Table 6.9-1. Preclosure Nuclear Safety Design Bases for the Subsurface ITS SSCs

| System or Facility (System Code) | Subsystem or Function (as Applicable) | Component | Nuclear Safety Design Bases | | Representative Event Sequence (Sequence Number) | Source |
|---|---|---|---|---|---|---|
| | | | Safety Function | Controlling Parameters and Values | | |
| **DOE and Commercial Waste Package System** | DOE and commercial waste package | Entire | Provide containment | 1. The mean conditional probability of breach of a sealed waste package resulting from a side impact shall be less than or equal to $1 \times 10^{-8}$ per impact. | SSO-ESD03-WP Seq. 6-3 | Table 6.3-7 |
| | | | | 2. The mean conditional probability of breach of a sealed waste package resulting from a drop of a load onto the waste package shall be less than or equal to $1 \times 10^{-5}$ per drop. | SSO-ESD01-WP Seq. 6-4 | Table 6.3-7 |
| | | | | 3. The mean conditional probability of breach of a sealed waste package inside the TEV resulting from an end-on impact or collision shall be less than or equal to $1 \times 10^{-8}$ per impact. | SSO-ESD03-WP Seq. 2-3 | Table 6.3-4 |
| | | | | 4. The mean conditional probability of breach of a canister inside a sealed waste package as a result of the spectrum of fires[c] shall be less than or equal to $3 \times 10^{-4}$ per fire event. | SSO-ESD05-WP Seq. 3-4 | Table 6.3-7 |
| **Emplacement and Retrieval/ Drip Shield Installation System** | Emplacement and retrieval/ drip shield installation system | TEV | Protect against[a] TEV runaway | 5. The mean probability of runaway of a TEV that can result in a potential breach of a waste package shall be less than or equal to $9 \times 10^{-9}$ per transport. | Initiating event does not require further analysis[b] | Fault tree gate "RNWY-INIT" (see Attachment B) |

Table 6.9-1. Preclosure Nuclear Safety Design Bases for the Subsurface Operations ITS SSCs (Continued)

| System or Facility (System Code) | Subsystem or Function (as Applicable) | Component | Nuclear Safety Design Bases | | Representative Event Sequence (Sequence Number) | Source |
|---|---|---|---|---|---|---|
| | | | Safety Function | Controlling Parameters and Values | | |
| **Emplacement and Retrieval/ Drip Shield Installation System (continued)** | Emplacement and retrieval/ drip shield installation system (continued) | TEV (continued) | Protect against[a] direct exposure of personnel | 6. The mean probability of inadvertent TEV door opening shall be less than or equal to $1 \times 10^{-7}$ per transport. | SSO-ESD-04-WP-Seq 4-2 | SHIELD-DOOR fault tree (see Attachment B) |
| **Naval SNF Waste Package System** | Naval SNF waste package | Entire | Provide containment | 7. The mean conditional probability of breach of a sealed waste package resulting from a side impact shall be less than or equal to $1 \times 10^{-8}$ per impact. | SSO-ESD03-WP Seq. 6-3 | Table 6.3-7 |
| | | | | 8. The mean conditional probability of breach of a sealed waste package resulting from a drop of a load onto the waste package shall be less than or equal to $1 \times 10^{-5}$ per drop. | SSO-ESD01-WP Seq. 6-4 | Table 6.3-7 |
| | | | | 9. The mean conditional probability of breach of a sealed waste package in the TEV resulting from an end-on impact or collision shall be less than or equal to $1 \times 10^{-8}$ per impact. | SSO-ESD03-WP Seq. 2-3 | Table 6.3-4 |

Table 6.9-1. Preclosure Nuclear Safety Design Bases for the Subsurface Operations ITS SSCs (Continued)

| System or Facility (System Code) | Subsystem or Function (as Applicable) | Component | Nuclear Safety Design Bases | | Representative Event Sequence (Sequence Number) | Source |
|---|---|---|---|---|---|---|
| | | | Safety Function | Controlling Parameters and Values | | |
| **Naval SNF Waste Package System (continued)** | Naval SNF waste package (continued) | Entire (continued) | Provide containment (continued) | 10. The mean conditional probability of breach of a canister inside a sealed waste package as a result of the spectrum of fires[c] shall be less than or equal to $1 \times 10^{-4}$ per fire event. | SSO-ESD05-WP Seq. 3-4[d] | Table 6.3-7 |

NOTE: [a] 'Protect against' in this table means either 'reduce the probability of' or 'reduce the frequency of'.
[b] Design requirement is applied to reduce the frequency of any event sequence that could result in damage to a waste container to the beyond Category 2 frequency range.
[c] Discussion on "the spectrum of fires" is provided in Attachment D, Section D2.1.5
[d] Although the failure probability of the Naval canister (considered as thick walled canister) inside a sealed waste package in a fire is $1 \times 10^{-4}$, the analysis for the event sequence does not differentiate between the Naval canister and other canisters inside the waste package, and as a result, a conservative value for the canister failure probability of $3 \times 10^{-4}$ is used for the analysis.
DOE = U.S. Department of Energy; SNF = spent nuclear fuel; TEV = transport and emplacement vehicle.

Source: Original

### 6.9.2 Procedural Safety Controls

Preclosure procedural safety controls (PSCs) are defined as procedures or administrative controls for the implementation of human activities that reduce the chance of or mitigate the consequences of event sequences. PSCs may also control the amounts and type of radioactive waste present in repository operations or locations. A PSC is a formally documented and controlled specific action or series of actions taken by the operating staff in preparation for, or during the execution of, a particular repository operation. A PSC may be a localized action that ensures that the prevention of, or the proper execution of, a given event is performed with the required reliability. A PSC may be a general requirement that ensures that the baseline operating conditions of repository SSCs used for PCSA screening and detailed analyses are in place prior to and during waste handling operations.

PSCs are derived from (1) event sequence quantification analyses in which a human interaction or a required operating condition affects the probability of an initiating event, affects the probability of a pivotal event, or is the basis for screening out a particular human failure event (HFE); (2) supporting analyses that provide the basis for screening out a potential hazard as an initiating event of an event sequence; (3) conditions necessary to prevent criticality scenarios; and (4) conditions necessary to ensure that the amounts and type of radioactive wastes are bounded by the source terms used in the radiological consequence analyses.

The process followed to identify the PSCs associated with subsurface operations includes the following steps:

- Identify the human actions that contribute to Category 1, Category 2, or Beyond Category 2 event sequences (in concert with the ITS SSCs) such that compliance to the requirements of 10 CFR 63.111(c) (Ref. 2.3.2) is achieved.

- Identify the human actions that are relied upon (in addition to the ITS SSCs) for preventing criticality for Category 1 and Category 2 event sequences.

- Identify the human actions that are relied upon for maintaining dose compliance with 10 CFR 63.111(Ref. 2.3.2)

- Assess and compile the operational and maintenance conditions required to ensure that the level of performance and reliability of ITS SSCs require in the PCSA is maintained.

Table 6.9-2 lists the PSCs that are required to support the event sequence analysis and categorization for subsurface operations.

Table 6.9-2. Summary of Procedural Safety Controls for the Subsurface Operations

| Item | Procedural Safety Controls | Basis for Selection | Event Sequence ID References |
|---|---|---|---|
| 1 | The amount of time that a waste form container spends in each process area or in a given process operation, including total residence time in a facility, is periodically compared against the average exposure times used in the PCSA. Additionally, component failures per demand and component failures per time period are compared against the PCSA. Significant deviations will be analyzed for risk significance. | PCSA uses exposure/residence times and reliability data to calculate the probability of an initiating event, or the probability of seismic induced failures that lead to an event sequence. This control ensures that the average exposure times and reliability data are maintained consistent with those analyzed in the PCSA. | Applies to all event sequence and fault tree quantification that uses data from Attachment C. Also applies to fire analysis per Section 4.3 and Attachment E. |
| 2 | Worker access to the emplacement drifts will be controlled and reinforced through appropriate training. This access control program will include controls for the locked drift access doors and include the installation of clearly posted warning signs. | This control is required to prevent direct radiological exposure to workers. | SSO-ESD-04-SEQ-2-2 |
| 3 | Only one TEV containing a waste package (i.e., a "loaded" TEV) is in transit at one time in the repository. In addition, an unloaded TEV is not operated at the same time a loaded TEV is in transit on a surface rail or on a subsurface rail. | The control is required to mitigate the potential for a TEV containing a WP colliding with another loaded or unloaded TEV by restricting the number of TEVs in operation at one time. However, the movement of an unloaded TEV at the surface is permitted concurrent with transit and emplacement operations of a TEV in the subsurface. | SSO-ESD-04-SEQ-3-2 |
| 4 | Workers are prevented from being in proximity to a TEV while the TEV contains a waste package. | The control is required to mitigate the potential of a worker radiological exposure due to close proximity to the TEV if a TEV system failure occurs. It also serves to reduce the long-term worker exposure due to proximity to a loaded TEV. | SSO-ESD-04-SEQ-3-2 |
| 5 | Vehicular crossings over the TEV railway are closed whenever a TEV is in transit to or from the subsurface. Traffic in the subsurface is restricted from operating in the same area as a loaded TEV. | The control is required to mitigate the potential for a loaded TEV derailment caused by a collision with another vehicle that is stalled or otherwise halted at a rail crossing. | SSO-ESD-02-SEQ-2-4 |

