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HAZARD IDENTIFICATION FOR THE GEOLOGIC REPOSITORY OPERATIONS AREA: A PROGRESS REPORT

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ABSTRACT

To comply with the requirements for preclosure safety analysis in 10 CFR 63.112, the U.S. Department of Energy (DOE) is required to conduct a systematic evaluation of the naturally occurring and human-induced hazards and identify potential hazards and initiating events that may result in radiological release to the public and facility workers at the proposed geologic repository operations area at Yucca Mountain. The DOE identification of hazards and initiating events is based on development of a generic list of hazards and evaluation of each hazard based on certain screening criteria. On behalf of the U.S. Nuclear Regulatory Commission, the Center for Nuclear Waste Regulatory Analyses is (i) reviewing the generic list of hazards and initiating events identified by DOE for completeness; (ii) systematically evaluating information, data, and analyses presented by DOE on identified hazards and initiating events in the generic event list for appropriateness to the proposed repository at Yucca Mountain, taking into consideration current knowledge of the facility design; and (iii) assessing the decision by DOE about whether to include these hazards in the preclosure safety analysis. Additionally, limited independent analyses were conducted to support this assessment. This report documents the review of the generic hazards list and provides an indepth review of a limited number of hazards. Hazards reviewed in detail pertain to seismicity and faulting, aircraft crash, tornado missile, volcanic ashfall, and facility operations. The report has been structured to provide an overview of the DOE analyses, staff assessments, and paths forward to address concerns identified herein for completing the generic hazards list and each hazard reviewed.

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA-generated original data contained in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Sources for other data should be consulted for determining the level of quality for those data.

ANALYSES AND CODES: The SAPHIRE Version 6.70 (Idaho National Engineering Laboratory, 1993) in this study is controlled by CNWRA Software Quality Assurance Technical Operating Procedures (TOP–018).

REFERENCE

Idaho National Engineering Laboratory. "Systems Analysis Programs for Hands-On Integrated Reliability Evaluations (SAPHIRE) Version 6.0, Technical Reference Manual." Idaho Falls, Idaho: Idaho National Engineering Laboratory. 1993.

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1 INTRODUCTION

1.1 Background

As part of any application for a license to construct and a subsequent application for amendment for a license to receive and possess waste at the proposed geologic repository at Yucca Mountain, the U.S. Department of Energy (DOE) must conduct and present a safety analysis of the repository operations area for the period until permanent closure. This preclosure safety analysis is necessary to demonstrate compliance with the preclosure performance objectives defined in 10 CFR 63.111 and must meet the requirements specified in 10 CFR 63.112. A proper preclosure safety analysis requires a systematic examination of the site, design, and hazards stemming from natural phenomena and human-induced activities that have the potential for initiating event sequences during the preclosure period, and radiological dose consequences to the public and workers. An initiating event can be a natural or human-induced occurrence that causes an event sequence with the potential for a radiological dose. Natural events result from processes in nature and are normally external to the facility, such as seismicity, tornadoes, and floods. Human-induced events, on the other hand, are hazards caused by human actions either from the internal operations at the facility, such as a canister drop, or external to the facility, such as an aircraft crash.

Yucca Mountain is located in the Basin and Range province of the western United States within the region known as the Great Basin. An overview of the characteristics of the Yucca Mountain site is provided by DOE (1998). The proposed geologic repository would combine two types of primary facilities: waste handling and temporary storage facilities constructed on the ground surface, and underground disposal facilities constructed approximately 320 m [1,050 ft] beneath the Earth's surface. Surface facilities will be provided for receiving, preparing, and packaging nuclear wastes received at the site before sending them underground for disposal. The underground facilities would include the underground structure; backfill materials, if any; ramps; and shafts and boreholes, including seals.

A comprehensive list of natural and human-induced events at the geologic repository operations area of the proposed repository at Yucca Mountain must be prepared based on known or predicted geological, seismological, hydrological, geochemical, geomechanical, and meteorological characteristics of the site and surface, subsurface, and airborne activities that occurred in the past, are currently ongoing, or could potentially occur. Additionally, operations envisioned to be performed at the proposed geologic repository operations area will dictate the list of potential operational initiating events that need to be considered in the preclosure safety analysis. Current plans for waste handling and emplacement operations include receiving transportation casks with spent nuclear fuel and vitrified high-level waste; transferring waste from transportation casks to waste packages in the Waste Handling Building, including blending of waste; transporting waste packages to the emplacement drifts; and positioning the waste packages in the drifts using an emplacement gantry. Events related to facility operations would be dominated by the complexity of construction and operations in the geologic repository operations area. Because DOE has not finalized the design and operations of the proposed repository, including the waste package, a comprehensive hazards list based on site information and facility design is not available at this time. However, DOE developed a generic list of natural hazards and initiating events for the geologic repository operations area at Yucca Mountain (CRWMS M&O, 1999a,b; DOE, 2001a). Additionally, DOE developed a preliminary list of operational hazards associated with the preclosure operations (CRWMS M&O, 1999c; DOE, 2001a). These generic lists serve as the starting point to develop a comprehensive list of site- and facility-specific hazards that have potentials to initiate event sequences with radiological consequences. Only events that have a probability of 1×10^{-6} or greater per year are included in these generic lists. This probability is based on the definition of Category 2 event in 10 CFR Part 63 and an assumption of 100 years of preclosure period.

1.2 Relevance to Repository Safety

One aspect of a risk-informed U.S. Nuclear Regulatory Commission review is to determine how identification of hazards and initiating events relates to that portion of the DOE repository safety strategy addressing compliance with performance objectives during the preclosure period. Demonstration of compliance with the preclosure performance objectives of 10 CFR 63.111 requires a safety analysis of the geologic repository operations area for the preclosure period that meets the requirements specified in 10 CFR 63.112. Both natural and human-induced initiating events, in addition to operational hazards, may lead to an event sequence with the potential for radiological release. Therefore, proper identification of hazards and initiating events is critical for demonstrating compliance with the preclosure performance objectives during operations, as identified in 10 CFR 63.21(c)(5).

1.3 Objectives and Scope

The overall objective of this report includes

- Reviewing the generic list of hazards and initiating events identified by DOE for completeness.

- Systematically evaluating information, data, and analyses presented by DOE about identified hazards and initiating events in the generic events list for appropriateness to the proposed repository at Yucca Mountain, taking into consideration current knowledge of the facility design.

- Assessing the decision by DOE about whether to include these hazards in the preclosure safety analysis. Additionally, limited independent analyses have been carried out, as warranted, to support this assessment.

Design of the proposed repository is not finalized, and changes are anticipated. Additionally, staff have not completed reviewing all documents developed by DOE on these hazards and initiating events or their independent assessments. Consequently, this is a progress report on the hazards and initiating events currently assessed. It is anticipated that this report will be updated periodically to document assessment of other hazards, including additional information and analyses developed by DOE for any hazards and initiating events.

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2 NATURALLY OCCURRING AND HUMAN-INDUCED EXTERNAL HAZARDS

2.1 Introduction

The U.S. Department of Energy (DOE) has developed a generic list of naturally occurring and human-induced hazards that need to be considered for potential radiological release from the proposed repository during the preclosure period (CRWMS M&O, 1999b). Events in this list are based on the hazard evaluation techniques described in American Institute of Chemical Engineers (1992) and System Safety Society (1997). This identification of hazards uses the DOE Enhanced Design Alternative II (CRWMS M&O, 1999d). CRWMS M&O (1999b) provides the background information on each identified hazard necessary to assess if it has sufficient potential to become an initiating event during the assumed 100-year preclosure period.

For each identified hazard, a consistent sequence of five evaluation criteria were applied by DOE to determine whether or not each hazard could be screened out from further consideration. The criteria were intended to ensure potentially significant hazards with event frequencies potentially exceeding 10^{-6} per year and that were not already incorporated within the definition and analysis of another event would be considered as potential Design Basis Events for the proposed 100-year operational period of a geological repository. Screening of the DOE generic hazards list resulted in 12 hazards applicable to the preclosure period that need further evaluation.

2.2 Development of Generic Hazards List

2.2.1 Overview of the DOE Analysis

DOE analysis to develop a generic list of natural and human-induced hazards began with the preparation of a generic list of potential events that, if determined to be applicable to Yucca Mountain during the preclosure period, could result in a radioactive release. The development of the generic list used existing documents from various sources for which similar work has been done. The generic hazard list contains 53 events at Yucca Mountain (CRWMS M&O, 1999b). The hazards in the generic list were screened for potential for becoming initiating events during an assumed 100-year preclosure period, taking into consideration the following 5 criteria.

(i) The potential exists for the initiating event to be applicable to the proposed repository site at Yucca Mountain. Additional and separate analyses may be needed to establish the potential.

(ii) The rate of the initiating event is sufficiently high to affect the potential repository during the 100-year operational period. If additional analysis can justify that the process is slow enough that it does not pose a potential hazard to the proposed repository during the 100-year period, the event will be screened out from further consideration as a Design Basis Event(s).

(iii) Consequence of the initiating event is sufficiently high to affect the potential repository during the 100-year operational period.

(iv) Initiating event annual frequency is greater than or equal to 1×10^{-6}. Any event with a probability of occurring at least one in 10,000 during the 100-year operational period is considered further.

(v) An initiating event is not bounded by analysis of another event.

If all these screening criteria are determined to be true for any external event, the event is included in the hazards list for the proposed repository. If any statement or screening criterion cannot be evaluated appropriately at this time because of lack of specific information, the outcome of the screening criterion is assumed to be true. The complete list of generic natural and human-induced external hazards considered by DOE is shown in Table 2-1.

2.2.2 Staff Assessment

The five-step screening approach employed by DOE is systematic and consistent with relevant approaches for overall screening of each identified external hazard. Staff review of the comprehensiveness of the generic hazards list is in progress. Review completed so far has identified some hazards that were not included in the generic hazards list. Examples include, but are not limited to, ice, snow, low temperature, hail, freezing rain, frost, fog, drought, high temperature, and toxic chemical releases.

DOE is also considering a low-temperature operating mode for the proposed repository (DOE, 2001a). Several options are being considered to lower the temperature and, thereby, extending the preclosure period to as long as 325 years. Consequently, adopting this option will change the threshold criterion (iv) given before. With an assumed preclosure period of 100 years, the regulatory probability limit of 1 event in 10,000 in a year translates to a threshold annual frequency of 1×10^{-6}. However, for a preclosure period of 325 years, the annual threshold frequency becomes 3.1×10^{-7}. Therefore, DOE should reevaluate each generic hazard in the list using a threshold frequency criterion of 3.1×10^{-7} per year, instead of 1×10^{-6} per year, if a preclosure period of 325 years is selected.

2.2.3 Path Forward

Staff review has identified some hazards that were not included in the generic hazards list developed by DOE. DOE needs to consider their applicability for the proposed repository during the preclosure period. Some or all of these events may ultimately be screened from further consideration in the preclosure safety analysis, but they need to be considered and systematically evaluated in the screening analysis.

Staff are continuing assessments of available DOE documents and analyses to develop positions on other hazards and initiating events. Additionally, staff are looking for additional information from independent sources, if available, to supplement the DOE-submitted information and analyses.

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Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a)

No.	Hazard	Hazard Definition	DOE Assessment
1	Avalanche	A large mass of snow, ice, soil, or rock or mixtures of these materials, falling, sliding, or flowing under gravity	Not applicable to the hazards list • High mountain ranges do not exist at Yucca Mountain
2	Coastal Erosion	Wearing away of soil and rock by waves and tidal action	Not applicable to the hazards list • Coastline does not exist at Yucca Mountain
3	Dam Failure	Failure of a large man-made barrier that creates and restrains a large body of water	Not applicable to the hazards list • No dam of sufficient size exits in proximity to Yucca Mountain
4	Debris Avalanche	Sudden and rapid movement of debris down steep slopes resulting from intensive rainfall	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficient to affect 100-year preclosure period • Consequence of process is significant • Annual event frequency $\geq 10^{-6}$ • Not included in another analysis
5	Denudation	Sum of processes that results in wearing away or progressive lowering of Earth's surface by weathering, mass wasting, and transportation	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is too low for 100-year preclosure period
6	Dissolution	Processes of chemical weathering by which mineral and rock material passes into solution	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high to affect 100-year preclosure period and may create rockfall • Consequence is indeterminant; assumed equivalent to significant enough to affect 100-year preclosure period • Annual event frequency is indeterminant; assumed $\geq 10^{-6}$ • Bounded by Key Block Analysis Report, which will address rockfall issue

Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
7	Eperogenic Displacement	Geomorphic processes of uplift and subsidence that produced broader features of continents and oceans	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is not sufficient to pose credible hazard during 100-year preclosure period
8	Erosion	Slow wearing of soil and rock by weathering, mass wasting, and action of streams	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is not sufficient to pose credible hazard during 100-year preclosure period
9	Extreme Weather Fluctuations	Various types of weather fluctuations that pose unusual design challenges	Not applicable to the hazards list • No potential exists at Yucca Mountain
10	Extreme Wind	"Fastest mile of wind" with 100-year return period	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficient during 100-year preclosure period • Potential consequence is indeterminant; assumed equivalent to true • Annual event frequency $\geq 10^{-6}$ • Not included in another analysis
11	Flood (Storm, River Diversion)	Area covered with water from storm or river diversion caused by inadequate drainage	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year preclosure period • Consequences of process are sufficiently high • Annual event frequency $\geq 10^{-6}$ • Not included in another analysis
12	Fungus, Bacteria, and Algae	General class of microorganisms that may be present in subsurface environment	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year preclosure period • Consequence of process not significant to affect 100-year preclosure period

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Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
13	Glacial Erosion	Lowering of Earth's surface caused by grinding and scouring by glacier ice armed with rock fragments	Not applicable to the hazards list • No potential exists at Yucca Mountain for a glacier
14	Glaciation	Formation, movement, and recession of glaciers or ice sheets	Not applicable to the hazards list • No potential exists at Yucca Mountain for a glacier and associated climate change
15	High Lake Level	Potential overflow or flooding of lake	Not applicable to the hazards list • No potential exits at Yucca Mountain because there is no lake nearby
16	High Tide	High tide in water connected with ocean having potential for flooding inland areas	Not applicable to the hazards list • No potential exits at Yucca Mountain because there is no ocean or coastal area
17	High River Stage	Potential flooding of river or natural permanent or seasonal surface stream with considerable volume	Not applicable to the hazards list • No potential exists at Yucca Mountain because there is no river nearby
18	Hurricane	Intense cyclone that forms over tropical oceans	Not applicable to the hazards list • No potential exists at Yucca Mountain because it is located approximately 360 km [225 mi] inland from nearest ocean, northeast of Santa Monica Bay near Los Angeles; based on American National Standards Institute/American Nuclear Society (1992), site needs to be within 160 to 320 km [100 to 200 mi] from ocean for hurricane to be potential natural hazard
19	Landslides	Wide variety of mass movement of land forms and processes involving downslope transport with gravitational influence	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high to affect 100-year preclosure period • Consequence is indeterminant; assumed equivalent to true • Annual event frequency $\geq 10^{-6}$ • Not part of another analysis

Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
20	Lightning	Flashing of light produced by discharge of atmospheric electricity between charged cloud and Earth	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year preclosure period • Consequence is indeterminant; assumed equivalent to true • Annual event frequency $\geq 10^{-6}$ • Not part of another analysis
21	Low Lake Level	Low level of lake water used for cooling	Not applicable to the hazards list • No potential exists at Yucca Mountain because it is not required for cooling system
22	Low River Level	Low level of river water used for cooling	Not applicable to the hazards list • No potential exists at Yucca Mountain because it is not required for cooling system
23	Meteorite Impact	Impact of meteoroid reaching Earth's surface without completely vaporizing	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year preclosure period • Consequence is indeterminant; assumed equivalent to true • Annual event frequency $\leq 10^{-6}$
24	Orogenic Diastrophism	Movement of Earth's crust produced by tectonic processes where structures within fold-belt mountain areas formed, including thrusting, folding, and faulting	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is too low to affect 100-year preclosure period
25	Rainstorm	Storm that produces 100-year or greater maximum rainfall rate occurring for 1 day	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year preclosure period • Consequence is indeterminant; assumed significant • Annual event frequency $\geq 10^{-6}$ • Bounded by debris avalanche, flooding, and landslide events for which this is initiator

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Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
26	Range Fire	Combustion of natural vegetation external to repository that propagates to combustible materials within operations area	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year operational period • Consequences are significant • Annual event frequency ≥ 10^{-6} • Will be addressed in fire hazard analyses
27	Sandstorm	Extreme wind capable of transporting sand and other unconsolidated surficial materials	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficient during 100-year preclosure period • Consequence is indeterminant; assumed significant • Annual event frequency ≥ 10^{-6} • Bounded by extreme wind and tornado events • Potential filter clogging is screened out from further consideration because of capability for orderly facility shutdown through technical specification—a to-be-verified item
28	Sedimentation	Process of forming or accumulating sediment in layers	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is too low in 100-year preclosure period
29	Seiche	Free or standing wave oscillation of water surface in enclosed or semienclosed basin	Not applicable to the hazards list • No potential exists at Yucca Mountain because there is no large body of water nearby
30	Seismic Activity (Uplifting)	Structurally high area in the crust, produced by positive movements over long time periods resulting in faults giving rise to upthrust of rocks	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is too slow in 100-year preclosure period

Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
31	Seismic Activity (Earthquake)	Earthquakes including those artificially induced	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year preclosure period • Consequence is significant • Mean annual probabilities of Frequency Categories 1 and 2 design basis ground motions are 1 × 10^{-3} and 1 × 10^{-4}; structures, systems, and components important to safety will be designed to withstand design basis earthquake (Frequency Categories 1 and 2), as appropriate • Not bounded by another analysis
32	Seismic Activity (Surface Fault Displacement)	Fracture or zone of fractures along which there is potential for displacement of sides relative to each other, parallel to fracture	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year preclosure period • Mean annual probabilities of Frequency Categories 1 and 2 design basis ground motions are 1 × 10^{-3} and 1 × 10^{-4}; structures, systems, and components important to safety will be designed to withstand fault displacements from design basis earthquakes (Frequency Categories 1 and 2), as appropriate • Not bounded by another analysis
33	Seismic Activity (Subsurface Fault Displacement)	Fracture or zone of fractures along which there is potential for displacement of sides relative to each other, parallel to fracture	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high during 100-year preclosure period • Mean annual probabilities of Frequency Categories 1 and 2 design basis ground motions are 1 × 10^{-3} and 1 × 10^{-4}; structures, systems, and components important to safety will be designed to withstand fault displacements from design basis earthquakes (Frequency Categories 1 and 2), as appropriate • Not bounded by another analysis

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Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)			
No.	**Hazard**	**Hazard Definition**	**DOE Assessment**
34	Static Fracturing	Break in rock caused by mechanical failure by stress	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high to affect 100-year preclosure period • Consequence is indeterminant; assumed significant • Annual event frequency ≥ 10^{-6} • Will be addressed in Key Block Analysis Report
35	Stream Erosion	Progressive removal of bedrock, overburden, soil, or other exposed matters from stream channel surface	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is too slow to affect 100-year preclosure period
36	Subsidence	Sudden sinking or gradual downward settling of Earth's surface with little or no horizontal motion	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high to affect 100-year preclosure period • Consequence is indeterminant; assumed significant • Annual event frequency ≥ 10^{-6} • Screened out because subsurface fault displacement will be only natural phenomenon that would result in collapse of underground excavations leading to subsidence; emplacement levels would be at least 200 m [656 ft] below the directly overlying ground surface; emplacement drifts will be supported by rock bolts, steel mesh, and steel sets; no surface-handling facilities will be directly over emplacement drifts
37	Tornado	Small cyclone generally less than 500 m [1,650 ft] in diameter with extremely strong winds	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficient to affect 100-year preclosure period • Consequence is indeterminant; hence, assumed significant • Annual event frequency ≥ 10^{-6} • Not bounded by another analysis

Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
38	Tsunami	Gravitational sea wave produced by large-scale, short-duration disturbance on ocean floor	Not applicable to the hazards list • No potential exists at Yucca Mountain because there is no coastal region
39	Undetected Geologic Features	Geologic features of concern to the 100-year preclosure period include natural events such as faults and volcanoes	Not applicable to the hazards list • No potential exists at Yucca Mountain; site characterization provided sufficient assurance that these types of activities would have been detected
40	Undetected Geologic Processes	Geologic processes of concern to the 100-year preclosure period include events such as erosion, tectonic, and seismic processes	Not applicable to the hazards list • No potential exists at Yucca Mountain; site characterization provided sufficient assurance that these types of activities would have been detected
41	Volcanic Eruption	Magma and associated gases rise into the crust and are extruded onto Earth's surface and into atmosphere	Not applicable to the hazards list • No potential exists at Yucca Mountain because there is no potential for volcanic center at the site
42	Volcanism (Intrusive Magmatic Activity)	Development and subsurface movement of magma and mobile rock materials	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficiently high to affect 100-year preclosure period • Consequence is indeterminant; assumed significant • Annual event frequency $\leq 10^{-6}$
43	Volcanism (Ash Flow, Extrusive Magmatic Activity)	Highly heated mixture of volcanic gases, magma, mobile rock material, and ash traveling down the flank of a volcano or along ground surface	Not applicable to the hazards list • No potential exists at Yucca Mountain for silicic volcanism

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Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
44	Volcanism (Ash Fall)	Airborne volcanic ash falling from eruption cloud	Not applicable to the hazards list • Potential exists for ash fall within 100-year preclosure period at Yucca Mountain • Rate of process is indeterminant; hence, assumed to be significant • Consequence not significant to affect 100-year preclosure period because—worst-case ash fall depth is 3 cm [1.2 in]—worst-case live load on flat roof is 868.5 Pa [18.14 lb/ft^2], which is less than minimum 1997 Uniform Building Code requirements • Filter clogging due to ash fall is bounded by filter clogging by sandstorm event
45	Waves	Oscillatory movement of water manifested by alternate rise and fall of water surface	Not applicable to the hazards list • No potential exists at Yucca Mountain because there is no large body of water nearby
46	Aircraft Crash	Accidental impact of aircraft on the site facilities	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process (i.e., impact of the crash) is immediate • Consequence is significant • Event frequency $\leq 10^{-6}$ per year
47	Inadvertent Future Intrusions (Human-Induced)	Human-induced inadvertent future intrusions with regard to 100-year preclosure period involve undetected surface access into proposed repository facilities	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficient to affect 100-year preclosure period • Consequence is indeterminant; hence, assumed significant • Annual event frequency is indeterminant; hence, assumed significant • Will be considered in future safeguards and security analyses—a to-be-verified item

Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
48	Intentional Future Intrusions (Human-Induced)	Human-induced intentional future intrusions with regard to 100-year preclosure period involve undetected surface access, sabotage, or both to the proposed repository facilities	Not applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficient to affect 100-year preclosure period • Consequence is indeterminant; hence, assumed significant • Annual event frequency is indeterminant, hence, assumed significant • Will be considered in future safeguards and security analyses—a to-be-verified item
49	Industrial Activity-Induced Accidents	Accidents resulting from industrial or transportation activities unrelated to proposed repository	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is sufficient to affect 100-year preclosure period • Consequence is indeterminant; hence, assumed significant • Annual event frequency is indeterminant at this time; hence, assumed significant • Not bounded by another analysis
50	Loss of Off-site/On-site Power	Loss of electric power either generated or controlled by persons outside repository system or loss of power within repository	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of the process is indeterminant at this time; hence, assumed significant • Consequence is indeterminant; hence, assumed significant • Annual event frequency is indeterminant at this time; hence, assumed significant • Not bounded by another analysis
51	Military Activity-Induced Accidents	Accidents resulting from military activities at Nevada Test Site or Nellis Air Force Range	Applicable to the hazards list • Potential exists at Yucca Mountain • Rate of process is indeterminant at this time; hence, assumed significant • Consequence of the process is indeterminant at this time; hence, assumed significant • Annual event frequency is indeterminant at this time; hence, assumed significant • Not bounded by another analysis

Table 2-1. List of Natural Hazards and Human-Induced Events with DOE Assessment (after CRWMS M&O, 1999a; DOE, 2001a) (continued)

No.	Hazard	Hazard Definition	DOE Assessment
52	Pipeline Accidents	Industrial pipeline transporting hazardous materials	Not applicable to the hazards list • No potential exists at Yucca Mountain; no industrial activities requiring pipelines containing hazardous materials exist or are planned to be located near the site
53	Undetected Past Intrusions	Past intrusions involve mining activities where deep shafts, drill holes, or tunnels may have been excavated	Not applicable to the hazards list • No potential exists at Yucca Mountain; site characterization provided sufficient assurance that these types of activities would have been detected

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2.3 Specific Hazards

An in-depth review of a limited number of naturally occurring and human-induced external hazards is provided in the following sections.

