Department of Energy
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QA: N/A
Project No. WM-00011

NOV 25 2005

OVERNIGHT MAIL

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RESPONSE TO PRELICENSING EVALUATION OF KEY TECHNICAL ISSUE (KTI) AGREEMENT ITEM PRECLOSURE (PRE) 3.01

References: (1) Ltr, Kokajko to Ziegler, dtd 8/2/05 (Prelicensing Evaluation of Preclosure KTI PRE 3.01)
(2) Ltr, Ziegler to Director, Division of High-Level Waste Repository Safety (NRC), dtd 5/16/05 (Transmittal of Aircraft Hazards Documents)

The purpose of this letter is to respond to "U.S. Nuclear Regulatory Commission (NRC) Staff Feedback on U.S. Department of Energy (DOE) Aircraft Hazards Analyses" (Reference 1) and to acknowledge closure of KTI Agreement Item PRE 3.01.

Several of the NRC staff comments are addressed by a recent revision of the *Frequency Analysis of Aircraft Hazards for License Application*, issued August 26, 2005 (Enclosure 1). Due to changes in the proposed no-fly zone under discussion and the assumed crash rates used in the analysis, several of the features described in the NRC comments are no longer credited in the revised analysis. The revised analysis addresses six of the thirteen items from the August 2, 2005 letter (Enclosure 2). The remaining seven items will be addressed in a future revision to the frequency analysis report. When the report is issued, DOE will make it publicly available via the DOE website.

One specific change to DOE's approach concerns the implementation of a no-fly zone surrounding the repository. During the June 1, 2005, Technical Exchange on Pre-Closure Interactions and Aircraft Hazards, DOE noted that a Memorandum of Understanding (MOU) was in development with the United States Air Force (USAF) to implement the no-fly zone. USAF representatives have advised DOE that they would comply with proposed DOE flight restrictions resulting from DOE's safety analysis. As a result, DOE is no longer pursuing the MOU approach. The DOE's current approach is to formally inform the USAF of the future restrictions on flight activities in the Yucca Mountain, Nevada, area that are credited in the safety analysis and that will go into effect prior to repository operations.

There are no new regulatory commitments in the body of this letter. If you have any questions regarding this response, please contact Robin L. Sweeney at (702) 794-1417 or e-mail robin_sweeney@ymp.gov, or contact David C. Haught at (702) 794-5474 or e-mail david_haught@ymp.gov.

April V. Gil

Claudia M. Newbury, Acting Director
Office of License Application and Strategy

OLA&S:DCH-1885

Enclosures:
1. *Frequency Analysis of Aircraft Hazards for License Application,* August 2005
2. DOE Responses to Six of the Thirteen NRC Staff Feedback Items on the Aircraft Hazard Analyses

BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA: QA
2. Page 1

3. System Waste Handling System	4. Document Identifier 000-00C-WHS0-00200-000-00D
5. Title Frequency Analysis of Aircraft Hazards for License Application	
6. Group Preclosure Safety Analyses	
7. Document Status Designation ☐ Preliminary ☒ Committed ☐ Final ☐ Cancelled	

8. Notes/Comments

A review per LP-2.14Q-BSC is not required since the results of this analysis have no impact on the use of technical output by other organizations.

This revision supersedes Rev. 00C. Changes with respect to Rev. 00C are marked by change bars, except for Attachment IV, which should be reviewed in its entirety.

Attachments	Total Number of Pages
I. Flights through Beatty Corridor	3
II. Flight Distribution in the NTTR and NTS Airspace	3
III. Information on a Sample of Military Aircraft Crashes	23
IV. Effective Target Areas and Crash Frequencies	6

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. Approved/Accepted (Print/Sign/Date)
00A	Initial issue	39	39	Guy Ragan	Peter Davis Nohemi Ramirez	Dennis Richardson 5/7/04
00B	Reflect changes in safety approach. Reflect changes in inputs. Supersede Rev. 00A	84	IV-8	Guy Ragan	Pierre Macheret John Wang	Dennis Richardson 2/14/05
00C	Change the size and shape of the no-fly zone. Cite a revised reference and delete another reference because copyright clearance for a reference was denied. Make other minor technical and editorial changes. Supersede Rev. 00B.	84	IV-8	Guy Ragan	Pierre Macheret	Dennis Richardson 5/2/05
00D	Reflect changes in safety approach. Include additional discussion and justification of assumptions. Address CR-5664 and CR-5665.	49+3+3+23+6=84	IV-6	K. L. Ashley K.L. Ashley 8/25/05	Pierre Macheret P. Maclt 08/25/05	Mark Wisenburg [signature] 08/26/2005

Enclosure 1

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FIGURES

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TABLES

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ACRONYMS AND ABBREVIATIONS

ACRAM	Airport Crash Risk Analysis Methodology
CDF	cumulative distribution function
CHF	Canister Handling Facility
DIRS	Document Input Reference System
DOE	U.S. Department of Energy
DTF	Dry Transfer Facility
EC South	Electronic Combat South
ESF	Exploratory Studies Facility
FAA	U.S. Federal Aviation Administration
FHF	Fuel Handling Facility
LLWH	Low Level Waste Handling
MGR	Monitored Geologic Repository
mi	statute mile
MOA	military operations area
MSL	mean sea level
MTHM	metric ton heavy metal
NM	nautical mile
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NTTR	Nevada Test and Training Range
PDF	probability density function
TCRRF	Transportation Cask Receipt/Return Facility
VORTAC	very high frequency omnidirectional range and tactical air navigation station
YMR	Yucca Mountain Repository

MATHEMATICAL NOMENCLATURE

δA	Size of an area exposed to the risk of aircraft crash
Φ_0	Crash frequency density outside the no-fly zone (crashes / y / mi^2)
Φ_c	Crash frequency density at the center of the no-fly zone (crashes / y / mi^2)
ϕ	Approach angle to the ground of a crashing aircraft (degrees)
γ	Decay constant for an exponential distribution of crash locations as a function of distance from the intended flight path (mi^{-1})
λ	Crash rate per mile flown or a vector of crash rates by aircraft type (mi^{-1})
ρ	A vector of edge adjustment factors by aircraft type (dimensionless)
A	Effective target area of a ground facility with respect to airborne hazards or a matrix of effective target areas by structure and aircraft type (mi^2)
$A_{\text{fly-in}}$	Effective target area of a ground facility with respect to airborne hazards ignoring skid impact (mi^2)
A_{skid}	Effective target area of a ground facility with respect to airborne hazards ignoring fly-in impact (mi^2)
A_z	Area of the no-fly zone
B	A vector of distances to barriers that would prevent a skid-in impact (ft)
C	A vector of cotangents of approach angles from horizontal (dimensionless)
d	Distance between the center of a facility outside an airway and the edge of an airway (mi)
D	Outside diagonal distance horizontally across a surface facility or a vector of such distances (ft)
F	Annual frequency of aircraft crashes into a surface facility or a matrix by structure and aircraft type of crash frequencies from aircraft originating on the Beatty Corridor (y^{-1})
F_0	Annual frequency of aircraft crashes into a surface facility located on the edge of an airway (y^{-1})
G	A wingspan or vector of wingspans (ft)
H	A vector of heights or a scalar height of a surface facility (ft)
K	A vector of skid distances by type of aircraft (ft)
l_m	Mean length of flights through a flight area (mi)

MATHEMATICAL NOMENCLATURE (continued)

L	A vector of lengths or a scalar length of a surface structure (ft)
L_z	Perimeter of the no-fly zone (mi)
n	Number of observations for a sample cumulative distribution function
N	Annual frequency of flights through a flight area or a vector of flight frequencies by aircraft type (y^{-1})
p_c	Fraction of crash initiating event that occur above the no-fly zone that result in a crash on the ground beneath the no-fly zone
Q	A vector that indicates the quantities of structures of a certain kind (dimensionless)
r	Distance that a fixed-wing military aircraft travels after the pilot ejects or otherwise loses control before crashing
R	Radius of the no-fly zone (mi)
S	Skid distance traveled on the ground by an aircraft before crashing into a ground facility or a matrix of effective skid distances by aircraft type and structure (ft)
T	Duration of exposure to aircraft crash risk
w	Width of an airway (mi)
W	A vector of widths or a scalar width of a surface structure (ft)
x	Distance perpendicular to an intended flight path (mi)
Y	A matrix of effective target areas of structures by aircraft type (mi^2)
Z	A matrix of fractional contributions to the total effective target area by structure and aircraft type (dimensionless)

1. PURPOSE

The preclosure safety analysis for the monitored geologic repository (MGR) at Yucca Mountain must consider the hazard that aircraft accidents may pose to surface structures. This analysis deals only with the MGR itself and not the transportation routes to the site. The relevant surface structures are to be located beneath the restricted airspace of the Nevada Test Site (NTS) on the eastern slope of Yucca Mountain, near the North Portal of the Exploratory Studies Facility (ESF) Tunnel (Figure 1). The North Portal is within several miles of the Nevada Test and Training Range (NTTR), which the U.S. Air Force uses extensively for training and test flights (Figure 1). By agreement with the U.S. Department of Energy (DOE), Air Force aircraft may also use the airspace above the NTS. Commercial, military, and general aviation aircraft fly within several miles to the southwest of the repository site in the Beatty Corridor, which is a broad air corridor that runs approximately parallel to U.S. Highway 95 and the Nevada-California border (Figure 2). These and other aircraft operations are identified and described in *Identification of Aircraft Hazards* (BSC 2005 [DIRS 173243], Sections 6 and 8).

The purpose of this analysis is to estimate crash frequencies for the aircraft hazards that were identified for detailed analysis in *Identification of Aircraft Hazards* (BSC 2005 [DIRS 173243], Section 8). This analysis is intended to provide a basis for:

- Categorizing event sequences related to aircraft hazards as Beyond Category 2
- Design or operational requirements related to aircraft hazards.

2. QUALITY ASSURANCE

The Office of Civilian Radioactive Waste Management's Quality Assurance program applies to this analysis because it is part of the preclosure safety analysis.

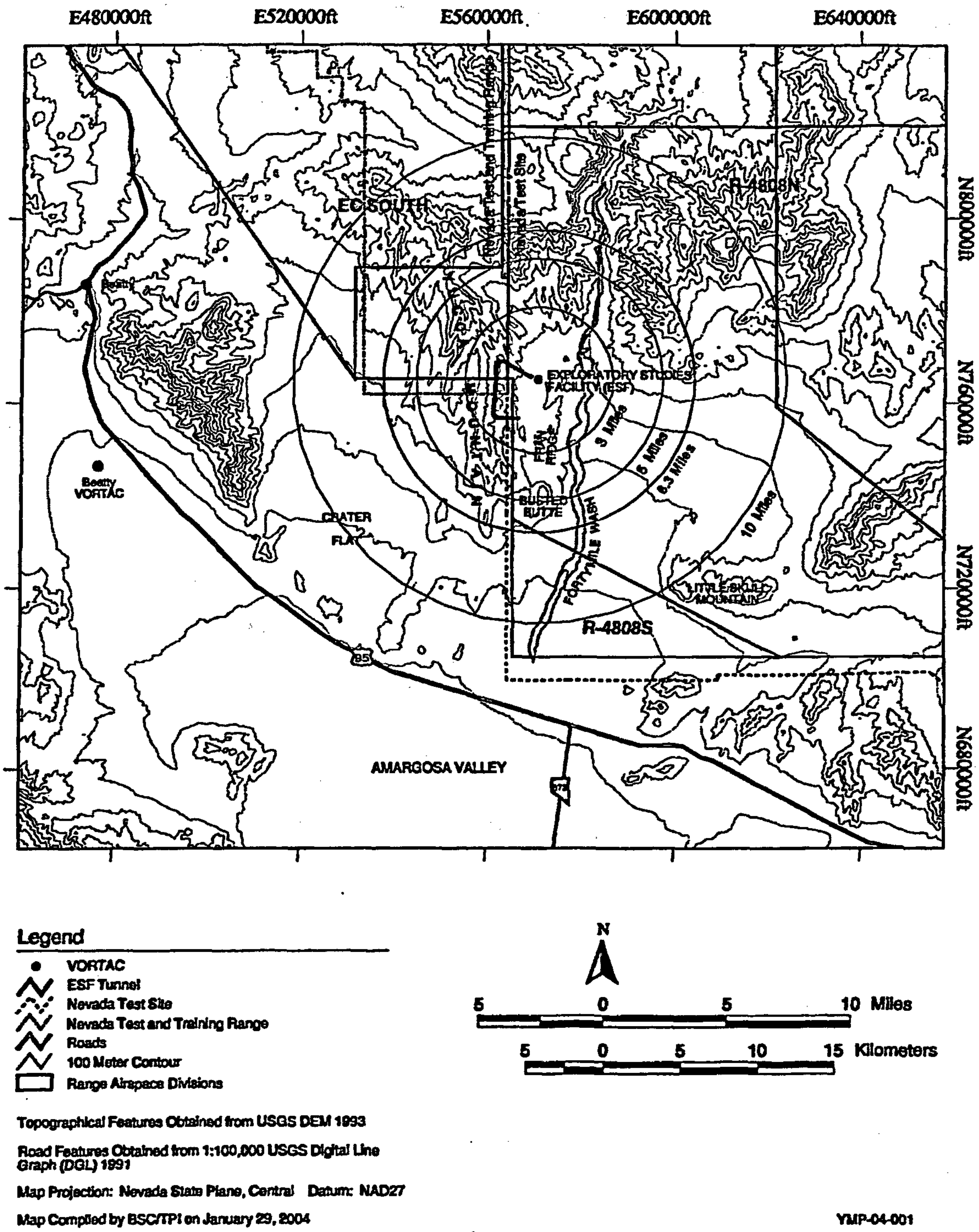
3. USE OF SOFTWARE

3.1 SOFTWARE APPROVED FOR QUALITY ASSURANCE WORK

None used.

3.2 COMMERCIAL OFF-THE-SHELF SOFTWARE USED

Microsoft Excel 97 SR-2 and Microsoft Access 97 SR-2, commercially available software packages, and Mathcad 11.2a were used to filter data and calculate results. These software applications are appropriate because only standard mathematical and sorting functions that are available in Excel, Mathcad, and Access were used to derive the results (which do not depend on the particular software program). The formulas used are presented in sufficient detail in Section 6.2 and elsewhere at the point of use to allow an independent check to reproduce or verify the results. Inputs are presented in Sections 4 and 5. Results are presented in Section 6.3 and elsewhere at the point of use.



NOTE: Subdivisions of R-4808N are shown but not labeled. R-4808N includes all of R-4808 north of R-4808S. The 6.3-mi circle represents the proposed no-fly zone and was superimposed on the original map after the date indicated.

Figure 1. Topography and Other Features Near the Repository Site

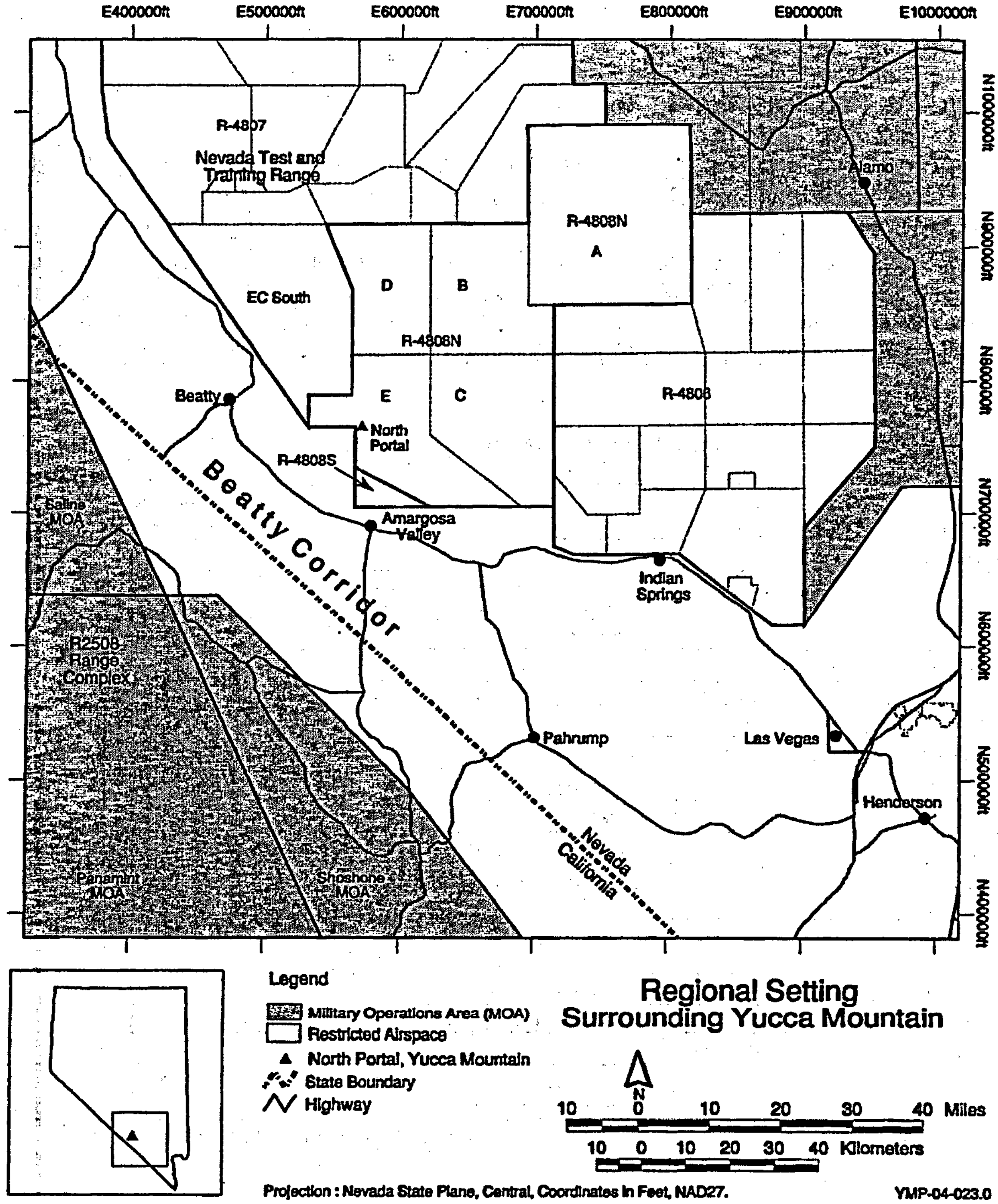


Figure 2. Beatty Corridor

4. INPUTS

4.1 HAZARDS CONSIDERED

The hazards considered in this analysis are listed in *Identification of Aircraft Hazards* (BSC 2005 [DIRS 173243], Section 8), which also provides more detail about the airspace near the repository site. Dropped ordnance is also considered as a hazard because live ordnance may be carried over EC South and NTS airspace; however, ordnance is not armed until over Air Force Land on the R-4807 or R-4806 bombing ranges (Wood 2004 [DIRS 169894], pp. 3 through 6). See Figure 1 and Figure 2 for depictions of the airspace in the vicinity. Table 1 maps the identified hazards to the sections in this analysis that treats them (BSC 2005 [DIRS 173243], Section 8).