Table 6.9-2. Summary of Procedural Safety Controls for the Subsurface Operations (continued)

| Item | Procedural Safety Controls | Basis for Selection | Event Sequence ID References |
|---|---|---|---|
| 6 | A Combustible Material Control Program requires that each emplacement drift is inspected to ensure that all combustibles have been removed from the drift at the completion of construction and outfitting operations, prior to the utilization of an emplacement drift for waste storage. The program prohibits the storage or accumulation of combustibles in access mains along the path of travel of the TEV. | The requirement is established to mitigate the potential for fire occurring in the emplacement drift (and potentially breaching a waste package). A fire can start in collections of combustible materials that were required for construction and inadvertently left behind. | SSO-ESD-05 |
| 7 | Rock condition is observed as emplacement drift tunnel-boring is accomplished. Observed faults are specifically evaluated to ensure that conditions cannot credibly lead to a breach of the waste package during the preclosure period. Otherwise a standoff distance from the fault is established. | This control is required to limit the potential for breach of a waste package (at rest in an emplacement drift) due to a seismic event-induced fault displacement (or related rockfall hazard) during the preclosure period. | SSO-ESD-03-SEQ-7-3 |
| 8 | Installation and configuration of the isolation barriers between the emplacement side and development side of the Subsurface Facility is controlled such that development operations do not impact emplacement operations. | This control is required to prevent the radiological exposure of construction personnel and/or impacts to the emplacement activities due to activities in the construction side of the repository. | N/A |
| 9 | Full-service fire and rescue capabilities are available to support subsurface activities. | This control is required to maintain frequency associated with fires and WPs within the limits established by the PCSA. | SSO-ESD-05 |

NOTE: PCSA = preclosure safety analysis; TEV = transport and emplacement vehicle, WP = waste package.

Source: Original

# 7. RESULTS AND CONCLUSIONS

This analysis and its predecessor, the event sequence development analysis (Ref. 2.2.40), are part of the PCSA for the GROA that supports the license application. In combination these documents identify, evaluate, quantify, and categorize event sequences for the GROA facilities and operations. They are part of a collection of analysis reports that encompass all waste handling activities and facilities of the GROA, from initial operations to the end of the preclosure period. Probabilistic risk assessment techniques derived from both nuclear power plant and aerospace methods are used to perform the analyses to comply with the risk-informed aspects of 10 CFR 63.111 and 63.112 (Ref. 2.3.2) and to be responsive to the acceptance criteria articulated in the *Yucca Mountain Review Plan, Final Report* NUREG-1804 (Ref. 2.2.71). The identification and development of the event sequences is limited to those event sequences that might lead to direct radiation exposure of workers or onsite members of the public, radiological releases that may affect the workers or public (onsite and offsite), and nuclear criticality.

The results of the analysis are discussed and presented in the logical progression through Section 6 of this document and are not reiterated here. Instead, only key points are highlighted. For the ungrouped event sequence results and the complete grouped event sequence summaries, electronic files are provided due to the large size of hard copy versions (refer to Attachments G and H). In addition, although the results from the SAPHIRE model are used and presented in Section 6 and Attachment B, the model itself is difficult to completely represent in paper form. Therefore, these outputs are also provided electronically (refer to Attachment H). Table 7-1 describes the results and indicates the location within this analysis for each result provided.

Table 7-1. Key to Results

| Result | Description | Cross Reference |
|---|---|---|
| Grouping & quantification of event sequences | Calculation of probability distributions for the numbers of occurrences of internal event sequence groups over the preclosure period | Table G-1 |
| Categorization of event sequences | Assignment of frequency categories Category 1, Category 2, or Beyond Category 2 to internal event sequence groups based on mean numbers of occurrences | Table 6.8-3<br>Table 6.8-4<br>Table 6-8-5 |
| Designation of SSCs as ITS | Identification of SSCs that are relied on in the quantification of internal event sequences for prevention or mitigation | Table 6.9-1 |
| Statement of nuclear safety design bases | Determination of nuclear safety design bases for SSCs that are relied on in the quantification of internal event sequences for prevention or mitigation | Table 6.9-1 |
| Statement of procedural safety controls | Determination of procedural safety controls that are relied on in the quantification of internal event sequences for prevention or mitigation | Table 6.9-2 |

NOTE: ITS = important to safety; SSCs = structures, systems, and components.

Source: Original

## Summary of Event Sequences

For the subsurface operations, as shown in Table 6.8-4, the analysis concludes that there are no Category 1 event sequences and two Category 2 event sequences.

Table 7-2. Summary of Category 2 Event Sequences

| End State | Description | Canister Types |
|---|---|---|
| | | Waste Package |
| DE-SHIELD-DEGRADE | Direct exposure due to degradation of shielding | None |
| DE-SHIELD-LOSS | Direct exposure due to loss of shielding | 2 |
| RR-UNFILTERED | Radionuclide release, unfiltered | None |
| RR-FILTERED | Radionuclide release, filtered | None |
| RR-UNFILTERED-ITC | Radionuclide release, unfiltered, also important to criticality | None |
| RR-FILTERED-ITC | Radionuclide release, filtered, also important to criticality | None |
| ITC | Important to criticality | None |

Source: Original

## Summary of Conservatisms

It is noted that the event sequence identification and categorization were conducted with conservatisms built into the analysis inputs, including the following:

1. Fire frequency and damage analyses are performed without relying on fire suppression. This increases the calculated frequency of large fires and also increases the duration and peak temperature of fires, thereby significantly increasing the calculated probability of waste container failure.

2. If a fire is calculated to propagate out of the initiating location fire zone, the entire building is considered to be involved in the fire.

3. In the PEFA for thermal and fire scenarios, conservatism is built into the boundary conditions, which consider the fire as occurring next to the waste forms instead of only a fraction of the fire occurrence being near the waste form. A fire closer to the target will lead to a higher target failure probability than a fire located further away. By considering all fires to be next to the waste forms, the thermal PEFA yields higher waste form failure probabilities than is likely.

4. For event sequences in which a cask containing a canister is subjected to a drop, slapdown, or in which a load is dropped onto the cask, the calculated containment failure probability pertains to the canister inside without regard to the integrity of the cask. That is, cask containment is not relied upon to reduce probability of containment failure.

5. The structural PEFA uses a conservative failure probability of 1E-5, whereas the actual PEFA assessment indicates values of less than 1E-8 failure probabilities (Table D1.2-7 of Attachment D). This conservatism provides event sequence quantification results of magnitude higher than what they would be if the actual PEFA assessment values are used.

6. The structural analyses for drops and collisions of canisters or casks model a rigid, unyielding surface as the target.

7. The structural analysis for drops of loads onto casks or canisters uses a rigid unyielding object for the dropped load.

8. The probabilities of event sequences involving drops of casks and canisters represent a drop height of 30 feet for casks and bare canisters. This is much higher than the normal operational lift height but is applied for all drop heights. Lower drop heights would result in less structural challenge to casks and canisters.

9. When a canister is inside a waste package, failure of the waste package is considered to fail containment. That is, the canister is not relied upon to reduce the probability of containment failure.

10. The speed limitation of crane and conveyances within facilities to 20 ft/min and 2.5 mph, respectively, is set to ensure no breach of casks of canisters. The probability of breach at such speeds is calculated to be less than 1E-08 per impact. Speeds could be considerably larger without changing the categorizations of event sequences.

11. The reliability evaluation of the ITS HVAC system, which provides confinement of radioactive material releases following a breach of a waste container, is based a mission time of 720 hrs (30 days). The use of this mission time in the analysis leads to a requirement that the emergency diesel generators provide power to the HVAC for 720 hours following a release. The analysis does not account for the high likelihood of recovering offsite power within the mission time. Recovery of offsite power would reduce the length of time that the diesel generators would be required to run and would thereby reduce the calculated unavailability of the diesel generators. This conservative consideration leads to a lower ITS HVAC availability than is realistically expected.

12. The human reliability analysis screening values used for human failure events are typically one or more orders of magnitude higher than values that are obtained through detailed analysis.

13. The probability of failure associated with the structural analysis of mechanical impact loads to casks and canisters is conservatively based on the maximum effective plastic strain of any brick (i.e., finite element mesh) in the modeled structure rather than on evidence of through-wall cracking.

