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OVERNIGHT MAIL

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FREQUENCY ANALYSIS OF AIRCRAFT HAZARDS FOR LICENSE APPLICATION

Reference: Ltr, Ziegler to Schlueter, dtd 7/9/02

This letter transmits the U.S. Department of Energy (DOE) calculation, *Frequency Analysis of Aircraft Hazards for License Application* (Enclosure).

This calculation estimates the crash frequencies for aircraft hazards that are identified for detailed analysis in the report, *Identification of Aircraft Hazards,* which was previously provided to the U.S. Nuclear Regulatory Commission in the reference letter. The purpose of this calculation is to estimate the frequencies of the identified aircraft hazards to the proposed Yucca Mountain repository surface facilities during emplacement operations. The scope of the calculation includes the hazards that are listed in Section 8 of *Identification of Aircraft Hazards*. In addition, hazards from objects dropped from aircraft are considered.

It should be noted that the calculation is based on the site and surface facility layout (for example, dimensions and layout of the surface facilities) that was current at the time the calculation was performed. Since that time, the design has continued to develop. As a result, this analysis will be revised once design decisions affecting the facility footprint are finalized.

The DOE will continue to gather information about aircraft operations. Through periodic contacts with U.S. Air Force representatives from Nellis Air Force Base, the DOE will monitor changes in military aircraft operations over the Nevada Test Site that may occur due to potential changes brought on by the evolving mission of the Nevada Test and Training Range.

The DOE recommends that this analysis be reviewed principally for the methodology, since the actual results are subject to design evolution.

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There are no new regulatory commitments in the body or the enclosure to this letter.

Please direct any questions concerning this letter and its enclosure to Joe C. Price at (702) 794-1441 or Timothy C. Gunter at (702) 794-1343.

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Office of License Application & Strategy

OLA&S:TCG-1460

Enclosure:
Frequency Analysis of Aircraft Hazards for License Application, CAL-WHS-RL-000001 Rev 00B

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ENCLOSURE

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☒ Preliminary ☐ Final ☐ Cancelled

8. Notes/Comments

This revision is not an update. Information that is more recent, including design information and flight information, is available but has not been incorporated. The twofold purpose of the revision is noted in Box 10.

Summary of changes in response to AP-6.28Q review. The changes involved amplification of the screening argument for general aviation aircraft below 10,000 ft, clarifications involving labeling of airspace areas on figures, explanations and footnotes added to tables, and other minor clarifications and editorial changes.

Summary of changes to address TER-03-0032. The noted transposition of digits and its downstream effects were corrected. In lieu of changing the inconsistent figure numbers in the reference to *Yucca Mountain Project Conceptual Design Report*, TDR-MGR-MD-000014 REV 01, references to that report were replaced with references to equivalent information elsewhere.

An interdisciplinary review of this revision has not been conducted because the changes are minor and do not affect scope, methods, or conclusions.

A formal impact review of this revision has not been conducted because the document has not been cited in any approved document except in one by the Preclosure Safety Analysis Department (*Industrial/Military Activity-Induced Accident Screening Analysis*, ANL-WHS-SE-000004 REV 01); there is no impact on that document.

Change bars in the left margin indicate the locations of changes. The following pages are substantively affected by the revision: 1, 8, 9, 15, 21, 22, 25, 27, 28, 29, 30, 31, 33, 34, 35, 37, I-1, I-2, I-3, I-5, IV-1, IV-2. Footers were changed to remove the spaces for originator's and checker's initials and dates because the related steps are no longer required by AP-3.12Q. Footers were also updated with the revision letter and date.

Attachments	Total Number of Pages
I	5
II	3
III	2
IV	2

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. QER (Print/Sign/Date)	16. Approved/Accepted (Print/Sign)	17. Date
A	Initial issue	37	37	Guy E. Ragan	Guy Martin, Jr.	Stephen F. Schuermann	Dennis Richardson	2/27/03
00B	Address TER-03-0032 and DOE comments from AP-6.28Q review.	37	37	Guy E. Ragan Guy E Ragan 6/17/03	Guy Martin, Jr. 6/17/03	Stephen F. Schuermann 6/17/03	Dennis Richardson Dennis Richardson 6/17/03	6/17/03

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FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

AGL	above ground level
DOE	U.S. Department of Energy
DEM	digital elevation model
EC	electronic combat
ESF	Exploratory Studies Facility
FAA	U.S. Federal Aviation Administration
IFR	instrument flight rules
IMC	instrument meteorological conditions
IR	military instrument flight training route
LATN	low altitude tactical navigation
MGR	monitored geologic repository
MOA	military operations area
MSL	above mean sea level
MTR	military training route
[n.d.]	no date
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NTSB	National Transportation Safety Board
NTTR	Nevada Test and Training Range
USGS	United States Geological Survey
VFR	visual flight rules
VR	military visual flight training route
VMC	visual meteorological conditions
VORTAC	very high frequency omnidirectional range and tactical air navigation station
YMP	Yucca Mountain Project