Table 1. Aircraft Hazards Considered

Type of Airspace/Airport	Aircraft	Cross Reference to Sections in the Present Analysis
DOE Designated Airspace		
R-4808	Small attack/fighter military aircraft, including dropped ordnance	5.1.4, 6.3.2, 6.3.3
Military Designated Airspace		
Electronic Combat (EC) South area of R-4807 and western portion of R-4806	Small attack/fighter military aircraft	6.3.2, 6.3.3
Civilian and DOE Airports		
DOE Area Pad 29	Helicopters	6.4
Field Operations Office Helipad	Helicopters	6.4
Federal Airways and Jet Routes (Beatty Corridor; Includes R-4808S)[a]		
Jet Route J-86	Military, commercial and general aviation aircraft	6.3.1
Jet Route J-92	Military, commercial and general aviation aircraft	6.3.1
Federal Airway V-105	Military and civilian aircraft	6.3.1
Federal Airway V-135	Military and civilian aircraft	6.3.1
Uncontrolled Airspace (Beatty Corridor)		
Class G airspace	Small piston-engine aircraft, helicopters, and gliders	6.3.1

NOTE: [a]These federal airways and jet routes are depicted in *Identification of Aircraft Hazards* (BSC 2005 [DIRS 173243], Figure 6-2).

4.2 INPUTS FROM EXTERNAL SOURCES

4.2.1. Aircraft Characteristics for Calculating Effective Target Areas

The effective target area of an object on the ground is the equivalent area on the ground of the object considering that the aircraft

- May have a significant wingspan compared to the dimensions of the object
- May skid some distance on the ground before striking the object
- Approaches the object at some angle ϕ from horizontal.

Therefore, the effective target area of an object on the ground depends on characteristics of the aircraft potentially involved in a crash. Aircraft characteristics used in this calculation (Table 2) are taken from *DOE Standard, Accident Analysis for Aircraft Crash into Hazardous Facilities* (DOE-STD-3014-96, [DIRS 101810] Tables B-16, B-17, and B-18).

Table 2. Aircraft Characteristics Used for Effective-Area Calculations

Aircraft Type	Representative Wingspan [a] G (ft)	Mean Skid Distance [b] S (ft)	ϕ [c] (degrees)	Cot(ϕ) [d] (unitless)
General Aviation				
Piston engine	50	60	7.0	8.2
Turboprop	73	60	7.0	8.2
Turbojet	50	60	7.0	8.2
Commercial Aviation				
Air carrier (14 CFR Part 121)[e]	98	1440	5.6	10.2
Air taxi (14 CFR Part 135)[e]	59	1440	5.6	10.2
Military Aviation				
Large aircraft	223	780	7.7	7.4
Fighter, attack, and trainer aircraft	78	246	6.8	8.4

SOURCES: [a]DOE-STD-3014-96, [DIRS 101810] Table B-16.

[b]DOE-STD-3014-96, [DIRS 101810] Table B-18. Takeoff values are used for in-flight crashes of military aircraft in accordance with the recommendations of DOE-STD-3014-96, [DIRS 101810] p. B-28.

[c]Impact angle is not provided in the reference; but is calculated here as $\tan^{-1}(1 / \cot \phi)$.

[d]Mean of the cotangent of the impact angle ($\cos \phi / \sin \phi$) from DOE-STD-3014-96, [DIRS 101810] Table B-17. Takeoff values for military aircraft are used for in-flight crashes in accordance with the recommendations of DOE-STD-3014-96, [DIRS 101810] p. B-28.

[e]The "air carrier" type includes major airlines that may be scheduled or unscheduled and cargo carriers that fly large aircraft. DOE-STD-3014-96 generally refers to flights regulated by 14 CFR Part 121 [DIRS 168506] as air carriers and those regulated under 14 CFR Part 135 [DIRS 168507] as air taxis. This corresponds to the usage by the Federal Aviation Administration (FAA) of the air-carrier (AC) and air-taxi (AT) types in data that was provided for this analysis (Buckingham 2004 [DIRS 168482]). The definition of air taxis used in DOE-STD-3014-96 (p. 10) includes aircraft "under 30 seats or a maximum payload capacity of less than 3,401 kg (7,500 lb)" that are operating in accordance with 14 CFR Part 135. In March 1997 (after DOE-STD-3014-96 was published) the definitions of 14 CFR Parts 121 and 135 operations changed (NTSB 2003 [DIRS 168398], pp. 1 and 2). Under the new rules most carriers known as commuters now operate under 14 CFR Part 121. Unscheduled 14 CFR Part 135 aircraft are a diverse group that includes small aircraft and large corporate jets (NTSB 2003 [DIRS 168398], p. 2).

4.2.2. Crash Rates for Aircraft

Statistics for crash rates of fixed-wing aircraft in the present analysis (Table 3 and Table 4) are extracted from *Data Development Technical Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard* (Kimura et al. 1996 [DIRS 137367]).

An estimate of crash rates per mile for unscheduled 14 CFR Part 135 [DIRS 168507] operations is made using the average hourly fatal accident rate for scheduled and unscheduled Part 135 operations for the years 1998 through 2003 (Table 5 and Table 6) and the average speed for scheduled Part 135 flights (Table 6) over the same period. Some fatal aircraft accidents are not the result of crashes. For example, a person could walk into a spinning propeller. Fatal accidents other than those associated with crashes, if any, are conservatively included in the computed crash rate. The crash rate per mile is computed by dividing the hourly accident rate by the speed and is provided in Table 7. The speed for scheduled Part 135 flights is used as a proxy for the speed of Part 135 flights in general because the distance flown is not available for unscheduled Part 135 flights. The fatal accident rate is used rather than the total accident rate (Assumption 5.3.5).

Table 3. Crash Rates for Military Aircraft

Military Aircraft Type	Crash Rate (mi^{-1})	Specific References from Kimura et al. 1996 [DIRS 137367]
F-16s (normal flight)	3.86E-08	Table 4.8
F-16s (special operations)	1.12E-07	Table 4.8
Large (normal flight)	1.90E-09	Table 4.8

Table 4. Crash Rates for General Aviation Aircraft

General Aviation Aircraft Type	Cruise or Normal-Flight Crash Rate (mi^{-1})	Specific References from Kimura et al. 1996 [DIRS 137367]
Total fixed wing	1.510E-07	Table 3.33
Single engine, piston	2.233E-07	Table 3.29
Turboprop	3.557E-08	Table 3.31
Turbojet	3.067E-09	Table 3.32

Table 5. Statistics for Unscheduled 14 CFR Part 135 Operations 1998-2003

Year	Number of Fatal Accidents	Hours Flown
1998	17	3,802,000
1999	12	3,204,000
2000	22	3,930,000
2001	18	2,997,000
2002	18	2,911,000
2003	19	2,955,000
Total	106	19,799,000

SOURCE: NTSB 2004 [DIRS 168511], Table 9. Data before 1998 is omitted due to the change in the scope of 14 CFR Parts 121 and 135 that occurred in March 1997 (NTSB 2003 [DIRS 168398], pp. 1 and 2).

Table 6. Statistics for Scheduled 14 CFR Part 135 Flights 1998-2003

Year	Number of Fatal Accidents	Hours Flown	Miles Flown	Average Speed (mi/h)
1998	0	353,670	50,773,000	-
1999	5	342,731	52,403,000	-
2000	1	369,535	44,944,000	-
2001	2	300,432	43,099,000	-
2002	0	251,481	36,492,000	-
2003	1	277,800	41,127,000	-
Total or average	9	1,895,649	268,838,000	142

SOURCE: NTSB 2004 [DIRS 168511], Table 8. Data before 1998 is omitted due to the change in the scope of 14 CFR Parts 121 and 135 that occurred in March 1997 (NTSB 2003 [DIRS 168398], pp. 1 and 2).

Table 7. Crash Rates for Commercial Aviation

Commercial Aviation Aircraft Type	Cruise or Normal-Flight Crash Rate (mi^{-1})	Reference
Air carrier (14 CFR Part 121)	3.094E-10	Kimura et al. 1996, [DIRS 137367] Table 2.15
Air taxi (14 CFR Part 135)	3.7E-08[a]	Table 5 and Table 6

NOTE: [a] The crash rate for Part 135 aircraft is estimated as (106 crashes + 9 crashes)/ (19,799,000 h + 1,895,649 h) / 142 mi/h.

4.2.3. Decay Constants for the Beatty Corridor Model

Section 6.2.4.2 uses a model by Solomon (1976 [DIRS 173314], p. 5) to develop formulas to estimate the frequency of crashes into the repository facilities. The model requires estimates of the exponential decay constant γ. For the exponential distribution of crash locations, $1/\gamma$ is the mean distance to the crash from the intended flight path. Based on an examination of crash histories, Solomon estimated the following exponential decay constants, depending on the type of aircraft.

- $\gamma = 1\ mi^{-1}$ for military aircraft.
- $\gamma = 2\ mi^{-1}$ for general aviation other than aerial application.
- $\gamma = 1.6\ mi^{-1}$ for air carriers.

The exponential decay constant γ is used in Attachment IV.

4.3 OTHER INPUTS

4.3.1. Distances Traveled by Military Aircraft after Ejection

Attachment III gives historical data for military aircraft crashes that are applicable to this analysis (Alston 2004 [DIRS 172743]).

5. ASSUMPTIONS

5.1 ASSUMPTIONS THAT CALL FOR DESIGN OR OPERATIONAL REQUIREMENTS

5.1.1. No-Fly Zone Surrounds the North Portal

Assumption: A no-fly zone for fixed-wing aircraft extending to 14,000 ft above mean sea level surrounds the North Portal. The no-fly zone is cylindrical in shape, with a radius of 5.5 NM (6.3 mi) (see Figure 1). The cylinder is centered on the smallest circle that encompasses the Transportation Cask Receipt/Return Facility (TCRRF), Dry Transfer Facilities (DTFs), Canister Handling Facility (CHF), Fuel Handling Facility (FHF), Low Level Waste Handling (LLWH) area, and the aging pads (Assumption 5.1.2). **Rationale:** A no-fly zone is credited in the crash frequency analysis to reduce the crash frequency due to flights through the NTTR and NTS airspace. The radius of the no-fly zone is an important determinant of its effectiveness, as shown in Section 6.2.2. The height of the no-fly zone is set to 14,000 ft so that aircraft that lose engine power while flying over the no-fly zone will often be able to glide most of the way through the no-fly zone (Assumption 5.3.9). Note that separate restrictions are imposed on helicopters (Assumption 5.1.3).

5.1.2. Maximum Dimension of the Site

Assumption: The radius of the smallest circle that encompasses the TCRRF, DTFs, CHF, FHF, LLWH area, and the aging pads is 0.6 mi. **Rationale:** This dimension is based on the site plan (BSC 2004 [DIRS 172171]).

5.1.3. Helicopter Flights Prohibited within One-Half Mile of Relevant Surface Facilities

Assumption: An operational requirement prohibits helicopter flights within one-half mile of the facilities listed in Table 8. A design requirement will require the heliport associated with the repository to be located at least one-half mile from the relevant surface facilities. **Rationale:** On an hourly basis, general aviation helicopters with reciprocating-piston engines crash at a rate of about 7.7×10^{-5} h^{-1} when crashes during takeoff and landing are omitted (Kimura et al. 1996 [DIRS 137367], Table 3.34). Such a high crash rate implies that very little helicopter activity within crash range of the relevant surface facilities can be tolerated without exceeding the 2×10^{-6} y^{-1} Category 2 frequency threshold (Section 6.1). DOE-STD-3014-96 ([DIRS 101810], pp. 45, 46) states that lateral variations in crash locations for a helicopter are conservatively assumed to be one-quarter mile on average from the centerline of its flight path. Doubling this distance to one-half mile adds further conservatism.

5.1.4. Restrictions on Overflights of the No-Fly Zone

Assumption: The annual number of overflights of the no-fly zone by fixed-wing aircraft is limited to 2,500 overflights per year. Tactical maneuvering is prohibited over the no-fly zone. Carrying armed live ordnance over the no-fly zone is prohibited. **Rationale:** A limited number of straight-line overflights can be tolerated, as discussed in Section 6.3.3. As can be determined from Table II-1, 2,500 overflights per year within 5.5 NM (6.3 mi) of the North Portal is lower than recently observed overflight rates. The prohibition of tactical maneuvering allows the crash rate for normal flight to be used and ensures that flight paths are approximately straight as required in the derivation of the crash-frequency model (Section 6.2.3). The prohibition of armed live ordnance is needed to preclude the threat from accidental release of armed live ordnance or explosion of ordnance in the event of an aircraft crash into the repository site.

5.1.5. Not used

5.1.6. Not used

5.1.7. Duration of Emplacement Activities

Assumption: An operational requirement will limit the duration of emplacement activities to 50 years or less. **Rationale:** Potential aircraft accidents only pose a hazard to radioactive waste prior to waste emplacement when the waste is located on the surface. Fifty years is a reasonable upper limit for useful life of the applicable surface structures and allows ample time for waste emplacement. Should a decision be made to retrieve waste or operate the surface facility for more than 50 years, the appropriate preclosure safety analyses would be revised and necessary approvals from the U. S. Nuclear Regulatory Commission would be sought.

5.2 ASSUMPTIONS USED TO DEVELOP ANALYTICAL FORMULAS

5.2.1. Crash-Impact Points Uniformly Distributed Beneath the No-Fly Zone

Assumption: The distribution of crash-impact points for crashes that originate above the no-fly zone is assumed uniform throughout the circular area beneath the no-fly zone. **Rationale:** Random variations in the distance traveled by aircraft after initiation of a malfunction causing a crash introduce randomness in the pattern of crashes on the ground. In addition, flight paths will be distributed throughout the area above the no-fly zone.

5.2.2. Flight Paths on Beatty Corridor Approximately Straight and Parallel Near Yucca Mountain

Assumption: Flight paths are considered straight lines parallel to the edge of the flight corridor for the derivation in Section 6.2.4.2. **Rationale:** The graphical display of flight paths in Attachment I shows that the assumption is valid for the Beatty Corridor near Yucca Mountain.

5.2.3. Flight Paths on Beatty Corridor Uniformly Distributed Near Yucca Mountain

Assumption: Flight paths are uniformly distributed across the width of the Beatty Corridor for the derivation in Section 6.2.4. **Rationale:** The radar tracks provided by the U.S. Federal Aviation Administration (FAA) (Attachment I) show that flight paths are concentrated toward the center and away from the edges of the corridor. (See Assumption 5.3.3 for the definition of the Beatty Corridor.) In this situation, the assumption is conservative because it exaggerates the flight density close to the facility. Although the flight density does not drop immediately to zero at the boundary of the Shoshone military operations area (MOA), defining the aviation corridor more narrowly with its southwestern edge at the Shoshone MOA exaggerates the crash rate density in the corridor and is therefore conservative.

5.2.4. Not Used

5.2.5. Uniform Distribution of Overflights of the No-Fly Zone

Assumption: Overflights of the no-fly zone are approximately uniformly distributed across the radius of the no-fly zone. **Rationale:** This assumption is consistent with recent historical observations as demonstrated in Attachment II.

5.3 ASSUMPTIONS USED TO DEVELOP INPUTS

5.3.1. Characteristics of Relevant Surface Structures

Assumption: Assumed dimensions of relevant structures and areas of the surface facility are given in Table 8. The dimensions of the structures do not include the entrance or exit vestibules. The included structures and areas are assumed to be in continuous use for waste transfer, staging, or aging throughout the analysis period. **Rationale:** The structure sizes are based on the references cited in the footnotes of Table 8. Construction will likely be staged such that some structures, such as the DTFs and the CHF may not be present during part of the preclosure period. The aging pads, even if fully available over the entire operational period, will take years to be filled and emptied. The open-air LLWH area is assumed always filled with waste out to its perimeter, although it will be emptied periodically. Fully including structures that are not always present or at full capacity results in conservatively large effective target areas.

Table 8. Characteristics of Relevant Surface Structures

Building, Structure, or Area	Quantity[a]	Length (ft)	Width (ft)	Height (ft)
Dry Transfer Facility (DTF)	2	492[a]	442[a]	100[b]
Canister Handling Facility (CHF)	1	309[a]	232.5[a]	64[b]
Transportation Cask Buffer Area (TCBA) (not a building)	1	604[a]	131[a]	15[d]
Transportation Cask Receipt/Return Facility (TCRRF)	1	231[a]	137[a]	80[a]
1,000-MTHM (Metric Ton Heavy Metal) Aging Pad (not a building)	1	745[c]	150[c]	20[d]
10,000-MTHM Aging Pad (not a building)	2[c]	1,500[c]	800[c]	20[d]
Loaded waste-package or cask transporters (not buildings)	2[e]	25[d]	25[d]	15[d]
Railcar buffer area (not a building)	1	1,700[g]	80[g]	15[d]
Truck buffer area (not a building)	1	220[g]	110[g]	15[d]
Fuel Handling Facility (FHF)	1	200[a]	146[a]	64[b]
Low Level Waste Handling (LLWH) area (not a building)	1	120[g]	80[g]	10[f]

RATIONALE: [a]BSC 2004 [DIRS numbers: {site plan: 171816} {DTF: 170345, 170347, 170381, 174587}; {CHF: 174744}; {TCRRF: 168443, 168463}; {FHF: 171716}; {TCBA: 172230, p. 6}]. The site plan indicates the numbers of the primary structures. Distances given for the FHF correspond to the distances between the insides of the exterior walls. This is appropriate because that is where the area that is protected by the walls begins.

[b]DTF is assigned a 100-ft height and CHF, and FHF are assigned a 64-ft height consistent with the concrete structures identified in BSC 2004 [DIRS numbers {DTF: 170381}, {CHF: 171812}, {FHF: 171844}].

[c]Pad dimensions from BSC 2004 [DIRS 168740]. Using the pad dimensions is conservative because the pad extends beyond the cask emplacement area. The total capacity of the aging pads is assumed to be 21,000 MTHM (BSC 2004 [DIRS 171816]), which includes the 1,000 MTHM pad and a group of four pads at 5,000 MTHM each.

[d]Vertical aging casks are assigned a 20-ft height (BSC 2005 [DIRS 174213], pg. B-29). Horizontal transportation casks staged on truck, rail, or site rail transport cart are assumed to be less than vertical aging casks and are assigned a height of 15 ft (BSC 2004 [DIRS 168463]). Assumed dimensions for transporters bound the dimensions of the shielded compartment for the waste package transporter (BSC 2004 [DIRS 168885]). The assumed transporter height also bounds the 20-ft height already assumed for vertical aging casks.

