QUANTIFYING LOW PROBABILITY HUMAN FAILURE EVENTS

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Prepared by

George Adams

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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ABSTRACT

This report, which has been prepared as a knowledge capture report for the U.S. Nuclear Regulatory Commission, Division of High-Level Waste Repository Safety, documents an approach that can be used to systematically examine and identify, in a risk-informed manner, dominant contributors to human failure event modeling. For an example set consisting of seven low probability human failure events, the report (i) identifies the extent to which various human reliability analysis methods included human (and hardware) factors and (ii) uses sensitivity analysis to examine how ranges of potential uncertainty in the human factors affect the calculated human error probabilities. The sensitivity analysis identified several potentially significant contributors to the human error probabilities for these seven examples; namely, working conditions, the availability of time to perform an activity, and dependency between operator actions. The overall result of the approach documented here is to afford a risk-informed estimate of the importance of individual human factor uncertainties on human error probabilities. This approach has a potential application in identifying which technical bases for human factors are the most significant on which to focus during a review of low probability human failure events.

CONTENTS

FIGURES

Figure Page

TABLES

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA data summarized in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Calculations have been recorded in CNWRA Scientific Notebook Number 1073E (Adams, 2011). Data used to support descriptions in this report are also taken from documents published by U.S. Department of Energy contractors and supporting organizations; the respective sources of these non-CNWRA data should be consulted for determining the level of quality assurance.

ANALYSES AND CODES: Microsoft® Excel® 2007 (Microsoft, 2006) was used to organize the data and produce graphs. SAPHIRE 7 (Idaho National Engineering and Environmental Laboratory, 2011) was used to generate event sequence results.

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ACRONYMS/ABBREVIATIONS

APOA	Assessed Proportion of Affects
ATHEANA	A Technique for Human Event Analysis
BSC	Bechtel SAIC Company, LLC
CFF	Cognitive Function Failure
CNWRA	Center for Nuclear Waste Regulatory Analyses
CPC	Common Performance Condition
CRCF	Canister Receipt and Closure Facility
CREAM	Cognitive Reliability and Error Analysis Method
CTM	Canister Transfer Machine
DOE	U.S. Department of Energy
EPC	Error-Producing Condition
ESD	Event Sequence Diagram
GTT	Generic Task Type
HEART	Human Error Assessment and Reduction Technique
IHF	Initial Handling Facility
NARA	Nuclear Action Reliability Assessment
NRC	U.S. Nuclear Regulatory Commission
RF	Receipt Facility
TAD	Transportation, Aging, and Disposal
THERP	Technique for Human Error Rate Prediction
WHF	Wet Handling Facility

1 INTRODUCTION

This report, which has been prepared as a knowledge capture report for the U.S. Nuclear Regulatory Commission, Division of High-Level Waste Repository Safety, documents an approach that can be used to systematically examine and identify, in a risk-informed manner, dominant contributors to human failure event modeling. For an example set of low probability human failure events, the report (i) identifies the extent to which various human reliability analysis methods included human (and hardware) factors and (ii) uses sensitivity analysis to examine how ranges of potential uncertainty in the human factors affect the calculated human error probabilities. The overall result of the approach is to provide a risk-informed estimate of the importance of individual human factor uncertainties on human error probabilities. This approach has a potential application in identifying which technical bases for human factors are the most significant to focus on during a review of low probability human failure events.

As described by the Human Factors and Ergonomics Society (2011), “human factors” is a term that is concerned with the application of what we know about people; their abilities, characteristics, and limitations to the design of equipment they use; environments in which they function; and jobs they perform. In the context of this report, the term refers more specifically to characteristics of the operators, supervisors, or workers (such as adequate training) and to characteristics of the working environment (such as advantageous working conditions). This report focuses on low probability human failure events, defined here as those events having a probability less than 1×10^{-4}, that are dominant contributors (i.e., contribute more than 50 percent) to event sequence frequency.

An event sequence is a schematic representation of the logical progression of an accident scenario leading to undesired consequences (Stewart and Melchers, 1997). It describes the order in which events occur in time, starting with an initiating event and followed by subsequent responses of systems and/or human actions to this initiator. The end state of an event sequence is a specific outcome, such as a direct radiation exposure or a particulate release, and is expressed in terms of a frequency. This frequency is the expected number of occurrences of the event sequence over a specified time period. Low probability human failure events, which are the subject of this report, can become dominant contributors to event sequence frequency when, for example, they are the only initiator in event sequences with no other systems in place to mitigate the consequences or reduce the frequency of the event sequence.

This report examines seven low probability human failure events, taken as examples from published human failure event analyses, and develops a sensitivity analysis for the human factors that were used to quantify these human failure events. The example human failure events and their calculated human error probabilities were taken from descriptions of low probability human failure events for hypothetical facilities that receive and handle radioactive waste. The U.S. Department of Energy (DOE) originally developed the examples, which involve surface facilities only and do not include fire-related event sequences, for various event sequences in a Canister Receipt and Closure Facility (CRCF) (BSC, 2009a), a Wet Handling Facility (WHF) (BSC, 2009b), a Receipt Facility (RF) (BSC, 2009c), and an Initial Handling Facility (IHF) (BSC, 2008).

The seven examples focus on human error as it relates to operations within surface facilities. In some cases, human failure events involve multiple human failure scenarios. For example, a human failure scenario might involve a worker receiving a direct exposure because someone mistakenly did not install shielding. Another human failure scenario might involve a worker receiving a direct exposure because someone installed shielding improperly. The sum of the failure probabilities from these two scenarios could represent the probability for a human failure event in which a worker receives a direct exposure during a cask preparation activity.

Each identified step in an event sequence can be quantified in terms of success or failure probabilities. In assessing the safety of work-related processes, the effect of human failure can be considered and quantified by a number of human reliability analysis methods. In the selected examples, DOE used a combination of five different human reliability analysis methods:

- Nuclear Action Reliability Assessment (NARA) (Corporate Risk Associates, 2006)
- Cognitive Reliability and Error Analysis Method (CREAM) (Hollnagel, 1998)
- Human Error Assessment and Reduction Technique (HEART) (Williams, 1986)
- The expert elicitation approach from A Technique for Human Event Analysis (ATHEANA) (NRC, 2000)
- Technique for Human Error Rate Prediction (THERP) (Swain and Guttmann, 1983)

Although DOE did not categorize human factors explicitly in the human reliability analyses, most of the examples included the use of the human reliability analysis method CREAM, a method that clearly addressed four areas involving human factors: (i) the presence of administrative controls or the availability of procedures, (ii) the adequacy of training, (iii) the availability of time to perform an activity, and (iv) working conditions. To develop the sensitivity analysis in this report, human factors are categorized into these four areas regardless of the human reliability analysis method.

2 QUANTIFICATION OF THE HUMAN FAILURE EVENT EXAMPLES

Ultimately in this report, a sensitivity analysis is used to assess the effect of uncertainty on calculated human failure event probabilities. However, when several facilities are considered and each facility has multiple potential human failure events, the sensitivity analysis can be large. To narrow the sensitivity analysis, a systematic approach is needed to rapidly identify the human failure events that are most important from a risk-informed perspective. This proposed systematic approach consists of a series of filters that are applied in succession followed by a sensitivity analysis as follows:

1. Filter Event Sequences: For all of the facilities under consideration, identify the higher frequency event sequences. In this report, event sequences with a frequency[1] of 1×10^{-2} or higher were examined because these event sequences are closer to the boundary between Category 1 and Category 2 defined in 10 CFR 63.2.