14. Categorization of event sequences is based on the highest category after application of a conservative adjustment to account for the uncertainty in the calculated uncertainties.

15. To preserve flexibility in the conduct of operations, the throughput analysis (Ref. 2.2.31) embeds multiple and bounding waste handling scenarios in the throughput numbers. For example, of approximately 350 DPCs available for transfer in the WHF, the throughput analysis includes the transfer of 350 DPCs from vertical transportation casks, the transfer of 350 DPCs from horizontal transportation casks, and the transfer of an additional 350 DPCs from the horizontal aging modules on the aging pad. Including this conservatism in the analysis yields calculated event sequence frequencies that are higher than are realistically expected.

# ATTACHMENT A
# EVENT TREES

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# ATTACHMENT A
# EVENT TREES

## A1 INTRODUCTION

This attachment presents event trees that are derived from the event sequence diagrams (ESDs) in Attachment F of the *Subsurface Operations Event Sequence Development Analysis* (Ref. 2.2.40). All initiator event trees and system response event trees are located at the end of this attachment. Refer to Table A5-1 for the figure locations of specific event and response trees. The event trees are presented in Figures A5-2 through A5-9; the ESD initiating event trees (ESDs 01-05) are presented first, followed by the corresponding response trees for ESDs 01-03. ESD-04 has no response tree and ESD-05 has the same response tree as ESD-02.

## A2 READER'S GUIDE TO THE EVENT TREE DESCRIPTIONS

The following sections are organized by ESD. The event trees that correspond to each ESD are presented as follows:

1. The event trees are briefly described and listed (initiator and system-response event trees or self contained event trees, as applicable).

2. The initiating events are described and listed. The listing is provided as a table that includes the assignments of fault trees or basic events to the initiating events. The assignments are made in SAPHIRE using basic rules or by fault-tree construction. The goal of the initiating event table is to provide a link to the underlying fault tree (covered in Section 6.2 and Attachment B) or basic event (covered in Section 6.3 and Attachment C). In a few cases, the assignment is not straightforward and a supplemental fault tree provides a link to the fault tree or basic event level (covered in Attachment B). Note that the initiating event frequencies are defined on a per-unit-handled basis. Thus, when the initiating event frequencies are multiplied by the number of waste packages handled over the preclosure period, the result is an initiating event frequency over the preclosure period.

3. The system-response event tree that corresponds to the initiator event tree or the system response for a self-contained event tree is covered as follows. Each pivotal event used in an event tree is listed in the event tree description section and summarized in Section A3. Each pivotal event is accompanied by a table that provides a link between the name given to the pivotal event in the event tree and the associated fault tree or basic event. The goal of the pivotal event table is to provide a link to the underlying fault tree (covered in Section 6.2) or basic event (covered in Section 6.3). In a few cases, the assignment is not straightforward and a supplemental fault tree provides a link to the fault tree or basic event level.

## A3 SUMMARY OF THE MAJOR PIVOTAL EVENT TYPES

A self-contained event tree or a system response event tree may include pivotal events of following types:

**WASTE PACKAGE**. This pivotal event represents the success or failure of the waste package to contain radioactive material after the impact caused by the initiating event. The failure of this pivotal event leads to loss of the waste package containment function. The failure probability for this pivotal event depends on the selection of initiating event and is determined by passive equipment failure analysis, and is given in Table 6.3-4 in Section 6.3.2.

**CANISTER**. This pivotal event represents the success or failure of the canister to contain radioactive material after the impact caused by the initiating event. Failure of a containment pivotal event means that a release could occur if the canister containment barrier is breached (along with the cask or waste-package containment, as applicable). In accordance with a simplifying approximation, the conditional probability of canister breach given waste package breach is taken to be 1.

**SHIELDING**. Failure of a shielding pivotal event means that a direct exposure could occur. Waste packages, some canister lids, and the TEV shielding structure (including shield doors) provide radiation shields that could be pierced or degraded in some impact or thermal challenges. In the subsurface analysis, waste packages and canisters are conservatively considered to provide no shielding; only the TEV provides the necessary radiation shielding. Thus, this pivotal event represents the success or failure of the shielding function provided by the TEV after the impact caused by the initiating event. Failure of shielding in this instance refers to an unspecified degree of the TEV shielding degradation due to the impact.

**CONFINEMENT**. This pivotal event represents the success or failure of the HVAC system in continuing to provide HEPA filtration (radiological confinement) after the initiating event has occurred. Success of the pivotal event requires that the facility structural integrity is maintained as well as the functioning of equipment associated with the HVAC system. Failure results in a potential airborne release that is not mitigated by the HEPA filtration system; in this case, the release is termed as unfiltered release.

This pivotal event only applies to the TEV when it is in the CRCF. The IHF does not have an ITS HVAC system, therefore, there is no confinement challenge (CONFINEMENT always fails (pivotal event is set to 1)). When the loaded TEV is outside of the CRCF, the confinement no longer exists and, thus, it is not modeled in the corresponding response event trees.

**MODERATOR**. This pivotal event represents the conditional probability of introducing liquid moderator (e.g., water) into a breached canister, given that a breached canister occurs. The conditional probability of failure (introduction of liquid moderator) is the same for all waste forms and all initiating events. Failure of a moderator pivotal event results in an end state that may be susceptible to nuclear criticality. In addition to the probability of the event MODERATOR being dependent upon the condition of the canister (intact vs. breached), the opportunity for criticality also depends on the physical properties of the waste form.

Specifically, HLW is not subject to the possibility of criticality; therefore, all moderator trees pertaining to criticality sequences for HLW are set to "0.00E+00."

Each of the specific failure events included in a self-contained or system-response event tree may be linked to a basic event or to the top event of a fault tree that represents equipment failure modes and human failure events that can initiate the specific event. The fault tree models are, in turn, linked to basic events that provide the failure frequencies. Some of the pivotal events represent failure of equipment whose failure probabilities are linked to a separately developed basic event and not to a fault tree.

# A4 EVENT TREE DESCRIPTIONS

## A4.1 EVENT TREES FOR SSO-ESD-01

SSO-ESD-01 covers event sequences associated with TEV activities inside a facility waste package load-out area (Ref. 2.2.40, Figure F-1). This ESD covers only waste packages; therefore, there is only one event tree associated with SSO-ESD-01. An initiator event tree and a system response event tree represent the ESD (Table A4.1-1).

Table A4.1-1. Summary of Event Trees for SSO-ESD-01

| Waste Form Unit | Associated Event Trees | Number of Waste Form Units |
|---|---|---|
| Waste package in CRCF | Initiator: SSO-ESD01<br>Response: RESPONSE-FACILITY | 11,668 |
| Waste package in IHF | Initiator: SSO-ESD01<br>Response: RESPONSE-FACILITY | 600 |

Source: Ref. 2.2.31, Table 4

### A4.1.1 Initiating Events for SSO-ESD-01

Initiating event assignments for SSO-ESD-01 are located in Table A4.1-2.

**Waste Package Impact –Facility Shield Door**. This initiating event accounts for the potential impact to the waste package due to a TEV collision with the facility shield door.

**Waste Package Impact –TEV Shield Door**. This initiating event accounts for the potential impact to the waste package due to the TEV shield door closing on the waste package.

**TEV Collision**. This initiating event accounts for the potential impact to the waste package due to a TEV collision with a structure.

**Drop of Waste Package**. This initiating event covers the potential impact to the waste package due a drop of the waste package.

**Heavy Load Dropped on TEV**. This initiating event covers the potential impact to the waste package due to the drop of a heavy object (e.g., empty waste package) by the waste package handling crane.

Table A4.1-2. Initiating Event Assignments for SSO-ESD-01

| Initiating Event Description | Initiator Event Tree | SAPHIRE Assignment at Fault Tree Level |
|---|---|---|
| WP impact – facility shield door | SSO-ESD-01 | TEV fault tree |
| WP impact – TEV shield door | SSO-ESD-01 | TEV fault tree |
| TEV collision | SSO-ESD-01 | TEV fault tree |
| Drop of WP | SSO-ESD-01 | TEV fault tree |
| Object dropped onto WP | SSO-ESD-01 | TEV fault tree |

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

Source: Original

### A4.1.2 System Response Event Tree RESPONSE-FACILITY

The pivotal events that appear in RESPONSE-FACILITY are listed below and summarized in Section A3.

- Waste Package
- Shielding
- Canister
- Confinement
- Moderator.

## A4.2 EVENT TREES FOR SSO-ESD-02

SSO-ESD-02 covers event sequences associated with TEV activities during transit (Ref. 2.2.40, Figure F-2). An initiator event tree and a system response event tree represent the ESD (Table A4.2-1).