[e]No estimate is available of the expected number of transporters in operation at any given time. Having two transporters in use at all times is believed to be conservative. In any case, the transporters are small compared to the buildings and the aging pads, so the overall effective target area is not sensitive to the precise number assumed.

[f]Height bounds waste stored in typically used 55-gal drums. Other containers may be used, but they are not expected to exceed 10 ft in height.

[g]Dimensions estimated from BSC 2004 [DIRS 171816].

5.3.2. Use of F-16 Crash Rates

Assumption: The crash rate (2.736×10^{-8} mi^{-1}) for overflights of the no-fly zone by military aircraft is the updated F-16 accident rate in normal in-flight mode from *Safety Evaluation Report Concerning the Private Fuel Storage Facility* (NRC [2000], [DIRS 154930], Section 15.1.2.11). Crash rates used for military aircraft flying in Beatty Corridor are the large military aircraft in normal operation (Section 4.2.2) and the updated crash rate (2.736×10^{-8} mi^{-1}) for F-16s.

Rationale: First, the crash rate used must be justified despite the fact that other aircraft fly near the repository site. F-16s, F-15s, and A-10s are historically and projected to be the commonly used aircraft for exercises in the NTTR (USAF 1999 [DIRS 103472], Tables 6 through 12). The repository is located in R-4808W (USAF 1999 [DIRS 103472], Figure 3.1-1), which is indicated as R-4808D and E in Figure 2. Of the 9,842 projected flights in R-4808W, over 87 percent are small military planes (All As, Fs, Mirage and Tornados for a total of 8,612); F-16s at 51 percent, F-15s at 28 percent, A-10s at 2 percent, and the balance at 7 percent (USAF 1999 [DIRS 103472], Table 6). Large military planes account for less than 3 percent of the projected annual flights (USAF 1999 [DIRS 103472], Table 6). Helicopters and other aircraft make up the balance. The estimated crash rate for F-16s in normal flight is greater than the corresponding crash rates of F-15s and A-10s (Kimura et al. 1996 [DIRS 137367], Table 4.8). The crash rate for the F-16 has been updated from crash data from 1989 to 1998 and has been deemed acceptable by the Nuclear Regulatory Commission because, given the trend toward lower crash rate, use of the lifetime (1975 through 1998) average crash rate would be overly conservative (NRC [2000] [DIRS 154930], Section 15.1.2.11). Thus, the crash rate given in Table 3 has been updated to 2.736×10^{-8} to better represent the contemporary flight operations experience.

The military aircraft may use the Beatty Corridor for transit to and from NTTR airspace. The normal flight crash rate for large military aircraft and the updated normal flight crash rate for the F-16 will be used for flights in the Beatty Corridor. It is appropriate to use the updated F-16 crash rate because it is based on the flights in the area, and it better represents the contemporary flight operations experience. The normal-operations rate is used because the purpose of flight is transit not combat training.

Second, the use of crash rates and effective target areas for small aircraft in NTTR and NTS airspace must be justified despite the fact that large aircraft are also used on the NTTR. The frequency of crashes into a surface facility is proportional to the crash rate and to the effective target area of the facility (see Equation 7, for example). The effective facility area seen by small aircraft is about a factor of two less than that seen by large aircraft (Section IV.1). However, the net effect of using the crash rate and effective target area for small aircraft is conservative because the crash rates for small aircraft are a factor of twenty or more higher than that of large aircraft (Section 4.2.2).

5.3.3. Definition of Beatty Corridor

Assumption: The Beatty Corridor is defined to be the band, with edges parallel to the Nevada-California border, passing between the edge of Shoshone MOA and passing within 5 mi of the North Portal at its closest. **Rationale:** The entire corridor between the R-2508 complex and the NTTR is used as a flight corridor (Shively 2002 [DIRS 158250]). Near Yucca Mountain, the width of the corridor (measured as the closest distance between the Shoshone MOA to R-4808N) is approximately 26 miles (NIMA 2001 [DIRS 158638]). If the edge of the Beatty Corridor is defined to follow the border between R-4808S and R4808N, and then angle slightly northward in a straight line to southernmost corner of EC South, then the closest distance to the North Portal at Yucca Mountain is about 5 miles (see Figure 2, DTN.MO0004YMP00017.000 [DIRS 149831], and NIMA 2001 [DIRS 158638]). The radar tracks for a typical day, as displayed in Attachment I, show that the northern half of R-4808S is infrequently used, so that the effective edge of the corridor is actually up to a few miles farther away (Ragan 2002 [DIRS 160817], Buckingham 2004 [DIRS 167725]). Radar tracks that enter the restricted airspace of the NTS correspond to military flights, which are not required to remain in the Beatty Corridor (Attachment I).

5.3.4. Assumed Frequency of Flights in the Beatty Corridor Under 10,000 ft

Assumption: The frequency of flights below 10,000 ft above mean sea level (MSL) in the Beatty Corridor is less than 10,000 y^{-1}. Flights below 10,000 ft are assumed to be general aviation piston-engine aircraft. **Rationale:** Radar coverage in the Beatty Corridor below 10,000 ft is not reliable (Ragan 2002 [DIRS 160817], Phone Contact Report). Piston-engine aircraft are more likely than other aircraft to fly at low altitudes. Assumption 5.3.6 discusses the projected flight frequency in the Beatty corridor. The projected frequency is twice the estimated 2002 annual count based on the average 7-day count. For the general aviation piston-engine flights, which occur below 10,000 ft, the projected frequency was further augmented by additional 10,000 flights. The calculated crash frequency due to piston-engine general aviation aircraft, including the addition assumed here, 9.78×10^{-10} y^{-1} (p. IV-6), is very low compared to the frequency threshold 2×10^{-6} y^{-1} (Section 6.1). Therefore, the conclusions of this report are insensitive to the assumed frequency of flights below 10,000 ft MSL. Even so, the assumed frequency is likely to be conservative for the following reasons. The assumed flight frequency is more than twice the estimated frequency of general aviation piston-engine flights above 10,000 ft (Assumption 5.3.6) and is equivalent to more than one flight every hour, 24 hours per day, 365 days per year. Flights below 10,000 ft MSL are less than 7,000 ft above ground level, given a valley elevation of about 3,000 ft at the foot of Yucca Mountain (NIMA 2001 [DIRS 158638]) and are easily seen from the ground. Such flight activity would be noticed; yet, the area is not known for frequent low-altitude flights (BSC 2005 [DIRS 173243], Section 6.7).

5.3.5. Use of Fatal Accident Rate for 14 CFR Part 135 Crash Rates

Assumption: The fatal-accident rate, rather than the total accident rate, is used to estimate crash rates for commercial flight operations regulated by 14 CFR Part 135. **Rationale:** The total accident rate includes accidents that occur on the ground as well as incidents such as turbulence that cause injury to passengers or crew. This assumption is made to discount minor accidents that are not relevant for this analysis. Any accident involving commercial flight that could affect the repository would originate on the Beatty Corridor at high altitude and would certainly involve fatalities. The calculated crash frequency due to commercial flight operations regulated by 14 CFR Part 135, 5.40×10^{-9} y^{-1} (p. IV-6) is very low compared to the frequency threshold of 2×10^{-6} y^{-1} (Section 6.1). Therefore, the conclusions of this report are insensitive to the assumed accident rate for commercial flight operations regulated by 14 CFR Part 135.

5.3.6. Beatty Corridor Flight Frequency

Assumption: Projected annual air-traffic counts in the Beatty Corridor are assumed as provided in Table 9. The projection is based on 2002 traffic counts augmented by a factor of two. **Rationale:** In response to requests for information, the U.S. Federal Aviation Administration (FAA) provided records of flights that the FAA tracked through the Beatty Corridor (Ragan 2002 [DIRS 160817], Buckingham 2004 [DIRS 167725]). The FAA provided tabular and graphical information, which is summarized in Table 10. These data are further discussed in Attachment I. The tabular information consists of records of each flight tracked from five weeks in 2002, including information such as the type of aircraft, engine type, weight class, and whether the flight is general aviation, air carrier (14 CFR Part 121 [DIRS 168506]), air taxi (14 CFR Part 135 [DIRS 168507]), or military. The information in Table 10 was extracted using Microsoft Access from the tables provided by the FAA. Attachment I explains how the FAA data were processed and displays an example of a day's flights on a background of the airspace divisions of the NTTR and the R-2508 Range complex. A factor-of-two allowance for growth bounds projected overall growth in numbers of airport operations for the civilian airports listed through 2030 (BSC 2005 [DIRS 173243], Table C-1). Projected annual counts from Table 9 are used in Attachment IV.

Table 9. Projection of Annual Traffic Counts for Beatty Corridor

Aircraft Type	Average 7-Day Count	Estimated 2002 Annual Count	Projected Annual Counts used in Crash Frequency Calculation
Small Military	98.8	5,138	10,300
Large Military	28.0	1,456	2,900
General Aviation Piston-Engine[a]	94.0	4,888	10,000 + 9,800
General Aviation Turboprop	121.4	6,313	12,600
General Aviation Turbojet	228.8	11,898	23,800
Air Taxi (14 CFR Part 135)	279.4	14,529	29,100
Air Carrier (14 CFR Part 121)	1,600.6	83,231	166,500

NOTE: [a]The general aviation piston-engine count is increased by 10,000 per year as discussed in Assumption 5.3.4.

Table 10. Aircraft Counts on Beatty Corridor from Five Weeks in 2002

Aircraft Type	7-Day Count Beginning				
	3/30/2002	8/4/2002	8/11/2002	11/4/2002	11/11/2002
Small Military	63	132	75	98	126
Large Military	16	32	21	38	33
General Aviation Piston-Engine	109	115	99	77	70
General Aviation Turboprop	101	119	127	120	140
General Aviation Turbojet	292	185	187	287	193
Air taxi (14 CFR Part 135)	253	283	225	343	293
Air carrier (14 CFR Part 121)	1,627	1,731	1,488	1,684	1,473
Sum	2,461	2,597	2,222	2,647	2,328

SOURCES: Ragan 2002 [DIRS 160817], Buckingham 2004 [DIRS 167725].

5.3.7. Crash Frequency Density Outside the No-Fly Zone

Assumption: A uniform crash-frequency density of 1.1×10^{-4} crashes / y / mi^2 applies to flight activities in the NTTR, NTS, and MOA airspace surrounding the no-fly zone out to an unlimited distance in all directions except the southwest quadrant. Furthermore, for crashes associated with pilot ejection, the corresponding ejection locations and directions of travel after ejection are assumed to be uniformly distributed. **Rationale:** The NTTR, NTS, and MOA airspace is not infinite in extent, but it is conservative to consider it so. The crash-frequency density estimated below pertains to the NTTR and MOA airspace. However, recent changes in Air Force plans regarding the use of NTS airspace make it necessary to assume that training activities in other portions of the NTTR will be extended into NTS airspace (Wood 2004 [DIRS 169894], pp. 5, 6). The assumed density is derived from the number of crashes observed over the 12-y period from 1993 through 2004 and the area of the NTTR and MOAs (excluding NTS). Table 11 lists 13 crashes involving fixed-wing aircraft. The airspace, which includes the MOAs, is approximately 1.2×10^4 mi^2 (USAF 2005 [DIRS 174432], p. 1). This is approximately the area of the restricted airspace of the NTTR and the MOA airspace, less the NTS. The crash frequency density is estimated to be

$$(13 \text{ crashes}) / (12 \text{ y}) / (1.2 \times 10^4 \text{ mi}^2) = 9.03 \times 10^{-5} \text{ crashes / y / mi}^2.$$

The assumed crash frequency density is conservative because the calculated frequency density (9.03×10^{-5} crashes / y / mi^2), which is based on 13 crashes, is bounded by the assumed frequency density (1.1×10^{-4} crashes / y / mi^2). A count of random events may be different for different realizations of the random process. For the Poisson distribution estimated from the 13 observations: $f(x) = \alpha^x e^{-\alpha}/x!$, with $\alpha = 13$, the probability of 15 or less crashes in the same time period is 0.764 and the probability of 16 or less crashes is 0.835 (Hines and Montgomery 1980 [DIRS 157562], pp. 143, 144, 590). Thus, the assumed frequency, which corresponds to 15.8 crashes, is approximately a 82 percent confidence upper bound.

The assumption of uniform distribution of ejection locations is conservative because

- In the case of engine failure, a pilot would tend to steer toward the landing fields at Indian Springs or Tonopah Test Range (see Assumption 5.3.8), which would ordinarily take the aircraft farther from the repository.

- For delayed cases in which there is some indication of a problem that later causes ejection, the pilot would likewise tend to steer toward an airstrip, and incidentally farther from the repository.

- The repository is near the edge of the airspace available for training activities. Therefore, aggressive maneuvering and simulated combat, which may lead to ejection, is less likely to take place near the repository as opposed to locations deeper into the NTTR.

The southwest quadrant is omitted because it is almost entirely within the Beatty Corridor, which is treated separately (See Assumption 5.3.6).

Table 11 Aircraft Crashes within the Nevada Test and Training Range

Date	Aircraft	Serial No.	Latitude	Longitude	Reference
18-May-93	F-16C	87-0269	3659	11440	Footnote 1 and Table III-I, #24
10-Aug-93	F-16C	-	3730	11616	Footnote 1
08-Nov-93	F-16C	88-0448	3711	11526	Footnote 1 and Table III-I, #27
14-Feb-94	F-16C	87-0309	3652	11540	Footnote 1 and Table III-I, #30
16-Jun-99	F-15C	82-0008	3755	11601	Footnote 1 and Table III-I, #62
16-Jun-99	F-15D	79-0013	3755	11601	Footnotes 1, 2 and Table III-I, #63
03-Aug-00	F-15C	86-0173	3751	11541	Footnote 1 and Table III-I, #76
08-Aug-00	F-16CG	88-0542	3658	11431	Footnote 1 and Table III-I, #77
04-Dec-02	A-10A	80-0225	3726	11624	Footnote 1 and Table III-I, #109
04-Dec-02	A-10A	79-0191	3726	11624	Footnotes 1, 2 and Table III-I, #110
17-Mar-03	F-15C	80-0040	3704	11436	Footnote 1 and Table III-I, #111
18-Nov-03	A-10A	79-0143	3645	11527	Footnote 1 and Table III-I, #119
04-Jun-04	F-15C	79-0054	3659	11440	Table III-1, #125 (See column 2 of Table III-1 for cited reference)

[1]Wood 2004 [DIRS169894], pp. 6, 7

[2]Wood 2004 [DIRS169894], pp. 6, 7 gives only one crash on this date, however the incident was a midair collision with the loss of both planes.

There were two additional crashes identified by Wood (2004 [DIRS 169894], pp. 6, 7) that were not included in the above table. The item dated October 2002 involved an F-15C that lost an engine, but the pilot shut down the engine and flew an uneventful single engine approach and landing (USAF 2002 [DIRS 174431]). The incident in May 2003 involved an engine undergoing test cell runs (USAF 2003 [DIRS 174430]). Although the events were Class A incidents, that is they involved a million dollar loss, neither incident involved a crash of an aircraft, and therefore, not included in the list of aircraft crashes. An additional event identified by Wood (2004 [DIRS 169894], pp. 6, 7) involved an HH-60 helicopter which is not included in the analysis due to the restrictions on helicopter flights (Assumption 5.1.3).

5.3.8. Crash Initiation Outside the No-Fly Zone

Assumption: If a pilot takes action to maximize the chance of survival, the actions would not result in an increase in the probability of a crash within the no-fly zone.

Rationale: Due to the locations of potential runways for an attempted emergency landing, a pilot flying beyond the radius of the no-fly zone, whose aircraft suffers a malfunction that is likely to lead to ejection, will not enter the no-fly zone and eject within or above the no-fly zone. This assumption does not imply that a crash cannot take place within the no-fly zone if the malfunction occurs outside the no-fly zone. The crash frequency density at the center of the no-fly zone due to flights outside the no-fly zone radius is discussed in Section 6.3.2.3. This assumption also does not take credit for the pilot to take action to avoid a surface facility. However, in the course of an emergency, if the pilot does take action, those actions will not naturally take the aircraft over the no-fly zone. The most common situation involving the potential for ejection is engine failure in an F-16 (Wood 2004 [DIRS 169894], p. 4). A pilot in this situation can be expected to take actions that maximize the pilot's chances of survival. Pilots flying below about 5,000 ft AGL who find themselves in this situation may initially climb rapidly (zoom) to avoid terrain and to improve the likelihood of restarting the engine (Wood 2004 [DIRS 169894], p. 4). After the initial climb to no more than about 5,000 ft above the initial altitude (Wood 2004 [DIRS 169894], p. 4), the pilot will need to decide where to point the aircraft for emergency landing or, if necessary, ejection. To maximize the probability of a successful emergency landing, the first task should be to point the aircraft toward the nearest suitable airfield. The second task is then to determine if the airfield can be reached from the current position. If not, ejection is called for while the pilot is still in control. The longest runways in the area are at Indian Springs (9,000 ft), Tonopah Test Range (12,000 ft), and Yucca Lake (9,000) ft (NIMA 2001 [DIRS 158638]). Tonopah Test Range is on the northern edge of the NTTR, outside the range of Figure 2. Because Yucca Airstrip is soft or unimproved (NIMA 2001 [DIRS 158638]) and has been unused since 1995 (BSC 2005 [DIRS 173243], Appendix C), it is less desirable for emergency landing. As demonstrated below, it is unlikely that a pilot in control of an aircraft without power would eject within or above the no-fly zone. No credit is taken for the airstrip at Yucca Lake or any of the shorter runways in the area (NIMA 2001 [DIRS 158638]).

- Portions of 4808D, 4808B, and the northern half of EC South are closer to Tonopah Test Range than to Indian Springs. However, because Indian Springs is at lower elevation, it can be reached from farther away for a given initial altitude. Therefore, a pilot experiencing engine failure in this region may choose to point the aircraft toward either Indian Springs or Tonopah Test Range. In either case, the resulting flight path would not cross the no-fly zone.

- The area north of EC South and the area north of 4808N are much closer to Tonopah Test Range than Indian Springs. A pilot experiencing engine failure in this region is expected to point the aircraft toward Tonopah Test Range. The resulting flight path would not cross the no-fly zone.

- 4808C, the southeastern leg of 4808E, and the area east of 4808N are much closer to Indian Springs than Tonopah Test Range. A pilot experiencing engine failure in this region is expected to point the aircraft toward Indian Springs. The resulting flight path would not cross the no-fly zone.