2. Filter Human Failure Events: Identify the low probability[2] human failure events in each of the higher frequency event sequences. In this report, human failure events with a probability less than 1×10^{-4} were examined because, in general, a detailed quantification analysis (as opposed to a screening analysis) is used at probabilities less than 1×10^{-4} and oftentimes in a detailed analysis, more than one human factor is needed to obtain the low probability.

3. Filter Contributors: Identify those human failure events that are dominant contributors to event sequence frequency. In this report, human failure events that are dominant contribute more than 50 percent to the event sequence frequency. The value of 50 percent was arbitrarily chosen. The assumption here is that if a single event (in this case, human failure event) in an event sequence contributes more than half to the event sequence frequency, then uncertainties in its quantification may significantly affect uncertainties in the overall event sequence frequency.

4. Perform a Sensitivity Analysis: For the resulting low probability human failure events that are dominant contributors to event sequence frequency, identify the human factors with the potential to significantly affect event sequence frequency. For the sensitivity analysis in this report, if a human factor can degrade to the point that the overall event sequence frequency approaches or crosses a categorization boundary (previously discussed in Step 1), then that human factor is considered to have the potential to significantly affect event sequence frequency.

To prepare for the sensitivity analysis, it is necessary to examine the methods used for human failure event quantification and to note which human (and hardware) factors were contributors to the human error probability. This section of the report describes the seven examples used for the subsequent sensitivity analysis and identifies the human reliability analysis methods DOE used to quantify the human failure events.

Table 2-1 lists the seven examples, A through G, of low probability human failure events and their associated event sequences. All the human failure events in the table have a probability less than 1×10^{-4} and contribute more than 50 percent to an event sequence frequency. The

[1]Event sequence frequency has units of estimated number of occurrences over the operational period. The operational period may be several years.
[2]A human error probability is the estimated likelihood that an individual will fail to accomplish the activity identified within an event sequence.

table shows cut sets of higher frequency (1×10^{-2} or higher) event sequences. (A cut set is a combination of one or more failure events—that is, human failures, system failures, or component failures—that when taken together, specify the accident progression for an event sequence.) In the examples, each human failure event was the only basic event (i.e., contributor to failure) in its cut set. Therefore, the cut set frequency represents the product of the human error probability and the throughput (e.g., number of canisters processed over a time period). Table 2-1 shows the percentage contribution of the cut set to the event sequence frequency. Because the human failure event is the only event in each cut set, this percentage contribution is also the human failure event contribution to the event sequence frequency.

All event sequences in Table 2-1 are direct exposure event sequences and are part of various event sequence diagrams (ESDs) that are detailed in the Table 2-1 supporting references. The ESD18 event sequences in the CRCF and the ESD11 event sequences in the RF are direct exposures during operations involving the canister transfer machine (CTM). The ESD19 event sequences in the CRCF and the ESD12C event sequence in the IHF are direct exposures during waste package closure and export. The ESD29 event sequence in the WHF involves direct exposure during closure activities for a transportation, aging, and disposal (TAD) canister.

2.1 Description of Examples

The seven examples are briefly described here. More detailed information about each example is provided in the Appendix, including the human reliability analysis methods, the estimated human error probabilities, and the human factors that contribute to the human error probabilities.

Table 2-1, Examples A and G, Exposure during Transport and Emplacement Vehicle Loading (BSC, 2009a, 2008) both represent human failure events that result in exposure while loading a waste package onto a transport vehicle. Example A is postulated to occur in the CRCF, and Example G is postulated to occur in the IHF. Both human failure events were quantified by the same human reliability analysis methods and used the same parameters within these methods (Table A–1), so the two examples are treated together for the sensitivity analysis. In Examples A and G, three scenarios with individual probabilities (Table A–1) were added together to estimate the overall human error probability for the human failure event. In the first scenario, a crew member remains in the Waste Package Loadout Room (possibly due to an operator failing to order an evacuation) and fails to exit, and a radiation protection worker fails to check or recognize that someone has remained in the room. Note the first scenario dominates the human error probability; therefore, it is described here and the other two scenarios are detailed in the Appendix.

Table 2-1, Example B, Operator Failure during Canister Staging (BSC, 2009a), has only one scenario (Table A–2) and is postulated to occur in the CRCF. In this scenario, an operator working from the CRCF control room fails to close the staging rack port gate before raising the CTM shield skirt and a supervisor fails to check that the port gate is closed at the end of operations (e.g., at the end of a shift).

Table 2-1, Examples C and F, Direct Exposure in Canister Transfer Room (BSC, 2009a,c), both involve a direct exposure during canister transfer. Example C is postulated to occur in the CRCF, and Example F is postulated to occur in the RF. Both human failure events were quantified using the same human reliability analysis methods and used the same parameters within these methods (Table A–3), so they are treated together in the sensitivity analysis. These human failure events consist of a scenario in which a worker violates an administrative

Table 2-1. Low Probability Human Failure Events That Are Dominant Contributors to Event Sequence Frequency

Human Failure Event	Description	Human Error Probability	Event Sequence Identifier*	Cut Set Frequency/Event Sequence Frequency	Percentage Contribution to Event Sequence Frequency
Canister Receipt and Closure Facility (CRCF)†					
Example A: 060–OPDIREXPOSE3–HFI–NOD	Exposure During Transport and Emplacement Vehicle Loading	3×10^{-5}	CRCF–ESD19–WP–TAD,3	0.244/0.244	100
			CRCF–ESD19–WP–H&D,3	0.099/0.099	100
Example B: 060–OPSTAGERACK1–HFI–NOD	Operator Failure During Canister Staging	3×10^{-5}	CRCF–ESD18–DSTD,2	0.186/0.302	62
Example C: 060–OPCTMDIREXP1–HFI–NOD	Direct Exposure in Canister Transfer Room	8×10^{-6}	CRCF–ESD18–TAD,2	0.121/0.130	93
			CRCF–ESD18–HLW,2	0.078/0.085	92
			CRCF–ESD18–DSTD,2	0.050/0.302	17
Example D: 060–OPWPINNERLID–HFI–NOD	Operator Fails To Install Waste Package Inner Lid	6×10^{-6}	CRCF–ESD19–WP–TAD,2	0.049/0.057	86
			CRCF–ESD19–WP–H&D,2	0.020/0.023	87
Wet Handling Facility (WHF)‡					
Example E: 050–OPSTCSHIELD1–HFI–COD	Operator Fails To Install Shielded Transfer Cask Shield Ring Properly	6×10^{-5}	WHF–ESD29–TAD,2	0.070/0.070	100
Receipt Facility (RF)§					
Example F: 200–OPCTMDIREXP–HFI–NOD	Direct Exposure in Canister Transfer Room	8×10^{-6}	RF–ESD11,2	0.059/0.067	88

Table 2-1. Low Probability Human Failure Events That Are Dominant Contributors to Event Sequence Frequency (continued)

Human Failure Event	Description	Human Error Probability	Event Sequence Identifier*	Cut Set Frequency/Event Sequence Frequency	Percentage Contribution to Event Sequence Frequency
Initial Handling Facility (IHF)‖					
Example G: 51A–OPDIREXPOSE3–HFI–NOD	Exposure During Transport and Emplacement Vehicle Loading	3×10^{-5}	IHF–ESD–12C–NVL,2	0.012/0.012	100

*The event sequence identifier contains two main parts and several subparts. For example, event sequence identifier "CRCF–ESD19–WP–TAD, 3" specifies event sequence 3 in event tree "CRCF–ESD19–WP–TAD" where the event tree graphically depicts a group of event sequences (in this case, associated with waste package closure activities). For this event tree, "CRCF" specifies event sequences in the CRCF, "ESD19" refers to event sequence diagram 19, and "WP–TAD" identifies that the event sequence is associated with a waste package containing a transportation, aging, and disposal canister.