Table A4.2-1. Summary of Event Trees for SSO-ESD-02

| Waste Form Unit | Associated Event Trees | Number of Waste Form Units |
|---|---|---|
| Waste package | Initiator: SSO-ESD02<br>Response: RESPONSE-TRANSIT | 12,268 |

NOTE: The value for this basic event is obtained by adding the number of waste packages from the CRCF (11,668) and from the IHF (600) which is documented in the throughput analysis. However the throughput analysis also shows a total number of waste packages of 12,068 assigned for the subsurface operations. The value of 12,268 used here is a conservative estimate.

Source: Ref. 2.2.31, Table 4

### A4.2.1 Initiating Events for SSO-ESD-02

Initiating event assignments for SSO-ESD-02 are located in Table A4.2-2.

**TEV Impact – Collision or Derail**. This initiating event accounts for the potential impact to the waste package due to a TEV collision into a structure or TEV derailment.

**TEV Impact During Transit**. This initiating event accounts for the potential impact to the waste package due to collision of another vehicle with the TEV.

**Drop of Waste Package**. This initiating event covers the potential impact to the waste package due a drop of the waste package.

**Heavy Load Dropped on TEV**. This initiating event covers the potential impact to the waste package due to the drop of a heavy object (i.e., rock fall) on the TEV.

Table A4.2-2. Initiating Event Assignments for SSO-ESD-02

| Initiating Event Description | Initiator Event Tree | SAPHIRE Assignment at Fault Tree Level |
|---|---|---|
| TEV impact – collision or derail | SSO-ESD-02 | TEV fault tree |
| TEV impact during transit | SSO-ESD-02 | TEV fault tree |
| Drop of WP | SSO-ESD-02 | TEV fault tree |
| Object dropped onto WP | SSO-ESD-02 | TEV fault tree |

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

Source: Original

### A4.2.2 System Response Event Tree RESPONSE-TRANSIT

The pivotal events that appear in RESPONSE-TRANSIT are listed below and summarized in Section A3.

- Waste Package
- Shielding
- Canister
- Moderator.

## A4.3 EVENT TREES FOR SSO-ESD-03

SSO-ESD-03 covers event sequences associated with TEV activities within the emplacement drift (Ref. 2.2.40, Figure F-3). An initiator event tree and a system response event tree represent the ESD (Table A4.3-1).

Table A4.3-1. Summary of Event Trees for SSO-ESD-03

| Waste Form Unit | Associated Event Trees | Number of Waste Form Units |
|---|---|---|
| Waste package | Initiator: SSO-ESD03<br>Response: RESPONSE-DRIFT | 12,268 |

Source: Ref. 2.2.31, Table 4

### A4.3.1 Initiating Events for SSO-ESD-03

Initiating event assignments for SSO-ESD-03 are located in Table A4.3-2.

**TEV Impact – Collision or Derail**. This initiating event accounts for the potential impact to the waste package due to a TEV collision into a structure or TEV derailment.

**Direct Impact to Waste Package - Collision**. This initiating event accounts for the potential impact to the waste package due to collision of the TEV or other structure, system, or component directly with the waste package.

**Drop or Drag of Waste Package**. This initiating event covers the potential impact to the waste package due a drop or drag of the waste package.

**Heavy Load Dropped on TEV**. This initiating event covers the potential impact to the waste package due to the drop of a heavy object (i.e., rock fall) on the TEV.

**Waste Package Impact Due to TEV Doors**. This initiating event covers the potential impact to the waste package by the TEV shield doors.

**Heavy Load Dropped on Waste Package**. This initiating event covers the potential impact to the waste package due to the drop of a heavy object (i.e., rock fall) on the waste package.

Table A4.3-2. Initiating Event Assignments for SSO-ESD-03

| Initiating Event Description | Initiator Event Tree | SAPHIRE Assignment at Fault Tree Level |
|---|---|---|
| TEV impact – collision or derail | SSO-ESD-03 | TEV fault tree |
| TEV collision | SSO-ESD-03 | TEV fault tree |
| Drop or drag of WP | SSO-ESD-03 | TEV fault tree |
| Object dropped onto TEV | SSO-ESD-03 | TEV fault tree |
| WP impact – TEV shield door | SSO-ESD-03 | TEV fault tree |
| Object dropped onto WP | SSO-ESD-03 | TEV fault tree |

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

Source: Original

### A4.3.2 System Response Event Tree RESPONSE-DRIFT

The pivotal events that appear in RESPONSE-DRIFT are listed below and summarized in Section A3.

- Waste Package
- Canister
- Moderator.

## A4.4 EVENT TREE FOR SSO-ESD-04

SSO-ESD-04 covers event sequences associated with loss or lack of shielding during subsurface operations (Ref. 2.2.40, Figure F-4). This self contained event tree represents the ESD (Table A4.4-1).

Table A4.4-1. Summary of Event Trees for SSO-ESD-04

| Waste Form Unit | Associated Event Trees | Number of Waste Form Units |
|---|---|---|
| Waste package | Initiator: SSO-ESD04<br>Response: RESPONSE-TRANSIT | 12,268 |

Source: Ref. 2.2.31, Table 4

### A4.4.1 Initiating Events for SSO-ESD-04

Initiating event assignments for SSO-ESD-04 are located in Table A4.4-2.

**Inadvertent Entry into Drift**. This initiating event accounts for the potential direct exposure of a worker due to his inadvertent entry into an active drift.

**Prolonged Worker Proximity to TEV**. This initiating event accounts for the potential direct exposure of a worker due to spending too much time near the TEV.

**Inadvertent TEV Door Open**. This initiating event accounts for the potential direct exposure of a worker due to inadvertent opening of the TEV shield door.

**Loss of Movement – Loss of Shielding**. This initiating event accounts for the potential direct exposure of a worker due to degraded shield of the TEV from solar insolation.

Table A4.4-2. Initiating Event Assignments for SSO-ESD-04

| Initiating Event Description | Initiator Event Tree | SAPHIRE Assignment at Fault Tree Level |
|---|---|---|
| Inadvertent entry into drift | SSO-ESD-04 | Screened – See Section 6.0 |
| Prolonged worker proximity to TEV | SSO-ESD-04 | Screened – See Section 6.0 |
| Inadvertent TEV door open | SSO-ESD-04 | TEV fault tree |
| Loss of movement – loss of shielding | SSO-ESD-04 | TEV fault tree |

NOTE: TEV = transport and emplacement vehicle.

Source: Original

## A4.5 EVENT TREES FOR SSO-ESD-05

SSO-ESD-05 covers event sequences associated with internal fires (Ref. 2.2.40, Figure F-5). An initiator event tree and a system response event tree represent the ESD (Table A4.5-1).

Table A4.5-1. Summary of Event Trees for SSO-ESD-05

| Waste Form Unit | Associated Event Trees | Number of Waste Form Units |
|---|---|---|
| Waste package | Initiator: SSO-ESD05<br>Response: RESPONSE-TRANSIT | 12,268 |

Source: Ref. 2.2.31, Table 4

### A4.5.1 Initiating Events for SSO-ESD-05

Initiating event assignments for SSO-ESD-05 are located in Table A4.5-2.

**TEV Fire Affects Waste Package in Drift**. This initiating event accounts for the potential damage to a waste package in the drift due to fire.

**TEV Fire Affects Waste Package on Subsurface Rail**. This initiating event accounts for the potential damage to a waste package in the access main due to fire.

**TEV Fire Affects Waste Package on Surface Rail**. This initiating event accounts for the potential damage to a waste package on the surface due to fire.

Table A4.5-2. Initiating Event Assignments for SSO-ESD-05

| Initiating Event Description | Initiator Event Tree | SAPHIRE Assignment at Fault Tree Level |
|---|---|---|
| TEV fire affects WP in drift | SSO-ESD-05 | TEV fault tree |
| TEV fire affects WP on subsurface rail | SSO-ESD-05 | TEV fault tree |
| TEV fire affects WP on surface rail | SSO-ESD-05 | TEV fault tree |