- A small geographical area in the southern half of EC South and in the tongue of R-4808N that protrudes against EC South is closer to Indian Springs than to Tonopah Test Range. A straight flight path from the area under consideration to Indian Springs would cross the no-fly zone. A pilot who experiences engine failure in this area may perform a zoom maneuver and point the aircraft toward Indian Springs to maximize the chances of being able to safely land the aircraft. If the trip to Indian Springs appears possible, then the pilot may attempt it. In that case, the trip over the no-fly zone is likely to be successful, in which case ejection would not occur within or above the no-fly zone. If the altitude of the aircraft after the zoom maneuver is insufficient for the trip to Indian Springs, the other option consistent with maximizing the chances of survival is to eject as soon as it is safe to do so and before the danger of doing so increases. The terrain in the southern half of EC South is mostly gently sloping and between 4,000 ft and 5,000 ft MSL. There are no roads or built-up areas in EC South to discourage ejection. Toward the southern end of the area under consideration, the elevation rises quickly and reaches above 6,000 ft MSL in some places. These conditions favor ejection before entering the mountainous terrain between EC South and the repository. In addition, the Air Force instructions advise aircrews to avoid populated areas (such as those associated with the repository) during in-flight emergencies (Wood 2004 [DIRS 169894], p. 1). Therefore, ejection will most likely take place before the aircraft enters the no-fly zone.

5.3.9. Crash Initiation Above the No-Fly Zone

Assumption: Thirty-three percent of aircraft that suffer crash-initiating events during overflight of the no-fly zone pose a risk to repository facilities and are assumed to hit the ground within 5.5 NM (6.3 mi) of the center of the no-fly zone.

Rationale: Due to the altitude ceiling of the no-fly zone, aircraft flying over it have an initial altitude of 14,000 ft MSL or above (Assumption 5.1.1). The elevations of the repository surface facilities are below 4,000 ft MSL (BSC 2004 [168740]). Therefore, the ceiling of the no-fly zone is at least 10,000 ft above repository surface facilities.

The following types of crash-initiating events are considered:

- Type 0 events are those that are not applicable to overflight of the no-fly zone.
- Type 1 events involve a loss of engine power without complete loss of aircraft controllability. Two subsets of Type 1 are considered. Type 1A is simple engine failure. Type 1B is engine failure with complications that may lead to immediate ejection, such as engine fire.
- Type 2 events may entail complete loss of controllability.

Table III-1 presents information on aircraft crashes suffered by military aircraft and assigns initiating-event types for each crash observation.

<u>Type 0 Events</u>. The following initiating events from Table III-1 do not apply to overflight of the no-fly zone for the reasons stated.

- Controlled flight into terrain. Not applicable because maneuvering is prohibited over the no-fly zone and because the altitude cap of the no-fly zone is 10,000 ft above repository facilities.

- Midair collision. Not applicable because maneuvering is prohibited over the no-fly zone and midair collision is much more likely during simulated combat maneuvers.

- Bird strike. Not applicable because bird strike is unlikely at 10,000 ft above repository facilities. The U.S. Air Force has collected information on reported bird strikes with aircraft. The statistics show that over 90 percent of bird strikes have occurred at altitudes less that 2,500-ft and only 0.16 percent of the bird strikes have occurred at altitudes between 10,000 and 15,000 ft. (USAF 2005 [DIRS 174423]).

- Insufficient altitude for maneuver. Not applicable over the no-fly zone because maneuvering is prohibited.

- Excessive sink rate during takeoff. Not applicable to the single observation of this cause because the aircraft did not successfully take off.

- G-induced Loss of Consciousness. Not applicable over the no-fly zone because maneuvering is prohibited.

- Unknown was used for those events where insufficient information for determining the cause of the initiating event was provided. The events with Unknown for the Initiation Event Description in Table III-1 are omitted from the calculation by labeling them Type 0. There is one exception, namely Event 124, as explained in Table III-1. This affects 8 of the 128 events listed in Table III-1.

Type 1 Events. Immediate ejection is not likely for Type 1A events because the pilot may try to restart the engine or to land at a suitable landing field. Even when the pilot chooses to eject after a Type 1A event, it is likely that the aircraft would have already flown out of range of the repository by the time the decision to eject has been made. However, in Type 1B cases, the pilot may eject immediately after engine failure. For conservatism, credit is not taken for the time elapsed after engine failure and before ejection. After ejection, according to information provided by the Air Force, "the airplane will typically begin an aggressive descent post ejection and impact at a very steep trajectory" (Wood 2004 [DIRS 169894], p. 4). However, as shown below, even a rather steep trajectory would often take the aircraft beyond repository surface facilities.

Consider an aircraft crossing directly above the center of the no-fly zone. This is the longest trip across the no-fly zone and therefore carries the greatest likelihood of a crash during overflight of the no-fly zone. An aircraft that has already flown beyond repository facilities when the engine fails can be eliminated from further consideration. The radius of the smallest circle that encompasses all relevant surface facilities is 0.6 mi (Assumption 5.1.2). Therefore, an aircraft that has already passed 6.3 mi + 0.6 mi = 6.9 mi from the edge of the no-fly zone will have traveled beyond all relevant surface facilities. The fraction of aircraft that are not beyond repository facilities when engine failure occurs can be estimated by the ratio (6.9 mi) / (12.7 mi) = 0.54, where 12.7 mi is the diameter of the no-fly zone (converted from 5.5 NM × 2 = 11 NM). For those flights that have not passed beyond repository facilities when engine failure occurs, approximately half of them, (0.5)(0.54) = 0.27, will experience engine failure in the first half of the 6.9-mi segment and the other half will experience power loss in the second half of the 6.9-mi segment.

For the fraction 0.27 of engine failures that occur in the first half of the 6.9-mi segment, the case that is most likely to result in a crash into repository facilities is ejection right at the edge of the no-fly zone. At 10,000 ft and 6.9 mi of horizontal travel, the required minimum glide ratio to carry the aircraft beyond repository facilities is

$$(6.9 \text{ mi})(5{,}280 \text{ ft / mi}) / (10{,}000 \text{ ft}) = 3.6.$$

For comparison, the glide ratio is about 8 when the pilot is still in control (BSC 2003 [DIRS 172742], pp. G-2 and G-4; DOE 1999 [DIRS 105155], p. H-11). An assessment of the glide capability of aircraft after ejection can be made from the data in Table III-1. There are twenty-one observations of Type 1 events for which the ejection altitude is known. Thirteen of the twenty-one (13 / 21 = 0.62) have glide ratios less than or equal to 3.6. Combining the two fractions, the fraction of Type 1 events from the first half of the 6.9-mi segment that could endanger the repository is (0.27)(0.62) = 0.17.

For those in the second half, the worst case is ejection right at the midpoint of the 6.9-mi segment. At 10,000 ft and 6.9 mi / 2 = 3.5 mi of horizontal travel, the required minimum glide ratio to carry the aircraft beyond repository facilities is

$$(3.5 \text{ mi})(5{,}280 \text{ ft / mi}) / (10{,}000 \text{ ft}) = 1.8.$$

Three of the twenty-one applicable Type 1 observations in Attachment III, (3 / 21 = 0.14), have glide ratios less than or equal to 1.8. Combining the two fractions, the fraction of Type 1 events from the second half of the 6.9-mi segment that could endanger the repository is (0.27)(0.14) = 0.038. Combining the results from each half of the 6.9-mi segment, gives 0.17 + 0.038 = 0.21 as the fraction of Type 1 events that could endanger the repository.

<u>Type 2 Events</u>. A Type 2 initiating event may involve a total loss of control. The location of ground impact is unpredictable. The following initiating events are considered Type 2 because they are applicable to overflight of the no-fly zone and may entail a total loss of controllability:

- Loss of control
- Centerline tank explosion
- Aircraft fire (except engine failure with engine fire, which is Type 1B).

As estimated above, the fraction of Type 1 events that could endanger repository facilities is 0.21. For Type 2 initiating events, all of the crashes could endanger repository surface facilities.

The fractions of Type 1 events and of Type 2 events as fractions of the number of applicable events (Type 1 or Type 2) can be estimated from the data in Table III-1. As noted in Table III-2, 85 percent of applicable events are of Type 1 and 15 percent are of Type 2. Thus, the fraction of the aircraft suffering crash-initiating events during overflight of the no-fly zone that pose a risk to repository facilities is estimated as

$$(0.85)(0.21) + (0.15)(1) = 0.33.$$

A more realistic estimate of the fraction would account for the time required to make a decision regarding ejection during a Type 1A event and the tendency of pilots to attempt to land whenever that appears to be the safest course of action. Because so little time is required to fly 6.9 mi or less at cruising speed, the fraction of Type 1A initiating events that would result in a crash inside the no-fly zone is near zero. As noted in Table III-2, 70 percent of applicable events are of Type 1A and 15 percent are Type 1B. Thus, for the more realistic case, the fraction of crashes that occur during overflight of the repository is estimated as

$$(0.70)(0) + (0.15)(0.21) + (0.15)(1) = 0.18.$$

Therefore, the conservatively estimated fraction of aircraft that pose a risk to repository facilities during overflight, 0.33, bounds 0.18, which is based on a more realistic assessment.

6. ENGINEERING ANALYSIS

6.1 FREQUENCY-SCREENING THRESHOLD

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" (10 CFR 63.2, [DIRS 173164]). "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" (10 CFR 63.2, [DIRS 173164]). Less likely event sequences are considered Beyond Category 2. Stating the screening threshold in terms of frequency requires knowledge of the duration of the potentially affected activities. Because aircraft do not pose a hazard to subsurface activities, the relevant time period is the duration of emplacement operations. The duration of emplacement operations will not exceed 50 years (Assumption 5.1.7). A 50-y emplacement period gives a threshold frequency of $(1/10{,}000) / 50 \text{ y} = 2 \times 10^{-6} \text{ y}^{-1}$.

6.2 METHODS

This section derives methods for estimating frequencies of aircraft crashes into surface facilities. A formula for calculating the effective target area of a surface facility is also presented. The methods presented in this section form the basis of the frequency calculations in Attachment IV.

6.2.1. Effective Target Areas of Surface Facilities

As discussed in Section 4.2.1, the effective target area A depends on characteristics of the crashing aircraft. The effective target area also depends on the size of the object on the ground and the characteristics of the site. Sanzo et al. (1996 [DIRS 158248], Section 4.4) approximate an object on the ground as a rectangular prism of length L, width W, and height H to derive a formula for effective target area. The formula depends on the wingspan G of the aircraft, the skid distance S (which may depend on characteristics of the site as well as those of the aircraft), and the approach angle ϕ to the ground (which may depend on site, aircraft, and flight characteristics). The fly-in area is the effective target area of the structure, considering an airborne approach at an angle, and ignoring the possibility of hitting the ground and skidding into the structure:

$$A_{\text{fly-in}} = L\,W\,(1+\frac{2G}{D}) + (G+D\,)H\;\cot\phi\,, \qquad \text{(Eq. 1)}$$

where the diagonal $D \equiv \sqrt{(L^2 + W^2)}$. The skid area, which is the effective target area that considers the possibility that the aircraft will hit the ground and skid into the structure and ignores the possibility of an airborne approach, is

$$A_{\text{skid}} = (D+G)S\,. \qquad \text{(Eq. 2)}$$

The total effective target area is $A_{\text{fly-in}} + A_{\text{skid}}$. The impact angle and the skid distance depend on characteristics of the aircraft, but may be limited by characteristics of the site such as topography and landscaping.

6.2.2. Effectiveness of a No-Fly Zone (Ignoring Overflights)

A pilot who experiences engine failure or some other event that is likely to lead to ejection may not eject immediately. However, the initiation of a crash beyond the radius of the no-fly zone followed by ejection within or above the no-fly zone is unlikely due to the locations of suitable emergency landing strips and nearby topographical features (Assumption 5.3.8). This assumption is important to the results of this section because the distance between the location where a problem first became apparent and the location where the pilot ejected is not usually known and may often exceed the diameter of the no-fly zone by a wide margin.

The no-fly zone that is assumed to surround the surface facilities (Assumption 5.1.1) will reduce the frequency of crashes into the facilities from tactical training that may occur outside the no-fly zone. To derive an expression that accounts for a no-fly zone, first consider a small area δA on the ground under a flight area. Suppose the flight area extends horizontally in all directions to an unlimited distance. Further, suppose that the locations of ejection events and the directions of travel after ejection are uniformly distributed throughout the flight area. For accidents in which ejection does not occur, the distance between ejection and crash is defined to be zero. Let $f(r)$ denote the probability density function (PDF) of the distance r that an aircraft travels after the pilot ejects and let Φ_0 denote the annual number of crashes initiated per unit flight area. The uniform PDF for direction of travel is $1/(2\pi)$.

With the passage of time, crashes into δA are expected. The sample of crashes that happen to strike the area δA are randomly selected and will have traveled distances distributed according to $f(r)$ and will have traveled in random directions according to the PDF $1/(2\pi)$. The precise locations of the initiation points of the crash trajectories and the directions of travel are not relevant, but the endpoints of the crash trajectories happen to be located within δA. Because the ejection locations and directions of travel are uniformly distributed over an infinite flight area, the crash frequency density on the ground is equal to the crash-initiation frequency density. With no restrictions on distance or direction of travel, the expected number of crashes into δA at time T is given by

$$\begin{aligned} M_0 &= \Phi_0\, \delta A\, T \int_{r=0}^{\infty}\int_{\theta=0}^{2\pi} \frac{1}{2\pi} f(r)\, \mathrm{d}\theta\, \mathrm{d}r \\ &= \Phi_0\, \delta A\, T . \end{aligned}$$

The double integral merely indicates that, with no restrictions on distance of travel or direction of travel, all possible crash trajectories may be realized.

Now consider a no-fly zone that prohibits aircraft travel within a radius R of δA, where the largest dimension of δA is much less than R. With a no-fly zone in place, the uniform crash initiation density applies only to the area beyond R. Other conditions remain the same. Again, with the passage of time, crashes into δA are expected. In this case, however, crashes with trajectories shorter than R are filtered out by the presence of the no-fly zone. The expected number M_c of crashes into δA at the center of the no-fly zone at time T is given by

$$\begin{aligned} M_c &= \Phi_0\ \delta A\, T \int_R^{\infty} \int_0^{2\pi} \frac{1}{2\pi} f(r)\, \mathrm{d}\theta\, \mathrm{d}r \\ &= \Phi_0\ \delta A\, T\,[1 - F(R)]. \end{aligned}$$

Thus, the no-fly zone reduces the expected number of crashes according to the ratio

$$\begin{aligned} \frac{M_c}{M_0} &= \frac{\Phi_0\ \delta A\, T\,[1 - F(R)]}{\Phi_0\ \delta A\, T} \\ &= [1 - F(R)]. \end{aligned} \qquad \text{(Eq. 3)}$$

So far, the flight area has been considered infinite in every direction from δA. However, the repository site is actually near the edge of the restricted NTTR and NTS airspace. Now assume that the ejection locations and directions of travel corresponding to Φ_0 are uniformly distributed outside the no-fly zone out to an infinite distance, except in the southwest quadrant from the center of the no-fly zone, which is almost entirely in the Beatty Corridor (Assumption 5.3.7) and is considered in Section 6.2.4. Excluding the southwest quadrant filters out crashes with angles from $3\pi/2$ to 2π. This results in an edge adjustment of approximately 0.75 (three quarters of the way around the repository). Considering the edge adjustment and the effectiveness of the no-fly zone for the restricted airspace, the annual crash frequency per unit area at the center of the no-fly zone, Φ_c, is given by

$$\begin{aligned} \Phi_c &= \frac{\text{Number of crashes expected in area } \delta A \text{ during time } T}{\text{Area and time under consideration}} \\ &= \frac{\Phi_0\ \delta A\, T \int_R^{\infty} \int_0^{3\pi/2} \frac{1}{2\pi} f(r)\, \mathrm{d}\theta\, \mathrm{d}r}{\delta A\, T} \\ &= 0.75\ \Phi_0 [1 - F(R)]. \end{aligned} \qquad \text{(Eq. 4)}$$

In this case, the double integral determines the filtering effect of the flight restrictions represented by the no-fly zone and the omission of the southeast quadrant. Section 6.3.2.1 provides an estimate of the complementary cumulative distribution function evaluated at the edge of the no-fly zone 1 - $F(R)$.

6.2.3. Allowing for Overflights of the No-Fly Zone by Fixed-Wing Aircraft

To allow flexibility in the use of the airspace near the repository, a specified annual frequency of overflights of the no-fly zone by fixed-wing aircraft is assumed (Assumption 5.1.4). Aircraft are assumed to pass straight through the area above the no-fly zone (Assumption 5.1.4) and to be approximately uniformly distributed across the radius of the no-fly zone (Assumption 5.2.5). Let N be the annual frequency of flights (y^{-1}) that pass over the no-fly zone, and λ be the crash rate (mi^{-1}). The expected annual frequency of crashes initiated over the no-fly zone is given by $N\lambda l_m$, where l_m is the mean length (mi) of flights over the no-fly zone. Some fraction p_c of the initiating events that occur above the no-fly zone are assumed to result in a crash on the ground within 5.5 NM of the center of the no-fly zone (Assumption 5.3.9). Assume that the impact points on the ground are uniformly distributed in the area 5.5 NM of the center of the no-fly zone, A_z (Assumption 5.2.1). Given an effective target area A of the relevant surface facilities, the crash frequency into relevant repository facilities is given by

$$F = \frac{N\lambda p_c l_m}{A_z} A . \qquad \text{(Eq. 5)}$$

For a convex area, the mean length l_m of a chord intersecting the area is given by π times the area divided by the perimeter (Santaló 1976 [DIRS 160334], p. 30). Thus, for a circle of radius R,

$$\begin{aligned} l_m &= \frac{\pi A_z}{L_z} \\ &= \frac{\pi(\pi R^2)}{2\pi R} \\ &= \frac{\pi R}{2}, \end{aligned} \qquad \text{(Eq. 6)}$$

where A_z is the surface area and L_z is the length of the perimeter. Combining Equations 5 and 6 gives the expected annual frequency of crashes that are initiated over the no-fly zone and strike relevant surface facilities:

$$\begin{aligned} F &= \frac{N\lambda p_c l_m}{A_z} A \\ &= \frac{N\lambda p_c \pi R}{2\pi R^2} A \\ &= \frac{N\lambda p_c}{2R} A . \end{aligned} \qquad \text{(Eq. 7)}$$

6.2.4. Crash Frequency Methods for Flights in the Beatty Corridor

6.2.4.1. NUREG-0800 Model for Airways

NUREG-0800, *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants* (NRC 1987 [DIRS 103124], Section 3.5.1.6) provides the following formula for conservatively calculating the frequency F of aircraft crashes into the facility when aviation corridors pass through the vicinity of the site:

$$F = \frac{N\lambda}{w+2d}A \quad \text{for } d>0; \qquad \text{(Eq. 8)}$$
$$F = \frac{N\lambda}{w}A \quad \text{otherwise},$$

where N is the annual frequency of flights (y^{-1}) passing through the flight area, λ is the crash frequency per mile (mi^{-1}), w is the width of an airway (mi), and d is the distance from the edge of the airway to the facility. The formula may be regarded as the product of two factors: (1) the uniform areal crash density per year associated with a band that includes the flight corridor and extends out the distance to the facility on either side, and (2) the effective target area of the facility.