MATHEMATICAL NOMENCLATURE

α	Average rate at which objects are unintentionally dropped from aircraft per sortie
A	A flight area or its surface area (mi^2) as viewed on a map
A_f	A flight area or its surface area (mi^2) as viewed on a map
$A_{\text{fly-in}}$	Effective area (mi^2) of a ground facility with respect to airborne hazards ignoring skid impact
A_{skid}	Effective area (mi^2) of a ground facility with respect to airborne hazards ignoring fly-in impact
A_c	Area (mi^2) of the circle with radius r_c centered on the facility under consideration
A_d	A subset of a flight area (mi^2) where flights pose a hazard to a surface facility
A_{eff}	Effective target area (mi^2) of a ground facility with respect to airborne hazards
β	Aircraft crash rate per hour flown (h^{-1})
d	Distance (mi) between the center of a facility outside an airway and the edge of an airway (becomes negative when the facility is inside the airway)
D	Average distance traveled in one flight (mi)
D_b	Outside diagonal distance (ft) horizontally across a surface facility (approximated as a rectangular prism)
F	Annual frequency (y^{-1}) of aircraft crashes into a surface facility
F_0	Annual frequency (y^{-1}) of aircraft crashes into a surface facility located on the edge of an airway
G	Wingspan (ft) of an aircraft
H_b	Height (ft) of a surface facility (approximated as a rectangular prism)
λ	Aircraft crash rate per mile flown (mi^{-1})
l	Length (mi) of an arbitrarily long section of an airway
L_b	Length (ft) of a surface facility
L	Perimeter (mi) of area A
l_m	Mean length (mi) of flights through a flight area
L_f	Perimeter (mi) of the flight area A_f
N	Annual frequency (y^{-1}) of flights through a flight area
ϕ	Approach angle (degrees) to the ground of a crashing aircraft or dropped object
P	Probability of a helicopter crash per flight
r_c	Maximum horizontal distance (mi) from the point of initiation of a crash that an aircraft destined to crash can travel before crashing
r_{eff}	Effective radius (mi) of a ground facility: $(A_{\text{eff}} / \pi)^{1/2}$
r_f	Radius (mi) of a circular flight area

MATHEMATICAL NOMENCLATURE (continued)

S	Skid distance (ft) traveled on the ground by an aircraft before crashing into a ground facility
T	Annual flight time (h/y) in a flight area
v	Distance (mi) on either side of a helicopter flight path over which crashes are assumed to be uniformly distributed
w	Width (mi) of an airway plus twice the distance (mi) from the edge of the airway to the facility when the facility is beyond the edge of the airway
w_0	Value of w when $d = 0$
w_f	Width (mi) of an airway
W_b	Width (ft) of a surface facility (approximated as a rectangular prism)

1. PURPOSE

Yucca Mountain is located, in part, beneath the restricted airspace of the Nevada Test Site (NTS) and the Nevada Test and Training Range (NTTR), which the U.S. Air Force uses intensively for training and test flights (Figure 1). The Air Force also crosses the airspace above the NTS while conducting training and test flights. Commercial, military, and general aviation aircraft fly within several miles to the southwest of Yucca Mountain on flight paths in a wide band that runs approximately parallel to U.S. Highway 95 and the Nevada-California border. These and other aircraft operations were identified and described in *Identification of Aircraft Hazards* (BSC 2002c). The proposed location of the surface facilities that are the subject of this analysis is within the Nevada Test Site, on the eastern slope of Yucca Mountain, near the North Portal of the Exploratory Studies Facility (ESF) Tunnel (Figure 1).

The preclosure safety analysis for the proposed repository at Yucca Mountain must consider the hazard that nearby aircraft operations may pose to surface facilities. The present analysis estimates crash frequencies for aircraft hazards that were identified for detailed analysis in *Identification of Aircraft Hazards* (BSC 2002c). The purpose and intended use of this analysis is to estimate the frequencies of the identified aircraft hazards to proposed repository surface facilities during emplacement operations. The analysis does not cover large-scale waste retrieval because retrieval operations would presumably require an extensive aboveground storage facility that is not included as a potentially affected facility in the analysis. The scope of the analysis includes the hazards that are listed in Section 8 of *Identification of Aircraft Hazards* (BSC 2002c). In addition, hazards from objects dropped from aircraft are considered. Information about the surface facilities used in this analysis (for example, dimensions and layout of the surface facilities) is preliminary and is not intended to represent the design of surface facilities that will be presented in the license application. The analysis will be revised based on the design to be presented in the license application, updated flight information, and any proposed changes in the use of the NTTR by the Air Force. Users of the results of this analysis should bear in mind its preliminary nature.

