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Design Calculation or Analysis Cover Sheet

Complete only applicable items.

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8. Notes/Comments

Revision C is a complete rewrite; therefore, no revision bars have been used.

Mike Ong, Chris Kimura and Wes Davis from Lawrence Livermore National Laboratory provided technical input.

This calculation supersedes the following:
Extreme Wind/Tornado/Tornado Missile Hazard Analysis, 000-00C-WHS0-00100-000-00C

Attachments		Total Number of Pages
ATTACHMENT A	TORNADO AND TORNADO MISSILE SCREENING ANALYSIS	~~22~~ 23 Kla 2/18/08
ATTACHMENT B	LIGHTNING STRIKE SCREENING ANALYSIS	11
ATTACHMENT C	E-MAIL FOR REFERENCE 2.2.65	1
ATTACHMENT D	CD AND FILE LISTING	1 + CD

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Revised extensively to enhance clarity and to reflect new or revised site designs and document references	66	66	Farzin R. Nouri	Terry Crump		Dennis Richardson
00B	Deleted Attachment A. Revised sections on lightning and ash fall. Added new discussions on debris flow and lahar, liquefaction and lateral spread, differential settling, and fissuring. Revised to be consistent with the license application and to incorporate editorial changes	64	64	Farzin R. Nouri	S. F. Deng (checked drafts 00Bb, 00Bc, 00Bd, and 00Be) Terry Crump (checked draft 00Ba)		Mark Wisenburg
00C	Complete rewrite. Incorporate changes from the design evolution of the surface facilities and changes in event categorization and analysis methods. Kla 2/18/08	~~100~~ 102	D-1	K.L. Ashley K.L. Ashley 2/14/08 J. Minarick (Attachment A) 2/14/08 except Section A3.5 Kla 2/18/08	S.E. Deng 2/14/08 M. Perkins (Attachment B) 2/13/08	M.V. Frank 2/18/08	M. Wisenburg 2/18/08

DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC) and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

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TABLES

ACRONYMS AND ABBREVIATIONS

Acronyms

CFR	Code of Federal Regulations
CMF	Cask Maintenance Facility
CRCF	Canister Receipt and Closure Facility
DOE	U.S. Department of Energy
EF-Scale	enhanced Fujita scale
EOL	End of Line facility
F-Scale	Fujita scale
GROA	geologic repository operations area
HLW	high-level radioactive waste
HVAC	heating, ventilation, and air-conditioning
IAEA	International Atomic Energy Agency
IHF	Initial Handling Facility
ITS	important to safety
LLNL	Lawrence Livermore National Laboratory
MTHM	metric tons of heavy metal
NEO	near-earth object
NLDN	National Lightning Detection Network
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
PCSA	preclosure safety analysis
PMF	probable maximum flood
PMP	probable maximum precipitation
REMY	Rail Equipment Maintenance Yard
RF	Receipt Facility
SNF	spent nuclear fuel
SSC	structures, systems, and components
TEV	transport and emplacement vehicle
USFS	U.S. Forest Service
WHF	Wet Handling Facility

ACRONYMS AND ABBREVIATIONS (Continued)

YMP	Yucca Mountain Project

Abbreviations

A	ampere
cm	centimeter(s)
ft	foot, feet
in.	inch (es)
km	kilometer(s)
m	meter(s)
Ma	millions of years ago
mi	mile(s)
mm	millimeter(s)
mph	miles per hour
s	second(s)
yr	year

1. PURPOSE

The purpose of this analysis is to identify potential external events at the repository for the preclosure period and to evaluate these external events to determine if they are credible for the Yucca Mountain Repository site.

The repository shall be designed for a 25-year receipt period and a 50-year emplacement period. This emplacement period defines the duration of the preclosure period for the surface facilities as 50 years. The additional subsurface ventilation required defines the duration of the preclosure period for the subsurface facilities as 100 years (Ref. 2.2.16, Section 2.2.2.7). In this analysis a credible external event is defined as one whose frequency of occurrence is greater than at least one chance in 10,000 of occurring before permanent closure, per 10 CFR 63.2 (Ref. 2.3.1), or 1×10^{-4} over the preclosure period of 100 years.

1.1 INTRODUCTION

External events may be either natural or man-induced, originate outside or external to the facility, and might be capable of initiating an event sequence as defined by 10 CFR 63.2 (Ref. 2.3.1).

The area considered in this screening document is contained within the geologic repository operations area (GROA) and defined by 10 CFR 63.2 (Ref. 2.3.1) as the high-level radioactive waste (HLW) portion of the surface and subsurface areas, where waste handling activities are conducted.

1.2 SCOPE

This revision incorporates changes from the design evolution of the surface facilities and changes in event categorization and analysis methods.

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URL: http://www.fws.gov/desertcomplex/ashmeadows/map.htm

The input from reference 2.2.71 is supplied from an outside source; it is suitable for use in this analysis. Although not established fact, it presents the published work of experts in the field and is the best available source.

2.2.72 Weast, R.C., ed. 1977. *CRC Handbook of Chemistry and Physics.* 58th Edition. Cleveland, Ohio: CRC Press. TIC: 242376. ISBN-0-8493-0458.

2.2.73 Younker, J.L.; Andrews, W.B.; Fasano, G.A.; Herrington, C.C.; Mattson, S.R.; Murray, R.C.; Ballou, L.B.; Revelli, M.A.: DuCharme, A.R.; Shepherd, L.E.; Dudley, W.W.; Hoxie, D.T. Herbst, R.J.; Patera, E.A.; Judd, B.R.; Docka, J.A.; and Ricketsen, L.D. 1992. *Report of Early Site Suitability Evaluation of the Potential Repository Site at Yucca Mountain, Nevada*. SAIC-91/8000. Las Vegas, Nevada: Science Applications International Corporation. ACC: NNA.19910708.0111. (DIRS 102883)

The input from reference 2.2.73 is supplied from an outside source; it is suitable for use in this analysis. Although not established fact, it presents the published work of experts in the field and is the best available source.

2.2.74 Klinkrad, H. 1999. "Evolution of the On-Ground Risk During Uncontrolled Re-Entries," *American Institute of Aeronautics and Astronautics (AIAA)*, Reston, VA. TIC: 259898. (DIRS 184805)

The input from reference 2.2.74 is supplied from an outside source; it is suitable for use in this analysis. Although not established fact, it presents the published work of experts in the field and is the best available source.

2.2.75 USGS (U.S. Geological Survey) 2008. Geographic Names Information System (GNIS), Reston, Virginia. ACC: MOL.20080122.0253. URL: http://geonames.usgs.gov/pls/gnispublic/.

2.3 ANALYSIS CONSTRAINTS

2.3.1 10 CFR 63 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Internet Accessible. (DIRS 180319)

2.4 ANALYSIS OUTPUTS

None.

2.5 ANALYSIS INPUTS USED IN THE ATTACHMENTS

Attachment analysis inputs are listed in the cross-referenced sections.

Attachment A – Section A5.

Attachment B – Section B6.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

None used.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Trajectory of a Meteorite

Assumption: The trajectory of a meteorite is assumed to be vertical to the ground (i.e., perpendicular to the repository).

Rationale: There is no direct input available relating meteorite or space debris flux and the corresponding angle of entry. However, kinetic studies of reentry debris indicate that such debris tends to hit the ground at a 90 degree angle regardless of the original reentry angle (Section 6.13). A vertical trajectory minimizes the kinetic energy absorbed in the atmosphere during entry and maximizes the impact velocity and kinetic energy.

3.2.2 Surface Areas of the Canister Receipt and Closure Facilities

Assumption: The surface areas of the Canister Receipt and Closure Facility (CRCF) 1, 2, and 3 are assumed to be the same.

Rationale–Detailed design drawings are available only for CRCF-1 (Ref. 2.2.15). The *Basis of Design for the TAD Canister-Based Repository Design Concept* specifies that the CRCF-1, CRCF-2, and CRCF-3 each be designed for an annual receipt rate of 700 metric tons of heavy metal (MTHM) of commercial spent nuclear fuel (SNF) and 378 canisters of Department of Energy SNF and HLW annually (Ref. 2.2.16, Sections 4.2.1.2 and 4.2.1.4). Assigning the same building size of CRCF 1 to CRCF-2 and CRCF-3, which have the same receipt rate, is appropriate.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This analysis was prepared in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses,* (Ref. 2.1.1) and LS-PRO-0201, *Preclosure Safety Analysis Process*, (Ref. 2.1.2). Therefore, the approved version is designated as QA:QA.

4.2 USE OF SOFTWARE

The commercially available Microsoft® Excel 2003, which is a component of Microsoft® Office 2003 Professional, is used in this analysis to perform standard mathematical functions, which do not depend on the particular software program. The formulas used in this analysis are presented in sufficient detail in Section 6 and elsewhere at the point of use to allow the independent check to reproduce or verify the results using hand calculations, which was performed. Plots created using Excel were verified by visual inspection. Calculations and plots in Attachment B were performed on a Mac Pro computer running operating system 10.4.10 with Excel version 11.3.7. The Excel files were then run on a PC with Microsoft® Excel 2003. The results and plots were verified and the Excel files are included in Attachment D. Usage of Microsoft® Office 2003 Professional constitutes Level 2 software usage, as defined in IT-PRO-0011 (Ref. 2.1.3), and as such is listed in the current Level 2 Usage *Controlled Software Report.*

4.3 EXTERNAL EVENTS IDENTIFICATION

External events are defined for this analysis as events that originate outside or external to the facility, that might be capable of initiating an event sequence as defined by 10 CFR 63.2 (Ref. 2.3.1).

In accordance with *External-Events PRA Methodology* (Ref. 2.2.5, Section 4.4.4, Requirement EXT-B1), if an event is slow in developing, and it can be demonstrated that there is sufficient time to eliminate the source of the threat or to provide an adequate response, then the event may be excluded from further consideration. In this context, an adequate response is defined as securing operations in the affected facility and removing all waste forms to another location. Depending on where the waste form is in the process, some processing may need to be continued before it can be removed, for example, the completion of welding of a waste package. However, in any case it will be possible to complete waste removal within seven days. Therefore, an external event is screened from further consideration if, using engineering judgment, the occurrence of onset of the phenomenon will manifest itself at least seven days prior to reaching the point of constituting a threat to waste forms in the building. Seven days is considered to be of sufficient time to take appropriate corrective actions. The use of engineering judgment is common practice in probabilistic risk analyses.

The same criterion is applied to external events that can affect the entire site if the case can reasonably be made that the affect will initially manifest itself in actual visible damage only in one area of the site and then will, over time, extend to other areas. In this case, as long as it will be possible to remove the waste from the affected area within seven days and then develop an adequate response over a longer period of time, on the order of months, to adapt to the threat, then this external event can also be screened from further consideration.

The facilities considered in this screening document are contained within the GROA and defined by 10 CFR 63.2 (Ref. 2.3.1) as the HLW facilities that are part of a geologic repository, including both surface and subsurface areas, where waste handling activities are conducted.

An event sequence is defined by 10 CFR 63.2 (Ref. 2.3.1) as a series of actions and/or occurrences within the natural and engineered components of a GROA that could potentially lead to exposure of individuals to radiation. An event sequence includes one or more initiating events and an associated combination of repository system and/or component failures, including those produced by the action or inaction of operating personnel. Those event sequences that are expected to occur one or more times before permanent closure of the geologic repository operations area are referred to as Category 1 event sequences. Other event sequences that have at least one chance in 10,000 of occurring before permanent closure are referred to as Category 2 event sequences.

A generic and detailed list of potential external events (Table 1), that are not specific to the repository, is compiled from: *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessment for Nuclear Power Plants* (Ref. 2.2.60, Table 10-1), *Guidelines for Chemical Process Quantitative Risk Analysis* (Ref. 2.2.1, Section 3.3.3), and *Preclosure Radiological Safety Analysis for Accident Conditions of the Potential Yucca Mountain Repository: Underground Facilities* (Ref. 2.2.55, Section 3.2).

Table 1. External Events Identification

HAZARD	
1. Aircraft impact	46. Meteorite impact
2. Avalanche	47. Military activity-induced accident
3. Barometric pressure	48. Missile impact
4. Coastal erosion	49. Onsite chemical release from storage
5. Dam failure	50. Orogenic diastrophism
6. Denudation	51. Perturbation of groundwater system
7. Dissolution	52. Pipeline accident
8. Drift degradation	53. Rainstorm (intense precipitation)
9. Drought	54. River diversion
10. Epeirogenic diastrophism	55. Rockburst
11. Erosion	56. Rock deformation
12. External flooding	57. Sabotage
13. External fire	58. Sandstorm-dust storm
14. Extreme wind	59. Sedimentation
15. Extreme weather and climate fluctuations	60. Seiche
16. Fog	61. Seismic activity-earthquake
17. Fracturing-fractures	62. Seismic activity-surface fault displacement
18. Frost	63. Seismic activity-subsurface fault displacement
19. Fungus, bacteria, and algae	64. Settlement

Table 1. External Events Identification (Continued)

HAZARD			
20.	Geochemical alterations	65.	Shipwreck
21.	Glacial erosion	66.	Snow
22.	Glaciation	67.	Soil shrink-swell consolidation
23.	Hail	68.	Static fracturing
24.	High lake level	69.	Storm surge
25.	High tide	70.	Stream erosion
26.	High river stage	71.	Subsidence
27.	High summer temperature	72.	Tectonic activity-uplift and depression
28.	Hurricane	73.	Terrorist attack
29.	Ice cover	74.	Thermal loading
30.	Improper design/operation	75.	Tornado
31.	Inadvertent future human intrusion	76.	Toxic gas
32.	Industrial activity-induced accident	77.	Transportation accidents
33.	Intentional future human intrusion	78.	Tsunami
34.	Internal fire	79.	Turbine-generated missile
35.	Internal flooding	80.	Undetected past human intrusions
36.	Lahar	81.	Undetected geologic features
37.	Landslide	82.	Undetected geologic processes
38.	Lateral spread	83.	Volcanic activity
39.	Lightning	84.	Volcanism-intrusive igneous activity
40.	Liquefaction	85.	Volcanism-extrusive igneous activity
41.	Loss of offsite-onsite power	86.	Volcanism-ash fall
42.	Low lake level	87.	War
43.	Low river level	88.	Waste and rock interaction
44.	Low winter temperature	89.	Waves
45.	Mass wasting		

Source: *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessment for Nuclear Power Plants* (Ref. 2.2.60), *Guidelines for Chemical Process Quantitative Risk Analysis* (Ref. 2.2.1, Section 3.3.3), and *Preclosure Radiological Safety Analysis for Accident Conditions of the Potential Yucca Mountain Repository: Underground Facilities* (Ref. 2.2.55, Section 3.2).

4.4 EXTERNAL EVENTS CATEGORIZATION

Due to the large number and common features of external events identified in Table 1, the identified external events are consolidated into categories of external events derived from six sources (Table 2). External events that exhibited similar characteristics are merged into common categories. Certain external events are identified in all of the references while other external events are unique to a particular reference. External events that are common to the references are grouped together. This grouping of external events is shown in Table 2.

Table 2. Categorization of External Events

NUREG-1804 Description (Ref. 2.2.64)	NUREG/ CR-5042 Description (Ref. 2.2.53)	NUREG-1407 Description (Ref. 2.2.62)	NUREG/ CR-2300 Description (Ref. 2.2.60)	AIChE 2000 Description (Ref. 2.2.2)	ANSI/ANS-58.21-2007 Description (Ref. 2.2.5)
Seismicity and faulting	Seismic/ earthquakes	Seismic events	Seismic activity	Seismic activity	Seismic activity
Slope instability	Others, earth movement		Avalanche, landslide	Avalanche, landslide	Avalanche, landslide
Other extreme geological conditions	Others, earth movement		Avalanche, landslide, soil shrink-swell consolidation	Avalanche, landslide, soil shrink-swell consolidation	Avalanche, landslide
Volcanic activity	Others, volcanic activity	Volcanic activity	Volcanic activity	Volcanic activity	Volcanic activity
Winds and tornadoes	High winds/ tornadoes	High winds and tornadoes	Extreme winds and tornadoes, hurricanes	Extreme winds and tornadoes, hurricanes, missile impact	Extreme winds and tornadoes, hurricanes
	External floods	External floods	Coastal erosion, external flooding, high tide, high lake level, high river stage, hurricanes, intense precipitation, river diversion, seiche, storm surge, tsunami, waves	Coastal erosion, external flooding, high tide, high lake level, high river stage, hurricanes, intense precipitation, river diversion, storm surge, tsunami, waves	Coastal erosion, external flooding, high tide, hurricanes, intense precipitation, river diversion, seiche, storm surge, tsunami, waves
	Others, lightning	Lightning	Lightning	Lightning	Lightning
Other extreme meteorological conditions	Others, severe temperature transients, severe weather storms, abrasive windstorms	Severe weather storms (extreme heat, extreme cold), severe weather storms	Drought, frost, hail, high summer temperatures, ice cover, low lake level, low river level, low winter temperature, sandstorm, snow	Barometric pressure, drought, frost, hail, high summer temperature, ice cover, low lake level, low river level, low winter temperature, sandstorm, snow	Drought, frost, hail, high summer temperature, ice cover, low lake level, low river, level, low winter temperature, sandstorm, snow

Table 2. Categorization of External Events (Continued)

NUREG-1804 Description (Ref. 2.2.64)	**NUREG/ CR-5042 Description (Ref. 2.2.53)**	**NUREG-1407 Description (Ref. 2.2.62)**	**NUREG/ CR-2300 Description (Ref. 2.2.60)**	**AIChE 2000 Description (Ref. 2.2.2)**	**ANSI/ANS-58.21-2007 Description (Ref. 2.2.5)**
Human-induced events	Transportation accidents	Transportation and nearby facility accidents	Aircraft impact, fog, transportation accidents	Aircraft impact, fog, missile impact, shipwreck, transportation accidents	Aircraft impact, fog, transportation accidents
Human-induced events	Others, nearby industrial/military facilities	Transportation and nearby facility accidents	Industrial/military facility accident, pipeline accident (gas, etc.)	Industrial/military facility accident, missile impact, pipeline accident	Industrial/military facility accident, pipeline accident
Human-induced events	Others, on-site Hazardous materials release		Onsite chemical Release, toxic gas	Onsite chemical Release, toxic gas	Onsite chemical Release, toxic gas
	Others, external fires	External fires (forest fires, grass fires)	Forest fire	Forest fire	Forest fire
	Others, extraterrestrial activity	Extraterrestrial activity (meteorite strikes, satellite falls)	Meteorite	Meteorite impact	Meteorite/satellite strikes
	Internal fires	Internal fires	Fire	Fire	
			Internal flooding	Internal flooding	Internal flooding
			Turbine-generated missile	Turbine-generated missile	Turbine-generated missile
					Biological events
				Sabotage, terrorist attack, war	

Sources: *Guidelines for Chemical Process Quantitative Risk Analysis* (Ref. 2.2.2, Section 3.3.3), *External-Events PRA Methodology*. ANSI/ANS-58.21-2007 (Ref. 2.2.5, Appendix A); *Evaluation of External Hazards to Nuclear Power Plants in the United States*, NUREG/CR-5042 (Ref. 2.2.53, Section 2.1), *PRA Procedures Guide, A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants*. NUREG/CR-2300 (Ref. 2.2.60, Table 10-1), *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities, Final Report.* NUREG-1407 (Ref. 2.2.62, Section 2), *Yucca Mountain Review Plan, Final Report*. NUREG-1804 (Ref. 2.2.64, Section 2.1.1.3).

From the list of potential external events of Table 2, the following categories of external events are developed:

A. Seismic activity

B. Non-seismic geologic activity (including landslides, avalanche)

C. Volcanic activity

D. High winds/tornadoes/hurricanes

E. External floods

F. Lightning

G. Loss of power event

H. Loss of cooling capability event (non-power cause, including biological events)

I. Aircraft crash

J. Nearby industrial/military facility accidents (including transportation accidents)

K. Onsite hazardous materials release

L. External fires (including forest fire, grass fire)

M. Extraterrestrial activity (including meteorite, satellite fall)

N. Internal fires

O. Internal flooding

P. Turbine-generated missile

Q. Security threats (includes sabotage, terrorist attack, and war)

R. Yucca Mountain unique hazards.

A crosswalk is performed on the list of external events identified in Table 1 with the categories of external events determined in Table 2. During the crosswalk, another external event category (R) was defined to cover those external events that applied only to the Yucca Mountain Repository and its operation.

Table 3. Crosswalk of External Events

EXTERNAL EVENT CATEGORY (from Table 2)	**IDENTIFIED EXTERNAL EVENT (from Table 1)**
A. SEISMIC ACTIVITY	38. Lateral spread
	40. Liquefaction
	61. Seismic activity-earthquake
	62. Seismic activity-surface fault displacement
	63. Seismic activity-subsurface fault displacement
B. NON-SEISMIC GEOLOGIC ACTIVITY	2. Avalanche
	4. Coastal erosion
	6. Denudation
	7. Dissolution
	8. Drift degradation
	10. Epeirogenic diastrophism
	11. Erosion
	17. Fracturing-fractures
	21. Glacial erosion
	22. Glaciation
	37. Landslide
	45. Mass wasting
	50. Orogenic diastrophism
	55. Rockburst
	56. Rock deformation
	59. Sedimentation
	64. Settlement
	67. Soil shrink-swell consolidation
	68. Static fracturing
	70. Stream erosion
	71. Subsidence
	72. Tectonic activity-uplift and depression
	81. Undetected geologic features
	82. Undetected geologic processes
C. VOLCANIC ACTIVITY	36. Lahar
	83. Volcanic activity
	84. Volcanism-intrusive igneous activity
	85. Volcanism-extrusive igneous activity
	86. Volcanism-ash fall

Table 3. Crosswalk of External Events (Continued)

EXTERNAL EVENT CATEGORY (from Table 2)	IDENTIFIED EXTERNAL EVENT (from Table 1)
D. HIGH WINDS/TORNADOES	3. Barometric pressure
	14. Extreme wind
	15. Extreme weather and climate fluctuations
	28. Hurricane (high wind effects)
	48. Missile impact
	75. Tornado
E. EXTERNAL FLOODS	5. Dam failure (flooding effects)
	12. External flooding
	15. Extreme weather and climate fluctuations
	24. High lake level
	25. High tide
	26. High river stage
	28. Hurricane (flooding effects)
	29. Ice cover (flooding effects)
	53. Rainstorm (intense precipitation)
	54. River diversion
	60. Seiche
	66. Snow
	69. Storm surge
	78. Tsunami
	89. Waves
F. LIGHTNING	39. Lightning
G. LOSS OF POWER EVENT	15. Extreme weather and climate fluctuations
	18. Frost
	23. Hail
	29. Ice cover
	41. Loss of offsite-onsite power
	58. Sandstorm-dust storm
H. LOSS OF COOLING CAPABILITY (NONPOWER CAUSE)	5. Dam failure (loss of water)
	9. Drought (loss of water)
	15. Extreme weather and climate fluctuations
	19. Fungus, bacteria, and algae
	27. High summer temperature
	29. Ice cover (loss of water)
	42. Low lake level
	43. Low river level
	44. Low winter temperature (loss of water)
	54. River diversion (loss of water)
	58. Sandstorm-dust storm

Table 3. Crosswalk of External Events (Continued)

EXTERNAL EVENT CATEGORY (from Table 2)	IDENTIFIED EXTERNAL EVENT (from Table 1)
I. AIRCRAFT CRASH	1. Aircraft impact
J. NEARBY INDUSTRIAL/MILITARY FACILITY ACCIDENT	16. Fog
	32. Industrial activity-induced accident
	47. Military activity-induced accident
	52. Pipeline accident
	65. Shipwreck
	77. Transportation accidents
K. ONSITE HAZARDOUS MATERIAL RELEASE	49. Onsite chemical release from storage
	76. Toxic gas
L. EXTERNAL FIRES	13. External fire
M. EXTRATERRESTRIAL ACTIVITY	46. Meteorite impact (including space debris)
N. INTERNAL FIRES	34. Internal fire
O. INTERNAL FLOODS	35. Internal flooding
P. TURBINE-GENERATED MISSILE	48. Missile impact
	79. Turbine-generated missile
Q. SECURITY THREATS	31. Inadvertent future human intrusion
	33. Intentional future human intrusion
	57. Sabotage
	73. Terrorist attack
	87. War
R. YUCCA MOUNTAIN UNIQUE HAZARDS	20. Geochemical alterations
	30. Improper design/operation
	51. Perturbation of groundwater system
	74. Thermal loading
	80. Undetected past human intrusions
	88. Waste and rock interaction

Source: Original

Internal fires and internal floods are internal events that are not addressed by this analysis. Turbine-generated missile events, which are analyzed for the large turbines in nuclear power plants, are not applicable to site operations, and are therefore, excluded from evaluation.