One feature of the NUREG-0800 model that restricts its applicability to the proposed Yucca Mountain surface facility is its treatment of edge effects. Because a uniform distribution is used, the crash-rate density assigned to the center of an airway is the same as that near the edge or beyond it as far away as the facility. The surface facilities for the Yucca Mountain repository will be several miles from the edge of an airway (Section 5.3.3), so edge effects are sure to be important, and the NUREG-0800 model may be too conservative.

6.2.4.2. An Exponential Model for the Beatty Corridor Airway

Solomon (1976 [DIRS 173314], p. 5) developed a model to estimate the frequency of aircraft crash into surface facilities. Solomon introduced the PDF $f(x)$ to describe the probability that a crash occurs at a distance x from an intended flight path. The size of the facility and its distance from the flight path are assumed to be such that $f(x)$ can be considered constant across the width of the facility in the x direction, that is, perpendicular to the intended flight path. The incremental distance dx, which is necessary to convert the probability density into a probability, is approximated as Δx, the width of the facility in the x direction, and is absorbed into the definition of the effective target area, A. The flight path is assumed straight as it passes near the facility (Assumption 5.2.2). Solomon argued that $f(x)$ should be symmetrical on either side of the intended flight path (that is, about $x=0$), and that it should decay monotonically with distance from the flight path. Solomon adopted the double exponential distribution with decay constant γ as follows:

$$f(x) = \frac{\gamma}{2} e^{-\gamma|x|} .$$

To apply the double-exponential model to the Beatty Corridor, assume that flights are uniformly distributed across the width w of the airway (Assumption 5.2.3). The applicable uniform PDF is $1/w$. Because the analysis only concerns one side of the airway, it can be assumed without loss of generality that $x \geq 0$. The distance from the facility to the edge of the airway is denoted by d. For a site outside the airway, $d > 0$. The annual crash frequency for N annual flights on the airway with crash rate λ (mi^{-1}) into effective target area A (mi^2) is given by

$$\begin{aligned} F &= N\lambda f(x)A \\ &= N\lambda\left(\frac{\gamma}{2} e^{-\gamma x}\right)A \ . \end{aligned}$$

The crash frequency due to uniformly distributed flight paths across the width w of the airway is given by

$$\begin{aligned} F &= \int_d^{d+w} \frac{N\lambda\gamma A}{2} e^{-\gamma x} \frac{1}{w} dx \\ &= \frac{N\lambda\gamma A}{2w}\left[-\frac{e^{-\gamma x}}{\gamma}\right]_d^{d+w} \\ &= \frac{N\lambda A}{w}\left[\frac{e^{-\gamma d}(1-e^{-\gamma w})}{2}\right] \ . \end{aligned} \qquad \text{(Eq. 9)}$$

Note that Equation 9 is the same as the NUREG-0800 model for a facility within the airway (Equation 8) except for the term in square brackets. Therefore, the edge adjustment, ρ, with respect to the NUREG-0800 model's value for a facility within the airway is $e^{-\gamma d}(1-e^{-\gamma w})/2$. For airways wide enough that $w >> 1/\gamma$, the term in parentheses is approximately equal to 1, so that the edge adjustment is approximately $e^{-\gamma d}/2$. A special case emerges when the facility is located on the edge of a wide airway such that $d = 0$ and $w >> 1/\gamma$. The term in square brackets becomes approximately equal to 0.5. In that case, the edge adjustment with respect to the NUREG-0800 model is 0.5.

6.2.4.3. Illustration of Airway Models

Recall that the edge adjustment for the exponential model is approximately $e^{-\gamma d}/2$. Similarly, the NUREG-0800 model has an edge adjustment if the facility is located outside the airway. Consider the edge adjustment for the NUREG-0800 model, defined as the ratio of crash frequency F (for a facility located outside the airway) to the frequency F_0 (for a facility located within or on the edge of the airway). Using Equation 8, it can be shown that the value of the ratio F/F_0 is $w/(w + 2d)$. The edge adjustment for the NUREG-0800 model depends on the width of the airway. To pick a concrete example that will allow an illustration of the two models, let the width of the airway be 26 mi and the decay constant for the exponential distribution be $\gamma = 1.6\ mi^{-1}$. In the example shown, for distances more than a few miles from a wide corridor, the edge adjustment of the NUREG-0800 model appears implausibly weak. Even ten miles from the airway, the crash frequency is not even reduced by half. The exponential model has a much more pronounced edge effect and appears more reasonable.

Table 12. Example Edge Adjustments as a Function of Distance from the Airway

Distance d from Airway (mi)	NUREG-0800 Model $w/(w+2d)$	Exponential Model $\exp(-\gamma d)/2$
0	1.0E+00	5.0E-01
1	9.3E-01	1.0E-01
2	8.7E-01	2.0E-02
3	8.1E-01	4.1E-03
4	7.6E-01	8.3E-04
5	7.2E-01	1.7E-04
6	6.8E-01	3.4E-05
7	6.5E-01	6.8E-06
8	6.2E-01	1.4E-06
9	5.9E-01	2.8E-07
10	5.7E-01	5.6E-08

NOTE: The example assumes $w = 26$ mi (Assumption 5.3.3) and $\gamma = 1.6\ mi^{-1}$ (Section 4.2.3) to be consistent with air carriers in the Beatty Corridor.

6.3 CRASH FREQUENCIES FOR FIXED-WING AIRCRAFT

6.3.1. Flights in Beatty Corridor

The exponential airway model (Equation 9) is used to estimate crash frequencies from air traffic passing through the Beatty Corridor. For this analysis, the Beatty Corridor is defined to be the band, with edges parallel to the Nevada-California border, passing between the edge of Shoshone MOA and within 5 mi of the North Portal at its closest (Assumption 5.3.3). For the frequency calculations, the general aviation piston-engine count is augmented by 10,000 y^{-1} as indicated in Assumption 5.3.4. As shown in Attachment IV the estimated crash frequency due to flights on the Beatty Corridor is about $2 \times 10^{-8}\ y^{-1}$, which is a negligible fraction of the Category 2 threshold, $2 \times 10^{-6}\ y^{-1}$.

The largest significant contributor to the crash frequency from Beatty Corridor is military aircraft.

6.3.2. Flights Beyond the Radius of the No-Fly Zone

6.3.2.1. Sample Distribution Function for Travel After Pilot Ejection

Attachment III reproduces historical data on distances that fixed-wing military aircraft traveled after the pilot ejected. If the pilot did not eject before impact, the distance traveled after ejection was taken to be zero. The cumulative distribution function (CDF), that is, the probability that the crashing aircraft traveled a distance less than r can be estimated from the data. The sample CDF as a function of the variable r, $F_n(r)$, is defined as the number of observations less than or equal to r divided by the total number of observations, n (Mood et al. 1974 [DIRS 122506], p. 264). The sample CDF (Figure 3) is an unbiased estimator of the true CDF, $F(r)$ (Mood et al. 1974 [DIRS 122506], p. 507).

Because the repository surface facilities are not concentrated at the North Portal, but are spread out over a 0.6-mi radius (Assumption 5.1.2), credit is only taken for a no-fly zone of 0.6 mi smaller radius. Thus, using Assumption 5.1.1, the no-fly zone radius credited is 5.7 mi (0.6 mi less than the 6.3-mi radius of the no-fly zone). For the sample of 78 observations for which a distance estimate is possible, 75 of the distances traveled are less than the reduced radius of the no-fly zone, 5.7 mi. Thus, $F_n(5.7 \text{ mi}) = 75 / 78 = 96$ percent. The estimated probability of exceeding 5.7 mi is $1 - F_n(5.7 \text{ mi}) = 1 - 75/78 = 3.8$ percent.

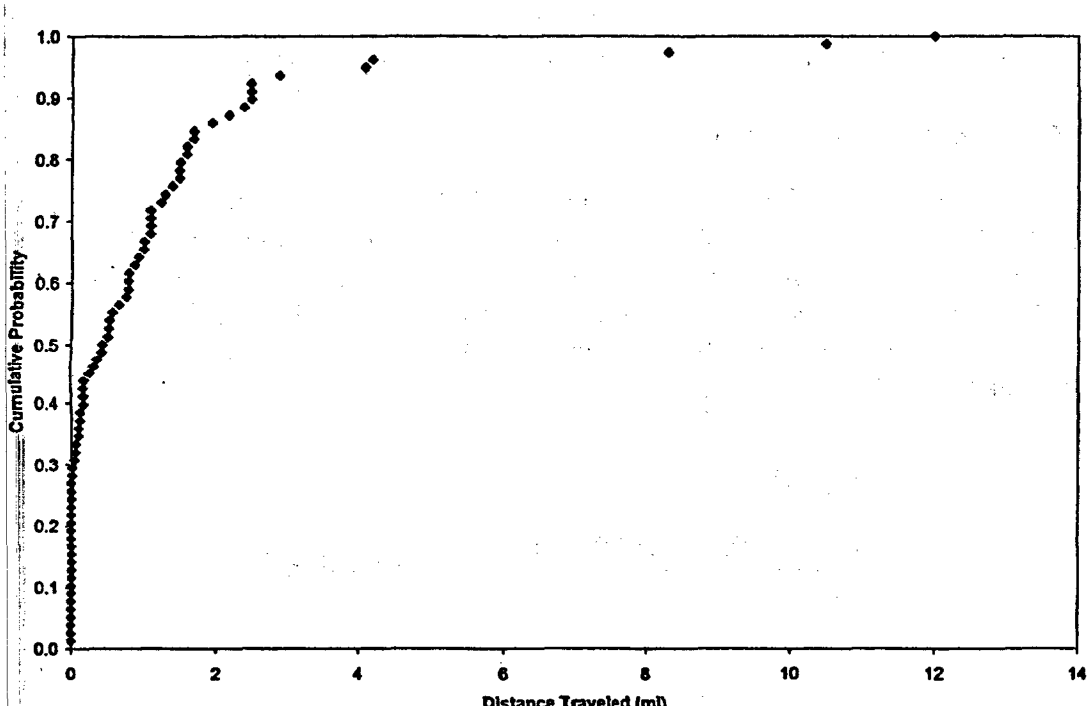


Figure 3. Sample Cumulative Distribution Function of Crash Distances

6.3.2.2. Crash Frequency Density Outside the Radius of the No-Fly Zone

Recent changes in Air Force plans regarding the use of NTS airspace make it necessary to assume that training activities in other portions of the NTTR and MOA will be extended into NTS airspace (Wood 2004 [DIRS 169894], pp. 5, 6). Therefore, the annual number of crashes initiated per unit flight area, $\Phi_0 = 1.1 \times 10^{-4}$ crashes / y / mi^2 in the NTTR and MOA (which was calculated without including NTS airspace) will be assumed to apply to all areas in NTS and NTTR and MOA airspace beyond the radius of the no-fly zone (Assumption 5.3.7).

6.3.2.3. Crash Frequency due to Flights Outside the Radius of the No-Fly Zone

Applying Equation 4, the crash frequency density at the center of the no-fly zone is

$$\begin{aligned}\Phi_c &= 0.75\,\Phi_0[1-F_n(5.7\text{ mi})]\\ &= 0.75\,(1.1\times10^{-4}\text{ crashes / y / mi}^2)(0.038)\\ &= 3.1\times10^{-6}\text{ crashes / y / mi}^2.\end{aligned}$$

The calculation in Attachment IV (*A* matrix, p. IV-3) estimates a 0.336 mi^2 effective target area of the surface facilities as seen by small military aircraft. Thus, the estimated frequency of event sequences due to flights outside the radius of the no-fly zone is

$$(3.1 \times 10^{-6}\text{ crashes / y / mi}^2)(0.336\text{ mi}^2) = 1.0 \times 10^{-6}\text{ crashes / y.}$$

6.3.3. Overflights of the No-Fly Zone

Equation 7 is used to estimate the crash frequency with a no-fly zone of radius 6.3 mi (Assumption 5.1.1), a crash rate of 2.736×10^{-8} mi^{-1} pertaining to normal-flight mode (Assumption 5.3.2), 33 percent of initiating events that occur above the no-fly zone assumed to result in a crash on the ground under the no-fly zone (Assumption 5.3.9), an effective target area of 0.336 mi^2 for small military aircraft (Attachment IV), and $N = 2{,}500$ overflights per year (Assumption 5.1.4):

$$\begin{aligned}F_o &= \frac{N\lambda p_c}{2R}A\\ &= \frac{(2{,}500\text{ y}^{-1})(2.736\times10^{-8}\text{ mi}^{-1})(0.33)}{2\,(6.3\text{ mi})}(0.336\text{ mi}^2)\\ &= 6.0\times10^{-7}\text{ y}^{-1}.\end{aligned}$$

In this case, the full 6.3-mi radius is used because the overflights are counted across the entire no-fly zone.

6.3.4. Total Crash Frequency Due to Fixed Wing Aircraft

Considering crash frequencies from Beatty Corridor (2.0×10^{-8} y^{-1}), flights outside the no-fly zone (1.0×10^{-6} y^{-1}), and overflights of the no-fly zone (6.0×10^{-7} y^{-1}), the total crash frequency is about 1.6×10^{-6} y^{-1}, which is less than the Category 2 frequency threshold 2×10^{-6} y^{-1}.

6.4 HELICOPTER CRASHES

To avoid the possibility of radiological release due to helicopter crash into repository surface facilities, helicopter flights within one-half mile horizontally from the relevant surface facilities are assumed to be prohibited (Assumption 5.1.3). To facilitate the prohibition, the heliport associated with the repository is assumed to be located at least one-half mile from the relevant surface facilities (Assumption 5.1.3).

6.5 UNCERTAINTIES

To cope with uncertainties, the analysis takes a conservative approach. Conservative assumptions are discussed in context elsewhere in the analysis as applicable, and are summarized below.

- No credit is taken for the ability of transportation casks, aging casks, or the CHF, DTF, or FHF to withstand impacts by aircraft. However, studies of Boeing 747-400 and Boeing 767-400 impacts into transportation casks, storage casks, and similar concrete structures show no breach (McGough and Pennington 2002 [DIRS 167732]; Nuclear Energy Institute 2002 [DIRS 167733]).

- Immediate ejection is assumed for engine failures that occur over the no-fly zone; that is, no credit is taken for assessment of the situation and a decision whether an emergency landing may be possible (Assumption 5.3.9).

- Flights over the no-fly zone are assumed to be at the lowest allowable elevation: 14,000 ft. This results in the quickest descent to ground in case of pilot ejection (Assumption 5.3.9).

- No credit is taken for a military pilot's preference to steer away from built-up areas before ejection.

- No credit is taken for phased construction of DTF and CHF or for the time needed to load and unload the aging pads (Assumption 5.3.1).

- No credit is taken for increased approach angles (and decreased skid and shadow areas) that result from topography and the proximity of nearby structures (Section 4.2.1).

- F-16 crash rate is used for all small military aircraft (Assumption 5.3.2).
- The assumed distance to the edge of the Beatty Corridor is conservatively short (Assumption 5.3.3).

7. RESULTS

The frequency analysis shows that crashes that result in radiological consequences are Beyond Category 2. The estimated frequency of crashes that may lead to radiological consequences is 1.6×10^{-6} y^{-1}, which is below the applicable Category 2 frequency screening threshold, 2×10^{-6} y^{-1}.

The analysis takes credit for a no-fly zone as described below:

- Flights by fixed-wing aircraft in NTS or NTTR airspace within 5.5 nautical miles (6.3 statute miles) of the North Portal and below 14,000 ft above mean sea level are prohibited.
- 2,500 overflights of the no-fly zone per year (above 14,000 ft MSL) are permitted for fixed-wing aircraft.
- Maneuvering over the no-fly zone is prohibited. Flight is straight and level.
- Carrying armed live ordnance over the no-fly zone is prohibited.
- Helicopter flights within 0.5 mile of surface facilities at the North Portal, including aging pads are prohibited. Helicopter flights are not affected by the no-fly zone for fixed-wing aircraft.

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ATTACHMENT I.

FLIGHTS THROUGH BEATTY CORRIDOR

Figure I-1 shows radar tracks for aircraft flying through the public airspace to the southwest of the repository site for a typical day (Ragan 2002 [DIRS 160817], Buckingham 2004 [DIRS 167725]). Note that flights are concentrated between the two restricted airspace complexes in what is designated here as the Beatty Corridor. The image indicates the locations of R-2505 on the R-2508 Range complex, R-4808N and R-4808S on the NTTR, and the approximate locations of the North Portal, Las Vegas, and the Beatty VORTAC (very high frequency omnidirectional range and tactical air navigation station) (NIMA 2001 [DIRS 158638]). R-4808N covers most of the NTS, although the southwest corner of the NTS is beneath the triangular R-4808S. The flights that passed through the Beatty Corridor are shown as dark gray traces. Flights that did not pass through the Beatty Corridor are not shown. Note that while some flights cross R-4808S, it is not heavily used, especially near the border with R-4808N. Three flights that also entered the Beatty Corridor crossed R-4808N that day. These flights are included in the counts provided by the FAA. Such flights are also counted as flights over the NTS and possibly through the other incursion-count areas around the North Portal. For the total crash-frequency estimate, this slight double counting is conservative. The loop-shaped flight may be undercounted, but such occurrences are rare and relatively far from the North Portal so that they do not significantly affect the accuracy of the results.

For this analysis, it is useful to separately count air carriers (14 CFR Part 121); air taxis (14 CFR Part 135); general aviation turbojets, turboprops, and reciprocating-piston aircraft; and small and large military aircraft. After a few minor enhancements and error corrections, as described below, the counts were performed as follows. Flights regulated by 14 CFR Part 121 (labeled AC for air carrier) and flights regulated by 14 CFR Part 121 (labeled AT for air taxi) were directly counted in the tabular information provided by the FAA. General aviation aircraft are identified and further classified by engine type: J = jet, T = turboprop, and P = reciprocating-piston, making counting straightforward. Military aircraft are identified and further classified by weight class. Military aircraft in the H weight class (>255,000 lb) were counted as large military, and military aircraft in other categories were counted as small military. The results of the counts produced according to the scheme outlined above are provided in Section 5.3.6.