†BSC. "CRCF Reliability and Event Sequence Categorization Analysis." 060–PSA–CR00–00200–000. Rev. 00B. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2009.

‡_____. "WHF Reliability and Event Sequence Categorization Analysis." 050–PSA–WH00–00200–000. Rev. 00B. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2009.

§_____. "RF Reliability and Event Sequence Categorization Analysis." 200–PSA–RF00–00200–000. Rev. 00B. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2009.

‖____. "IHF Reliability and Event Sequence Categorization Analysis." 51A–PSA–IH0–00200–000. Rev. 00A, CACN 001. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2008.

control and enters the Canister Transfer Room during a transfer, combined with the failure of the control room operator to close the port gate before raising the CTM shield skirt.

Table 2-1, Example D, Operator Fails to Install Waste Package Inner Lid (BSC, 2009a), has the lowest human error probability (6×10^{-6}) of the seven low probability human failure events. It is postulated to occur in the CRCF. This human failure event consists of a single scenario (Table A–4), in which an operator fails to install the waste package inner shield lid, and a worker, violating an administrative control, enters the Waste Package Closure Room prior to the start of welding.

Table 2-1, Example E, Operator Fails to Install Shielded Transfer Cask Shield Ring Properly (BSC, 2009b), has the highest human error probability (6×10^{-5}) of the seven low probability human failure events. It is postulated to occur in the WHF and consists of two scenarios with individual probabilities that are added to estimate the human error probability (Table A–5). Prior to draining the TAD canister in preparation for closure, a shield ring must be installed. In the first scenario, the crane operator fails to install the shield ring; crew members do not realize this step in the process was missed, and before approaching the TAD canister, they fail to notice the shield ring is not in place. Note the first scenario dominates the human error probability; therefore, it is described here and the second scenario is detailed in the Appendix.

Most of the human failure events listed in Table 2-1 contribute more than 85 percent to their event sequence frequency. For the two human failure events with lower contributions, both occur in Event Sequence 2 of CRCF–ESD18–DSTD; taken together, they account for 79 percent (i.e., the sum of 62 percent and 17 percent) of the event sequence frequency.

2.2 Summary of Methods and Factors Applied in the Human Reliability Analysis

Table 2-2 identifies the human reliability analysis methods and the human and hardware factors that DOE used to determine the human error probability for the seven example human failure events. The human reliability analysis methods and factors applied for the specific examples are detailed in the Appendix. For all but one of the human failure events, DOE developed the human error probability using more than one human reliability analysis method. As shown in Table 2-2, NARA is common to all seven examples and CREAM is common to all of the examples except Example D. In addition to NARA and CREAM, HEART and THERP were used for Examples A and G and ATHEANA and THERP were used in addition to NARA and CREAM for Example E. Example D was the only human failure event of the seven to use just one human reliability analysis method (i.e., NARA).

Three of the human failure events (Examples A, G, and E) include a hardware failure (e.g., the failure of an interlock, pressure sensor, or radiation sensor) in addition to human failures. However, for Examples A and G, the hardware failure occurs only in the third scenario and results in only a minor contribution to event sequence frequency (Table A–1). For Example E, the probability of the hardware failure (a radiation sensor failure) is at least an order of magnitude lower than the human errors associated with the radiation protection worker and therefore has little effect on the results.

Table 2-2. Summary of Methods and Factors Used in Human Failure Analyses

Human Reliability Analysis Method						Factors DOE Described in Human Failure Analysis				
NARA*	CREAM†	HEART‡	ATHEANA§	THERP‖	**Human Failure Event or Scenario (Human Error Probability)**	Hardware	Administrative Controls or Available Procedures	Adequate Training	Adequate Time	Advantageous Working Conditions
✓	✓	✓		✓	Example A (060–OPDIREXPOSE3–HFI–NOD) Example G (51A–OPDIREXPOSE3–HFI–NOD) (3×10^{-5})	✓	✓	✓	✓	✓
✓	✓				Example B (060–OPSTAGERACK1–HFI–NOD) (3×10^{-5})		✓	✓	✓	✓
✓	✓				Example C (060–OPCTMDIREXP1–HFI–NOD) Example F (200–OPCTMDIREXP1–HFI–NOD) (8×10^{-6})		✓	✓	✓	✓
✓					Example D (060–OPWPINNERLID–HFI–NOD) (6×10^{-6})		✓	✓		
✓	✓		✓	✓	Example E (050–OPSTCSHIELD1–HFI–COD) (6×10^{-5})	✓		✓	✓	

*NARA = Nuclear Action Reliability Assessment
†CREAM = Cognitive Reliability and Error Analysis Method
‡HEART = Human Error Assessment and Reduction Technique
§ATHEANA = A Technique for Human Event Analysis
‖THERP = Technique for Human Error Rate Prediction

3 SENSITIVITY ANALYSIS OF FACTORS AFFECTING HUMAN FAILURE EVENT PROBABILITIES

As shown in Table 2-2, the human reliability analysis methods NARA and CREAM were used more frequently to quantify the human failure events in the seven example cases than any of the other human reliability analysis methods. In addition, the human factors that were described in the human reliability analyses were primarily associated with NARA and CREAM. Consequently, the sensitivity analysis focuses primarily on these two methods and their application to the seven examples.

For CREAM, the human factors (administrative controls or availability of procedures, adequate training, adequate time, advantageous working conditions) and their effects on common performance conditions (CPCs) are assessed by a sensitivity analysis in the sections that follow. Similarly, for NARA, the human factors and their effects on assessed proportion of affects (APOA) for error-producing conditions (EPCs) are described and assessed in the sections that follow. Note that for CREAM and for NARA, the human factors shown in Table 2-2 may also have been associated with generic task types (GTTs) in NARA or cognitive function failures (CFFs) in CREAM. Rather than focusing specifically on uncertainties associated with GTTs or CFFs, the sensitivity analysis focuses on ranges of potential uncertainty once the generic failure type pertaining to a GTT or CFF is identified. This approach assumes the type of human error is adequately reflected by the GTTs or CFFs that DOE assigned, and the uncertainty lies in context-specific human factors reflected by EPCs, APOAs, and CPCs. The following equations show these quantification parameters for human error probabilities calculated using NARA [Eq. (3-1)] and CREAM [Eq. (3-2)].

$$\text{NARA: Probability} = \text{GTT} \times [(\text{EPC1}-1) \times \text{APOA1} + 1] \times \ldots \times [(\text{EPC}n-1) \times \text{APOA}n + 1], \text{ for } n \text{ EPCs} \quad (3\text{-}1)$$

$$\text{CREAM: Probability} = \text{CFF} \times \text{CPC1} \times \text{CPC2} \times \ldots \times \text{CPC}n, \text{ for } n \text{ CPCs} \quad (3\text{-}2)$$

For further descriptions of these parameters and how they are applied in the individual human reliability analysis methods, see the supporting references for NARA (Corporate Risk Associates, 2006) and CREAM (Hollnagel, 1998).

If the same human reliability analysis method was used multiple times to quantify a human failure event and it used the same factor every time, then this factor was changed in all instances of the sensitivity analysis. This was done to reflect the effect of this factor on a specific human reliability analysis method and to show a potential worst case for one human factor in a particular method.