Security threats are not within the scope of this evaluation and are the subject of *Safeguards and Security System* section of Ref. 2.2.16 (Section 23).

Most of the external events included under the category of Yucca Mountain Unique Hazards (Table 2) are considered in the post-closure time period. The effects of these external events proceed at a rate too slow to affect the repository in the preclosure time period, thus are excluded from further consideration on this basis. Improper design and operation is an internal event, and therefore, not addressed by this analysis.

The final list of external event categories includes the following:

A. Seismic activity

B. Non-seismic geologic activity

C. Volcanic activity

D. High winds/tornadoes/hurricanes

E. External floods

F. Lightning

G. Loss of power event

H. Loss of cooling capability event (non-power cause)

I. Aircraft crash

J. Nearby industrial/military facility accidents

K. Onsite hazardous materials release

L. External fires

M. Extraterrestrial activity (including meteorite, space debris).

4.5 EXTERNAL EVENTS HAZARDS SCREENING

To evaluate external events for relevance (screening) during the preclosure period, four questions are asked for each external event category.

1. Can the external event occur at the repository?

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period?

3. Can the external event severe enough to affect the repository and its operation occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period?

4. Can a radioactive release that results from the external event severe enough to affect the repository and its operations, occur with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period?

These questions are applied in sequence. If the first question is answered "no," the analysis is stopped, the external event category is screened from further evaluation and no other questions are asked. If the first question is answered "yes," then the second question is applied. If the answer to the second question is also "yes," the third question is applied. This process is followed until all questions are asked for an external event category or a "no" response is received. In all cases, the external event category is screened from further evaluation when a question is answered "no." If all four questions are answered "yes," then the external event category is retained for further evaluation.

Those external event categories not screened are compiled in the External Event Category List and are identified as subjects for further evaluation. The external event categories retained for further evaluation are considered as initiating events in event sequences for the Preclosure Safety Analysis (PCSA).

The evaluation of the external event categories is performed in Section 6.2.

5. LIST OF ATTACHMENTS

	Number of Pages
ATTACHMENT A. TORNADO AND TORNADO MISSILE SCREENING ANALYSIS	23
ATTACHMENT B. LIGHTNING STRIKE SCREENING ANALYSIS	11
ATTACHMENT C. E-MAIL FOR REFERENCE 2.2.65	1
ATTACHMENT D. CD AND FILE LISTING	1 + CD

6. BODY OF CALCULATION

Each external event category is evaluated separately with a definition and the required conditions for the external event to be present at the repository. The four questions from Section 4.5 are then applied. Those external event categories which are not screened out are compiled in the External Event Category List and are identified as subjects for further evaluation. The external event categories retained for further evaluation are considered as initiating events in the event sequences for the PCSA.

6.1 SEISMIC ACTIVITY

6.1.1 Definition

Seismic activity is defined as a sudden motion or trembling in the earth caused by the abrupt release of accumulated strain (Ref. 2.2.7, p. 156).

Also included within seismic activity are:

1. Lateral spread - Defined as the lateral movements in a fractured mass of rock or soil that result from liquefaction or plastic flow of subjacent materials (Ref. 2.2.52, p. 359)
2. Liquefaction - Defined as the transformation from a solid to liquid state as a result of increased pore pressure and reduced effective stress in cohesionless soil (Ref. 2.2.52, p. 370)
3. Surface fault displacement - A general term for the relative movement of the two sides of a fault, measured in any chosen direction and occurs at or near the surface (Ref. 2.2.7, p. 144)
4. Subsurface fault displacement - A general term for the relative movement of the two sides of a fault, measured in any chosen direction and occurs below the surface (Ref. 2.2.7, p. 144).

6.1.2 Evaluation

1. Can the external event occur at the repository? **YES**.

   Vibratory ground motion can occur at Yucca Mountain, as discussed in *Yucca Mountain Site Description* (Ref. 2.2.9, Section 4.3).

   Lateral spread and liquefaction cannot occur at Yucca Mountain because the seismic activity must involve saturated soils. The repository soil is dry and dense. There is no potential for liquefaction as the water table is located about 1,270 ft (390 m) below the surface of the repository, as discussed in *Supplemental Soils Report* (Ref. 2.2.17, Section 6.1.4.4).

Fault displacement, both surface and subsurface, has been determined by *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (Ref. 2.2.46, Table ES-3) as occurring at Yucca Mountain.

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **YES**.

   Vibratory ground motion could damage structures, systems, and components (SSCs) determined to be important to safety (ITS).

   For fault displacement, both surface and subsurface, the 10^{-5} per year fault displacement hazards for the block-bounding faults, Solitario Canyon and Bow Ridge, is estimated to be 7.8 and 32 cm, respectively (Ref. 2.2.46, Table ES-3).

   Yucca Mountain is situated in an area of active seismicity and the frequency of occurrence of a seismic event at Yucca Mountain is greater than 10^{-6}/yr.

3. Can the external event severe enough to affect the repository and its operation occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **YES.**

   Credible rockfalls of emplacement drifts during the preclosure period are considered in Ref. 2.2.18. Severe earthquakes with an annual exceedance frequency of 10^{-5} or less could cause the partial to complete collapse of emplacements drifts (Ref. 2.2.18, Section 7). Seismic events should be evaluated further for Subsurface Operations in the preclosure period. Furthermore, equipment, unless designed for site specific earthquakes, may fail during an earthquake with an exceedance frequency of 10^{-6} or greater.

4. Can a radioactive release that results from the external event severe enough to affect the repository and its operations occur with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **YES.**

   It is unknown whether a rockfall in an emplacement drift would be of sufficient energy to breach a waste package and its contents and whether earthquake induced equipment failures may cause a radiological release, therefore, this question is answered in the affirmative.

Should the external event be retained for further evaluation? **YES**.

6.2 NON-SEISMIC GEOLOGIC ACTIVITY

6.2.1 Definition

Non-seismic geologic activity is defined as the modification of the earth's features through natural or non-seismic processes. Included within non-seismic geologic activity are:

1. Avalanche – Defined as any large mass of snow, ice, soil, or rock, or mixture of these materials, falling, sliding, or flowing very rapidly under the force of gravity (Ref. 2.2.7, p. 36)

2. Coastal erosion - Defined as the wearing away of soil and rock by waves and tidal action

3. Denudations – Defined as the sum of the processes that result in the wearing away or the progressive lowering of the earth's surface by weathering, mass wasting, and transportation and their combined destructive effects (Ref. 2.2.7, p. 132)

4. Dissolution – Defined as a process of chemical weathering by which minerals pass into solution

5. Drift degradation – Defined as the partial or complete collapse of access tunnels, ramps, turnouts, or emplacement drifts as a result of non-seismic rockburst or rockfall. Rockburst is a sudden breaking of a mass of rock from the walls of a tunnel, mine, or deep quarry caused by the release of accumulated strain energy. It may result in closure of a mine opening, or projection of broken rock into it, accompanied by ground tremors, rockfalls, and air concussions (Ref. 2.2.7, p. 436). Rockfall is the relative free falling of a newly detached segment of bedrock of any size from a cliff, steep slope, cave or arch (Ref. 2.2.7, p. 436)

6. Epeirogenic diastrophism - Diastrophism is defined as a general term for all movement of the crust produced by tectonic processes, including the formation of ocean basins, continents, plateaus, and mountain ranges (Ref. 2.2.7, p. 138). Epeirogeny is a major subdivision of diastrophism, defined as the uplift and subsidence movements that have produced the broader features of the continents and oceans in contrast to the more localized process of orogeny which produced mountain ranges (Ref. 2.2.7, p. 167)

7. Erosion – Defined as the wearing away of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, wind, and underground water (Ref. 2.2.7, p. 170)

8. Fracturing-fractures - Defined as the breaking of rocks caused by stress, including cracks, joints, and faults

9. Glacial erosion – Defined as the reduction of the earth's surface as a result of grinding and scouring by glacier ice armed with rock fragments together with erosive action of melt water streams (Ref. 2.2.7, p. 211)

10. Glaciation – Defined as the formation, movement, and recession of glaciers or ice sheets (Ref. 2.2.7, p. 212)

11. Mass wasting – Defined as the large scale mass movement or transfer of generally unconsolidated surface material under gravitational forces. Examples of mass wasting include debris avalanche, debris flow, debris slide, earth flow, mud flow, and landslide

12. Orogenic diastrophism – Diastrophism is defined as a general term for all movement of the crust produced by tectonic processes, including the formation of ocean basins, continents, plateaus, and mountain ranges (Ref. 2.2.7, p. 138). Orogeny is a major subdivision of diastrophism, defined as the process by which structures within fold-belt mountainous areas were formed, including thrusting, folding, and faulting in the outer and higher layers, and plastic folding, metamorphism, and plutonism in the inner and deeper layers (Ref. 2.2.7, p. 360)

13. Sedimentation – Defined as the process of deposition of sediment, especially by mechanical means, from a state of suspension in air or water (Ref. 2.2.7, p. 454)

14. Settlement – Defined as the settling of a structure, caused by the compression or movement of the soil below the foundation (Ref. 2.2.52, p. 177). If the settling is non-uniform, then it is called differential settlement (Ref. 2.2.52, p. 177)

15. Stream erosion – Defined as the progressive removal of bedrock, overburden, soil, or other exposed matter from the surface of a channel by a stream

16. Subsidence – Defined as the sinking or downward settling of the earth's surface (Ref. 2.2.7, p. 503)

17. Tectonic activity-uplift and depression – Defined as the development of a structurally high area in the crust, produced by movements that raise the rocks (Ref. 2.2.7, p. 547). Depression is the development of a structurally low area in the crust, produced by negative movements that either sink or down thrust the rocks (Ref. 2.2.52, p. 170).

6.2.2 Evaluation

1. Can the external event occur at the repository? **YES**.

   Avalanche – Steeply sloped terrain found in high mountain ranges in conjunction with an accumulation of snow, ice, loose rocks, or a mixture thereof, must exist at the repository site. The repository facilities are located at elevations ranging from approximately 3,650 ft to about 3,800 ft. In the vicinity, the elevation rises to the west to approximately 4,200 ft with the peak elevation at a distance of over 1,000 ft from a waste facility. Thus, at its greatest, there is about a 600 ft rise over a distance of 1,000 ft (Ref. 2.2.28). In order to have an avalanche, there must be an accumulation of snow, ice or loose rocks. The repository is designed for a maximum monthly snowfall of 6.6 in. and a temperature environment of 2^{o}F to 116^{o}F (Ref. 2.2.21, Sections 6.1.1 and 6.1.6). The lack of significant snowfall and the expected temperature profile does not support an accumulation of snow or ice. The area will be compacted and leveled to support construction. Thus, the slope of the terrain and the lack of an accumulation of snow, ice or loose rocks exclude this event from further consideration.

   Coastal erosion –A coastline must exist at the repository site. There is no coastline anywhere near the site, thus this external event is excluded from further consideration.

Denudation – Weathering, mass wasting, and transportation processes must exist at the repository site. The effects of this external event will progress slowly over time providing adequate time for remedial actions. This type of effect will not occur uniformly over the site, as the site topography will have a significant impact on the location and degree of the affect. There will therefore be places available to place waste forms until a longer term solution is implemented. This external event is excluded from further consideration on this basis.

Dissolution – The weathering process, precipitation, groundwater, and minerals and rocks that are soluble must exist at the repository site. However, the effects of this external event will progress slowly over time providing adequate time for remedial actions. This type of effect will also not occur uniformly over the site, as the site topography, geology, and hydrology will have a significant impact on the location and degree of the affect. There will therefore be places available to place waste forms until a longer term solution is implemented. This external event is excluded from further consideration on this basis.

Drift degradation – Any combination of deep and extensive tunneling, excavation, brittle rock, or unstable fault structures, and high in situ stresses are required for rockburst. A fractured-fissured rock mass, low rock mass strength and low stress to strength ratios in the rock are factors that tend to promote rockfall and drift degradation. Due to tunneling and excavation of drifts, this event could occur at the repository.

Epeirogenic diastrophism – Broad scale primarily vertical movements that affect larger features of the continents must exist at the repository site. This type of effect could occur relatively uniformly over the site, but the specific effects will manifest themselves randomly (e.g., one building will show cracking before the others) and progress slowly over time. There will be adequate time to find a long term solution before all areas of the site are rendered unsuitable to hold waste forms. This external event is excluded from further consideration on this basis.

Erosion – Evidence of weather and mass wasting must exist at the repository site. However, the effects of this external event will progress slowly over time providing adequate time for remedial actions. This type of effect will not occur uniformly over the site, as the site topography will have a significant impact on the location and degree of the affect. There will therefore be places available to place waste forms until a longer term solution is implemented. This external event is excluded from further consideration on this basis.

Fracturing-fractures - Stress accumulation capable of creating cracks, joints, and faults in rocks must exist at the repository site. This type of effect could occur relatively uniformly over the site, but the specific effects will manifest themselves randomly (e.g., one building will show cracking before the others) and progress slowly over time. There will be adequate time to find a long term solution before all areas of the site are rendered unsuitable to hold waste forms. This external event is excluded from further consideration on this basis.

Glacial erosion and glaciation – Glaciers and a climate capable of sustaining them must be present at the repository site. There are no glaciers in the vicinity of the repository and it would require a climate change over an extremely long period of time in order to sustain the formation of a glacier. Therefore, these external events are excluded from further consideration on this basis.

Mass wasting – Soil debris must be present on slopes sufficiently steep such that the addition of water turns the soil mass unstable because of an increase in mass and a decrease in friction. The topography and geology of the site is such that the necessary conditions do not exist at the site. This external event is excluded from further consideration on this basis.

Orogenic diastrophism – Compressional tectonic deformation style must exist at or near the repository site. This type of effect could occur relatively uniformly over the site, but the specific effects will manifest themselves randomly (e.g., one building will show cracking before the others) and progress slowly over time. There will be adequate time to find a long term solution before all areas of the site are rendered unsuitable to hold waste forms. This external event is excluded from further consideration on this basis.

Sedimentation – The potential for transport and deposition of particulate matter by a fluid must exist at the repository site. However, the effects of this external event will progress slowly over time providing adequate time for remedial actions. This type of effect will not occur uniformly over the site, as the site topography will have a significant impact on the location and degree of the affect. There will therefore be places available to place waste forms until a longer term solution is implemented. This external event is excluded from further consideration on this basis.

Settlement – Potential natural geologic processes that result in a subsurface void space must exist at the repository site. However, the effects of this external event will progress slowly over time providing adequate time for remedial actions. This type of effect will not occur uniformly over the site, as the site topography will have a significant impact on the location and degree of the affect. There will therefore be places available to place waste forms until a longer term solution is implemented. This external event is excluded from further consideration on this basis.

Stream erosion – Intermittent or continuous flowing streams must exist at or near the repository site that transport material out of the drainage basis, producing a net lowering of the base of the channel. No such streams exist and it would require a climate change over an extremely long period of time in order to sustain the formation of streams that could then lead to sufficient erosion to be of concern. Thus, this external event is excluded from further consideration on this basis.

Subsidence – Potential natural geologic processes or human-induced activity that results in a large consolidated subsurface void space must exist at the repository site. This type of effect could occur relatively uniformly over the site, but the specific effects will manifest themselves randomly (e.g., one building will show cracking before the others) and progress slowly over time. There will be adequate time to find a long term solution before all areas of the site are rendered unsuitable to hold waste forms. This external event is excluded from further consideration on this basis.

Tectonic activity-uplift and depression – A tectonic environment capable of producing structurally high areas must exist at or around the repository site. This type of effect could occur relatively uniformly over the site, but the specific effects will manifest themselves randomly (e.g., one building will show cracking before the others) and progress slowly over time. There will be adequate time to find a long term solution before all areas of the site are rendered unsuitable to hold waste forms. This external event is excluded from further consideration on this basis.

Based on the above, only drift degradation is retained for further consideration.

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have an 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO**.

   Ref. 2.2.19, Section VI states that ground motion with 1×10^{-4} probability of annual occurrence causes rockfall by shaking down already damaged rock mass around the drift. Heating induces damage in addition to the damage caused by the excavation of the drift itself, but does not necessarily result in a rockfall under static loading conditions. As drift degradation due to seismic ground motion is the controlling mechanism during the preclosure period and is considered as part of the seismic external event (Section 6.1), drift degradation due to non-seismic mechanisms will not be evaluated further.

Should the external event be retained for further evaluation? **NO**.

6.3 VOLCANIC ACTIVITY

6.3.1 Definition

Volcanic activity is defined as the ejection of volcanic materials, such as lava pyroclasts and volcanic gases, onto the earth's surface (Ref. 2.2.7, p. 170).

Also included within volcanic activity are:

1. Lahar – Defined as a mud flow composed chiefly of volcaniclastic materials on the flank of an active or erupting volcano. The debris carried in the flow includes pyroclasts, blocks from primary lava flows, and epiclastic material (Ref. 2.2.52, p. 354). This event is related to the more comprehensive phenomenon of mass wasting (Section 6.2) but requires recent volcanic activity with extensive unconsolidated volcaniclastic deposits.

2. Volcanism-intrusive igneous activity – Defined as the development and movement of magma and mobile rock material underground

3. Volcanism-extrusive igneous activity – Defined as the rising and ejection onto the earth's surface of molten rock, pyroclastic material, and gases

4. Volcanism-ash fall – Defined as airborne volcanic ash, such as fine pyroclastic material, falling from an ash cloud and accumulating on the surface of the earth.

6.3.2 Evaluation

1. Can the external event occur at the repository? **YES**.

   Volcanism and volcanic ash fall can occur at the repository because of the proximity of the site to nearby areas where volcanic activity has occurred.

   There are seven Quaternary volcanoes in the Yucca Mountain region (Ref. 2.2.20, Table 3). Table 4 presents a summary of the volcanic centers near Yucca Mountain.

Table 4. Quaternary Volcanic Centers in the Yucca Mountain Region

Volcano Name	**Volume (km^3)[a]**	**North Latitude[b]**	**West Longitude[b]**	**Distance (mi) and Direction from Yucca Mtn. Site[c]**
Lathrop Wells Cone	0.12	36.7	116.5	16.3 S
Little Black Peak Cone	0.014	37.1	116.8	20.0 NW
Hidden Cone	0.03	37.2	116.7	24.0 NW
Little Cones	0.03	36.8	116.6	8.6 WSW
Red Cone	0.06	36.8	116.6	8.9 WSW
Black Cone	0.06	36.8	116.6	9.2 W
Mikani Cone (Northern Cone)	0.004	36.9	116.6	7.6 W

Source: [a] Ref. 2.2.20, Table 4.
[b]Ref. 2.2.66, Section 3.V.D, Table 3.1.
[c]Ref. 2.2.58, as measured.

   In addition to the direct effects of a volcano, lahar and igneous activity, volcano activity in the surrounding area could have an affect on the site due to the resultant ash fall. Volcanic ash can clog or block the natural circulation vent paths of the aging overpacks on the aging pads and clog filters. Another concern is roof loading due to ash fall.

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO**.

   The mean frequency of intersection of the repository by a volcanic event is about 1.7×10^{-8} per year, and the conditional frequency of occurrence of one or more eruptive centers within the repository is 0.28, as given by Ref. 2.2.20. Thus, the mean frequency of one or more eruptive conduits forming within the repository, conditional upon dike intersection is the product of the two, or 4.7×10^{-9} per year. Both of the frequencies estimated by Ref. 2.2.20 relate to the possibility of a volcanic event interacting with the Yucca Mountain Repository in the post-closure period. Because of the low frequencies of a volcanic event interacting with the Yucca Mountain Repository in the post-closure period, the frequency of a volcanic event interacting with the Yucca Mountain Repository in the preclosure is considered to be less than 10^{-6}/yr.

To determine the frequency and magnitude of ash fall on the Yucca Mountain site from volcano activity in the surrounding area during the preclosure period, an estimate must be made of volcanic eruptions which might occur during the preclosure period, and the magnitude of ash fall resulting from that eruption that are "large" enough or close enough to result in significant ash fall on the repository site.

The ash fall analysis for the North Portal operations area estimated the ash fall hazard due to potential basaltic volcanism based on a probabilistic dispersal of ash fall surrounding the Yucca Mountain site. The estimated mean frequency for an ash fall aerial density of 10 g/cm^2 is 6.4×10^{-8}/yr (Ref. 2.2.20). This is equivalent to 10 cm for a density of 1 g/cm^3 or 20 cm for a density of 0.5 g/cm^3. The *Project Design Criteria Document* (Ref. 2.2.21, Section 6.1.11) specifies that "structural loading shall take into account volcanic ash fall with a roof live load of 21 lb/ft^2." This is equivalent to an aerial density of 10.25 g/cm^2. Thus the surface facilities at the Yucca Mountain Repository are designed with a roof live load at the estimated mean frequency that is less than 10^{-6}/yr.

The average uncompacted bulk density for the downwind ash for the May 18, 1980, Mount St. Helens eruption was 0.45 g/cm^3. The density for the May 25 and June 12 eruptions at Mount St. Helens was about 1.0 and 1.25 g/cm^3, due to the compaction by rain that fell during or shortly after the two eruptions (Ref. 2.2.68, Abstract). Using the lower density of 0.45 g/cm^3 to determine the depth of an ash fall with an aerial density of 10 g/cm^2 gives a depth of 22.2 cm or about 9 inches of non-compacted ash. Aging overpacks have passive cooling by means of vent openings at the bottom and the top of the overpacks (Ref. 2.2.13) with the bottom vent 1 ft, 4 in. high (Ref. 2.2.14). Thus, clogging the vent openings for the aging overpacks has an estimated mean frequency that is less than 10^{-6}/yr. In addition, if an ash fall event were to occur, maintenance and remediation on HVAC equipment and Aging Facility components during an assumed outage period would furthermore ensure that there are no clogging concerns. Such remedial efforts could include ash removal.

Should the external event be retained for further evaluation? **NO.**

6.4 HIGH WINDS/TORNADOES/HURRICANES

6.4.1 Definition

Wind is a meteorological term for the component of air that moves parallel to the earth's surface.

NUREG-0800 specifies design requirements for structures that must withstand the effects of the design basis wind (Ref. 2.2.61, Section 3.3.1). ASCE 7-98, *Minimum Design Loads for Buildings and Other Structures* (Ref. 2.2.6, Section 6), discusses designs for wind loading and defines the extreme wind as the maximum 3-second gust speed at 10 m above ground level.

Tornadoes are defined as small-scale cyclones, generally less than 500 m (1,640 ft) in diameter with very strong winds. Intense thunderstorms in the desert Southwest are capable of producing tornadoes. ANSI/ANS-2.12-1978 (Ref. 2.2.3, Section 2) defines this event as:

> . . . a violently rotating column of air pendent from a convective type cloud and nearly always observable as funnel cloud or tube. Tornadoes have large rotational wind speeds, pressure gradients along their radii and translational movement. A tornado can create structural loadings and . . . missiles . . . .

This hazard includes hurricanes. Hurricanes are defined as tropical cyclones which occur in the Northeast Pacific or North Atlantic in which the sustained near-surface wind speed equals or exceeds 118 km/hr (74 mph).

Missile impact is considered as an effect of tornadoes in Attachment A.

6.4.2 Evaluation

1. Can the external event occur at the repository? **YES**.

   ANSI/ANS 2.8-1992 (Ref. 2.2.4, Section 7.2.1.1) states that hurricanes:

   > . . . shall be considered for U.S. coastline areas and areas within 100 to 200 miles bordering the Pacific Ocean, Atlantic Ocean, Gulf of Mexico and possessions within the Caribbean Sea. In addition, influence along estuaries and rivers connecting with those bodies of water should also be considered because hurricane storm surges will be transmitted upstream to some degree.

   The repository is located approximately 225 mi (360 km) to the northeast of Santa Monica Bay near Los Angeles, California (Ref. 2.2.48, Vol. 1, Part A, Chapter 1, p. 1-83), the nearest such feature defined in the standard. The potential energy of a hurricane would dissipate as it moves over the mountainous terrain between the Pacific Coast and the Yucca Mountain region, and no interconnecting rivers or estuaries can act as potential pathways. Therefore, the hurricane hazard is not applicable to the Yucca Mountain site.

   Extreme winds and tornadoes can occur at the repository. See Attachment A.

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **YES**.

The frequency of tornadoes at the repository is estimated in Attachment A using data from *Tornado Climatology of the Contiguous United States,* NUREG/CR-4461 (Ref. 2.2.67). From Attachment A, Table A2, the frequency of a tornado strike is greater than 10^{-6}/yr for the CRCF, Initial Handling Facility (IHF), Receipt Facility (RF), Wet Handling Facility (WHF), railcar and truck buffer areas and aging pads.

3. Can the external event severe enough to affect the repository and its operation occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO**.