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

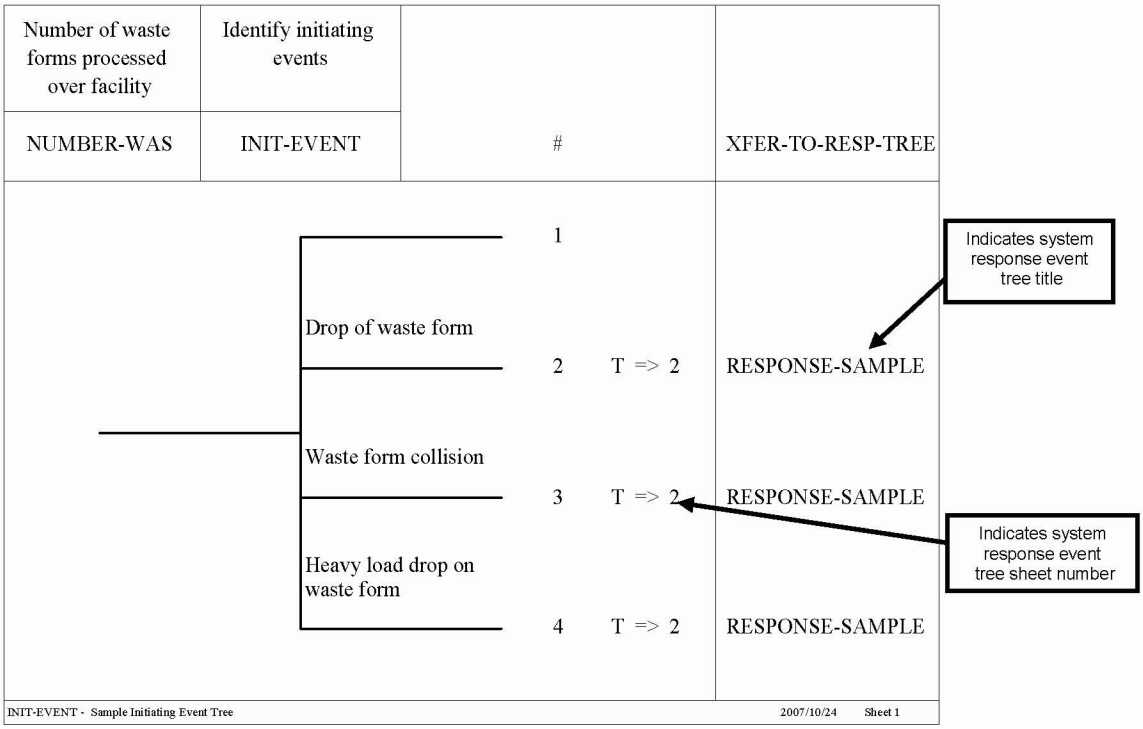
Source: Original

### A4.5.2 System Response Event Tree RESPONSE-TRANSIT

The pivotal events that appear in RESPONSE-TRANSIT as well as the association of pivotal event names with basic event or fault tree names have been described in Section A4.2.2.

## A5 EVENT TREES

Navigation from an initiator event tree to the corresponding response event tree is assisted by the rightmost two columns on the initiator event trees as shown in Figure A5-1. The numbers under the "#" symbol may be used by the reader to refer to a particular branch of an event tree, but it is not used elsewhere in this analysis.




Source: Original

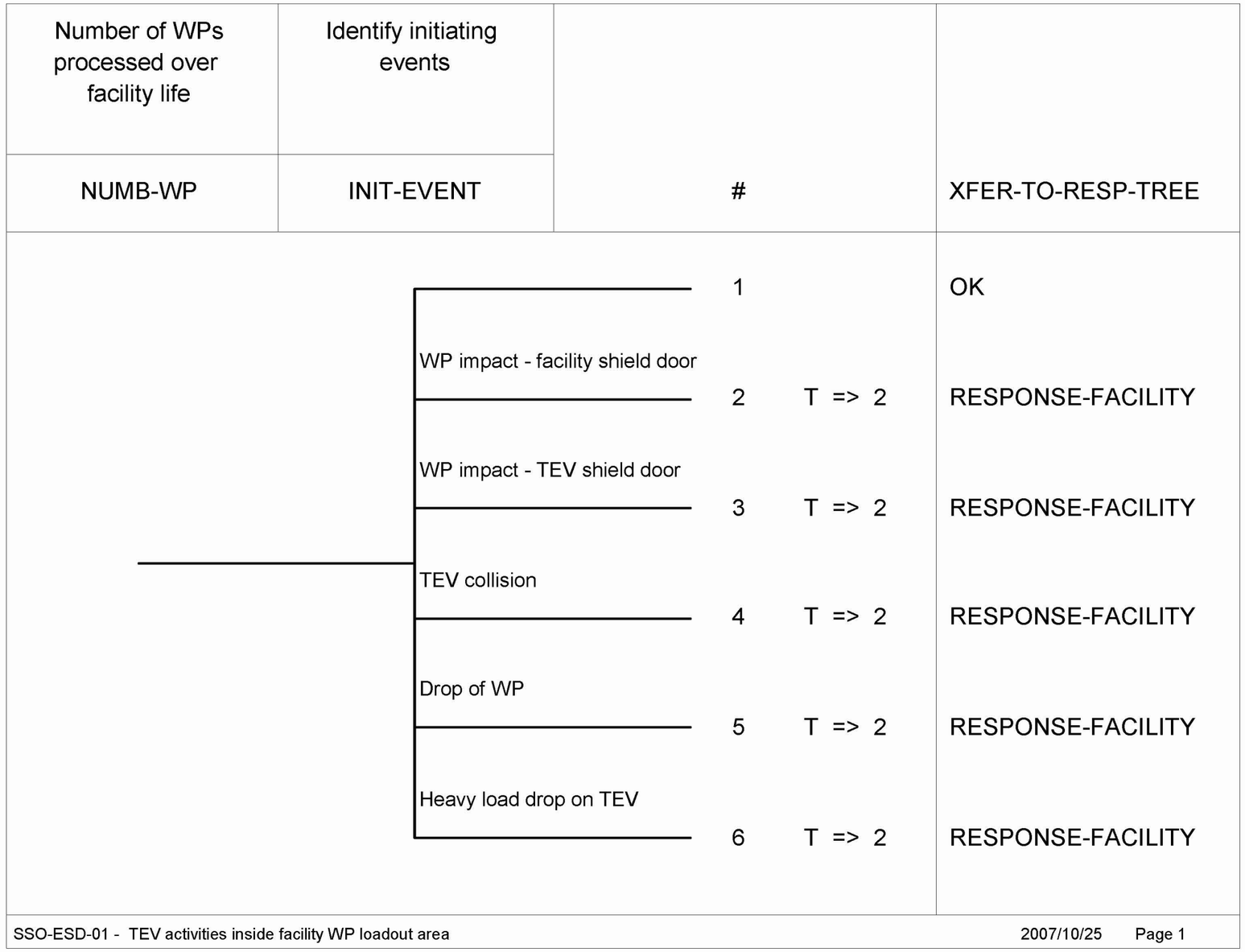
Figure A5-1. Example Initiator Event Tree Showing Navigation Aids

Table A5-1. ESDs to Event Trees

| ESD# | ESD Title | IE Event Tree Name | IE Event Tree Location | Response Tree Name | Response Tree Location |
|---|---|---|---|---|---|
| SSO-ESD-01 | Event sequences for TEV activities inside facility WP load-out area | SSO-ESD-01 | Figure A5-2 | RESPONSE-FACILITY | Figure A5-7 |
| SSO-ESD-02 | Event sequences for TEV activities during transit | SSO-ESD-02 | Figure A5-3 | RESPONSE-TRANSIT | Figure A5-8 |
| SSO-ESD-03 | Event sequences for TEV activities within the emplacement drift | SSO-ESD-03 | Figure A5-4 | RESPONSE-DRIFT | Figure A5-9 |
| SSO-ESD-04 | Event sequences for loss or lack of shielding | SSO-ESD-04 | Figure A5-5 | No response tree | N/A |
| SSO-ESD-05 | Event sequences for internal fires | SSO-ESD-05 | Figure A5-6 | RESPONSE-TRANSIT | Figure A5-8 |

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

Source: Original




Source: Original

Figure A5-2. Event Tree SSO-ESD-01 – TEV Activities inside Facility Waste Package Loadout Area

