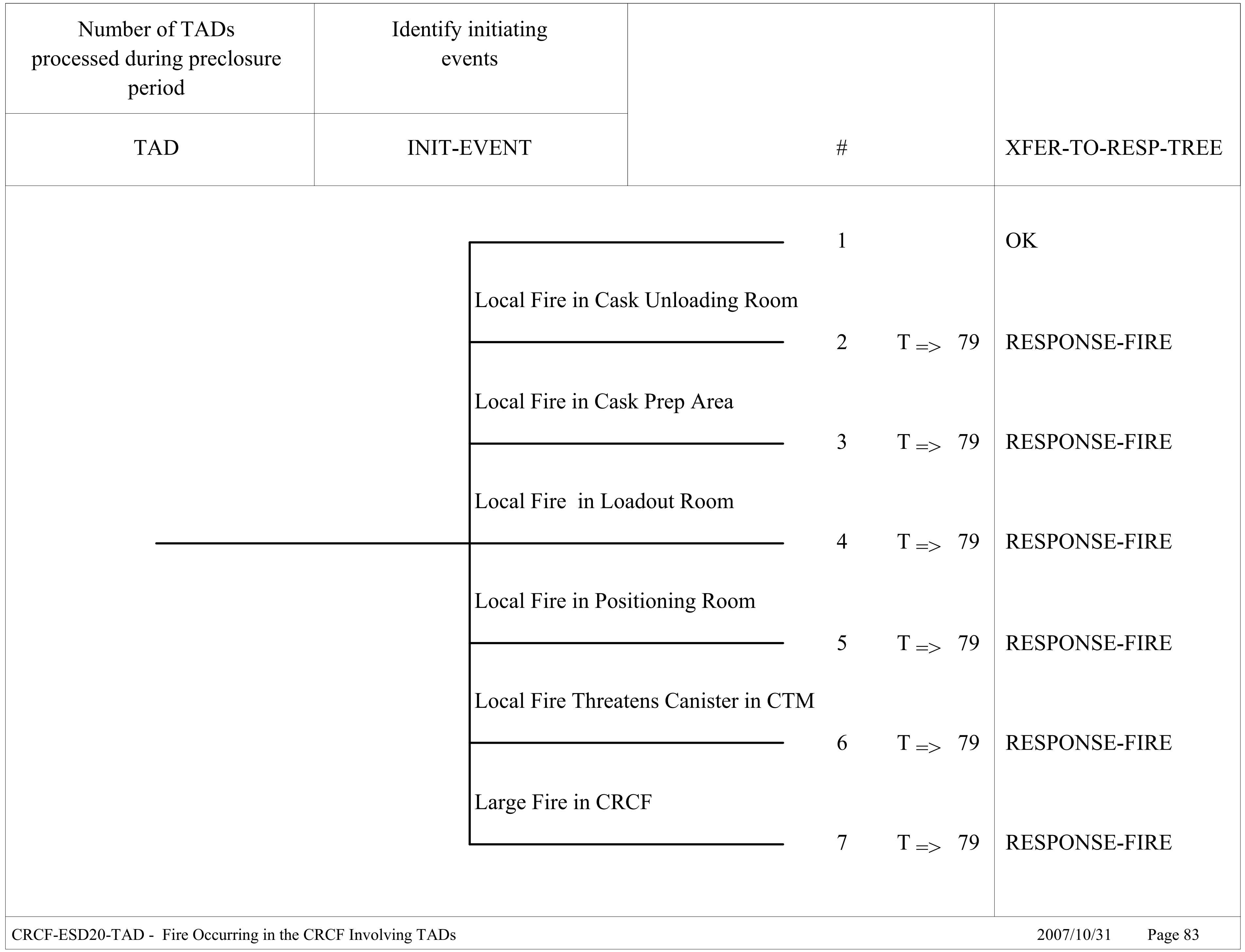
Source: Original

Figure G-82. Event Tree CRCF-ESD20-HLW – Fire Occurring in the CRCF Involving HLW Canisters



