INTENTIONALLY LEFT BLANK

Table E6.2-1. Descriptions and Preliminary Analysis for Intra-Site Operation HFEs (Continued)

HFE ID	HFE Brief Description	ESD	Preliminary Value	Justification
ISO-OPHTCOLLIDE1-HFI-NOD	*Operator Causes Collision of HCTT while Leaving the Facility*: Operator causes a collision of the HCTT unit with a facility structure, piece of equipment, or an auxiliary vehicle while moving through the Entrance Vestibule of a facility.	3	3E−03	In this step, the HCTT enters the WHF with a loaded HSTC or exits the RF with a loaded HTC. There are three observers with clear visibility, the operation is simple, the conveyance speed is low, the distance is short and the operators are expected to perform this operation on a very regular (almost daily) basis. There are no interlocks, and it would be normal for an obstruction (e.g., door) to be in place during movement. The possibilities for collision involving a cask transfer trailer are limited, and include: • Improper (i.e., backward or lateral) motion could result in collision with the end stops, wall, or vestibule doors. • Improperly attached cask transfer trailer could continue moving when cask tractor stops, resulting in collision with the end stops, wall, or vestibule doors. • Forklift or other auxiliary vehicle could collide into the conveyance. The preliminary value was chosen based on the determination that this failure is “Highly Unlikely” (0.001) and was adjusted (×3) consistent with other collision events.
ISO-OPHTINTCOL01-HFI-NOD	*Operator Causes Collision of HCTT due to Overspeed*: Operator causes a collision of the HCTT unit at a speed higher than design requirements. If the cask tractor speed limiter fails, the operator could collide the cask transfer trailer into an SSC.	3	1	The cask tractor can over speed, resulting in collision. In order to accomplish this, the speed governor must fail. To be conservative, unsafe actions that require an equipment failure to cause an initiating event have generally been assigned an HEP of 1.0.
ISO-OP-HAMIMPACT-HFI-NOD	*Operator Causes HAM Impact with Crane*: Operator impacts HAM with door removed using the mobile crane.	4	3E−03	In this HFE, the operator impacts the HAM with the door that has already been removed using a mobile crane. Crane operations are performed frequently by this team and is a very simple task. A preliminary value based on the determination that this failure is “Highly Unlikely” (0.001) has been used, but adjusted (×3) because there are several ways for this impact to occur, including: • Crane moved outside its safe load path (e.g., operators cut corners) • Crane moved in wrong direction • Operator failed to maintain proper vertical and horizontal distance between cask and SSCs during crane operations.
ISO-OP-HAMINSERT-HFI-NOD	*Operator Misaligns Transport and HAM Opening*: Cask transfer trailer is not properly oriented by operator to ensure that the centerline of the HAM and the HTC coincide.	4	1E−03	The cask transfer trailer is supposed to be positioned to within a few feet of the HAM and the position of the trailer checked to ensure that the centerline of the HAM and cask approximately coincide. If the trailer is not properly oriented, the trailer is supposed to be repositioned as necessary. The preliminary value was chosen based on the determination that this failure is “Highly Unlikely” (0.001) since the operator can take the time needed to properly align the cask transfer trailer and the HAM opening, with assistance from other personnel watching the operation.
ISO-VEH-COLISION-COL-RAT	*Vendor Vehicle Collision:* RC, TT, HCTT or ST collides with auxiliary vehicle or SSC during transit across the GROA (non-facility related).	8	7E−07 [a]	A separate analysis using historical data was performed to evaluate the likelihood of a collision occurring on intra-site roadways that would involve the transport of waste forms or used HEPA filters, and therefore could potentially result in a radioactive release. Considerations were that the nature of the materials transported would be considered hazardous (hazmat), the speed at which the vehicle would be traveling would be very slow, and that vehicle escorts would be provided on-site, further monitoring and restricting the vehicle speed. The data and the sources used for this portion of the analysis are summarized in Tables E6.2-2 and 6.2-3.
ISO-OPSICOMPDROP-HFI-NOD	*Operator Drops Object onto Transportation Cask*	1	N/A[a]	This Intra-Site Operation involves a drop of an object from a mobile crane onto a transportation cask. A human-induced drop HFE was not explicitly quantified because the probability of crane drop due to human failure is incorporated in the historical data used to provide a general failure probability for jib crane drops (CRJ-DRP). Documentation for this failure can be found in Attachment C.
ISO-PMRC-DERAIL-PER-MILE	*Railcar Derailment*	1	N/A[a]	This event deals with the derailment of the prime mover railcar. An HFE was not explicitly quantified because historical data was used to provide a general failure probability for railcar derailments (DER-FOM). Documentation for this failure can be found in Attachment C.
ISO-HEPA-XFER-L-FORKLIFT	*Operator Punctures Drum of LLW with Forklift*	5	N/A[a]	This Intra-Site Operation involves a drum of low level waste being punctured by an improper operation of a forklift during transfer of HEPA filters. A human-induced forklift HFE was not explicitly quantified because historical data was used to provide a general failure probability for forklift punctures (FRK-PUN). Documentation for this failure can be found in Attachment C.

NOTE: a HRA preliminary value replaced by use of historic data See Attachment C on active component reliability data for more information.
ESD = event sequence diagram; GROA = geologic repository operations area; HAM = horizontal aging module; HCTT = cask tractor and cask transfer trailer; HEP = human error probability; HEPA = high efficiency particulate air; HFE = human failure event; HSTC = horizontal shielded transfer cask; HTC = a transportation cask that is never upended; ID = identification; LLW = low-level radioactive waste; N/A = not applicable; PMRC = prime mover railcar; RC = railcar; RF = Receipt Facility; SPM = site prime mover; SSC = structure, system, or component; SSCs = structures, systems, and components; ST = site transporter; TT = truck trailer; WHF = Wet Handling Facility.

Source: Original

INTENTIONALLY LEFT BLANK

Table E6.2-2. Vendor Vehicle Collision Data

Source	Description	Value
Comparative Risks of Hazardous Materials and Non-Hazardous Materials Truck Shipment Accidents/Incidents, Final Report. (Ref. E8.1.12, Table 9, p. 4-1).	Annual en route release accidents for HM Category 7 vehicles (Radioactive materials)	6
Comparative Risks of Hazardous Materials and Non-Hazardous Materials Truck Shipment Accidents/Incidents, Final Report. (Ref. E8.1.12, Table 9, p. 4-1).	Annual en route leaks for HM Category 7 vehicles (Radioactive materials)	4
Original: sum of en route release accidents and leaks for HM Category 7 (Radioactive materials) [6 + 4 = 10]	**Total en route incidents**	**10**
Traffic Safety Facts 2002: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System. (Ref. E8.1.13, Table 29, p. 51).	Percent of all single and multiple vehicle crashes at 40 mph or less	0.57
Original: product of total en route incidents and percent of crashes at 40 mph or less. [0.57 × 10 = 5.7]	Total estimated en route incidents at 40 mph or less	5.7
Large Truck Crash Causation Study (Ref. E8.1.14, Table 14).	Percent of truck crash factors not mitigated by use of escorting vehicle [See separate table]	48%
Original: total estimated en route incidents at 40 mph or less, adjusted by the percent of crash factors not mitigated by use of escort vehicle. [5.7 × 0.48 = 2.7]	**Total estimated en route incidents at 40 mph or less not mitigated by use of escorting vehicle**	**2.7**
Comparative Risks of Hazardous Materials and Non-Hazardous Materials Truck Shipment Accidents/Incidents, Final Report. (Ref. E8.1.12, Table 24, p. 4-13).	Hazmat miles traveled for 1996 for HM Category 7 vehicles (Radioactive materials)	3.00E+07
"Speeding Counts...on All Roads!" (Ref. E8.1.11).	Percent of annual vehicle-miles traveled on local roads, with posted speed limits usually between 20 and 45 mph	0.134
Original: Hazmat miles adjusted by percentage of miles traveled between 20 and 45 mph. [3.00E+07 × 0.134 = 4.02E+06]	**Estimated annual vehicle-miles traveled on local roads between 20 - 45 mph**	**4.02E+06**
Original: total en route incidents at 40 mph or less divided by the total vehicle-miles traveled at between 20 and 45 mph for Hazmat Category 7 vehicles (Radioactive materials). [2.7 / 4.02E+06 = 7.E−07]	**Estimated radioactive hazmat vehicle crashes per vehicle mile traveled below ~40 mph per year**	**7.E−07**

Source: Original

Table E6.2-3. Vendor Vehicle Crash Factors Mitigated by Escorting

Truck Crash Factors	Amt in 1000's	Percent	Addressed by Escorting
Driver Factors			
Prescription drug use	37	8.0%	—
Traveling too fast for conditions	33	7.2%	7.2%
Unfamiliar with roadway	31	6.7%	—
Over-the-counter drug use	25	5.4%	—
Inadequate surveillance	20	4.3%	4.3%
Fatigue	18	3.9%	—
Illegal maneuver	13	2.8%	2.8%
Inattention	12	2.6%	—
Exterior distraction	11	2.4%	—
Inadequate evasive action	9	2.0%	2.0%
Aggressive driving behavior	9	2.0%	2.0%
Unfamiliar with vehicle	9	2.0%	—
Following too closely	7	1.5%	1.5%
False assumption of others' actions	7	1.5%	1.5%
Under pressure to accept additional loads	6	1.3%	1.3%
Conversation	5	1.1%	—
Under pressure to operate even if fatigued	4	0.9%	—
Misjudgment of gap distance	4	0.9%	0.9%
In a hurry prior to crash	4	0.9%	0.9%
Illness	4	0.9%	—
Interior distraction	3	0.7%	—
Illegal drug use	3	0.7%	—
Uncomfortable with some aspect of vehicle or load	4	0.9%	—
Self induced legal work pressure	3	0.7%	—
Required to accept short notice trips	3	0.7%	0.7%
Work schedule pressure	3	0.7%	—
Upset prior to crash	3	0.7%	—
Alcohol use	1	0.2%	—
Other decision factors – includes proceeding with obstructed view, stopping when not required to, failing to yield, and others	13	2.8%	2.8%
Other physical factors – includes hearing problems, prosthesis, paraplegia, strenuous activities, sleep apnea, as well as others	11	2.4%	—
Other motor carrier work pressure	9	2.0%	—
Other recognition factors – includes impending problem masked by traffic flow pattern, driver focused on extraneous issues	4	0.9%	0.9%
Environment Factors			
Traffic flow interruption – includes work zones, roadway immersion, prior crash, and traffic congestion	40	8.7%	8.7%
Roadway related factors	29	6.3%	6.3%

Table E6.2-3. Vendor Vehicle Crash Factors Mitigated by Escorting (Continued)

Truck Crash Factors	Amt in 1000's	Percent	Addressed by Escorting
Driver Factors			
Stop required prior to crash—includes stop required for traffic control device, and yield right of way requirement	28	6.1%	6.1%
Weather related factors	20	4.3%	—
Sight obstructed by road/other vehicle	6	1.3%	1.3%
Other traffic/vehicle factors— includes any factors not listed causing the driver to feel uncomfortable with surrounding traffic or the vehicle	7	1.5%	1.5%
Other vehicle obscured (by glare/headlights, etc)	2	0.4%	—
Other environmental factors	1	0.2%	—
Total	461	100%	52%
Percent of truck crash factors not mitigated by use of escorting vehicle	—	—	**48%**

Source: Ref. E8.1.14, Table 14

E6.3 DETAILED ANALYSIS

There are no HFEs in this group that require detailed analysis; the preliminary values in the facility model do not result in any Category 1 or Category 2 event sequences that fail to comply with the 10 CFR 63.111 performance objectives, therefore, the preliminary values were sufficient to demonstrate compliance with 10 CFR Part 63 (Ref. E8.2.1).