The flight-count information for 3/30/02 through 4/4/02 was enhanced and corrected as follows. "U" (for unknown) was given as the engine type for the aircraft that corresponds to the type designator "GALX." The corresponding aircraft is the 1126 Galaxy business jet (Schuster 2002 [DIRS 160820]), which is manufactured by IAI and was delivered to the first customer in January 2000 (Jackson et al. 2001 [DIRS 158255], pp. 264-265). Accordingly, the engine type was changed from "U" to "J" for the GALX aircraft type. This change affected 10 records. Two other instances of unknown engine type may be found in the FAA information for 3/30/02 through 4/4/02. The first is resolved by noting that the aircraft type "T210" probably corresponds to Cessna C210, which has one reciprocating-piston engine (Schuster 2002 [DIRS 160820]). Accordingly, the engine type was changed from "U" to "P" for the T210 aircraft type. This change affected one record. In the second, the aircraft type "EXP" was listed as having unknown engine type, but these aircraft are probably experimental piston-engine aircraft (Schuster 2002 [DIRS 160820]). The engine type was changed from "U" to "P" for the "EXP" aircraft type. This change affected one record. The engine type for the "AC95" was changed from "P" to "T" to correspond to a two-engine turboprop (Schuster 2002 [DIRS 160820]). This change affected one record.

The flight-count information for 8/4/02 through 8/16/02 and 11/3/02 through 11/17/02 had missing information that was addressed as follows. For carrier types listed as "uuuu" for unknown, general aviation turboprop was assigned. This assignment is conservative because turboprops have a higher crash rate than general aviation turbojets (Section 4.2.2). The unknown aircraft could have been assigned to general aviation piston, but that would not be conservative if credit were taken for the ability of structures to withstand a piston-engine crash. This change affected 177 records. For general aviation aircraft, some of the engine types were unidentified; the 71 affected records were also assigned to general aviation turboprop. For military aircraft, some of the weight classes were unidentified; the 65 affected records were considered to be small military aircraft due to their higher crash rate (Section 4.2.2).

SOURCE: *Buckingham 2004 [DIRS 167725]*

Figure I-1. Flights through Beatty Corridor on 8/8/02

ATTACHMENT II.

FLIGHT DISTRIBUTION IN NTTR AND NTS AIRSPACE

The conceptual model for estimating crash frequencies for overflights of the no-fly zone assumes that overflights of the no-fly zone are approximately straight and are distributed uniformly over the no-fly zone (Assumption 5.2.5). The concept of uniform distribution of flights within a flight area requires clarification. The concept of uniformly distributed points on a plane is more often encountered, and more readily understood. For example, suppose a hailstorm is said to have distributed hailstones uniformly throughout the front lawn. This is taken to mean that if the lawn is divided into smaller zones, the ratio of the number of hailstones counted in each zone to the area of the zone will be approximately equal for all zones. The shapes of the zones are irrelevant. The sizes are also irrelevant, except that the statistical precision of the calculated density degrades as the size gets smaller. Now consider an example of lines in a plane: suppose the claim is made that the tracks left by slugs crossing a large leaf are uniformly distributed across the leaf. Attempting to apply the same method for lines as for points runs into mathematical difficulties. To illustrate, suppose the outline of the central vein on the surface of the leaf is used as a zone. The area of the zone is a very small fraction of the leaf's surface due to the narrow width of the vein, but there may be many crossings—perhaps a substantial fraction of the number that cross the entire leaf. The result is a large number of crossings per unit area. In fact, the number of crossings per unit area can be made arbitrarily large by narrowing the zone further. Clearly, a different measure of traffic density is needed.

The literature of integral geometry shows that the conditional probability that a random line that intersects a convex area also intersects a smaller convex area within the larger area is given by the ratio of the perimeters of the two areas (Santaló 1976 [DIRS 160334], p. 30). Taking for granted the fact that the larger area has been intersected, the result indicates that the probability of crossing an arbitrarily selected convex area within the larger area is proportional to the perimeter of the smaller area. Thus, a useful measure of traffic density across a convex flight area is the number of crossings divided by the perimeter of the flight area. As an intuitive illustration of this claim, imagine marbles rolling randomly, one at a time, on a table where a coffee mug is resting. The probability of a given marble hitting the mug is proportional to the diameter of the mug, not its footprint area. The diameter of the mug, in turn, is proportional to the perimeter of the mug. Finally, note that the crash frequency estimated by Equation 7 (Section 6.2.3) is proportional to the number of crossings divided by the perimeter of the flight area.

Incursions into concentric circles centered on the North Portal, a 5.8-by-7-mile area (the Yucca Mountain Repository [YMR] Box) roughly centered on the North Portal, and an incursion area that approximates the NTS, are being counted on a monthly basis (Mignard 2003 [DIRS 166809]). The circles used for the counts are 1, 2, 3, 5, 7 and 10 mi in radius (Takenaka 2003 [DIRS 161341]) and are designated here as YMR-1, YMR-2, and so on. The coordinates of the YMR incursion area are as follows. Northwest corner: 36° 54.00' north latitude, 116° 28.00' west longitude; southeast corner: 36° 48.00' north latitude, 116° 22.00' west longitude (Mignard 2003 [DIRS 166809]). The resulting YMR rectangle is about 7 mi long north and south, 5.8 mi wide east and west, and roughly centered on the North Portal (NIMA 2001); this gives a perimeter length of about 25.6 mi. The NTS incursion area is composed of three separate areas: a triangle and two rectangles (Takenaka 2002 [DIRS 160821]), which together form a single polygon that approximately coincides with the NTS (excluding R-4808S). The three areas are defined as follows:

- First rectangle. Northwest corner: 37° 16.00' north latitude, 116° 27.00' west longitude; southeast corner: 36° 46.25' north latitude, 115° 56.00' west longitude.
- Second rectangle. Northwest corner: 36° 46.25' north latitude, 116° 14.75' west longitude; southeast corner: 36° 41.00' north latitude, 115° 56.00' west longitude.
- Triangle. First corner: 36° 46.25' north latitude, 116° 27.00' west longitude; second corner: 36° 41.00' north latitude, 116° 14.75' west longitude; third corner: 36° 46.25' north latitude, 116° 14.75' west longitude.

The perimeter of the NTS incursion area is about 133 mi (NIMA 2001 [DIRS 158638]).

An examination of the ratios of the total incursion counts to the perimeters of the corresponding flight areas for a recent 18-month period (Table II-1) indicates that flights are approximately uniformly distributed within about 7 miles of the North Portal and within the YMR Box. Air traffic is denser for the NTS as a whole and for the larger concentric circle. Thus, traffic density is nearly uniform within about 7 miles of the North Portal, but increases beyond 7 miles from the North Portal. The count for the YMR Box is representative of air traffic within about 7 miles of the North Portal.

Table II-1. Aircraft Incursion Counts by Month and Flight Area

Flight Area Designator	NTS	YMR Box	YMR-1	YMR-2	YMR-3	YMR-5	YMR-7	YMR-10
Radius of Concentric Circle (mi)	-	-	1	2	3	5	7	10
Perimeter of Flight Area (mi)	133	25.6	6.3	12.6	18.8	31.4	44.0	62.8
Month in 2003								
January	1437	118	7	12	21	53	87	216
February	1205	98	13	45	58	128	224	491
March	1679	207	34	91	139	289	434	757
April	2347	222	47	92	130	301	432	930
May	2418	304	98	196	246	421	634	1999
June	2184	110	30	68	87	184	334	718
July	1499	121	31	57	84	186	290	693
August	2505	185	46	99	143	295	452	846
September	1308	130	36	71	96	187	274	586
October	2904	326	69	129	226	455	664	1097
November	2460	266	48	103	167	392	592	977
December	1735	120	32	56	95	162	228	496
Month in 2004								
January	1525	170	25	76	130	227	311	545
February	1332	183	63	96	142	254	340	533
March	3006	410	55	223	298	660	896	1314
April	1930	274	38	99	169	384	531	927
May	3231	600	80	211	393	828	1317	2191
June	1978	276	62	254	154	280	464	884
Average monthly	2038	229	45	110	154	316	472	900
Average annual	24455	2747	543	1319	1852	3791	5669	10800
Average annual / Perimeter (mi^{-1})	184	107	86	105	98	121	129	172

NOTE: The flight areas are the NTS, the 5.8-by-7-mile YMR Box, and concentric circles surrounding the North Portal.

SOURCES: Mignard 2003 [DIRS 166809], Langendorf 2004 [DIRS 171184]; Langendorf 2004 [DIRS 171185]; Langendorf 2004 [DIRS 171303].

ATTACHMENT III.

INFORMATION ON A SAMPLE OF MILITARY AIRCRAFT CRASHES

To support the analysis in this report, U.S. Air Force fighter aircraft crash data was compiled by evaluating information from aircraft crash investigation reports (Alston 2004 [DIRS 172743]). These reports are compiled and maintained at the Air Force Safety Center located at Kirtland Air Force Base in Albuquerque, New Mexico. The primary data extracted from the reports was the distance a disabled aircraft traveled after pilot ejection. Also obtained from the reports was information about crashes wherein the pilot did not eject. Visits to the safety center were undertaken in late August and early September 2004. Investigation reports for all Air Force fighter aircraft (F-16, F-15, and A-10) crashes which occurred worldwide from 1990 to 2000, and additional crashes for flights originating from Nellis Air Force Base in Nevada through 2003 were requested. Some of the air crash investigation reports may have been checked out of the Safety Center library or were otherwise unavailable when the crash data was compiled.

A direct indication of the distance traveled by the aircraft to the crash point after ejection was not provided in most of the reports. In most cases, the actual location of the aircraft at the time of ejection was not provided. In these cases, the ground impact location of the canopy (which is released from the aircraft just prior to ejection) or the ejection seat was generally used as an estimate of the ejection point. This procedure introduces uncertainties since the canopy or ejection seat could be transported by wind. However, this potential is negligible in most cases because ejection altitudes (above ground level) were found to be small, which would tend to minimize the drop time (and lateral movement) of the canopy or seat. Further, this error is expected to be random, i.e. it could either increase or decrease the actual distance from ejection to crash location so that use of the entire data set would tend to obscure this error.

As noted, in most cases the ejection-to-crash distance estimates had to be calculated, or inferred, depending on information included in the reports. The following methods were used:

- Scaling from crash maps, or, if not possible, locating crash and canopy or ejection seat on scaled maps based on map locations included in the crash reports.
- Using the Haversine formula (Sinnott 1984 [DIRS 172067], p. 159) when longitude and latitude coordinates of canopy or ejection seat and crash location were provided in the reports. As explained in Sinnott (1984 [DIRS 172067], p. 159), this method is appropriate for calculations involving small angular differences. The calculations of distance require the mean radius of the Earth, taken as 6,371 km (Weast 1978 [DIRS 128733], p. F-193).
- Using angle of descent and elevation of ejection.

When information on the locations of both the canopy and ejection seat was available, the ejection-to crash distance was calculated as the average of the distances from the crash site to the canopy and ejection seat.

The data obtained is provided in Table III-1, arranged chronologically. The table gives:

- the information source for the event (page number in Alston 2004 [DIRS 172743])
- a description of the initiating event (engine failure, midair collision, etc.)
- the type of aircraft involved
- the serial number of the aircraft
- the date of the event
- the ejection altitude
- the distance traveled from actual or inferred ejection point to the crash site
- the method used to estimate the ejection to crash distance
- comments that provide additional relevant information
- the glide ratio (applicable only to Type 1 events)
- the initiating event type (as defined in Assumption 5.3.9).

All crash reports provided from 1990 are included in the table, even if an ejection to crash distance estimate could not be made because of lack of information, or if no ejection occurred. Table III-2 provides a summary of information from Table III-1.

Table III-1. Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
1	pp. 174 and 175	Controlled flight into terrain	F-16A	81-0798	25-May-90	N/A	0	Text	No pilot ejection.	N/A	0
2	p. 172	Engine failure, mechanical	F-16D	84-1321	7-Aug-90	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A
3	p. 173	Engine failure, fire	F-16C	83-1151	3-Sep-90	Unknown	Unknown	N/A	Ejection was successful.	N/A	1B
4	pp. 170 and 171	Engine failure, mechanical	F-16D	85-1510	20-Sep-90	1665 AGL	1.51	Lat, Long	Based on canopy and seat distance from crash site.	4.8	1A
5	pp. 99 and 100	Engine failure, mechanical	F-16C	86-0354	23-Oct-90	1500 AGL	Unknown	N/A	Ejection was successful.	N/A	1A
6	p. 169	Engine failure, mechanical	F-16A	79-0400	13-Jan-91	20,000 MSL	Unknown	N/A	Ejection was successful.	N/A	1A
7	pp. 167 and 168	Centerline fuel tank explosion	F-16A	83-1089	15-Jan-91	3,500 AGL	4.2	Map, in combination with Rand McNally (1995 [DIRS 172083], p. 23)	Distance from ejection to aircraft impact.; map distances transposed to Rand McNally (1995 [DIRS 172083]) and scaled.	6.3	2
8	pp. 104 to 106	Engine failure, mechanical	F-16C	86-0329	20-Feb-91	300 AGL	0.1	Map	Based on indicated distance from canopy to initial impact point, and scaled distance from ejection seat to initial impact point. Ejection distance taken as mean of two distances.	1.8	1A
9	p. 164	Loss of control	F-16C	89-2061	4-Apr-91	Unknown	Unknown	N/A	Aircraft went into steep nose-low spiral. Ejection was successful.	N/A	2

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
10	pp. 107 to 109	Engine failure, mechanical	F-16C	87-0302	7-May-91	Unknown	0.17	Map	Based on distance from canopy and ejection seat to crash site given on map in crash report (900 ft). Event occurred at takeoff.	N/A	1A
11	pp. 160 and 161	Engine failure, mechanical	Not given	Not given	8-Jun-91	900 AGL	0.5		Distance calculated as mean of distances from canopy and seat to impact crater, indicated on diagram adjoined to report.	2.9	1A
12	pp. 112 and 113	Engine failure, fire	F-16C	86-0045	17-Jul-91	Unknown	Unknown	N/A	Aircraft crashed in sea.	N/A	1B
13	pp. 54 to 56	Airframe failure	F-16C	84-1267	13-Jan-92	Unknown	Unknown	N/A	Pilot was able to land but engine did not shut down. Pilot elected to take off again and subsequently successfully ejected after climb-out.	N/A	1A
14	pp. 28 to 30	Engine failure, mechanical	F-16C	90-0749	31-May-92	<3000 AGL	Unknown	N/A	Scaling from map was not performed because scale is given under a text form (as "1 500"). Because map may have been resized when formatted into the compilation report, this form of scaling cannot be trusted for estimating distances.	N/A	1A
15	pp. 31 and 32	Engine failure, mechanical	F-16ADF	81-0697	31-Aug-92	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A
16	pp. 33 to 38	Engine failure, mechanical	F-16C	83-1139	1-Sep-92	Unknown	1.40	Map	Distance from parachute (near canopy and seat) to center of main crash site as provided on map.	N/A	1A

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
17	pp. 39 to 41	Engine failure, mechanical	F-16A	80-0566	18-Sep-92	900 AGL	0.93	Map	Distance scaled on map from ejection point to crash site.	5.5	1A
18	pp. 44 to 47	Unknown	F-16C	85-1485	22-Oct-92	310 AGL	Unknown	N/A	Crash site survey information is provided but text is illegible. Ejection was successful.	N/A	0
19	pp. 62 to 64	Controlled flight into terrain	A-10A	81-0993	6-Dec-92	N/A	0	Text	No ejection.	N/A	0
20	pp. 244, and 258 to 260	Unknown	F-16A	83-1078	17-Dec-92	Unknown	0.17	Map	Based on distance between seat and approximate center of crash site (ventral fin).	N/A	0
21	pp. 72 to 76	Aircraft fire	F-16A	83-1102	19-Feb-93	Unknown	0.19	Map	Distance calculated as mean of distances from center of crash debris (engine) to canopy and *ejection seat; scaled on* map.	N/A	2
22	pp. 145 and 146	Engine failure, mechanical	F-16CG	88-0523	23-Feb-93	1210 AGL	Unknown	N/A	Several air-start attempts. Ejection was successful.	N/A	1A
23	pp. 153 and 154	Engine failure, mechanical	Not given	Not given	21-Apr-93	Unknown	Unknown	N/A	Map supplied but locations of canopy and ejection seat are illegible. Several air-start attempts. Ejection was successful.	N/A	1A

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
24	pp. 110 and 111	Unknown	F-16C	87-0269	18-May-93	Unknown	8.3	Map, in combination with USGS (1986 [DIRS 156950])	Distance from canopy to crash site; map distances transposed to Nevada state map USGS (1986 [DIRS 156950]) and scaled. Given uncertainties, value calculated is taken as the average of distance range found (8.0 mi to 8.6 mi).	N/A	0
25	pp. 151 and 152	Engine failure, mechanical	F-16C	Unknown	11-Aug-93	1700 AGL	Unknown	N/A	Ejection was successful.	N/A	1A
26	pp. 148 to 150	Engine failure, fire	F-16A	81-0779	11-Sep-93	Unknown	0.17	Map	Distance calculated as mean of distances from canopy and ejection seat to crash site (distances indicated on map).	N/A	1B
27	p. 77 and 78	Controlled flight into terrain	F-16C	88-0448	8-Nov-93	N/A	0	Text	No ejection.	N/A	0
28	pp. 84 and 85	Engine failure, mechanical	F-16CJ	90-0823	2-Feb-94	2000 AGL	Unknown	N/A	Ejection was successful.	N/A	1A
29	pp. 86 to 88	Engine failure, mechanical	F-16CG	90-0764	7-Feb-94	2200 AGL	0.78	Map	Distance provided on map from ejection seat to crashed aircraft.	1.9	1A
30	p. 10	Controlled flight into terrain	F-16C	87-0309	14-Feb-94	N/A	0	Text	No ejection.	N/A	0
31	pp. 245 to 249	Engine failure, mechanical	F-16B	83-1173	1-Jul-94	Unknown	0.75	Map	Distance calculated as mean of distances from canopy and seat to crash site; scaled from map. Engine failure was caused by bird ingestion.	N/A	0