2.3.1 Seismic and Faulting Hazards

2.3.1.1 Overview of the DOE Analysis

DOE developed probabilistic seismic and faulting hazard assessments to characterize the potential earthquake and faulting hazards at Yucca Mountain (CRWMS M&O, 1998a; Stepp, et al., 2001). The approach was similar to that suggested for a Level 4 probabilistic seismic hazard assessment, as defined in Budnitz, et al. (1997). The Level 4 probabilistic seismic hazard assessment includes the use of expert elicitation. Because of the limited availability of sufficient strong motion data and uncertainties in the seismologic characteristics of the Yucca Mountain site and region, DOE convened two expert panels. One panel evaluated the seismic source characterization. The other panel developed probabilistic models for ground motion attenuation specific to the regional conditions of the western Basin and Range in proximity to Yucca Mountain.

Development of Budnitz, et al. (1997) followed a methodology first proposed by Cornell (1986) and McGuire (1976) and used a modified version of the FRISK88 computer code (Risk Engineering, Inc., 1998). Within this approach, uncertainties were propagated through the analyses, and the results were presented as mean, median, and fractile hazard curves that incorporate uncertainties in the input parameters.

2.3.1.1.1 Seismic Source and Fault Displacement Characterization

For this elicitation, DOE assembled 18 experts, divided into 6 expert teams. Six elicitation workshops were held between 1995 and 1998 (CRWMS M&O, 1998a), where the experts exchanged information on seismic sources. Details of the workshops are given in CRWMS M&O (1998a) and Stepp, et al. (2001). In addition to developing seismic hazard assessments, the seismic source zone characterization experts also were tasked to develop fault-specific probabilistic fault displacement hazards. These fault displacement hazard assessments used an approach similar to the one used in the seismic source zone characterization. To assess seismic sources and fault sources, the expert teams mainly relied on information provided by U.S. Geological Survey and DOE maps and reports (e.g., U.S. Geological Survey, 1996; Piety, 1995; Anderson, et al., 1995a,b; Simons, et al.,1995), published scientific literature (e.g., Scott, 1990; Zhang, et al.,1990; Reheis and Dixon, 1996; Reheis and Sawyer, 1997), and Center for Nuclear Waste Regulatory Analyses publications (e.g., Ferrill, et al., 1996; McKague, et al., 1996; Stamatakos, et al., 1997). More detailed staff discussions are provided by NRC (1999b).

2.3.1.1.2 Ground Motion Attenuation

DOE assembled seven experts for the ground motion elicitation, and the elicitation process was conducted in parallel with that of the seismic source zone elicitation. The ground motion experts were tasked to provide input (e.g., data, scientific interpretations, and estimates of parameter uncertainties) for developing the probabilistic ground motion attenuation model (i.e., mathematical relationships between ground motion and earthquake magnitude, distance, site conditions, and style of faulting). Unlike the case for seismic source characterization, experts for this elicitation team were asked to provide intermediate results that were then used to develop the final probabilistic seismic hazard assessment (Budnitz, et al.,1997) ground motion relationships. These models were subsequently aggregated to (probabilistically) represent the current state of knowledge with regard to ground motions possible at the Yucca Mountain site caused by earthquake phenomena. More detailed discussions by staff are provided by NRC (1999b).

2.3.1.2 Staff Assessment

The staff reviewed the information developed by DOE through the documentation process on seismic source zone and fault displacement characterization (CRWMS M&O, 1998a; Stepp, et al., 2001) and found it sufficient to use in a potential Yucca Mountain license application. DOE adequately justified the need for the elicitation and conducted the elicitation in accordance with the guidance set forth in NUREG–1563 (NRC, 1996).

Staff have concerns, however, regarding the ground motion characterization component of the Yucca Mountain seismic hazard analysis. Specific staff concerns relate to the ground motion expert elicitation process and lack of site-specific seismic data, including inputs to the site response model. Because the ground motion experts provided intermediate results, it is uncertain if the experts considered the application of those results to the aggregate ground

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motion model appropriate. In addition, DOE has not yet published specific seismic site response models and site-specific seismic design input for surface and subsurface facilities.

2.3.1.3 Path Forward

To close the seismic and faulting hazards subissue, DOE needs to provide the documentation originally requested by NRC during the October 2000 Structural Deformation and Seismicity Key Technical Issue Technical Exchange[1] to establish that the ground motion experts agree with and understand the application of their results to the final ground motion models. The staff seek DOE documentation of the extent to which each of the seven ground motion experts understood the probabilistic modeling concepts associated with the respective inputs to the attenuation models, as well as the subsequent implementation of the model in the broader probabilistic seismic hazard assessment. DOE agreed to provide information that includes the Seismic Design Inputs Report and the Seismic Topical Report Number 3. In addition, DOE needs to provide data and interpretations for the site response models for the surface and subsurface facilities.

2.3.2 Aircraft Crash Hazard

2.3.2.1 Overview of the DOE Analysis

DOE conducted an analysis to estimate the hazards to the proposed repository at Yucca Mountain from potential aircraft crashes (CRWMS M&O, 1999e). CRWMS M&O (1999e) used the suggested methodology of NUREG–0800 (NRC, 1981a, Section 3.5.1.6) to estimate the probability of aircraft crash onto the proposed high-level waste repository. Additionally, CRWMS M&O (1999e) used the methodology suggested in the DOE (1996) to estimate the effective area of a particular structure and the crash rate data for different aircraft developed by Kimura, et al. (1996). These documents are commonly used for estimating aircraft crash hazard to a facility and are, therefore, acceptable.

NUREG-0800 (NRC, 1981a, Section 3.5.1.6) specifies that the probability of aircraft crash is considered to be less than about 10^{-7} per year by inspection if the distance from the facility meets all the following requirements:

(a) The facility-to-airport distance, D, is between 8 and 16 km [5 and 10 statute miles], and the projected annual number of operations is less than $500 \times D^2$, or D is greater than 16 km [10 statute miles], and the projected annual number of operations is less than $1{,}000 \times D^2$.

(b) The facility is at least 8 km [5 statute miles] from the edge of military training routes, including low-level training routes, except for those associated with a usage greater than 1,000 flights per year, or where activities (such as practice bombing) may create an unusual stress situation.

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[1] Schlueter, J.R. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Structural Deformation and Seismicity (October 11–12, 2000)." Letter (October 27) to S. Brocoum, DOE. Washington, DC: NRC. 2000.

(c) The facility is at least 3.2 km [2 statute miles] beyond the nearest edge of a federal airway, holding pattern, or approach pattern.

If the previous proximity criteria are not satisfied or if sufficiently hazardous military activities are identified, a detailed review of aircraft crash hazards must be performed (NRC, 1981a). These criteria, given in NUREG–0800, are applicable for a nuclear power plant. The methodology in NUREG–0800 (NRC, 1981a, Section 3.5.1.6) has been adopted for the proposed repository at Yucca Mountain.

CRWMS M&O (1999e) concluded that proximity criteria (a) and (c) are satisfied for commercial aircraft, private aircraft, DOE aircraft, and aircraft chartered by the DOE. Proximity criterion (b) is not applicable for these types of aircraft. Proximity criteria (a) and (b) are also satisfied for military aircraft. Only criterion (c) is not satisfied for military aviation in the vicinity of the proposed site and, therefore, an analysis estimating the annual crash frequency of military aviation is provided in CRWMS M&O (1999e).

Commercial and limited chartered aircraft use both McCarran International and North Las Vegas Airports. Chartered aircraft also utilize Tonopah Airport (CRWMS M&O, 1999e). All three airports are more than 48 km [30 mi] from the proposed site. Commercial aircraft flying in the vicinity of the proposed repository site use federal airways V105–V135 (CRWMS M&O, 1999e). Airways V105–V135 are for air traffic below 5,400 m [18,000 ft] above mean sea level. Jet Route J–92 overlies V105 and is used by air traffic over 5,400 m [18,000 ft] above mean sea level (CRWMS M&O, 2000a). These airways are used by commercial air traffic between Las Vegas, Reno, and other airports in the southwestern and northwestern United States. CRWMS M&O (2000a) stated that the commercial air traffic is generally jet liners flying over 5,400 m [18,000 ft] above mean sea level through J–92. In addition, private aircraft use McCarran International, North Las Vegas, Beatty, Frans Star, and Jackass airports (CRWMS M&O, 1999e). Private aircraft use federal airways V105–V135 while flying near the proposed repository site (CRWMS M&O, 1999e). The distance from the nearest edge of this 16-km [10-mi] wide airway to the proposed site is 17.6 km [11 statute miles]. CRWMS M&O (1999e) did not estimate the annual frequency of crash onto the proposed repository for aircraft flying these federal airways because Criterion (c) of NRC (1981a) has been satisfied.

General aviation aircraft flying under visual flight rules occasionally use U.S. Highway 95 for navigation and fly below 5,400 m [18,000 ft] above mean sea level (CRWMS M&O, 2000a). CRWMS M&O (1999e) also indicated that private aircraft primarily use McCarran International, North Las Vegas, Beatty, Frans Star, and Jackass Airports. CRWMS M&O (1999e) stated that the closest point from the surface facilities of the proposed repository to the edge of the restricted airspace over the Nevada Test Site is 3.2 km [2 statute miles]. Additionally, DOE may permit private aircraft to fly through the restricted airspace of R–4808S on a per flight basis. The nearest edge of R–4808S airspace is 7.2 km [4.5 statute miles] from the surface facilities of the proposed repository. Consequently, CRWMS M&O (1999e) did not estimate the annual crash frequency of general aviation aircraft onto the proposed repository because Criterion (c) of NRC (1981a) has been satisfied.

The DOE aircraft and aircraft chartered by DOE also use the federal airways near the proposed site. These aircraft can use any airfield or landing strip within the Nevada Test Site (CRWMS M&O, 1999e). Airports controlled by DOE within 48 km [30 mi] of the proposed repository site are Desert Rock, Yucca, and Pahute Mesa. Aircraft chartered by DOE for flying between Desert Rock airfield and laboratories in California and New Mexico use federal airways V105–V135. The approach pattern to the Desert Rock airfield is outside the restricted area and at least 16 km [10 mi] from the proposed repository site (CRWMS M&O, 1999e). Airways V105–V135 are 16 km [10 mi] wide and the nearest edge is 17.6 km [11 statute miles] from the proposed repository surface facilities. A total of 54,000 operations take place annually at Desert Rock, Yucca, and Pahute Mesa airfields (CRWMS M&O, 1999e). CRWMS M&O (1999e) did not estimate the annual probability of crash because Criterion (c) of NRC (1981a) has been satisfied.

Helicopters routinely fly in most areas within the restricted airspace of the Nevada Test Site. Based on the information provided by CRWMS M&O (1999e), at least 1,440 helicopter flights take place annually within 3.2 km [2 mi] of the proposed repository surface facilities. These helicopters fly along 40 Mile Wash, located 2.4 km [1.5 mi] from the proposed repository site. CRWMS M&O (1999e) Assumption 4.3.4 states that helicopter routes would be adjusted 3.2 km [2 mi] away from the surface facilities of the proposed repository.

Military aircraft use Nellis Air Force Base, Tonopah Test Range, and Indian Springs Air Force Auxiliary Base airports located at distances greater than 48 km [30 mi] from the proposed site. Military aircraft, DOE aircraft, and aircraft chartered by DOE fly through restricted airspace R–4808. There is a classified memorandum of understanding between the U.S. Air Force and DOE Nevada Operations that allows military aircraft flying through the restricted airspace R–4808 to transit the 60 and 70 series ranges of the Nellis Air Force Base Range (CRWMS M&O, 1999e). The entire area is available for an aircraft to transit. No prior approval from DOE is needed unless specifically notified to the contrary by DOE (Kimura, et al., 1998).

Restricted airspace R–4808 is divided into R–4808N and R–4808S. Restricted airspace R–4808N is controlled by DOE for activities in the Nevada Test Site. R–4808S is jointly used by the Nevada Test Site, Nellis Air Force Base, and the Federal Aviation Administration, Los Angeles Air Traffic Route Traffic Control Center for overflight of civilian aircraft. Southwestern and western parts of these restricted airspaces are used by military aircraft transiting restricted airspaces R–4807A and R–4807B. R–4808B is also used by DOE for flights to the Pahute Mesa area as an extension of the Nevada Test Site. Additionally, there are 21 military training routes within the Nellis Range Complex (U.S. Air Force, 1999). Some of these routes are located close to the proposed repository site. Information about potential aircraft traffic in these restricted airspaces and military training routes is necessary to estimate the potential hazards to the proposed facility.

CRWMS M&O (1999e) estimated the military aircraft annual crash frequency onto surface facilities at the proposed repository assuming F-16, F-15, and A-10 aircraft is representative of all aircraft. In this analysis, F-16 aircraft conduct 29 percent of all sorties in a year. The remaining 71 percent of the sorties are by F-15 and A-10 aircraft, with F-15s flying 90 percent of the remaining sorties. CRWMS M&O (1999e) fitted a normal distribution to 6 months of flight data and developed 3 estimates of monthly sorties: (i) a mean of 1,059.67 sorties, (ii) a 90-percent confidence interval of 1,059.67 sorties, and (iii) a 95-percent confidence interval of 1,575.87 sorties. Calculation of the effective area was accomplished two ways: using the Bounding Case that includes the Waste Handling Building, Waste Treatment Building, Carrier Preparation Building, Parking Area for loaded trucks, and Parking Area for loaded rail carriers, and a Best Estimate Case using only the Waste Handling Building.

CRWMS M&O (1999e) estimated the annual frequency of aircraft crashes onto the surface facilities at the proposed repository using only military aircraft. This estimation was calculated in three ways:

(1) Assuming the crash rate of small aircraft including all fighter, attack, and training aircraft, is representative of the aircraft flying in the vicinity of the proposed repository. This analysis was termed the Bounding Case.

(2) Assuming a mix of F-16, F-15, and A-10 aircraft and the Bounding Case effective area. This analysis was termed the Sensitivity Case.

(3) Assuming the same mix of F-16, F-15, and A-10 aircraft and the Best Estimate Case effective area. This analysis was termed the Best Estimate Case.

The annual frequency was estimated using two methodologies, NUREG–0800 (NRC, 1981a) and Kimura, et al. (1998). Annual crash frequencies estimated by CRWMS M&O (1999e) for the proposed repository by military aircraft using NUREG–0800 methodology are given in Table 2-2. Annual crash frequencies estimated by CRWMS M&O (1999a) using Kimura, et al. (1998) are given in Table 2-3. Based on the results in Tables 2-2 and 2-3, DOE has excluded aircraft crash hazard from further consideration (CRWMS M&O, 1999e, 2000a; DOE, 2001a; Bechtel SAIC Company, LLC, 2001).

2.3.2.2 Staff Assessment

Staff reviewed CRWMS M&O (1999e) and disagree with the conclusion that aircraft crash is not a credible hazard at the proposed repository during the preclosure period. Staff also do not agree with several assumptions made in CRWMS M&O (1999e) without defensible bases. Lack of specific information on flight activities near the proposed repository does not allow development of a defensible estimate of aircraft crash frequency, considering all potential sources. Additionally, staff conducted a few confirmatory and sensitivity analyses with alternative scenarios and assumptions based on the same data in CRWMS M&O (1999e). These analyses show that lack of justifiable and specific information introduces significant uncertainties in the estimated crack frequency. Details of the staff review follow.

2.3.2.2.1 Effective Area Estimation

CRWMS M&O (1999e) assumed that considering the Waste Handling Building alone would be the Best Estimate Case for estimating the aircraft crash hazard. Staff do not agree with this assumption. The site plan shows that the Waste Handling Building and the Waste Treatment Building are adjacent. Any aircraft crash on the Waste Treatment Building has the potential to affect the Waste Handling Building and any operations being conducted therein at the time of the crash. Therefore, for estimating the effective area of the buildings, these two structures should be considered as one, as suggested in the DOE Standard (DOE, 1996a).

CRWMS M&O (1999e) erroneously used the formulas specified in the DOE (1996a, Appendix B) to calculate the effective area of a structure. As a consequence, the estimated effective area is smaller and results in underestimating the crash frequency. The difference is

Table 2-2. Estimated Annual Crash Frequency Using NUREG–0800 Methodology (CRWMS M&O, 1999e)			
Number of Annual Sorties	**Bounding Case**	**Sensitivity Case**	**Best Estimate Case**
12,716 (Mean)	6.55×10^{-7}	5.98×10^{-7}	2.80×10^{-7}
17,542 (90-percent confidence level)	9.04×10^{-7}	8.24×10^{-7}	3.86×10^{-7}
18,910 (95 percent confidence level)	9.74×10^{-7}	8.89×10^{-7}	4.16×10^{-7}
Reference: CRWMS M&O. "MGR Aircraft Crash Frequency Analysis." ANL–WHS–SE–000001. Rev. 00. Las Vegas, Nevada: CRWMS M&O. 1999e.			

Table 2-3. Estimated Annual Crash Frequency Using Kimura, et al. (1998) Methodology (CRWMS M&O, 1999e)			
Number of Annual Sorties	**Bounding Case**	**Sensitivity Case**	**Best Estimate Case**
12,716 (Mean)	3.71×10^{-7}	3.39×10^{-7}	1.59×10^{-7}
17,542 (90-percent confidence level)	5.12×10^{-7}	4.67×10^{-7}	2.19×10^{-7}
18,910 (95-percent confidence level)	5.52×10^{-7}	5.04×10^{-7}	2.36×10^{-7}
References: Kimura, C.Y., D.L. Sanzo, and M. Sharirli. "Crash Hit Frequency Analysis of Aircraft Overflights of the Nevada Test Site (NTS) and the Device Assembly Facility (DAF)." UCRL–ID–131259. Rev. 1. Livermore, California: Lawrence Livermore National Laboratory. 1998. CRWMS M&O. "MRG Aircraft Crash Frequency Analysis." ANL–WHS–SE–000001. Rev. 00. Las Vegas, Nevada: CRWMS M&O. 1999e.			

more pronounced for structures that are more equidimensional, such as the Waste Handling Building.

2.3.2.2.2 Commercial Aircraft Operations at McCarran International and North Las Vegas Airports

McCarran International, North Las Vegas, and Tonopah airports are more than 48 km [30 mi] from the proposed site. Consequently, more than 900,000 annual take-off and landing operations by commercial and chartered aircraft would be necessary at these airports to have a crash probability of 10^{-7} per year at the proposed repository site based on NUREG–0800 Criterion (a). The number of commercial and chartered aircraft taking off and landing at these airports, currently, is less than 900,000. Therefore, current operations (landings and takeoffs) at these airports by commercial and chartered aircraft may be assumed to be negligible contributors to the overall aircraft crash hazard probability at the proposed site. However, if the projected traffic growth at any of these airports increases significantly during the preclosure period of the proposed facility so as to violate the 1,000 D^2 criterion [Criterion (a)] of NUREG–0800 (NRC, 1981a), a detailed analysis will be necessary.