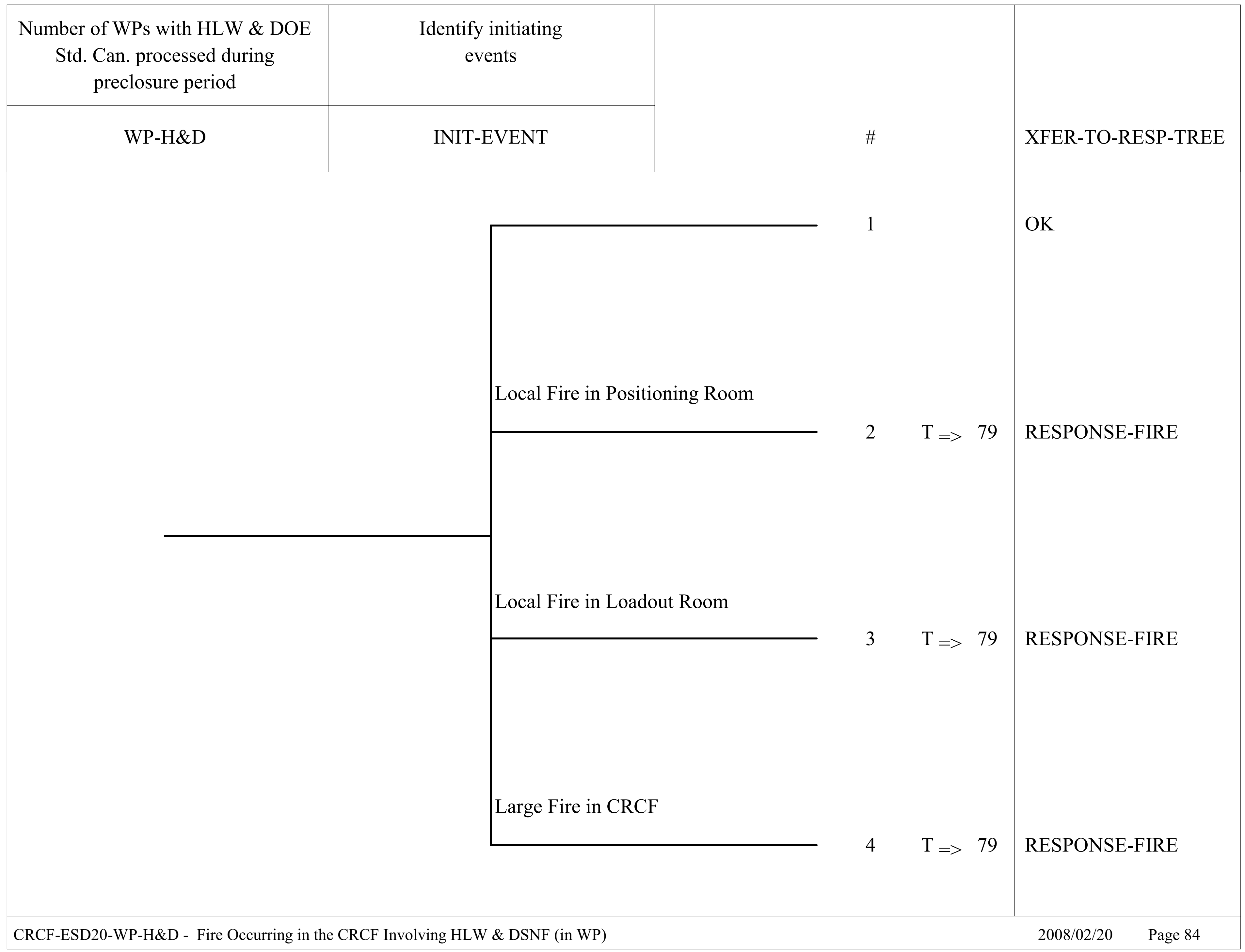
Source: Original

Figure G-83. Event Tree CRCF-ESD20-MCO – Fire Occurring in the CRCF Involving MCO