The figures in the sections that follow show the effects individual factors within a human reliability analysis method may have on a human error probability. Each figure has a baseline curve (represented by a dotted line) that corresponds to the human error probability for that example in Table 2-1 . The value DOE specified for a human factor is indicated by the point along the x-axis (Range of Factors) where the curve for one of the four human factors categories (i.e., administrative controls or availability of procedures, adequate training, adequate time, advantageous working conditions) crosses the baseline. The upper ends of the probability curves are truncated by the maximum end of the range for a particular factor (which differs depending on the factor and the human reliability analysis method used). Factors with a potential to have a significant effect on human error probability are summarized in Section 3.6. The figures also display (as horizontal dashed lines) one or more categorization boundaries, in terms of probability, for specific event sequences identified for that example in Table 2-1. If the human error probability curve for a sensitivity analysis factor falls below the dashed line, then the associated cut set frequency for that event sequence is in the Category 2 range, as defined in 10 CFR 63.2. Above the dashed line, the cut set frequency and therefore the associated event sequence frequency fall in the Category 1 range.

3.1 Examples A and G: Exposure During Transport and Emplacement Vehicle Loading (060–OPDIREXPOSE3–HFI–NOD and 51A–OPDIREXPOSE3–HFI–NOD)

Figure 3-1 shows that the probability for the human failure events in Examples A and G (060–OPDIREXPOSE3–HFI–NOD and 51A–OPDIREXPOSE3–HFI–NOD) increases as parameters associated with the four human factors categories (e.g., CPCs for CREAM or APOAs for NARA) are increased individually. The baseline curve shows DOE's human error probability of 3×10^{-5}. The leftmost curve shows the effect of one factor (i.e., working conditions) associated with NARA, and the remaining curves show the effect of each of the four human factors on the quantification associated with CREAM. As described in Table 2-1, human failure events 060–OPDIREXPOSE3–HFI–NOD and 51A–OPDIREXPOSE3–HFI–NOD are dominant contributors in three event sequences (two event sequences in the CRCF and one event sequence in the IHF). The dashed lines in Figure 3-1 are the points where the human error probabilities would be sufficiently high such that the cut set frequency and therefore the event sequence frequency would cross a categorization boundary from Category 2 to Category 1. The dashed lines are calculated as one divided by the throughput to reflect at least one occurrence of the human failure event.

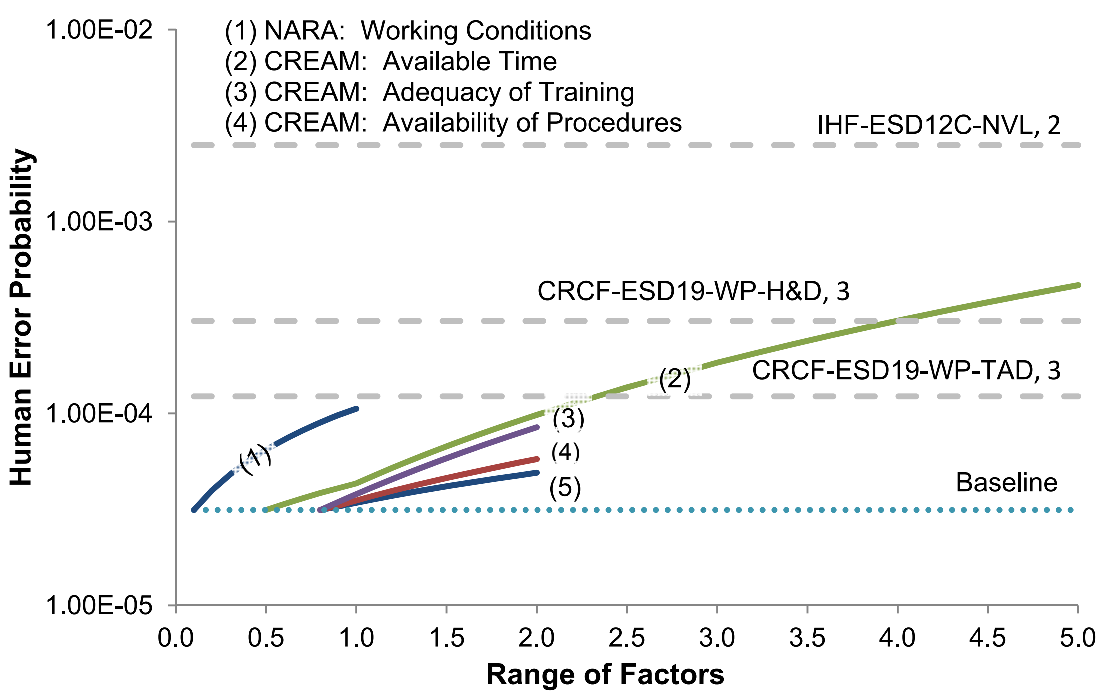

Figure 3-1. Examples A and G: 060/51A–OPDIREXPOSE3–HFI–NOD Sensitivity Analysis

Because DOE identified a small level of distraction for a crew member hearing an announcement to evacuate, this part of the NARA quantification is categorized under "working conditions" in this report. The original DOE analysis also described training and procedures in its NARA quantification and allowed some credit for available time for a crew member to exit the Waste Package Loadout Room. The factor having the greatest influence on human error probability in the NARA quantification involves working conditions, and therefore it is shown in the figure. Figure 3-1 shows that as the working conditions degrade for a crew member (possibly from increasing machine noise), the human error probability and resulting event sequence frequency may increase significantly. For Event Sequence 3 of CRCF–ESD19–WP–TAD, at the hypothetical upper extreme involving working conditions, the human error probability is high enough that the resulting event sequence frequency approaches the categorization boundary (i.e., Curve 1 in Figure 3-1).

More significant effects are shown in the quantifications associated with CREAM. Within the 060–OPDIREXPOSE3–HFI–NOD and 51A–OPDIREXPOSE3–HFI–NOD human failure event quantification, DOE credited adequate available time (i.e., CPC = 0.5) in one case and also identified some time pressure (i.e., CPC = 1.0) in other cases. As shown in Figure 2-1, as the adequacy of available time lessens from adequate available time (i.e., CPC = 0.5) to continuously inadequate available time at the hypothetical upper extreme (i.e., CPC = 5.0), the human error probability increases significantly, resulting in the cut set frequency and therefore also the event sequence frequency crossing a categorization boundary for two of the event sequences in the CRCF. Additionally, for adequacy of training (although the human error probability would not be high enough to result in an event sequence frequency that would cross a categorization boundary), Figure 3-1 shows that the frequency would approach the boundary for one event sequence in the CRCF as the adequacy of training moves from adequate and is associated with high experience (i.e., CPC = 0.8) to a value of inadequate (i.e., CPC = 2.0).

3.2 Example B: Operator Failure During Canister Staging (060–OPSTAGERACK1–HFI–NOD)

The human error probability for Example B (060–OPSTAGERACK1–HFI–NOD) is based on the failure of both an operator and a supervisor in a control room. DOE credited a supervisor (who is in the control room with the operator) for understanding the consequences of not closing a port gate and understanding his or her value within the organization and in the task being undertaken. Therefore, this part of the NARA quantification is categorized under working conditions in this report and is shown as a small curve in Figure 3-2. To quantify the supervisor failure, DOE accounted for some complacency on the part of the supervisor who trusts the operator. Figure 3-2 shows the effect of increasing an APOA from 0.5 to 1.0 for an EPC involving low workforce morale or adverse organizational environment. The EPC has a value of 2, which results in a factor of about 1.3 increase in the supervisor's failure probability (i.e., Curve 2 in Figure 3-2). This is in contrast to the result shown for Examples A and G in Section 3.1 where the EPC had a value of 10 and the crew member's individual failure probability increased by a factor of about 5 as the associated APOA was changed from 0.1 to 1.0.