2.3.2.2.3 Commercial Air Traffic through Federal Airways J–92 and V105–V135

CRWMS M&O (1999e) should provide the number of annual commercial air flights through Jet airway J–92 and Victor airways V105–V135 and estimate the probability of crash for aircraft flying these airways. The estimated crash probability of aircraft flying airways J–92 and V105–V135 will be components of the total aircraft crash probability onto the proposed site. In addition, there are other federal airways near the proposed site that need to be considered in the analysis.

2.3.2.2.4 General Aviation Aircraft

DOE should provide the number of annual flights and flight paths of general aviation aircraft near the proposed facility. Reliable information is necessary for estimation of the aircraft crash hazard onto the proposed repository.

2.3.2.2.5 Private Aircraft

DOE should clarify if the private aircraft, which use McCarran International, North Las Vegas, Beatty, Frans Star, and Jackass airports, include general aviation aircraft and business jets. Other airports in the vicinity are small with low traffic counts. Only Beatty, Frans Star, and Jackass airports are within 32 km [20 mi] of the proposed site. DOE should provide information regarding the flight patterns of the private aircraft in the vicinity of the proposed facility. DOE should also provide detailed information on the number of annual flights, type(s) of aircraft, and any flight activity of these aircraft within the restricted airspace. This information should be based on historical record. Additionally, DOE should estimate the annual crash frequency on the proposed repository by private aircraft.

2.3.2.2.6 Helicopter Flights

It is not clear what fraction of the helicopter flights overfly the proposed repository surface facilities. Assumption 4.3.4 of CRWMS M&O (1999e) states that DOE Nevada Operations would adjust the helicopter routes to maintain a separation of 3.2 km [2 mi] from the surface facilities of the proposed repository. This is a to-be-verified item.

2.3.2.2.7 DOE Aircraft and DOE Chartered Aircraft

DOE should identify the number of annual operations at Desert Rock, Yucca, and Pahute Mesa airfields and the year in which the stated 54,000 operations took place (CRWMS M&O, 1999e). Additionally, DOE should indicate the type(s) of aircraft that utilize the airfields and the flight path(s) taken to reach the airfields.

The number of annual operations (landings and takeoffs) at Desert Rock, Yucca, and Pahute Mesa airfields, as reported in CRWMS M&O (1999e), is sufficiently small not to pose a credible hazard to the proposed site based on the distance and number of operations criterion of NUREG–0800 (NRC, 1981a, Section 3.5.1.6). However, any projected traffic increase during the preclosure period should also be considered in the analysis. DOE should also estimate the potential crash probability of the DOE aircraft and aircraft chartered by DOE onto the proposed repository while flying to Desert Rock, Yucca, and Pahute Mesa airfields.

Staff performed a preliminary analysis to estimate the crash probability of the DOE aircraft and aircraft chartered by DOE crashing onto the proposed facility while transiting airways V105–V135, as an example (Ghosh and Sagar, 2001). Because many flights to Desert Rock, Yucca, and Pahute Mesa airfields use charter aircraft (CRWMS M&O, 1999e), staff assumed the aircraft would be similar to commercial aircraft in crash statistics. Therefore, air carrier characteristics in DOE (1996) were used. Specific information on the type(s) of aircraft used by DOE, however, should be provided to verify this assumption. Crash rate, *C*, for commercial aircraft is assumed to be 4×10^{-10} per flight mile (NRC, 1981a) for lack of information on specific aircraft type(s). Because V105–V135 are heavily traveled air corridors (more than 100 daily flights), DOE also should provide a more accurate estimation of the crash rate of the aircraft flying these airways (NRC, 1981a).

Because information is not available regarding the number of annual flights to Desert Rock, Yucca, and Pahute Mesa airfields, staff assumed, in one scenario, that all 54,000 flights use Desert Rock airfield. Staff also calculated another estimate assuming one-third of the 54,000 flights use each airfield, which, by nature of the runway surfaces, is not a valid assumption. The effective area of the surface facilities at the proposed repository has been calculated as the sum of the effective areas of each of the five structures where radioactive materials can be potentially located (CRWMS M&O, 1999e) and is equal to 0.64 km^2 [0.251 mi^2] (Ghosh and Sagar, 2001). The effective width of the airway, *W*, is $16 + 2 \times 17.6$ or 51.2 km [32 mi] because airways V105–V135 are 16 km [10 mi] wide and at a distance of 17.6 km [11 statute miles] from the proposed site (CRWMS M&O, 1999e). Therefore, the annual probability of a crash, *P*, by DOE aircraft and aircraft chartered by DOE, based on NUREG–0800 (NRC, 1981a), is

$$P = N \times C \times \frac{A_{\text{eff}}}{W} = 54{,}000 \times 4 \times 10^{-10} \times \frac{0.251}{32} = 1.7 \times 10^{-7} \qquad (2\text{-}1)$$

Assuming only one-third of the aircraft use Desert Rock airfield, the annual crash probability is 6×10^{-8}. As discussed before, these scenarios may not be representative of the actual situation. Reliable information is needed to conduct a realistic analysis of crash hazard. Estimation of crash hazard for aircraft specifically flying to Yucca and Pahute Mesa airfields also requires information about flight path(s). This analysis shows the effects of lack of specific information on the estimated crash probability. Lack of specific information introduces significant uncertainty in the estimated probability of crashes. Several different scenarios seem probable. Development of a bounding scenario becomes quite difficult because of lack of the defensible information.

2.3.2.2.8 Military Aircraft

Staff disagrees with the conclusion that Criterion (b) of NUREG–0800 (NRC, 1981a, Section 3.5.1.6), has been met for the proposed repository site. The number of flights per year by the military aircraft, as stated in CRWMS M&O (1999e), significantly exceeds 1,000 by 12 to 15 times, and these flights may create unusual stress situations because of maneuvering operations as they fly in the restricted airspaces. The screening criteria in NUREG–0800 are for nuclear power plants, none of which are located under a restricted military airspace. Therefore, Criterion (b) has not been satisfied, and, consequently, a detailed analysis is necessary using NUREG–0800 (NRC, 1981a, Section 3.5.1.6) for every type of aircraft flying in the vicinity of the proposed site. The annual aircraft crash frequency at the proposed repository will be the summation of crash frequencies from all types of aircraft operations or activities.

CRWMS M&O (1999e) assumed information provided by Nellis Air Force Base in 1997 about the numbers and types of aircraft currently flying through restricted airspace R–4808N is representative of those flying at the time of repository operation. DOE (CRWMS M&O, 1999e) did not consider reasonable changes in flight activities in the vicinity of the proposed repository site.

CRWMS M&O (1999e) did not provide sufficient information about the flight activities by military aircraft while transiting restricted airspace R–4808 or in other nearby restricted airspaces to make a defensible estimate of aircraft crash frequency at the proposed repository. Information currently provided lacks sufficient detail to develop an understanding of military activities near the proposed repository that may affect safety of the proposed repository. Estimation of aircraft crash probability requires reliable information about the parameters to be used in the estimation. In addition, defensible information, for example, about the number of flights by different types of aircraft, flight path and activities conducted during flight, and ordnance carried onboard for air-to-air and air-to-ground training, is required for military aviation especially when a facility is beneath a restricted military airspace. This information which should be based on historical records with appropriate projections to assess hazards during the preclosure period of the proposed repository and is vital for aircraft crash hazard analysis, as will be discussed further.

2.3.2.2.8.1 Number of Flights

Because the probability of aircraft crash is directly proportional to the number of aircraft flying nearby, it is necessary to get a good estimate of the number of aircraft overflights. Kimura, et al. (1998) analyzed the crash frequency for aircraft overflying the Device Assembly Facility, located in Area 6 of the Nevada Test Site under restricted airspace R–4808. Kimura, et al. (1998) identified the number of overflights by military aircraft as a major source of uncertainty in estimating aircraft crash frequency. The reported estimates vary from 13,000 to 73,000 overflights per year. The number of overflights varies as the mission of Nellis Air Force Base Range evolves. In CRWMS M&O (1999e), only 6 months of flight data through restricted airspace R–4808N were presented. The number of flights per year, *N*, has been estimated by fitting a normal distribution to the 6 months of data (the same approach was also applied to 5 months of data because the data for September 1996 were determined to be suspicious) using the Bestfit program (Palisade Corporation, 1994). Both the 90-and 95-percent confidence levels were estimated from the fitted distribution, as given in Tables 2-2 and 2-3. It was concluded that the fitted distribution is conservative (CRWMS M&O, 1999e). Staff disagree with this approach. Fitting a normal distribution to five or six data points provides too few degrees of freedom to carry out a meaningful statistical analysis. Goodness-of-Fit tests are very sensitive to the number of data points. For a small number of data points, the tests will only measure a large difference between the input data and the distribution function. Consequently, the null hypothesis that the data were generated by a process that follows a particular distribution (in this case, a normal distribution) will be accepted more often than is appropriate. Standard textbooks in statistics (e.g., Scheaffer and McClave, 1982) suggest that a sample size of less than 20 does not discriminate among distributions. Many different distributions may appear to fit equally well to the data, which can be seen in the results for the Bestfit program given in CRWMS M&O (1999e) because no single distribution produced the best fit using all three Goodness-of-Fit tests. The Yucca Mountain Site Characterization Project is collecting overflight information by military aircraft in the vicinity of the proposed geologic repository site. Recent information (Bechtel SAIC Company, LLC, 2001) shows that the average number of annual overflights has increased approximately 37 percent (from 12,716 to 17,394) during the period of monitoring. This information makes the estimated annual number of sorties presented in CRWMS M&O (1999e) questionable.

2.3.2.2.8.2 Mode of Flight

DOE should justify classifying the modes of flights by all military aircraft in the vicinity of the proposed repository surface facilities as normal inflight (CRWMS M&O, 1999e). Normal inflight mode, as defined by Kimura, et al. (1996), includes "climb to cruise, cruise between an originating airfield and an operations area, if applicable, and cruise descent portions." Special inflight mode includes "low level and maneuvering operations in restricted area." The crash rates of military aircraft are different in normal and special inflight modes (Kimura, et al., 1996). The proposed site lies under a restricted airspace and close to other restricted airspaces and military training routes. Therefore, without specific information, the possibility that the pilots may be flying in special inflight mode cannot be ruled out. Consequently, reliable information is needed for the activities conducted by the pilots while flying in the restricted areas near the proposed repository.

2.3.2.2.8.3 Aircraft Types

CRWMS M&O (1999e) assumed 29 percent of all aircraft will be F-16s, 63 percent will be F-15s, and 7 percent will be A-10s. However, no justification has been provided why particular fractions of F-16, F-15, and A-10 aircraft were assumed in the analysis. Data from Nellis Air Force Base, presented in Table 7.2-3 of CRWMS M&O (1999e), do not indicate the assumed distribution of aircraft into these three types is reasonable. Crash rates for different aircraft are different in each flight mode. A reasonable change in this distribution of the aircraft types, even with 12,716 flights in a year and normal inflight mode, may raise the crash probability to more than 10^{-6} per year. Consequently, reliable information is needed for the mix of aircraft flying in the restricted areas near the proposed repository.

CRWMS M&O (1999e) assumed F-16, F-15, and A-10 aircraft are representative of all types of aircraft flying near the proposed site without supporting justification. Tullman (1997) stated, "any aircraft in the Department of Defense inventory, or other NATO country, could fly these routes." A typical red flag exercise includes attack, fighter, bomber, air superiority, reconnaissance, electric countermeasures suppression, aerial refueling, and search and rescue aircraft (U.S. Air Force, 1999). Therefore, reliable information based on historic records is necessary for assuming the types of aircraft flying in the vicinity of the proposed repository.

2.3.2.2.8.4 Crash Rate

It is not clear why the Bounding Case estimates in Tables III-3 and IV-3 of CRWMS M&O (1999e) use the crash rate of all small aircraft (all types of fighter, trainer, and attack aircraft) instead of F-16 aircraft, which has the highest crash rate in normal and special inflight modes and would provide a bounding estimate. Trainer aircraft have much lower crash rates than fighter and attack aircraft (Kimura, et al., 1996) and, therefore, produce an estimated crash frequency less than actual. CRWMS M&O (1999e) did not report if trainer aircraft fly in the vicinity of the proposed repository. Therefore, a rationale based on historic information will be needed to assume the small aircraft type would be the appropriate aircraft type in the frequency estimation.

2.3.2.2.8.5 Ordnance Carried Onboard an Aircraft

CRWMS M&O (1999e) did not provide information on the ordnance carried onboard these aircraft. The pilot of an aircraft experiencing onboard emergencies will attempt to jettison the ordnance first to gain altitude and more time to glide and take corrective measures such as airstart. The jettisoned ordnance could pose significant hazards to the proposed repository depending on the type and number of weapons. Additionally, live ordnance could pose additional hazards from flying fragments and air overpressure. Therefore, jettisoning of ordnance is a concern for the site and should be investigated as a part of the analysis.

2.3.2.2.8.6 Staff Preliminary Confirmatory Assessment

As discussed previously, CRWMS M&O (1999e) did not provide justification for the proportion of F-16, F-15, and A-10 aircraft assumed in the analysis. Staff conducted a preliminary sensitivity analysis to estimate the crash probability of military aircraft onto the proposed facility using several different plausible scenarios (Ghosh and Sagar, 2001) not considered in CRWMS M&O (1999e). The effective areas of the surface facilities were estimated for each of the three aircraft types assumed in the analysis, F-16, F-15, and A-10, (the same types as in CRWMS M&O, 1999e) using the DOE (1996). Using both normal and special inflight crash rates for the F-16, F-15, and A-10 from Kimura, et al. (1996), the estimated probabilities of crash are given in Table 2-4. This sensitivity analysis shows the importance of having justifiable and specific information on the number of military aircraft flights and associated activities by different aircraft types. The analysis also shows that lack of reliable and specific information introduces substantial uncertainties in the estimated annual frequency of crash onto the surface facilities of the proposed repository.

2.3.2.3 Path Forward

DOE excluded aircraft crash hazard from the credible hazard list (CRWMS M&O, 1999e, 2000a; DOE, 2001a; Bechtel SAIC Company, LLC, 2001). NRC staff conclude, however, that exclusion of aircraft crash hazard during the preclosure period is premature. There is significant lack of specific information about the potential aircraft activities in the vicinity of the proposed site. Explicit and inherent assumptions taken and the associated technical bases were not adequately justified. Additionally, uncertainties in the data, compounded by the lack of specific information, were not adequately characterized. Staff communicated these concerns to DOE at the Technical Exchange and Management Meeting for Preclosure Safety[2], and DOE

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[2] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Preclosure Safety (July 24–26, 2001)." Letter (August 14) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

Table 2-4. Estimated Probabilities of Crash, *P*, for Military Aircraft for Different Scenarios

Number of Aircraft Flights	F-16 (percent)	F-15 (percent)	A-10 (percent)	Flight Mode	Annual Crash Probability
12716	29	63.9	7.1	Special	3.8×10^{-6}
17542	29	63.9	7.1	Special	5.2×10^{-6}
18910	29	63.9	7.1	Special	5.6×10^{-6}
12716	100	0	0	Special	4.5×10^{-6}
18910	100	0	0	Special	6.7×10^{-6}
12716	100	0	0	Normal	1.5×10^{-6}
18910	100	0	0	Normal	2.3×10^{-6}
12716	50	40	10	Special	4.0×10^{-6}
18910	50	40	10	Special	5.9×10^{-6}
12716	50	40	10	Normal	1.0×10^{-6}
18910	50	40	10	Normal	1.5×10^{-6}

agreed that exclusion of this hazard is premature. DOE agreed to provide justifiable information on aircraft types, number of flights, proportion of flights conducted by each aircraft type, and associated flight activities with appropriate future projection during the anticipated preclosure period in the revised aircraft crash hazard analysis. DOE produced a report to support a comprehensive aircraft crash hazard assessment for the proposed repository site at Yucca Mountain (Bechtel SAIC Company, LLC, 2002b). This report, which is currently being reviewed, uses information from the U.S. Air Force (e.g., U.S. Air Force, 1999) to develop a map of all flight-related activities in the vicinity of the proposed repository site.

In addition, staff are aware that Kistler Aerospace Corporation has proposed to launch satellites using fully reusable launch vehicles from a facility to be located at the Nevada Test Site (U.S. Department of Transportation and Federal Aviation Administration, 2002). DOE should evaluate the potential effects of these reusable launch vehicles at Kistler Aerospace Corporation facility on the proposed repository during the preclosure period.

Additionally, ground-launched rockets (both high and low altitudes), air-launched rockets, and cruise missiles are tested at Tonopah Test Range of Nellis North Range located 56 km [35 mi] from the proposed repository site (CRWMS M&O, 1999k). DOE should evaluate the potential effects of the rockets and cruise missile tests on the proposed repository during the preclosure period.

2.3.3 Tornado Missile Hazard

2.3.3.1 Overview of the DOE Analysis

CRWMS M&O (1999f) used NUREG–0800 (NRC, 1981b, Section 3.5.1.4) to identify the tornado missile characteristics, together with the expected impact velocity, appropriate for the proposed Yucca Mountain repository site. Additionally, DOE (CRWMS M&O, 1999f) identified the preliminary list of Quality Level 1 systems that need to be protected against the postulated tornado missiles impacts: (i) assembly transfer, (ii) canistered spent nuclear fuel disposal container, (iii) canister transfer, (iv) defense high-level waste disposal container, (v) DOE spent nuclear fuel disposal container, (vi) Waste Handling Building, (vii) nonfuel components disposal container, (viii) uncanistered spent nuclear fuel disposal container, (ix) Naval spent nuclear fuel disposal container, (x) waste emplacement, and (xi) waste retrieval. NUREG–0800 (NRC, 1981b, Section 3.5.1.4) provides an acceptable methodology to determine appropriate characteristics of tornado missiles that should be considered for demonstrating compliance with the design of structures, systems, and components that need to withstand a postulated impact of tornado missiles.

At the Technical Exchange and Management Meeting on Preclosure Safety,[3] DOE proposed to screen out any effects of tornado missiles impacting a transporter carrying waste packages between the surface and subsurface facilities during the preclosure period. The rationale behind this approach is the waste package would be exposed to any potential tornado missile impact approximately 225 hours in a year. Assuming an annual frequency of missile-generating design basis tornadoes to be 1×10^{-6}, the effective frequency of the transporters with waste packages being exposed to a tornado missile would be approximately 10^{-8} per year.

2.3.3.2 Staff Assessment

DOE should specify whether Spectrum I or Spectrum II missiles have been selected to demonstrate that all structures, systems, and components important to safety would be protected from the selected tornado missiles. DOE estimated that the frequency of transporters exposed to a tornado missile would be approximately 10^{-8} per year. NRC staff questioned the basis for assuming the annual frequency of missile-generating tornadoes at the proposed site to be equal to 10^{-6} per year. DOE needs to demonstrate that any impact from missiles generated by tornadoes with an annual frequency higher than 10^{-6} and with lower speed would not impact any structures, systems, and components, causing unacceptable radiological release. An agreement with the DOE was reached on this issue. DOE proposes to consider any administrative procedures to implement when tornadoes would be predicted in the vicinity of the proposed site as a defense-in-depth measure. Additionally, current DOE tornado analysis does not consider the option of retrieval of waste packages. DOE needs to consider the effects of tornado missile impact on structures, systems, and components important to safety during potential retrieval operations.

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[3] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Preclosure Safety (July 24–26, 2001)." Letter (August 14) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

2.3.3.3 Path Forward

Eliminating potential tornado missile hazard from further consideration is not supported by acceptable data, analysis, and technical bases. This concern was communicated to DOE at the Technical Exchange and Management Meeting on Preclosure Safety,[4] and DOE agreed to conduct an analysis either to include the potential effects of tornado missiles or justify exclusion of this hazard from further consideration.

2.3.4 Volcanic Ashfall

2.3.4.1 Overview of the DOE Analysis

CRWMS M&O (1999b) concluded in analyzing potential natural hazards to the proposed repository that a maximum 3 cm [1.2 in] thick volcanic tephra may be deposited at the proposed repository site. DOE thus excluded roof loading caused by tephra fall from further consideration, because the load imparted by a 3 cm [1.2 in] thick tephra deposit is bounded by the minimum design load requirements specified by the Uniform Building Code.

2.3.4.2 Staff Assessment

NRC staff agree with the methodology of excluding hazardous events through bounding analyses; however, NRC staff do not agree with the conclusion that a 3 cm [1.2 in] thick volcanic tephra deposit is the Bounding Case event to be expected at the proposed repository site. Basis for this conclusion is not supported by available analysis or data. The 3 cm [1.2 in] thick deposit, cited in CRWMS M&O (1999c), applies only for a volcanic eruption occurring 150 km [94 mi] from the proposed repository site (i.e., Perry and Crowe, 1987). Basaltic volcanic eruptions have an annual probability of occurrence that exceeds 1×10^{-6} within 10 km [6.25 mi] of the proposed repository site (e.g., NRC, 1999a). Tephra-fall deposits measured approximately 10 km [6.25 mi] from volcanoes analogous to those within 20 km [12.5 mi] of Yucca Mountain are approximately 1–100 cm [0.4–40 in] thick (e.g., NRC, 1997). These deposits increase in thickness to approximately 400 cm [160 mi] within 1 km [0.625 mi] of the volcanic event. In addition, Perry and Crowe (1987) conclude that a 1 m [3.3 ft] thick tephra fall could occur approximately 3 km [1.9 mi] from a basaltic volcanic event. Because the volcanic event may take place anywhere within 10 km [6.25 mi] of the proposed repository site, tephra fall deposit with a thickness of 100–400 cm [40–160 in] on the surface facilities is a potential hazard that needs to be considered. Noncompacted, dry basaltic volcanic tephra has bulk deposit densities that can range 1,200–1,700 kg/m^3 [75–106 lb/ft^3] (e.g., Hill, et al., 1998; NRC, 1999a). The density of these deposits can increase by a rough factor of two when wet, depending on average grain-size and sorting of the deposit. Thus, a basaltic volcanic eruption in the area around Yucca Mountain represents a Category 2 event that could deposit 100–400 cm [40–160 in] of tephra on surface structures, resulting in loads greater than 240 lb/ft^2, [115 kPa] significantly larger than those assumed to screen out this event as a potential natural hazard to the proposed repository.