E7 RESULTS: HUMAN RELIABILITY ANALYSIS DATABASE

Table E7-1 presents a summary of all of the human failures identified in this analysis, and provides a link between the HFE and the ESD in which the human failure is modeled.

Table E7-1. HFE Data Summary

Basic Event Name	HFE Description	ESD	Basic Event Mean Probability	Error Factor	Type of Analysis
ISO-OPSICOMPDROP-HFI-NOD	Operator drops object onto transportation cask	1	N/A [a]	N/A	Historic Data
ISO-HEPA-XFER-L-FORKLIFT	Operator punctures drum of LLW with forklift	5	N/A [a]	N/A	Historic Data
ISO-OPHTCOLLIDE1-HFI-NOD	Operator causes collision of HCTT in the facility	3	3.00E−03	5	Preliminary
ISO-OPHTINTCOL01-HFI-NOD	Operator causes collision of HCTT due to cask tractor overspeed	3	1.0	N/A	Preliminary
ISO-OP-HAMIMPACT-HFI-NOD	Operator causes HAM impact with crane	4	3.00E−03	5	Preliminary
ISO-OP-HAMINSERT-HFI-NOD	Operator misaligns transport and HAM opening	4	1.00E−03	5	Preliminary

Table E7-1. HFE Data Summary (Continued)

Basic Event Name	HFE Description	ESD	Basic Event Mean Probability	Error Factor	Type of Analysis
ISO-OPRCCOLLIDE1-HFI-NOD	Operator causes SPM/railcar collision in the facility	1	3.00E−03	5	Preliminary
ISO-OPRCINTCOL01-HFI-NOD	Operator initiates PMRC runaway	1	1.0	N/A	Preliminary
ISO-OPSTCOLLIDE2-HFI-NOD	Operator error causes site transporter collision in the facility	2	3.00E−03	5	Preliminary
ISO-OPTTCOLLIDE1-HFI-NOD	Operator causes SPM/truck trailer collision in the facility	1	3.00E−03	5	Preliminary
ISO-OPTTINTCOL01-HFI-NOD	Operator initiates truck trailer runaway	1	1.0	N/A	Preliminary
ISO-PMRC-DERAIL-PER-MILE	PMRC derailment	1	N/A [a]	N/A	Historic Data
ISO-VEH-COLISION-COL-RAT	Collision of RC, TT, ST or HCTT with SSC during transport across the GROA	8	7.00E−07	10	Historic Data

NOTE: [a] Historical data was used to produce a probability of crane drops; this historical data is not included as part of the HRA, but is addressed in Attachment C.

ESD = event sequence diagram; GROA = geologic repository operations area; HAM = horizontal aging module; HCTT = cask tractor and cask transfer trailer; HFE = human failure event; LLW = low-level radioactive waste; N/A = not applicable; PMRC = prime mover railcar; RC = railcar; SPM = site prime mover; SSC = structure, system, or component; ST = site transporter; TT = truck trailer.

Source: Original

E8 REFERENCES

E8.1 DESIGN INPUTS

The PCSA is based on a snapshot of the design. The reference design documents are appropriately documented as design inputs in this section. Since the safety analysis is based on a snapshot of the design, referencing subsequent revisions to the design documents (as described in EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Ref. 2.1.1, Section 3.2.2.F)) that implement PCSA requirements flowing from the safety analysis would not be appropriate for the purpose of this document. There are no superseded or cancelled documents associated with the modifications that led to the issuance of this revision. Cancelled or superseded documents associated with the portions of this document for which the snapshot has not yet been updated are designated herein with a dagger (†).

The inputs in this section noted with an asterisk (*) indicate that they fall into one of the designated categories described in Section 4.1, relative to suitability for intended use.

E8.1.1 *AIChE (American Institute of Chemical Engineers) 1992. *Guidelines for Hazard Evaluation Procedures.* 2nd Edition with Worked Examples. New York, New York: American Institute of Chemical Engineers. TIC: 239050. ISBN: 0-8169-0491-X..

E8.1.2 *ASME NUM-1-2004. 2005. *Rules for Construction of Cranes, Monorails, and Hoists (with Bridge or Trolley or Hoist of the Underhung Type).* New York, New York: American Society of Mechanical Engineers. TIC: 259317. ISBN: 0-7918-2938-3.

E8.1.3 *ASME RA-S-2002. *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications.* New York, New York: American Society of Mechanical Engineers. TIC: 255508. ISBN: 0-7918-2745-3.

E8.1.4 *Benhardt, H.C.; Eide, S.A.; Held, J.E.; Olsen, L.M.; and Vail, R.E. 1994. *Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities (U).* WSRC-TR-93-581. Aiken, South Carolina: Westinghouse Savannah River Company, Savannah River Site. ACC: MOL.20061201.0160.

E8.1.5 *BSC (Bechtel SAIC Company) 2006. *Engineering Standard for Repository Component Function Identifiers.* 000-30X-MGR0-00900-000 REV 000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20060816.0001.

E8.1.6 *BSC 2007. *Engineering Standard for Repository Area Codes.* 000-3DS-MGR0-00400-000 REV 004. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070911.0015.

E8.1.7 †*BSC 2007. *Repository System Codes.* 000-30X-MGR0-01200-000 REV 00E. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071101.0022.

E8.1.8 BSC 2008. *Intra-Site Operations and BOP Event Sequence Development Analysis.* 000-PSA-MGR0-00800-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080212.0004.

E8.1.9 *CRA (Corporate Risk Associates) 2006. *A User Manual for the Nuclear Action Reliability Assessment (NARA) Human Error Quantification Technique.* CRA-BEGL-POW-J032, Report No. 2, Issue 5. Leatherhead, England: Corporate Risk Associates. TIC: 259873.

E8.1.10 †DOE (U.S. Department of Energy) -STD-1090-2004. *Hoisting and Rigging (Formerly Hoisting and Rigging Manual).* 800-30R-SS00-00400-000-000. Washington, D.C.: U.S. Department of Energy. ACC: ENG.20060407.0002.

E8.1.11 DOT (U.S. Department of Transportation). 2000. "Speeding Counts...on All Roads!" Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration. ACC: MOL.20080228.0001.

E8.1.12 *Battelle 2001. *Comparative Risks of Hazardous Materials and Non-Hazardous Materials Truck Shipment Accidents/Incidents, Final Report.* Washington, D.C.: U.S. Department of Transportation, Federal Motor Carrier Safety Administration. ACC: MOL.20080228.0002.

E8.1.13 *DOT 2004. *Traffic Safety Facts 2002: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System.* DOT HS 809 620. Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration. ACC: MOL.20080228.0003.

E8.1.14 *DOT [n.d.]. "Summary Tables." *Large Truck Crash Causation Study.* Washington, D.C.: U.S. Department of Transportation. ACC: MOL.20080227.0020.

E8.1.15 *Dougherty, E.M., Jr. and Fragola, J.R. 1988. *Human Reliability Analysis: A Systems Engineering Approach with Nuclear Power Plant Applications.* New York, New York: John Wiley & Sons. TIC: 3986. ISBN: 0-471-60614-6.

E8.1.16 *Gertman, D.; Blackman, H.; Marble, J.; Byers, J.; and Smith, C. 2005. *The SPAR-H Human Reliability Analysis Method.* NUREG/CR-6883. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20061103.0009.

E8.1.17 *Hall, R.E.; Fragola, J.R.; and Wreathall, J. 1982. *Post Event Human Decision Errors: Operator Action Tree/Time Reliability Correlations.* NUREG/CR-3010. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20071220.0211.

E8.1.18 *Hannaman, G.W. and Spurgin, A.J. 1984. *Systematic Human Action Reliability Procedure (SHARP).* EPRI-NP-3583. Palo Alto, California: Electric Power Research Institute. TIC: 252015.

E8.1.19 *Hollnagel, E. 1998. *Cognitive Reliability and Error Analysis Method, CREAM.* 1st Edition. New York, New York: Elsevier. TIC: 258889. ISBN: 0-08-0428487.

E8.1.20 *Lloyd, R.L. 2003. *A Survey of Crane Operating Experience at U.S. Nuclear Power Plants from 1968 through 2002.* NUREG-1774. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20050802.0185.

E8.1.21 NRC (U.S. Nuclear Regulatory Commission) 1980. *Control of Heavy Loads at Nuclear Power Plants.* NUREG-0612. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 209017.

E8.1.22 NRC 1983. *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants.* NUREG/CR-2300. Two volumes. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 205084.

E8.1.23 NRC 2000. *Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (ATHEANA).* NUREG-1624, Rev. 1. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 252116.

E8.1.24 NRC 2007. *Preclosure Safety Analysis - Human Reliability Analysis.* HLWRS-ISG-04. Washington, D.C.: Nuclear Regulatory Commission. ACC: MOL.20071211.0230.

E8.1.25 *Rasmussen, J. 1983. "Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models." *IEEE Transactions on Systems, Man, and Cybernetics, SMC-13*, (3), 257–266. New York, New York: Institute of Electrical and Electronics Engineers. TIC: 259863.

E8.1.26 *Swain, A.D. 1987. *Accident Sequence Evaluation Program Human Reliability Analysis Procedure*. NUREG/CR-4772. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20061103.0026.

E8.1.27 *Swain, A.D. and Guttmann, H.E. 1983. *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications Final Report.* NUREG/CR-1278. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 246563.

E8.1.28 *Williams, J.C. 1986. "HEART - A Proposed Method for Assessing and Reducing Human Error." *9th Advances in Reliability Technology Symposium - 1986.* Bradford, England: University of Bradford. TIC: 259862.