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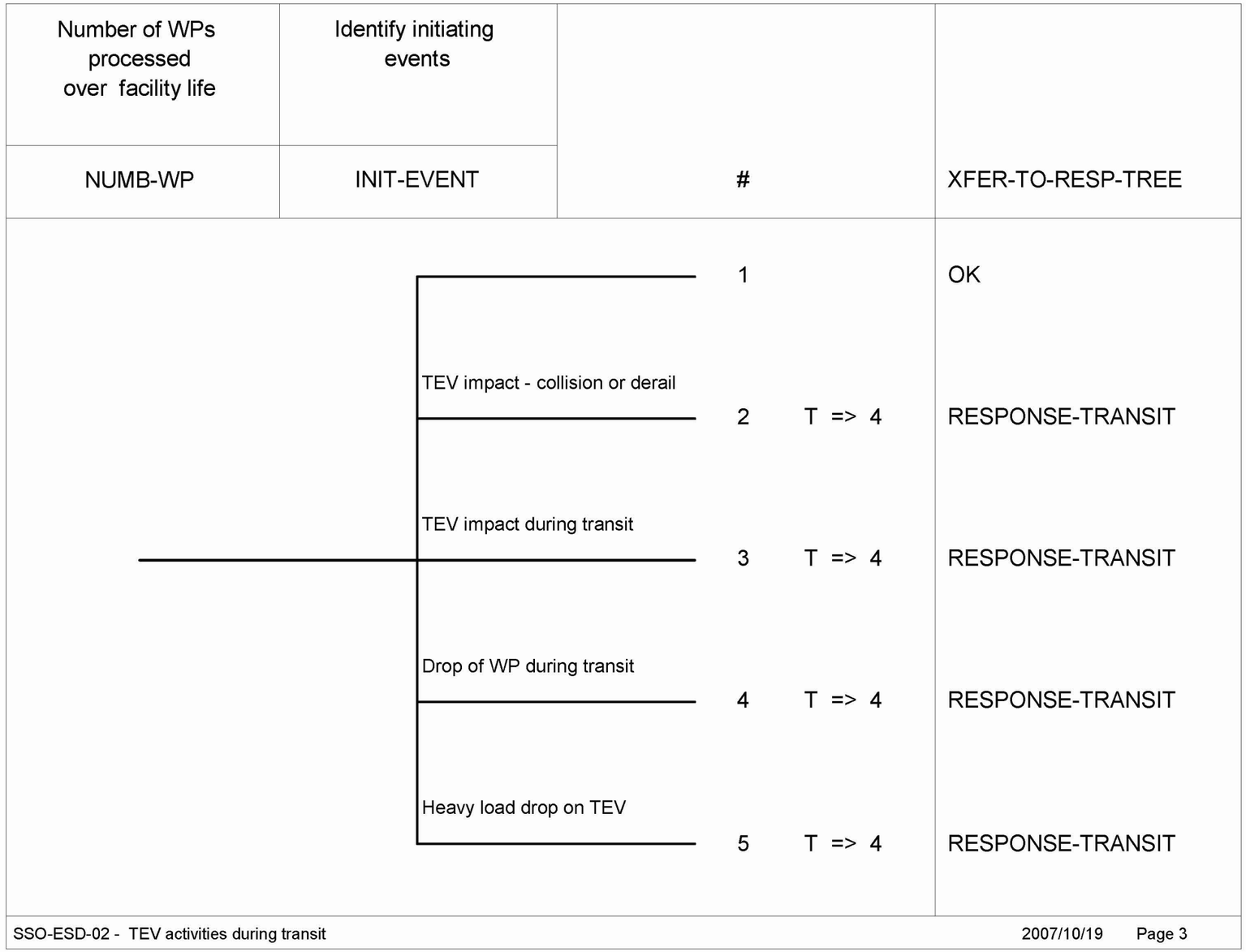


Source: Original

Figure A5-3. Event Tree SSO-ESD-02 – TEV Activities during Transit

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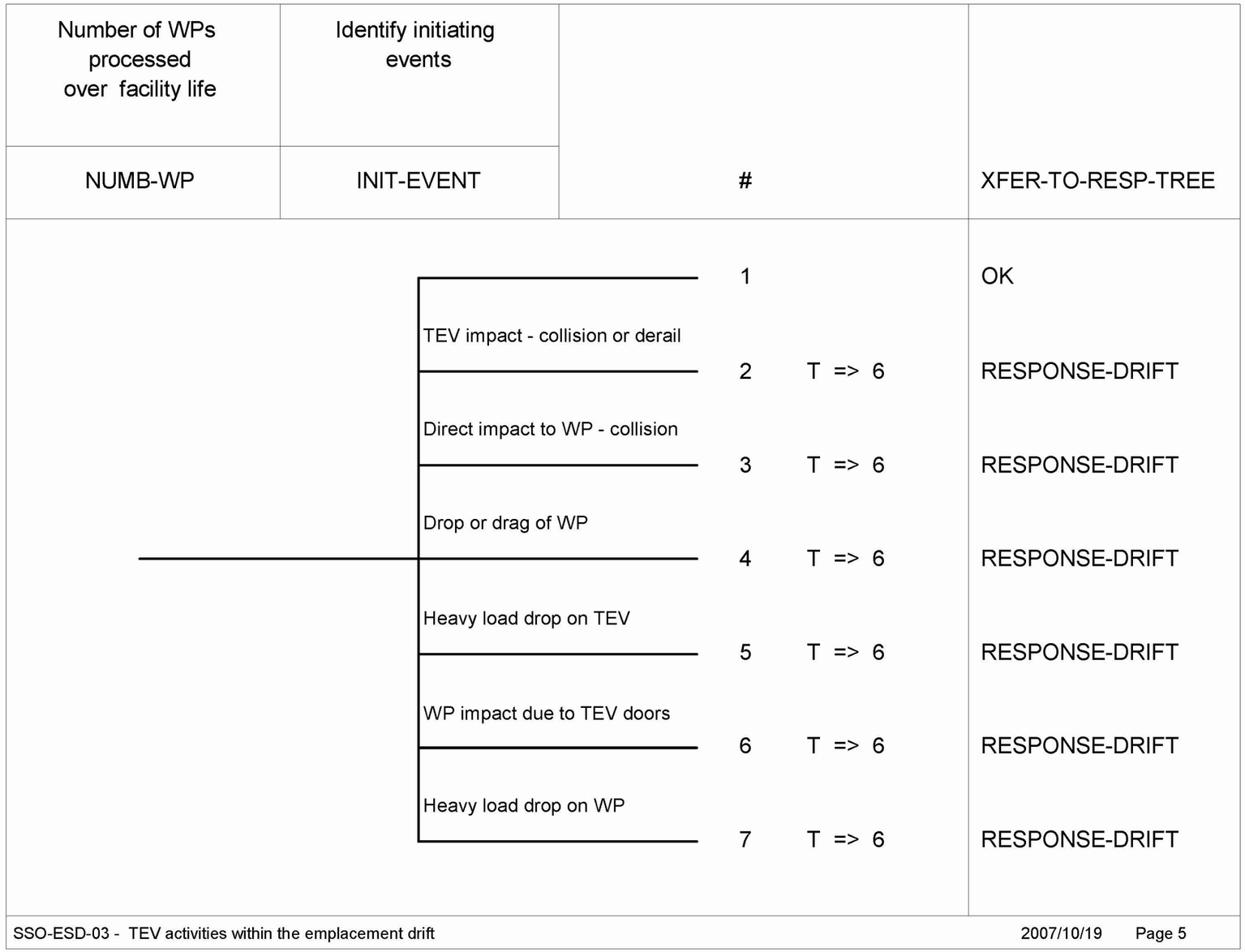


Source: Original

Figure A5-4. Event Tree SSO-ESD-03 – TEV Activities within the Emplacement Drift

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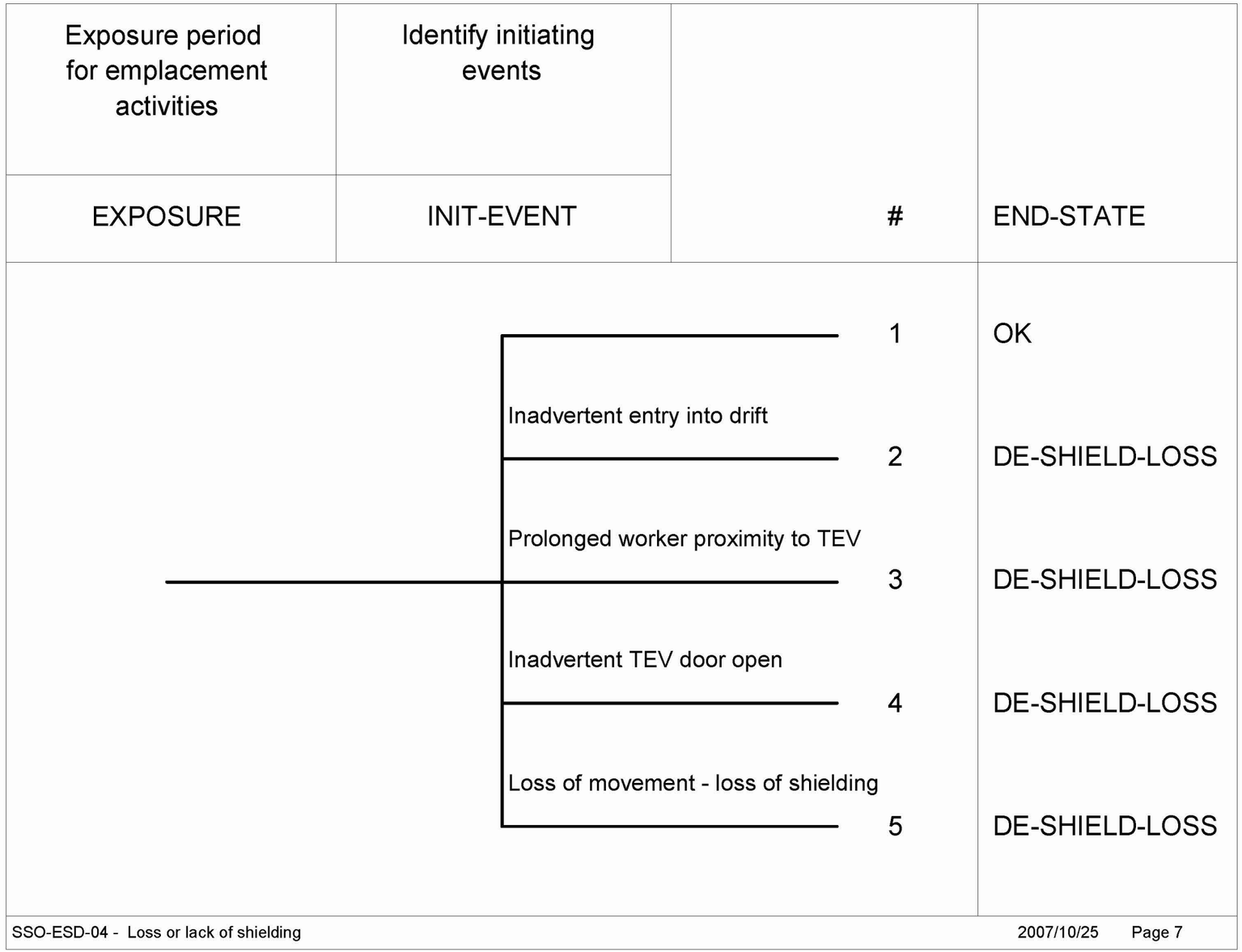