The portion of the human failure event quantification involving CREAM (i.e., the operator failure) shows more significant increases in human error probability. As shown in Figure 3-2, as human factors such as working conditions, availability of procedures, or adequacy of training worsen, the human error probability increases significantly. For these factors, the resulting human error probability is not high enough to result in a cut set frequency that crosses a categorization boundary. However, this is not the case for availability of time. As shown in Figure 3-2, as the

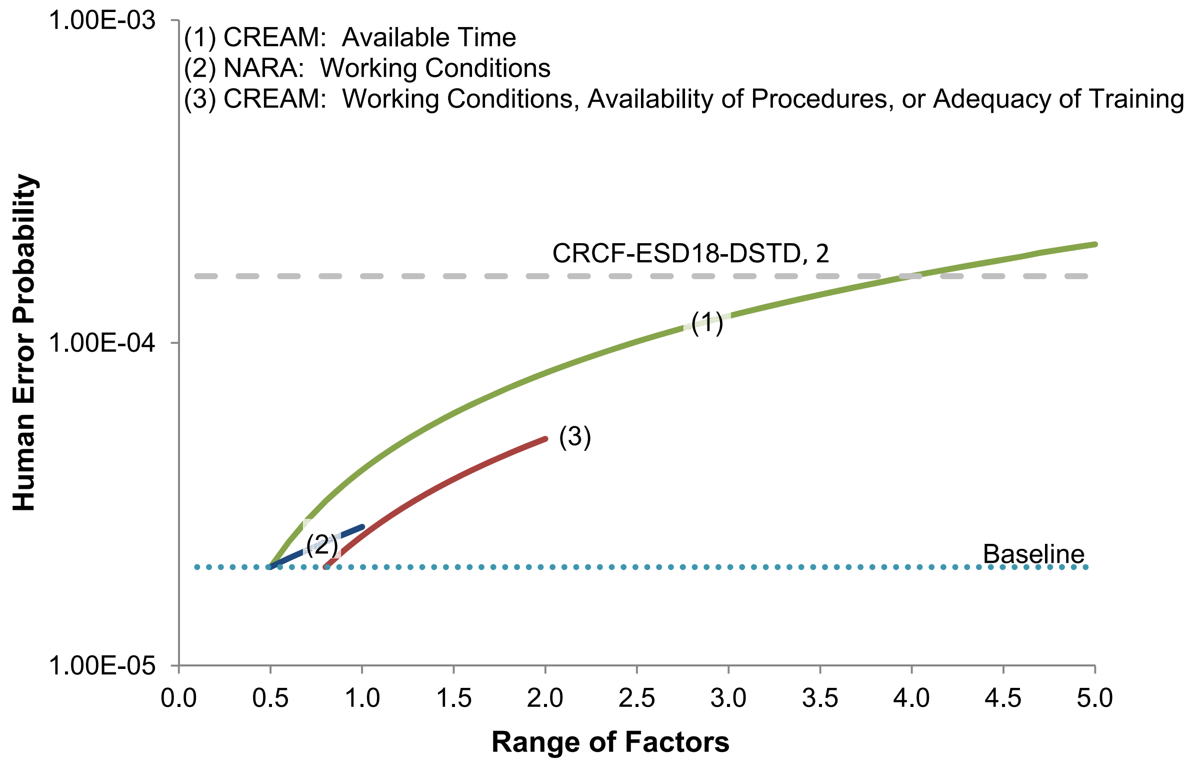

Figure 3-2. Example B: 060–OPSTAGERACK1–HFI–NOD Sensitivity Analysis

adequacy of available time lessens from adequate available time (i.e., CPC = 0.5) to a hypothetical extreme condition of continuously inadequate available time (i.e., CPC = 5.0), the cut set frequency and therefore the event sequence frequency cross a categorization boundary from Category 2 to Category 1.

3.3 Example C and Example F: Direct Exposure in Canister Transfer Room (060–OPCTMDIREXP1–HFI–NOD and 200–OPCTMDIREXP1–HFI–NOD)

Figure 3-3 shows the increase in probability for Examples C and F, human failure events 060–OPCTMDIREXP1–HFI–NOD and 200–OPCTMDIREXP1–HFI–NOD, as parameters associated with the human factors categories are increased individually. Although DOE used both NARA and CREAM, Figure 3-3 shows only the sensitivity analysis for CREAM. For the worker violating an administrative control and entering the Canister Transfer Room, DOE used the full effect of an EPC in its NARA analysis by assigning a value of 1 to the APOA. Therefore, no additional sensitivity analysis was performed for worker failure, because the maximum value was already assigned and the condition could be no worse. The results shown in Figure 3-3 are similar to the results for CREAM described in Section 3.2 because the operator's failure to close a port gate is quantified in the same way. The factor shown in Figure 3-3 that has the greatest effect is the availability of time. As conditions worsen from adequate available time (i.e., CPC = 0.5) to a hypothetical extreme condition of continuously inadequate available time (i.e., CPC = 5.0), the cut set frequency crosses a categorization boundary for one event sequence (Table 2-1) in the CRCF.

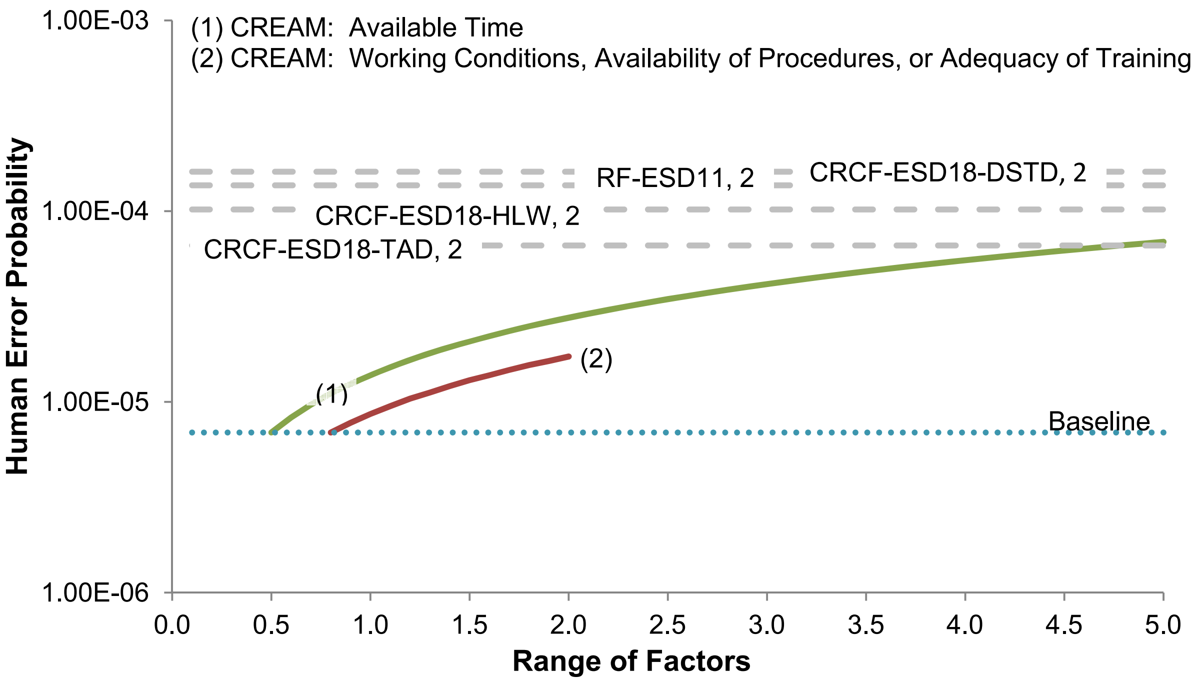

Figure 3-3. Examples C and F: 060/200–OPCTMDIREXP1–HFI–NOD Sensitivity Analysis

3.4 Example E: Operator Fails To Install Shielded Transfer Cask Shield Ring Properly (050–OPSTCSHIELD1–HFI–COD)

Figure 3-4 shows the increase in probability for Example E (human failure event 050–OPSTCSHIELD1–HFI–COD) as parameters associated with two of the four human factors categories are increased individually. Using CREAM in this example, DOE described adequate time available to perform the tasks (i.e., CPC = 0.5) and adequate training (i.e., CPC = 0.8). As shown in Figure 3-4, variation in the conditions of available time and adequacy of training with respect to CREAM have significant effects on the human error probability, resulting in values in these categories that are significantly higher than the specified baseline values. However, in neither case would a cut set frequency cross a categorization boundary (i.e., Curves 2 and 3 in Figure 3-4). The result is different, however, if the level of dependence between the crew members and the crane operator is considered.