The Office of Civilian Radioactive Waste Management's Quality Assurance program applies to the activity under which this analysis was developed because an aircraft crash may affect the integrity of items important to public radiological safety. The analysis was prepared in accordance with AP-3.12Q, *Design Calculations and Analyses*, AP-3.15Q, *Managing Technical Product Inputs*, and other applicable procedures.

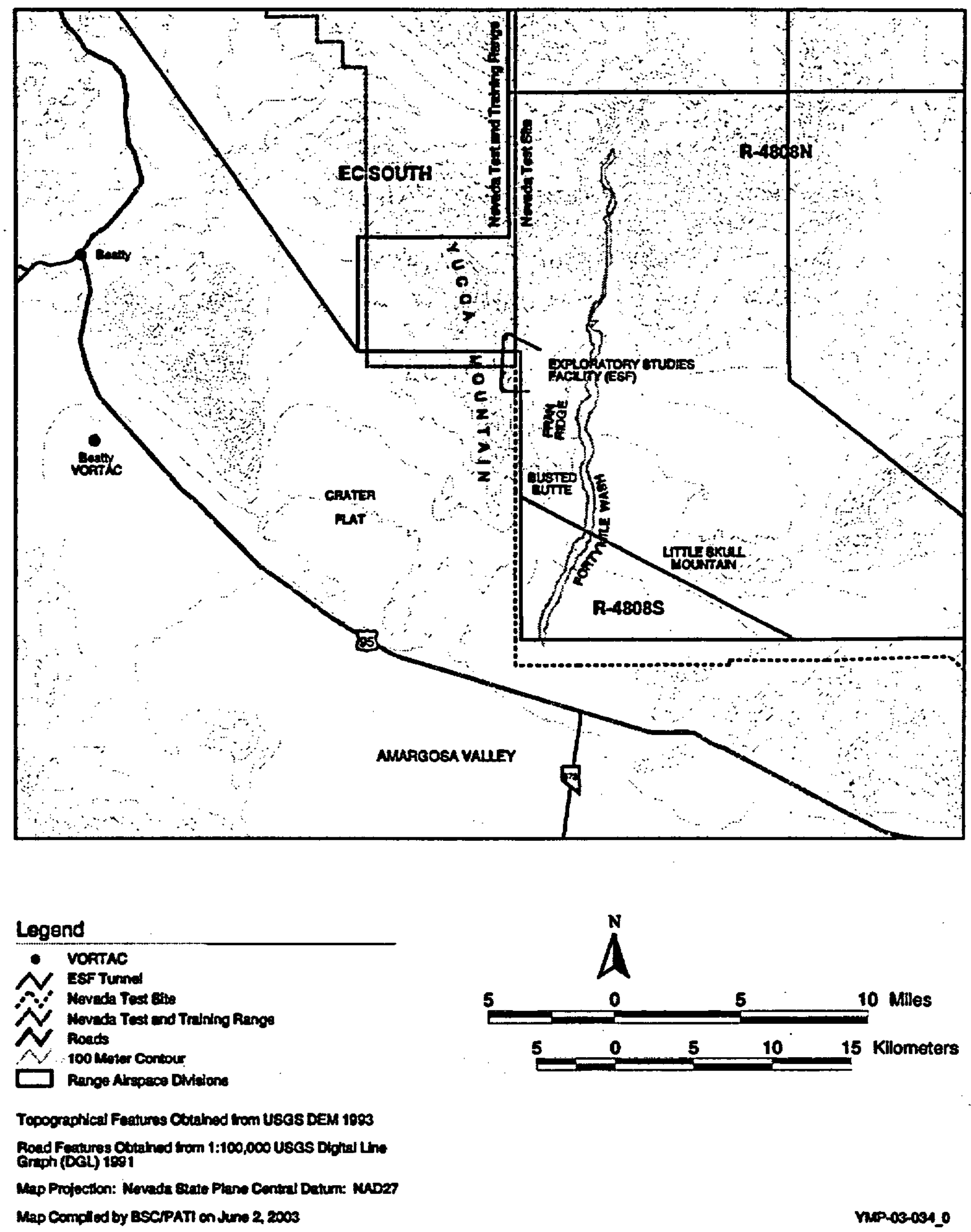

Figure 1. Topographical and Other Features Near the Proposed Repository Site

2. METHODS

This section derives methods for estimating frequencies of aircraft hazards to surface facilities. The hazards considered include fixed-wing crashes, helicopter crashes, and objects inadvertently dropped from aircraft. 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 Section 5.