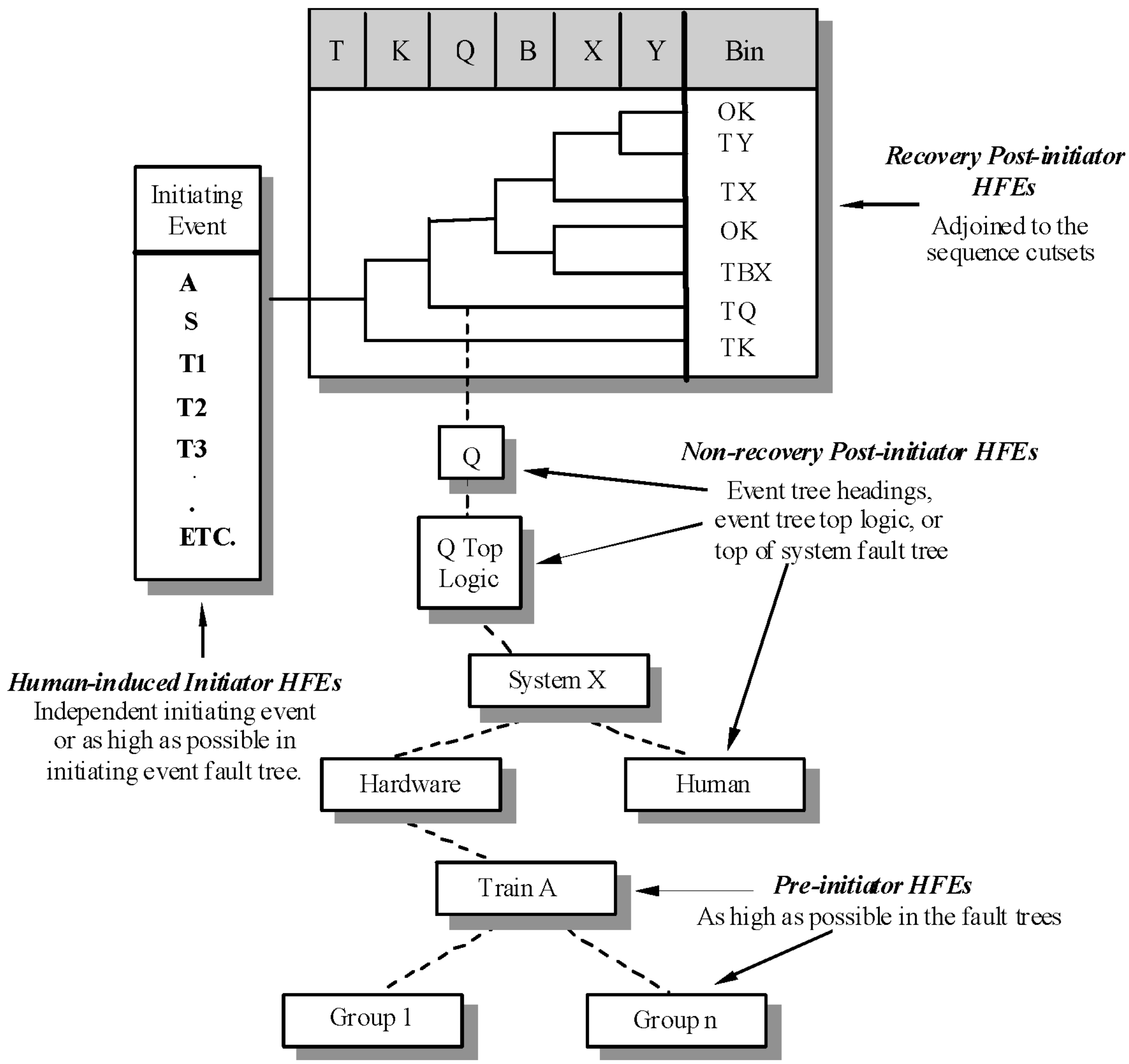
E8.1.29 *Williams, J.C. 1988. "A Data-Based Method for Assessing and Reducing Human Error to Improve Operational Performance." *[Conference Record for 1988 IEEE Fourth Conference on Human Factors and Power Plants].* Pages 436–450. New York, New York: Institute of Electrical and Electronics Engineers. TIC: 259864.

E8.2 DESIGN CONSTRAINTS

E8.2.1 †10 CFR (Code of Federal Regulations) Part 63. 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. U.S. Nuclear Regulatory Commission.

APPENDIX E.I
RECOMMENDED INCORPORATION OF HUMAN FAILURE EVENTS IN THE YMP PCSA

Figure E.I-1 provides a graphical illustration of how HFEs are incorporated into the PCSA.

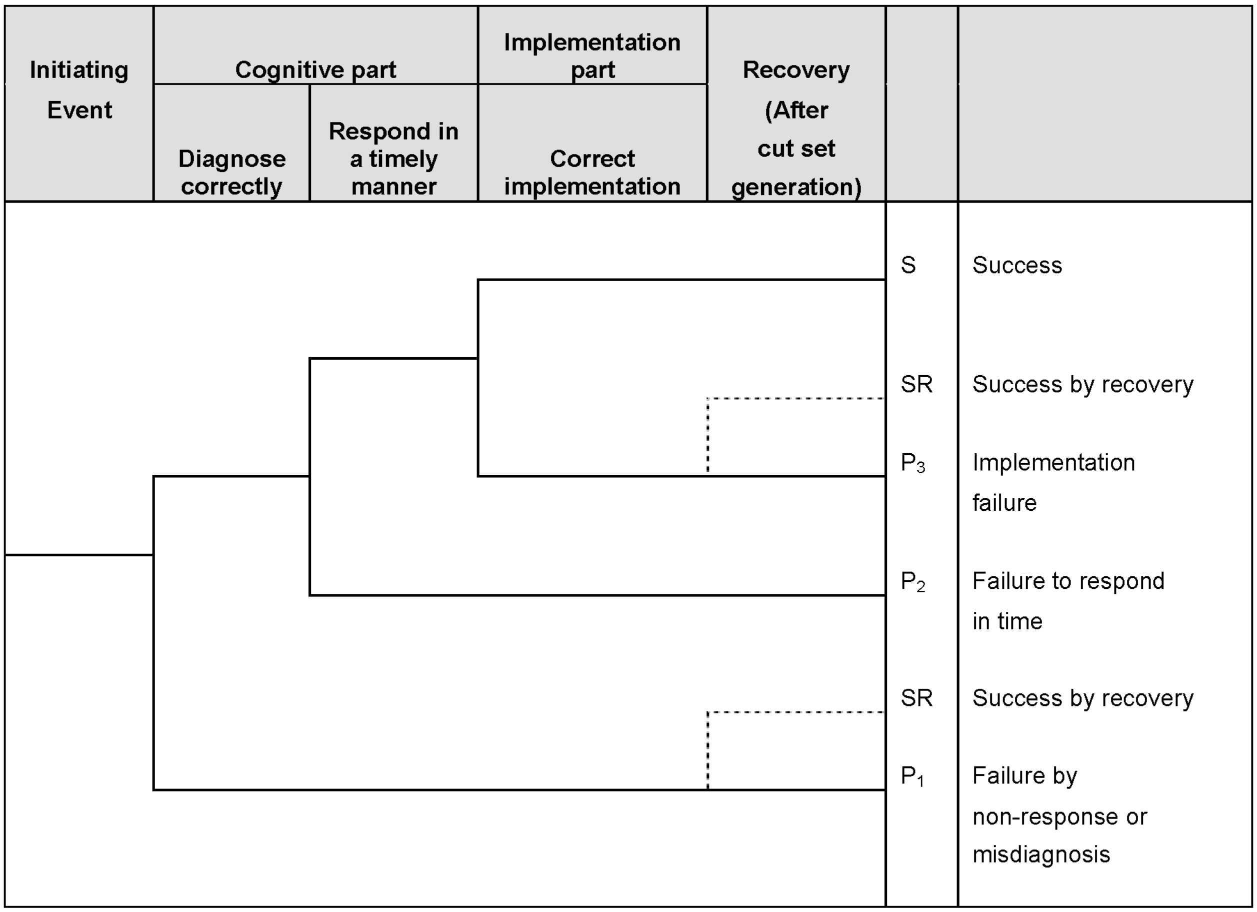


NOTE: HFE = human failure event.

Source: Original

Figure E.I-1. Incorporation of Human Reliability Analysis within the PCSA

APPENDIX E.II
GENERAL STRUCTURE OF POST-INITIATOR HUMAN ACTIONS



Source: Original

Figure E.II-1 Post Initiator Operator Action Event Tree

The representation in Figure E.II-1 consists of two elements, corresponding to a cognitive part (detection, diagnosis, and decision making) and an implementation (i.e., action) part.

P_1 represents the probability that operators make an incorrect diagnosis and decision and do not realize that they have done so. Some of the reasons for such mistakes are: incorrect interpretation of the procedures, incorrect knowledge of the plant state owing to communication difficulties, and instrumentation problems.

Given that the crew decides what to do correctly, there is still a possibility of failure to respond in time (represented by P_2) or making an error in implementation (represented by P_3).

However, it may be probable in certain scenarios that a recovery action can be taken. This consideration is taken into account after the initial quantification is completed and is applied as appropriate to the dominant cut sets.

APPENDIX E.III
PRELIMINARY (SCREENING) QUANTIFICATION PROCESS FOR HUMAN FAILURE EVENTS

The preliminary quantification process consists of the following:

Step 1—Complete the Initial Conditions Required for Quantification.

The preliminary quantification process requires the following:

- The baseline scenarios are available.
- The HFEs and their associated context have been defined.
  - Collect any additional information that is not already collected and that is needed to describe and define the HFEs (and associated contexts).
  - Review all information for clarity, completeness, etc.
  - Interpret and prioritize all information with respect to relevance, credibility, and significance.

Table E.III-1 provides examples of information normally identified using the ATHEANA method (*Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis* (Ref. E8.1.23) that serve as inputs to the quantification process. The HFE/context descriptions in Table E.III-1 touch briefly on the information that is relevant to the screening-level quantification of the HFE. Since the baseline scenario generally touches on much of this information, the point of including the HFE/context descriptions is to summarize the information that pertains to the specific HFE to minimize the need for the analysts to refer back to the baseline scenario, except to obtain additional detail.

Table E.III-1. Examples of Information Useful to HFE Quantification

Information Type	Examples
Facility, conditions, and behavior for possible deviations of the scenarios	Reasonably possible unusual plant behavior and failures of systems; equipment, and indications, especially those that may be unexpected or difficult to detect by operators. Includes presence of interlocks that would have to fail to promote the deviation.
Operating crew characteristics (i.e., crew characterization)	Crew structure, communication style, emphasis on crew discussion of the "big picture."
Features of procedures	Structure, how implemented by operating crews, opportunities for "big picture" assessment and monitoring of critical safety functions, emphasis on relevant issue, priorities, any potential mismatches with deviation scenarios.
Relevant informal rules	Experience, training, practice, ways of doing things—especially those that may conflict with informal rules or otherwise lead operators to take inappropriate actions.
Timing	Plant behavior and requirements for operator intervention versus expected timing of operator response in performing procedure steps, etc.

Table E.III-1. Examples of Information Useful to HFE Quantification (Continued)

Information Type	Examples
Relevant vulnerabilities	Any potential mismatches between the scenarios and expected operator performance with respect to timing, formal and informal rules, biases from operator experience, and training, etc.
Error mechanisms	Any that may be particularly relevant by plant context or implied by vulnerabilities; applicable mechanisms depend upon whether HFE is a slip or mistake. Examples include: failures of attention, possible tunnel vision, conflicts in priorities, biases, missing or misleading indications, complex situations, lack of technical knowledge, timing mismatches and delays, workload, and human–machine interface concerns.
Performance-shaping factors	Those deemed associated with, or triggered by, the relevant plant conditions and error mechanisms.