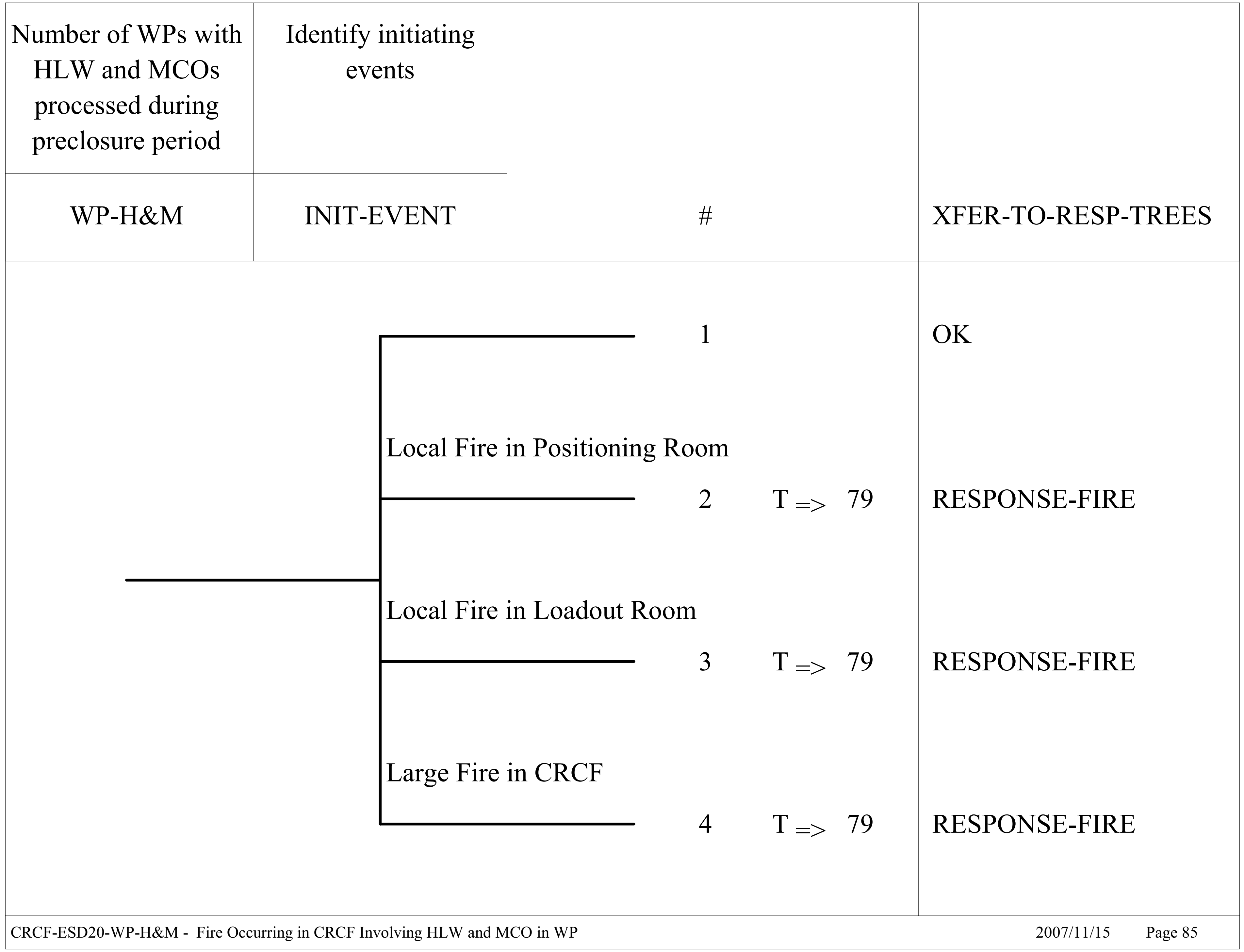
Source: Original

Figure G-84. Event Tree CRCF-ESD20-TAD – Fire Occurring in the CRCF Involving TAD Canisters



Source: Original

Figure G-85. Event Tree CRCF-ESD20-WP-H&D – Fire Occurring in the CRCF Involving HLW and DSTD in Waste Package



Source: Original

Figure G-86. Event Tree CRCF-ESD20-WP-H&M – Fire Occurring in the CRCF Involving HLW and MCO in Waste Package