For structures that could potentially be damaged by tornado (tornadoes with a strike probability during the preclosure period of 1.0×10^{-4} or greater), the probability of damage is estimated by calculating the conditional probability of damage from tornado impact and combining this with the tornado strike probability. The tornado wind speed utilized in the analysis is the highest wind speed expected for tornadoes with strike probabilities at the 1.0×10^{-4} screening probability, approximately 89 mph for the IHF, 94 mph for the CRCFs, WHF and RF, 106 mph for the railcar and truck buffer areas, and 114 mph for the aging pads. In all cases the probability is well below the 1.0×10^{-4} screening probability or frequency of 10^{-6}/yr over the preclosure period (Attachment A).

For straight winds, *Straight Wind Hazard Curve Analysis* (Ref. 2.2.22) estimated the maximum 3-second gust straight wind for the 1,000,000 yr recurrence interval as 117.5 mph, conservatively rounded up to 120 mph. According to Section 6.1.4 of the *Project Design Criteria Document* (Ref. 2.2.21), the maximum design tornado wind speed for ITS structures is 189 mph. As the design tornado wind speed exceeds the mean frequency 10^{-6}/yr straight wind speed, straight winds are not considered severe enough to affect the repository.

An assessment of the potential for structural damage from tornado missiles at the tornado wind speeds expected at the repository site is performed in Attachment A. Tornado wind speeds as high as 114 mph can potentially occur at the aging pads. The straight line wind is conservatively rounded up to 120 mph. As stated in Attachment A, Section A3.3, light-object missiles are first generated in tornadoes associated with minimum wind speeds of 111 mph while heavy missiles are only generated in tornadoes with minimum wind speeds of 166 mph. Items in the small missile category include roof gravel, tree branches and pieces of lumber and the heavy weight missile category includes items such as utility poles, large diameter pipes, and automobiles. At the low tornado wind speeds expected at the repository site, no heavy (typically damaging) tornado missiles would be generated. Construction materials can generate light-weight missiles; however, construction materials are expected to be at the site for limited periods of time once the facility is in operation. These short time periods preclude such material as potential missiles at probabilities above the screening probability. However, there still exists the potential to have small debris on-site during the non-construction period of the repository, although the population of construction-type debris, such as 2×4 lumber, would most certainty be lower during the non-construction phase. Therefore, an assessment was made on the effect of a 189 mph 2×4 lumber missile, which shows that the penetration depth is much less than the wall thicknesses of structures, aging overpacks, transportation casks and the TEV.

Should the external hazard be retained for further evaluation? **NO.**

6.5 EXTERNAL FLOODS

6.5.1 Definition

External floods are defined as the inundation of land surface by water caused by a storm or river diversion (Ref. 2.2.7, p. 187).

Considered within external floods are the following external events:

1. Dam failure – Defined as the failure of a man-made barrier that creates and restrains a body of water
2. High lake level – Where a lake is an inland body of standing water occupying a depression in the earth's surface
3. High tide – Where tides are the rhythmic alternate rise and fall of the ocean surface, resulting from the gravitational attraction of the moon and the sun (Ref. 2.2.7, p. 525) and high tide is the maximum level reached during the tidal cycle (Ref. 2.2.7, p. 235)
4. High river stage – Where a river is defined as a natural, permanent, or seasonal, freshwater surface stream of considerable volume and the high river stage is a flow condition characterized by a high river water surface above an established datum plane
5. Flooding effects from hurricane – Defined as the intense rain effects, tidal surge, and other water related effects from hurricanes
6. Rainstorms – Defined as a rainstorm of sufficient severity that it could potentially produce flooding or trigger other events such as debris flows
7. Seiche – Defined as an oscillation of a body of water in an enclosed or semi-enclosed basin, such as a lake, bay or harbor (Ref. 2.2.7, p. 455)
8. Tsunami – Defined as a great sea wave produced by a submarine earthquake or volcanic eruption (Ref. 2.2.7, p. 539)
9. Waves – Defined as an oscillatory movement in a body of water manifested by an alternate rise and fall of the water surface (Ref. 2.2.7, p. 560).

External flooding is considered an aspect of extreme weather and climate fluctuations, when weather or climatic conditions exceed the normal limits of variability. However, extreme weather and climate fluctuations are not considered explicitly within external flooding but are incorporated within the external flooding frequency data.

6.5.2 Evaluation

1. Can the external event occur at the repository? **YES**.

   In order to have flooding, there must be a source of water and topography that does not allow adequate drainage. For dam failure, a man-made barrier must exist at the repository that creates and restrains a body of water. There are no rivers or streams that flow past the site and as such, no upstream dams. Therefore, dam failure, river diversion, flooding effects due to ice cover, and high river stage are not considered.

   For flooding effects from a hurricane, high tide, seiche, tsunami, aquatic waves or storm surge, the repository must be close to the coastal areas of the United States or a body of water sufficiently large to support standing waves. The repository is located approximately 225 mi (360 km) to the northeast of Santa Monica Bay near Los Angeles, California (Ref. 2.2.48, Vol. 1, Part A, Chapter 1, p. 1-83), the nearest such body of water. The potential energy of a hurricane or tsunami would dissipate as it moves over the mountainous terrain between the Pacific Coast and the Yucca Mountain region, and no interconnecting rivers, estuaries, or large bodies of water can act as potential pathways. Therefore, these events are not considered further.

   External flooding by high lake level requires a lake at or near the repository. Permanent lakes or reservoirs in the vicinity of the repository (Table 5) are Crystal Reservoir, Lower Crystal Marsh, Horseshoe Reservoir, and Peterson Reservoir. These lakes are artificial impoundments that store the discharge of springs in the Ash Meadows National Wildlife Refuge (Ref. 2.2.71), which is located approximately 32 miles south-southeast of the repository (Ref. 2.2.75). The Yucca Mountain Repository is located at 36^{o} 51’ 9” North Latitude, and 116^{o} 25’ 41” West Longitude and at an elevation of 3,684 ft (Ref. 2.2.39). Because of the size, distance, and elevation of these lakes and reservoirs to the repository, external flooding due to dam failure or high lake level is screened from further consideration.

Table 5. Lakes and Reservoirs Near Yucca Mountain Repository

Name	North Latitude	West Longitude	Elevation (ft)	USGS ID
Crystal Reservoir (Crystal Springs Dam)	36.410 (36^{o} 24’ 36”)	116.326 (116^{o} 19’ 33”)	2182	863097
Horseshoe Reservoir (Horseshoe Marsh)	36.405 (36^{o} 24’ 18”)	116.342 (116^{o} 20’ 30”)	2159	863102
Lower Crystal Marsh (Lake No. 1)	36.483 (36^{o} 29’ 00”)	116.321 (116^{o} 19’ 15”)	2287	863494
Peterson Reservoir (Upper Crystal Marsh)	36.448 (36^{o} 26’ 53”)	116.356 (116^{o} 21’ 23”)	2172	863101

Source: Ash Meadows National Wildlife Refuge Map (Ref. 2.2.71) and Geographic Names Information System (GNIS) (Ref. 2.2.75).

For rainstorms, potential for severe rainstorms must exist at the repository. Locations on the Nevada Test Site average less than 254 mm (10 in) of precipitation per year (Ref. 2.2.45, p. xi; Ref. 2.2.49, p. 2-23, Table 12). Thunderstorms can produce locally heavy downpours (Ref. 2.2.45, p. 4-20) and a maximum daily precipitation value is projected to not exceed 125 mm (5 in) within 50 km (31 mi) of Yucca Mountain (Ref. 2.2.45, p. 4-21). For a 6-hour period, the probable maximum precipitation (PMP), developed for the flood hazard curve evaluation, is 11.91 in. (Ref. 2.2.23, Section 6.2.1). Because intense precipitation can occur at Yucca Mountain, external flooding due to rainstorms must be evaluated further.

Snow and ice effects are less severe and less frequent than rain effects.

The hydrological study of Ref. 2.2.23 concludes that the cause of a PMP and subsequent probable maximum flood (PMF) is associated with rainfall at the site. The site is designed with flood mitigation channels and levees to divert flood waters around the waste handling areas of the site. (Ref. 2.2.10, Section 6.2).

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **YES**.

   External flooding due to intense precipitation can be expected to occur more frequently than 10^{-6}/yr. See answer to question 1 above.

3. Can the external event severe enough to affect the repository and its operation occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO**.

   Flood Hazard Curve of the Surface Facility Area in the North Portal Pad and Vicinity (Ref. 2.2.23, Sections 3.2.5, 6.5, and 7) determined that the frequency of the PMF is less than 10^{-7} per year. The frequency of the PMF is based on the joint probability of the three major independent events contributing to the PMF. These major independent events are the PMP, the antecedent moisture condition, and the storm orientation and temporal distribution. The exceedance probability of the PMP is estimated to be less than 1.43×10^{-5}/yr. The antecedent moisture condition is assigned a probability of 7.69×10^{-4}/yr which represents a totally saturated watershed that is developed with an initial condition that a 25-year storm has hit the area prior to the PMP. The storm orientation and temporal distribution is assigned a probability of 0.1 which represents a storm perfectly aligned to the shape of the basin and a temporal distribution optimized with the center of the storm situated in the latter half of the storm. The product of the three parameters results in the joint probability of 1.1×10^{-9}, which is equivalent to a return period of approximately 90.9 million years. Converting this to a frequency, this equates to 1.1×10^{-9} per year, which is less than the screening criteria of 10^{-6} per year.

   The flood flow rate of the million year return period flood is approximately 40,000 cubic feet per second, which is less than the capacity of the flood mitigation features of the site over the same area of 55,000 cubic feet per second (Ref. 2.2.23, Section 7). Building roof drainage systems are of an adequate size to accommodate rainfall criteria (Ref. 2.2.21, Section 4.2.12.3.6). Because the frequency of the PMF is less than 10^{-6} per year; the PMF does not exceed the site's flood diversion capacity; and building roof drainage system is designed to accommodate rainfall criteria, further analysis is not needed.

Should the external hazard be retained for further evaluation? **NO**.

6.6 LIGHTNING

6.6.1 Definition

Lightning is defined as the discharge of atmospheric static electricity between a cloud and the ground.

6.6.2 Evaluation

1. Can the external event occur at the repository? **YES**.

   Lightning strikes are anticipated to occur in Southern Nevada (Ref. 2.2.45, Section 4.2.2.4).

   Lightning strikes could also ignite onsite fires. This aspect of lightning strikes will be covered by external fires (Section 6.12). Lightning strikes could also initiate a loss of power event. This aspect of lightning strikes will be covered by the loss of power event (Section 6.7).

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **YES**.

   Based on a 1991 to 1996 analysis of lightning strike data over a 3,600 km^2 (1,400 mi^2) region around Yucca Mountain, the flash density range is 0.06 to 0.4 strikes/km^2-yr (Ref. 2.2.45, Section 4.2.2.4). A National Oceanic and Atmospheric Administration (NOAA) study of lightning strike density for various areas on the Nevada Test Site (NTS) for the time period of 1993 through 2000 (Ref. 2.2.50, Abstract) showed an average of 0.35 flashes/km^2/yr. The data showed about 0.2 flashes/km^2/yr for the Yucca Mountain area (Ref. 2.2.50, Table 3). Using the Yucca Mountain specific results of 0.2 flashes/km^2/yr and the GROA protected area of 2.7 km^2 (Ref. 2.2.39), the annual lightning strike rate is 0.54 strikes/yr.

   The lightning strike frequency of 0.54 strikes/yr at the repository is greater than 10^{-6}/yr. Thus, this event shall be evaluated further.

3. Can the external event severe enough to affect the repository and its operation occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO**.

Attachment B evaluates the effects of lightning strikes on repository facilities and outside areas where waste maybe present. Protecting high-risk assets like those at the YMP from lightning damage is a very complex process. National codes are mostly focused on protecting common structures from a lightning strike. For example, as stated in Attachment B, the National Fire Protection Association (NFPA) 780 code was originally concerned with wooden structures, and the specified lightning rods, down conductors and earth ground system were developed to prevent fires. In the 1990's measurements in a modern steel reinforced concrete building struck by rocket-triggered lightning showed that the NFPA 780 lightning protection system carried 10% or less of the lightning current. The vast majority of the electrons were carried by the more numerous rebar in the concrete. The DOE and other governmental organizations that must provide lightning protection for high-risk assets and operations, such as with high-explosives, are adapting the most advanced approach around a "Faraday cage" (Attachment B). This type of safety system has been implemented at a number of DOE facilities, including Lawrence Livermore National Laboratory (LLNL), and the NFPA continues to update their specifications to incorporate some of the basic ideas.

Ref. 2.2.21, Section 4.3.1.5 states that a lightning protection system shall be installed for all buildings and outdoor elevated structures in accordance with NFPA 780-2004, *Standard for the Installation of Lightning Protection Systems*, and UL 96A, *Installation Requirements for Lightning Protection Systems,* and in accordance with Regulatory Guide 1.204, *Guidelines for Lightning Protection of Nuclear Power Plants*. As stated previously, the lightning current is carried by the rebar in the reinforced concrete and damage to such buildings is not a high risk area when compared to the outside areas where waste may be present. Thus, based on the application of this design criteria (Ref. 2.2.21, Section 4.3.1.5), and the fact that the facilities are constructed of reinforced concrete, the Receipt Facility, Initial Handling Facility, Wet Handling Facility, and the Canister Receipt and Closure Facilities are considered protected against the effects of lightning and the waste forms within the buildings are at a much lower risk than from lightning damage then when they are exposed outside.

The design criteria also apply to the truck and rail buffer areas as well as the aging facility (Ref. 2.2.21, Section 4.3.1.5). The protection system shall consist of air terminals bussed together and connected by a least two down conductors to the site grounding system (Ref. 2.2.21, Section 4.3.1.5) (Faraday cage). These areas, even with a lightning safety system, might allow a side-flash. In addition, casks and canisters may be vulnerable during movement between facilities and protected areas.

The effects of a lightning strike on a representative transportation cask, aging overpack, and a transport and emplacement vehicle (TEV) are evaluated in Attachment B. A simplified quantitative analysis is used to evaluate the affect of lightning directly striking the TEV, the transportation cask, or the canister within an aging overpack, focusing on a limiting-case temperature verses temperature criterion comparison. The analysis shows that if there is a lightning strike and the metal wall thickness of the component is greater than 12 mm (~0.3 in); the average interior wall temperature under the strike point will not exceed 570°C. Furthermore, the analysis shows that the pit depth from the strike is less than 3 mm. As the thicknesses of the representative TEV, transportation cask and canister within an aging overpack are much greater than the estimated penetration depth of a lightning strike on these containers, there will be no breach of containment, thus no radioactive release.

Although the lightning analysis was performed using the material properties of 304 stainless steel, the results and conclusions are applicable to all steel casks and canisters because the material properties used in the calculation (specific heat, resistivity) are similar and thus produce similar results.

Should the external event be retained for further evaluation? **NO**.

6.7 LOSS OF POWER EVENT

6.7.1 Definition

The loss of electrical power event includes those events either generated or controlled by entities outside the repository system or the loss of power within the repository caused by external events. Loss of electrical power may also be caused by internal events and is expected to be a normal occurrence as it is for all nuclear facilities. As such, the loss of electrical power is retained for further evaluation.

Should the external event be retained for further evaluation? **YES**.

6.8 LOSS OF COOLING CAPABILITY EVENT

6.8.1 Definition

The loss of cooling capability event includes those events caused by external events.

1. Dam failure – Defined as the failure of man-made barrier that creates and restrains a body of water. This section considers only the loss of cooling water to the repository from a dam failure. The flooding effect created by the dam failure is considered in Section 6.5, External Floods.

2. Drought – Considered an aspect of extreme weather and climate fluctuations

3. Extreme weather and climate fluctuations – Defined as weather or climatic conditions exceeding the normal limits of variability

4. Fungus, bacteria, and algae – Defined as the general class of microorganisms present in the environment whose growth could restrain and even block the flow of cooling water. Microbial induced and influenced corrosion effects are considered to be long-term effects that affects the repository during the post-closure period only.

5. High summer temperature – Considered an aspect of extreme weather and climate fluctuations

6. Ice cover – The blockage of a large stream of water by ice flows
7. Low lake level – Where a lake is defined as an inland body of standing water occupying a depression in the earth's surface
8. Low river level – Where a river is defined as a natural, permanent, or seasonal, freshwater surface of considerable volume and the low river stage is a flow condition characterized by a low river water surface below an established datum plane
9. Low winter temperature – Considered an aspect of extreme weather and climate fluctuations
10. River diversion – Defined as a diversion of a stream of water from its normal course due to natural causes (e.g., landslide, seismic) or man-made causes (dam diversion)
11. Sandstorm-dust storm –Defined as strong wind carrying sand through the air.

6.8.2 Evaluation

1. Can the external event occur at the repository? **YES.**

   The Yucca Mountain Repository draws its water supply from three underground wells which will supply an 850,000-gallon raw water storage tank (Ref. 2.2.12). The raw water system supplies water to the fire water system, deionized water system, potable water system and cooling tower water (Ref. 2.2.16, Section 9.10.2.2.1). Only the deionized water system is needed for makeup water for the fuel handling pool and for decontamination, if required (Ref. 2.2.16, Section 24.2.2.3.2). Raw water will be pumped from the raw water storage tank to the deionized water system where the raw water will be prepared for use within the surface facilities (Ref. 2.2.34). Water is also used for chilled water needs of the heating, ventilation and air-conditioning (HVAC) system. As the Yucca Mountain Repository draws its water supply from underground wells, dam failure, ice cover, low lake level, low river level and river diversion are screened from further consideration. With the entire system either underground, in pipes, or in covered tanks, its water supply is not subject to sandstorm or dust storm blockage.

   Climate fluctuations and drought impacts severe enough to disrupt groundwater sources are events that are slow in developing and will manifest themselves in sufficient time allow alternatives to a source of water.

   Extreme weather, specifically freezing temperatures, can occur at the repository and the storage tank could be susceptible to bacteria or algae growth.

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **YES.**

This question is answered in the affirmative to bypass the frequency of occurrence determination and proceed to the consequence discussion in question 3.

3. Can the external event severe enough to affect the repository and its operation occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO**.

   The primary requirements for cooling water at the Yucca Mountain site during the preclosure period is makeup water for the WHF pool and chilled water needs of the HVAC system.

   Pool Water Treatment and Cooling System states that the WHF pool has a water depth of 48 feet at normal operational capacity (Ref. 2.2.41, Section 6.1.1). To reach the minimum pool water shielding level of 35 ft, the pool would need to lose 13 ft of pool water. Assuming the maximum heat load, the maximum evaporation rate, and a pool temperature of approximately 102°F, it would take approximately 180 days without makeup water to the pool for the pool water level to reach the minimum shielding level of 35 ft (Ref. 2.2.41, Section 6.4.1.4).

   Because of the amount of time available for operations personnel to respond to loss of water from the WHF pool to the point where radiation protection shielding could be compromised, the loss of cooling water event is not considered as an initiating event due to the slow development of the event providing sufficient time for an adequate response (Section 4.3).

   Portions of the HVAC systems use chilled water and a loss of the water supply would reduce the cooling capability of the system. The surface nuclear confinement HVAC system, classified as ITS, are those systems required to mitigate the consequences of a radioactive release and systems that provide cooling to ITS electrical and controls equipment. The remainder of the surface nuclear confinement HVAC systems is non-ITS (Ref. 2.2.16, Section 19.1.2), that is, the cooling portion of the nuclear confinement HVAC system is non-ITS. The functionality of the ITS confinement HVAC system is not compromised by a loss of water supply, only the cooling capability of the system and the cooling function is not ITS. Therefore, room heat-up from a loss of cooling is not considered a hazard. This is supported by *Thermal Evaluation of the CRCF-1 Lower Transfer Room Cells* (Ref. 2.2.38, Section 7) and *WHF and RF Thermal Evaluation* (Ref. 2.2.42, Section 7), which conclude that under off-normal condition with no HVAC flow for 30 days, waste forms do not exceed their temperature limits.

   The ITS HVAC servicing electrical and battery rooms for the WHF and RF are chilled with refrigerant, thus are not affected by an external loss of cooling event (Ref. 2.2.25 and Ref. 2.2.26). Although not specified, it is reasonable to expect the same design for the CRCF electrical and battery rooms (Ref. 2.2.27).

Should the external event be retained for further evaluation? **NO**.

6.9 AIRCRAFT CRASH

6.9.1 Definition

This event includes the accidental impact of an aircraft or parts, as well as ordnance from military aircraft, on the repository.

6.9.2 Evaluation

1. Can the external event occur at the repository? **YES.**

   The repository is near the flight path of military aircraft that fly from Nellis Air Force Base (AFB) to their practice area. This event is identified in *Identification of Aircraft Hazards* (Ref. 2.2.35).

2. Can the external event occur at the repository with a frequency greater than $10^{-}6$/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO.**

   Frequency Analysis of Aircraft Hazards for License Application (Ref. 2.2.36, Section 7) estimated an aircraft crash frequency occurrence of approximately 5.9×10^{-7}/yr.

Should the external event be retained for further evaluation? **NO.**

6.10 NEARBY INDUSTRIAL/MILITARY FACILITY ACCIDENTS

6.10.1 Definition

This event includes an accident resulting from industrial, military or transportation activities unrelated to the repository. In addition, ANSI/ANS-2.12-1978 (Ref. 2.2.3, Section 2) states:

> A fixed industrial or military facility presents several types of potential hazards to a nearby nuclear power plant including fire (and resulting smoke and gases from combustion), explosion (with attendant pressure wave, ground shock, and missiles), other missiles, and release of toxic or flammable gases.

Also included within nearby industrial/military facility accidents are pipeline accidents, which are defined by ANSI/ANS-2.12-1978 (Ref. 2.2.3, Section 2) as a rupture of a pipeline carrying a gas or liquid under pressure, which can explode or ignite or create a toxic gas cloud or environment that incapacitates personnel or degrades equipment operation.

Fog is not explicitly included as an aspect of industrial/military facility accidents but its effect is incorporated within the accident data.

6.10.2 Evaluation

1. Can the external event occur at the repository? **YES.**

The repository borders the Nevada Test Site (NTS) and the Nevada Test and Training Range. Potential effects that could be credible for the 100-year preclosure period include ground motion caused by nuclear testing (which is currently banned), facility accidents, missile firings, and objects dropped from aircraft (Ref. 2.2.73, Sections 3.3.1.4.2 and 3.3.1.4.5.4). The potential also exists for nearby military exercises in the area of electronic warfare and jamming to impact sensitive devices, as well as interfere with the proper operation of devices. Electronic jamming, missile firings and objects dropped from aircraft are addressed in Ref. 2.2.35 and Ref. 2.2.36 and are not addressed further.

U.S. Highway 95 is the only primary transportation route near the Yucca Mountain site and is the major route between Las Vegas and Reno, Nevada. U.S. Highway 95 lies in a northwest/southeast orientation and passes approximately 13 mi to the southwest of Yucca Mountain (Ref. 2.2.47, Section 2.4 and Ref. 2.2.58). Hazardous materials are shipped on U.S. Highway 95. There are also roads on the NTS, the closest primary paved road to the repository being the Lathrop Wells Road located approximately 7 mi from the Yucca Mountain Repository site at its closest point (Ref. 2.2.37, Section 6.3.5.1). Hazardous materials are shipped on the Lathrop Wells Road. There are no shipping routes near the repository.

There are no liquid petroleum or natural gas pipelines within the land withdrawal area for the repository and no construction of a pipeline would be permitted within the land withdrawal area of the repository (Ref. 2.2.37, Section 6.3.3.1). Pipeline accidents are screened from further consideration.

Ground motion caused by nuclear testing (currently banned) is considered to be bounded by seismic activity (Section 6.1).

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO.**

   The effects of explosions from military/industrial activity accidents and from transportation accidents could affect the repository if it occurs close enough to the repository.

   A methodology given in NRC Regulatory Guide 1.91 (Ref. 2.2.59, Section B), *Evaluations of Explosions Postulated to Occur on Transportation Routes Near Nuclear Power Plants*, determines the safe distance from a postulated explosion. This safe distance is based on a level of peak positive incident overpressure below which no significant damage would be expected. It is the judgment of the NRC staff (as described in Ref. 2.2.59, Section B) that, for the SSCs of concern, a pressure level of 1 psi is appropriate. Based on experimental data on hemispherical charges of TNT, a safe distance can conservatively be defined by the following relationship (Ref. 2.2.59, Section B) as:

$$R_{safe} > k \times W^{1/3} \qquad \text{(Eq. 1)}$$

where

R_{safe} = safe distance from explosion in feet; based on maximum "no damage" overpressure of 1.0 psi

k = constant; equal to 45 when R_{safe} is in feet and W is in lb TNT equivalent

W = lb TNT equivalent.