NOTE: HFE = human failure event.

Source: Original

In Step 1, interpreting and prioritizing all information with respect to relevance, credibility, and significance is especially important if:

- Some information is applicable only to certain scenarios, HFEs, or contexts
- There are conflicts among information sources
- Information is ambiguous, confusing, or incomplete
- Information must be extrapolated, interpolated, etc.

Completion of the initial conditions is primarily performed by a single individual, using the results of the YMP HAZOP evaluation process and reviews of other relevant information sources. Discussions are also held with the Operations Department to augment that information, and the resulting write-ups are reviewed by the PCSA facility leads and the HRA team. The initial conditions are refined as part of an open discussion among the experts (in this case, the HRA team for the study) involved in the expert opinion elicitation process. The goal of this discussion is not to achieve a consensus but, rather, to advance the understanding of all the experts through the sharing of distributed knowledge and expertise. In each case, the scenario (or group of similar scenarios) and the HFE in question are described and the vulnerabilities and strong points associated with taking the right action are discussed openly among the HRA team.

Step 2—Identify the Key or Driving Factors of the Scenario Context.

The purpose of Step 2 is to identify the key or driving factors on operator behavior/performance for each HFE and associated context. Each expert participating in the elicitation process individually identifies these factors based on the expert's own judgment. Usually, these factors are not formally documented until Step 4.

Typically, there are multiple factors deemed most important to assessing the probability for the HFE in question. This is due to the focus of the ATHEANA search process on combinations of factors that are more likely to result in an integrated context (Ref. E8.1.23). When there is only a single driving factor, it is usually one that is so overwhelming that it alone can easily drive the estimated probability. For example, if the time available is shorter than the time required to perform the actions associated with the HFE, quantification becomes much simpler and other factors need not be considered.

Step 3—Generalize the Context by Matching it With Generic, Contextually Anchored Rankings, or Ratings.

In Step 3, each expert participating in the elicitation process must answer the following question for each HFE: based upon the factors identified in Step 2, how difficult or challenging is this context relative to the HFE being analyzed?

Answering this question involves independent assessments by each expert. In order to perform this assessment, the specifics of the context defined for an HFE must be generalized or characterized. These characterizations or generalizations then must be matched to general categories of failures and associated failure probabilities.

To assist the experts in making their judgments regarding the probability of events, some basic guidance is provided. In thinking about what a particular HEP associated with an HFE may be, they are encouraged to think about similar situations or experiences and use that to help estimate how many times out of 10, 100, 1,000, etc., would they expect crews to commit the HFE, given the identified conditions. The following examples of what different probabilities mean are provided to the experts to help them scale their judgments:

"Likely" to fail (extremely difficult/challenging)	~0.5	(5 out of 10 would fail)
"Infrequently" fails (highly difficult/challenging)[8]	~0.1	(1 out of 10 would fail)
"Unlikely" to fail (somewhat difficult/challenging)	~0.01	(1 out of 100 would fail)
"Highly unlikely" to fail (not difficult/challenging)	~0.001	(1 out of 1000 would fail)

The experts are allowed to select any value to represent the probability of the HFE. That is, other values (e.g., 3E−2, 5E−3) can be used. The qualitative descriptions above are provided initially to give analysts a simple notion of what a particular probability means. For exceptional cases, the quantification approach allows an HEP of 1.0 to be used when failure was deemed essentially certain. The following general guidance in Table E.III-2 is also provided to help calibrate the assessment by providing specific examples that fall into each of the above bins, and is based on the elicited judgment and consensus of the HRA team based on their past experience. This guidance applies to contexts where generally optimal conditions exist during performance of the action. Therefore, the experts should modify these values if they believe that the action may be performed under non-optimal conditions or under extremely favorable conditions. Values may also be adjusted to take credit for design features, controls and interlocks, or procedural safety controls[9,10]. Examples of such adjustments are also provided below; however

[8] The default value is 0.1. This value is used if no preliminary assessment is performed.

[9] As an initial preliminary value, unsafe actions that are backed up by interlocks are assigned a human error probability of 1.0 such that no credit for human performance is taken (i.e., only the interlocks are relied upon to demonstrate 10 CFR Part 63 (Ref. E8.2.1) compliance). If this proves insufficient, a more reasonable preliminary value is assigned to the unsafe action in accordance with this Appendix.

these values are not taken to be firm in any sense of the word, but rather simply as examples of where in general terms HEPs may fall and how they may relate to each other. Types of HFEs not listed here can be given values based on being "similar to" HFEs that are listed. Whatever value is selected, the basis is briefly documented.

Table E.III-2. Types of HFEs

PRE-INITIATOR HFEs	
Fail to properly restore a standby system to service	0.1
Failure to properly restore an operating system to service when the degraded state is not easily detectable	0.01
Failure to properly restore an operating system to service when the degraded state is easily detectable	0.001
Calibration error	0.01
HUMAN-INDUCED INITIATOR HFEs	
Failure to properly conduct an operation performed on a daily basis	0.001
Failure to properly conduct an operation performed on a very regular basis (on the order of once/week)	0.01
Failure to properly conduct an operation performed only very infrequently (once/month or less)	0.1
Operation is extremely complex OR conducted under environmental or ergonomic stress	×3
Operation is extremely complex AND conducted under environmental or ergonomic stress	×10
NON-RECOVERY POST-INITIATOR HFEs	
Not trained or proceduralized, time pressure	0.5
Not trained or proceduralized, no time pressure	0.1
Trained and/or proceduralized, time pressure	0.1
Trained and/or proceduralized, no time pressure	0.01

Source: Original

Step 4—Discuss and Justify the Judgments Made in Step 3

In Step 3, each expert independently provides an estimate for each HFE. Once all the expert estimates are recorded, each expert describes the reasons why they chose a particular failure probability. In describing their reasons, each expert identifies what factors (positive and negative) are thought to be key to characterizing the context and how this characterization fit the failure category description and the associated HEP estimate.

After the original elicited estimates are provided, a discussion is held that addresses not only the individual expert estimates but also differences and similarities among the context characterizations, key factors, and failure probability assignments made by all of the experts. This discussion allows the identification of any differences in the technical understanding or interpretation of the HFE versus differences in judgment regarding the assignment of failure probabilities. Examples of factors important to HFE quantification that might be revealed in the discussion include:

[10] Note that if such credit is taken, then it may be necessary (based on the PCSA results) to include these items in the nuclear safety design basis or the procedural safety controls for the YMP facilities.

- Differences in key factors and their significance, relevance, etc., based upon expert-specific expertise and perspective.
- Differences in interpretations of context descriptions.
- Simplifications made in defining the context.
- Ambiguities and uncertainties in context definitions.

A consensus opinion is not required following the discussion.

Step 5—Refinement of HFEs, associated contexts, and assigned HEPs (if needed)

Based upon the discussion in Step 4, the experts form a consensus on whether or not the HFE definition must be refined or modified, based upon its associated context. If the HFE must be refined or redefined, this is done in Step 5. If such modifications are necessary, the experts "reestimate" based upon the newly defined context for the HFE (or new HFEs, each with an associated context).

The experts participating in the elicitation process are also allowed to change their estimate after the discussion in Step 4 based on the discussions during that step, whether or not the HFE definition and context are changed. Once again, a consensus is not required.

Step 6—Determine final preliminary HEP for HFE and associated context

The final preliminary value to be incorporated into the PCSA for each HFE is determined in Step 6.

The failure probabilities assigned in the preliminary HRA quantification are based on the context outlined in the base case scenarios and deemed to be "realistically conservative." To help ensure this conservatism, if a consensus value could not be reached, the final failure probability that was assigned to each HFE was determined by choosing the highest assigned probability among the final estimates of the experts participating in the expert elicitation process.

APPENDIX E.IV
SELECTION OF METHODS FOR DETAILED QUANTIFICATION

There are a number of methods available for the detailed quantification of HFEs (preliminary quantification is discussed in Appendix E.III of this analysis). Some are more suited for use for the YMP PCSA than others. A number of methods were considered, but many were rejected as inapplicable or insufficient for use in quantification. Several sources were examined as part of the background analysis for selecting a method for detailed quantification (Ref. E8.1.18; Ref. E8.1.15; Ref. E8.1.25; and Ref. E8.1.22). As discussed in Section E3.2 the following four were chosen:

- ATHEANA expert judgment (Ref. E8.1.23)
- CREAM (Ref. E8.1.19)
- HEART (Ref. E8.1.28)/NARA (Ref. E8.1.9)
- THERP (Ref. E8.1.27).

This appendix discusses the selection process.

Basis for Selection—The selection process was conducted with due consideration of the HRA quantification requirements set forth in the ASME Level 1 PRA standard (Ref. E8.1.3) to the extent that those requirements, which were written for application to NPP PRA, apply to the types of operations conducted at the YMP. Certainly, all of the high level HRA quantification requirements were considered to be applicable. Further, all of the supporting requirements to these high level requirements were considered applicable, at least in regards to their intent. In some cases, the specifics of the supporting requirements are only applicable to NPP HRA and some judgment is needed on how to apply them. This was particularly true of those supporting requirements that judged certain specific quantification methods acceptable. This appendix lays out the specific case for the methods selected for use at the YMP (or, more to the point, the exclusion of certain methods that would normally be considered acceptable under the standard, but are deemed inappropriate for use for the YMP PCSA).

Differences between NPP and the YMP Relevant to HRA Quantification—There are a number of contrasts between the operations at the YMP and the operations at a NPP that affect the selection of approaches to performing detailed HRA quantification (Table E.IV-1).

Table E.IV-1. Comparison between NPP and YMP Operations

NPP	YMP
Central control of operations maintained in control room.	Decentralized (local), hands on control for most operations.
Most important human actions are in response to accidents.	Most important human actions are initiating events.
Post-accident response is important and occurs in minutes to hours. Short time response important to model in HRA.	Post-accident response evolves more slowly (hours to days). Short time response not important to model.
Multiple standby systems are susceptible to pre-initiator failures.	Standby systems do not play major role in the YMP safeguards, therefore few opportunities for pre-initiator failures.
Auxiliary operators sent by central control room operators to where needed in the plant.	Local control reduces time to respond.
Most actions are controlled by automatic systems.	Most actions are controlled by operators.
Reliance on instrumentation /gauges as operators' "eyes".	Most actions are local, either hands on or televised. Less reliance on man–machine interface.
High complexity of systems, interactions, and phenomena. Actions may be skill, rule, or knowledge based.	Relatively simple process with simple actions. Actions are largely skill based.
Many in operation for decades; HRA may include walk-downs and consultation with operators.	First of a kind; HRA performed for construction application, therefore walk-downs and consultation with operators not feasible.

NOTE: HRA = human reliability analysis; NPP = nuclear power plant; YMP = Yucca Mountain Project.

Source: Original

Assessment of Available Methods—There are essentially four general types of quantification approaches available:

1. Procedure focused methods:

   A. Basis: These methods concentrate on failures that occur during step-by-step tasks (i.e., during the use of written procedures). They are generally based on observations of human performance in the completion of manipulations without much consideration of the root causes or motivations for the performance (e.g., how often does an operator turn a switch to the left instead of to the right).