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
32	pp. 147, 234 and 235	Engine failure, mechanical	F-16C	88-0488	20-Sep-94	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A
33	pp. 89 to 91	Engine failure, mechanical	F-16CJ	90-0814	25-Oct-94	1380 AGL	0.51	Map	Map indicates polar coordinates of canopy and ejection seat relative to the impact point (coordinates expressed as distance from impact point, and angle from North, eastward). Ejection distance calculated as mean of distances from seat and canopy to impact point.	2.0	1A
34	pp. 70 and 71	Unknown	F-16D	90-0849	13-Jan-95	Unknown	Unknown	N/A	Ejection 9 minutes after takeoff.	N/A	0
35	pp. 52 and 53	Engine failure, mechanical	F-16CG	89-2000	5-Feb-95	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A
36	p. 131	Engine failure, mechanical	F-16B	78-0093	15-May-95	1500 AGL	Unknown	N/A	Ejection was successful.	N/A	1A
37	pp. 68 and 69	Engine failure, mechanical	F-16C	87-0273	25-Jun-95	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A
38	pp. 57 to 59	Engine failure, mechanical	F-16CJ	88-0455	21-Aug-95	4000 AGL	1.7	Text	Distance given from ejection location to aircraft impact. Several engine restarts attempted.	2.2	1A
39	pp. 48 and 49	Engine failure, mechanical	F-16C	84-1250	21-Dec-95	Unknown	Unknown	N/A	Coordinates supplied on map are illegible.	N/A	1A
40	pp. 127 and 128	Engine failure, mechanical	F-16C	86-0361	19-Mar-96	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
41	pp. 101 to 103	Excessive sink rate	F-15C	82-0023	21-Mar-96	Unknown	0.06	Map	Distance calculated as mean of distances from canopy and seat to center of impact scars, scaled from map. Event occurred at takeoff.	N/A	0
42	pp. 129 and 130	Engine failure, mechanical	F-16C	85-1545	7-Jun-96	1500 AGL	1.1	Map, in combination with Rand McNally (1995 [DIRS 172083], p. 89)	Distance from ejection to aircraft impact.; map distances transposed to Rand McNally (1995 [DIRS 172083]) and scaled. Return to airport attempted, restarts attempted.	3.9	1A
43	pp. 114 and 115	Engine failure, mechanical	F-16CJ	91-0354	11-Jul-96	209 AGL	0.10	Impact Angle	Distance from ejection to impact based on tangent of impact angle and ejection altitude. Angle of descent was taken as average of range provided (18 to 25 degrees).	2.5	1A
44	pp. 95 to 98	Engine failure, mechanical	F-16CG	89-2101	3-Aug-96	Unknown	Unknown	N/A	Map provided but not enough information was given to enable scaling. Ejection was successful.	N/A	1A
45	pp. 60 and 61	Engine failure, mechanical	F-16A	82-1020	21-Nov-96	4500 AGL	Unknown	N/A	Map is provided but scale, given under a text format (1:50,000) is not usable since map may have been resized for formatting into the compilation report. Restart attempted; pilot ejected.	N/A	1A

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
46	pp. 116 to 118	Engine failure, mechanical	F-16C	83-1134	29-Jan-97	870 AGL	Unknown	N/A	Map provided with latitude and longitude coordinates of impact crater and ejection seat, but they are illegible. Also, the scale, given under a text format (1"=10,000') is not usable since map may have been resized for formatting into the compilation report. Restart attempted; pilot ejected	N/A	1A
47	pp. 122 to 124	Engine failure, mechanical	F-16D	87-0385	4-Feb-97	10,100 MSL	2.5	Map: Rand McNally 1995 [DIRS 172083], p. 97)	Distance based on ejection location to impact site. Distances on map transposed to referenced map and scaled. Multiple restarts attempted.	N/A	1A
48	pp. 141 and 142	Engine failure, mechanical	F-16CG	89-2095	21-Apr-97	1500 AGL	0.36	Map	Distance calculated as mean of distances from approximate center of impact area to canopy and ejection seat; scaled from map.	1.3	1A
49	pp. 42 and 43	Engine failure, mechanical	F-16B	82-1037	22-Aug-97	Unknown	1.0	Map	Distance from ejection seats to impact location; scaled from map.	N/A	1A
50	p. 143	Mid-air collision	F-16D	84-1320	16-Sep-97	Unknown	Unknown	N/A	Second aircraft damaged but returned to base.	N/A	0
51	pp. 50 and 51	Engine failure, mechanical	F-16CG	89-2131	8-Jan-98	1700 AGL	0.87	Map	Distance calculated as mean of distances (indicated on map) from edge of aircraft impact area to canopy and seat.	2.7	1A

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
52	pp. 125 and 126	Engine failure, mechanical	F-16CJ	91-0397	22-Jul-98	3000 AGL	N/A	Unknown	Ejection was successful.	N/A	1A
53	pp. 65 to 67	Engine failure, mechanical	F-16CG	88-0519	24-Aug-98	1100 AGL	1.5	Map	Two maps provided. One (without scale) shows the ejection location above the shore line and indicates that aircraft was flying true North at time of ejection. The other map (with scale) shows coast outline with debris field in sea. Distance from ejection to crash site was calculated as distance, on a line North/South, from shore line to center of debris field and scaled.	7.2	1A
54	pp. 183 to 185	Engine failure, mechanical	F-16DG	88-0154	7-Jan-99	Unknown	0.05	Map	Distance calculated as mean of distances from approximate center of aircraft impact point to canopy and front seat; scaled from map.	N/A	1A
55	pp. 3 and 4	Loss of control	OA-10A	78-0628	21-Jan-99	11,000	4.1	Lat, Long	Distance based on estimated map coordinates for pilot recovery and aircraft impact location. Altitude basis (AGL or MSL) unknown.	N/A	2

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
56	pp. 180 to 182	Engine failure, mechanical	F-16CJ	92-3900	21-Jan-99	Unknown	0.26	Map	Distance calculated as mean of distances from location of ejection seat and canopy to final aircraft impact location; scaled on map. Engine failed after aircraft struck trees on a ridgeline.	N/A	0
57	p. 176	Mid-air collision	F-15C	84-0011	28-Jan-99	Unknown	Unknown	N/A	Ejection was successful.	N/A	0
58	p. 176	Mid-air collision	F-15C	82-0020	28-Jan-99	Unknown	Unknown	N/A	Ejection was successful.	N/A	0
59	pp. 177 to 179	Engine failure, mechanical	F-16C	84-1304	3-Feb-99	Unknown	2.19	Lat, Long	Distance calculated as mean of distances from point of impact to canopy and seat, based on longitude/latitude coordinates. In flight fire after engine failure.	N/A	1B
60	pp. 206 to 208	Engine failure, mechanical	F-16C	88-0490	26-Mar-99	Unknown	0.78	Map	Distance calculated as mean of distances from first impact point to canopy and ejection seat, indicated on map.	N/A	1A
61	pp. 204 and 205	Engine failure, mechanical	F-16DG	89-2125	26-Apr-99	Unknown	1.6	Map	Distance calculated as mean of distances from approximate impact site center to canopy and ejection seat; scaled from map. Aircraft ran out of fuel.	N/A	1A

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
62	pp. 79 to 83	Mid-air collision	F-15C	82-0008	16-Jun-99	3050 AGL	Unknown	N/A	Maps are provided but scales, given under a text format (1"=100' and 1"=200') are not usable since maps may have been resized for formatting into the compilation report. Ejection was successful.	N/A	0
63	pp. 79 to 83	Mid-air collision	F-15D	79-0013	16-Jun-99	3375 AGL	Unknown	N/A	Maps are provided but scales, given under a text format (1"=100' and 1"=200') are not usable since maps may have been resized for formatting into the compilation report. Ejection was successful.	N/A	0
64	pp. 192 and 193	Engine failure, mechanical	F-16DG	87-0396	18-Jun-99	1490 AGL	1.3	Map	Distance calculated as mean of distances from ejection seat and canopy to approximate center of impact area; scaled from map.	4.6	1A
65	p. 191	Controlled flight into terrain	F-16C	84-001268	1-Jul-99	N/A	0	Text	Pilot did not eject.	N/A	0
66	pp. 186 to 190	Engine failure, mechanical	F-16C	86-0284	12-Jul-99	1600 AGL	Unknown	N/A	Map provided but without sufficient information to estimate ejection to crash site distance. Ejection was successful.	N/A	1A
67	pp. 201 to 203	Mid-air collision	F-16C	88-0403	11-Aug-99	Unknown	Unknown	N/A	Second plane involved in collision landed uneventfully.	N/A	0

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
68	p. 200	Mid-air collision	F-15A	76-0117	19-Aug-99	Unknown	1.7	Text	Distance calculated as mean distances from crash site to canopy and ejection seat, indicated in text. Second plane involved in collision returned to base.	N/A	0
69	pp. 194 to 196	Mid-air collision	F-16C	87-0240	17-Nov-99	Unknown	1.1	Map, in combination with Rand McNally (1995 [DIRS 172083], p. 29)	Distance calculated as mean of distances from canopy and ejection seat to crash site; map distances transposed to Rand McNally (1995 [DIRS 172083]) and scaled. Given uncertainties, value calculated is taken as the average of distance range found (0.9 mi to 1.3 mi). Second plane involved in collision returned to base.	N/A	0
70	p. 5	Controlled flight into terrain	A-10A	80-0266	20-Jan-00	N/A	0	Text	Pilot did not eject. Crash was 12 miles from destination airfield.	N/A	0
71	pp. 210 to 212	Engine failure, mechanical	F-16D	90-0794	16-Feb-00	2300 AGL	1.1	Map	Distance from impact point to seat location. Scaled from map. Three restarts attempted.	2.5	1A
72	pp. 213 to 215	Engine failure, mechanical	F-16CG	89-2094	16-Feb-00	2000 AGL	0.79	Lat, Long	Distance based on coordinates provided for flight data recorder (near canopy) and impact site.	2.1	1A
73	p. 209	Controlled flight into terrain	F-16CJ	Not given	19-Mar-00	N/A	0	Text	Pilot did not eject.	N/A	0

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
74	pp. 218 and 219	Engine failure, fire	F-16C	84-1311	16-Jun-00	2700 AGL	2.9	Map	Distance calculated as mean of distances from seat and canopy to approximate center of main crash site; scaled from map.	5.7	1B
75	pp. 216 and 217	Canopy penetrated by bird	F-16CG	87-0357	21-Jun-00	2200 AGL	2.5	Map	Distance from ejection seat to impact crater scaled from map.	6.0	0
76	pp. 23 to 25	Loss of control	F-15C	86-0173	3-Aug-00	5300 AGL	Unknown	N/A	Aircraft entered spin condition.	N/A	2
77	pp. 18 to 22	Mid-air collision	F-16CG	88-0542	8-Aug-00	Unknown	0.43	Map	Distance calculated as mean of distances from canopy and ejection seat to crash debris as indicated on map. Second aircraft returned to base.	N/A	0
78	p. 228	Controlled flight into terrain	F-16C	85-1456	28-Aug-00	N/A	0	Text	Pilot did not eject.	N/A	0
79	p. 222	Engine failure, mechanical	F-16C	(not given)	31-Aug-00	1700 AGL	Unknown	N/A	Ejection was successful.	N/A	1A
80	pp. 220 and 221	Engine failure, mechanical	F-16CG	89-2088	12-Oct-00	12,600 AGL	0.42	Impact angle	Distance based on ejection altitude and angle of impact.	0.2	1A
81	pp. 224 to 227	Mid-air collision	F-16CJ	90-0811	13-Nov-00	Unknown	Unknown	N/A	Aircraft and ejected pilot both landed in sea.	N/A	0
82	pp. 224 to 227	Mid-air collision	F-16CJ	90-0801	13-Nov-00	N/A	0	Text	Pilot apparently did not eject. Plane crashed into sea.	N/A	0

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
83	pp. 250 to 252	Mid-air collision	F-16CG	89-2104	16-Nov-00	Unknown	0.12	Map	Distance calculated as mean of distances from ejection seat and canopy to approximate center of crash area (ventral fin), scaled from map. Collision was with light civil aircraft.	N/A	0
84	pp. 197 to 199	Loss of control	T-38A	67-4938	5-Dec-00	Unknown	0.65	Map	Distance from impact point to front seat, indicated on map.	N/A	2
85	pp. 229 and 230	Engine failure, fire	F-16C	86-0313	13-Dec-00	11,000 AGL	10.5	Map, in combination with Rand McNally (1995 [DIRS 172083], p. 23)	Distance from ejection to approximate center of radar crash plots and debris accumulated on sandbar; map distances transposed to Rand McNally (1995 [DIRS 172083]) and scaled. Given uncertainties, value calculated is taken as the average of distance range found (10 mi to 11 mi).	5.0	1B
86	pp. 277 to 279	Engine failure, mechanical	A-10A	80-0158	12-Jan-01	Unknown	Unknown	N/A	Scaling from map was not performed because scale is given under a text form (1"=75'). Because map may have been resized when formatted into the compilation report, this form of scaling cannot be trusted for estimating distances.	N/A	1A

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
87	pp. 253 to 256	Engine failure, mechanical	F-16C	87-0330	21-Mar-01	2,000 AGL	1.1	Map	Distance calculated as mean of distances from canopy and ejection seat to initial impact. Scaled from map.	2.9	1A
88	pp. 261 to 263	Unknown	F15-C	86-0169	26-Mar-01	Unknown	Unknown	N/A	Mid-air collision may be the cause of this event.	N/A	0
89	pp. 261 to 263	Unknown	F15-C	86-0180	26-Mar-01	Unknown	Unknown	N/A	Mid-air collision may be the cause of this event.	N/A	0
90	pp. 280 to 282	Engine failure, mechanical	F-16D	90-0837	03-Apr-01	Unknown	~0	Map	Ejection seat located in wreckage area.	N/A	1A
91	pp. 283 to 286	Loss of control	F-16CG	89-2063	12-Jun-01	Unknown	~0	Text	Ejection was attempted but interrupted by ground impact.	N/A	2
92	pp. 264 to 266	Unknown	F-16CJ	90-0815	06-Jul-01	Unknown	0.02	Map	Distance (indicated on map) based on location of ejection seat and center of debris field.	N/A	0
93	pp. 316 to 319	Loss of control	F-16B	78-0100	17-Jul-01	Unknown	~0	Text	Ejection was attempted but interrupted by ground impact.	N/A	2
94	pp. 267 to 271	Engine failure, mechanical	F-16CG	89-2050	18-Jul-01	Unknown	1.50	Map	Distance (indicated on map) based on location of seat and canopy and initial impact.	N/A	1A
95	pp. 320 to 325	Engine failure, fire	F-16DG	88-0167	23-Jul-01	6200 AGL	Unknown	N/A	Ejection was successful.	N/A	1B

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
96	pp. 272 to 276	Engine failure, mechanical	F-16C	86-0226	26-Jul-01	< 7076 MSL	1.6	Map, in combination with Rand McNally (1995 [DIRS 172083], p. 29)	Distance calculated as mean of distances from canopy and seat to impact; map distances transposed to Rand McNally (1995 [DIRS 172083]) and scaled. Given uncertainties, value calculated is taken as the average of distance range found (1.5 to 1.7 mi).	N/A	1A
97	pp. 346 to 350	Mid-air collision	A-10A	80-0233	17-Jan-02	Unknown	0.52	Lat, Long	Distance calculated as mean of distances from location of aircraft to canopy and ejection seat.	N/A	0
98	pp. 346 to 350	Mid-air collision	A-10A	79-0085	17-Jan-02	Unknown	1.01	Lat, Long	Distance based on location of aircraft and ejection seat.	N/A	0
99	pp. 339 to 343	Controlled flight into terrain	F-16CJ	91-0415	20-Mar-02	N/A	0	Text	Pilot did not eject.	N/A	0
100	pp. 344 and 345	Engine failure, mechanical	F-16CJ	92-3919	15-Apr-02	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A
101	pp. 326 to 329	High-speed dive; airframe failure	F-15C	80-0022	30-Apr-02	N/A	0	Text	No apparent ejection.	N/A	0
102	pp. 330 and 331	Controlled flight into terrain	A-10A	82-0655	27-Jun-02	N/A	0	Text	Pilot did not eject.	N/A	0
103	pp. 351 and 352	Loss of control	F-15C	78-0541	21-Aug-02	Unknown	Unknown	N/A	Ejection was successful.	N/A	2
104	pp. 332 and 333	Loss of control	F-16C	87-0316	09-Sep-02	N/A	0	Text	Pilot did not eject.	N/A	2

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
105	pp. 334 to 338	Engine failure, mechanical	F-16C	86-0348	11-Sep-02	Unknown	0.32	Text	Distance based on locations of ejected pilot and crash site relative to end of runway.	N/A	1A
106	pp. 11 to 17	Mid-air collision	F-16CG	89-2006	25-Oct-02	Unknown	1.24	Lat, Long	Distance based on coordinates provided for pilot location and crash site.	N/A	0
107	pp. 11 to 17	Mid-air collision	F-16CG	89-2111	25-Oct-02	Unknown	2.50	Lat, Long	Distance based on coordinates provided for pilot location and crash site.	N/A	0
108	p. 27	Controlled flight into terrain	F-16C	88-0397	13-Nov-02	N/A	0	Text	Pilot did not eject.	N/A	0
109	pp. 6 to 9	Mid-air collision	A-10A	80-0225	4-Dec-02	N/A	0	Map	Ejection was initiated but was unsuccessful. Map shows wreckage of the two aircraft involved in the mishap (see Event 110). Ejection seat is shown inside wreckage of plane.	N/A	0
110	pp. 6 to 9	Mid-air collision	A-10A	79-0191	4-Dec-02	Unknown	0.02	Map	See Event 109. Map shows wreckage of the two aircraft involved in the mishap. Distance based on location of ejection seat and impact crater of the aircraft that does not contain the ejection seat. Scaled from map.	N/A	0

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
111	pp. 132 to 134, and 241 to 243	Mid-air collision	F-15C	80-0040	17-Mar-03	Unknown	0.06	Map	Distance calculated as mean of distances from approximate center of impact crater (cockpit) to ejection seat and canopy. Scaled from map (horizontal and vertical axes do not have the same scale). Second aircraft damaged but returned to base.	N/A	0
112	pp. 236 to 240	Engine failure, mechanical	F-16C	89-2052	29-May-03	320 AGL	Unknown	N/A	Catastrophic engine failure immediately after takeoff, most likely due to bird strike.	N/A	0
113	pp. 360 to 362	Loss of control	F-15E	87-0186	04-Jun-03	9,080 MSL	Unknown	N/A	Map is supplied but uncertainties about exact locations of canopy and seat are too significant to derive a meaningful ejection distance.	N/A	2
114	pp. 138 to 140	Engine failure, mechanical	F-16C	88-0451	10-Jun-03	2,040 MSL	0.56	Map	Distance based on mean of distances from point of aircraft impact to canopy and ejection seat. Scaled from map.	N/A	1A
115	pp. 119 to 121	Engine failure, mechanical	F-16CG	88-0424	12-Jun-03	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A
116	p. 26	Unknown	F-16CG	89-2084	9-Sep-03	400 AGL	Unknown	N/A	Crash into sea.	N/A	0
117	pp. 135 to 137	Insufficient altitude for maneuver	F-16C	87-0327	14-Sep-03	Unknown	~0	Map	Pilot ejected when he determined maneuver could not be successfully completed. Canopy located in crash debris field.	N/A	0