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[4] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Preclosure Safety (July 24–26, 2001)." Letter (August 14) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

2.3.4.3 Path Forward

DOE eliminated the potentially adverse effects of volcanic eruptions characteristic of the Yucca Mountain region from the list of Category 2 events during preclosure without adequate justification for assuming the distance of nearby volcanic events and the thickness of associated tephra fall deposit. Adequate rationale is needed to justify exclusion of this event from the Category 2 events list.

DOE eliminated the potential effects of volcanic tephra particles on high-efficiency particulate air filters and heating, ventilation, and air conditioning systems based on the analogy with the effects of wind-blown sand particles during a sandstorm. DOE has assumed that the effects of volcanic tephra on high-efficiency particulate air filters and heating, ventilation, and air conditioning systems would be bounded by sandstorms (CRWMS M&O, 1999b) without providing any information about the particle sizes in both events. Volcanic tephra-fall deposits contain a greater range of particle sizes than wind-blown sands, which may have different effects on high efficiency particulate air filters and heating, ventilation, and air conditioning systems. This concern was outside the scope for the Technical Exchange and Management Meeting on Preclosure Safety.[5]

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[5] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Preclosure Safety (July 24–26, 2001)." Letter (August 14) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

3 OPERATIONAL HAZARDS

3.1 Introduction

To demonstrate compliance with the requirements of preclosure safety analysis in 10 CFR 63.112, the U.S. Department of Energy (DOE) is required to address hazards and initiating events resulting from facility operations. The hazards and initiating events associated with the surface and subsurface operations that may lead to radiological release to the public and workers are identified through operational hazard analyses. The operational events may result from hardware failure, human error, or a combination of both during the surface and subsurface operations. In addition, operational events may result from the failure of software and electronic hardware that may be used in the repository facility for remote operations. The hazard analysis forms the basis for selection of initiating events and subsequent development of event scenarios and comprehensive identification of potential event sequences. Inadequate identification of hazards and inaccurate evaluation of the frequency of initiating events can lead to potential miscategorization of event sequences and erroneous safety assessment. This section uses the guidance on review methods and acceptance criteria documented in NRC (2002, Section 4.1.1.3) for identification of hazards and initiating events. The guidance provides the scope of review that encompasses the technical basis and assumptions for the methods used for hazard analysis, use of relevant data, determination of frequency or probability of initiating events, technical basis for inclusion and exclusion, and developing a list of hazards and initiating events.

The main hazards associated with the preclosure operations arise from (i) the large inventory of radioactive wastes received at the site; (ii) the large number of surface processing operations that will have to be performed, many in parallel, to transfer and repackage the waste; and (iii) the subsurface operations associated with transportation and emplacement of waste packages in the underground drifts. The facility will be designed to handle approximately 70,000 MTU of nuclear waste during the preclosure period. During this period, the facility would receive commercial spent nuclear fuel, commercial high-level waste, defense high-level waste, and DOE spent nuclear fuel with a peak annual receipt rate of about 3,000 MTU of nuclear waste (CRWMS M&O, 1999g). Although the annual handling rate of waste would vary, 10 CFR Part 63 requires that the peak annual handling rate be used in the preclosure safety analysis. Table 2-1 (CRWMS M&O, 1999g) shows that the facility would handle 800 canisters, 12,250 fuel assemblies, and 524 disposal containers and waste packages during the year of peak operations.

The identification of preclosure operational hazards and initiating events was not discussed with DOE in the first DOE and U.S. Nuclear Regulatory Commission (NRC) Technical Exchange and Management Meeting;[1] it will be discussed in a future technical exchange. In that technical exchange, however, staff comments and discussions resulted in preclosure agreement PRE 6.02, which stipulates DOE will provide a guide describing its preclosure safety analysis methodology. Bechtel SAIC Company, LLC (2002a), provided in response to agreement PRE 6.02, describes the overall DOE approach and strategy to conduct preclosure safety

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[1] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Preclosure Safety (July 24–26, 2001)." Letter (August 14) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

analyses; identify and categorize structures, systems, and components important to safety; and develop design bases. In addition, external and internal hazard analysis methodologies; event sequence analyses, including effects of seismic events on facility operations, human reliability, and common-cause and dependent failures; technical information related to failure rates of components; consequence analyses; and uncertainty analyses are discussed in the guide. The guide presents information on a general methodology for conducting safety analyses using the principles of risk assessment and the results to demonstrate compliance with the regulatory requirements in 10 CFR Part 63.

3.2 Overview of the DOE Analysis

3.2.1 Systems and Operations

For evaluation of hazards associated with a process or activity, a systematic analysis requires a description of the surface facilities, including facilities design, and a description of the systems and operations. A brief description of the surface and subsurface facility design and operations is provided next.

3.2.1.1 Surface Facility

3.2.1.1.1 Systems

During the operations phase, the two main activities of the repository surface facilities would be receiving and preparing waste. The facilities would be located at the North Portal. The major North Portal facilities would be the Carrier Preparation Building, where rail and truck carriers would be prepared for receiving and shipping, and the Waste Handling Building, where shipping casks would be unloaded and the waste placed in disposal containers for emplacement. In addition, surface facilities would include a Waste Transfer Building, where liquid and solid low-level waste would be processed and packaged for off-site shipment; the Transport Maintenance Building, where the site prime movers and underground transporters would be serviced; and the Carrier Washdown Building, where road grime would be removed from the carriers.

The primary systems and the subsystems associated with receiving and handling operations in surface facilities (DOE, 2001a; CRWMS M&O, 1999a,b) include

- Cask/Carrier Shipping and Receiving System
  —cask/carrier transport system
  —carrier preparation material handling system
- Waste Preparation System
  —carrier/cask handling system
  —canister transfer system
  —assembly transfer system
  —disposal containers handling system
- Essential Support Systems
  —electrical power system
  —fire protection system
  —radiation monitoring and control system

—ventilation system
—treatment and cooling system for pool water
  –water treatment system
  –leak detection system
  –water level management system
  –supplemental water system to control water temperature

3.2.1.1.2 Operations

Operations in the surface facility are briefly described based on the information obtained from DOE (2001a,b) and CRWMS M&O (1999h). The carrier/cask receiving system would receive casks by rail and truck and provide parking for carriers and prime movers. The off-site transporters would be disengaged from the carriers, and site prime movers would be engaged for transport to the Carrier Preparation Building and then to the Waste Handling Building. The operations in the Carrier Preparation Building would include moving a loaded carrier/cask into an available preparation bay using the site prime mover, removing the personnel barriers, retracting impact limiters, surveying the cask surface for radiation, and measuring cask temperature. The system would support both manual and remote handling of carrier/cask materials. The prepared carrier/cask would then be taken to the carrier parking area to await clearance from the Waste Handling Building for unloading. The carrier/cask handling system in the Waste Handling Building would unload casks and dual-purpose canisters from the trucks and rail carriers using a bridge crane and place them on a cask transfer cart in the carrier bay. The transfer cart, operated remotely, would carry the casks to either the canister transfer system or the assembly transfer system.

The carrier transfer system would receive casks containing waste in disposal canisters and transfer the canisters to disposal containers/waste packages. The vertically loaded cask would enter the cask preparation area through an airlock with two remotely operated isolation doors. In the cask preparation area, the cask would be vented, gasses sampled, lid bolts removed, the cask opened with the outer cask lid removed and decontaminated using the remotely operated cask preparation manipulator and required tools. The transfer cart would then move the canister to the shielded canister transfer cell. At the unloading station of the canister transfer cell, the cask inner lid would be removed, and the canisters would be lifted from the cask to be loaded into a disposal container. At the disposal container loading station, the large canisters would be loaded directly into a disposal container using a remotely operated overhead bridge crane, manipulator, and canister lifting fixtures, while small canisters would either be loaded directly into a disposal container or accumulated in a staging rack for temporary storage.

The assembly transfer system receives casks and dual-purpose canisters. The cask, on a remotely operated cart, would pass through an airlock and into the cask preparation area. A large bridge crane would then move the cask into a cask unloading pool. In the pool, depending on the cask type, either the cask shield would be removed, providing direct access to the fuel assemblies, or the welded lid of the dual-purpose canister would be cut open. The exposed assemblies would be transferred by a wet assembly transfer machine to baskets in the assembly staging pool. The baskets would be transferred to assembly handling cells for disposal container loading on an inclined cart or to a fuel inventory storage in an underwater transfer cart through transfer canal. Baskets selected for placement in disposal container based on full blending requirements would be transferred from storage area to staging pool and then to disposal container loading area on inclined transfer cart. In the assembly handling cell, a vacuum drying system would dry the assemblies before their transfer to an empty disposal container by a dry assembly transfer handling machine. During the transfer, the disposal container would be mated to the cell through a transfer port to limit any spread of contamination. The loaded disposal container would receive a temporary lid, be disengaged from the port, and be transferred on a cart to the decontamination cell where it would be decontaminated, temporarily filled with nitrogen, and temporarily sealed before transfer to the disposal container handling system for permanent welding. All operations in the hot cell are conducted remotely.

A remotely operated cart would move the disposal container from the assembly transfer system or canister transfer system in a vertical position to within the reach of a large bridge crane. The crane would move the disposal container to the disposal container staging area or directly to a disposal container welding station. At the welding station, the inner and outer lids would be welded, inspected, and filled with helium. The welding will be accomplished using a robotic welder mounted on a gantry. The disposal container would be placed on a rotating turntable during welding at the welding head station. The welded and loaded disposal container would be called a waste package, which would be lifted from the welding station and placed in a staging fixture or directly in a waste package tilting fixture. A crane would lower the waste package onto a horizontal transfer cart. The cart would transfer the waste package from a disposal container handling cell to a waste package transporter loading cell, then to the waste package transporter.

3.2.1.2 Subsurface Facility

3.2.1.2.1 Systems

The subsurface facilities infrastructure would include access tunnels, emplacement drifts, shafts, rails, and support systems, including the subsurface ventilation system and the electrical power system. The primary tunnels, North Ramp, North Ramp Extension, Main Access Drift, and turnouts provide pathways for transport of waste packages to the emplacement drifts (DOE, 2001b). All the tunnels would be 7.62 m [25 ft] in diameter, and would have rail track installed on concrete invert, and have a trolley cable suspended from the crown. The North Ramp has a downward grade of 2.15 percent. The emplacement drifts would be approximately 5.5 m [18.4 ft] in diameter. The concrete invert would support rails and pedestals that receive and support waste packages. The waste packages would be placed axially along the length of each emplacement drift. The ground support system for the tunnels and drifts would consist of rock bolts, steel sets, or cast-in-place concrete segment liners.

The primary systems and subsystems associated with subsurface operations would be the waste package transport train system, rail system for transporter train, and waste package emplacement gantry system (DOE, 2001b; CRWMS M&O, 1997a, 1999i). The transporter train would consist of two locomotives and the transporter. The two locomotives would be driven by an overhead electric trolley. The primary locomotive would be permanently coupled to the transporter, while the secondary locomotive would be frequently coupled to and decoupled from the transporter. The train may be operated either remotely from the centralized control room via radio signals or by on board manual control. The maximum speed of the fully loaded transporter would be 8 km/hr [4.97 m/hr]. The subsurface rail (track) system would extend from the exit of the Waste Handling Building to the North Portal and into the North Ramp and

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throughout the Main Access Drifts and turnouts. There would be many switch tracks to accommodate operations such as coupling and decoupling of locomotives to the transporter and reorientation of the transporter as necessary in the main access drifts and turnouts. Each switch track would be remotely operated and instrumented for remote position indication. The waste package emplacement gantry system would be a remotely controlled device for the waste package emplacement functions in the emplacement drifts. The gantry would be self-powered through a direct current, third-rail system. Other systems that contribute to the subsurface operations would be the (i) remote control and data communications system, (ii) central control room, (iii) rail electrification system, (iv) subsurface ventilation system, and (v) performance confirmation system for the gantry.

3.2.1.2.2 Operations

Operations in the surface facility are briefly described based in the information obtained from DOE (2001b) and CRWMS M&O (1997a, 1999i). At the Waste Handling Building, the waste package would be transferred to the reusable railcar and loaded into shielded transporter railcars by remote control; and the transporter would be pulled away by the primary locomotive by remote control. After coupling a secondary locomotive to the transporter, the transporter train (two locomotives and a transporter) would be driven under onboard manual control from the surface at the Waste Handling Building, down the North Ramp and Main Access Drift, and then to the turnout and to the destination emplacement drift. After decoupling the secondary locomotive, the drivers would vacate the locomotive. The transporter would be backed into the turnout (pushed by the primary locomotive by remote control) and to the vicinity of the emplacement drift isolation doors. The emplacement drift isolation doors would be opened by remote control, and the transporter would be backed to the emplacement drift transfer dock. The waste package would be moved out of the transporter on the reusable railcar and transferred to the emplacement gantry; all operations would be by remote control. The emplacement gantry would raise the waste package, transport it into the emplacement drift to the desired location, lower it to the pedestals, and return to the emplacement drift entrance; all operations would be by remote control (DOE, 2001b). After the train moved away from the transfer dock, the emplacement drift isolation doors would be closed. After arrival of the train in the main drift, drivers would return to the locomotive for recoupling of the secondary locomotive and a return trip to the surface to receive another waste package.

3.2.1.3 Functional Areas

DOE divided the repository operations area and the processes into functional areas to facilitate preclosure safety analysis (Bechtel SAIC Company, LLC, 2002a, DOE, 2001a; CRWMS M&O, 1999a). Functional areas are established by specific functions and/or physical boundaries. For each area, DOE conducted a preliminary hazard analyses for identification of hazards and initiating events. Further, DOE analyzed event sequences and consequences in each functional areas. The nine functional areas are

(1) Waste Receipt and Carrier or Cask Transport
(2) Carrier Preparation
(3) Carrier Bay—Waste Handling Building
(4) Canister Transfer—Waste Handling Building
(5) Assembly Transfer—Waste Handling Building

(6) Disposal Container Handling and Waste Package Remediation—Waste Handling Building
(7) Subsurface Transport, Emplacement, and Monitoring
(8) Site-Generated Waste Treatment—Liquid Low-Level Waste
(9) Site-Generated Waste Treatment—Solid Low-Level Waste

The operations and equipment/components for major systems involved in handling high-level waste are associated with seven functional areas, as summarized in Table 3-1. This information was compiled from a diverse set of DOE documents (DOE 2001a,b; CRWMS M&O, 1997a, 1998b, 1999g,h,i).

3.2.2 Hazard Analysis Methodology

The DOE operational hazard analysis methodology is documented in CRWMS M&O (1999a), DOE (2001a), and Bechtel SAIC Company, LLC (2002a). This hazard analysis technique consists of a generic checklist of events to identify the energy sources contained in a system (e.g., kinetic mechanical energy, electrical energy, chemical energy, thermal energy) that can interact with the waste and potentially cause a radiological release to the public or facility workers. DOE used three safety analysis methodologies, Energy Analysis, Energy Trace and Barrier Analysis, and Energy Trace Checklist (System Safety Society, 1997), to develop the generic checklist of hazards applicable to the preclosure surface and subsurface operations. As shown in Table 3-2, the operational hazards have been classified into the following five categories: (i) collision/crushing, (ii) chemical contamination/flooding, (iii) explosion/implosion, (iv) fire/thermal, and (v) radiation/magnetic/electrical/fissile materials. The screening criteria are applied to the surface and subsurface functional areas of the geologic repository operations area to identify operational hazards and initiating events. Screening criteria for each hazard category comprise a set of questions to explore the presence of hazardous material or conditions that can potentially interact with the waste form to cause radiological release.

3.2.3 Inclusion and Exclusion of Hazards and Initiating Events

The DOE inclusion and exclusion of hazards from the facility operations is based on the operational hazard analysis. The product of the hazard analysis is the list of operational hazards that contains potentially credible operational hazards (Bechtel SAIC Company, LLC, 2002a).

3.2.4 Preliminary List of Hazards

DOE developed a preliminary list of hazards from the repository operations. Possible hazards resulting from surface and surface operations in each functional area and in each hazard category are shown in Table 3-3. The list is based on the DOE preliminary internal hazards analysis (DOE, 2001a; CRWMS M&O, 1999a).

3.2.5 Initiating Events

The initiating events identified and analyzed for event frequency evaluation are shown in Table 3-4. The table shows the initiating events for all functional areas. The information in the table was compiled from CRWMS M&O (1997b, 1998b, 2000b,c). Further analysis of initiating

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Table 3-1. Operational Hazards for Surface and Subsurface Facilities		
Functional Area	**Operations**	**Component/Equipment**
Transport System Site Boundary to Carrier Preparation Building	Cask from distant site received Offsite rail/truck disengaged from cask carrier Site prime mover engaged to cask carrier Cask carrier transported to Carrier Preparation Building	Rail cask carrier Truck cask carrier Site prime mover Equipment to engage and disengage carriers
Carrier Preparation Material Handling System, Carrier Preparation Building	Carrier and cask surveyed for radiation Personnel barriers removed Contaminants sampled Cask temperature measured Cask impact limiters removed	Site prime mover Overhead bridge cranes Gantry mounted manipulator Fixtures for removing barriers and impact limiters
Carrier Cask Handling System, Waste Handling Building	Cask tilted from horizontal to vertical Cask unloaded from rail/truck carrier Cask placed on transfer carts	Site prime mover Remotely operated overhead bridge cranes Gantry-mounted manipulator Lifting yoke, tools, and fixtures Transfer carts
Canister Transfer System, Waste Handling Building	Canister unloaded from cask Canisters stored in staging rack Canisters loaded into disposal container Large canisters loaded directly from transportation cask to disposal container Lid unbolted Lid removed Decontamination	Area-shielded hot cell Remote-operated cask transfer carts Cask preparation manipulators Equipment for samples Bridge crane Shield door Cameras Various lifting fixtures

Table 3-1. Operational Hazards for Surface and Subsurface Facilities (continued)

Functional Area	Operations	Component/Equipment
Assembly Transfer System (Uncanistered Waste Transfer)	Cask placed in unloading pool Inner shield plug removed under water Spent nuclear fuel assemblies individually removed from open cask into assembly basket Assembly basket transported from basket staging rack to incline underwater transfer cart Assembly transferred to drying vessels Dry assembly placed into a disposal container Disposal container inner lid installed Decontamination of disposal container	Bridge crane Underwater camera Manipulator Area shielded hot cell Wet assembly transfer machine Disposal container transfer cart Incline and cross-transfer cart Dry-fuel-handling machine Cameras Decontamination equipment Staging basket Underwater camera Shielded door
Disposal Container Welding and Transfer, Waste Handling Building	Disposal container transferred to and from assembly transfer and canister transfer system Inner and outer lids welded Disposal containers temporarily loaded before and after welding Disposal containers tilted to horizontal position Disposal containers loaded onto waste emplacement transport Decontamination	Area shielded hot cell Remotely operated overhead bridge crane with lifting fixtures Transfer carts Disposal container welding/inspection Welding station jib cranes Weld turn table Horizontal transfer cart Horizontal lifting system Decontamination and inspection manipulate Robotic welding machine
Subsurface Repository Emplacement	Waste package transported to underground drift Waste package emplaced in the drift	Transport locomotive Remote-controlled gantry for waste package emplacement Drift isolation door

Table 3-2. List of Potential Generic Events	
Category of Generic Events	**Description**
Collision/Crushing	Potential for release of kinetic and potential energy from uncontrolled mass or force
Chemical Contamination/Internal Flooding	Potential for release of corrosive/reactive chemicals that react with system material causing system deterioration
	Potential for release of volatile/condensable material (off-gassing)
	Presence for leaking or venting of materials, gases, or liquids
	Potential for debris or fluid leaks
	Potential for release of water (flooding)
Explosion/Implosion	Potential for release of pressure energy, electrical energy, chemical energy, and mechanical energy from equipment in motion
Fire/Thermal	Presence of sufficient quantity fuel, oxidizers, and ignition sources to cause fire
Radiation/Magnetic/Electrical/ Fissile Materials	Potential for release of radioactive/magnetic/electrical energy Potential for arranging of fissile material to result in criticality

Table 3-3. Status of the DOE Operational Hazard Analysis (CRWMS M&O, 1999a)			
No.	Functional Areas	Generic Events	DOE Preliminary Events
1	Waste Receipt and Carrier/Cask Transport	Collision/Crushing	Cask collision, railcar derailment, overturning of truck trailer involving cask, drop of cask from carrier cradle
		Chemical Contamination/Internal Flooding	Not identified
		Explosion/Implosion	Not identified
		Fire/Thermal	Diesel fuel fire/explosion
		Radiation/Fissile Materials	Radiation exposure to facility worker Criticality associated with cask collision, railcar derailment, overturned truck trailer, and rearrangement of cask internals
		Human Reliability	Not addressed
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events
2	Carrier/Cask Preparation	Collision/Crushing	Cask collision Handling equipment drop on cask
		Chemical Contamination/Internal Flooding	Not identified
		Explosion/Implosion	Not identified
		Fire/Thermal	Diesel fuel fire/explosion
		Radiation/Fissile Materials	Radiation exposure to facility worker Criticality associated with cask collision, rearrangement of cask internals
		Human Reliability	Not addressed
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events
3	Carrier Bay	Collision/Crushing	Transportation cask drop, cask slap down, cask collision, shield door (isolation door) jams or closes on transportation cask, crane drops cask during normal operations, crane drops cask onto transfer cask during normal lift, cask slap down and drop during normal lift, cask slap down because of failure of transport cask support, crane two-block drop of cask
		Chemical Contamination/Internal Flooding	Not identified
		Explosion/Implosion	Not identified
		Fire/Thermal	Diesel fuel fire/explosion
		Radiation/Fissile Materials	Radiation exposure to facility worker Criticality associated with cask collision/drop or rearrangement of cask internals