   B. Methods considered: THERP (Ref. E8.1.27).

   C. Applicability: This method is of limited use for the YMP because important actions are not procedure driven. Many operations are skill-based and/or semi-automated (e.g., crane operation, trolley operation, canister transfer machine operation, transport and emplacement vehicle operation). However, there are some instances where such an approach would be applicable to certain unsafe actions within an HFE. In addition, the THERP dependency model is adopted by NARA as being appropriate to use within a context-based quantification approach.

D. Assessment: THERP is retained as an option in the detailed quantification for its dependency model and for limited use when simple, procedure-driven unsafe actions are present within an HFE.

2. Time-response focused methods:

A. Basis: These methods focus on the time available to perform a task, versus the time required, as the most dominant factor in the probability of failure. They are, for the most part, based on NPP control room observations, studies, and simulator exercises. They also tend to be correlated with short duration simulator exercises (i.e., where there is a clear time pressure in the range of a few minutes to an hour to complete a task in response to a given situation).

B. As discussed in *Human Reliability Analysis: A Systems Engineering Approach with Nuclear Power Plant Applications* (Ref. E8.1.15), examples of time-response methods include: HCR (Ref. E8.1.15) and TRCs (Ref. E8.1.17).

C. Applicability: These methods are not applicable to the YMP because most actions do not occur in a control room and, in addition, are generally not subject to time pressure. This is particularly true of the most important HFEs, those that are human-induced initiators. Other than a desire to complete an action in a timely fashion to maintain production schedules, time is irrelevant to these actions, especially in the context of the type of time pressure considered by these methods. Even those actions at the YMP that may take place in a control room in response to an event sequence and have time as a factor would only require response in the range of hours or days, which is outside the credible range for these methods.

D. Assessment: No use can be identified for these methods within the YMP PCSA. None of them are retained.

3. Context and/or cognition driven methods:

A. Basis: These methods focus on the context and motivations behind human performance rather than the specifics of the actions, and as such are independent of the specific facility and process. To the extent that some of the methods are data-driven (i.e., they collect and use observations of human performance) the data utilized is categorized by generic task type rather than by the type of facility or equipment where the human failure occurred. This makes them more broadly applicable to various industries, tasks, and situations, in large part because they allow context-specific PSFs to be considered. This allows for them to support a variety of contexts, individual performance factors (e.g., via PSFs) and human factor approaches.

B. Methods considered: HEART (Ref. E8.1.28 and Ref. E8.1.29)/NARA (Ref. E8.1.9), CREAM (Ref. E8.1.19), and ATHEANA (Ref. E8.1.23) expert judgment.

C. Applicability: The broad applicability of these methods and their flexibility of application make them most suited for application at the YMP. The use of information from a broad range of facilities and other performance regimes (e.g., driving, flying) support their use as facility-independent methods. The generic tasks considered can be applied to the types of actions of most concern to the YMP (i.e., human-induced initiators) as opposed to the more narrow definitions used in other approaches that make it difficult to use them for other than post-initiator or pre-initiator actions.

D. Assessment: Optimally it would be convenient to use only one of the three methods of this type for all the detailed quantification. However, HEART (Ref. E8.1.28)/NARA (Ref. E8.1.9) and CREAM (Ref. E8.1.19) approach their generic task types slightly differently and also use different PSFs and adjustment factors. There are unsafe actions within the YMP HFEs that would best fit the HEART (Ref. E8.1.28)/NARA (Ref. E8.1.9) approach and others that would best fit the CREAM (Ref. E8.1.19) approach. In addition, the union of the two approaches still has some gaps that would not cover a small subset of unsafe actions for the YMP (primarily in the area of unusual acts of commission). One gap relates to dependencies between actions, but in this case NARA (Ref. E8.1.9) specifically endorses the THERP (Ref. E8.1.27) approach and so this is used. However, other gaps exist. For these cases, the ATHEANA (Ref. E8.1.23) expert judgment approach provides a viable and structured framework for the use of judgment to establish the appropriate HEP values in a manner that would meet the requirements of the ASME RA-S-2002 (Ref. E8.1.3) standard. Therefore, all three of these methods are retained for use and the selection of one versus the other is made based on the specific unsafe action being quantified. This is documented as appropriate in the actual detailed quantification of each HFE.

4. Simplified methods:

A. Basis: These methods use the results of past PRAs to focus attention on those HFEs that have dominated risk. These are essentially PRA results from NPPs. As such, they presuppose NPP situations and actions, and define important PSFs based on these past NPP PRAs. They have very limited (if any) ability to investigate context, individual and human factors that are beyond NPP experience. The HEPs that result from applying these methods are calibrated to other NPP methods.

B. Methods considered: ASEP (Ref. E8.1.26), SPAR-H (Ref. E8.1.16).

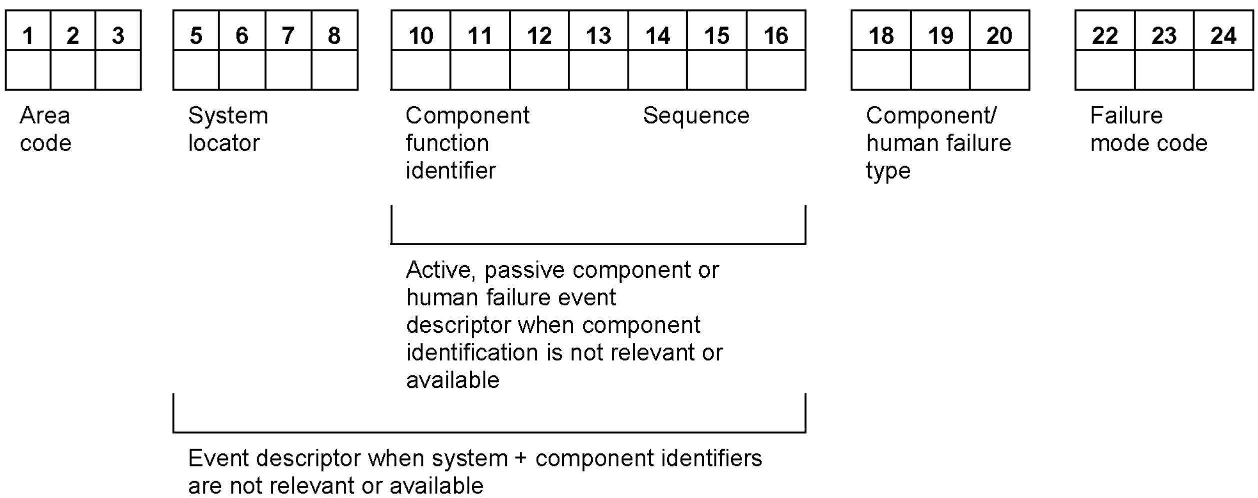
C. Applicability: These methods are clearly biased by their very close dependence on the results of past NPP PRAs. They are too limited for application beyond the NPP environment. They are not simply inappropriate for this application, but it would be extremely difficult to make a sound technical case regarding technical validity.

D. Assessment: No use can be identified for these methods within the YMP PCSA or any technical case made supporting them for a non-NPP application. None of them are retained.

APPENDIX E.V
HUMAN FAILURE EVENTS NAMING CONVENTION

Event names for HFEs in the YMP PCSA model follow the general structure of the naming convention for fault tree basic events. This is true whether the HFE is modeled in a fault tree, directly on an event tree, or as an initiating event. The convention, as adapted for HFEs, is as follows:

This basic event naming convention in Figure E.V-1 below is provided to ensure consistency with project standards and to permit this information to fit into a 24-character SAPHIRE field such that each basic event can be correlated to a unique component or human failure.



Source: Original

Figure E.V-1. Basic Event Naming Convention

The area code defines the physical design or construction areas where a component would be installed. Area codes are listed in *Engineering Standard for Repository Area Codes,* (Ref. E8.1.6). These codes are used rather than the facility acronyms to maintain consistency with Engineering. In this system, the CRCF is designated by area code 060, the WHF is 050, the RF is 200, the Initial Handling Facility is 51A, and Subsurface is 800. Intra-Site Operations could fall under one of several repository area codes and therefore the most appropriate code to use was the repository general area code. However, this code was insufficient for the purposes of this analysis, and a designator of ISO was substituted instead. For the majority of cases, the area coding of HFEs in Attachment E reflects the location of the operations being evaluated, such as ISO for Intra-Site Operations. However, for certain HFEs, the coding corresponds to the location of the systems impacted by the human failure, such as heating, ventilation and air conditioning (HVAC), which is specific to the CRCF and therefore retains the 060 coding, and AC power, which retains the 26x and 27x coding. For these specific instances, such coding provides better traceability of the HFE back to the affected equipment.

The system locator code identifies operational systems and processes. System locator codes (four characters) are listed in Table 1 of *Repository System Codes* (Ref. E8.1.). These are generally three or four characters long, such as VCT for tertiary confinement HVAC.

The component function identifiers identify the component function and are listed in the *Engineering Standard for Repository Component Function Identifiers* (Ref. E8.1.5). These are generally three or four characters long. Some BSC component function identifiers for typical components are shown in Table E.V-1, but in cases where there is not an equivalent match, the most appropriate PCSA type code should be used (also given in Table E.V-1).

The sequence code is a numeric sequence and train assignment (suffix), if appropriate, that uniquely identifies components within the same area, system, and component function.

If an HFE is related to the failure of an individual component with an existing component function identifier and sequence code, the naming scheme should utilize these codes in the event name. If an HFE is such that these codes do not apply, the basic event name can be a free form field for describing the nature of the event, such as HCSKSCF for operator topples cask during scaffold movement or HFCANLIDAJAR for operator leaves canister lid ajar, utilizing either seven characters when there is a relevant system locator code, or 12 characters when no system codes are applicable.

The human failure type and failure mode codes are three characters each, consistent with the coding provided in Table E.V-1 below.

For HFEs, the type code always begins with HF and continues with a one letter designator for the HFE temporal phase: P for pre-initiator, I for human-induced initiator, N for non-recovery post-initiator, R for recovery post-initiator (this latter code is not used during preliminary analysis).