DOE used THERP to quantify the failure of crew members to realize that a shield ring has not been installed. As part of this quantification, DOE accounted for dependency between the crew members and the crane operator. As shown in Figure 3-4 at the intersection of curve 1 with the baseline, DOE assigned a value of 0.05 to the crew members' failure, and this value reflects a low level of dependence with the crane operator. As the level of dependence is increased to a hypothetical extreme of complete dependence (i.e., a value of 1.0), the human error probability increases rapidly, and the cut set frequency and therefore the event sequence frequency cross the Category 1 boundary. Figure 3-4 shows that the level of dependence between the crane operator and the crew members has a significant effect on human error probability and the resulting event sequence frequency.

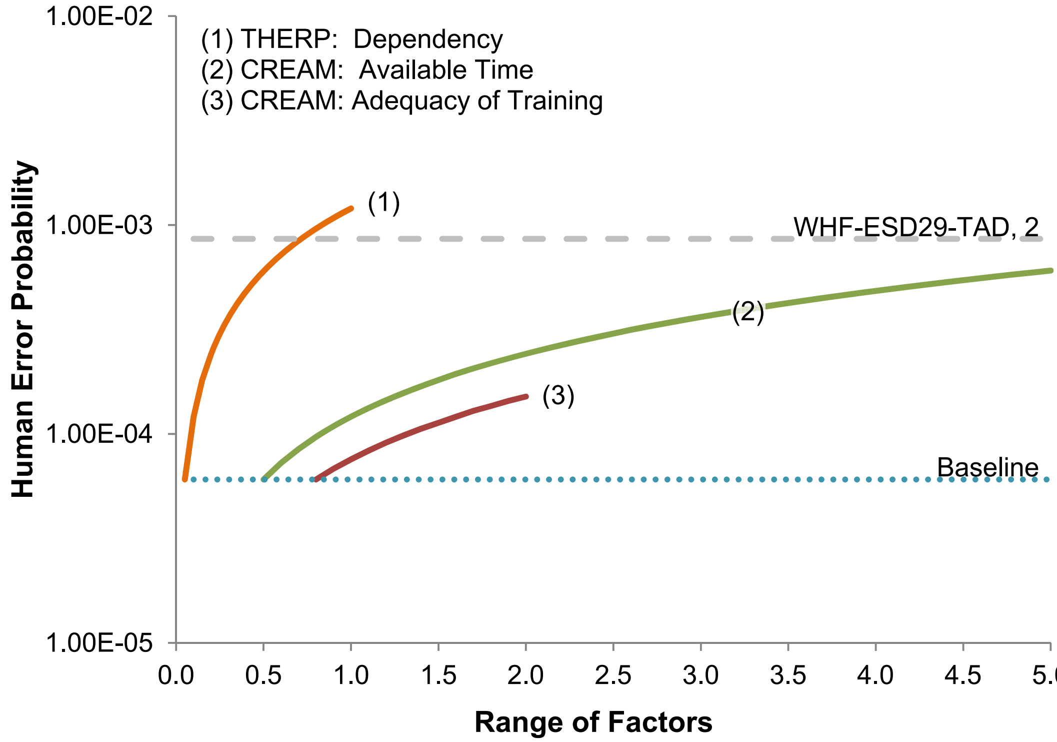

Figure 3-4. Example E: 050–OPSTCSHIELD1–HFI–COD Sensitivity Analysis

3.5 Example D: Operator Fails To Install Waste Package Inner Lid (060–OPWPINNERLID–HFI–NOD)

No sensitivity analysis was conducted for Example D (060–OPWPINNERLID–HFI–NOD). In developing the human error probability for this example, DOE used NARA to quantify both an operator failure and a worker failure. For the operator failure, DOE did not assign an EPC, and for the worker failure, DOE used the full effect of an EPC by assigning the maximum value of 1 to the APOA. Except for identifying administrative controls and training as part of the generic tasks (i.e., GTTs), DOE did not reflect any additional credit in its quantification of this example. Therefore, no sensitivity analysis was needed for the human failure event.

3.6 Significant Contributors to Human Error Probability

The preceding sensitivity analyses show three potentially significant contributors to human error probability that were associated with the seven examples of human failure events discussed in this report. As described in Section 3.1, a crew member being able to hear an announcement (i.e., a low level of distraction) to evacuate was categorized in this report under the “working conditions” human factors category. As illustrated in Figure 3-1, if the working conditions in the Waste Package Loadout Room degrade so that the crew member becomes less able to hear an announcement (e.g., if machine noise were to increase significantly), then the event sequence frequency increases significantly. In addition, as described in Section 3.4, the event sequence frequency increases significantly if the level of dependence between workers increases significantly. Finally, the availability of time appears to have a significant effect on more than one human error probability and resulting event sequence frequency as the adequacy of available time lessens. These three results show that characteristics relating to the environment, such as background noise or machine noise, relationships between different people performing a single activity or process step, or the availability of time to perform an activity, can significantly affect the human error probability in these examples. For low probability human failure events that are dominant contributors to event sequence frequency, the worst case hypothetical result is that the associated event sequence frequency approaches or crosses a categorization boundary. Therefore, understanding the significant contributors to human error probability can help in determining aspects of human error quantification that are important for a risk-informed review. In these three cases, understanding how the environment would support a low level of distraction, how operators work together with a low level of dependence, or how process steps are accomplished with adequate available time would be important aspects of the technical basis for supporting event sequence frequencies where human errors are dominant contributors.

4 SUMMARY

This report illustrates an approach that can be used to systematically examine and identify, in a risk-informed manner, dominant contributors to human failure event modeling. This approach uses a series of filters to identify a small set of low probability human failure events that are dominant contributors to event sequence frequency. Using this approach, seven example human failure events were identified. These example human failure events, which DOE originally developed, are in event sequences involving direct exposures and occur during CTM operations in a CRCF and the RF, during waste package closure and export in a CRCF and IHF, and during TAD canister closure activities in a WHF. After identifying the low probability human failure events, a sensitivity analysis was performed to identify any human factors that may have the potential to significantly affect event sequence frequency. This sensitivity analysis was performed rapidly because only seven human failure events needed to be analyzed.

This report quantified human failure events in terms of the human reliability analysis methods that DOE used and in terms of the human factors that DOE described for the selected examples. In this report, human factors are grouped into four categories: the presence of administrative controls or availability of procedures, adequacy of training, available time to perform an activity, and working conditions. For all but one of the seven low probability human failure events, DOE developed the failure probability using more than one human reliability analysis method. However, the human reliability analysis method NARA was used in all the examples, and six out of the seven were quantified using CREAM, so much of the quantitative analysis in this report focused on factors associated with NARA and CREAM. To prepare for a sensitivity analysis, the human factors identified in each example were organized by human reliability analysis method for each of the low probability human failure events that are dominant contributors to event sequence frequency.