Table 3-3. Status of the DOE Operational Hazard Analysis (CRWMS M&O, 1999a) (continued)

No.	Functional Areas	Generic Events	DOE Preliminary Events
		Human Reliability	Not addressed
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events
4	Waste Handling Canister Transfer	Collision/Crushing	Cask: slap down, handling equipment drop on cask Canister: drop, slap down, collision, canister drop on disposal container, canister drop on sharp object, canister drop on another canister in staging rack Shield door close on cask, disposal container Disposable Container: slap down, collision, handling equipment drop on disposal container
		Chemical Contamination/Internal Flooding	Not identified
		Explosion/Implosion	Not identified
		Fire/Thermal	Not identified
		Radiation/Fissile Materials	Exposure to facility worker Criticality associated with small canister staging rack, collision/drop of cask/canister, rearrangement of container internals
		Human Reliability	Not addressed
		Remote Operations/Software-Hardware Reliability	Not addressed
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events
5	Waste Handling Assembly Transfer	Collision/Crushing	Cask: drop, slap down, collision, handling equipment drop on cask Spent nuclear fuel assembly: drop on pool floor, slap down, collision, spent nuclear fuel assembly staging rack, drop on assembly dryer, drop on disposal container, drop on dryer, drop on hot cell floor Loaded spent nuclear fuel assembly basket: drop on pool floor, drop on spent nuclear fuel assembly staging rack, drop on assembly hot cell floor, collision with other basket, uncontrolled descent of inclined transfer cart, drop on assembly dryer, collision, uncontrolled descent of incline basket transfer cart
		Chemical Contamination/Internal Flooding	Flood caused by uncontrolled pool water drain-down/fill
		Explosion/Implosion	Not identified
		Fire/Thermal	Spent nuclear fuel overheating resulting in excessive clad temperature and Zircalloy cladding fire in assembly transfer basket or dryer and in pool because of loss of pool water

Table 3-3. Status of the DOE Operational Hazard Analysis (CRWMS M&O, 1999a) (continued)

No.	Functional Areas	Generic Events	DOE Preliminary Events
		Radiation/Fissile Materials	Uncontrolled pool water drain-down/fill resulting in flooding and radioactive contamination of adjoining Waste Handling Building areas, increased radiation levels in assembly transfer area, potential uncovering of fuel assemblies, exposure of facility worker Criticality associated with cask collision/drop, rearrangement of cask internals, spent nuclear fuel assembly staging rack, misload of assembly dryer, misload of disposal container
		Remote Operations/Software-Hardware Reliability	Not addressed
		Human Reliability	Not addressed
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events
6	Waste Handling Disposal Container and Waste Package Remediation	Collision/Crushing	Waste package: drop, slap down, drop on sharp object, collision, handling equipment drop Disposal container: drop, slap down, drop on sharp object, collision, handling equipment drop
		Chemical Contamination/Internal Flooding	Not identified
		Explosion/Implosion	Not identified
		Fire/Thermal	Fire, fuel damage by burn-through during welding process, spent nuclear fuel overheating in disposal container resulting in excessive clad temperature and possible Zircalloy cladding fire
		Radiation/Fissile Materials	Exposure of facility worker Criticality associated with cask collision/drop, rearrangement of cask internals, spent nuclear fuel assembly staging rack, misload of assembly dryer, misload of disposal container
		Remote Operations/Software-Hardware Reliability	Not addressed
		Human Reliability	Not addressed
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events
7	Subsurface Transport, Emplacement, and Monitoring	Collision/Crushing	Transporter: derailment outdoors, derailment in ramp or main drift, collision with stationary or moving equipment, runaway, waste package reusable railcar rolls out, rockfall Emplacement gantry: derailment Waste package: drop from emplacement gantry, rockfall, steel set drop, waste package/emplacement gantry collision with equipment or another waste package, failure of isolation air lock caused by rockfall

Table 3-3. Status of the DOE Operational Hazard Analysis (CRWMS M&O, 1999a) (continued)

No.	Functional Areas	Generic Events	DOE Preliminary Events
		Chemical Contamination/Internal Flooding	Flooding from water pipe break
		Explosion/Implosion	Not identified
		Fire/Thermal	Fire associated with waste package transporter/locomotive or development equipment
		Radiation/Fissile Materials	Exposure of facility worker, early or juvenile failure, and resultant release of radioactive waste Criticality associated with collision/drop of waste package and rearrangement of waste package internals
		Human Reliability	Not addressed
		Remote Operations/Software-Hardware Reliability	Not addressed
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events
8	Waste Treatment (Liquid Low Level)	Collision/Crushing	Handling equipment drop on liquid low-level waste
		Chemical Contamination/Internal Flooding	Uncontrolled release of liquid low-level waste
		Explosion/Implosion	Not identified
		Fire/Thermal	Not identified
		Radiation/Fissile Materials	Operator exposure to radioactive material
		Human Reliability	Not addressed
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events
9	Waste Treatment (Solid Low Level)	Collision/Crushing	Solid low-level waste drop, handling equipment drop on solid low-level waste
		Chemical Contamination/Internal Flooding	Not identified
		Explosion/Implosion	Not identified
		Fire/Thermal	Fire involving combustible low-level waste
		Radiation/Fissile Materials	Operator exposure to radioactive material
		Human Reliability	Not considered
		Natural and Human-Induced Events	Structures, systems, and components designed to withstand events

Reference:
CRWMS M&O. "Monitored Geologic Repository Internal Hazards Analysis." ANL–MGR–SE–000003. Rev. 00. Las Vegas, Nevada: CRWMS M&O. 1999a.

Table 3-4. DOE Identification of Initiating Event and Estimation of Frequencies at Functional Areas

Functional Area	Event Description	Frequency (per year)	Reference
Carrier Bay	Shipping cask drop (no impact limiters)	1.86×10^{-3}	CRWMS M&O, 1998b
Waste Handling Canister Transfer	Canister drop on floor in canister transfer system hot cell	1.4×10^{-2}	CRWMS M&O, 1998b
Waste Handling Assembly Transfer	Spent nuclear fuel assemblies drop on other spent nuclear fuel assemblies in cask unloading pool	2.34×10^{-1}	CRWMS M&O, 2000c
	Spent nuclear fuel assemblies collision in pool	3.9×10^{-2}	CRWMS M&O, 2000c
	Spent nuclear fuel assemblies drop on empty basket in pool	4.1×10^{-2}	CRWMS M&O, 2000c
	Spent nuclear fuel assemblies drop on other spent nuclear fuel assemblies in basket in pool	1.93×10^{-1}	CRWMS M&O, 2000c
	Basket drop on other basket in basket staging rack in pool	4.1×10^{-2}	CRWMS M&O, 2000c
	Basket collision during transfer to pool storage	6.84×10^{-3}	CRWMS M&O, 2000c
	Basket drop on other basket while lowering basket in pool storage	4.1×10^{-2}	CRWMS M&O, 2000c
	Basket drop on other basket while lifting basket out of pool storage	4.1×10^{-2}	CRWMS M&O, 2000c
	Basket collision during transfer to incline transfer canal in pool	6.84×10^{-3}	CRWMS M&O, 2000c
	Basket drop on transfer cart or pool floor	4.1×10^{-2}	CRWMS M&O, 2000c
	Uncontrolled descent of incline transfer cart with basket	6.84×10^{-3}	CRWMS M&O, 2000c
	Basket drop back in pool while lifting basket off incline transfer in hot cell	4.1×10^{-2}	CRWMS M&O, 2000c
	Basket drop on assembly transfer system hot cell floor	4.1×10^{-2}	CRWMS M&O, 2000c
	Basket drop on other basket in dryer	4.1×10^{-2}	CRWMS M&O, 2000c

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Table 3-4. DOE Identification of Initiating Event and Estimation of Frequencies at Functional Areas (continued)			
Functional Area	**Event Description**	**Frequency (per year)**	**Reference**
Waste Handling Assembly Transfer	Spent nuclear fuel assemblies drop on other spent nuclear fuel assembly in dryer	2.34×10^{-1}	CRWMS M&O, 2000c
	Spent nuclear fuel assemblies drop on assembly transfer system hot cell floor	2.34×10^{-2}	CRWMS M&O, 2000c
	Spent nuclear fuel assemblies drop on other spent nuclear fuel assembly in disposal container	2.34×10^{-1}	CRWMS M&O, 2000c
	Handling equipment drop on spent nuclear fuel assemblies in pool	2.38×10^{-3}	CRWMS M&O, 2000c
	Handling equipment drop on spent nuclear fuel assemblies in hot cell	2.38×10^{-3}	CRWMS M&O, 2000c
	Handling equipment drop on spent nuclear fuel assemblies basket in pool	1.74×10^{-3}	CRWMS M&O, 2000c
	Handling equipment drop on spent nuclear fuel assemblies basket in hot cell	1.08×10^{-4}	CRWMS M&O, 2000c
	Shipping cask drop on floor	8.68×10^{-3}	CRWMS M&O, 2000c
	Shipping cask tipover	8.68×10^{-3}	CRWMS M&O, 2000c
	Shipping cask drop in cask preparation pit	8.68×10^{-3}	CRWMS M&O, 2000c
	Shipping cask drop into cask unloading pool	8.68×10^{-3}	CRWMS M&O, 2000c
Disposal Container and Waste Package Remediation	Unsealed disposal container collision while transfer was unsealed disposal container from assembly transfer system to disposal container handling cell	1.8×10^{-3}	CRWMS M&O, 2000c
	Unsealed disposal container drop and slapdown while lifting disposal container on welding table	8.4×10^{-3}	CRWMS M&O, 2000c
	Handling equipment drop on unsealed disposal container while lifting disposal container on welding table	1.08×10^{-4}	CRWMS M&O, 2000c

Table 3-4. DOE Identification of Initiating Event and Estimation of Frequencies at Functional Areas (continued)

Functional Area	Event Description	Frequency (per year)	Reference
Disposal Container and Waste Package Remediation	Waste form fall on disposal container	8.8×10^{-2}	CRWMS M&O, 1997b
	Waste Handling Building equipment fall on waste package	1.77×10^{-4}	CRWMS M&O, 2000b
	Aboveground lifting system drop waste package vertically oriented	4.0×10^{-3}	CRWMS M&O, 2000b
		2.9×10^{-2}	CRWMS M&O, 1997b
	Aboveground lifting system drop waste package horizontally oriented	1.0×10^{-2}	CRWMS M&O, 2000b
	Waste package tipover and slap down on a flat surface	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Waste package collide in lag storage area	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Pressurized system missile strike waste package	1.6×10^{-4}	CRWMS M&O, 2000b
	Waste package missile strike from battery	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Thermally overloaded waste package	3.5×10^{-4} to 3.5×10^{-1}	CRWMS M&O, 2000b
		PWR: 6.9×10^{-3} BWR: 1.8×10^{-2}	CRWMS M&O, 2000b
	Fire in the disposal container cell	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
Subsurface Transport, Emplacement, and Monitoring	Underground handling equipment fall on waste package	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Drift liner/ground support fall on waste package	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	One waste package fall on to other	Event cannot occur	CRWMS M&O, 2000b
	Greater than 6 MT [6.6 tons] rockfall on waste package	5×10^{-7}	CRWMS M&O, 2000b
	Greater than 6 MT [6.6 tons] rockfall on transporter	4×10^{-10}	CRWMS M&O, 2000b

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Table 3-4. DOE Identification of Initiating Event and Estimation of Frequencies at Functional Areas (continued)			
Functional Area	**Event Description**	**Frequency (per year)**	**Reference**
Subsurface Transport, Emplacement, and Monitoring	Static fracturing of rock	$<1 \times 10^{-4}$	CRWMS M&O, 1997b
	Bed plate roll out of the transporter	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
		2.3×10^{-4}	CRWMS M&O, 1997b
	Emplacement gantry drop horizontally oriented waste package	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Waste package fall on sharp object	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Transporter collision at normal operating speed	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Transporter derail without tipover, waste package restraint failure	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
		1.5×10^{-2}	CRWMS M&O, 1997b
	Transporter derail with tipover	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Transporter runaway	1.18×10^{-7}	CRWMS M&O, 2000b
		2×10^{-8} through 5×10^{-5}	CRWMS M&O, 1997b
	Transporter door close on waste package	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Operation of emplacement gantry cause waste package collision	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Transporter breakdown outside North Portal (insolation)	2.2×10^{-3}	CRWMS M&O, 2000b
	Thermally overloaded emplacement drift	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Underground ventilation loss	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Waste package buried with debris by rockfall	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Fuel rod rupture	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b

Table 3-4. DOE Identification of Initiating Event and Estimation of Frequencies at Functional Areas (continued)

Functional Area	Event Description	Frequency (per year)	Reference
Subsurface Transport, Emplacement, and Monitoring	Waste package criticality misload	Assumed $>1 \times 10^{-6}$	CRWMS M&O, 2000b
	Waste package flooding	Assumed $<1 \times 10^{-6}$	CRWMS M&O, 2000b
	Waste package internal geometry failure	Assumed $<1 \times 10^{-6}$	CRWMS M&O, 2000b
	Early failure of waste package	Assumed $<1 \times 10^{-6}$	CRWMS M&O, 2000b
	Surface fault displacement	1.4×10^{-27}	CRWMS M&O, 1997b
	Earthquake	1×10^{-4}	CRWMS M&O, 1997b

References:
CRWMS M&O. "Preliminary Preclosure Design Basis Event Calculations for the Monitored Geologic Repository." BCA000000–01717–0210–00001. Rev. 00. Las Vegas, Nevada: CRWMS M&O. 1998b.
———. "Preclosure Design Basis Events Related to Waste Package." ANL–MGR–MD–000012. Rev. 00. Las Vegas, Nevada: CRWMS M&O. 2000b.
———. "Design Basis Event Frequency and Dose Calculation for Site Recommendation." CAL–WHS–SE–000001. Rev. 01. Las Vegas, Nevada: CRWMS M&O. 2000c.
———. "Waste Package Design Basis Events." BBA000000–01717–0200–00037. Rev. 00. Las Vegas, Nevada: CRWMS M&O. 1997b.
Notes: PWR represent pressurized water reactor
BWR represent boiling water reactor

events for subsurface operations is given in CRWMS M&O (1997a). The current status of all hazards analyzed by DOE is provided in Appendix A.

3.3 Staff Review

3.3.1 Facility Description and Design Details

Comprehensive identification of hazards and initiating events depends on details of facility design and processes. Bechtel SAIC Company, LLC (2002a) gives the impression the License Application for construction authorization will be based on a preliminary layout and functional description, and conceptual design. It is also stated in the guide that the hazards and potential event sequences associated with facility operations can be identified and evaluated and structures, systems, and components important to safety can be identified "even with limited design detail." Further, DOE plans to categorize structures, systems, and components important to safety into Quality Levels 1–3, based on preliminary design. Staff concern with this approach was discussed at the DOE and NRC Technical Exchange and Management Meeting[2]

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[2] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Preclosure Safety (July 24–26, 2001)." Letter (August 14) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

in which staff stated that DOE identification of structures, systems, and components important to safety and their further quality level categorizations should be based on results of a robust preclosure safety analysis. Although all the design information may not be needed for the license application for construction authorization, the level of detail should be sufficient to demonstrate compliance based on an acceptable preclosure safety analysis.

In particular, the level of detail provided by DOE on the human actions anticipated as part of operations and the software systems used for computer control of equipment do not appear to be sufficient for even a preliminary evaluation of safety, including the identification of structures, systems, and components important to safety. Fundamental characteristics of the system needed to evaluate reliability and safety at a preliminary level that have not yet been specified include (i) designation of operations to be human or computer controlled, (ii) requirements for computer software and personnel, and (iii) central versus distributed control of human actions, computer systems, or both.

Segmenting the facility repository into several functional areas for convenience of preclosure safety analysis is reasonable; however, DOE should assure that all systems and processes of repository operations and all physical areas of repository operations have been included in the proposed nine functional areas.

3.3.2 Hazard Analysis Methodology

The initial task in a preclosure safety analysis is a hazard analysis that systematically identifies and evaluates facility hazards. Hazard analysis examines the spectrum of potential events that could expose the public or worker to radiological dose. Largely qualitative techniques are used in the hazard analysis to identify weaknesses in the design and operation of a facility that could lead to such events. Although several methodologies and techniques for hazard analysis exist, the choice of a particular method or combination of methods should be based on a number of factors that include the purpose, result needs, availability of information, complexity of the process or operations, and available personnel experience (NRC, 2001; American Institute of Chemical Engineers, 1992). The Yucca Mountain Review Plan (NRC, 2002) and 10 CFR Part 63 do not identify or designate any specific methodologies. DOE should assure the hazard analysis methodology has the capability to identify all significant hazards with potential to cause radiological release to the public or facility workers.

The DOE methodology to identify hazards and initiating events is based on standard hazard analysis techniques. Appropriateness and capability of the hazard analysis methodology for comprehensive identification of potential hazards at the proposed repository facility are being reviewed by staff. Preliminary review suggests that the DOE method has a potential weakness. For example, hazards arising from incorrect actions because of human error have not been defined by the hazard analysis methodology. Numerous probabilistic risk assessment studies have shown that human errors can be important contributors to the risk associated with the operations of a nuclear facility (Swain and Guttman, 1983). It is expected that human error also will be a significant contributor to risk in the operations of the proposed repository (Eisenberg, 2001a). DOE consideration of human factors in the preliminary preclosure safety assessment is confined to limited fault tree models to estimate the probability of events, such as a yoke drop from a bridge crane onto the fuel assemblies in the assembly transfer system (CRWMS M&O, 2000c); a runaway transporter carrying waste packages down the North Ramp (CRWMS M&O,

2000d); or heating, ventilation, and air conditioning system unavailability (CRWMS M&O, 1999j). DOE should identify hazards and initiating events associated with human error in preclosure safety analysis in a consistent and unified manner in all the functional areas. DOE has discussed the methods it plans to use for identification of human actions that can affect the risk associated with preclosure operations (Bechtel SAIC Company, LLC, 2002a).

The hazard analysis methodology proposed by DOE also does not identify potential hazards resulting from failure of the software and electronic hardware systems used in remote operations. During the preclosure period, surface and subsurface facility operations for various equipment are expected to be remotely controlled (e.g., overhead bridge cranes, trolleys, waste-container transporters, and emplacement gantries to move casks, canisters, bare-fuel assemblies, or waste packages) (DOE, 2001b). Software reliability may be a significant factor in the safe operation of the proposed Yucca Mountain repository (Eisenberg, 2001b). DOE should identify hazards and initiating events associated with reliability of electronic hardware and software used in the operations in preclosure safety analysis.

3.3.3 Preliminary Hazards Identification

DOE developed a preliminary list of operational hazards and initiating events that have the potential for a radiological release during the preclosure period (CRWMS M&O, 1999a) based on the facility design and operations and the functions of the structures, systems, and components described in several system description documents. The preclosure hazards and initiating events are associated with receiving, preparing, packaging, transporting, and emplacement operations at the surface and subsurface facility of the proposed repository (DOE, 2001b). Status for the DOE identification of operational hazards and initiating events from surface and subsurface operations in each of the functional areas is compiled in Table 3-3, including those hazard categories not considered or addressed by DOE.

Table 3-3 also includes natural and human-induced hazards that may become potential initiating events during facility operations. DOE stated it plans to design the facility to withstand initiating events resulting from such hazards and, therefore, eliminated the impact of natural and human-induced hazards on facility operations from further consideration in the preclosure safety analysis (CRWMS M&O, 1999b,e). DOE presented its current conceptual approach to seismic design of structures, systems, and components important to safety and its relationship to the preclosure safety analysis (Bechtel SAIC, Company, LLC, 2002a). Staff agree with DOE that two different design basis earthquakes, as originally proposed in Seismic Topical Report 2, for the seismic design of structures, systems, and components important to safety, can still be used to meet the regulatory requirements of 10 CFR Part 63. However, each design basis earthquake needs to be treated as an initiating event, and the probability of exceeding the dose limits of 10 CFR Part 63 should be determined by considering the event sequences attributable to the initiating event. In other words, assessment of the event sequences should consider the probabilities of the initiating event (e.g., earthquake) and the associated combinations of repository system and/or component failures. DOE proposed using fragility and seismic margin analyses to demonstrate that the probability of an unacceptable dose as a result of an earthquake initiating event will be less than 1 in 10,000 within the preclosure period. Bechtel SAIC Company, LLC (2002a), however, does not clearly define the circumstances or conditions that govern the use of these analysis methodologies. DOE indicated that details regarding the implementation of the proposed seismic design and associated dose consequence assessment methods are being developed and will be discussed by NRC and DOE in future interactions.

3.3.4 Initiating Events

Staff conducted a preliminary review of DOE reports about the estimation of probability and frequency of occurrence of initiating events. The review findings discussed here concentrate on the DOE analysis of drop events during the handling of waste during surface operations. Staff are also in the process of reviewing the DOE evaluation of initiating events for subsurface operations, and preliminary findings of the subsurface transporter analysis are discussed.

3.3.4.1 Drop Events

DOE identified drops of casks, canisters, and assemblies from cranes and lifting machines as potential hazards in its preliminary hazard analysis (CRWMS M&O, 1999d,e). DOE further analyzed these drops as initiating events and established through event sequence analysis that there are 14 Category 1 event sequences and 12 Category 2 event sequences (CRWMS M&O, 2000c). The categorization of event sequences and subsequent demonstration of compliance with performance objectives depends on the frequency of the initiating drop events and the probability of the event sequences. These drop events specifically relate to drop of fuel assemblies in the assembly transfer system, drop of the lifting yoke from the bridge crane on the waste form, and drop of cask and disposal canisters from bridge cranes. Preliminary staff review of the DOE estimation of probability of initiating events associated with drop events is discussed next.