Ref. 2.2.61 (Section 2.2.1 and 2.2.2) gives a 5-mile criterion for evaluating hazards. Rearranging Eq. 1 to solve for W, and setting R_{safe} equal to the 5-mile criterion, 7-mile distance to the nearest paved road on the NTS and the 13-mile distance to the nearest public highway yields:

$$W = (R_{safe}/k)^3 \qquad \text{(Eq. 2)}$$

Table 6. Mass of TNT Required to Exceed Safe Distance from an Explosion

Distance from Explosion (R_{safe})	**Pounds Mass of TNT (W)**	**Tons of TNT**
5 miles	2.0×10^8	100,000
7 miles	5.5×10^8	275,000
13 miles	3.5×10^9	1,770,000

Source: Equation 2.

An explosion at 7 miles from the repository would have to involve more than 275,000 tons of TNT to generate a damaging overpressure of more than 1 psi. An explosion at 13 miles from the repository would have to involve more than 1,770,000 tons of TNT to generate a damaging overpressure of more than 1 psi. Both of these masses of calculated TNT are far beyond military/industrial activity or transportation shipments as described below.

Industrial/Military Activity-Initiated Accident Screening Analysis (Ref. 2.2.37) identifies and evaluates the nearby industrial and military operations, and transportation routes on the NTS and Nellis Air Force Base. This study concludes that there were no events and/or hazards that impact the repository during the preclosure period. This conclusion is based on the remote location of the repository site (over 5 miles to the NTS facilities; over 13 miles from any nearby industrial facilities; over 25 miles from Nellis Air Force Base activities) and the absence of large explosive resources and/or sources of toxic or hazardous chemicals. On this basis, this external event cannot affect the repository or its operation during the preclosure period and is screened from further evaluation.

The only non-repository facilities planned to be located within the 5-mile radius during the repository preclosure period are the Rail Equipment Maintenance Yard (REMY) also known as the End of Line (EOL) Facility, and the Cask Maintenance Facility (CMF) (Ref. 2.2.37, Section 6.2.1). The REMY will include a rail yard, as well as a locomotive diesel fuel storage tank will have a capacity of 50,000 gallons, approximately 2 miles from the GROA (Ref. 2.2.37, Section 6.4). An evaluation of the potential for an impact to the repository associated with an explosion involving the 50,000 gallon storage tank for diesel fuel can be found in Ref. 2.2.37, Appendix A. The safe distance from such an explosion, based on a maximum "no damage" overpressure of 1 psi, was conservatively calculated to be less than 600 feet. Based on this evaluation, it is concluded that there are no hazards associated with this tank that could impact the repository (Ref. 2.2.37, Section 6.4). The REMY is the closest approach of any offsite transportation activity and any transport vehicle would have less storage capacity than the diesel fuel storage tank.

Should the external event be retained for further evaluation? **NO.**

6.11 ONSITE HAZARDOUS MATERIALS RELEASE

6.11.1 Definition

The release of hazardous or toxic materials from onsite sources could result in making the operations room or waste handling facilities uninhabitable, forcing abandonment (Ref. 2.2.64).

Table 1 of NRC Regulatory Guide 1.78, Rev. 1 *Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Chemical Release* (Ref. 2.2.63) defines a list of hazardous chemicals that should be considered in the evaluation of control room habitability. This table is used as the definition of onsite hazardous materials that are evaluated in this screening analysis.

6.11.2 Evaluation

1. Can the external event occur at the repository? **YES.**

   In order for a release of hazardous or toxic materials to occur, hazardous materials would have to be stored onsite and used in sufficient quantities (and exist in the proper physical form) such that their accidental release could disrupt operations at the repository and potentially lead to the subsequent release of radioactive materials.

   The hazardous material listed in Table 1 of Ref. 2.2.63 that will be stored onsite includes chlorine, used for the water treatment system, and helium and argon service gases. The onsite water treatment system will use an ACCU-TAB® tablet chlorinator system, which is designed to utilize solid calcium hypochlorite tablets (Ref. 2.2.65). Due to the early nature of the design of the water treatment system, the only available reference (Ref. 2.2.65) for this information is included in Attachment C and is appropriate for use.

   Hazardous chemicals, other that those listed in Ref. 2.2.63, Table 1, were also considered. The only other hazardous chemical identified that will be stored onsite in sufficient quantities to potentially disrupt repository operations is diesel fuel and is included for evaluation (Ref. 2.2.16, Section 24.2.1.7).

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO.**

   The movement of radioactive waste within or among the nuclear facilities and the subsurface requires the active permission or action from operators. Helium and argon gases are supplied to the surface facilities from storage tanks or mobile tube trailers located outside buildings (Ref. 2.2.16, Section 24.2.1.6). Any gases released from these vessels would dissipate in the atmosphere. Any release of diesel fuel will be localized and will have no affect on operations at other locations. Solid chlorine cannot become airborne and pose a hazard to personnel.

Should the external event be retained for further evaluation? **NO**.

6.12 EXTERNAL FIRES

6.12.1 Definition

An external fire is the combustion of vegetation external to the repository that propagates to combustion of materials within the repository.

6.12.2 Evaluation

1. Can the external event occur at the repository? **YES.**

   Combustible grasses, low shrubs and detritus (i.e., twigs and dead plants) can be found at the Yucca Mountain Repository site in sufficient quantities to sustain a wildfire in close proximity to the site (Ref. 2.2.11).

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **YES.**

   Characterizing Wildfire Regimes in the United States (Ref. 2.2.56, Table 1) tabulates the number of fires occurring in U.S. Forest Service (USFS) lands from 1970-2000 by Bailey ecoregion division. The Yucca Mountain site is located in temperate desert (Bailey ecoregion division code 340) or in tropical/subtropical desert (Bailey ecoregion division code 320) (Ref. 2.2.56, Figure 1A). For temperate deserts, 2,391 fires occurred on 39,210 km^2 of USFS land in the 30-year period (Ref. 2.2.56, Table 1). With a GROA protected area of 2.7 km^2 (Ref. 2.2.39), an annual fire density is calculated as:

$$(2{,}391 \text{ fires} \times 2.7 \text{ km}^2)/(39{,}210 \text{ km}^2 \times 30 \text{ years}) = 5.5 \times 10^{-3} \text{ fires/year.} \qquad \text{(Eq. 3)}$$

   The annual fire density is greater than 10^{-6}/yr. The tabulated number of fires occurring in USFS lands from 1970-2000 incorporate fires due to all causes which includes lightning.

3. Can the external event severe enough to affect the repository and its operation occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO.**

   Ref. 2.2.11 (Section 7) determined the minimum stand-off separation distance for vegetation of 10 m (32.8 ft) for the protection of combustible structures from the effects of a wildfire and conservatively applied this stand-off separation to non-combustible structures. In addition, it has been shown that a waste package containing a TAD canister or 5 DOE SNF/HLW canisters can withstand being totally immersed in a flame of temperature equal to at least 800 °C, for a period of 30 minutes without breach or exceeding maximum allowable waste form temperatures (Ref. 2.2.24, Section 7). A procedural safety control to maintain the distance for cleared vegetation, and the analysis that shows no breach following a 30-minute 800 C fire provides reasonable assurance that such a fire will not affect waste containers.

Should the external event be retained for further evaluation? **NO.**

6.13 EXTRATERRESTRIAL ACTIVITY

6.13.1 Definition

Extraterrestrial activity is defined as an external event involving objects outside the earth's atmosphere, entering and surviving the entry through the earth's atmosphere, and striking the surface of the earth. Extraterrestrial activity includes: meteorites, asteroids, comets, satellites, and any other space debris.

Meteorites

A meteorite is a mass of stone or metal that enters the earth's atmosphere (Ref. 2.2.70, p. 68). Several definitions and classification schemes have been proposed for differentiate meteorites from asteroids. The Near-Earth Object (NEO) study team defined meteoroids as objects less than 50 m (164 ft) and asteroids as objects greater than 50 m (164 ft) (Ref. 2.2.57, Section 4.1).

Micrometeoroids are very small particles in interplanetary space. No exact definition for micrometeoroids has been found although they are generally referred to as particles weighing less than a gram or with a diameter of less than two millimeters. Micrometeorites (micrometeoroids that enter the earth's atmosphere) that are near the upper limit for size or mass, melt or vaporize to destruction in their journey through the earth's atmosphere. Remnants of these micrometeorites may descend to the surface as dust particles. Micrometeorites may pose a hazard to space vehicles and satellites but because of their small size, they are not considered a hazard to the Yucca Mountain Repository and will not be evaluated further in this analysis.

Meteorites in this evaluation are considered as interplanetary objects larger than micrometeoroids but less than 50 m in diameter (considering meteorites as spheroid objects). Meteorites are categorized according to their composition with iron meteorites constituting about 5% of the total meteorites found (Ref. 2.2.69, p. 480), hard stone meteorites constituting about 4-18% depending on their initial mass (Ref. 2.2.44, Figure 2) and the remainder being soft stone or ice meteorites. Iron meteorites are the densest (approximately 8000 kg/m^3) (Ref. 2.2.51, Figure

1) compared to stone meteorites (3700 kg/m^3 for hard dense stone) (Ref. 2.2.44, Table 1) and 1100 kg/m^3 for soft stone or ice (Ref. 2.2.44, Table 3). Thus for meteorites of the same mass, iron meteorites would be smaller than stone meteorites or soft stone/ice meteorites. The earth's atmosphere is an effective shield against most meteorites. The smallest stone and iron meteorites, that is, the meteorites slightly larger than micrometeoroids, tend to burn up in their descent through the atmosphere. Larger stone meteorites begin to breakup in the upper reaches of the atmosphere then burst apart as the outer portion of the meteorites undergoes compression heating due to atmospheric friction heating. As the stone meteorites become larger, their atmospheric breakup and air burst occurs at lower and lower altitudes until the stone meteorites impact the ground in a broken condition. Larger iron meteorites tend to impact the ground intact due to their greater density and smaller volume for the same given mass. As iron meteorites become larger, they also undergo breakup then burst apart as the outer portion also undergoes compression heating due to atmospheric friction heating. The breakup and air burst for iron meteorites begin at lower altitudes and the fragments have higher velocities when compared with stone meteorites of similar mass. Again, as the iron meteorites become larger, the breakup and air burst begins at lower altitude. Thus larger meteorites have a higher tendency to hit the ground either broken or unbroken. It should be noted that even if a meteorites, stone or iron, breaks up or burst apart, the fragments may have considerable velocity and may be capable of causing significant damage (Ref. 2.2.43; Ref. 2.2.54). Soft stone and ice meteorites suffer to a greater extent than iron and hard stone meteorites and burn up completely or breakup at even higher altitudes than iron and hard stone meteorites (Ref. 2.2.44, pp. 967-970).

Asteroids

Asteroids are generally rocky or metallic objects without atmospheres that appear as a star-like point of light.

An asteroid could enter the earth's atmosphere at approximately 17 km/s (Ref. 2.2.54). Using the definition of the NEO study for asteroids as objects greater than 50 m (164 ft) in diameter, a stone asteroid of density 3700 kg/m^3 (Ref. 2.2.44, Table 1) can have a mass of about 240 metric tons and a rock asteroid of density 8000 kg/m^3 (Ref. 2.2.51, Figure 1), can have a mass of more than 500 metric tons. Iron or stone asteroids of this size can be expected to impact the earth's surface in a broken condition, having broken up at low altitudes and with fragments traveling at high velocities. Asteroids of larger size can be expected to cause proportionately greater damage. While asteroids have considerable potential for causing widespread damage should they impact the earth's surface, the frequency of such an event is relatively small with return periods for the smallest asteroids in the hundreds to thousands of years (Ref. 2.2.54). Asteroids will not be evaluated further in this analysis due to the relative infrequency of their impact with the earth and an even lower frequency of impact on the GROA. Furthermore, asteroid impact is a global threat, not a repository specific threat.

Comets

Comets are composed in part of volatiles such as water ice that vaporize when heated. Comets orbit around the sun and rarely intersect Earth's orbit. Comets that are far from the sun or those that have lost most of their volatiles often look like asteroids. A volatile-rich object will develop an atmosphere only when heated sufficiently by a relatively close approach to the sun (Ref. 2.2.57, Section 4.1).

If a comet were to enter the earth's atmosphere, its velocity would be approximately 51 km/s (Ref. 2.2.54). Their behavior in their journey through the earth's atmosphere will approximate that of asteroids although comets will tend to breakup at higher altitudes due to their lower density (1000 kg/m^3 for ice). Again, as for asteroids, the frequency of comets impacting the GROA is quite small, is not a repository specific threat, and will not be evaluated further in this analysis.

Near-Earth Objects

NEOs are asteroids and comets in orbits that allow them to enter earth's neighborhood, defined by astronomers as having a perihelion (closest approach to the sun) of less than 1.3 AU (Astronomical Units or approximately the mean distance between the sun and earth). Extinct comets may make up 5 to 15 percent of the NEO population (Ref. 2.2.57, Section 4.1).

Potentially hazardous objects (PHOs) are asteroids and comets that have a potential to someday impact the earth. A PHO is an object in our solar system that passes within 0.05 AU (about 7.5 million km or 4.7 million mi) of earth's orbit and is large enough to pass through earth's atmosphere (i.e., about 50 meters and larger (in diameter). Approximately 21 percent of the NEOs of any given size class are expected to be potentially hazardous (Ref. 2.2.57, Section 4.1).

The threat of NEOs is a subject area for continued international attention. Studies have been conducted on the threat posed by NEOs and to formulate mitigation strategies and techniques to reduce the threat of NEOs. Such a threat is a global threat and is not a repository specific threat.

Space Debris from Man-made Objects

Space debris is defined as man-made objects such as satellites, launch vehicles, and parts thereof that are in orbit around earth and have the potential for reentry.

6.13.2 Evaluation

1. Can the external event occur at the repository? **YES.**

   Meteorites fall randomly and uniformly throughout the surface of the earth (Ref. 2.2.70, p. 69).

   The impact of meteorite on the earth's surface has the potential to cause damage in the immediate area surrounding the impact point.

   Space debris fall to earth at a rate of roughly 409 objects per year (Ref 2.2.74, p. 1). Many of these objects burn up in the atmosphere; however, some may have the potential to reach the earth's surface and cause damage in the immediate area surrounding the impact point.

2. Can the external event occur at the repository with a frequency greater than 10^{-6}/yr, that is, have a 1 in 10,000 chance of occurring in the 100-year preclosure period? **NO.**

   Meteorites: The number of meteorites entering the earth's atmosphere annually as a function of mass at initial atmospheric entry is found in Table 1 of Ref. 2.2.8. Multiplying the total number of meteorites striking the Earth's atmosphere of a particular mass by the fraction of iron meteorites (5%, Ref. 2.2.69, p. 480), the number of iron meteorites striking the earth's atmosphere as a function of mass is obtained. Dividing the number of iron meteorites striking the earth's atmosphere by the earth's surface area yields the earth atmospheric iron meteorite flux. The mean radius of the earth is 6,371 km and the mean surface area of 5.1×10^{8} km^{2} (Ref. 2.2.72, p. F-193). Multiplying the earth atmospheric meteorite flux by the GROA protected area of 2.7 km^{2} (Ref. 2.2.39) yields the iron meteorite impact frequency to the GROA. A similar calculation is done for hard stone meteorites except the fraction of hard stone meteorites of 4-18% is taken from Ref. 2.2.44, Figure 2. For soft stone and ice meteorites, their fraction is obtained by subtracting the iron and hard stone meteorite fraction from one. The results of this calculation are shown Table 7.

Table 7. Earth Atmospheric Meteorite Flux and Impact Frequency

Iron Meteorites						
Mass (kg)	**No. of Earth Atmospheric Events/yr N_{total} (Ref. 2.2.8, Table 1)**	**Iron Meteorites Fraction (Ref. 2.2.69, p. 408)**	**No. of Earth Atmospheric Iron Meteorite Events/yr N_{iron} (Calculated)**	**Earth Atmospheric Iron Meteorite Flux (calculated) (events/ km^{2}-yr)**	**GROA Protected Area (Ref. 2.2.39) (km^{2})**	**Iron Meteorite Impact Frequency (calculated) (/yr)**
0.1	111,800	5%	5,590	1.09×10^{-5}	2.7	2.95×10^{-5}
1	37,020	5%	1,851	3.62×10^{-6}	2.7	9.78×10^{-6}
10	6,497	5%	325	6.35×10^{-7}	2.7	1.72×10^{-6}
100	770	5%	39	7.53×10^{-8}	2.7	2.03×10^{-7}
1,000	91	5%	4.55	8.90×10^{-9}	2.7	2.40×10^{-8}
10,000	11	5%	0.55	1.08×10^{-9}	2.7	2.90×10^{-9}
100,000	1.3	5%	0.065	1.27×10^{-10}	2.7	3.43×10^{-10}
1,000,000	0.152	5%	0.0076	1.49×10^{-11}	2.7	4.01×10^{-11}

Table 7 Earth Atmospheric Meteorite Flux and Impact Frequency (Continued)

Hard Stone Meteorites						
Mass m (kg)	**No. of Earth Atmospheric Events/yr N_{total} (Ref. 2.2.8, Table 1)**	**Hard Stone Meteorites Fraction (Ref. 2.2.44, Figure 2)**	**No. of Earth Atmospheric Hard Stone Meteorite Events/yr N_{iron} (Calculated)**	**Earth Atmospheric Hard Stone Meteorite Flux (calculated) (events/ km^2-yr)**	**GROA Protected Area (Ref. 2.2.39) (km^2)**	**Hard Stone Meteorite Impact Frequency (calculated) (/yr)**
0.1	111,800	16%	17,888	3.50×10^{-5}	2.7	9.45×10^{-5}
1	37,020	16%	5,923	1.16×10^{-5}	2.7	3.13×10^{-5}
10	6,497	18%	1,169	2.29×10^{-6}	2.7	6.18×10^{-6}
100	770	14%	108	2.11×10^{-7}	2.7	5.69×10^{-7}
1,000	91	10%	9.1	1.78×10^{-8}	2.7	4.81×10^{-8}
10,000	11	8%	0.88	1.72×10^{-9}	2.7	4.65×10^{-9}
100,000	1.3	6%	0.978	1.53×10^{-10}	2.7	4.12×10^{-10}
1,000,000	0.152	4%	0.00608	1.19×10^{-11}	2.7	3.21×10^{-11}
Soft Stone, Ice Meteorites						
Mass m (kg)	**No. of Earth Atmospheric Events/yr N_{total} (Ref. 2.2.8, Table 1)**	**Soft Stone, Ice Meteorites Fraction (1-iron-hard stone calc.)**	**No. of Earth Atmospheric Ice Meteorite Events/yr N_{iron} (Calculated)**	**Earth Atmospheric ice Meteorite Flux (calculated) (events/ km^2-yr)**	**GROA Protected Area (Ref. 2.2.39) (km^2)**	**Ice Meteorite Impact Frequency (calculated) (/yr)**
0.1	111,800	79%	88,322	1.73×10^{-4}	2.7	4.66×10^{-4}
1	37,020	79%	29,246	5.72×10^{-5}	2.7	1.54×10^{-4}
10	6,497	77%	5,003	9.79×10^{-6}	2.7	2.64×10^{-5}
100	770	81%	624	1.22×10^{-6}	2.7	3.29×10^{-6}
1,000	91	85%	77	1.57×10^{-7}	2.7	4.09×10^{-7}
10,000	11	87%	9.57	1.87×10^{-8}	2.7	5.05×10^{-8}
100,000	1.3	89%	1.157	2.26×10^{-9}	2.7	6.11×10^{-9}
1,000,000	0.152	91%	0.13832	2.71×10^{-10}	2.7	7.31×10^{-10}

Sources: See heading row.

The process that a meteorite undergoes in its journey through the earth's atmosphere is a very complex process. Ablative friction heating of the meteorite results in the outside heating up and compressing the inner parts of the meteorite. For meteorites larger than a few kilograms, the breaking up and fragmenting of the meteorite typically occurs (Ref. 2.2.8, p. 609). Discussion in "Meteorites and their Properties" (Ref. 2.2.54) and Ref. 2.2.70 indicates that iron and hard stone meteorites smaller than about 10 kg in mass tend to burn up (ablative melting) in their journey through the earth's atmosphere and do not impact the ground. Soft stone and ice meteorites of any mass tend to also burn up or break up at high altitudes. Iron meteorites (8000 kg/m^3) greater than about 10 kg to greater than 100,000 kg mass tend to impact the earth's surface intact but at terminal velocities of approximately several hundred mph for the smallest bodies, to near entry velocities of approximately several km/sec for the largest bodies. Iron meteorites larger than 100,000 kg mass tend to breakup or burst apart close to the earth's surface with the fragments impacting the ground at near atmospheric entry velocities in the range of km/sec. Hard stone meteorites (3700 kg/m^3) greater than 10 kg to greater than 1,000,000 kg mass tend to breakup or burst apart in the earth's atmosphere with the smallest objects breaking up at high altitudes and the larger objects breaking up closer to the surface. Fragments formed by the breakup of hard stone meteorites will impact the ground at near atmospheric entry velocities of km/sec.

Because the iron and hard stone meteorites between 10 and 1000 kg mass either impact the ground at terminal velocity of several hundred mph or breakup in the atmospheric with the fragments impacting the ground at atmospheric entry velocities of several km/sec, the frequency of these meteorite masses interacting with the Yucca Mountain Repository needs to be evaluated further. Meteorites greater than 1000 kg mass of all compositions (iron, hard stone, soft stone, ice) will not be evaluated further based on their low frequency as shown in Table 7.

The number of meteorites striking the Earth annually as a function of mass at initial atmospheric entry is found in Table 1 of Ref. 2.2.8. Performing the same numerical calculation as Table 7 above, using 5% for the fraction of iron meteorites (Ref. 2.2.69, p. 480), 4-18% for the fraction of hard stone meteorites (Ref. 2.2.44, Figure 2), and 2.7 km^2 for the GROA protected area (Ref. 2.2.39), the earth ground impact meteorite flux and impact frequency are determined in Table 8. As stated earlier, soft stone and ice meteorites of any mass tend to burn up or break up at high altitudes, thus they are not evaluated further.

Table 8. Earth Ground Impact Meteorite Flux and Impact Frequency

<table>
<tr><th colspan="7">Iron Meteorites</th></tr>
<tr><th>Mass
m (kg)</th><th>No. of Earth Atmospheric Events/yr
N_{total}
(Ref. 2.2.8, Table 1)</th><th>Iron Meteorites Fraction (Ref. 2.2.69, p. 408)</th><th>No. of Earth Atmospheric Iron Meteorite Events/yr
N_{iron}
(Calculated)</th><th>Earth Atmospheric Iron Meteorite
Flux (calculated) (events/ km^2-yr)</th><th>GROA Protected Area (Ref. 2.2.39) (km^2)</th><th>Iron Meteorite Impact Frequency (calculated) (/yr)</th></tr>
<tr><td>10</td><td>674</td><td>5%</td><td>34</td><td>6.59×10^{-8}</td><td>2.7</td><td>1.78×10^{-7}</td></tr>
<tr><td>100</td><td>40</td><td>5%</td><td>2</td><td>3.91×10^{-9}</td><td>2.7</td><td>1.06×10^{-8}</td></tr>
<tr><td>1,000</td><td>2.2</td><td>5%</td><td>0.11</td><td>2.15×10^{-10}</td><td>2.7</td><td>5.81×10^{-10}</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="7">Hard Stone Meteorites</th></tr>
<tr><th>Mass
m (kg)</th><th>No. of Earth Atmospheric Events/yr
N_{total}
(Ref. 2.2.8, Table 1)</th><th>Hard Stone Meteorites Fraction (Ref. 2.2.44, Figure 2)</th><th>No. of Earth Atmospheric Hard Stone Meteorite Events/yr
N_{iron}
(Calculated)</th><th>Earth Atmospheric Hard Stone Meteorite
Flux (calculated)
(events/ km^2-yr)</th><th>GROA Protected Area (Ref. 2.2.39) (km^2)</th><th>Hard Stone Meteorite Impact Frequency (calculated) (/yr)</th></tr>
<tr><td>10</td><td>674</td><td>18%</td><td>121</td><td>2.37×10^{-7}</td><td>2.7</td><td>6.41×10^{-7}</td></tr>
<tr><td>100</td><td>40</td><td>14%</td><td>6</td><td>1.10×10^{-8}</td><td>2.7</td><td>2.96×10^{-8}</td></tr>
<tr><td>1,000</td><td>2.2</td><td>10%</td><td>0.22</td><td>4.30×10^{-10}</td><td>2.7</td><td>1.16×10^{-9}</td></tr>
</table>

Sources: See heading row.