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
118	pp. 355 and 356	Engine failure, fire	F-16C	84-1303	22-Sep-03	4,000 AGL	1.95	Lat, Long	Distance calculated as mean of distances from center of crater impact to ejection seat and canopy. Although text describes the end part of coordinates as seconds of arc, they clearly are decimal fractions of minutes, because they are greater than 60.	2.6	1B
119	pp. 353 and 354	Engine failure, mechanical	A-10A	79-0143	18-Nov-03	Unknown	0.12	Map	Speed brakes stuck open. Distance based on location of canopy and fuselage. Scaled from map.	N/A	1B
120	pp. 357 to 359	Loss of control	A-10A	78-0700	25-Feb-04	N/A	0	Text	Pilot did not eject.	N/A	2
121	p. 287	Engine failure, mechanical	F-15E	88-1701	06-May-04	Unknown	Unknown	N/A	Bird strike. Ejection was successful.	N/A	0
122	pp. 288 to 311	Mid-air collision	F-16C	85-1555	17-May-04	N/A	0	Text	Pilot did not eject.	N/A	0
123	pp. 288 to 311	Mid-air collision	F-16C	86-0260	17-May-04	Unknown	Unknown	N/A	Ejection was successful.	N/A	0

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
124	pp. 312 to 314	Unknown	F-15C	81-0027	21-May-04	14,500 AGL	12	Map, in combination with Rand McNally (1995 [DIRS 172083], p. 23)	Distance from ejection to aircraft impact.; map distances transposed to Rand McNally (1995 [DIRS 172083]) and scaled. Given uncertainties in scaling from two maps, ejection distance is rounded off to the closest mile. Because the aircraft flew 12 mi after ejection, it appears to have retained much of its aerodynamic capability after the unknown cause of ejection. Hence, the classification as 1B rather than 0.	4.4	1B
125	p. 315	Engine flameout	F-15C	79-0054	04-Jun-04	Unknown	Unknown	N/A	Ejection was successful.	N/A	1A
126	pp. 157 to 159	Engine failure, fire	Not given	Not given	Not given	Unknown	Unknown	N/A	Report did not provide information on type of aircraft or date of mishap. Maps of crash site are given, but without sufficient information to determine ejection location to crash site distance	N/A	1B
127	pp. 162 and 163	Engine failure, mechanical	Not given	Not given	Not given	Unknown	Unknown	N/A	Report did not provide information on type of aircraft or date of mishap. Map of crash site is given, but without sufficient information to determine ejection location to crash site distance.	N/A	1A

Table III-1 (continued). Information Extracted from Air Force Aircraft Mishap Reports

No.	Source: Alston 2004 [DIRS 172743]	Initiating Event Description	Aircraft Type	Aircraft Serial No.	Date[a]	Ejection Altitude[b] (Feet)	Distance to Crash (Miles)[c]	Distance Method[d]	Comment	Glide Ratio for Type 1 Events after Ejection[e]	Initiating Event Type[f]
128	pp. 155 and 156	Engine failure, fire	Not given	Not given	Not given	11,000 MSL	2.4	Lat, Long	Report did not provide information on type of aircraft or date of mishap. Distance calculated as mean of distances from crash site to seat and canopy, based on latitude and longitude coordinates.	N/A	1B

SOURCE: Extracted or calculated from excerpts of accident reports (Alston 2004 [DIRS 172743]).

NOTES:

[a]The dates of occurrence of a few events reported (Alston 2004 [DIRS 172743]) are not available. Because these events provide additional insight in determining the characteristics of military aircraft crashes, they were kept for consideration and grouped at the end of the table. It cannot be ensured, however, that they occurred over the study period (1990 to September 2004). This uncertainty does not affect the conclusions of the analysis.

[b]The "Altitude/Elevation" provided in the Aircraft Flight Mishap Report provided in most of the accident reports did not always correspond to the ejection altitude. Thus, it was not used to determine altitude at ejection. When no ejection occurred, "N/A" was used in this column.

[c]The ejection-to-crash distances are shown with the number of significant digits that can be obtained from the data of the relevant event. When no pilot ejection occurred, a value of zero (0) is used.

[d]The following abbreviation is used for the ninth column, "Distance Method":

Lat, Long — Using latitude and longitude coordinates given in accident report text or on maps

[e]The dimensionless glide ratio is calculated as (distance to crash in mi)(5,280 ft/mi) / (ejection altitude in ft AGL, if known). When there was no ejection, the glide ratio is considered to be undefined.

[f]Event type is described in Assumption 5.3.9.

Table III-2. Summary Information Derived from the Crash Data

Description[a]	Value (dimensionless)	Fraction of Applicable Events (Type 1 or Type 2)
Number of Type 1 events	68	0.85
Number of Type 1A events	56	0.70
Number of Type 1B events	12	0.15
Number of Type 2 events	12	0.15

SOURCE: Table III-1.

NOTES: [a]See Assumption 5.3.9 for a discussion of event types.

ATTACHMENT IV.

EFECTIVE TARGET AREAS AND CRASH FREQUENCIES

(A MATHCAD 11.2a FILE)

IV.1 EFFECTIVE AREAS

As discussed in Assumption 5.3.1, a number of structures and areas are potentially included in the effective-area calculation, indexed by n varying from 1 through 11 as follows.

$n \equiv 1..11$

1 Dry Transfer Facility (including Remediation)
2 Canister Handling Facility
3 Transportation Cask Buffer Area
4 Transportation Cask Receipt/Return Facility
5 1,000 MTHM aging pad
6 10,000 MTHM aging pad
7 Loaded waste-package or cask transporter
8 Railcar buffer area
9 Truck buffer area
10 Fuel Handling Facility
11 Low Level Waste Handling Area

This calculation considers two DTFs, two 10,000 MTHM aging areas, and two generic transporters carrying waste packages, transportation casks, or aging casks. To allow for duplicates, the vector Q gives the numbers of each structure or area to be included. Additional vectors specify, in ft, the lengths L, widths W, and heights H of the relevant structures and areas (Assumption 5.3.1).

$$Q \equiv \begin{pmatrix} 2 \\ 1 \\ 1 \\ 1 \\ 1 \\ 2 \\ 2 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} \qquad L \equiv \begin{pmatrix} 492 \\ 309 \\ 604 \\ 231 \\ 745 \\ 1500 \\ 25 \\ 1700 \\ 220 \\ 200 \\ 120 \end{pmatrix} \qquad W \equiv \begin{pmatrix} 442 \\ 232.5 \\ 131 \\ 137 \\ 150 \\ 800 \\ 25 \\ 80 \\ 110 \\ 146 \\ 80 \end{pmatrix} \qquad H \equiv \begin{pmatrix} 100 \\ 64 \\ 15 \\ 80 \\ 20 \\ 20 \\ 15 \\ 15 \\ 15 \\ 64 \\ 10 \end{pmatrix}$$

The effective-area formula is simplified by defining the diagonal D (in ft) across the floor of each structure or area.

$$D \equiv \sqrt{L^2 + W^2}$$

The effective areas depend on characteristics of the aircraft types included. Subscripts distinguish the aircraft characteristics and the effective areas for each aircraft type as follows (Section 4.2.1).

$m \equiv 1..7$

1	Small military aircraft
2	Large military aircraft
3	General aviation, piston-engine
4	General aviation, turboprop
5	General aviation, turbojet
6	Commercial air taxi (that is, 14 CFR Part 135 flights)
7	Commercial air carrier (that is, 14 CFR Part 121 flights)

The wingspans G (ft), cotangents C of the approach angle from horizontal (dimensionless), and mean skid distances K (ft) according to aircraft type are as follows (Section 4.2.1):

$$G \equiv \begin{pmatrix} 78 \\ 223 \\ 50 \\ 73 \\ 50 \\ 59 \\ 98 \end{pmatrix} \qquad C \equiv \begin{pmatrix} 8.4 \\ 7.4 \\ 8.2 \\ 8.2 \\ 8.2 \\ 10.2 \\ 10.2 \end{pmatrix} \qquad K \equiv \begin{pmatrix} 246 \\ 780 \\ 60 \\ 60 \\ 60 \\ 1440 \\ 1440 \end{pmatrix}$$

The effective areas of each structure or area (indexed by n=1,..., 11) and for each type of aircraft (indexed by m=1,..., 7) are given by Equations 1 and 2 as follows, with a conversion to mi²:

$$Y_{n,m} \equiv \left[L_n \cdot W_n \cdot \left(1 + 2 \cdot \frac{G_m}{D_n}\right) + (G_m + D_n) \cdot H_n \cdot C_m + (D_n + G_m) \cdot (K_m) \right] \cdot \frac{Q_n}{5280^2}$$

$Y =$

	1	2	3	4	5	6	7
1	$7.69 \cdot 10^{-2}$	$1.23 \cdot 10^{-1}$	$6.29 \cdot 10^{-2}$	$6.54 \cdot 10^{-2}$	$6.29 \cdot 10^{-2}$	$1.46 \cdot 10^{-1}$	$1.54 \cdot 10^{-1}$
2	$1.67 \cdot 10^{-2}$	$3.30 \cdot 10^{-2}$	$1.24 \cdot 10^{-2}$	$1.32 \cdot 10^{-2}$	$1.24 \cdot 10^{-2}$	$3.68 \cdot 10^{-2}$	$4.03 \cdot 10^{-2}$
3	$1.28 \cdot 10^{-2}$	$3.18 \cdot 10^{-2}$	$7.68 \cdot 10^{-3}$	$8.04 \cdot 10^{-3}$	$7.68 \cdot 10^{-3}$	$4.21 \cdot 10^{-2}$	$4.47 \cdot 10^{-2}$
4	$1.32 \cdot 10^{-2}$	$2.72 \cdot 10^{-2}$	$9.74 \cdot 10^{-3}$	$1.05 \cdot 10^{-2}$	$9.74 \cdot 10^{-3}$	$2.81 \cdot 10^{-2}$	$3.16 \cdot 10^{-2}$
5	$1.73 \cdot 10^{-2}$	$3.91 \cdot 10^{-2}$	$1.10 \cdot 10^{-2}$	$1.15 \cdot 10^{-2}$	$1.10 \cdot 10^{-2}$	$5.29 \cdot 10^{-2}$	$5.56 \cdot 10^{-2}$
6	$1.47 \cdot 10^{-1}$	$2.37 \cdot 10^{-1}$	$1.19 \cdot 10^{-1}$	$1.22 \cdot 10^{-1}$	$1.19 \cdot 10^{-1}$	$3.00 \cdot 10^{-1}$	$3.08 \cdot 10^{-1}$
7	$3.27 \cdot 10^{-3}$	$1.71 \cdot 10^{-2}$	$1.29 \cdot 10^{-3}$	$1.65 \cdot 10^{-3}$	$1.29 \cdot 10^{-3}$	$1.10 \cdot 10^{-2}$	$1.55 \cdot 10^{-2}$
8	$2.91 \cdot 10^{-2}$	$6.77 \cdot 10^{-2}$	$1.67 \cdot 10^{-2}$	$1.69 \cdot 10^{-2}$	$1.67 \cdot 10^{-2}$	$1.06 \cdot 10^{-1}$	$1.08 \cdot 10^{-1}$
9	$5.74 \cdot 10^{-3}$	$1.74 \cdot 10^{-2}$	$3.16 \cdot 10^{-3}$	$3.48 \cdot 10^{-3}$	$3.16 \cdot 10^{-3}$	$1.87 \cdot 10^{-2}$	$2.12 \cdot 10^{-2}$
10	$1.09 \cdot 10^{-2}$	$2.41 \cdot 10^{-2}$	$7.71 \cdot 10^{-3}$	$8.39 \cdot 10^{-3}$	$7.71 \cdot 10^{-3}$	$2.46 \cdot 10^{-2}$	$2.78 \cdot 10^{-2}$
11	$3.35 \cdot 10^{-3}$	$1.27 \cdot 10^{-2}$	$1.57 \cdot 10^{-3}$	$1.80 \cdot 10^{-3}$	$1.57 \cdot 10^{-3}$	$1.19 \cdot 10^{-2}$	$1.42 \cdot 10^{-2}$

The total effective areas (mi²) of the relevant surface structures and areas by aircraft type are given by

$$A_m := \sum_n Y_{n,m}$$

$A =$

	1
1	$3.36 \cdot 10^{-1}$
2	$6.29 \cdot 10^{-1}$
3	$2.53 \cdot 10^{-1}$
4	$2.63 \cdot 10^{-1}$
5	$2.53 \cdot 10^{-1}$
6	$7.77 \cdot 10^{-1}$
7	$8.22 \cdot 10^{-1}$

The fractional contributions to the effective area from each structure or area by aircraft type are given by:

$$Z_{n,m} \equiv \frac{Y_{n,m}}{\left[\sum_{n}(Y_{n,m})\right]}$$

Z =

	1	2	3	4	5	6	7
1	0.23	0.19	0.25	0.25	0.25	0.19	0.19
2	0.05	0.05	0.05	0.05	0.05	0.05	0.05
3	0.04	0.05	0.03	0.03	0.03	0.05	0.05
4	0.04	0.04	0.04	0.04	0.04	0.04	0.04
5	0.05	0.06	0.04	0.04	0.04	0.07	0.07
6	0.44	0.38	0.47	0.46	0.47	0.39	0.37
7	0.01	0.03	0.01	0.01	0.01	0.01	0.02
8	0.09	0.11	0.07	0.06	0.07	0.14	0.13
9	0.02	0.03	0.01	0.01	0.01	0.02	0.03
10	0.03	0.04	0.03	0.03	0.03	0.03	0.03
11	0.01	0.02	0.01	0.01	0.01	0.02	0.02

IV.2 CRASH FREQUENCY CONTRIBUTION FROM BEATTY CORRIDOR

The frequency of crashes into repository facilities for each aircraft type on the Beatty Corridor depends on the crash rate per mile λ, (Section 4.2.2 and Assumption 5.3.2) and annual flight frequencies N (Section 5.3.6).

$$\lambda \equiv \begin{pmatrix} 2.736\cdot 10^{-8} \\ 1.9\cdot 10^{-9} \\ 2.233\cdot 10^{-7} \\ 3.557\cdot 10^{-8} \\ 3.067\cdot 10^{-9} \\ 3.7\cdot 10^{-8} \\ 3.094\cdot 10^{-10} \end{pmatrix} \qquad N \equiv \begin{pmatrix} 10300 \\ 2900 \\ 19800 \\ 12600 \\ 23800 \\ 29100 \\ 166500 \end{pmatrix}$$

In addition, the distance d (Assumption 5.3.3) to the airway in miles and the width w of the airway in miles are needed.

$$d \equiv 5$$

$$w \equiv 26$$

The exponential decay constants γ in mi^{-1} for each aircraft type (Section 4.2.3) are needed to compute the edge adjustment factors ρ for the Beatty Corridor calculation (Section 6.2.4.2).

$$\gamma := \begin{pmatrix} 1 \\ 1 \\ 2 \\ 2 \\ 2 \\ 1.6 \\ 1.6 \end{pmatrix}$$

The edge adjustment factors ρ_m indexed by aircraft type are given by the bracketed part of Equation 9 as follows:

$$\rho_m := \frac{exp(-\gamma_m \cdot d)\cdot(1 - exp(-\gamma_m \cdot w))}{2}$$

$\rho =$

	1
1	$3.37 \cdot 10^{-3}$
2	$3.37 \cdot 10^{-3}$
3	$2.27 \cdot 10^{-5}$
4	$2.27 \cdot 10^{-5}$
5	$2.27 \cdot 10^{-5}$
6	$1.68 \cdot 10^{-4}$
7	$1.68 \cdot 10^{-4}$

Using Equation 9 and the effective target areas that were computed above, the estimated annual crash frequencies for each aircraft type in the Beatty Corridor are given by:

$$F_m := \frac{(N_m \cdot \lambda_m \cdot \rho_m)}{w} \cdot A_m$$

$F =$

	1
1	$1.23 \cdot 10^{-8}$
2	$4.49 \cdot 10^{-10}$
3	$9.78 \cdot 10^{-10}$
4	$1.03 \cdot 10^{-10}$
5	$1.62 \cdot 10^{-11}$
6	$5.40 \cdot 10^{-9}$
7	$2.73 \cdot 10^{-10}$

The total crash frequency due to aircraft on the Beatty Corridor is

$$\sum_m F_m = 1.95 \times 10^{-8}$$

ENCLOSURE 2:
DOE RESPONSES TO SIX OF THE THIRTEEN NRC STAFF FEEDBACK ITEMS ON THE AIRCRAFT HAZARD ANALYSES

The revised Frequency Analysis of Aircraft Hazards for License Application includes the following changes to DOE's approach for analyzing aircraft hazards:

- The number of assumed overflights of the no-fly zone has been reduced from 5,000 annual overflights above a 14,000-ft mean sea-level ceiling to 2,500 annual overflights above a 14,000-ft mean sea-level ceiling. Communication is ongoing with the USAF and indications are that the number of overflights may be further reduced.

- The crash rate for military flights outside the no-fly zone has been determined using the historical data on military crashes that have occurred in the Nevada Test and Training Range as well as the adjacent Military Operations Areas. This change takes into consideration a more robust data set for historical aircraft crashes due to military training in the area surrounding the Yucca Mountain repository.

- The updated F-16 crash rate for normal operations (2.736E-08 mi^{-1}) from the *Safety Evaluation Report Concerning the Private Fuel Storage Facility* has been used to estimate the crash frequency due to flights over the no-fly zone and military flights in the Beatty Corridor. This change in crash rate follows the Private Fuel Storage Facility precedent for the use of an F-16 crash frequency that is more representative of contemporary flight operations experience and was deemed appropriate for use in assessing the aircraft hazards associated with the Yucca Mountain repository.

Six of the thirteen items from the August 2, 2005 letter (Reference 1) have been addressed in the revised frequency analysis. Items 2, 5, 10, 11, 12 and 13 from Reference 1 are addressed as follows:

2. Pilot Actions Outside of No-Fly Zone:

Response: No credit is taken for pilot action. There are three contributors to the overall crash frequency; crashes from flights in the Beatty Corridor, crashes from overflights of the no-fly zone, and crashes from flights outside of the no-fly zone. The highest contribution to the overall crash frequency is from crashes that originate from flights outside the no-fly zone. If pilot action were credited in the analysis, the crash frequency from flights outside the no-fly zone could essentially be eliminated.

5. Categorizing USAF Mishap Reports

Response: The categorization of the mishap events is based on the identified cause of the event from the USAF Safety Reports. A revised discussion clarifying the process of categorizing the events has been included in the August revision of the analysis.

10. *Bird Strikes*

Response: A reference supporting the assumption on bird strikes has been included in the August revision of the analysis.

11. *Utilization Factor – Aging Pads:*

Response: No utilization factor for the aging pad is used in the August revision of the analysis. The aging pads have been assumed to be at full capacity for the entire emplacement period.

12. *Structural Credit – Analysis Methodology:*

Response: No credit is taken for the robustness of any of the facilities and no credit is taken for any engineered barrier.

13. *Structural Credit – Transportation Casks:*

Response: No credit is taken for the robustness of transportation casks, with or without impact limiters.