3.3.4.1.1 Drop of Fuel Assemblies

The wet-assembly-transfer machine in the assembly transfer system would be used to handle spent nuclear fuel assemblies and spent nuclear fuel assembly baskets. The functions associated with the wet-assembly-transfer machine are lifting of assemblies out of casks and dual-purpose canisters and placing them in spent nuclear fuel baskets, moving the baskets on the transfer casks for storage in assembly staging pools, and moving the baskets from the transfer carts to inclined transfer carts for transporting to the dry assembly handling cell. The DOE evaluation of initiating event frequency for the assembly and basket drop in the assembly transfer pool is based on the drop rate experience in fuel handling operations at commercial nuclear reactor facilities (CRWMS M&O, 2000c). Data presented in CRWMS M&O (1997b, Sections 4.1.3.1 and 7.2.2.1.1) show 26 fuel assembly drop events were identified from 1970 to 1991 in 110 nuclear power plants. During that period, 119,814 assemblies were handled. Each fuel assembly was handled 5 times prior to being irradiated and either 10 times or 4 times after being irradiated, depending on core loading practices (full core unloading or partial unloading with shuffling). The DOE calculations indicated that the number of handling operations performed on unirradiated fuels was 599,070 and on irradiated fuel was 851,061, and the total handling operations during the 22-year period were 1,445,131. The 26 drop events consists 8 drops of unirradiated and 18 drops of irradiated fuel assemblies. The drop frequency was estimated as 1.5×10^{-5} by dividing the total number of drops by the total number of handlings (26/1,445,131).

While the DOE use of the drop rate for the assembly transfer machine based on the analysis of actuarial data from similar handling equipment in the nuclear reactor industry is acceptable, a few questions remain on the direct applicability of these data to repository operations.

(i) The number of assemblies handled in the assembly transfer system at the Yucca Mountain project is envisaged to be 219,144 during a period of approximately 24 years (Table 2-2, CRWMS M&O, 1999g). Each spent nuclear fuel assembly will be handled 10 times [4 times individually and 6 times in a commercial spent nuclear fuel basket (CRWMS M&O, 2000c Assumptions 3.9 and 3.10)] and the total handling operations for spent nuclear fuel assemblies would be 2,191,440 in 2 assembly transfer system lines (DOE, 2001b). Assembly handlings at the repository would be approximately 1.5 times that of cumulation handing in 110 power plants. In addition, the operations at the repository would be continuous, whereas the cranes or lifting devices in the nuclear power plants typically handle fuel assemblies once a year during refueling operations. Therefore, Yucca Mountain represents a more severe environment of the demand on the machines and staff used in handling spent nuclear fuel assemblies.

(ii) DOE estimated the drop rate using drop events from both irradiated and unirradiated fuel assemblies. Out of a total of 26 drop events, 18 drops occurred during handling of irradiated assemblies and 8 drops during handling of unirradiated assemblies. There appears to be different drop rates for irradiated and unirradiated fuel. The data indicate the drop rate for irradiated fuels is 2.11×10^{-5} [18/851,064], approximately 1.5 times higher than the rate of 1.33×10^{-5} [8/599,070] for unirradiated fuel. Because irradiated fuel assemblies will be handled at the repository site, DOE needs to perform an analysis to substantiate the use of all handling and drop events, instead of the irradiated data that produce a higher failure rate. In addition, the apparent high drop rate of irradiated fuel over unirradiated fuel needs investigation.

(iii) If a repository begins operation, the failure rates for mechanical and electrical components and human actions are expected to be higher than after operations have been established for some time and the defects in equipment and problems in operations have been corrected. As with most technological devices and engineered systems, experience suggests that the failure rate during time for a crane systems follows a pattern commonly known as a bathtub curve (NRC, 1994 Figure C.3.1, page C–43). This failure pattern exhibits three distinct phases: (i) high failure rate during initial period because of design, manufacturing, and assembly errors; (ii) decrease in failure rate because these errors are identified and rectified, reaching a steady state for a long period; and (iii) increase in failure rate caused by aging and wear out of components. The data used by DOE from power plants between 1970 and 1991 are probably in the middle phase of the bathtub curve, because most nuclear power plants were constructed and began operation prior to that time period. Thus, the actuarial data do not include early failures. Because preclosure safety analysis would be used by DOE during the construction authorization to demonstrate regulatory compliance, establish the design bases and design criteria; and assign quality level categorizations of structures, systems and components including the crane system; a full spectrum of failure dependence during time needs to be considered. In particular, consideration needs to be given to the implications of initially higher rates of occurrence of initiating events for the demonstration of compliance. In addition, DOE needs to consider how failure rates of cranes may increase with use and how effectively maintenance procedures mitigate the increased failure rate.

(iv) DOE used the reactor fuel assembly handling and drop data from 1970 to 1991 because they were the only data available when DOE was preparing its report in 1997 (CRWMS M&O, 1997b). DOE should update and refine its analysis by including more recent drop data in its calculations; however, the application of these data should be constrained by the considerations described in (iii).

(v) DOE used data from the nuclear industry to estimate the failure rate of the wet-assembly-transfer machines. Currently, the wet-assembly-transfer machine is designated as Quality Level 2 (DOE, 2001a). The structures, systems, and components used in the nuclear industry, which are designed, constructed, maintained, and operated at a high quality level, are expected to be lower than the failure rates of components of commercial quality. DOE needs to ensure the lower failure rates associated with nuclear-quality components are not inadvertently used to screen out event sequences and assign a lower quality level designation for the crane system. DOE should also ensure that quality levels of the assembly transfer machines are commensurate with the quality levels in the nuclear industry if nuclear data is used to estimate the failure rate.

3.3.4.1.2 Bridge Cranes

The DOE estimation of crane drop frequency for heavy lifts, such as shipping casks, disposal containers, and canisters is based on actuarial data on crane operations available from Newport News Shipbuilding Facility (CRWMS M&O, 1998b, Attachment X). DOE used an estimated probability of drops for analysis of event sequences associated with normal operation drop events and two-block drop events in the canister transfer system, assembly transfer system, and disposal handing system (CRWMS M&O, 1998b, 2000c). Data used for the evaluation are based on the total number of dropped loads and total number of lifts of nonmagnetic cranes during 1996 and 1997. The total number of lifts using nonmagnetic cranes (the type of crane that would be used at the repository) during the 2-year period was 933,000, and the total number of dropped loads was 13 in the same period. The failure rate of bridge cranes was calculated as 1.4×10^{-5} drops per lift from the ratio of the number of drop events to total lifts. In addition, DOE estimated the failure probability of two-block failures based on the data provided by the Department of the Navy to DOE on the drop accidents that occurred between 1994 and 1996 (CRWMS M&O, 1998a). In a two-block event, a bridge crane drops a load from the highest point physically possible. The data from the Department of the Navy showed that the number of 2-block events was 11, and the total number of drop events was 45 in the same period. DOE assumed that two-block drops were a subset of the total drop events and estimated the two-block failure probability as 0.24 (i.e., 24 percent of the total drop events were two-block failures). Data on the total lifts were not available during this period.

The estimated drop rates for a normal operation drop events and a two-block drop events are based on data during a relatively short period of 2 years and require justification. By comparison, crane failure data from approximately 22 years of operations were used in evaluating drop frequencies for fuel assemblies (CRWMS M&O, 1997b). In addition, data from a 2-year period do not reflect the initial high failure rates of mechanical and electrical components immediately after a crane is commissioned. Further, the type and complexity of operations at the shipbuilding facility are likely to be substantially different from the cask and disposal container lifting operations at a repository, which would be performed remotely in a hot cell environment. For the two-block analysis, the justification that two-block drops are a subset of total drop events is not substantiated. This assumption implies that, for every lift, the crane operator depends on the hoist travel-limit switch to restrict the crane height, however, it is not likely that the two-block switch is challenged on every lift. The probability of two-block failure should be based on an estimation of the demand on the limit switch.

3.3.4.1.3 Handling Equipment Drop from Overhead Cranes

Overhead bridge cranes would be used in several functional areas of the repository for lifting heavy objects such as casks, canisters, and disposal containers. The DOE preliminary hazard analysis identified drop of handling equipment (e.g., a lifting yoke) from the crane in the assembly transfer system and disposal container handling system as potential hazards. The lifting yoke, which is attached to the crane, can potentially drop on spent nuclear fuel and produce radiological doses to the public or workers. DOE estimated the probability of a yoke drop to be 1.8×10^{-7} using fault tree analysis (CRWMS M&O, 2000c, Attachment VI, page VI-5). The top event of the yoke drop was either a human-induced event sequence or failure of electrical/mechanical components. The estimated probability was used in event sequence analysis for drop events on spent nuclear fuel assemblies in the pool and hot cell, on spent nuclear fuel baskets in the pool and hot cell, and on unsealed disposal canisters in the hot cell. The frequencies for corresponding event sequence numbers 2-04, 2-05, 2-06, 2-07, and 2-10 (CRWMS M&O, 2000c, page VII-5) was categorized as Category 2 events. Preliminary review of a DOE fault tree generated several concerns regarding human error probabilities and human actions and the failure of electrical and mechanical components. Possible deficiencies in the fault tree analysis are discussed next.

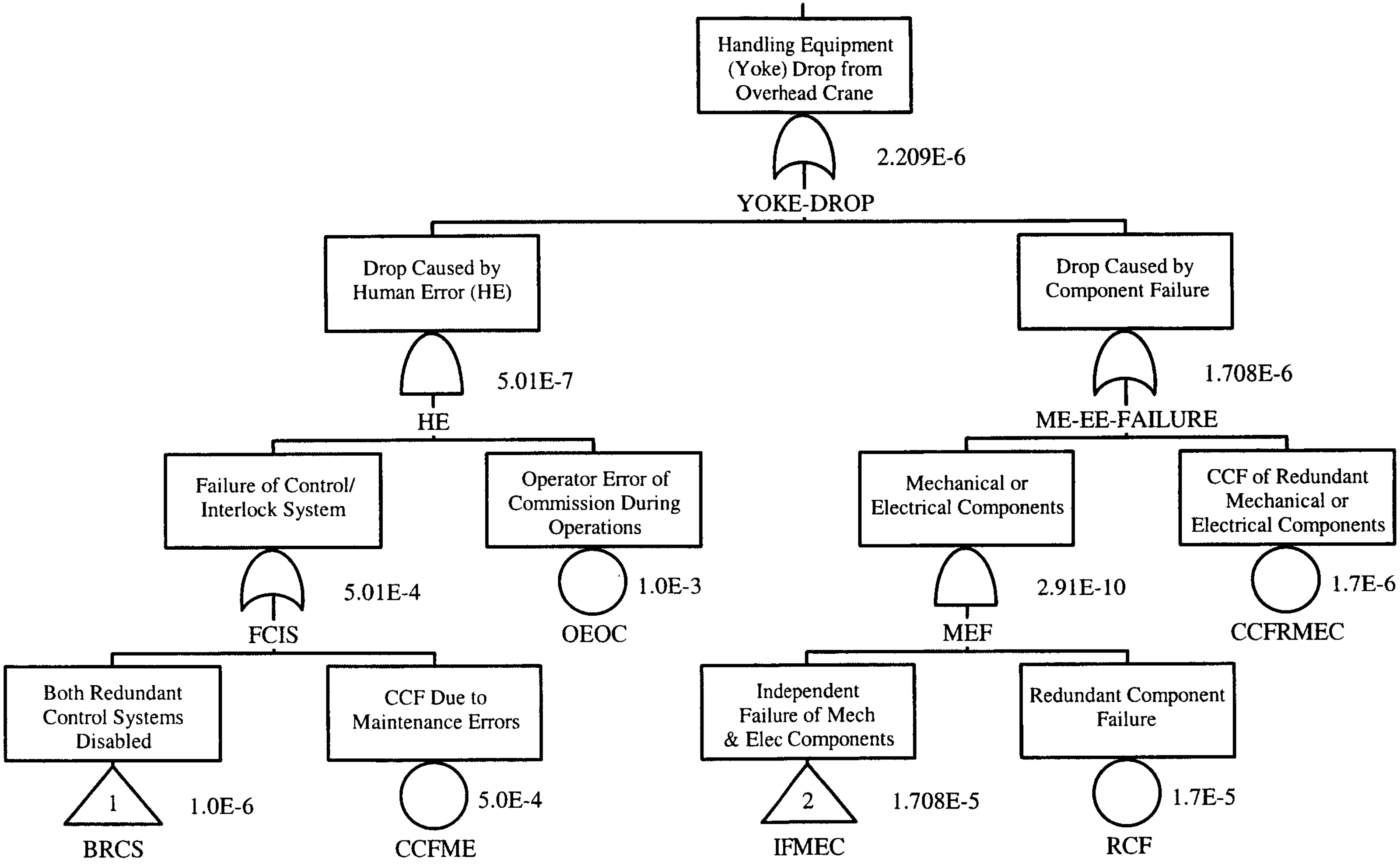
Level of Detail: The basic events for human error are failure to follow written procedures during maintenance and checker failure to detect error during maintenance. The maintenance procedure for the crane is likely to be composed of several tasks, rather than one. If the entire sequence were considered, there may be many steps that could disable the crane. A full analysis that considered several possibilities for disabling the crane during maintenance, as well as recovery from them, might lead to a higher (or perhaps lower) basic failure rate. In other words, the failure rate assumed (0.01) may be more reflective of a single task performed according to written instructions (Swain and Guttman, 1983,Table 20-6, line 1), rather than the entire maintenance sequence. In the same Table 20-6, line 7 provides a much higher human error probability (0.3) for "use written maintenance procedures." Use of this higher value would have a substantial effect on the overall probability of the top event. This fault tree may have been trimmed at too high a level to determine with sufficient precision the probability of disabling the crane from a maintenance procedure. A more detailed fault tree that evaluates the entire maintenance procedure may be needed. Alternatively, rather than using generic error rates, if the error rate for crane maintenance is known, that could be used.

The failure of mechanical and electrical components has been considered in the fault tree analysis (CRWMS M&O, 2000c, Figure 1). Independent failure of active components such as cable, hoisting drum, brake clutch, and control system was considered. It appears that a composite failure rate determined by the union of failure rates of all the components was used in the analysis (CRWMS M&O, 2000c). A generic crane system consists of additional mechanical and electrical components, (e.g., hook, gearbox, gearbox/brake shaft, gearbox/coupling, motor) (Duke, 1985). Failure of these components may alter the failure probability of the top event. A more detailed fault tree modeling of components and systems needs to be considered.

<u>Incompatibility of Error Rates</u>: It appears that there may be an incompatibility in error rates used for mechanical equipment and human actions. The failure rates used for mechanical and electrical components appear to be rates of failure on demand (i.e., each attempt to use the equipment). The operator error of commission permitting a yoke drop also appears to be a rate of failure for each operation of the crane. The rates used for human error related to maintenance, however, appear to be rates of failure for each maintenance operation and each check. Because maintenance is usually performed far less frequently than each use, these failure rates may have a different basis. If both crane control systems are disabled during maintenance, a yoke drop through an operator error of commission is enabled. To be correct, the failure rates used in the fault trees should be compatible.

<u>Dependent Human Errors</u>: Disabling the redundant crane control systems should not be considered independent because maintenance will likely be performed on both by the same person. The same dependence is true for checking maintenance. The fault tree appears to consider this dependence by using the β factor methodology with an assumed β value of 0.1. Using the beta factor methodology means the probability of a failure occurring in both systems because of a common cause of failure is $\beta\lambda$, where β is defined as $\beta = \lambda_{cc}/\lambda$; where λ_{cc} is the common cause failure rate, and λ is the overall failure rate for each component (human action in this case). The treatment of dependency of human actions in Swain and Guttman (1983) is different from the β factor methodology. The result, however, is similar because the error probability for two different, but dependent, human actions are related by the conditional probability of error in Task B, given failure to perform Task A without error. Equation (10-17) in Swain and Guttman (1983) indicates that, for tasks with high dependence, the probability of error for Task B, given a failure for Task A, is $(1 + N) / 2$, where N is the failure probability for Task A. In this fault tree, the failure probability for maintenance is 0.01, so the conditional failure probability is $(1 + 0.01) / 2 \approx 0.5$. Because the probability of failure for both tasks is $N(1 + N) / 2 \approx (0.01) \times (0.5)$ this is equivalent to a β of 0.5 and an increase in the common cause failure rate by a factor of 5. It may be more appropriate to treat the dependency of human actions as complete dependence, because it is likely that the same person will be involved in maintenance of crane systems A and B. In that case, the value of β will change from 0.5 to 1.0 [Swain and Guttman, 1983, Eq. (10-18)] translating into a higher overall failure rate.

<u>Estimation of Probability</u>: The fault tree accompanying this commentary is an example of how an alternative set of assumptions and failure rates can lead to a substantial difference in probability for this event initiator. The fault tree and accompanying commentary are based on a preliminary, limited review and are not intended to be definitive or final. The concerns raised are intended to be illustrations of the type of considerations DOE should make in moving toward a complete preclosure safety analysis to be included in any license application. The DOE fault tree (CRWMS M&O, 2000c, Figure 1) was revised based on the previously suggested modifications, and a scoping fault tree analysis was conducted using SAPHIRE Version 6.70 software. The fault tree structure using SAPHIRE Version 6.70 is shown in Figure 3-1(a–g). As discussed previously, higher dependency ($\beta = 0.5$) was assumed for the common cause failure caused by maintenance errors. Failure of the mechanical and electrical components was modeled after the hoist failure logic diagram (Duke, 1985). The mechanical failure of a crane



Note: CCF - Common-Cause Failure

Figure 3-1 (a). Fault Tree Handling Equipment (Yoke-Drop) from Overhead Cranes

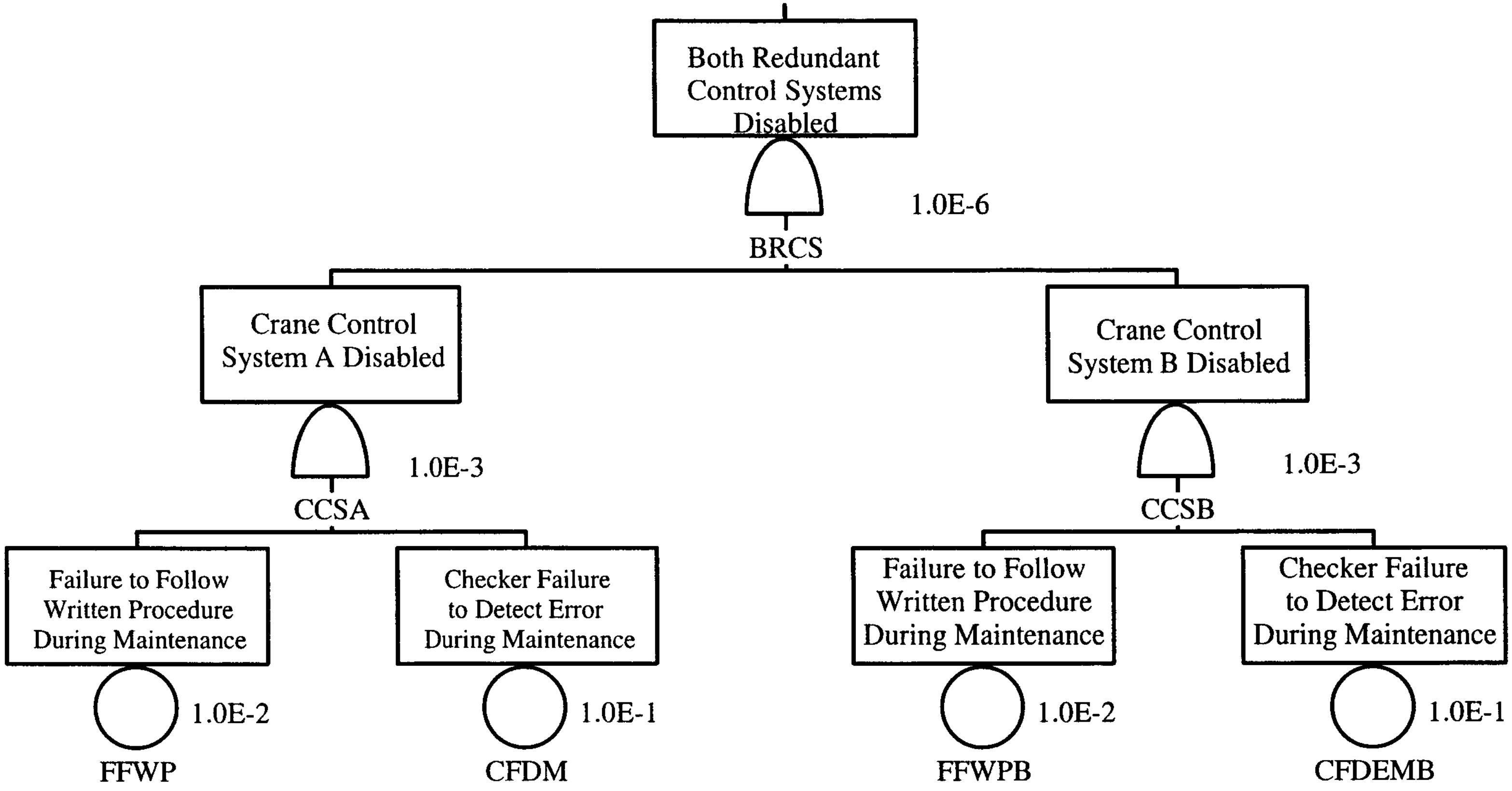


Figure 3-1 (b). Fault Tree of Transfer Gate 1, Both Redundant Control Systems Disabled [see Figure (3-1a)]