Table E.V-1. Human Failure Event Type Codes and Failure Mode Codes

PRE-INITIATOR HFEs; TYP=HFP		FMC=
Fail to properly restore a standby system to service		RSS
Failure to properly restore an operating system to service when the degraded state is not easily detectable		ROH
Failure to properly restore an operating system to service when the degraded state is easily detectable		ROE
Calibration error		CAL
HUMAN-INDUCED INITIATOR HFEs; TYP=HFI		
Failure to properly conduct an operation	Operation is performed on a daily basis.	NOD
	Operation is performed on a very regular basis (on the order of once per week)	NOW
	Operation is performed only very infrequently (once per month or less)	NOM
Operation is extremely complex OR conducted under environmental or ergonomic stress	Operation is performed on a daily basis.	COD
	Operation is performed on a very regular basis (on the order of once per week)	COW
	Operation is performed only very infrequently (once per month or less)	COM
Operation is extremely complex AND conducted under environmental or ergonomic stress	Operation is performed on a daily basis.	CSD
	Operation is performed on a very regular basis (on the order of once per week)	CSW
	Operation is performed only very infrequently (once per month or less)	CSM
NON-RECOVERY POST-INITIATOR HFEs; TYP=HFN		
Not trained or proceduralized, time pressure		NPT
Not trained or proceduralized, no time pressure		NPN
Trained and/or proceduralized, time pressure		TPT
Trained and/or proceduralized, no time pressure		TPN
RECOVERY POST-INITIATOR HFEs; TYP=HFR		
Not trained or proceduralized, time pressure		NPT
Not trained or proceduralized, no time pressure		NPN
Trained and/or proceduralized, time pressure		TPT
Trained and/or proceduralized, no time pressure		TPN

NOTE: FMC = failure mode code; HFE = human failure event; HFI = human-induced initiator HFE; HFN = human failure non-recovery post-initiator HFE; HFP = pre-initiator HFE; HFR = human failure recovery post-initiator HFE; TYP = type.

Source: Original

ATTACHMENT F
FIRE ANALYSIS

INTENTIONALLY LEFT BLANK

CONTENTS

Page

FIGURES

Page

TABLES

INTENTIONALLY LEFT BLANK

ACRONYMS AND ABBREVIATIONS

Acronyms

CRCF	Canister Receipt and Closure Facility
FEMA	Federal Emergency Management Agency
IHF	Initial Handling Facility
LLW	low-level radioactive waste
LLWF	Low-Level Waste Facility
NAICS	North American Industry Classification System
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
PCSA	preclosure safety analysis
RF	Receipt Facility
SPM	site prime mover
TEV	transport and emplacement vehicle
WHF	Wet Handling Facility
YMP	Yucca Mountain Project

Abbreviations

m^2	square meter

INTENTIONALLY LEFT BLANK

F1 INTRODUCTION

This document describes the work scope, definitions and terms, methodology, and results for the fire analysis performed as part of the Yucca Mountain Project (YMP) preclosure safety analysis (PCSA). Fire analysis is divided into four major areas:

1. Initiating event identification
2. Initiating event quantification (including both ignition frequency and propagation probability)
3. Fragility analysis (including convolution of fragility and hazard curves)
4. Fire analysis model development and quantification.

Within the task, the internal events PCSA model is evaluated with respect to fire initiating events, and modified as necessary to address fire-induced failures that lead to exposures. The lists of fire-induced failures that are included in the model are evaluated as to fire vulnerability, and fragility analyses are conducted as needed.

INTENTIONALLY LEFT BLANK

F2 REFERENCES

This PCSA is based on a snapshot of the design. The reference design documents are appropriately documented as design input in this section. Since the safety analysis is based on a snapshot of the design, referencing subsequent revisions to the design documents, as described in EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Ref. 2.1.1 , Section 3.2.2.F), that implement PCSA requirements flowing from the safety analysis would not be appropriate for the purpose of the PCSA.

The inputs in this Section noted with an asterisk (*) indicate that they fall into one of the designated categories described in Section 4.1, relative to suitability for intended use.

Design Inputs

F2.1 *Amico, P.J. 2007. "Re: NFPA Correspondence." E-mail from P.J. Amico to J. Lorenz, December 3, 2007, with attachment. ACC: MOL.20071211.0227; MOL.20071211.0228.

F2.2 *ANSI/ANS (American National Standards Institute/American Nuclear Society) 58.23-2007. 2007. *Fire PRA Methodology*. La Grange Park, Illinois: American Nuclear Society. TIC: 259894.

F2.3 *ASME RA-S-2002. 2002. *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications*. New York, New York: American Society of Mechanical Engineers. TIC: 255508. ISBN: 0-7918-2745-3.

F2.4 *BSC (Bechtel SAIC Company) 2007. *Low-Level Waste Facility General Arrangement Ground Floor Plan*. 160-P10-LW00-00102-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070924.0026.

F2.5 *BSC 2007. *Low-Level Waste Facility General Arrangement Second Floor & Mezzanine Plan*. 160-P10-LW00-00103-000 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070924.0027.

F2.6 BSC 2007. *Waste Form Throughputs for Preclosure Safety Analysis*. 000-PSA-MGR0-01800-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071106.0001.

F2.7 *EPRI (Electric Power Research Institute) and NRC (U.S. Nuclear Regulatory Commission) 2005. *Detailed Methodology*. Volume 2 of *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*. EPRI TR-1011989 and NUREG/CR-6850. Palo Alto, California: Electric Power Research Institute. ACC: MOL.20070323.0062.

F2.8 *EPRI and NRC 2005. *Summary & Overview*. Volume 1 of *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*. EPRI-1011989 and NUREG/CR-6850. Palo Alto, California: Electric Power Research Institute. ACC: MOL.20070323.0061.

F2.9 *Ahrens, M. 2000. *Fires in or at Industrial Chemical, Hazardous Chemical and Plastic Manufacturing Facilities, 1988 - 1997 Unallocated Annual Averages and Narratives*. Quincy, Massachusetts: National Fire Protection Association. TIC: 259997.

F2.10 *SAIC (Science Applications International Corporation) 2002. *Chemical Agent Disposal Facility Fire Hazard Assessment Methodology*. SAIC-01/2650. Abingdon, Maryland: Science Applications International Corporation. ACC: MOL.20080115.0138.

F2.11 *Tillander, K. 2004. *Utilisation of Statistics to Assess Fire Risks in Buildings*. Ph.D. Dissertation. Espoo, Finland: VTT Technical Research Centre of Finland. TIC: 259928. ISBN: 951-38-6392-1.

F2.12 *U.S. Census Bureau 2000. "Manufacturing United States." *1997 Economic Census: Summary Statistics for the United States*. Washington, D.C.: U.S. Census Bureau. Accessed March 7, 2008. ACC: MOL.20080310.0082. URL: http://www.census.gov/epcd/ec97/ustotals.htm.

F2.13 *Winkler, R. L. and Hays, W. L. 1975. *Statistics: Probability, Inference, and Decision*. Series in Quantitative Methods for Decision Making. 2nd Edition. Winkler, R.L., ed., New York, New York: Holt, Rinehart, and Winston. TIC: 259976. ISBN: 0-03-014011-0.

F2.14 BSC 2008. *Intra-Site Operations and BOP Event Sequence Development Analysis*. 000-PSA-MGR0-00800-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080212.0004.

F2.15 *Benhardt, H.C. 1994. *Savannah River Site Human Error Data Base Development for Nonreactor Nuclear Facilities (U)*. WSRC-TR-93-581. Aiken, South Carolina: Westinghouse Savannah River Company, Savannah River Site. ACC: MOL.20061201.0160.

F3 BOUNDARY CONDITIONS

The general boundary conditions used during the analysis of fire vulnerabilities and fire model development are clearly stated and documented. In general, the conditions are compatible with those usually applied to internal events due to fire events. The principal boundary conditions for the fire analysis are listed in the following sections.

F3.1 PLANT OPERATIONAL STATE

The initial state of the facility is normal with each system operating within its limiting condition of operation limits.

F3.2 NUMBER OF FIRE EVENTS TO OCCUR

The facility is analyzed to respond to one fire event at a given time. Additional fire events, as a result of independent causes or of reignition once a fire is extinguished, are not considered.

F3.3 RELATIONSHIP TO PROCESS BUILDINGS

Fires that occur during Intra-Site Operation activities take place outside of the main process buildings. With regard to the frequency of such fires, based on historical fire ignition frequencies from other facilities, the fire frequency across the site is proportional to the number of main process buildings on the site. That is, the number of opportunities for fires outside buildings is affected by the number of main process buildings being serviced. The number of main waste handling buildings at YMP is six (Initial Handling Facility (IHF), Receipt Facility (RF), Wet Handling Facility (WHF), and three Canister Receipt and Closure Facilities (CRCFs)).

F3.4 IRRELEVANCY OF INDUSTRIAL FACILITY TYPE TO OUTSIDE FIRE FREQUENCY

The frequency of outside fires at YMP is expected to be similar to those from other industrial facilities. The specific type of facility, the type of construction of the buildings and other features, are not considered relevant to the frequency of outside fires since the ignition sources that exist outside of the buildings are considered to be generic to any industrial facility. This does not extend to the assessment of fire severity, since the type of facility could affect the type and availability of combustibles. Fire severity is addressed in Attachment D and, as such, is not relevant here.

F3.5 NO OTHER SIMULTANEOUS INITIATING EVENTS

It is standard practice to not consider the occurrence of other initiating events (human-induced and naturally occurring) during the time span of an event sequence because: (1) the probability of two simultaneous initiating events within the time span is small, and (2) each initiating event causes operations of the waste handling facility to cease, which further reduces the conditional probability of the occurrence of a second initiating event, given the first has occurred.

F3.6 COMPONENT FAILURE MODES

The failure mode of a structure, system, or component affected by a fire is the most severe, with respect to consequences. For example, the failure mode for a canister could be the overpressurization of a reduced-strength canister.

F3.7 COMPONENT FAILURE PROBABILITY

Fires large enough to fail waste containment components are large enough to fail all active components in the immediate vicinity. Active components fail in a de-energized state for such fires.

F3.8 INTERNAL EVENTS PCSA MODEL

To implement the systems analysis guidance contained herein, the fire PCSA team uses the internal events PCSA model, which is developed concurrently with the fire PCSA. This internal events PCSA is used as the basis for the fire PCSA. The internal events PCSA is in general conformance with the ASME PRA *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications* (Ref. F2.3).

F4 ANALYSIS METHODOLOGY

F4.1 INTRODUCTION

The general methodological basis of this analysis is the *Chemical Agent Disposal Facility Fire Hazard Assessment Methodology* (Ref. F2.10). Chemical agent disposal facilities are similar to those in the geologic repository operations area in that these facilities are handling and disposal facilities for highly hazardous materials, and so the analysis of fires in those facilities has similar issues and needs. This is a "data based" approach in that it utilizes actual historical experience on fire ignition and fire propagation to determine fire initiating event frequencies. That approach has been adapted to utilize data applicable to the YMP waste handling facilities. To the extent applicable to a non-reactor facility, NUREG/CR-6850, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*, Volumes 1 (Ref. F2.8) and 2 (Ref. F2.7) are also considered in the development of this analysis method. The method complies with the applicable requirements of the American Nuclear Society fire probabilistic risk assessment standard (Ref. F2.2) that are relevant to a non-reactor facility. Many of the definitions, modeling approximations, and requirements of these documents were used to develop this analysis.

F4.2 IDENTIFICATION OF OUTSIDE FIRE INITIATING EVENTS

Outside fire initiating events at YMP are considered for the potential for a fire to directly affect the waste containers and cause a breach that would result in a release. The fire analysis, therefore, focused on the potential for a fire to directly affect the waste containers and cause a breach that would result in a release. The initiating events for Intra-Site Operations were identified in *Intra-Site Operations and BOP Event Sequence Development Analysis* (Ref. F2.14). The steps of this process are as provided in the following sections.