Source: Original

Figure A5-5. Event Tree SSO-ESD-04 – Loss or Lack of Shielding

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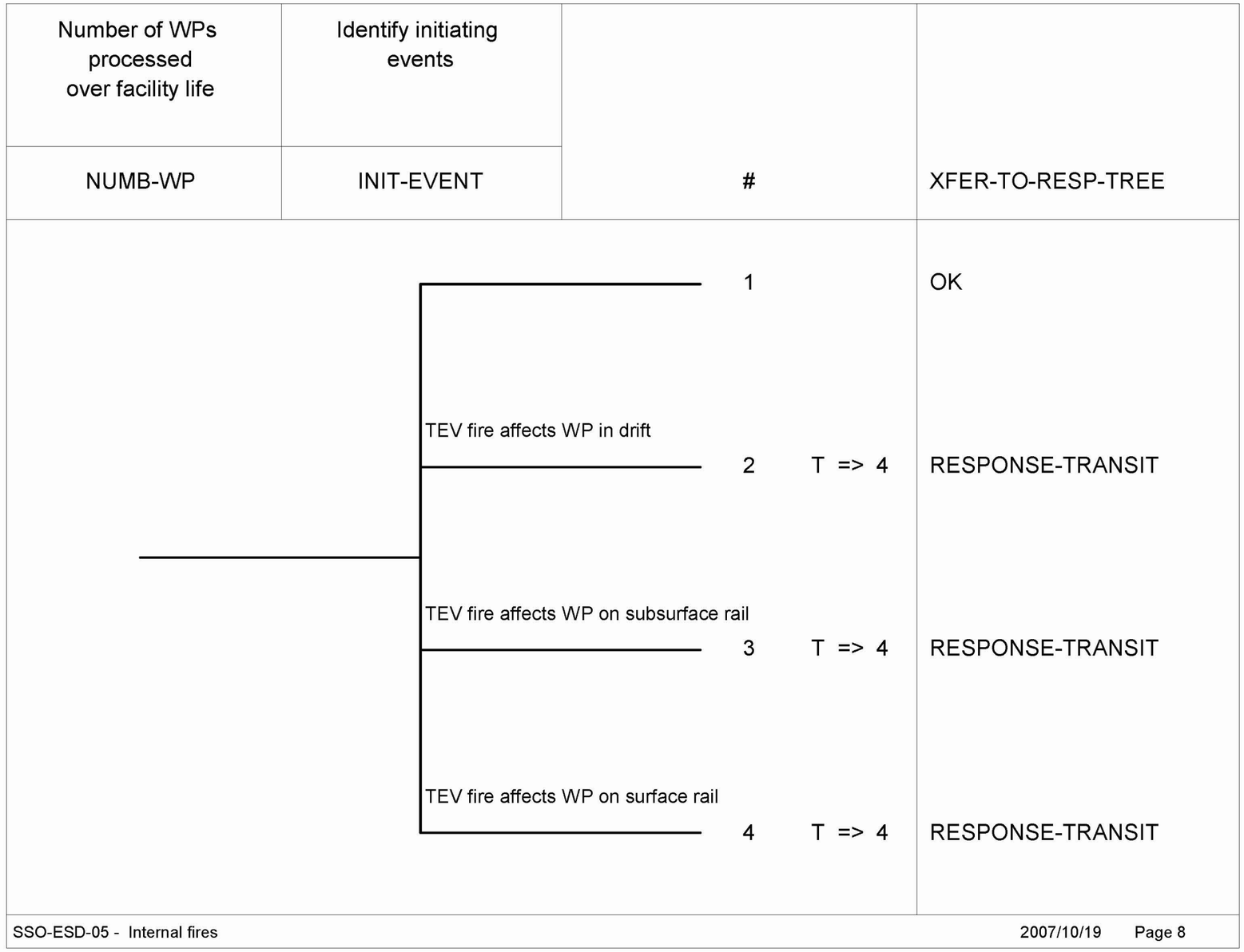


Source: Original

Figure A5-6. Event Tree SSO-ESD-05 – Internal Fires

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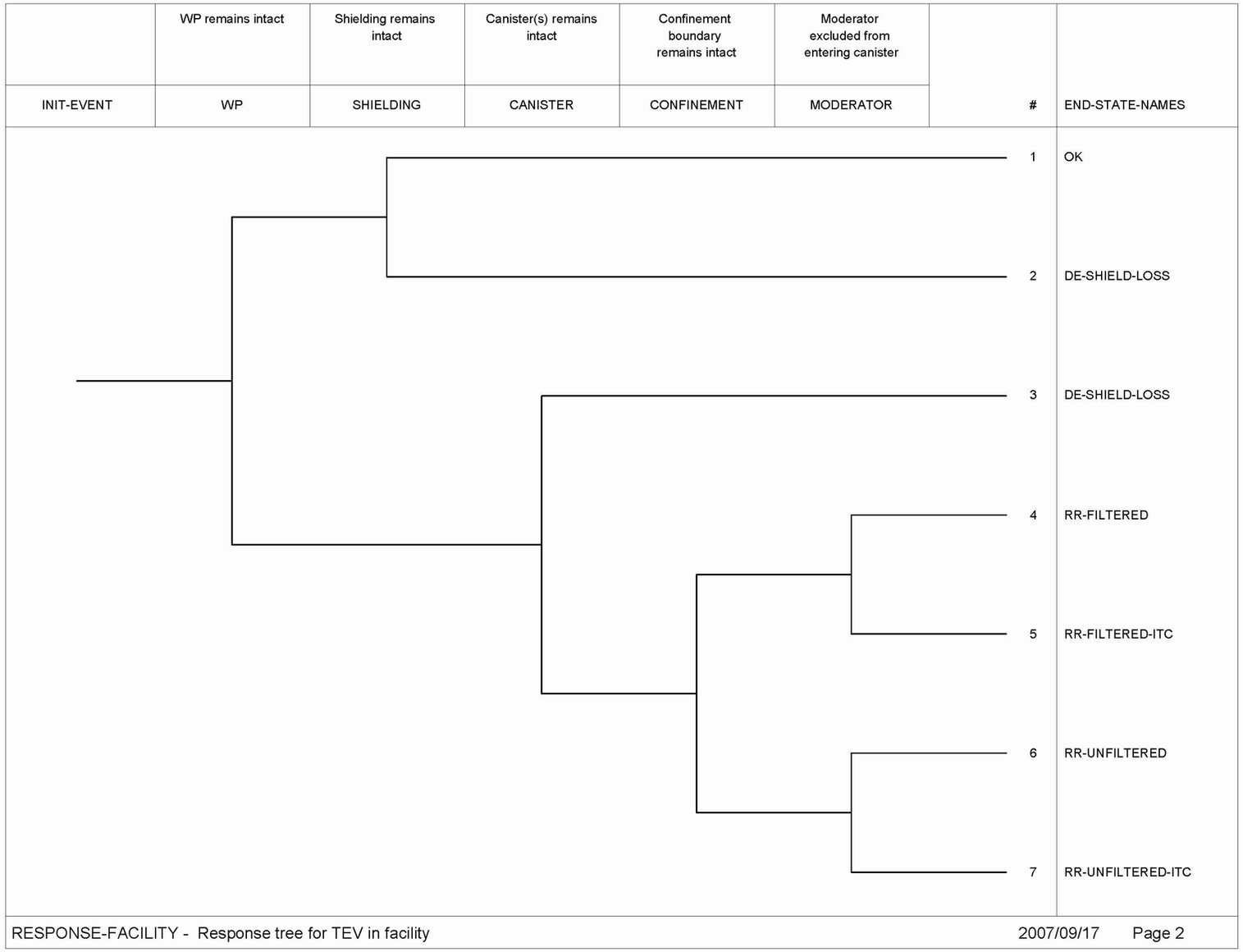