Iron meteorites (8000 kg/m^3) greater than 10 kg to 1000 kg have an impact frequency that ranges from 1.78×10^{-7} to 5.81×10^{-10}/yr from Table 8. Based on impact frequency, iron meteorites will not be evaluated further because smaller meteorites tend to burn up before hitting the ground. Hard stone meteorites (3700 kg/m^3) greater than 10 kg to 1000 kg will tend to breakup or burst apart high in the earth's atmosphere with the fragments impacting the surface with near atmospheric entry velocities of km/sec based on the discussion in Ref. 2.2.54 and Ref. 2.2.70. Hard stone meteorites greater than 10 kg to 1000 kg have an impact frequency that ranges from 6.41×10^{-7} to 1.16×10^{-9}/yr from Table 8, which is less than 10^{-6}/yr and thus stone meteorites will not be evaluated further.

Satellites: According to Ref. 2.2.74 (p. 1), roughly 17,000 tracked objects have re-entered the earth atmosphere between 1957 and 1999, where most of these objects burnt up without posing a risk on the ground. Ref. 2.2.74 (p. 1) goes on to state that about one object re-enters the earth's atmosphere per day and 1 to 2 objects of 1 m^2 radar cross section re-enter per week, which is approximately equivalent to 17,000 objects over a 42-year period. Those objects greater than 1 m^2 radar cross section are monitored more closely until their atmospheric entry due to the higher potential of reaching the earth's surface. Thus, using two objects per week, it is estimated that 104 objects per year enter the earth's atmosphere without burning up before reaching the earth's surface. For conservatism, this value is doubled and rounded up to 210 objects/yr. Note that untracked objects are too small to be of consequence.

The mean radius of the earth is 6,371 km and the mean surface area of 5.1×10^8 km^2 (1.97×10^8 mi^2) (Ref. 2.2.72, p. F-193). For conservatism, only half of the earth's surface area is used.

Table 9 determines the area of the impact of concern as 3,369,200 ft^2 (0.12 mi^2), assuming that the debris impacts at a 90 degree angle regardless of the original reentry angle (Assumption 3.2.1).

Area of concern/Area of earth used = 0.12 mi^2/($0.5 \times 1.97 \times 10^8$ mi^2) = 1.2×10^{-9}.

The period of operations that is of concern for space debris impact is during the surface operations, which is 50 years (Section 1). Probability of a piece of debris impacting an area of concern over the emplacement period then equals:

(210 object re-entry/year) × (50 years) × $1.2 \times 10^{-9} = 1.3 \times 10^{-5}$ impacts over the preclosure period, which is sufficient to screen out this event on the basis of probability.

Back calculating the smallest percentage of the earth's surface area required that still results in a probability of impacts at less than 1×10^{-4} over the preclosure period results in 6.4%. Thus, even if all of the satellite debris falls within 6.4% of the earth's surface area, including the area of the GROA, the space debris impacts would screen out on the basis of probability.

Table 9. Surface Area of Facilities

Building/Area	Length (ft)	Width (ft)	Total (ft^2)	References
Aging Pad 17P	1030 (=1180-75-75)	1155 (1302 rounded up to 1305; =1305-75-75)	1,189,650	Ref. 2.2.29
Aging Pad 17R	1525 (1661 rounded up to 1675; -1675-75-75)	750 (900-75-75)	1,143,750	Ref. 2.2.30
Wet Handling Facility	400 (385 rounded up to 400)	400 (349’ 6” + 45’ 8” rounded up to 400)	160,000	Ref. 2.2.31
Initial Handling Facility	400 (386’ 2” rounded up to 400)	265 (222’ 6” + 40’ rounded up to 265)	106,000	Ref. 2.2.32
Canister Receipt and Closure Facility 1	420 (419 rounded up to 420)	400 (392 rounded up to 400)	168,000	Ref. 2.2.15
Canister Receipt and Closure Facility 2	420	400	168,000	(Assumption 3.2.2)
Canister Receipt and Closure Facility 3	420	400	168,000	(Assumption 3.2.2)
Receipt Facility	315	320 (318 rounded up to 320)	100,800	Ref. 2.2.33
Railcar staging area (railcar buffer area 33A)	800	150	120,000	Ref. 2.2.40
Truck staging area (truck buffer area 33B)	300	150	45,000	Ref. 2.2.40 and Ref. 2.2.16, Section 9.8.2.1.3
TOTAL			3,369,200	

Sources: See Reference column.

Should the external event be retained for further evaluation? **NO**.

7. RESULTS AND CONCLUSIONS

Table 10 presents a summary of the external events screening analysis.

Table 10. External Events Category List

External Event Category	Retained for Further Evaluation
A. Seismic activity (Section 6.1)	**YES**
B. Non-seismic geologic activity (Section 6.2)	**NO**
C. Volcanic activity (Section 6.3)	**NO**
D. High winds/tornadoes (Section 6.4)	**NO**
E. External floods (Section 6.5)	**NO**
F. Lightning (Section 6.6)	**NO**
G. Loss of power event (Section 6.7)	**YES**
H. Loss of cooling capability event (Section 6.8)	**NO**
I. Aircraft crash (Section 6.9)	**NO**
J. Nearby industrial/military facility accidents (Section 6.10)	**NO**
K. Onsite hazardous materials release (Section 6.11)	**NO**
L. External fires (Section 6.12)	**NO**
M. Extraterrestrial activity (Section 6.13)	**NO**

Source: Original

ATTACHMENT A

TORNADO AND TORNADO MISSILE SCREENING ANALYSIS

A1. PURPOSE

Hazards from tornadoes and tornado missiles were determined in the main report to be potentially applicable to the repository during the preclosure period. This analysis estimates tornado probabilities and tornado missile impacts for surface facilities and small targets using recently published tornado incident data applicable to the Yucca Mountain site. Quantitative screening analyses are utilized to exclude tornadoes and tornado missiles as realistic threats to SSCs that are ITS based on the probabilistic screening criteria applicable to the surface facilities.

A2. ANALYSIS APPROACH

The frequency of tornadoes at the Yucca Mountain site was estimated using data from *Tornado Climatology of the Contiguous United States,* NUREG/CR-4461 (Ref. A5.7). Tornado strike probabilities were estimated for structures at the repository based on the repository tornado frequency, the preclosure period, the percentage of the preclosure period during which the structures will be utilized and the dimensions of those structures.

Structures with tornado strike probabilities over the preclosure period less than the screening probability (1.0×10^{-4}) were excluded from further analysis. Structures with strike probabilities greater than the screening probability were further analyzed using screening conditional probabilities of structural damage given a tornado strike to estimate the frequency of structural damage. Tornado wind speeds, estimated for structures with tornado strike probabilities greater than or equal to the screening probability were used to determine the potential for structural damage caused by tornado-generated missiles.

A3. BODY OF ANALYSIS

A3.1 TORNADO STRIKE FREQUENCY

The frequency of tornadoes at the Yucca Mountain site was estimated using data from *Tornado Climatology of the Contiguous United States,* NUREG/CR-4461 (Ref. A5.7). Tornado wind speeds in this document are based on the Enhanced Fujita Scale (EF-Scale) that correlates wind speeds with damage caused by tornadoes, as described in *A Recommendation for an Enhanced Fujita Scale (EF-Scale)* (Ref. A5.8). These wind speeds are lower than the wind speeds in the original Fujita Scale. Another difference from earlier tornado wind speed estimates is that the wind speed in the EF-Scale is based on nominal three-second average wind speeds instead of the nominally fastest quarter-mile wind speeds used in the original Fujita Scale. Regulatory Guide 1.76, *Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants* (Ref. A5.9) incorporated the tornado data from Ref. A5.7 in formulating nuclear power plant design-basis tornado characteristics.

Ref. A5.7 used data from tornadoes reported in the United States from January 1950 through August 2003 to determine tornado strike frequencies and maximum wind speeds. Tables included in the document identify characteristics and estimates of strike frequencies and maximum wind speeds for tornadoes located in one-, two- and four-degree latitude and longitude boxes.

Ref. A5.7 estimated tornado strike frequencies by developing separate point source and life-line strike frequencies. The point source strike frequency is the tornado strike frequency at one particular location (point source). The life-line frequency adds an additional contribution to address the size of a structure.

The point source strike frequency is estimated using the area within a region that has been impacted by tornadoes in a specific time period, the area of the region and the time period (Ref. A5.7, Section 4.1):

$$\lambda_{point\ source} \quad \frac{A_t}{NA_r} \qquad \text{(Eq. A1)}$$

where

A_t = total area impacted by tornadoes within a region of interest in N years

N = number of years of tornado record used to determine A_t, and

A_r = area of region of interest.

Since structures are not point sources, the life line term is used to correct for the finite size of actual structures. The life line frequency is estimated using the lengths of observed tornadoes, the characteristic dimension of a structure (200 ft was utilized to develop data in Ref. A5.7 [Section 4.2]), the area of the region that has been impacted by tornadoes and the time period:

$$\lambda_{life-line} \quad \frac{w_s L_t}{NA_r} \qquad \text{(Eq. A2)}$$

where

w_s = characteristic horizontal dimension of a finite structure, and

L_t = total tornado path length in region of interest.

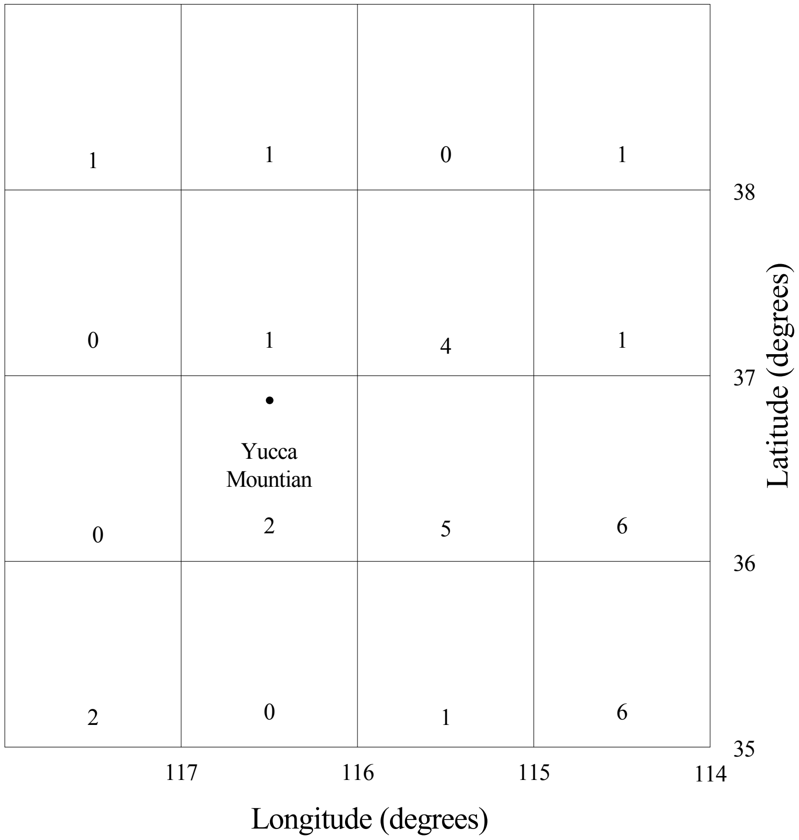
The tornado strike frequency is the sum of the point source and life-line terms:

$$\lambda_{tornado\ strike} \quad \lambda_{point\ source} + \lambda_{life\text{-}line} \qquad \text{(Eq. A3)}$$

Based on tornado incidents throughout the United States, Ref. A5.7 lists recommended tornado design wind speeds in three regions of the country to be used for nuclear power plant design. For the Western region, in which the Yucca Mountain Repository is located, a wind speed of 130 mph at a recurrence rate of 1.0×10^{-6} yr^{-1} is specified (Table 8-1 of Ref. A5.7). However, a review of the tornado data for the repository location indicates a smaller number of observed tornadoes in the Yucca Mountain area than in other parts of the Western region. Because of this, the underlying data included in Ref. A5.7 for the Yucca Mountain region was used as the basis for estimating the frequency and associated tornado wind speeds at the repository.

As noted above, Ref. A5.7 includes three tables that specify estimated tornado characteristics for one-, two- and four-degree latitude and longitude blocks within the continental United States. The document cautions that some of the smaller blocks do not contain sufficient data to specify tornado characteristics with confidence (20 or more tornadoes per box; see Section 5.2, first paragraph and the first paragraphs of Appendices A, B and C of Ref. A5.7). That is the case for the Yucca Mountain region, an area with very low tornado activity. Only the four-degree box surrounding the repository contains enough data to adequately estimate tornado characteristics. Unfortunately, the four-degree box in which the repository is located places the site near the upper (northern) boundary of the box. The box includes an area of relatively high tornado activity near its lower boundary that strongly influences the tornado frequency estimated in the four-degree box but which is not representative of the Yucca Mountain site.

To more accurately estimate the tornado frequency in the vicinity of Yucca Mountain, a new four-degree box was drawn with Yucca Mountain closer to the center. This new box encompasses the 16 one-degree boxes shown in Figure A1. The numeric value included in each one-degree box is the number of tornadoes observed from January 1950 – August 2003 in the box.



Source: Ref. A5.7.

Figure A1. Yucca Mountain Four-Degree Latitude and Longitude Box.

The data associated with this four-degree box was developed based on the one-degree box data included in Appendix C to Ref. A5.7. Mean tornado impact areas and path lengths were estimated for each one-degree box based on the 5 – 95% uncertainty data listed for each box. The one-degree mean data were then weighted based on the number of observed tornadoes in each one-degree box and the overall number of tornadoes in the four-degree box and summed to estimate an overall frequency for the new four-degree box[1].

$$\lambda_{tornado\,strike} \quad \frac{1}{NA_T}\sum_{i\ 1}^{16} A_{t,i}(mean)\frac{n_i}{n_T} + \frac{w_s}{NA_T}\sum_{i\ 1}^{16} L_{t,i}(mean)\frac{n_i}{n_T} \qquad \text{(Eq. A4)}$$

where:

A_T = total area of 16 one-degree boxes

$A_{t,i}$(mean) = mean impacted area for box i

$L_{t,i}$(mean) = mean tornado length for box i

n_i = number of tornadoes observed in box i

n_T = total number of tornadoes observed in 16 one-degree boxes.

As an example of this calculation, consider the data for a one-degree box with a southeast corner located at Latitude 35° north and 114° west (Ref. A5.7, Appendix C, p. C-39):

Number of tornadoes observed	6
Area of one-degree box	3.887×10^3 mi^2
Tornado area (5th percentile)	6.619×10^{-3} mi^2
Tornado area (95th percentile)	2.002 mi^2

Ref. A5.7 utilized a lognormal distribution to describe tornado characteristics. This was based on its use in tornado studies since 1963 and a review of data from the current tornado database that indicated its use was reasonable (Ref. A5.7, p. 2-4). In a lognormal distribution, the mean (expected), 5th and 95th percentile values can be calculated from the median and variance of the transformed variables μ and ν:

$$mean \quad e^{(\mu+\nu/2)} \qquad \text{(Eq. A5a)}$$

$$5th\ percentile \quad e^{(\mu-1\ 645\sqrt{\nu})} \qquad \text{(Eq. A5b)}$$

$$95th\ percentile \quad e^{(\mu+1\ 645\sqrt{\nu})} \qquad \text{(Eq. A5c)}$$

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[1] This weighting approach was used to calculate the 4 degree box data in Ref. A5.7 (Ref. A5.10).

To estimate the mean tornado area from the 5th and 95th percentile data, logarithms of the 5th and 95th percentile equations A5b and A5c were solved for μ and ν:

$$\mu \quad [\ln(\mathit{95th\ percentile}) + \ln(\mathit{5th\ percentile})]/2 \qquad \text{(Eq. A6a)}$$

$$\nu \quad [\ln(\mathit{95th\ percentile}) - \ln(\mathit{5th\ percentile})]/(2 \times 1.645)]^2 \qquad \text{(Eq. A6b)}$$

For the tornado area 5th and 95th percentile values given for the 35° north and 114° west one-degree box: $\mu = -2.161$, $\nu = 3.014$, and the tornado mean area = 5.196×10^{-1} mi^2. The weighted tornado area for the one-degree box is calculated by multiplying the mean tornado area by the number of tornadoes observed in the box and then dividing by the total number of tornadoes observed in the 16 one-degree boxes (31, see Figure A1): $(5.196 \times 10^{-1}) \times 6/31 = 1.006 \times 10^{-1}$ miles squared.[2]

The tornado strike frequency per year for a point source at the repository is finally calculated by multiplying the total number of tornadoes observed in the 16 one-degree box area (31) by the weighted average tornado areas for the 16 one-degree boxes (2.040×10^{-1} mi^2, see Table A6) and dividing by the product of the sum of the one-degree box areas (6.100×10^4 mi^2) and the number of years in the observation period (53.67, Ref. A5.7, p. 4-2): $31 \times 2.040 \times 10^{-1}$ mi^2/(6.100×10^4 mi$^2 \times 53.67$ yr) = 1.9×10^{-6}/yr (this is the first term of equation A3). Relevant data for each of the 16 one-degree boxes is shown in Table A6 at the end of this analysis.

Using the same approach as used above to estimate a revised point source strike frequency results in an estimated life-line frequency of 4.2×10^{-7}/yr for a 200 ft-long building (Table A7 at the end of this analysis). The life-line term is adjusted based on structure length by multiplying the life-line frequency by the ratio of the actual building length to that of a 200-ft-long building (the basis for life-line data included in Ref. A5.7). The adjusted life-line term is added to the point frequency to obtain the overall tornado strike frequency for the structure.[3]

To estimate an effective length of each large structure, an average length was calculated from building north-south, east-west, northeast-southwest and northwest-southeast dimensions indicated or measured on the references in Table A1.

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[2] For traceability the data in the examples included in this analysis is provided to the same level of detail as in Reference A5.7. However, analysis results are presented to two significant figures.

[3] All of the calculations described above are included in *Tornado Frequency.xls* Excel file located in Attachment D used to develop the estimates applicable to this analysis.

Table A1. Structures and Areas Exterior Dimensions

Facility	North-South Dimension (ft)	East-West Dimension (ft)	Northeast - Southwest Dimension[b] (ft)	Northwest-Southeast Dimension[b] (ft)	Effective Length[a] (ft)	Reference
Canister Receipt and Closure Facility	392	419	468	460	435	Ref. A5.3
Initial Handling Facility	235	385	355	310	232	Ref. A5.5
Receipt Facility	318	315	343	398	344	Ref. A5.4
Wet Handling Facility	385	355	355	420	378	Ref. A5.2
Railcar and Truck Buffer Area	2025 (length)	300 (width)	1500 (+45 deg)	1430 (-45 deg)	1314	Ref. A5.21
Aging Pads	2480	1500	2540	2480	2250	Ref. A5.6
Site Transporter	17.5	23	28.5	28.5	24.4	Ref. A5.12
Transport and Emplacement Vehicle	16	60	50	50	44	Ref. A5.13

Note: [a] Average of four dimensions.
[b] Based on a box at 45% with its lines typically touching the corners of each facility measuring the dimensions using the scale on the drawings.

Sources: See Reference column.

The yearly frequency of tornado strike on a structure was estimated as described earlier (equation A3) using the point source and life-line frequencies calculated for the 4-degree box and the effective building length:

$$\lambda_{tornado\ strike} \quad \lambda_{point\ source} + \lambda_{life\text{-}line} \frac{effective\ length\ (ft)}{200\ ft}. \qquad \text{(Eq. A7)}$$

The probability of tornado strike over the preclosure period is estimated using the tornado strike frequency, the preclosure period and the fraction of time a facility is in operation during the preclosure period (exposure):

$$\text{p(tornado strike)} = 1 - \exp(-\lambda_{tornado\ strike} \times \text{preclosure period} \times \text{exposure}) \qquad \text{(Eq. A8)}$$

$$\approx \lambda_{tornado\ strike} \times \text{preclosure period} \times \text{exposure.}$$

Table A2 lists each of the large repository structures that were assessed for tornadoes, their effective length and the overall tornado strike frequency. In addition, the table lists the facility preclosure period, the percentage of time (exposure) during the preclosure period during which the structure is at risk from a tornado strike (the percentage of the preclosure period during which SNF is present in a structure) and finally the probability of a tornado strike over the preclosure period on an in-use structure.

The percentage of time during which each structure is at risk (exposure) was based on the overall time periods during which the structures are expected to be used: 50 years of the 100 year preclosure period for all structures (including the railcar and truck buffer areas and aging pads) (Ref. A5.1, p. 170).

Table A2. Large Repository Structure Effective Length and Tornado Strike Probability

Structure	Effective Length	Overall Strike Frequency (yr^{-1})	Preclosure Period (yrs)	Exposure During Preclosure Period	Probability of Tornado Strike in Preclosure Period
Canister Receipt and Closure Facilities (3)	435 ft	2.8×10^{-6} (ea)	100	0.5	1.4×10^{-4} (ea)
Initial Handling Facility	232 ft	2.4×10^{-6}	100	0.5[a]	1.2×10^{-4}
Receipt Facility	344 ft	2.7×10^{-6}	100	0.5	1.4×10^{-4}
Wet Handling Facility	378 ft	2.7×10^{-6}	100	0.5	1.4×10^{-4}
Railcar and Truck Buffer Area	1314 ft	4.7×10^{-6}	100	0.5	2.3×10^{-4}
Aging Pads	2250 ft	6.7×10^{-6}	100	0.5	3.4×10^{-4}

Note: [a]The IHF may be used for less than 50 years. If this is the case, this assessment is conservative.

Source: Original

Again using the CRCF as an example,

$$\lambda_{CRCF\ strike} \quad 1.9E-6/\text{yr} + 4.2E-7/\text{yr} \times = \frac{435\text{ ft}}{200\text{ ft}} \quad 2.8E-6/\text{yr} \tag{Eq. A9}$$

The CRCF is to operate for 50 years of the 100-year preclosure period, which results in an exposure of 0.5 (50 yrs/100 yrs). Applying this, the CRCF yearly strike frequency and the 100 yr preclosure period results in the following CRCF strike probability:

$$\text{p(CRCF tornado strike)} = 1 - \exp(-2.8 \times 10^{-6}/\text{yr} \times 100\text{ yr} \times 0.5) = 1.4 \times 10^{-4} \tag{Eq. A10}$$

Smaller items, such as site transporters or TEVs can also be struck by tornadoes. Using the same approach described above, tornado strike probabilities were estimated for these items. The site transporter and TEV effective lengths used in the analysis were developed from the following:

A. *Site Transporter Mechanical Equipment Envelope.* (Ref. A5.12).

B. *Emplacement and Retrieval Transport and Emplacement Vehicle Mechanical Equipment Envelope* (Ref. A5.13).

Exposure fractions for these items were estimated as follows:

A. The site transporter will move casks with associated aging overpacks between facilities and to and from the aging pads, as required. Based on the data included in *Waste Form Throughputs for Preclosure Safety Analysis* (Ref. A5.14, Table 4), 8,489 × 2 trips are estimated between the facilities and aging pads. Utilizing the 2-hr facility-to-aging pad transit time specified in *Yucca Mountain Repository Concept of Operations* (Ref. A5.16, pp. G-5 and G-6), canisters and aging overpacks will be moving between the facilities and aging pads during 8,489 × 2 × 2 hours of site operations during the preclosure period. This results in an estimated exposure of ~34,000 hr/(100 yr × 8,760 hr/yr) = 0.039. Some of the transits are expected to be between facilities, which will reduce the exposure somewhat because of the slightly shorter transit times.

B. The TEV will move waste packages from the facilities to the underground repository. Based on estimated transit numbers (12,068 trips, Ref. A5.14, Table 4) and durations [1 – 4 hr (3 hr used in the analysis), Ref. A5.16, p. I-19], waste packages will be moving on the TEV during ~36,200 hours of site operation over the preclosure period. This results in an estimated exposure of 36,200 hr /(100 y × 8,760 hr/yr) = 0.041.

Resulting effective lengths and tornado strike probabilities during the preclosure period for the site transporter and TEV are listed in Table A3.[4]

Table A3. Site Transporter and TEV Effective Length and Tornado Strike Probability

Structure	Effective Length	Overall Strike Frequency (yr^{-1})	Preclosure Period (yrs)	Exposure During Preclosure Period	Probability of Tornado Strike in Preclosure Period
Site transporter	24 ft	2.0×10^{-6}	100	0.039	7.8×10^{-6}
Transport and emplacement vehicle	44 ft	2.0×10^{-6}	100	0.041	8.2×10^{-6}

Source: Original

A tornado strike probability in the preclosure period of 1.0×10^{-4} is utilized as a screening value to exclude tornadoes as risk contributors (Ref. A6.1). Structures and equipment with strike probabilities below this value include a site transporter and TEV. Based on this, the site transporter and TEV are screened out and not addressed further in the analysis.