F4.2.1 Identify Areas Onsite Where Waste Containers Can Be Present

The processes for the movement of waste containers onsite but outside of buildings are evaluated, and the areas where the waste containers either sit or traverse are identified. Each area where waste can be present, even if only for a brief time, is listed.

F4.2.2 Correlate These Areas with National Fire Protection Association Historical Data for Outside Fires

The National Fire Protection Association (NFPA) historical data identifies the areas outside buildings where fires have occurred (Ref. F2.9). These have been grouped into broader categories for use in this study. These groupings are as follows in Table F4.2-1.

Table F4.2-1. Outside Fire Area Categories

Area
Storage areas[a] —To include all areas where products are held while awaiting process, shipment, or use.
Receiving areas[b] —To include all areas where products are moved into or out of a building while onsite, but are still outside the building.
Trash/rubbish areas
Areas containing equipment[c] —To include all areas outside the building that contain operating process, HVAC, maintenance, or other machinery and equipment.
Open areas[d] —To include fields, roads, and right of ways.
Vehicles[e]
Other —Primarily applies to exterior structural areas of buildings.

NOTE: [a] The sum of the following NFPA areas are (1) product storage area, tank, or bin, (2) unclassified storage area, and (3) supply storage room or area.

[b] The sum of the following NFPA areas are (1) shipping, receiving, or loading area, (2) court, terrace, or patio, and (3) conveyor.

[c] The sum of the following NFPA areas are (1) process or manufacturing area, (2) unclassified service or equipment area, (3) heating equipment room or area, (4) incinerator room or area, (5) unclassified service facility, (6) machinery room or area, and (7) maintenance shop or area.

[d] The sum of the following NFPA areas are (1) lawn, field, or open areas, (2) railroad right of way or embankment, and (3) highway, public right of way, or street.

[e] The sum of the following NFPA areas are (1) engine, wheel, or running area of vehicle, (2) exterior surface of vehicle, (3) truck or load-carrying area of vehicle, and (4) unclassified vehicle area.

HVAC = heating, ventilation, and air conditioning; NFPA = National Fire Protection Association.

Source: Original

F4.2.3 Define Initiating Events

Fire ignition occurrences are identified for each outside area where a waste container can be present.

F4.3 QUANTIFICATION OF FIRE IGNITION FREQUENCY

In order to assess the total fire frequency, two pieces of information are required: the number of facilities, and the number of fires at these facilities. The first piece of data is maintained by the U.S. Census Bureau, which conducts an economic census (Ref. F2.12, Codes 324, 325, and 3261). The second piece of data is tracked by NFPA. This approach uses historical data over a 10-year period (1988 to 1998) from these databases. Specifically, the fire data used in this report were taken from a report authored by the NFPA Division of Fire Analysis and Research: *Fires in or at Industrial Chemical, Hazardous Chemical, and Plastic Manufacturing Plants, 1988 - 1997 Unallocated Annual Averages and Narratives* (Ref. F2.9)[1]. These data are used to develop

[1] As stated in the boundary conditions, the type of facility is considered to be irrelevant to the frequency of ignition of outside fires.

estimates for the total frequency of fires and the distribution of fires on the grounds of the facility.

The primary source of data on the number of fires is the National Fire Incident Reporting System (NFIRS), which is jointly administered by the Federal Emergency Management Agency (FEMA) and NFPA. NFIRS provides annual computerized databases of fire incidents. It is a voluntary program wherein individual fire departments fill out data forms and submit them through their state NFIRS coordinator to FEMA/NFPA. Because it is a voluntary program, it is recognized that the NFIRS database only captures about one third to one half of all U.S. fires each year. Projecting NFIRS results develops NFPA's national fire estimates. To project NFIRS results, at least an estimate of the NFIRS fires as a fraction of the total, is needed. However, the NFIRS data does not provide any information on the total population from which the data is collected, nor do they address the nonuniformity of the data due to the voluntary collection methods used. To address the limitations of the NFIRS data, and to extend the NFIRS data to provide a more complete analysis of the U.S. fire problem, the NFPA conducts an additional annual survey to augment the FEMA NFIRS program.

The NFPA survey is based on a stratified random sample of roughly 3,000 (of 30,000) U.S. fire departments. The survey is stratified by the population size (i.e., the number of people protected by the department) to reduce the uncertainty of the final estimates. Small rural communities protect fewer people and are less likely to respond, so a large number are surveyed to obtain an adequate sample. Large city fire departments are few in number, so all are surveyed and have a high response rate so that an excellent estimate is obtained. A variety of data is collected during the NFPA survey process, which allows the NFIRS data to be projected on a nationwide basis with some accuracy. The NFPA survey also allows individual component parts of the NFIRS data to be projected on a national basis. This multiple calibration approach makes use of the NFPA survey where its statistics design advantages are the strongest and yields scaling ratios to extend the fractional NFIRS data to a true nationwide estimate of the U.S. fire problem.

Data on the number and type of facilities is maintained by the U.S. Census Bureau, which conducts an economic census (Ref. F2.12). The U.S. Census Bureau performs a count of all businesses in the United States and categorizes them in accordance with the North American Industry Classification System (NAICS) (Ref. F2.12). As this program is not voluntary, these data are believed to be accurate as reported.

The NFPA does not use the NAICS to categorize the type of facility, so there is a need to correlate the two systems in order to ensure that both the number of facilities and the number of fires represent counts from the same population. This is relatively straightforward at the level of the major categories of facilities. Table F4.3-1 gives a cross-reference between the two systems at that level. Some of the cross reference matching of categories shown in the table may not seem obvious from the titles, but a review of the definitions used by NFPA/FEMA (Ref. F2.9) and NAICS (Ref. F2.12) clearly leads to the classifications shown in Table F4.3-1.

Table F4.3-1. Types of Facilities: Cross Reference Between NFPA and NAICS

NFPA Facility Categories	NAICS Facility Categories
Food Products	Food Products
Beverage, Tobacco, or Related Oil Products	Beverage and Tobacco Products
Textiles	Textile Mills Textile Product Mills
Wearing Apparel, Leather, Rubber Products	Apparel Products Leather and Allied Products Plastics and Rubber (Rubber subgroup)
Wood, Furniture, Paper, or Printing Products	Wood Products Paper Products Printing and Related Support Activities Furniture and Related Products
Chemical, Plastic, or Petroleum Products	Petroleum and Coal Products Chemical Products (Except photographic) Plastics and Rubber (Plastics subgroup)
Metal or Metal Products	Primary Metal Products Fabricated Metal Products Machinery Computer and Electronic Products Electrical Equipment, Appliances, and Components
Vehicle Assembly or Manufacturing	Transportation Equipment
Other	Miscellaneous Chemical Products (photographic)
Unclassified or Unknown	Nonmetallic Mineral Products

NOTE: NFPA = National Fire Protection Association; NAICS = North American Industry Classification System.

Source: Ref. F2.9 and Ref. F2.12

Two different calculations are performed on two different sub-populations in order to test the sensitivity of the overall fire frequency to the type of process facility. The first calculation uses facilities classified by NFPA under, "Chemical, Plastic, or Petroleum Products." According to NFPA data (Ref. F2.1), there are approximately 287 outside fires involving property of value annually (2,870 total fires in the ten year period) in such facilities. Ref. F2.1 contains an e-mail that was sent from the author of *Fires in or at Industrial Chemical, Hazardous Chemical and Plastic Manufacturing Facilities, 1988 - 1997 Unallocated Annual Averages and Narratives* (Ref. F2.9) (M. Ahrens) to the originator of this Attachment, Paul Amico. The information from this correspondence is being used to provide information based on the NFIRS and NFPA survey to supplement the information from Ref. F2.9.

According to NAICS (Ref. F2.12, Codes 324, 325, and 3261), the total number of facilities of this type is 29,303. Therefore, the frequency of potentially significant fires in these facilities is:

$$F = \frac{287\ \text{fires/yr}}{(29{,}303\ \text{facilities})} = 9.8\text{E-03 fires/facility-yr} \qquad \text{(Eq. F-1)}$$

The second calculation uses subcategories within the classification systems to determine whether a particular subcategory of, "Chemical, Plastic, or Petroleum Products" would yield a different result (i.e., whether the answer was significantly related to facility type).

According to NFPA data (Ref. F2.1), each year there are approximately 62 outside fires involving property of value per year (620 total fires in the ten year period) in the subcategory, "Industrial Chemical, Hazardous Chemical, and Plastics Facilities." According to NAICS (Ref. F2.12), the total number of facilities in the corresponding subcategories is 5,870. Therefore, the frequency of potentially significant fires in these facilities is:

$$F = \frac{62 \text{ fires/yr}}{(5{,}870 \text{ facilities})} = 1.1\text{E-02 fires/facility-yr} \qquad \text{(Eq. F-2)}$$

Thus, the two estimates of the outside fire frequency are virtually the same. Overall, the use of a total mean outside fire frequency of 1E-02 fires per facility, per facility-year is deemed to be appropriate.

The next refinement is to determine where these outside fires start. One analysis performed by the NFPA was in terms of this distribution (Ref. F2.9, Section 5). With some interpretation, these data can be used to estimate the fraction of the total fire frequency that should be assigned to the various onsite areas outside the building. The results of this assessment are provided in Table F4.3-2.

Table F4.3-2. Fraction of Fires and Fire Frequency for Outside Areas of a Facility

Area	# of Fires[a]	Fraction	Fire Frequency per Facility-year
Storage areas – To include all areas where products are held while awaiting process, shipment, or use	125	0.20	2.0E-03
Receiving areas – To include all areas where products are moved into or out of a building while onsite but are still outside the building	57	0.092	9.2E-04
Trash/rubbish areas	84	0.135	1.4E-03
Areas containing equipment – To include all areas outside the building that contain operating process, HVAC, maintenance, or other machinery and equipment	121	0.195	2.0E-03
Open areas – To include fields, roads, and right of ways	84	0.135	1.4E-03
Vehicles	16	0.025	2.5E-04
Other	136	0.22	2.2E-03

NOTE: [a] Does not total 620 due to rounding after weighted allocation of fires coded in database as starting in unknown location (6.2% of fires).
HVAC = heating, ventilation, and air conditioning.

Source: Derived from Ref. F2.9, Section 5

As shown in Table F4.3-2, the frequency is expressed in terms of facility-year (since the number of NFPA fires is divided by the number of NAICS facilities). There is some uncertainty as to what is meant by a "facility" in this context. The NAICS does not make clear whether multiple process buildings can be considered a single facility, although, noting in this context, that the purpose of the NAICS is an economic census, implies that the number of main process buildings (i.e., the throughput of a given site) is more important than the number of sites. Because of this, in order to avoid potentially non-conservative probabilistic results, a boundary condition has been established that each main process building at the YMP constitutes a facility, and the outside fire frequency pertains to each of them (i.e., each of these buildings generates the necessary conditions to contribute a full measure of potential fire ignitions). The aging pads, buffer areas and subsurface are not considered as separate facilities, but rather as support areas for the process buildings (i.e., they are an integral part of a typical facility in that they supply the "raw materials" to the process and take the "product" from the process). In addition, the other support buildings are also not considered facilities for the purpose of determining the overall frequency of outside fires, for a similar reason. Therefore, the overall frequency of outside fires for the geologic repository operations area is the frequency per facility-year, times the number of main process buildings (six: IHF, WHF, RF, and three CRCFs).