Source: Original

Figure A5-7. Event Tree RESPONSE-FACILITY – Response Tree for TEV in Facility (Response for SSO-ESD-01)

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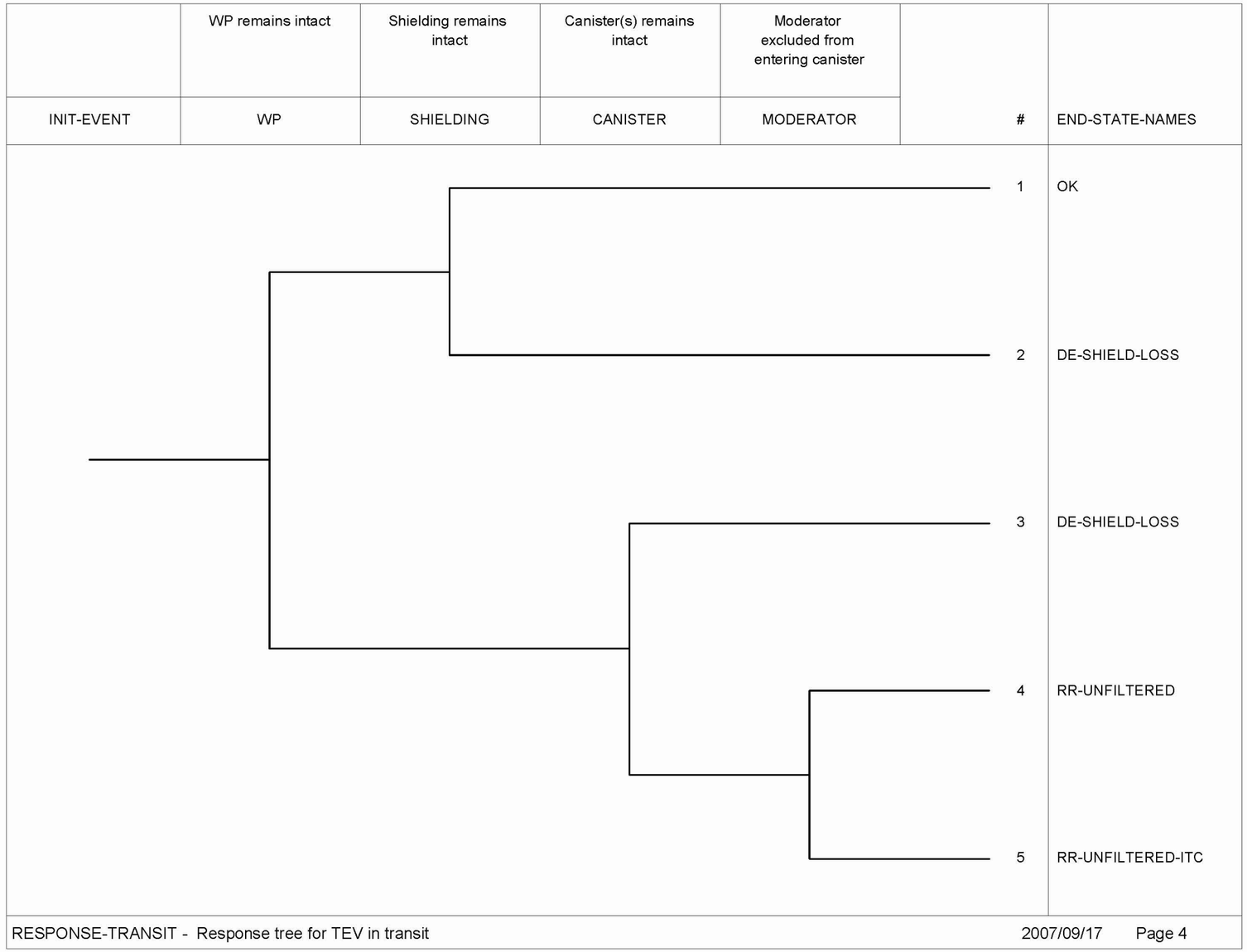


Source: Original

Figure A5-8. Event Tree RESPONSE-TRANSIT – Response Tree for TEV in Transit (Response for SSO-ESD-02 and SSO-ESD-05)

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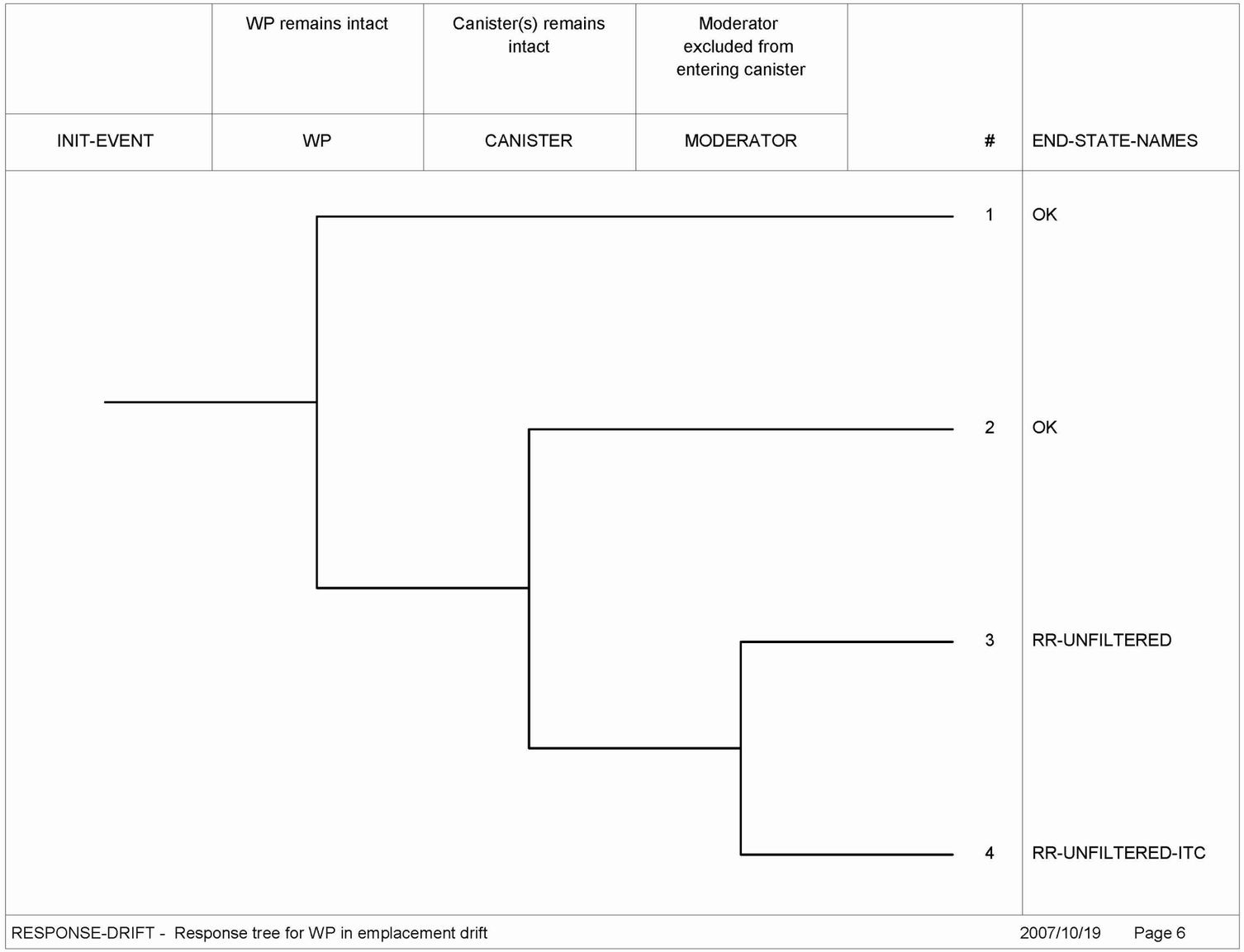


Source: Original

Figure A5-9. Event Tree RESPONSE-DRIFT – Response Tree for TEV in Emplacement Drift (Response for SSO-ESD-03)

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# ATTACHMENT B
# SYSTEM/PIVOTAL EVENT ANALYSIS – FAULT TREES

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