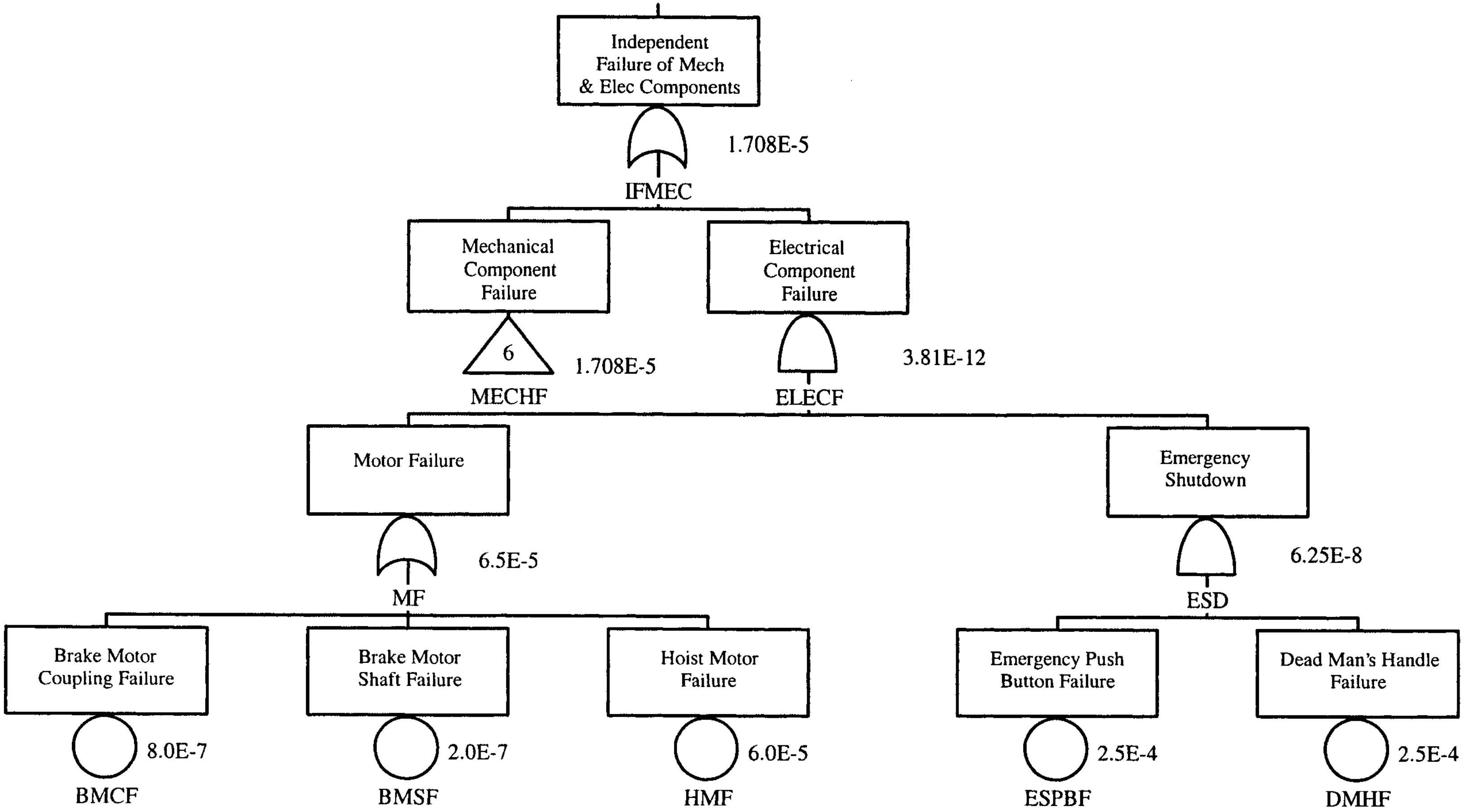


Figure 3-1 (c). Fault Tree of Transfer Gate 2, Independent Failure of Mechanical and Electrical Components [see Figure (3-1a)]

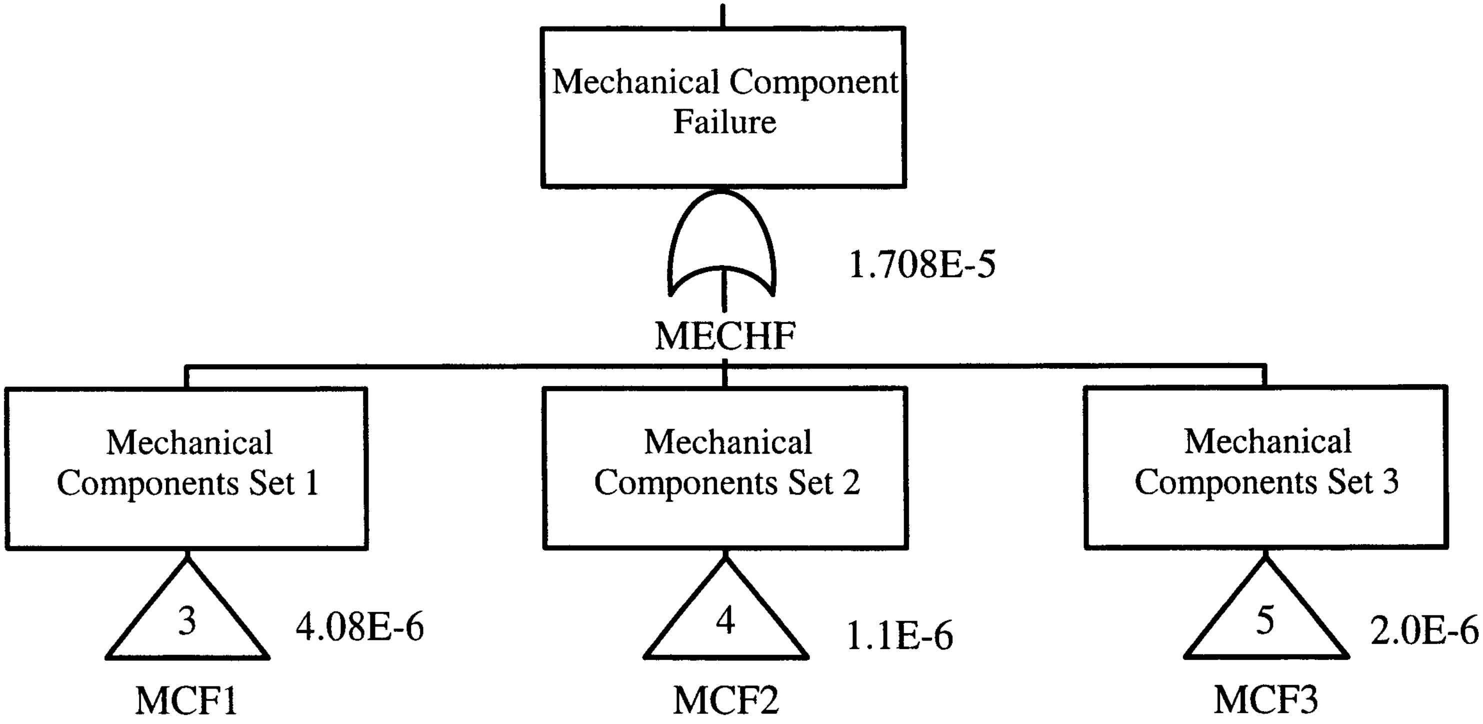


Figure 3-1 (d). Fault Tree of Transfer Gate 6, Mechanical Component Failure [see Figure (3-1c)]

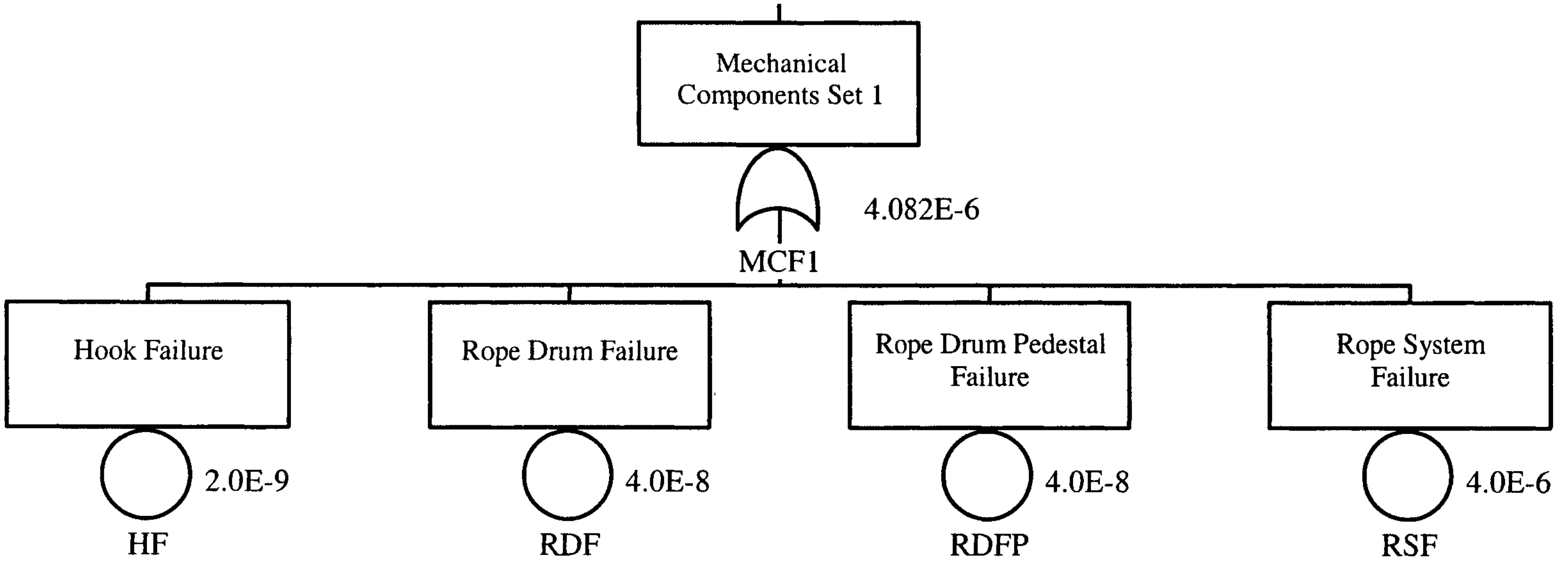


Figure 3-1 (e). Fault Tree of Transfer Gate 3, Mechanical Components Set 1 [see Figure (3-1d)]

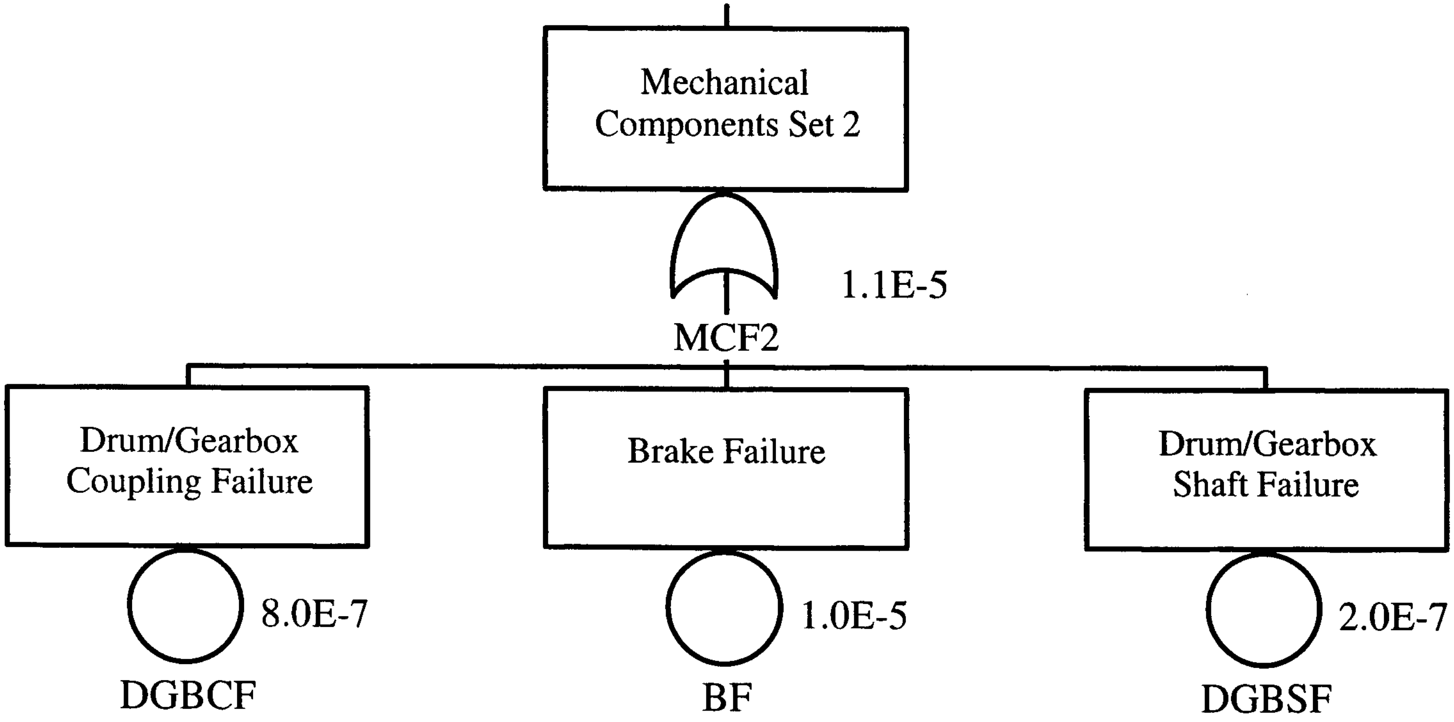


Figure 3-1 (f). Fault Tree of Transfer Gate 4, Mechanical Components Set 2 [see Figure (3-1d)]

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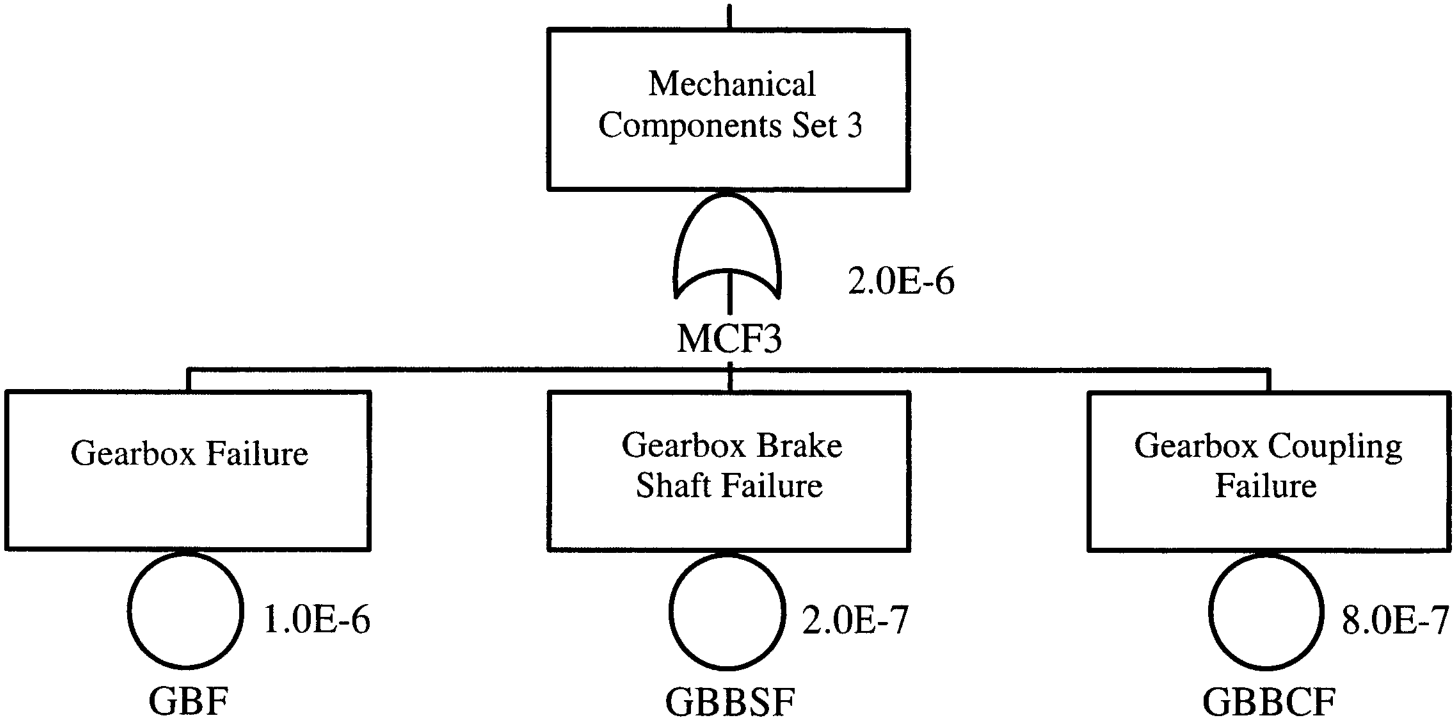

Figure 3-1 (g). Fault Tree of Transfer Gate 5, Mechanical Components Set 3 [see Figure (3-1d)]

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may be caused by any of 10 basic events that constitute failure of independent components: hook, rope (cable) system, rope drum, rope drum pedestal, drum/gearbox shaft, drum/gearbox coupling, gearbox, gearbox/brake shaft, gearbox/brake coupling, and brake. The basic events are connected by an OR gate. The electrical failure is a combination of six basic events connected by AND/OR gates.

The components that constitute basic events are brake/motor shaft, brake/motor coupling, hoist motor, emergency stop push button, and dead man's handle. Modeling of other electrical components such as contactors and controllers, and such was not considered in this analysis, for simplicity. For this analysis, the fault tree model assumes redundancy for all mechanical and electrical components, and the β factor for components and common cause failure is 0.1 (CRWMS M&O, 2000c). The failure probability per demand for all the failure modes is shown in Table 3-5. The source of the failure data used in the analysis is Duke (1985). The probability data in the SAPHIRE analysis were entered as a point estimate without assigning any distribution. The fault tree analysis shows the probability of the top event (i.e., bridge crane failure) to be 2.209×10^{-6} per demand, which is approximately one order of magnitude higher than the DOE calculations. For this modified fault tree, however, no modification has been made to account for the possible incompatibility of exposures for maintenance and operational tasks (as discussed previously in Incompatibility of Error Rates). The frequency and categorization of event sequences 2-04, 2-05, 2-06, 2-07, and 2-10 by DOE and the revised analysis are shown in Table 3-6. The event sequences 2-04 and 2-05, designated as Category 2, would be changed to Category 1 event sequences. The data on the maximum number of lifts per year used to determine the initiating event frequency and conditional probability of event sequences were adopted from CRWMS M&O (2000c) for this analysis, and they have not been reviewed. Although the crane system was not modeled in detail, this scoping analysis shows that, based on existing information on a generic crane design and failure rate, the probability of the top event handling equipment drops influenced categorization of event sequences. Revision of event sequence categories will result in modification of the Category 1 performance evaluation required by 10 CFR Part 63.

3.3.4.1.4 Control Systems

DOE calculated the probability of spurious movement or equipment failure for four events attributed to the failure of control systems during the transfer operations in the assembly transfer pool (Attachment VII, CRWMS M&O, 2000c). The four events are (i) collision of spent nuclear fuel assemblies during transfer from cask to basket staging rack (event 1-02), (ii) collision of the spent nuclear fuel basket during transfer to pool storage (event 2-01), (iii) collision of the basket during transfer to the incline transfer cart (event 2-02), and (iv) uncontrolled descent of inclined transfer cart (event 2-03). DOE based its Design Basis Event frequency calculations on a control systems failure rate of 6.00×10^{-6} failures per hour. This rate was obtained from IEEE Std. 500 (1984, page 573) (CRWMS M&O, 2000b, VII-4) and has been described as all failure modes for instruments, controls, and sensors. The failure rate appears to be a generic overall failure rate number, which may not adequately represent or bound the real failure rate that will depend on the specific type of control system chosen for the wet-assembly- transfer machine or the transfer cart. Furthermore, IEEE Std. 500 (1984,p. 573) indicates the failure rate may be for a velocity/flow control device, which would be inappropriate for the planned system. The appropriateness of the failure rate of components used in the repository operations must be justified.

Table 3-5. Failure Rate of Basic Events and β Factors for Fault Tree Analysis and Source of Data

Description	Data	Source
Hook	2×10^{-9} per demand	Duke (1985)
Rope system	4×10^{-6} per demand	Duke (1985)
Rope drum	4×10^{-8} per demand	Duke (1985)
Rope drum pedestal	4×10^{-8} per demand	Duke (1985)
Drum/gearbox shaft	2×10^{-7} per demand	Duke (1985)
Drum/gearbox coupling	8×10^{-7} per demand	Duke (1985)
Gearbox	1×10^{-6} per demand	Duke (1985)
Gearbox/bake shaft	2×10^{-7} per demand	Duke (1985)
Gearbox/bake coupling	8×10^{-7} per demand	Duke (1985)
Brake	1×10^{-5} per demand	Duke (1985)
Brake/motor shaft	2×10^{-7} per demand	Duke (1985)
Brake/motor coupling	8×10^{-7} per demand	Duke (1985)
Hoist motor	6×10^{-5} per demand	Duke (1985)
Emergency stop push button	2.5×10^{-4} per demand	Duke (1985)
Dead man's handle	2.5×10^{-4} per demand	Duke (1985)
Failure to follow written procedure during maintenance	1×10^{-2} per demand	CRWMS M&O (2000c)
Failure to detect error during maintenance	1×10^{-1} per demand	CRWMS M&O (2000c)
Error of commission during operation	1×10^{-3} per demand	CRWMS M&O (2000c)
Common cause failure caused by maintenance (β)	0.5	Swain and Guttman (1983)
Common cause failure of electrical and mechanical components (β)	0.1	CRWMS M&O (2000c)

References:

Duke, A.J. "Reliability Techniques Used in the Assessment of Cranes." NCSR/GR/64. Warington, United Kingdom: National Center of Systems Reliability, United Kingdom Atomic Energy Authority. 1985.