2.1 RANDOMLY ORIENTED FLIGHTS

The NUREG-0800 airways model (NRC 1987, Section 3.5.1.6) is designed for conservatively estimating crash frequencies related to a nearby airway or aviation corridor. Other methods address point-to-point flights not restricted to airways (Sanzo et al. 1996, Section 4.3.2) and randomly oriented flights in military operations areas (Kimura et al. 2002, Section 5). This section develops methods for estimating the frequency of aircraft crashes into a surface facility located near or within an airspace where flights are randomly distributed.

The small dark shape near the center of Figure 2 represents the view from above of a surface facility that may be damaged by an airplane crash. For the purposes of this analysis, airspace volumes are defined by vertical extensions of areas on the ground. Therefore, for simplicity, the airspace volumes can be discussed in terms of their defining areas on the ground. The area A_f represents the airspace where aircraft crashes could originate. A small circle is drawn around the facility as a simplified representation of the facility's effective area with respect to plane crashes. The effective area is larger than the footprint of the facility to account for wingspan, skid, and shadow effects (Section 2.5). To avoid clutter, the effective area, A_{eff}, is not labeled and the corresponding radius, r_{eff}, is not depicted. The crash range, that is, the maximum horizontal distance an airplane destined to crash can travel before reaching ground level is shown as r_c. A crash-initiating event that occurs to an airplane while it is within the area A_d, which is defined as the intersection of the flight area A_f and a circle of radius $r_c + r_{eff}$ centered at the facility, could cause the plane to crash into the facility. A typical crash-initiation point within area A_d is shown as a black dot. The surrounding area A_c in which the typical crashing plane could hit the ground is delimited by a dashed circle of radius r_c, centered at the crash-initiation point.

Although Figure 2 depicts the facility outside the flight area, the general models to be developed apply whether the facility is inside or outside the flight area. Special cases will be considered in which specific assumptions are made with respect to the location of the facility with respect to the flight area.

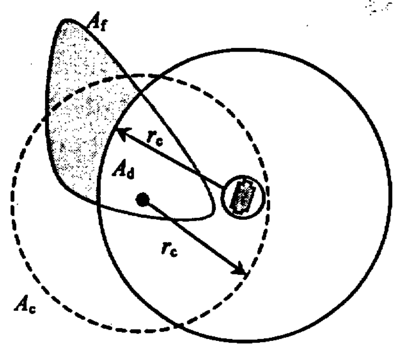

Figure 2. Surface Facility Near a Convex Flight Area

2.1.1. Known Time in Flight

Let T be the expected total annual flight time in hours per year (h/y) of all flights in flight area A_f. If β is the mean crash rate per hour of flight, then the expected annual frequency of crashes initiated in the flight area is $T\beta$. Only those crashes that are initiated within range of the facility (that is, in the area A_d, which is a subset of the flight area A_f as shown in Figure 2) pose any hazard to the facility. On the assumption that crash-initiation events are uniformly distributed throughout the flight area (Assumption 3.1), the frequency of crashes that may hit the facility is given by $T\beta\ (A_d / A_f)$. Finally, assume that crashes are uniformly distributed throughout the circular area defined by the crash range (Assumption 3.2). Using the full effective area of the facility even when part of the facility is out of reach (Assumption 3.3), the frequency of crashes into the facility (y^{-1}) depends on the effective area of the facility A_{eff} and the size of the potential crash area A_c as follows:

$$F = T\beta \frac{A_d}{A_f} \frac{A_{eff}}{A_c} \quad . \qquad \text{(Eq. 1)}$$

Equation 1 may be regarded as the general case. A special case emerges when the flight area completely surrounds the facility and includes the entire area that is within crash range of the facility. In that case, $A_d = \pi(r_{eff} + r_c)^2$ and $A_c = \pi(r_c)^2$. If the facility is small compared to the crash range (Assumption 3.4), that is, $r_{eff} << r_c$, then $(A_d / A_c) \cong 1$ and

$$F = \frac{T\beta}{A_f} A_{eff} \quad . \qquad \text{(Eq. 2)}$$

Note that the crash range r_c does not appear in the formula for the special case. The formula may be regarded as the product of two factors: (1) the uniform areal crash-initiation density per year associated with the flight area and (2) the effective area of the facility. Three additional special cases are worth mentioning for the insight they provide.