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[4] This analysis considered only one site transporter or TEV to be in use at any time. This is reasonable considering the estimated number of hours per day, 34,000 hr / (50 y × 365 d/y) = 1.9 hr/day for a site transporter and 36,200 hr / (50 y × 365 d/y) = 2.0 hr/day for a TEV, based on the number of transits and time periods involved (items A and B, above). In addition, the fraction of a day that a site transporter or TEV would be in use is about 2hr/24hr or 0.08. The probability that two would be in use is the overlap of these values, which is much smaller than 0.08. For a tornado to impact two vehicles, it would need a footprint that encompasses the positions of both vehicles. However, the widths of the widths of F0, F1, and F2 tornado footprints that are predicated to impact the GROA are below 100 ft (Ref. A5.7, Table 2-8), so the tornado paths would only impact one vehicle.

Structures and equipment with tornado strike probabilities at 1.0×10^{-4} or above are further assessed in Section A3.2, where the likelihood of structural damage given a tornado strike is considered.

A3.2 PROBABILITY OF STRUCTURAL DAMAGE

The potential for damage from direct effects (wind pressure and pressure drop) if a tornado were to strike one of the structures at the repository depends on the potential for damage at the wind speed associated with the tornado. The probability of damage is estimated based on the probability of a tornado strike and the conditional probability of structural damage given the tornado wind speed:

$$\text{p(structural damage)} = \text{p(tornado strike)} \times \text{p(structural damage | tornado strike)}. \qquad \text{(Eq. A11)}$$

The maximum wind speed of concern is the speed associated with a tornado with a frequency of 1.0×10^{-6}/yr. The frequency of 1.0×10^{-6}/yr was chosen based on the required screening probability in the preclosure period (1.0×10^{-4}, Ref. A6.1) and the preclosure period (100 yrs): 1.0×10^{-4}/(100 y).[5] The estimated maximum tornado wind speed at a frequency of 1.0×10^{-6}/yr was calculated using the approach taken in Ref. A5.7, in which tornado frequency as a function of wind speed is described using a Weibull model with parameters developed for the three tornado regions (Table 5-1 of Ref. A5.7)[6]. In this approach, the frequency of a tornado strike with wind speed exceeding a value u_0 is represented as the sum of two Weibull distributions, the first representing the point strike frequency (using equation A1) and the second the life-line frequency (using equation A2) (Ref. A5.7, Section 4.3):

$$p(u \geq u_0) \quad \frac{A_t}{NA_r} e^{-\left(\frac{u_0 - 65}{a_p}\right)^{b_p}} + \frac{w_s L_t}{NA_r} e^{-\left(\frac{u_0 - 65}{a_l}\right)^{b_l}} \qquad \text{(Eq. A12)}$$

where

a_p = scale parameter for the Weibull distribution function for the conditional point strike probability[7] (25.46).

b_p = shape parameter for the Weibull distribution function for the conditional point strike probability (1.188[9])

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[5] The exposure fractions were utilized in the tornado strike probability calculations to address only the period of time during the preclosure period when a facility was at risk because spent fuel was present. The exposure fractions were not used to reduce the time in the preclosure period when estimating tornado wind speed; this would have resulted in a reduction in the maximum wind speed expected during the preclosure period.

[6] Insufficient data exists to estimate these parameters for smaller areas of the country (Ref. A5.10).

[7] The Weibull distribution parameters are mean values developed from 5th and 95th percentile values listed in Table 5-1 of Ref. A5.7, shown in *Tornado Frequency.xls* spreadsheet, "Tornado Freq" worksheet, cells A50 to E54, contained in Attachment D. The means were calculated using the same method as described above for tornado mean area (See discussion of the estimation of the mean from the 5th and 95th percentile values following Equation A6a and A6b).

a_l = scale parameter for the Weibull distribution function for the conditional life-line strike probability (30.80^9)

b_l = shape parameter for the Weibull distribution function for the conditional life-line strike probability (1.317^9).

Equation A12 was solved by iteration, by varying the wind speed to determine the wind speeds that result in a tornado frequency less than 1.0×10^{-6}/yr:

Table A4. Maximum Tornado Wind Speeds at Screening Probability

Facility or Structure	Maximum Tornado Wind Speed (mph)
Canister Receipt and Closure Facility	94
Initial Handling Facility	89
Receipt Facility	92
Wet Handling Facility	93
Rail Car and Truck Buffer Area	106
Aging Pads	114

Source: Original

These wind speeds correspond to an *EF1* tornado on the EF-Scale (see Table 2-1 of Ref. A5.7) for all structures except the aging pads. For the aging pads, the maximum wind speed at a frequency of 1.0×10^{-6}/yr. corresponds to a low *EF2* tornado. An *EF1* tornado corresponds in observed damage to an *F1* (moderate damage) tornado in Fujita's 1971 classification. An *F1* tornado can cause surfaces to peel off roofs, broken windows, trailer homes moved or overturned, some trees snapped and moving autos pushed off roads [see, for example, *Natural Phenomena Hazards Modeling Project: Extreme Wind/Tornado Hazard Models for Department of Energy Sites*, (Ref. A5.15, Table 3)]. An *EF2* tornado corresponds to an *F2* (moderate damage) tornado in Fujita's 1971 classification. An *F2* tornado can cause roofs to be torn off of frame houses, destruction of house trailers, large trees snapped and uprooted and cars blown off highways (Ref. A5.15, Table 3). Since the repository structures are much more substantial than the objects described as damaged in an *F1* or *F2* tornado, little damage is anticipated if the repository were to be struck by a tornado with a frequency of concern in this analysis. In actuality, the large structures and aging overpacks are designed to withstand the wind effects of a 189 mph tornado (Ref. A5.1, Section 6.1.4). The exterior of the IHF, however, is a metal structure rather than a concrete structure. Because of the closeness of the tornado strike probabilities over the preclosure period for the CRCFs, IHF, RF and WHF to the 1.0×10^{-4} screening criteria, only a modest conditional probability of building damage will reduce the probability of structural damage below the screening value. This analysis did not attempt to estimate a realistic conditional probability of structural damage for these structures, but instead considered the potential for damage of a surrogate object. The CRCFs, IHF, RF and WHF all utilize an overhead door at the entry vestibule to each building. This overhead door, which is considerably weaker than the rest of the reinforced concrete CRCF, RF and WHF structures, was used as the surrogate to estimate a conservative screening probability for structural damage to these structures from a tornado strike. An overhead door was also used as a surrogate for the

IHF sheet metal exterior wall. While the sheet metal wall is not as strong as reinforced concrete, it is less susceptible to tornado damage than the overhead door, as described later in this analysis.

The screening estimate for the CRCFs, RF and WHF was developed by establishing a probability distribution for overhead door failure at different wind speeds and then convolving this distribution with the frequency of a tornado strike as a function of wind speed. The probability of the surrogate overhead door failing is developed from data included in Ref. A5.8. This reference addresses the inward or outward collapse of an overhead door that is part of a Metal Building System (e.g., warehouses and industrial facilities) during a tornado. In developing Ref. A5.8, six experts provided estimates of the wind speed at which door failure will occur (Ref. A5.8, pp 4 – 6 and Appendix B). The six experts included two meteorologists, two engineers, one architect and one individual with both a meteorological and engineering background. Column 1 of Table A5 is a distribution of the experts' estimates of the tornado wind speeds at which an overhead door will fail due to direct tornado effects at the wind speed shown in Column 2 of Table A5 (Ref. A5.8, p. B-8).

The probability of door failure at the wind speeds shown in Table A5 were combined with the frequencies of a tornado strike at the same wind speeds to estimate an overall frequency of overhead door failure due to a tornado at the repository site. The total failure frequency is the sum of the strike frequency at each wind speed weighted by the conditional probability of failure at that wind speed.

The CRCF was chosen for this calculation because it has a slightly higher tornado strike frequency than the RF and WHF. The results of the calculation will therefore bound the frequency of overhead door failure for the other two facilities:

Table A5. CFCF Surrogate Failure Probability at Different Wind Speeds and Surrogate Failure Frequency

Overhead Door (Surrogate) Failure Probability	Overhead Door (Surrogate) Failure Wind Speed (mph)	Strike Frequency (yr^{-1}) at Wind Speed	Surrogate Failure Frequency (yr^{-1})
0.167	80	1.8×10^{-6}	3.0×10^{-7}
0.167	85	1.4×10^{-6}	2.3×10^{-7}
0.500	90	1.2×10^{-6}	6.0×10^{-7}
0.167	100	7.3×10^{-7}	1.2×10^{-7}
Total			1.2×10^{-6}

Source: Original.

The results of the calculation are shown in columns 3 and 4 of Table A5. The strike frequency at each wind speed is estimated using equation A12. The overall frequency of surrogate failure is estimated at 1.2×10^{-6}/yr. This corresponds to a failure probability in the preclosure period of 6.0×10^{-5}, which is below the 1.0×10^{-4} screening probability. Since this is true for the weakest part of the structure it is also true for the rest of the structure and therefore the CRCF, and hence the RF and WHF are screened out based on probability and are not considered further for direct tornado impacts.[8]

For the IHF, the overhead door surrogate analysis demonstrates that it can also be screened out based on probability. However, an overhead door will fail at a wind speed that is about 6 mph less than the sheet metal wall panels utilized in metal building systems. Utilizing the Ref. A5.8 estimates for metal wall panels (Ref. A5.8, p. B-7, item 3) and taking the same approach as for the surrogate overhead door, a failure frequency of 8.5×10^{-7} yr^{-1} is estimated for sheet metal wall panels (4.3×10^{-5} failure probability over a 50-year period). This confirms that the IHF exterior metal walls can be screened out based on probability and not considered further for direct tornado impacts.

The remaining large "structures" of concern are the railcar and truck buffer areas and the aging pads, with a tornado strike probabilities of 2.3×10^{-4} and 3.4×10^{-4}, respectively, over the preclosure period (Table A2) and associated maximum tornado wind speeds of 106 and 114 mph (Table A4) at the screening probability. The railcar and truck buffer areas serve as staging areas for canisters and associated transport casks that have not been processed trough the IHF, CRCF, RF or WHF. The transportation casks (multiple manufacturers) are substantial steel protective structures. Maximum dimensions for a transportation cask is 333 in. long and 126 in. in diameter, with a loaded weight of 360,000 lb., all with impact limiters installed (Ref. A5.20, Section 33.2.3.5). The aging pads function as holding areas for canisters with decay heat levels that are too high to be emplaced upon receipt. On the aging pads each canister is protected by an aging overpack, which provides protection and shielding. The aging overpacks are substantial concrete cylindrical structures 12 ft in diameter with a maximum weight of 500,000 lbs designed to withstand the wind and missile impacts of a 189 mph tornado (Ref. A5.19 and Ref. A5.11, Section 3.3.2 and p. D-1).

The transportation casks in the railcar and truck buffer areas and the aging overpacks sitting on the aging pads were screened for tornado damage using a different approach than that used for the RF, CRCF and WHF. This was done because no realistic surrogates could be identified for these items.

The probability of structural damage for the buffer areas and the aging pads from direct wind effects was estimated using data included in *External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Guide* (Ref. A5.18, Table II-2). This document lists static load pressures at which selected components and structural elements fail. For rugged vessels and heat exchangers with steel thicknesses that are typically much thinner than the transportation cask thickness, a failure probability of 0.01 is reported at a static load of ~10 psi. For approximately 8 – 12 in thick reinforced concrete walls (much thinner than the aging overpack thicknesses at the Yucca Mountain site), a failure probability of 0.01 is reported at a static load of ~2 psi.

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[8] This conclusion is supported by estimates in Reference A5.8 (item 20) for tornado wind loadings that can result in the uplift of concrete roof slabs on a typically reinforced concrete institutional building (Ref. A5.1, Section 4.2.12.1 specifies the use of concrete roof slabs for the CRCF, RF and WHF). Uplift of concrete roof slabs is predicted to occur before exterior wall failure. Using the same approach as described for an overhead door, a structural failure probability in the preclosure period of 1.1×10^{-7} is estimated, well below the screening probability (*Tornado Frequency.xls,* worksheet Tornado Freq, cells AA32 to AD43 found in Attachment D).

The static wind pressure resulting from wind impinging on a structure can be calculated using Bernoulli's equation:

$$\text{Wind pressure} = 1/(2g) \times \rho \times v^2 \qquad \text{(Eq. A13)}$$

where

ρ = mass density of air,

g = gravitational constant,

v = wind velocity relative to the structure.

$$\text{Wind pressure (psf)} = ½ \times \rho\ (\text{lbm/ft}^3) \times 1/32.17\ (\text{lbf•sec}^2/\text{lbm•ft}) \times v^2\ (\text{mi/hr})^2 \times [(5280\ \text{ft/mi})/(3600\ \text{sec/hr})]^2$$

$$\text{Wind pressure}^9\ \text{(psf)} = ½ \times 0.07654\ (\text{lbm/ft}^3) \times 1/32.17\ (\text{lbf•sec}^2/\text{lbm•ft}) \times v^2\ (\text{mi/hr})^2 \times [(5280\ \text{ft/mi})/(3600\ \text{sec/hr})]^2$$

$$\text{Wind pressure (psf)} = 0.00256 \times [v\ (\text{mph})]^2\ .$$

Solving for v for a 2 psi load,

$$v\ (\text{mph}) = \sqrt{}\ [p(\text{psf})/0.00256]$$

$$= \sqrt{}\ [2\ (\text{lbf/in}^2) \times 12^2\ (\text{in/ft})^2/0.00256]$$

$$= 335\ \text{mph}.$$

For a 10 psi load the estimated wind speed approaches the speed of sound. Even for the 2 psi load, no tornadoes with such a wind speed have ever been observed.

A conservative estimate of the structural damage probability was calculated by combining the probability of structural failure at the high wind speeds (0.01) with the tornado strike probability at the screening wind speed, ignoring the conditional probability of a tornado strike at a 335+ mph wind velocity given a tornado strike at 106 mph for a cask and 114 mph for the aging pads:

$$\begin{aligned} \text{p(transportation cask failure)} &= \text{p(106 mph tornado)} \times \\ &\quad \text{p(335 mph tornado | 106 mph tornado)} \times \\ &\quad \text{p(structural failure at 335 mph)} \qquad \text{(Eq. A14)} \\ &< \text{p(106 mph tornado)} \times \\ &\quad \text{p(structural failure at 335 mph)} \\ &< (1.0 \times 10^{-4}) \times (1.0 \times 10^{-2}) \\ &< 1.0 \times 10^{-6} \end{aligned}$$

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[9] Ref. A5.9, p 5, equation (2).

and

$$\begin{aligned}
\text{p(aging overpack failure)} &= \text{p(114 mph tornado)} \times \\
&\quad\ \text{p(335 mph tornado | 114 mph tornado)} \times \\
&\quad\ \text{p(structural failure at 335 mph)} \qquad \text{(Eq. A15)} \\
&< \text{p(114 mph tornado)} \times \\
&\quad\ \text{p(structural failure at 335 mph)} \\
&< (1.0 \times 10^{-4}) \times (1.0 \times 10^{-2}) \\
&< 1.0 \times 10^{-6}.
\end{aligned}$$

The 1.0×10^{-6} conservative failure probability for the railcar and truck buffer areas and aging pads is substantially below the 1.0×10^{-4} screening probability. The buffer areas and aging pads are not considered further for direct tornado wind impacts.

A3.3 TORNADO MISSILE IMPACTS

Potential wind-borne tornado missiles range in size from roof gravel to large objects such as tanks and automobiles. *Rationale for Wind-Borne Missile Criteria for DOE Facilities* (Ref. A5.17) describes earlier work that categorized tornado missiles as small, medium or heavy. The small missile category includes roof gravel, tree branches and pieces of lumber. Small diameter pipes, steel roof joists and small beams comprise typical missiles in the medium category. Utility poles, large diameter pipes, automobiles, railroad cars and storage tanks fit into the heavyweight missile category. Heavyweight missiles are found only in damage associated with very strong tornadoes. Fujita's 1971 F-scale classification described in Ref. A5.15 supports this; light-object missiles are first generated in that classification in an *F2* tornado [minimum wind speed of 111 mph in the revised EF-Scale (Ref. A5.8)] while heavy missiles are only generated in *F4* or greater tornadoes [minimum wind speed of 166 mph in the revised EF-Scale (Ref. A5.8)].

Table 9 of Ref. A5.15 provides further justification to eliminate heavy missiles as a concern at the wind velocities that meet the probabilistic screening criteria for the repository. This table reports the results of computer analyses that predict no heavy missiles (i.e., a utility pole or automobile) will be picked up or sustained in tornadoes with wind speeds below 250 mph. The table addresses light-weight missiles at tornado velocities as low as 100 mph; below this velocity no data is provided for any missile.

Ref. A5.17, p. 56, estimates the wind speeds at which 2 in. × 4 in. planks and 3 in. diameter pipes are released from attachments at 100 mph and 150 mph, respectively. Potential missiles that are unattached to a structure, such as at a construction site, are typically near the ground, where horizontal and vertical wind speeds are lower than the nominal tornado wind speed (Ref. A5.17, p. 57, notes that tornado wind speeds approach zero at ground level). During completion of construction of the first two CRCFs, the RF and WHF and construction of the third CRCF (Ref. A5.20, Section 2.2.1.10), the potential exists for construction materials to be located on the roof or upper walls of the structure. This material could be a source of missiles if a tornado were to strike during construction. However, time periods during which construction is taking place are small compared to the lifetime of the facility.

The structures scheduled for construction after the first facility (the IHF) is operational are expected to require 5.5 years for completion (Ref. A5.20, Section 2.2.1.10). This is conservatively increased to 10.5 yrs. If construction materials were located at the construction sites for the 10.5-year period, the probability of potential missile generation from these materials is estimated [using the CRCF tornado strike frequency because it is higher than those for the RF and WHF (Table A2)] as

$$\begin{aligned} \text{p(construction missile generation)} &= \lambda_{\textit{tornado strike frequency}} \times \text{construction exposure period} \qquad \text{(Eq. A16)} \\ &= 2.8 \times 10^{-6}\ \text{yr}^{-1}\ \text{(Table A2)} \times \text{(10.5 yrs)} \\ &= 2.9 \times 10^{-5}. \end{aligned}$$

This probability is below the 1.0×10^{-4} screening criteria. Based on this assessment, construction missiles are screened from further analysis.

A tornado with wind speeds as high as 106 mph can potentially occur at the railcar and truck buffer areas and as high as 114 mph at the aging pads and still satisfy the 1.0×10^{-4} probabilistic screening criteria for the repository. Such tornadoes are capable of generating light-weight missiles from objects, such as timber beams and 3-in. diameter steel pipe (Ref. A5.15, Table 8), provided such objects are located in the vicinity.

This could be the case for timber beams and other light-weight material if the aging pads were being expanded (construction material), but such material is expected to be located on the ground. Even if such materials could be lifted from the ground, the small time periods during which construction could occur would reduce the overall probability of missile generation to below the screening criteria, as for the facilities undergoing construction.[10]

Pipes could also be used as supports for the fence surrounding the aging pads but such supports would be imbedded in the earth. As noted above, imbedded piping has a release wind speed of 150 mph, well above the maximum expected tornado wind speed for the buffer areas and aging pads. Because of this, light-weight piping is not considered a potential missile threat.

Since light-weight missiles are not considered a risk and heavier-weight missiles cannot be generated at the wind speeds associated with tornadoes with probabilities above the screening probability, tornado missile generation is not considered a risk for the repository.

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[10] Using a 5.5-y construction period (Ref. A5.20, Section 2.2.1.10)] results in a potential tornado missile generation probability of $2.8 \times 10^{-6}\ \text{yr}^{-1}$ (Table A2) × 5.5 yr = 1.5×10^{-5}.

A3.4 ANALYSIS SENSITIVITY AND UNCERTAINTY

A review of the data included in Ref. A5.7 as well as anticipated ranges of other data utilized provides insight into the potential variation in tornado strike probabilities and structural damage probabilities estimated herein.

Tornado strike probabilities were estimated using the observed tornado data for the Yucca Mountain region, the exterior dimensions of the repository structures and the exposure fractions during the preclosure period. At this point in the repository design the layout of each structure is well defined, and little change in building exterior dimensions is expected. The life-line contribution to the overall strike frequency is approximately 22 % of the point strike contribution (4.2×10^{-7}/yr for a 200-ft long building vs. 1.9×10^{-6}/yr, Section A3.1), so even a 50-ft increase in building characteristic length (an 11% increase for the CRCF) would result in only a 4% increase in the overall strike frequency (again for the CRCF).

The uncertainty in the point-strike and life-line terms is much greater. A review of the 5% - 95% data for the 4 degree boxes with between 20 – 40 tornadoes (31 observed tornadoes are recorded for the 4 degree box developed in this analysis) included in Appendix B to Ref. A5.7 indicates a factor of ~3 - ~14 between the 95% and 5% values (error factors of ~1.7 - ~3.8). Applying the maximum error factor in the Ref. A5.7 data to the tornado strike frequency estimated herein for Yucca Mountain results in (probably conservative) 5% and 95% values of 4.4×10^{-7}/yr and 6.4×10^{-6}/yr, respectively.[11] The use of a tornado strike frequency at the upper end of such a distribution would result in an estimated structural failure probability above the screening probability if the same surrogate-based approach was used. However, using the data from Table II-2 of Ref. A5.18 and the approach that was used to assess the structural damage probability for the transportation casks would result in an estimated probability for the repository structures analyzed herein that is well below the screening probability.

The Weibull parameters used to estimate the maximum wind speeds associated with different tornado strike probabilities (equation A12) can also consider a range of values. Table 5-1 of Ref. A5.7 provides 5% and 95% values for these parameters. Utilizing the 95% values in equation A12 results in maximum wind speeds that are only slightly higher than the mean values used in this analysis (e.g., 118 mph for the aging pads instead of 114 mph estimated using the mean values). This small increase in the maximum expected tornado wind velocity would have no impact on the conclusions. These sensitivity and uncertainty considerations strongly indicate that the results of this assessment would still hold for variations in the data used in the analysis.

A3.5 LOCAL RESPONSE EVALUATION

Missiles generated by tornado, as well as straight-line winds, was previously screened out during the construction period of the repository (Section A3.3). However, there still exists the potential to have small debris on-site during the non-construction period of the repository, although the population of construction-type debris, such as 2×4 lumber, would most certainty be lower during the non-construction phase. For completeness, this section evaluates the effects an impact from 2×4 piece of lumber generated by a 189 mph tornado or straight-line wind.

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[11] For mean = 2.349×10^{-6} and EF = 3.8, $\sigma = \ln(EF)/1.645 = 0.812$. $\mu = \ln(\text{mean}) - \sigma^2/2 = -13.29$. median = $e^{\mu} = 1.689 \times 10^{-6}$. 5% value = median/EF = 4.4×10^{-7}, 95% value = median × EF = 6.4×10^{-6}.

DOE Standard, Accident Analysis for Aircraft Crash into Hazardous Facilities (Ref. A5.22) provides a methodology for evaluating the effects of wind generated missiles. Section 6 of Ref. A5.22 provides equations for determining minimum thicknesses for penetration, concrete scabbing, and perforation. Penetration is the displacement of the missile into the target. Penetration depth of a wind generated missile is used to evaluate the effect of the missile on structures and concrete aging overpacks. The penetration depth of the missile is given as (Ref. A5.22, Appendix C):

$$x \quad \sqrt{4\times K\times N\times W\times D\times\left(\frac{V}{1000\times D}\right)^{1\ 8}} \qquad \text{(Eq. A17)}$$

For $\frac{x}{D} \leq 2.0$

where

x = penetration depth of missile (in.),

K = concrete penetrability factor = $[180/(f'_c)^{1/2}]$,

f'_c = ultimate compressive strength of concrete (lb/in^2),

N = missile shape factor = 0.72 for flat-nosed bodies, 0.84 for blunt-nosed bodies, 1.0 for average bullet-nosed (spherical end) bodies, and 1.14 for very sharp-nosed bodies;

W = missile weight (lb);

D = effective missile diameter (in);

V = missile impact velocity (ft/sec).

The compressive strength of concrete is taken as 2,000 lb/in^2 (Ref. A5.23, Table 6.9.5), which is the lowest value presented in the reference, and thus conservative. The missile shape factor is conservatively taken as the highest value of 1.14 for very sharp-nosed bodies. The missile weight is taken as 5 lbs, although using the density for pine of 42 lb/ft^3 (Ref. A5.23, p. 6-8), 10 lbs is equivalent to over a 25-ft long 2×4. The effective missile diameter for a 2×4 in board is 3.2 in. Using the design basis tornado of 189 mph, the missile impact velocity is 277 ft/sec. The penetration depth of concrete calculated for a 189 mph 2×4 missile is 3.5 in. This formula is for a rigid missile, which is very conservative for a 2×4 piece of lumber that would deform on impact. Because buildings and concrete aging overpacks have wall thicknesses in the order of several feet, a 2×4 missile generated by a 189-mph wind is not a threat to these structures.