The sensitivity analysis was based on ranges for these human factors specific to the human reliability analysis method. This analysis identified two human factors, in particular, that appear to significantly affect human error probability in the examples. One of them involves working conditions and relates to the ability of a worker to hear an announcement to evacuate a room. It accounts for the worker's level of distraction, possibly due to machine noise. The other one involves the available time for a worker to perform an activity and appears to significantly affect the human error probability for six out of the seven low probability human failure events. Although not summarized directly in this report as a human factor, dependency between operator actions also appears to have a significant effect on the human error probability for one of the examples.

For the examples in this report, these three results show that characteristics relating to the work environment, such as background noise or machine noise, relationships between different people performing a single activity or process step, or the available time to perform an activity, can significantly affect human error probability. For low probability human failure events that are dominant contributors to event sequence frequency, the worst case hypothetical result can be that the associated event sequence frequency approaches or crosses a categorization boundary as defined in 10 CFR 63.2. Therefore, understanding the significant contributors to human error probability can help in determining aspects of human error quantification that are important for a risk-informed review. In these three cases, understanding how the environment would support a low level of distraction, how operators work together with a low level of dependence, or how process steps are accomplished with adequate available time would be important aspects of the technical basis for supporting event sequence frequencies where human errors are dominant contributors.

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APPENDIX A

A DESCRIPTION OF HUMAN FAILURE EVENTS

The tables in the sections that follow show details of the human reliability analysis methods and certain factors the U.S. Department of Energy (DOE) described when determining the human error probability for the seven human failure events (BSC, 2009a,b,c; 2008). Although DOE did not explicitly categorize human factors in its human reliability analyses, its analyses using the Cognitive Reliability and Error Analysis Method (CREAM) explicitly addressed four areas involving human factors (i.e., the presence of administrative controls or availability of procedures, adequacy of training, available time to perform an activity, and working conditions). Because DOE used CREAM several times to quantify the seven human failure events, these four areas (i.e., human factors categories) were used in this report to categorize human factors regardless of the human reliability analysis method. However, for human reliability analysis methods other than CREAM, it is not always clear whether a human factor falls under one of the four categories. Therefore, if DOE appeared to credit activities relating to one of the human factors categories when using a human reliability analysis method other than CREAM, then these activities were included under one of the four human factors categories. Specific instances where this occurred for the Nuclear Action Reliability Assessment (NARA) and A Technique for Human Event Analysis (ATHEANA) expert elicitation are described in the following sections. Note that the tables in the sections that follow also include a hardware category because, in some cases, DOE relied on hardware such as an interlock in its human failure quantification.

A.1 Exposure During Transport and Emplacement Vehicle Loading (060–OPDIREXPOSE3–HFI–NOD and 51A–OPDIREXPOSE3–HFI–NOD)

DOE associated human failure event 060–OPDIREXPOSE3–HFI–NOD with the Canister Receipt and Closure Facility (CRCF) (BSC, 2009a) and human failure event 51A–OPDIREXPOSE3–HFI–NOD with the Initial Handling Facility (IHF) (BSC, 2008). DOE quantified these events using the same human reliability analysis methods and the same parameters within these methods; therefore, the events are described together in this section.

These human failure events include three scenarios with individual probabilities that are added to estimate the human error probability. The first scenario (i.e., Scenario 1a) consists of a crew member remaining in the Waste Package Loadout Room (possibly due to the Waste Package Transfer Trolley Operator failing to order an evacuation) and failing to exit and a radiation protection worker failing to check or recognize that someone has remained in the room. The second scenario (i.e., Scenario 1b) involves a crew member reentering the Waste Package Loadout Room after operations have begun with the supervisor allowing access. The third scenario (i.e., Scenario 1c) involves a personnel access shield door being left open combined with a hardware failure, and the Waste Package Transfer Trolley entering the Waste Package Loadout Room.

For these human failure events, Table A–1 summarizes the factors DOE described in each scenario and the human reliability analysis method DOE used in each scenario. This table shows that Scenario 1a accounts for the majority of the human error probability. The probabilities for the remaining two scenarios are one or more orders of magnitude less than that of Scenario 1a. Also, these events are the only low probability human failure events out of the seven for which DOE used the Human Error Assessment and Reduction Technique (HEART). DOE used HEART in Scenario 1a. In Scenario 1c, when the hardware failure probability of

Table A–1. 060/51A–OPDIREXPOSE3–HFI–NOD Summary										
Human Reliability Analysis Method						Factors DOE Described in Human Failure Analysis				
NARA*	CREAM†	HEART‡	ATHEANA§	THERP‖	Human Failure Event or Scenario (Human Error Probability)	Hardware	Administrative Controls or Available Procedures	Adequate Training	Adequate Time	Advantageous Working Conditions
✓	✓	✓		✓	060–OPDIREXPOSE3–HFI–NOD 51A–OPDIREXPOSE3–HFI–NOD (3×10^{-5})	✓	✓	✓	✓	✓
✓	✓	✓			Scenario 1a (3×10^{-5})		✓	✓	✓	✓
✓					Scenario 1b (2×10^{-6})		✓	✓		
✓				✓	Scenario 1c (4×10^{-7})	✓	✓			

*NARA = Nuclear Action Reliability Assessment
†CREAM = Cognitive Reliability and Error Analysis Method
‡HEART = Human Error Assessment and Reduction Technique
§ATHENA = A Technique for Human Event Analysis
‖THERP = Technique for Human Error Rate Prediction

4×10^{-3} is combined with a human error probability of 1×10^{-4}, the Scenario 1c probability becomes approximately an order of magnitude or more lower than that of the other two scenarios involving only human errors and has only a small contribution on the event sequence frequency.

As part of its NARA quantification, DOE identified the level of distraction for a crew member hearing an announcement to evacuate was small (i.e., not a significant amount of machine noise to mask the announcement). Although DOE did not explicitly characterize the small level of distraction as an advantageous working condition, in this report, this environment is assumed to provide an advantageous working condition.

A.2 Operator Failure During Canister Staging (060–OPSTAGERACK1–HFI–NOD)

DOE associated human failure event 060–OPSTAGERACK1–HFI–NOD with the CRCF (BSC, 2009a). This human failure event consists of only one scenario in which an operator working from the control room fails to close the staging rack port gate before raising the Canister Transfer Machine (CTM) shield skirt combined with the supervisor failing to check that the port gate is closed at the end of operations (e.g., at the end of a shift). DOE described administrative controls or available procedures, adequate training, adequate time, and advantageous working conditions when quantifying the failure of the operator to close the port gate. In addition, DOE described administrative controls or available procedures for the supervisor failing to check that the port gate was closed. DOE quantified the operator failure using CREAM and the supervisor failure using NARA. Table A–2 shows the human reliability analysis methods and the factors DOE described in the human failure analysis.

Table A–2. 060–OPSTAGERACK1–HFI–NOD Summary										
Human Reliability Analysis Method						**Factors DOE Described in Human Failure Analysis**				
NARA*	CREAM†	HEART‡	ATHEANA§	THERP‖	**Human Failure Event or Scenario (Human Error Probability)**	Hardware	Administrative Controls or Available Procedures	Adequate Training	Adequate Time	Advantageous Working Conditions
✓	✓				060–OPSTAGERACK1–HFI–NOD (3×10^{-5})		✓	✓	✓	✓

*NARA = Nuclear Action Reliability Assessment
†CREAM = Cognitive Reliability and Error Analysis Method
‡HEART = Human Error Assessment and Reduction Technique
§ATHENA = A Technique for Human Event Analysis
‖THERP = Technique for Human Error Rate Prediction

DOE credited a supervisor (who is also in the control room with the operator) for understanding the consequences of not closing the gate. The supervisor has at least some understanding of his or her value within the organization and in the task being undertaken. Although DOE did not explicitly characterize the supervisor's actions with advantageous working conditions, in this report, this environment is assumed to provide an advantageous working condition.