CRWMS M&O. "Design Basis Event Frequency and Dose Calculation for Site Recommendation." CAL–WHS–SE–000001. Rev. 01. Las Vegas, Nevada: CRWMS M&O. 2000c.

Swain, A.D. and H.E. Guttman. NUREG/CR–1278, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications." Final Report. SAND80–0200. Albuquerque, New Mexico: Sandia National Laboratories. 1983.

Table 3-6. Change in Event Sequence Frequency with Modified Analysis				
Event Sequence Identifier (CRWMS M&O 2000c)	**Event Sequence Frequency and Category**			
	DOE Calculation (CRWMS M&O 2000c)	**DOE Category (CRWMS M&O 2000c)**	**Revised Analysis**	**Revised Category**
2-04	2.38×10^{-3}	2	5.75×10^{-2}	1
2-05	2.38×0^{-3}	2	5.75×10^{-2}	1
2-06	1.74×10^{-3}	2	2.51×10^{-2}	1
2-07	6.95×10^{-5}	3	5.03×10^{-3}	2
2-10	1.1×10^{-4}	2	1.32×10^{-3}	2

Reference:
CRWMS M&O. "Design Basis Event Frequency and Dose Calculation for Site Recommendation." CAL–WHS–SE–000001. Rev. 01. Las Vegas, Nevada: CRWMS M&O. 2000c.

3.3.4.2 Subsurface/Transportation System

This section discusses the status of the staff review of the subsurface transporter safety systems. The events, event sequences, and safety systems related to the waste package transporter have been discussed in CRWMS M&O (1997a,c, 2000d). The transporter is a radiation-shielded rail car driven by two locomotives, one on either end. The transporter is 22 m [72.4 ft] in length and carries a total weight of 387.4 MT [427.04 tons] including the waste package. The transporter will travel a distance of 2,187 m [7,173.36 ft] along North Ramp, which slopes at 2.15 percent, and follows the North Ramp Extension curve to the North Ramp Extension (Figure 5, CRWMS M&O, 2000d). At the end the North Ramp Extension, it meets the North Main. In a preliminary hazard analysis, DOE identified transporter runaway as a possible hazard with the potential for radiological release. The report included an analysis of the possibility of transporter derailment and tipover conditions (using Newtonian equations) based on a runaway event. In addition, the report evaluated the theoretical probability of a runaway event based on fault tree analysis techniques.

CRWMS M&O (2000d) presents a detailed analysis of the potential for track derailment of the transporter during runaway conditions. Runaway train speeds were calculated for frictionless conditions using rolling resistance based on empirical calculations from both Mark's Standard Handbook for Mechanical Engineers and Goodman's Equipment calculations (CRWMS M&O, 2000d). DOE analyzed several runaway scenarios and evaluated runaway speed at different locations from the entrance of the North Ramp to the end of the North Ramp Extension. The maximum speeds derived from the calculations were 30.82 m/s [68.94 mph] at the North Ramp Extension curve and 35.61 m/s [79.6 mph] at the point where the North Ramp Extension meets the North Main. The Nadal Criterion was used to calculate the potential for track derailment at maximum speed locations. The Nadal Criterion is implemented in a monogram chart to make a determination of the likelihood of derailment based on coefficient of friction and flange angle of the rail. A coefficient of friction of 0.42 (hard steel sliding on hard steel) and a flange angle of

55 degrees (corresponding to tracks showing severe wear) were used for the analysis. Based on graphical interpretation of the Nadal Criterion, no possibility for derailments was anticipated at the maximum speed locations unless conditions of extreme track/wheel wear are anticipated or maintenance problems were allowed to occur with the track system. DOE indicated the track system is expected to undergo rigorous inspections during routine operation, and therefore, such track problems are considered an unlikely scenario. The procedure and schedule for track inspection have yet to be developed to confirm this assumption. The report did not consider certain dynamic conditions such as seismic activity for the potential of a transporter derailment. In addition, lightning strike or the effect of temperature extremes on exposed portions of the track between the Waste Handling Building and the North Ramp Portal, which may increase the possibility of a derailment during waste transport, have not been considered.

The report also included an analysis of tipover potential at various locations on the North Ramp considering a runaway situation and the speed of the loaded transporter. For tipover calculations, the transporter was assumed to be a rigid body (no suspension sway), and the sum of the tipover moments in the curve was used to determine the overturning speed. The calculations indicated that the tipover speed for the transporter is 31.85 m/s [71.25 mph] at the North Ramp Extension curve. At the North Ramp Extension curve, DOE calculated the transporter speed is 3.2 percent less than the tipover speed, and, therefore, DOE considered the transporter is likely to tip during a runaway event. At the curved point where the North Ramp Extension meets the North Main, the transporter speed exceeds the tipover speed by 11.7 percent. Therefore, these calculations indicate the potential for transporter tipover at the North Ramp at two locations.

DOE evaluated the probability of a runaway event using fault tree analysis. The fault tree discussed in this report is based on an earlier fault tree analysis in CRWMS M&O (1997c). This failure analysis derived a top level probability for an uncontrolled runaway on the North Ramp of 5.88×10^{-4}/year (CRWMS M&O, 2000d, page 93). The transporter runaway event is considered a Category 2 event. In CRWMS M&O (2000d), DOE evaluated the probability with an alternate design with an added safety feature to reduce the postulated frequency. The probability of an uncontrolled runaway transporter is calculated by multiplying the probability of a runaway initiated event and the probability of failure to stop. The probability of runaway initiation was analyzed considering human error and hardware failures. DOE has modified the initiation fault tree by adding three safety features to reduce the probability of runaway initiation. The three safety features added to the basic system were (i) an automatic speed control, which consists of an electronic logic module to automatically control the transporter speed; (ii) a brake interlock, which prevents transporter descent without actuating the dynamic braking system; and (iii) a speed alarm, which alerts the operators to an overspeed condition. In addition, DOE considered adding two safety features that affected the probability of failure to apply brakes (i.e., failure to stop after runaway is initiated). These safety features include an automatic brake actuation system, which engages the brake system whenever an overspeed condition is detected, and the addition of a diverse, independent hydraulic brake system. When these safety features were added, the analysis indicated that the probability for initiation of a runaway event in the North Ramp dropped to 7.38×10^{-10}/year. Many combinations of these safety features were shown to reduce the probability of a runaway situation to an incredible event. A more realistic combination of safety features will be known as the transporter design is defined.

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Some critical observations of the fault tree analysis include the following.

- Many of the baseline event probabilities were derived from data based on nuclear power plant events. These data may or may not be applicable to mining/waste emplacement operational conditions. For example, a runaway initiated by a malfunction in an electrical system of the train is given as 2.5×10^{-4}, which is based on the failure rate of a spurious switch in a nuclear power plant (CRWMS M&O, 2000d).
- Certain probabilities used in the fault tree analysis did not include weighting factors, that were used in reference material analysis. For example, a runaway event initiated by human error was shown as 0.446/year in the reference data (CRWMS M&O, 1997c); the probability of human error is multiplied by the probability of recovery (0.50). There was no justification for why the calculation did not include the weighting factor for the probability of recovery after initial human error occurs.
- Probability factors used in the failure tree analysis did not always use the same failure rate basis. Top-level events were always given as failures per year, whereas some basic events were input as failures per hour or failures per demand. For example, the probability of failure for an automatic speed controller (AUTSPD1) was input into the failure tree as 1.65×10^{-6} per demand while Alarm System Fails (ALARM) was input as 5.5×10^{-7} fails/descent (CRWMS M&O, 2000d, Section 6.8.3.1), which should be converted to fails/year.

The staff will continue the technical review of this report with an indepth analysis of the derivation of each of the events used to calculate the top-level probability (e.g., runaway train on North Ramp) in the fault tree analysis. The staff will conduct a detailed review of the logical combination of the events in the fault tree and independently analyze and review the source material for the basic event probabilities.

3.4 Path Forward

Staff review of the DOE reports about operational hazard analysis is in progress. The current status of the DOE operational hazard analysis and staff assessment based on preliminary review of the DOE documents was presented.

The level of detail provided by DOE about the human actions anticipated as part of operations and about the software systems used for computer control of equipment does not appear to be sufficient for a preliminary evaluation of safety, including the identification of structures, systems, and components important to safety. Staff communicated at the DOE and NRC Technical Exchange and Management Meeting on Preclosure Safety[3] that the level of detail should be sufficient to conduct an acceptable preclosure safety analysis.

In the DOE hazard analysis, DOE does not identify potential hazards resulting from human error and failure of the software and electronic hardware systems used in the remote

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[3] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Preclosure Safety (July 24–26, 2001)." Letter (August 14) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

operations. Hazards and initiating events associated with human error in preclosure safety analysis need to be addressed in a consistent and unified manner in all functional areas. DOE discussed its plans to identify human actions that can affect the risk associated with preclosure operations and quantify probabilities (Bechtel SAIC Company, LLC, 2002a). In addition, the reliability of the software and electronic hardware on the facility hazards needs to be considered in the preclosure safety analysis.

DOE has used actuarial data to estimate failure probability or frequency of initiating events. DOE needs to address the sufficiency and appropriateness of the data for evaluation of the failure rate for repository operations. Because these data will be used in assessing preclosure safety of a new facility, consideration should be given to the higher initial failure rate of equipment should be included. In addition, the evaluation of initiating event frequency is based on point estimates of probability of failure of different components (CRWMS M&O, 2000b). It is not clear if the probability estimates used by DOE represent mean, median, or some other point estimate. Frequency of component failure is, however, highly uncertain. The staff concerns about uncertainty and variability of probability data used in the event sequence analysis were discussed at the DOE and NRC Technical Exchange and Management Meeting on Preclosure Safety.[4] Although no agreements were formulated regarding these concerns, DOE agreed that it would, as appropriate, assign probability distributions to component failure rate estimates. DOE discussed the approach to address the uncertainties with the failure rates in Bechtel SAIC, LLC (2002a).

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[4] Reamer, C.W. "U.S. Nuclear Regulatory Commission/U.S. Department of Energy Technical Exchange and Management Meeting on Preclosure Safety (July 24–26, 2001)." Letter (August 14) to S. Brocoum, DOE. Washington, DC: NRC. 2001.

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APPENDIX A

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STATUS OF DOE PRELIMINARY HAZARDS ANALYSIS

The current status of the U.S. Department of Energy (DOE) preliminary hazards analysis is presented in this appendix. The information presented in tabular form includes descriptions of events, DOE strategy, data source reference for operational hazards, and natural and human-induced hazards affecting all functional areas. The contents of this table were compiled from CRWMS M&O (1997, 1998, 1999, 2000a,b) and DOE (2001).

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Table A–1. Status of DOE Hazard Analysis at Functional Areas			
Functional Area	**Event Description**	**DOE Strategy**	**Source**
Waste Receipt and Carrier/Cask Transport	Cask carrier rail car accident	Event sequence prevented by design.	CRWMS M&O, 1999; DOE, 2001
	Diesel fire	Not expected. Event frequency expected beyond regulatory limit.	CRWMS M&O, 1999; DOE, 2001
	Loss of offsite power	Expected to be Category 1 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Earthquake-vibratory ground motion	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Flood	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado missiles	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado wind	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
Carrier/Cask Preparation	Shipping cask collide with wall, shield door, another cask, or heavy object	Event sequence prevented by design.	CRWMS M&O, 1999; DOE, 2001
	Lifting yoke or crane fixtures fall on cask	Event sequence prevented by design.	CRWMS M&O, 1999; DOE, 2001
	Loss of offsite power	Expected to be Category 1 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Earthquake-vibratory ground motion	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Flood	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado missiles	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado wind	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
Waste Handling Carrier Bay	Shipping cask drop onto floor (no impact limiters)	Event sequence prevented by design.	CRWMS M&O, 1998, 2000a

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Table A–1. Status of DOE Hazard Analysis at Functional Areas (continued)			
Functional Area	**Event Description**	**DOE Strategy**	**Source**
Waste Handling Canister Transfer	Shipping cask tipover/slapdown (no impact limiters)	Bounded by shipping cask drop onto floor	CRWMS M&O, 1999
	Shipping cask collide with wall, shield door, another cask, or heavy object	Event sequence prevented by design	CRWMS M&O, 1999; DOE, 2001
	Lifting yoke or crane fixtures fall on the cask	Event sequence prevented by design	CRWMS M&O, 1999; DOE, 2001
	Two-block shipping cask drop	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 1999
	Loss of offsite power	Expected to be Category 1 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Earthquake-vibratory ground motion	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Flood	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado missiles	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado wind	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Canister drop on floor in canister transfer system hot cell	Event sequence prevented by design	CRWMS M&O, 1998; DOE, 2001
	Handling equipment drop on canister	Bounded by canister drop onto floor	CRWMS M&O, 1999; DOE, 2001
	Canister tipover/slapdown	Bounded by canister drop onto floor	CRWMS M&O, 1999
	Canister drop on sharp object	Bounded by canister drop onto floor	CRWMS M&O, 1999
	Canister drop on disposal canister	Bounded by canister drop onto floor	CRWMS M&O, 1999
	Canister collision	Bounded by canister drop onto floor	CRWMS M&O, 1999
	Small canister drop on another small canister in staging rack	Bounded by canister drop onto floor	CRWMS M&O, 1999
	Two-block canister drop	Event frequency expected to be beyond regulatory limit	CRWMS M&O 1999; DOE, 2001
	Shielding door close on cask	Event sequence prevented by design	CRWMS M&O, 1999; DOE, 2001

Table A–1. Status of DOE Hazard Analysis at Functional Areas (continued)			
Functional Area	**Event Description**	**DOE Strategy**	**Source**
Waste Handling Canister Transfer	Fire in Waste Handling Building	Prevent radiological release from fire. Event frequency expected to be less than Category 2 limit	CRWMS M&O, 1999; DOE, 2001
	Criticality associated with small canister staging rack	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 1999; DOE, 2001
	Loss of offsite power	Expected to be Category 1 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Earthquake-vibratory ground motion	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Flood	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado missiles	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado wind	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
Waste Handling Assembly Transfer	Spent nuclear fuel assemblies drop on other spent nuclear fuel assemblies in cask unloading pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Spent nuclear fuel assemblies collision in pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Spent nuclear fuel assemblies drop on empty basket in pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Spent nuclear fuel assemblies drop on other spent nuclear fuel assemblies in basket in pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket drop on another basket in basket staging rack in pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket collision during transfer to pool storage	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket drop onto another basket while lowering basket into pool storage	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket drop onto another basket while lifting basket out of pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket collision during transfer to incline transfer canal in pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket drop onto transfer cart or pool floor	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a

Table A–1. Status of DOE Hazard Analysis at Functional Areas (continued)			
Functional Area	**Event Description**	**DOE Strategy**	**Source**
Waste Handling Assembly Transfer	Uncontrolled descent of incline transfer cart with basket	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket drop back into pool while lifting basket off incline transfer in hot cell	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket drop on assembly transfer system hot cell floor	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Basket drop on another basket in dryer	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Spent nuclear fuel assemblies drop on other spent nuclear fuel assemblies in dryer	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Spent nuclear fuel assemblies drop on assembly transfer system hot cell floor	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Spent nuclear fuel assemblies drop on other spent nuclear fuel assemblies in disposal container	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Handling equipment drop on spent nuclear fuel assemblies in pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Handling equipment drop on spent nuclear fuel assemblies in hot cell	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Handling equipment drop on spent nuclear fuel assemblies basket in pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Handling equipment drop on spent nuclear fuel assemblies basket in hot cell	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Waste form fall on disposal container	Potential for release	CRWMS M&O, 1997
	Shipping cask drop onto floor	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Shipping cask tipover	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Shipping cask drop into cask preparation pit	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Shipping cask drop into cask unloading pool	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Shielding door close on cask	Event sequence prevented by design	CRWMS M&O, 1999; DOE, 2001
	Cask cooldown system overpressurization	Event sequence prevented by design.	CRWMS M&O, 1999; DOE, 2001
	Flooding due to uncontrolled pool water fill/drain down	Event sequence prevented by design.	CRWMS M&O, 1999; DOE, 2001

Table A–1. Status of DOE Hazard Analysis at Functional Areas (continued)

Functional Area	Event Description	DOE Strategy	Source
Waste Handling Assembly Transfer	Catastrophic pool failure	Prevent pool failure. Event frequency expected to be less than Category 2 limit.	CRWMS M&O, 1999
	Criticality event in pool	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 1999; DOE, 2001
	Loss of pool water resulting in Zircalloy cladding fire	Event frequency expected to be less than regulatory limit	CRWMS M&O, 1999; DOE, 2001
	Cladding fire in dryer	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 1999; DOE, 2001
	Fire	Prevent radiological release from fire. Event frequency expected to be less that Category 2 limit.	CRWMS M&O, 1999; DOE, 2001
	Loss of offsite power	Expected to be Category 1 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Earthquake-vibratory ground motion	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Flood	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado missiles	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado wind	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Unsealed disposal container collision while transfer from assemblies transfer system to disposal container handling cell	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
Waste Handling Disposal Container and Waste Package Remediation	Unsealed disposal container drop and slapdown while lifting disposal container on welding table	Potential for release. Event sequence analyzed.	CRWMS M&O, 2000a
	Unsealed disposal container drop on cell floor	Event frequency expected to be beyond regulatory limit	DOE, 2001
	Handling equipment drop on unsealed disposal container while lifting disposal container on welding table	Event sequence prevented by design	CRWMS M&O, 2000a
	Waste Handling Building handling equipment fall on waste package	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001

Table A–1. Status of DOE Hazard Analysis at Functional Areas (continued)

Functional Area	Event Description	DOE Strategy	Source
Waste Handling Disposal Container and Waste Package Remediation	Aboveground lifting system drop waste package vertically oriented	Event sequence prevented by design	CRWMS M&O, 2000b, 1997; DOE, 2001
	Aboveground lifting system drop waste package horizontally oriented	Event sequence prevented by design	CRWMS M&O, 2000b, 1997; DOE 2001
	Waste package tipover and slap down on flat surface	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Waste package collide in lag storage area	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
Waste Handling Disposal Container and Waste Package Remediation	Pressurized system missile strike waste package	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Waste package missile strike from battery hydrogen explosion	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Thermally overloaded waste package	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Fire in disposal container cell	Event sequence prevented by design	CRWMS M&O, 2000b, 1997; DOE, 2001
	Two-block disposal/waste package drop	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 1999; DOE, 2001
	Shield door close on disposal container	Event sequence prevented by design	CRWMS M&O, 1999; DOE, 2001
	Welding burn through	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 1998; DOE, 2001
	Slapdown due to vertical drop or seismic tipover	Event sequence prevented by design	CRWMS M&O, 1997 DOE, 2001
	Disposal container/waste package preclosure criticality due to accidental misloading	Event sequence prevented by design	CRWMS M&O, 1999; DOE, 2001
	Criticality due to waste package flooding	Event frequency expected to be beyond regulatory limit	DOE, 2001
	Criticality due to internal geometry failure	Event frequency expected to be beyond regulatory limit	DOE, 2001

Table A–1. Status of DOE Hazard Analysis at Functional Areas (continued)			
Functional Area	**Event Description**	**DOE Strategy**	**Source**
Waste Handling Disposal Container and Waste Package Remediation	Transporter breakdown between Waste Handling Building and North Portal (insolation)	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Loss of offsite power	Expected to be Category 1 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Earthquake-vibratory ground motion	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Flood	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado missiles	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
	Tornado wind	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999
Subsurface Transfer Emplacement and Monitoring	Underground handling equipment fall on waste package	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Drift liner/ground support fall on waste package	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	One waste package fall on an other	Event cannot occur	CRWMS M&O, 2000b
	Greater than 6-MT rockfall on waste package	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 2000b
	Greater than 6-MT rockfall on transporter	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 2000b
	Bed plate roll out of transporter	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
		Event sequence prevented by design	CRWMS M&O, 1997
	Emplacement gantry drop on horizontally oriented waste package	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
		Event sequence prevented by design	CRWMS M&O, 1997; DOE, 2001
	Waste package fall on sharp object	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Transporter collision at normal operating speed	Event sequence prevented by design	CRWMS M&O, 2000b DOE, 2001

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Table A–1. Status of DOE Hazard Analysis at Functional Areas (continued)			
Functional Area	**Event Description**	**DOE Strategy**	**Source**
Subsurface Transfer Emplacement and Monitoring	Transporter derail without tipover, waste package restraint failure	Event sequence prevented by design	CRWMS M&O, 2000b, 1997; DOE, 2001
	Transporter derail with roll over	Event sequence prevented by design	CRWMS M&O, 1997; DOE, 2001
	Transporter derail with tipover	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Transporter runaway	Event frequency expected to beyond regulatory limit	CRWMS M&O, 2000b, 1997; DOE, 2001
	Transporter door close on waste package	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Emplacement gantry operation cause waste package collision	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Thermally overloaded emplacement drift	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Loss of underground ventilation	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Rockfall bury waste package with debris	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Fuel rod rupture/internal pressurization	Event sequence prevented by design	CRWMS M&O, 2000b; DOE, 2001
	Waste package criticality misload	Event sequence prevented by design	CRWMS M&O, 2000b
	Waste package early failure	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 2000b; DOE, 2001
	Seismic activity, surface fault displacement	Event frequency expected to be beyond regulatory limit	CRWMS M&O, 1997
	Seismic activity, earthquake	Event sequence prevented by design	CRWMS M&O, 1997
	Underground Fire	Prevent radiological release from fire. Event frequency expected to be less than Category 2 limit.	CRWMS M&O, 1999; DOE, 2001
	Loss-of-offsite power	Expected to be Category 1 event. Event sequence prevented by design.	CRWMS M&O, 1999

Table A–1. Status of DOE Hazard Analysis at Functional Areas (continued)			
Functional Area	**Event Description**	**DOE Strategy**	**Source**
Subsurface Transfer Emplacement and Monitoring	Flood	Expected to be Category 2 event. Event sequence prevented by design.	CRWMS M&O, 1999

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