Concrete structures are more vulnerable than steel targets, as demonstrated below. The following formula provides the penetration distance for a steel target (Ref. A5.22, Section 6.3.2.2).

$$T^{1.5} \quad \frac{0.5 \times M \times V^2}{17400 \times K_s \times D^{1.5}} \qquad \text{(Eq. A18)}$$

where

T = predicted thickness to just perforate a steel plate (in.),

M = W/g missile mass (lb-sec^2/ft)

g = 32.2 ft/sec^2

V = missile impact velocity (ft/sec)

K_s = constant depending on the grade of steel (usually ~1),

D = effective missile diameter (in).

Again, using 5 lbs as the weight and an effective diameter of 3.2 in, the predicted thickness to just perforate a steel plate with a 189 mph 2×4 missile is about 2 in. Again, this equation is for a rigid non-deformable missile and a 2×4 piece of lumber would deform on impact. Thus, steel vessels, such as transportation casks and the TEV, are not vulnerable to missile impacts.

A4. RESULTS AND CONCLUSIONS

The intent of this analysis was to determine the need for detailed probabilistic analyses of the risk associated with tornadic initiating events. This analysis used tornado data to estimate tornado strike frequencies for the following Yucca Mountain Repository structures and equipment: WHF, CRCF, RF, IHF, the railcar and truck buffer areas, the aging pads, a site transporter and a TEV (Ref. A5.7). Based on these frequencies and the expected exposure of the structures and equipment, the probability of a tornado strike during the preclosure period was estimated. Comparing the tornado strike probabilities with the 1.0×10^{-4} preclosure period screening probability specified in 10 CFR 63.2 (Ref. A6.1) results in the conclusion that the tornado strike probabilities for the following structures and equipment are below the screening value and therefore are excluded from further analysis for tornado effects: the site transporters and TEVs.

For structures that could potentially be damaged by a tornado (tornadoes with a strike probability during the preclosure period of 1.0×10^{-4} or greater), the probability of damage is estimated by calculating the conditional probability of damage from tornado impact and combining this with the tornado strike probability: p(structural damage) = p(tornado strike) × p(structural damage | tornado strike). The tornado wind speed utilized in the analysis was the highest wind speed expected for tornadoes with strike probabilities at the 1.0×10^{-4} screening probability, approximately 89 mph for the IHF, 94 mph for the CRCFs, WHF and RF, 106 mph for the railcar and truck buffer areas and 114 mph for the aging pads. The use of simplified analyses of weaker associated (surrogate) structures and screening structural damage probabilities results in the conclusion that those structures that could not be screened out from further consideration based on tornado strike probability (the CRCFs, IHF, RF, WHF, railcar and truck buffer areas and aging pads) could be screened out from detailed analysis based on the probability of tornado-caused structural damage. The total probability is well below the 1.0×10^{-4} screening probability.

An assessment of the potential for structural damage from tornado missiles results in a similar conclusion. At the low tornado wind speeds expected at the repository site, no heavy (typically damaging) tornado missiles would be generated. Construction materials can generate light-weight missiles; however, construction materials are expected to be at the site for limited periods of time once the facility is in operation. These short time periods preclude such material as potential missiles at probabilities above the screening probability. However, an assessment was made on the effect of a missile, which shows that the penetration depth is much less than the wall thicknesses of structures, aging overpacks, transportation casks and the TEV.

Based on this quantitative screening analysis, tornadoes and their potential for structural damage from direct effects and missiles are eliminated from further detailed analysis.

Table A6. Tornado Point Strike Frequency Data for Four-Degree Box Surrounding Yucca Mountain

Latitude	**Longitude**	**Area of 1° Square[1] (mi^2)**	**Number of Observed Tornadoes[1]**	**Tornado Area[1] (Median) (mi^2)**	**Tornado Area[2] (5th percent) (mi^2)**	**Tornado Area[2] (95th percent) (mi^2)**	**Tornado Area[3] (mean) (mi^2)**	**Weighted Tornado Area[3] (mean) (mi^2)**
35	114	3.887×10^{3}	6	1.151×10^{-1}	6.619×10^{-3}	2.002	5.196×10^{-1}	1.006×10^{-1}
35	115	3.887×10^{3}	1	1.136×10^{-2}	-	-	1.138×10^{-2}	3.665×10^{-4}
35	116	3.887×10^{3}	0	0	-	-	0	0
35	117	3.887×10^{3}	2	8.533×10^{-4}	5.569×10^{-4}	1.307×10^{-3}	8.823×10^{-4}	5.692×10^{-5}
36	114	3.887×10^{3}	6	5.773×10^{-3}	7.853×10^{-4}	4.244×10^{-2}	1.204×10^{-2}	2.331×10^{-3}
36	115	3.887×10^{3}	5	1.681×10^{-1}	1.721×10^{-2}	1.642	4.389×10^{-1}	7.079×10^{-2}
36	116	3.887×10^{3}	2	8.533×10^{-4}	5.569×10^{-4}	1.307×10^{-3}	8.823×10^{-4}	5.692×10^{-5}
36	117	3.887×10^{3}	0	0	-	-	0	0
37	114	3.887×10^{3}	1	1.136×10^{-3}	-	-	1.136×10^{-3}	3.665×10^{-5}
37	115	3.887×10^{3}	4	1.321×10^{-2}	2.668×10^{-4}	6.544×10^{-1}	2.203×10^{-1}	2.843×10^{-2}
37	116	3.887×10^{3}	1	5.682×10^{-4}	-	-	5.682×10^{-4}	1.833×10^{-5}
37	117	3.887×10^{3}	0	0	-	-	0	0
38	114	3.887×10^{3}	1	3.977×10^{-2}	-	-	3.977×10^{-2}	1.283×10^{-3}
38	115	3.887×10^{3}	0	0	-	-	0	0
38	116	3.887×10^{3}	1	1.705×10^{-4}	-	-	1.705×10^{-4}	5.500×10^{6}
38	117	3.887×10^{3}	1	1.136×10^{-3}	-	-	1.136×10^{-3}	3.665×10^{-5}
Total		6.100×10^{4}	31					2.040×10^{-1}

Notes:

[1] Data from Ref. A5.7, Appendix C.

[2] Data from Ref. A5.7, Appendix C. For latitude and longitude boxes with 0 or 1 observed tornado, the point estimate was utilized as the median and the 5th and 95th percentiles were not estimated.

[3] See Section A3.1 for the approach used to estimate the mean and weighted mean. For boxes with 0 or 1 observed tornado, the point estimate was used as the mean.

Source: See Notes.

Table A7. Tornado Life-Line Frequency Data for Four-Degree Box Surrounding Yucca Mountain

Latitude	Longitude	Area of 1° Square[1] (mi^2)	Number of Observed Tornadoes[1]	Tornado Length[1] (Median) (mi^2)	Tornado Length[2] (5th percent) (mi^2)	Tornado Length[2] (95th percent) (mi^2)	Tornado Length[3] (mean) (mi^2)	Weighted Tornado Length[3] (mean) (mi^2)
35	114	3.887×10^{3}	6	8.043×10^{-1}	2.049×10^{-1}	3.158	5.196×10^{-1}	2.200×10^{-1}
35	115	3.887×10^{3}	1	1.000	-	-	1.000	3.226×10^{-2}
35	116	3.887×10^{3}	0	0	-	-	0	0
35	117	3.887×10^{3}	2	1.502×10^{-1}	9.802×10^{-2}	2.301×10^{-1}	1.553×10^{-1}	1.002×10^{-2}
36	114	3.887×10^{3}	6	2.170×10^{-1}	1.341×10^{-1}	3.512×10^{-1}	2.265×10^{-1}	4.384×10^{-2}
36	115	3.887×10^{3}	5	1.512	8.261×10^{-1}	2.769	1.618	2.610×10^{-1}
36	116	3.887×10^{3}	2	1.502×10^{-1}	9.802×10^{-2}	2.301×10^{-1}	5.233×10^{-2}	3.376×10^{-3}
36	117	3.887×10^{3}	0	0	-	-	0	0
37	114	3.887×10^{3}	1	1.000×10^{-1}	-	-	1.000×10^{-1}	3.226×10^{-3}
37	115	3.887×10^{3}	4	1.828	2.170×10^{-1}	1.539×10^{1}	4.228	5.456×10^{-1}
37	116	3.887×10^{3}	1	1.000×10^{-1}	-	-	1.000×10^{-1}	3.226×10^{-3}
37	117	3.887×10^{3}	0	0	-	-	0	0
38	114	3.887×10^{3}	1	1.000	-	-	1.000	3.226×10^{-2}
38	115	3.887×10^{3}	0	0	-	-	0	0
38	116	3.887×10^{3}	1	1.000×10^{-1}	-	-	1.000×10^{-1}	3.226×10^{-3}
38	117	3.887×10^{3}	1	2.000×10^{-1}	-	-	2.000×10^{-1}	6.452×10^{-3}
Total		6.100×10^{4}	31					1.164

Notes:

[1] Data from Ref. A5.7, Appendix C.

[2] Data from Ref. A5.7, Appendix C. For latitude and longitude boxes with 0 or 1 observed tornado, the point estimate was utilized as the median and the 5th and 95th percentiles were not estimated.

[3] See Section A3.1 for the approach used to estimate the mean and weighted mean. For boxes with 0 or 1 observed tornado, the point estimate was used as the mean.

Source: See Notes.

A5. ANALYSIS INPUTS

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The input from reference A5.8 is supplied from an outside source; it is suitable for use in this analysis. Although not established fact, it presents the published work of experts in the field and is the best available source.

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The input in reference A5.15 is from an outside source; it is suitable for use in this analysis. Although not established fact, it presents the published results of work completed by Lawrence Livermore National Laboratory in accordance with their quality assurance program.

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A5.18. IAEA (International Atomic Energy Agency) 2003. *External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Guide.* Safety Standards Series No. NS-G-1.5. Vienna, Austria: International Atomic Energy Agency. TIC: 259902. (DIRS 177342)

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A6. ANALYSIS CONSTRAINTS

A6.1. 10 CFR 63 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Internet Accessible. (DIRS 180319)

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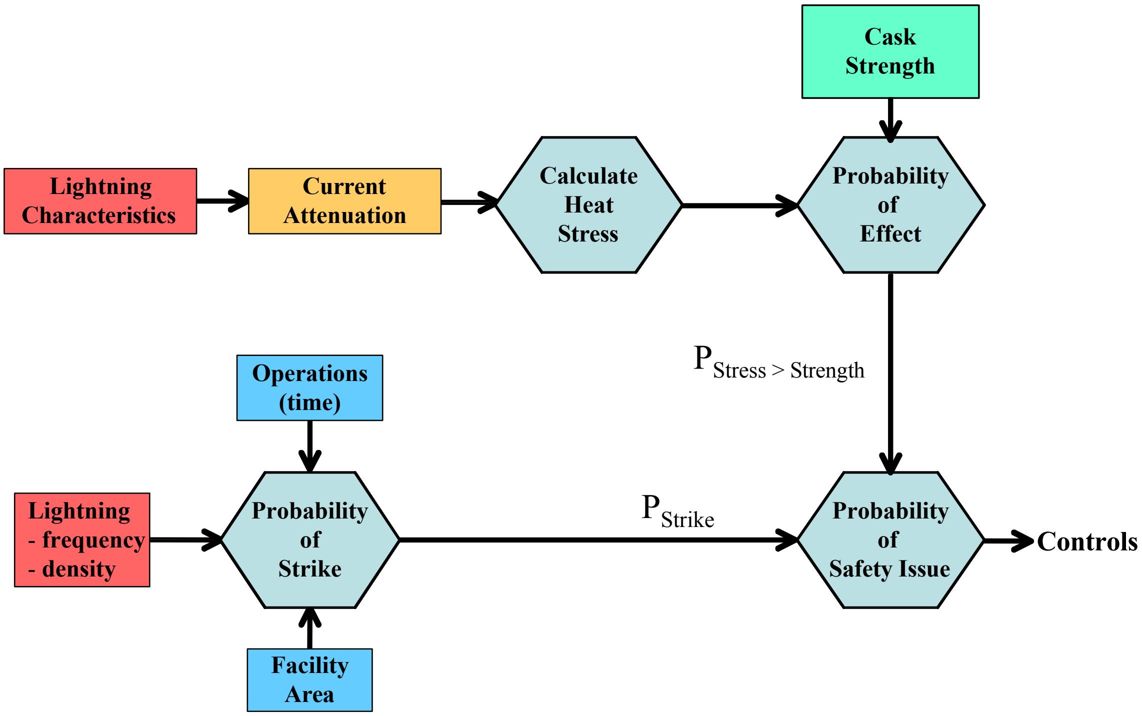
ATTACHMENT B
LIGHTNING STRIKE SCREENING ANALYSIS

B1. INTRODUCTION

Protecting high-risk assets like those at the YMP from lightning damage is a very complex process. National codes are mostly focused on protecting common structures from a lightning strike. For example, the National Fire Protection Association (NFPA) 780 code (Ref. B6.1) was originally concerned with wooden structures, and the specified lightning rods, down conductors and earth ground system were developed to prevent fires. In the 1990's measurements in a modern steel reinforced concrete building struck by rocket-triggered lightning showed that the NFPA 780 (Ref. B6.1) lightning protection system carried 10% or less of the lightning current. The vast majority of the electrons were carried by the more numerous rebar in the concrete (Ref. B6.2). The DOE (Ref. B6.3, Chapter X) and other governmental organizations that must provide lightning protection for high-risk assets and operations, such as with high-explosives, are adapting the most advanced approach around a "Faraday cage." This type of safety system has been implemented at a number of DOE facilities, including Lawrence Livermore National Laboratory (LLNL), and the NFPA continues to update their specifications to incorporate some of the basic ideas.

B2. RISK ASSESSMENT METHODOLOGY AND FOCUS

The risk analysis process is shown in Figure B1. The concern is electrical heating of a cask, raising the wall temperature. The thermal design criteria states the peak cladding temperature should be less than 400°C for normal conditions and 570°C for abnormal conditions (Ref. B6.4, pp. 2-3). Applying these temperature limits to the cask will ensure that the heat-up as a result of a lightning strike will ensure that the cladding temperatures will not approach the limits. Lightning is an off- normal condition, and the temperature rise from the maximum normal condition must be less than 170°C. The bottom half of the diagram shows the components needed to calculate the likelihood of a strike to a Yucca Mountain facility or other area. The factors that go into this calculation are lightning density, operational time, and facility size.



Source: Original

Figure B1. Lightning Strike Risk Calculation Process

The blocks in the upper half of the drawing depict the process of calculating the probability of release given a strike. The lightning threat (upper red block) is a current, and the lightning protection system (orange) attenuates currents that could arc onto a cask. This cask current creates a thermal stress that can be mitigated with a thick layer of steel. The strength of the canister to resist rupture (green block) depends on factors such as electrical properties, wall thicknesses, type of metal joints, and internal pressures.

The goal of the assessment is to determine if there is a much less than 1 in 10,000 chance of a release caused by lightning strikes to YMP facilities over a 100-year pre-closure period, or much less than 10^{-6} release per year.

After examining a number of facility drawings and based on experience hardening other facilities into "Faraday cages," the analysis should focus on two scenarios: (1) The aging pads, even with a catenary-type NFPA (Ref. B6.1) lightning safety system, might allow a side-flash (arcing from the catenary system) due to the long exposure times (years); (2) Casks, during their window of vulnerability during transport or staging. Reinforced concrete buildings, as noted earlier, transmit lightning through the rebar to the ground.

The different configurations considered are shown in Figure B2 showing various levels of shielding. The deep tunnels are likely the most secure. Most of the YMP facilities will be constructed of steel (rebar) reinforced concrete and/or metal, and they are good barriers against a lightning strike. The multiple layers of protection are effective because they divert more current away from the critical assets. The facilities, even if they are not "Faraday cages," will still attenuate currents that might arc over to a canister. No more will be written about these two types of structures. The aging pad even with a lightning protection system will be more exposed. Casks during transport are most exposed.

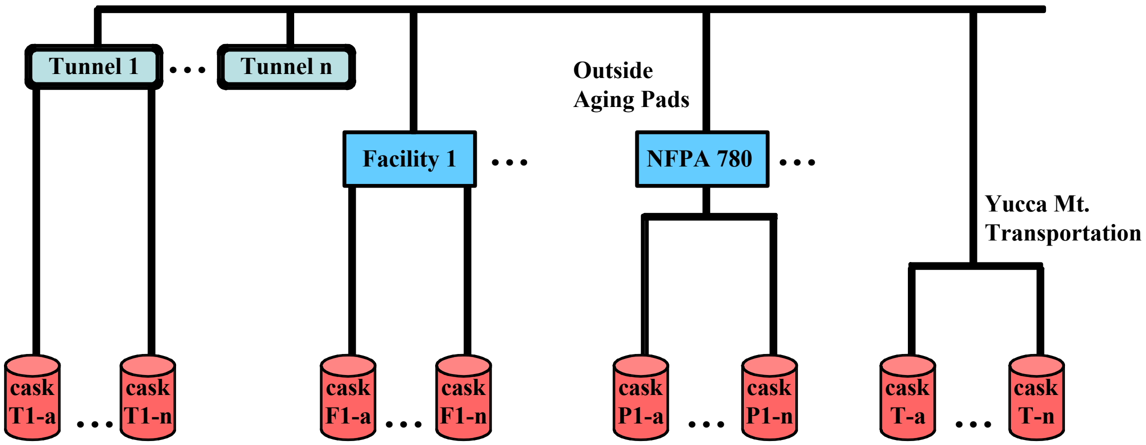


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Figure B2. Yucca Mountain Repository Lightning Protection Considerations

B3. PROBABILITY OF A LIGHTNING STRIKE

Dr. Darryl Randerson from the National Oceanic and Atmospheric Administration (NOAA) performed a multi-year and detailed study of lightning strike density in the 1990s for different areas at the Nevada Test Site (NTS) (Ref. B6.6). He estimated that the Yucca Mountain area should experience about 0.2 flashes per square kilometer per warm season (Ref. B6.6, Table 3). Given the combined areas of the two aging pads, 17R and 17P, of 0.22 km^2 (Table 9), the probability of a strike should be about 0.044 per year. Therefore, the vulnerability of the casks must be evaluated.

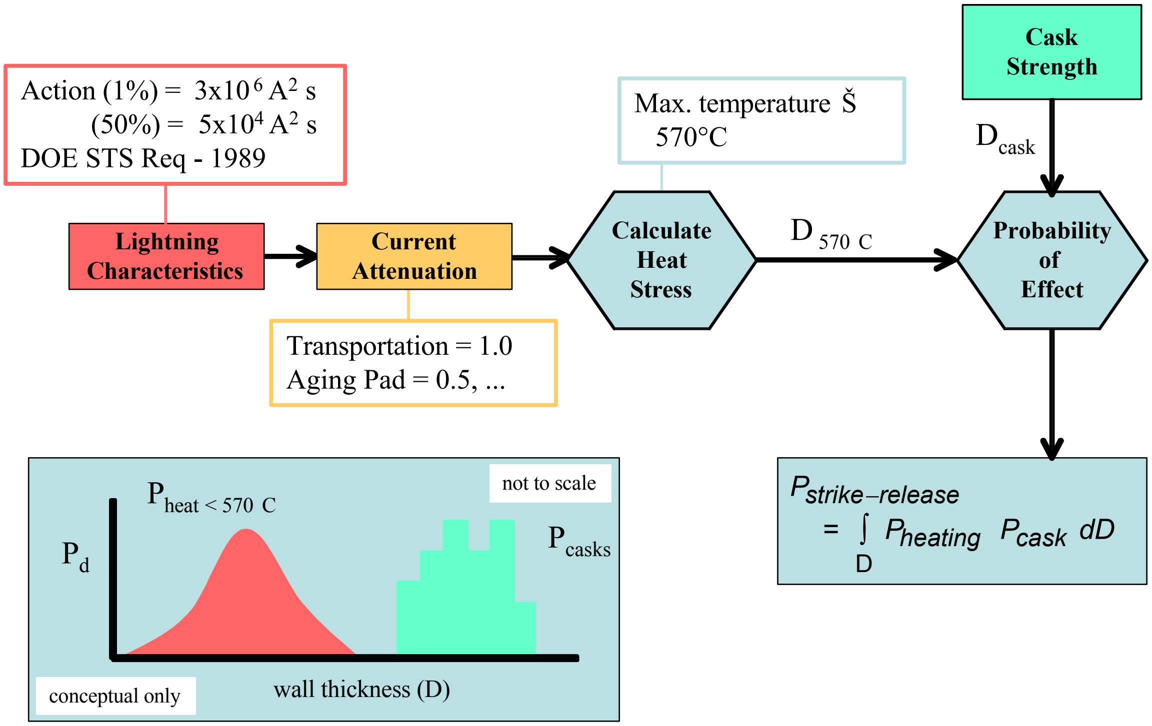
$$\begin{aligned} N_{strike} &= \mathrm{P}_{\text{density}}\ \mathrm{A}_{\text{pads}}\ t_{exposure} \\ &= \left(\frac{0.20 \text{ flash}}{\text{km}^2 \ \text{ year}}\right) 0.22 \text{ km}^2 \ (1\ year) \\ &= 4.4 \text{ x } 10^{-2} \text{ strikes/year} \end{aligned} \qquad \text{(Eq. B1)}$$

The probability of a strike to a cask in the transportation phase is much lower than when sitting on the aging pad because of the smaller number of casks being moved and the short duration of the move. At this point, the risk assessment will be simplified by focusing on the vulnerability of casks directly struck by lightning.

B4. CASK VULNERABILITY ASSESSMENT

A lightning strike causes ohmic heating of the metal walls of a cask. All lightning strikes are different with some depositing more electrons and others less. The duration of the flash also varies. Therefore different wall thicknesses (D) are needed to forestall the temperature rise to 570°C. A hypothetical probability density distribution denoted in red is shown in Figure B3.

The casks with hypothetical wall thicknesses are shown in green. The space between the two distributions is a measure of safety in that the wall thicknesses are greater than the wall thicknesses used in the probability density distribution. The 570°C maximum temperature limit is very conservative because of the conservative selection of a 400°C peak normal condition temperature.



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Note: Action (1%) and Action (50%) are from Ref. B6.7, Table 1.

Figure B3. Casks Vulnerability Determination Process

The lightning threat will be specified as an action that is the time integral of the current squared (Ampere^2 s or A^2 s). An extreme lightning strike [Action (1%)] has an action of 3×10^6 A^2 s. A median strike [Action (50%)] is 5×10^4 A^2 s (Ref. B6.7, Table 1). For a worst-case analysis, the current attenuation will be set to one. This means that there is no safety barrier to divert current. In the following section, minimum thicknesses that assure the wall does not exceed 570°C for different actions will be calculated.

To reduce the number of cask types for evaluation, a typical material is selected (304 stainless steel) and an appropriate safety factor is added at the end to account for small variations. Type 304 stainless steel is common in waste storage containers.

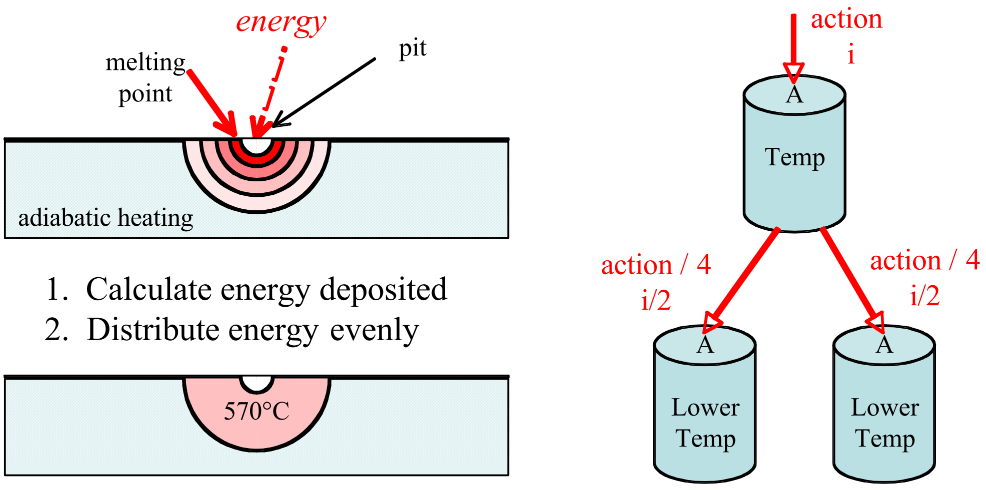
The calculation is preformed using Microsoft Excel version 11.3.7, an accepted software, on a Mac Pro computer running operating system 10.4.10 (files *Heat_Cal_Wrost_-_v3.xls, Heat_Cal_median_-_v3.xls, and Heat_Cal_half_i_-_v3.xls* are included in Attachment D). Ohmic heating must be viewed as a three dimensional problem. Therefore, the wall will be divided into hemispherical shells centered at the strike and sub-divided into sections. The temperature rise will be determined for each shell. The energy and temperature rise equations are as follows:

$$energy = \int R(temp)\ i^2(t)\ dt \qquad \text{(Eq. B2)}$$

$$\Delta Temp = \frac{energy}{\text{mass}\ c_p\,(temp)}$$

Energy is integral of the product of resistance, R, and current squared. A complexity is the resistance increasing with temperature. The temperature rise depends on the energy, mass of the hemisphere, and the specific heat, C_p. The specific heat also increases with temperature. Using the room temperature value of C_p is a conservative simplification.