A suitable uncertainty distribution is applied to the results of the initiating event frequency analysis to represent the significant uncertainty that results from the application of this methodology. The distribution is selected to reflect that, in particular recognition of the discussion above, it is likely that the calculated mean is conservative.

F5 ANALYSIS

F5.1 INTRODUCTION

Fire initiating event frequencies have been calculated for each initiating event identified for Intra-Site Operations. This section details the analysis performed to determine these frequencies, using the methodology documented in section F4. The discussion of the analysis below presupposes that the reader has developed a thorough understanding of the details of that methodology, as those details are not repeated in this section.

F5.2 INITIATING EVENT FREQUENCIES

There were three initiating events identified for Intra-Site Operations:

1. Fire threatens a waste container during onsite transport (site transporter, cask tractor/cask transfer trailer, or site prime mover (SPM))

2. Fire threatens a waste container in buffer area

3. Fire threatens a waste container on aging pad.

The selection of these events is documented in *Intra-Site Operations and BOP Event Sequence Development Analysis* (Ref. F2.14). This section addresses the quantification of these events.

F5.2.1 Fire Threatens a Waste Container during Transport (Site Transporter, Cask Tractor/Cask Transfer Trailer, or Site Prime Mover)

This represents fires that ignite on/in the transportation vehicles used to move containerized waste forms around the site. Transportation vehicles include the site transporter, cask tractor, the SPM, and the transport and emplacement vehicle (TEV) (the TEV is not included as part of Intra-Site Operations, but rather is included as part of Subsurface Operations). While it could be argued that a vehicle fire can occur at any time, it is more likely that it occurs while the vehicle is in use. For that reason, the fire frequency per year is converted to a frequency per vehicle operation by dividing by the total average number of operations of all such vehicles (both when loaded with a waste container and when not) per year. This allows initiating event frequencies over the preclosure period to be determined for each vehicle, and waste container to be quantified by multiplying by the total number of operations for each vehicle and waste container when the waste container is present.

The outside area that is relevant to this event, from Table F4.3-2, is "vehicles." That is, the waste container is vulnerable to a vehicle fire during transport. The total frequency per facility-year of such fires is, from the same table, 2.5E-04 per facility-year. As discussed in the methodology, this value is multiplied by six to determine the overall frequency of vehicle fires on the site.

$$\begin{aligned}\text{Site vehicle fire frequency/year} &= \text{2.5E-04 fires/facility-year} \times \text{6 facilities}\\ &= \text{1.5E-03 fires/year}\end{aligned}$$

This is then converted to the total expected number of vehicle fires over the 50-year preclosure period.

Site vehicle fire frequency (preclosure period) = 1.5E-03 fires/year × 50 years
= 7.5E-02 fires

This needs to be converted into a frequency per vehicle operation, which is the final form of the initiating event frequency. In actuality, a vehicle fire can start in any type of vehicle (e.g., service vehicle, delivery vehicle, etc.), not just in a vehicle that transports waste. There is no estimate available for the number of onsite vehicle movements; however, the number of waste container movements is estimated since this is integral to the throughput of the site (Ref. F2.6). Therefore, the potential for fires in other types of vehicles is ignored, which adds a level of conservatism to the results.

The PCSA throughput analysis (Ref. F2.6, Table 4) estimates that there are approximately 40,000 waste container movements outside of the process buildings during the preclosure period. This includes operations of the site transporter, cask tractor, SPM, and TEV.[2] For each waste container movement, there is another movement of the vehicle when a waste container is not present. Thus, the total number of operations of the transport vehicles is approximately 80,000. The fire initiating event frequency per operation is therefore:

Fire threatens a waste container during onsite transport
= 7.5E-02 fires/80,000 operations
= 9E-07 fires/operation[3]

F5.2.2 Fire Threatens a Waste Container in Buffer Area

The outside area that is relevant to this event, from Table F4.3-2, is "receiving areas." That is, the waste container is vulnerable to a fire in an outside receiving area for a short term while awaiting processing. The total frequency per facility-year of such fires is, from the same table, 9.2E-04 per facility-year. As discussed in the methodology, this value is multiplied by six to determine the overall frequency of storage area fires on the site.

Site receiving fire frequency/year = 9.2E-04 fires/facility-year × 6 facilities
= 5.5E-03 fires/year

This is then converted to the total expected number of buffer area fires over the 50-year preclosure period.

---

[2] When determining the fire ignition rate per operation on the site, the operation of all site vehicles needs to be considered in the allocation, not just those involved in Intra-Site Operations. When assembling the risk model for Intra-Site Operations, the resultant rate is used as the initiating event frequency and is multiplied only by the number of Intra-Site vehicle operations involving waste movements.

[3] Given the broad range of the approximations used in this analysis, there is no justification for using a mean to more than one significant digit.

Site receiving fire frequency (preclosure period) = 5.5E-03 fires/year × 50 years
= 3E-01 fires

This is the final form of the initiating event frequency. This event is not conducive to converting into a frequency per operation, since individual operations do not affect whether a waste container is present in a storage area (only how much is present, which is not important to the analysis since a release from even a single waste container has unacceptable consequences).

Fire threatens a waste container in buffer area = 0.3 fires

F5.2.3 Fire Threatens a Waste Container on Aging Pad

The outside area that is relevant to this event, from Table F4.3-2, is "storage areas." That is, the waste container is vulnerable to a fire in an outside storage area over a longer term while awaiting handling. The total frequency per facility-year of such fires is, from the same table, 2E-03 per facility-year. As discussed in the methodology, this value is multiplied by six to determine the overall frequency of storage area fires on the site.

Site storage fire frequency/year = 2E-03 fires/facility-year × 6 facilities
= 1.2E-02 fires/year

This is then converted to the total expected number of aging pad fires over the 50-year preclosure period.

Site storage fire frequency (preclosure period) = 1.2E-02 fires/year × 50 years
= 6E-01 fires

This is the final form of the initiating event frequency. This event is not conducive to converting into a frequency per operation, since individual operations do not affect whether a waste container is present in a storage area (only how much is present, which is not important to the analysis since a release from even a single waste container has unacceptable consequences).

Fire threatens a waste container on aging pad = 0.6 fires[4]

F5.2.4 Uncertainty

Formal analysis of the uncertainties in this estimate is not appropriate given the sources of information used. It was decided that the use of analyst judgment was most appropriate. A team of three individuals held a discussion of the sources of uncertainty and their potential effects on the calculated mean value.

First, the uncertainties are expected to be large. The use of two different data bases for the numerator and denominator offer the opportunity for a mismatch in the populations covered. The accuracy of the databases is also unclear. The NFPA data on fires is based on voluntary

[4] Given the broad range of the approximations used in this analysis, there is no justification for using a mean to more than one significant digit.

compliance by fire departments, and while NFPA adjusts the data for this and has a substantial past history of this type of analysis, the level of uncertainty is still greater than for a more rigorous system of data collection. Further, the data collectors (the individuals assigned to collect the data by each fire department) are not subject to a single consistent training course.

The census bureau data is likely to be more accurate, however there is still a potential for error in determining the number of actual buildings that constitute a facility for counting purposes. The methodology states that "A company operating at more than one location is required to file a separate report for each store, factory, shop, or other location." This is clear in regards to physical locations, but not clear in regards to multiple operations at one location. The approach used in this analysis to consider each of the six main waste handling buildings as a facility for counting purposes is conservative, but it increases uncertainty and also skews the distribution towards the high side (i.e., there is more room for the actual value to be lower than higher).

Taking all of this into consideration, the team selected a lognormal distribution (to address the issue of the conservative mean) with an error factor of 15 (to address the nature of the uncertainties).

F5.3 RESULTS

The results of the analysis are the fire initiating event frequencies and their associated distributions. The initiating event frequencies represent the probability, over the length of the preclosure period, that a fire threatens the stated waste container during the stated vulnerability. The results are summarized in Table F5.3-1.

Table F5.3-1. Outside Fire Initiating Event Frequencies and Associated Distributions

Initiating Event	Mean frequency (per 50 years)	Error Factor	Distribution
Fire threatens a waste container during transportation	9E-07 fires/operation	15	lognormal
Fire threatens a waste container in buffer area	0.3 fires	15	lognormal
Fire threatens a waste container on aging pad	0.6 fires	15	lognormal

Source: Original

F6 SPECIAL STUDY – FIRE THREATENS LOW-LEVEL RADIOACTIVE WASTE IN THE LOW-LEVEL WASTE FACILITY

In addition to outside fires, Intra-Site Operations analysis also considers fires that affect the Low-Level Waste Facility (LLWF). The methodology used for the analysis of outside fires is not applicable to a fire in this facility. Instead, the fire ignition frequency for the LLWF was developed from the approach to fire ignition frequencies by building type that was used for the other surface facilities (Ref. F2.11). This methodology provides Equation F-3 (Ref. F2.11, Section 5.3.3.1):

$$f_m(A) = c_1 A^r + c_2 A^s \qquad \text{(Eq. F-3)}$$

where f_m is the fire ignition frequency per m^2-yr, A is the floor area (in m^2) and c_1, c_2, r, and s are coefficients that were determined from historical data observations for different types of facilities. It was determined that the facility type 'warehouse' best suits the LLWF. The coefficients for a warehouse are 3.82, 2.0E-06, -2.08, and -0.05 for c_1, c_2, r, and s respectively (Ref. F2.11, Section 5.3.3.2). Utilizing general layout drawings *Low-Level Waste Facility General Arrangement Ground Floor* (Ref. F2.4) and *Low-Level Waste Facility General Arrangement Second Floor & Mezzanine Plan* (Ref. F2.5), the total area (in m^2) was determined to be 5,514, yielding an ignition frequency of 1.36E-06 (per m^2/year). This frequency is then multiplied by the area of the facility and the preclosure period to determine the overall frequency of LLWF fires on the site.

Low-level radioactive waste (LLW) fire frequency/m^2/year
= 1.4E-06 fires/facility-year $\times$ 5,514 m^2
= 7.52E-03 fires/year

This is then converted to the total expected number of LLWF fires over the 50-year preclosure period.

LLW fire frequency (preclosure period) = 7.5E-03 fires/year $\times$ 50 years
= 3.8E-01 fires

An uncertainty distribution was estimated for the LLWF based on the distribution derived in Appendix F.I. The approach to determining the distribution is the same as was developed for the industrial facility-type analysis that was used for other YMP facilities. It was determined that the effort required to perform a specific uncertainty assessment for warehouse-type facilities for the purpose of developing an uncertainty value for the LLWF was not required. Although the two different facility types have different coefficients for Equation F-1, it is not expected that the error factors on the final frequency values would be sufficiently different to merit a special analysis.

The estimated error factor obtained from Appendix F.I (Ref. F2.15) is utilized in Equation F-4 to convert the median LLW fire frequency to the mean LLW fire frequency (4.1E-01).