A.3 Direct Exposure in Canister Transfer Room (060–OPCTMDIREXP1–HFI–NOD and 200–OPCTMDIREXP1–HFI–NOD)

DOE associated human failure event 060–OPCTMDIREXP1–HFI–NOD with the CRCF (BSC, 2009a) and human failure event 200–OPCTMDIREXP–HFI–NOD with the Receipt Facility (RF) (BSC, 2009b). DOE quantified these events using the same human reliability analysis methods and the same parameters within these methods; therefore, these events are described together in this section.

These human failure events consist of one scenario in which a worker violates an administrative control and enters the Canister Transfer Room during a transfer combined with the failure of the control room operator to close the port gate before raising the CTM shield skirt. DOE used NARA to quantify the worker violating administrative controls (e.g., entering at prescheduled times and getting permission from the control room prior to entering) and used CREAM to quantify the operator failing to close the port gate. Similar to its quantification for the control room operator in Section A.2, DOE described administrative controls or available procedures, adequate training, adequate available time, and advantageous working conditions for failure of the control room operator to close the port gate. Table A–3 shows the human reliability analysis methods and the factors DOE described in the human failure analysis.

A.4 Operator Fails To Install Waste Package Inner Lid (060–OPWPINNERLID–HFI–NOD)

DOE associated human failure event 060–OPWPINNERLID–HFI–NOD with the CRCF (BSC, 2009a). This human failure event consists of one scenario in which an operator fails to

Table A–3. 060/200–OPCTMDIREXP1–HFI–NOD Summary										
Human Reliability Analysis Method						**Factors DOE Described in Human Failure Analysis**				
NARA*	CREAM†	HEART‡	ATHEANA§	THERP‖	**Human Failure Event or Scenario (Human Error Probability)**	Hardware	Administrative Controls or Available Procedures	Adequate Training	Adequate Time	Advantageous Working Conditions
✓	✓				060–OPCTMDIREXP1–HFI–NOD 200–OPCTMDIREXP1–HFI–NOD (8×10^{-6})		✓	✓	✓	✓

*NARA = Nuclear Action Reliability Assessment
†CREAM = Cognitive Reliability and Error Analysis Method
‡HEART = Human Error Assessment and Reduction Technique
§ATHEANA = A Technique for Human Event Analysis
‖THERP = Technique for Human Error Rate Prediction

install the waste package inner shield lid combined with a worker violating an administrative control and entering the Waste Package Closure Room prior to the start of welding. The CTM operator installs this inner shield lid on waste packages containing unshielded canisters (e.g., DOE standardized canisters and high-level waste canisters) in the Canister Transfer Room as the last step of CTM operations. Alternatively, it is installed on waste packages containing a Transportation, Aging, and Disposal (TAD) canister (i.e., a shielded canister) during waste package closure. For the operator, DOE quantified the failure of the operator to install the inner shield lid (possibly mistaking the type of container inside the waste package) using NARA and identified training as part of this quantification. As was done for the worker in Section A.3, DOE used NARA to quantify the worker violating administrative controls (e.g., entering at prescheduled times and getting permission from the control room prior to entering) for this human failure event. Table A–4 shows the human reliability analysis method and the factors DOE described in the human failure analysis.

Out of the seven low probability human failure events, 060–OPWPINNERLID–HFI–NOD has the lowest human error probability. It is an order of magnitude lower than the one having the highest human error probability, 050–OPSTCSHIELD1–HFI–COD, described next.

A.5 Operator Fails To Install Shielded Transfer Cask Shield Ring Properly (050–OPSTCSHIELD1–HFI–COD)

DOE associated human failure event 050–OPSTCSHIELD1–HFI–COD with the WHF (BSC, 2009c). This human failure event consists of two scenarios with individual probabilities that are added to estimate the human error probability. A shield ring is required to be installed prior to draining the TAD canister in preparation for closure. In the first scenario (i.e., Scenario 1a), the crane operator fails to install the shield ring; crew members do not realize this step in the process was missed and, before approaching the TAD canister, fail to notice the shield ring is not in place. In the second scenario (i.e., Scenario 1b), the crane operator improperly installs the shield ring (e.g., the ring is not seated properly); the radiation protection

Table A–4. 060–OPWPINNERLID–HFI–NOD Summary											
Human Reliability Analysis Method						**Factors DOE Described in Human Failure Analysis**					
NARA*	CREAM†	HEART‡	ATHEANA§	THERP‖	**Human Failure Event or Scenario (Human Error Probability)**	Hardware	Administrative Controls or Available Procedures	Adequate Training	Adequate Time	Advantageous Working Conditions
✓					060–OPWPINNERLID–HFI–NOD (6×10^{-6})		✓	✓		

*NARA = Nuclear Action Reliability Assessment
†CREAM = Cognitive Reliability and Error Analysis Method
‡HEART = Human Error Assessment and Reduction Technique
§ATHEANA = A Technique for Human Event Analysis
‖THERP = Technique for Human Error Rate Prediction

worker fails to check radiation levels, misreads the meter or the meter itself fails, and the crew members fail to notice the ring is out of position before approaching the TAD canister.

Table A–5 shows the human reliability analysis methods and the factors DOE described in the human failure analysis. As shown in this table, Scenario 1a accounts for the majority of the human error probability. The probability for the remaining scenario is more than an order of magnitude less than that of Scenario 1a. Human failure event 050–OPSTCSHIELD1–HFI–COD has the highest human error probability among the seven low probability human failure events, and it is the only event out of the seven to use ATHEANA's expert elicitation approach.

In terms of ATHEANA's expert elicitation approach, DOE identified ample opportunity for the crew to recognize that the shield ring was not properly in place. Therefore, in this report, adequate available time is assumed to be part of the ATHEANA expert elicitation quantification. In addition, DOE identified the crew performing the task often. Because DOE frequently associated routine operations with training, the consideration of training may also have been a factor in its ATHEANA expert elicitation quantification for this human failure event. Therefore, in this report, adequate training is assumed to be part of the ATHEANA expert elicitation quantification for human failure event 050–OPSTCSHIELD1–HFI–COD.

Table A–5. 050–OPSTCSHIELD1–HFI–COD Summary											
Human Reliability Analysis Method						**Factors DOE Described in Human Failure Analysis**					
NARA*	CREAM†	HEART‡	ATHEANA§	THERP‖	**Human Failure Event or Scenario (Human Error Probability)**	Hardware	Administrative Controls or Available Procedures	Adequate Training	Adequate Time	Advantageous Working Conditions
✓	✓		✓	✓	050–OPSTCSHIELD1–HFI–COD (6×10^{-5})	✓		✓	✓	
	✓		✓	✓	Scenario 1a¶ (6×10^{-5})			✓	✓	
✓	✓		✓	✓	Scenario 1b (1×10^{-6})	✓		✓	✓	

*NARA = Nuclear Action Reliability Assessment
†CREAM = Cognitive Reliability and Error Analysis Method
‡HEART = Human Error Assessment and Reduction Technique
§ATHEANA = A Technique for Human Event Analysis
‖THERP = Technique for Human Error Rate Prediction
¶For Scenario 1a, due to round-off error, the Scenario 1a probability is listed as 5×10^{-5} by BSC. "WHF Reliability and Event Sequence Categorization Analysis." 050–PSA–WH00–00200–000. Rev. 00B. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2009.

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