Heating and cooling of the steel is a dynamic process. The temperature is computed in two steps: (1) The instantaneous temperature rise in hemispherical shells generated by the lightning current will be computed; (2) The heat is redistributed to a hemisphere that has an average temperature of 570°C. (Figure B4, left side.) The radius of the new hemisphere is defined as the calculated wall thickness. Both steps conservatively analyze the process as adiabatic, without heat lost elsewhere.



Source: Original

Figure B4. Wall Thickness Requirements Determination Process

The temperature is lower away from the strike point because the current density is lower. This is depicted on the right side of Figure B4 where the current is divided in half. The action is related to the current squared and must be divided by four.

An ohmic heating and temperature rise derivation is provided in Equation B3. It starts with a balanced power differential equation for the heating of a conductor. The left side of Equation B3a computes the incremental energy deposited in time by the electric current, *i,* in a conductor of a given length and area. The resistivity, ρ, and its temperature coefficient, α, length and area determine the resistance. The right side of the equation gives the incremental temperature rise for the same volume of material with a given density and specific heat, C_p.

$$i^2 \; \rho \, (1 + \alpha \, Temp) \, \frac{\text{length}}{\text{Area}} \, dt = \text{Area length Density } \mathrm{C_p} \; dTemp \tag{Eq. B3a}$$

$$\int i^2 \; dt = \text{Area}^2 \, \frac{\text{Density } \mathrm{C_p}}{\rho} \int \frac{dTemp}{(1 + \alpha \, Temp)} \tag{Eq. B3b}$$

$$\int i^2 \; dt = \text{Area}^2 \, \frac{\text{Density } \mathrm{C_p}}{\rho \, \alpha} \; \text{Ln} \, (1 + \alpha \, Temp) \tag{Eq. B3c}$$

for an initial of Temp_1

$$\int i^2 \; dt = \text{Area}^2 \, \frac{\text{Density } \mathrm{C_p}}{\rho \, \alpha} \; \text{Ln} \left[\frac{1 + \alpha \, Temp_2}{1 + \alpha \, Temp_1} \right] \tag{Eq. B3d}$$

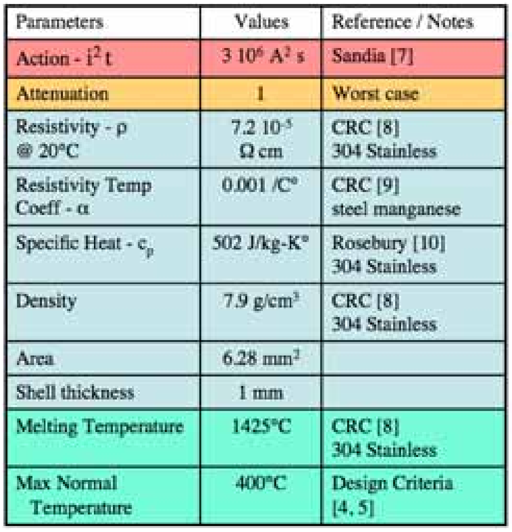
after Taylor series expansion, an approximation is

$$\approx \text{Area}^2 \, \frac{\text{Density } \mathrm{C_p}}{\rho \, \alpha} \; \text{Ln} \left[1 + \alpha \, (Temp_2 - Temp_1) \right] \tag{Eq. B3e}$$

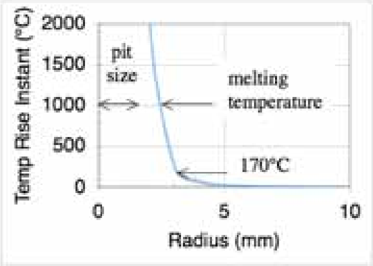
$$\Delta Temperature = Temp_2 - Temp_1$$

$$= \frac{1}{\alpha} \left(\mathrm{e}^{\frac{\rho \, \alpha}{\text{Density } \mathrm{C_p}} \frac{1}{\text{Area}^2} \int i^2 \, \mathrm{dt}} - 1 \right) \tag{Eq. B3f}$$

The values for the different parameters and the instantaneous temperature rise for the extreme (1%) action are shown in Figure B5 (Ref. B6.7; Ref. B6.8; and Ref. B6.9, p. E-91). The area of the sections in the hemispherical shells was selected to be a constant 6.28 mm^2, and the temperature was calculated at 1 mm steps.



Parameters	Values	Reference / Notes
Action - $i^2 t$	$3\ 10^6\ A^2\ s$	Sandia [7]
Attenuation	1	Worst case
Resistivity - ρ @ 20°C	$7.2\ 10^{-5}$ Ω cm	CRC [8] 304 Stainless
Resistivity Temp Coeff - α	0.001 /C°	CRC [9] steel manganese
Specific Heat - c_p	502 J/kg-K°	Rosebury [10] 304 Stainless
Density	7.9 g/cm^3	CRC [8] 304 Stainless
Area	6.28 mm^2	
Shell thickness	1 mm	
Melting Temperature	1425°C	CRC [8] 304 Stainless
Max Normal Temperature	400°C	Design Criteria [4, 5]



Notes: Reference Sandia [7] refers to Ref. B6.7, CRC [8] refers to Ref. B6.8 (provided for temperature at 20°C), CRC [9] refers to Ref. B6.9, p. E-91, Rosebury [10] refers to Ref. B6.10, p. 502, and Design Criteria [4, 5] refers to Ref. B6.4, pp. 2-3, and Ref. B6.5

Source: Original

Figure B5. Physical Parameters Used in Lightning Temperature Rise Calculation

The thermal rise calculations start at 400°C, the peak normal temperature. The resistivity is also increased from the value at 20°C to $1.0\ 10^{-4}\ \Omega$ cm using the temperature coefficient. At the strike point, the temperature is very high and the metal is vaporized, leaving a pit. Based on the thermal calculations, the pit has a radius of approximately 1 to 2 mm. The melting temperature of 304 stainless steel is about 1425°C, and this temperature occurs between the 2 mm and 3 mm shells. The instantaneous temperature drops quickly with increasing radius, and the wall temperature is less than 570°C (170°C plus 400°C) beyond the 3 mm shell (plot in Figure B5).

The instantaneous heating occurs extremely fast, in much less than a second. Later, heat will radiate into the air and dissipate into the cooler metal at a much slower rate. A conservative method to incorporate this diffusion effect is to calculate an average temperature for different hemispheres by adiabatic heating, (i.e., no heat is lost outside the hemisphere). The average temperature of a hemisphere is calculated by adding the temperature of all the sections and dividing by the total number of sections. The hemispherical pit represented by the first section is not included in the average temperature calculation. The maximum average temperature rise of 170°C is the difference between the abnormal maximum temperature (570°C) and the normal maximum temperature (400°C).

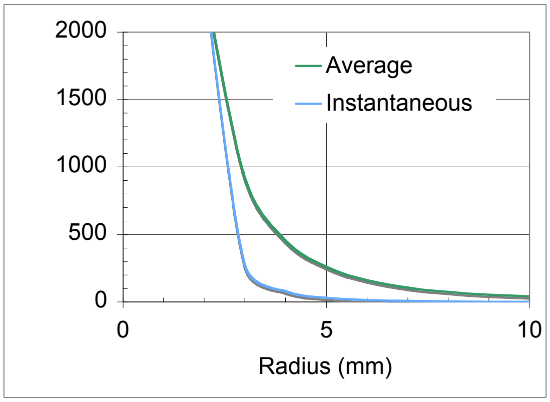
$$\Delta Temperature_{avg}(radius) = \frac{1}{\text{total section (radius)}} \sum_{\text{total section}} \Delta Temperature_{section} \qquad \text{(Eq. B4)}$$

$$\Delta \mathrm{Temp}_{\text{avg-max}} = \mathrm{Temp}_{\text{max-abnormal}} - \mathrm{Temp}_{\text{max-normal}}$$
$$= 570^\circ\mathrm{C} - 400^\circ\mathrm{C} = 170^\circ\mathrm{C}$$

Table B1. Temperature Rise for Hemispherical Shells

Radius (mm)	1	2	3	4	5	6
No. of Sections	1	4	9	16	25	36
Average Section Area (cm²)	0.031	0.063	0.063	0.063	0.063	0.063
Total Sections	1	4	13	29	54	90
Instantaneous Temp Rise (°C)	1.28E+36	2,291	265	77	31	15
Average Temp. Rise (°C)	pit	2,291	889	441	251	157

Source: Original



Source: Original

Figure B6. Instantaneous and Average Temperature Rise

The instantaneous (denoted in blue) and average (green) temperatures are compared in Figure B6. At a radius of 6 mm, the average temperature rise is below the required 170°C. Therefore, a cask with a wall thickness of greater than 6 mm when struck by extreme lightning should maintain an interior temperature of less than 570°C.

To account for different cask designs (e.g., material type) a safety factor of two will be used to specify the minimum wall thickness. This thickness is a conservative number for a 304 stainless steel-like material because the temperature drops very quickly with radius:

- Calculated thickness = 6 mm
- Safety factor = 2
- Minimum wall thickness = 12 mm

The 1% and 50% action levels and the required minimum wall thickness are shown in Table B2. A median action strike during transportation requires a minimum wall thickness of 8 mm.

Table B2. Minimum Wall Thickness for Different Levels of Action during Transportation

Action	Action Normalized	Min. wall thickness (incl. safety factor)	Note
$3x10^6$ A^2 s	1	12 mm	1%, worst case; during transportation
$5x10^4$ A^2 s	0.013	8 mm	50%, median case; during transportation

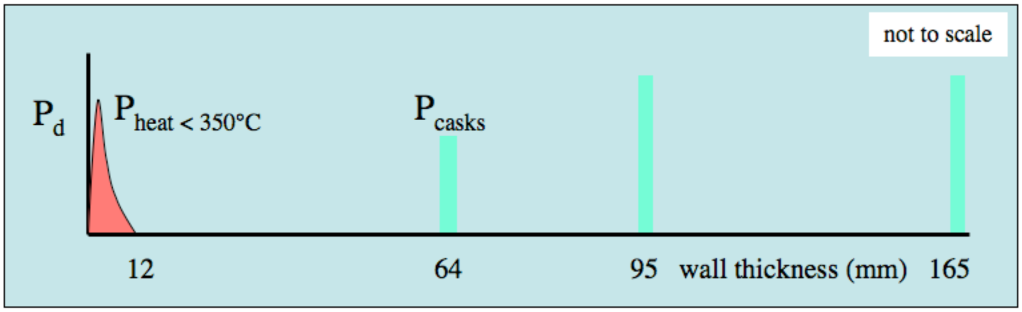
Source: Original

There are many cask designs, and they are robust because of other safety threats, such as drops, crashes, and fire. After examining a number of designs, the TEV seems to have the thinnest wall (Ref. B6.11, Table 3). The properties are listed in Table B3. There are three layers of stainless steel with a polymer between the outer and middle layers, and 1.5 in. of depleted uranium between the second and inner layers. The outer layer of steel is 0.5-inch thick and is sufficient to meet the minimum thickness requirement of 12 mm. The three layers have a combined width of 2.5 in. or 64 mm that provides additional shielding beyond the first 0.5-inch wall. Figure B7 shows an estimated minimum wall thickness probability density distribution in red, and combined wall thicknesses of the mentioned cask, and two other proprietary-design casks that were examined. The number of casks, cask types and duration of exposure are not yet known; nonetheless the safety margin should be very large.

Table B3. The Transport and Emplacement Vehicle Properties

Cask Type	Wall Thickness	Material	Purpose	Note
Transportation and Emplacement Vehicle	0.5" + 1.5" + 0.5" = 2.5" (64mm)	stainless	move from buildings to tunnel	Worst case - also has 6" polymer and 1.5" depleted uranium shield

Source: Ref. B6.11, Table 3.



Source: Original

Figure B7. Combined TEV Walls Thickness

B5. CONCLUSIONS AND RECOMMENDATIONS

A simplified quantitative approach was applied to the risk assessment focusing on worst-case stress-versus-strength comparison rather than rigorous probabilistic analysis. The chance of a cask being struck by lightning is small. If there is a strike to a cask and its metal wall thickness is greater than 12 mm, the average interior wall temperature under the strike point will not exceed 570°C. Based on designs meeting the temperature criteria of less than 570°C peak for abnormal conditions, such as lightning strikes, there will be no radioactive release.

If a NFPA 780 (Ref. B6.1) lightning protection system must be developed for the aging pads, a catenary design is recommended but this analysis did not rely on a lightning protection system.

B6. ANALYSIS INPUTS

B6.1. NFPA 780. 2004. *Standard for the Installation of Lightning Protection Systems.* 2004 Edition. Quincy, Massachusetts: National Fire Protection Association. TIC: 257246. (DIRS 173517)

B6.2. Schnetzer, G.H.; Charel, J.; Davis, R.; Fisher, R.J.; and Magnotti, P.J. 1995. "Test Description and Data Summary." Volume 1 of *1994 Triggered Lightning Test Program: Measured Responses of a Reinforced Concrete Building Under Direct Lightning Attachments.* SAND95-1551/1. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.20071113.0094. (DIRS 183850)

The input in reference B6.2 is from an outside source; it is suitable for use in this analysis. Although not established fact, it presents the published results of work completed by Sandia National Laboratory in accordance with their quality assurance program.

B6.3. “DOE Explosive Safety Manual”, DOE M 440.1-1A, Jan 2006, Department of Energy, Available On-Line at www.directives.doe.gov. ACC: MOL.20080122.0255.

B6.4. NRC (U.S. Nuclear Regulatory Commission) 2003. *Interim Staff Guidance - 11, Revision 3. Cladding Considerations for the Transportation and Storage of Spent Fuel.* ISG-11, Rev. 3. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: MOL.20040721.0065. (DIRS 170332)

B6.5. BSC 2007. *Project Design Criteria Document.* 000-3DR-MGR0-00100-000-007. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071016.0005; ENG.20071108.0001; ENG.20071220.0003; ENG.20080107.0001; ENG.20080107.0002; ENG.20080107.0016; ENG.20080107.0017.

B6.6. Randerson, D. and Sanders, J.B. 2002. *Characterization of Cloud-to-Ground Lightning Flashes on the Nevada Test Site.* NOAA Technical Memorandum OAR ARL-242. Silver Spring, Maryland: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. ACC: MOL.20070227.0026. (DIRS 183552)

The input from reference B6.6 is supplied from an outside source; it is suitable for use in this analysis. Although not established fact, it presents the published work of experts in the field and is the best available source.

B6.7. Fisher, R.J. and Uman, M.A. 1989. *Recommended Baseline Direct-Strike Lightning Environment for Stockpile-to-Target Sequences.* SAND89-0192. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.20071115.0066. (DIRS 183931)

The input in reference B6.7 is from an outside source; it is suitable for use in this analysis. Although not established fact, it presents the published results of work completed by Sandia National Laboratory in accordance with good laboratory practices.

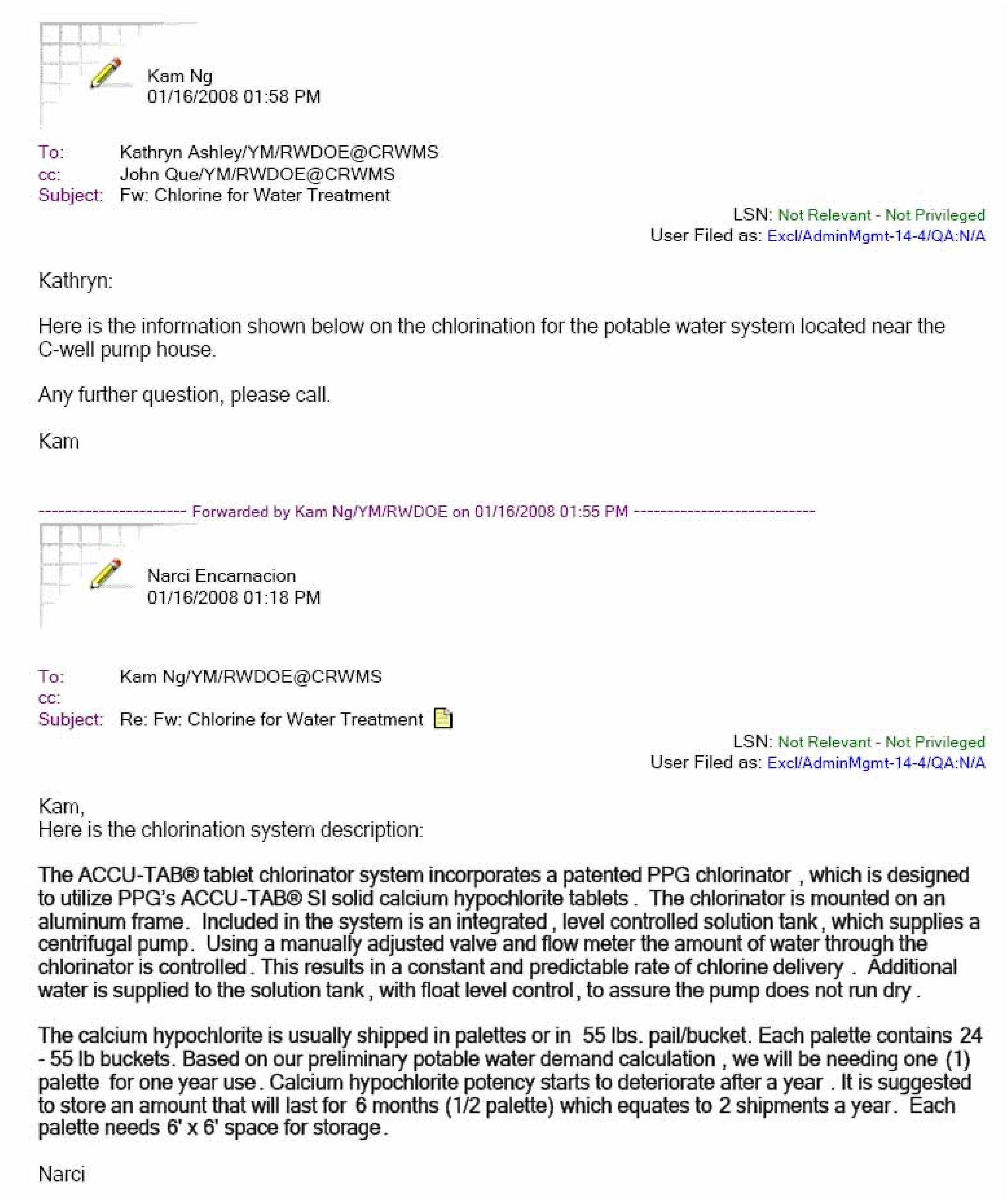
B6.8. Lide, D.R., ed. 2008. *CRC Handbook of Chemistry and Physics.* 88th Edition. Boca Raton, Florida: CRC Press. TIC: 259851 ISBN - 0849304881.

B6.9. Weast, R.C., ed. 1987. *CRC Handbook of Chemistry and Physics: 1987-1988.* 68th Edition. Boca Raton, Florida: CRC Press. ISBN - 0849304687.

B6.10. Rosebury, F. 1965. *Handbook of Electron Tube and Vacuum Techniques.* Reading, Massachusetts: Addison-Wesley Publishing Company. TIC: 259846. (DIRS 184094)

B6.11. BSC 2007. *Mechanical Handling Design Report: Waste Package Transport and Emplacement Vehicle.* 000-30R-HE00-00200-000-001. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071205.0002.

ATTACHMENT C
E-MAIL FOR REFERENCE 2.2.65



Kam Ng
01/16/2008 01:58 PM

To: Kathryn Ashley/YM/RWDOE@CRWMS
cc: John Que/YM/RWDOE@CRWMS
Subject: Fw: Chlorine for Water Treatment

LSN: Not Relevant - Not Privileged
User Filed as: Excl/AdminMgmt-14-4/QA:N/A

Kathryn:

Here is the information shown below on the chlorination for the potable water system located near the C-well pump house.

Any further question, please call.

Kam

---------------------- Forwarded by Kam Ng/YM/RWDOE on 01/16/2008 01:55 PM ---------------------------

Narci Encarnacion
01/16/2008 01:18 PM

To: Kam Ng/YM/RWDOE@CRWMS
cc:
Subject: Re: Fw: Chlorine for Water Treatment

LSN: Not Relevant - Not Privileged
User Filed as: Excl/AdminMgmt-14-4/QA:N/A

Kam,
Here is the chlorination system description:

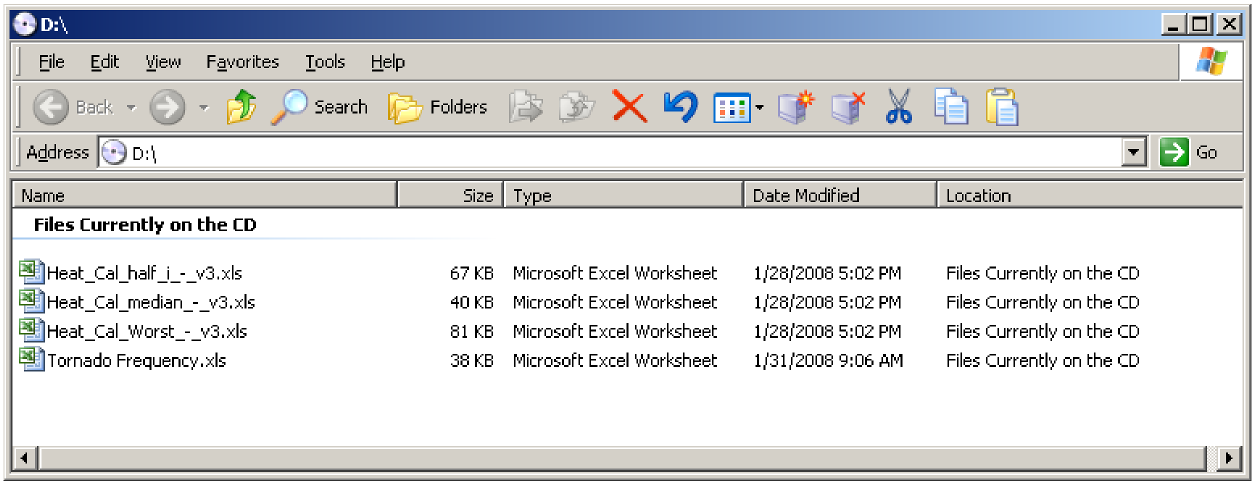
The ACCU-TAB® tablet chlorinator system incorporates a patented PPG chlorinator , which is designed to utilize PPG's ACCU-TAB® SI solid calcium hypochlorite tablets . The chlorinator is mounted on an aluminum frame. Included in the system is an integrated , level controlled solution tank , which supplies a centrifugal pump. Using a manually adjusted valve and flow meter the amount of water through the chlorinator is controlled . This results in a constant and predictable rate of chlorine delivery . Additional water is supplied to the solution tank , with float level control , to assure the pump does not run dry .

The calcium hypochlorite is usually shipped in palettes or in 55 lbs. pail/bucket. Each palette contains 24 - 55 lb buckets. Based on our preliminary potable water demand calculation , we will be needing one (1) palette for one year use . Calcium hypochlorite potency starts to deteriorate after a year . It is suggested to store an amount that will last for 6 months (1/2 palette) which equates to 2 shipments a year. Each palette needs 6' x 6' space for storage .

Narci

ATTACHMENT D
CD AND FILE LISTING

This attachment includes the CD containing the Excel files used in this analysis. The files contained on the CD are listed below:



Files Currently on the CD

Name	Size	Type	Date Modified	Location
Heat_Cal_half_i_-_v3.xls	67 KB	Microsoft Excel Worksheet	1/28/2008 5:02 PM	Files Currently on the CD
Heat_Cal_median_-_v3.xls	40 KB	Microsoft Excel Worksheet	1/28/2008 5:02 PM	Files Currently on the CD
Heat_Cal_Worst_-_v3.xls	81 KB	Microsoft Excel Worksheet	1/28/2008 5:02 PM	Files Currently on the CD
Tornado Frequency.xls	38 KB	Microsoft Excel Worksheet	1/31/2008 9:06 AM	Files Currently on the CD