The first additional special case demonstrates a pure edge effect. If the facility is located right on the edge of a large rectangular flight area (and far from any corner) then the area A_d is a semicircle and the potential crash area A_c is a circle of approximately the same radius. The ratio of the two areas, A_d / A_c, is one-half. So the pure edge effect reduces the crash frequency by one-half.

The second additional special case demonstrates a pure 90-degree corner effect. If the facility is located right on a corner of a large rectangular flight area, then the area A_d is a quarter circle and the potential crash area A_c is a circle of approximately the same radius. The ratio of the two, A_d / A_c, is one-quarter. So the pure 90-degree corner effect reduces the crash frequency by three-quarters.

The third case applies when the crash range completely encompasses the flight area. Then $A_d = A_f$, and $F = T\beta A_{eff} / (\pi r_c^2)$. Note that, in this special case, a greater crash range implies a lower frequency of crashes into the facility. When, as in the first two additional special cases, the crash range partially extends outside the flight area, an edge effect appears. In this special case, edge effects occur throughout the flight area.

2.1.2. Straight-Line Flights

For this case, the total flight time in the flight area is not known, but the frequency of flights is known and the flight paths are assumed to be straight lines (Assumption 3.5). Let N be the annual frequency of flights (y^{-1}) passing through the flight area, and λ be the crash frequency per mile (mi^{-1}) of flight. The expected frequency of crashes initiated in the flight area is given by $N\lambda l_m$, where l_m is the mean length of flights through the flight area (mi). The areal density of crashes initiated in the flight area is $N\lambda l_m / A_f$.

For a convex area (Assumption 3.6), the mean length of a chord intersecting the area is

$$l_m = \frac{\pi A}{L}, \qquad \text{(Eq. 3)}$$

where A is the surface area and L is the length of the perimeter (Santalo 1976, p. 30). Thus, the areal density of crashes originating in the flight area is $N\lambda l_m / A_f = N\lambda\pi / L_f$, where L_f is the perimeter of the flight area. Only those crashes that occur within the crash range (that is, in the area A_d, which is a subset of the flight area A_f as shown in Figure 2) pose any hazard to the facility. On the assumption that crash-initiation events are uniformly distributed throughout the flight area (Assumption 3.1), the frequency of crashes that may hit the facility is given by $(N\lambda\pi / L_f)A_d$. Finally, assume that crashes are uniformly distributed throughout the circular area defined by the crash range (Assumption 3.2). Using the full effective area of the facility even when part of the facility is out of reach (Assumption 3.3), the frequency of crashes into the facility (y^{-1}) depends on the effective area of the facility, A_{eff}, and the size of the potential crash area A_c as follows:

$$F = \frac{N\lambda\pi}{L_f}\frac{A_d}{A_c}A_{eff} \quad . \qquad \text{(Eq. 4)}$$

Again, a special case emerges when the flight area completely surrounds the facility and includes the entire area that is within crash range of the facility. In that case, $A_d = \pi(r_{eff} + r_c)^2$ and $A_c = \pi r_c^2$. If the facility is small compared to the crash range, that is, $r_{eff} << r_c$, then $(A_d / A_c) \cong 1$ and

$$F = \frac{N\lambda\pi}{L_f}A_{eff} \quad . \qquad \text{(Eq. 5)}$$

Note that the crash range does not appear in the formula for the special case. The right-hand side of Equation 5 makes intuitive sense if it is regarded as the product of two factors: (1) the uniform areal crash-initiation density per year associated with the flight area and (2) the effective area of the facility.

The pure edge and corner effects that were discussed in Section 2.1.1 for known time in flight apply to straight-line flights as well. A similar special case also emerges when the crash range completely encompasses the flight area. Then $A_d = A_f$, and the term A_d / A_c in Equation 4 becomes $A_f / (\pi r_c^2)$, so that a greater crash range implies a lower frequency of crashes into the facility.

2.2 EXTENSION OF THE NUREG-0800 METHOD FOR AIRWAYS

The *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants* (NRC 1987, Section 3.5.1.6) provides the following formula for calculating the frequency F of aircraft crashes into the facility when aviation corridors pass through the vicinity of the site.

$$F = \frac{\lambda N}{w}A_{eff} \quad , \qquad \text{(Eq. 6)}$$

where N is the annual frequency of flights (y^{-1}) passing through the flight area, λ is the crash frequency per mile (mi^{-1}), and w is the width of an airway plus twice the distance from the edge of the airway to the facility when the facility is beyond the edge of the airway (mi). 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 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. Note that the crash-rate density assigned to the center of an airway is the same as that near the edge or beyond it. Considering the simple treatment of edge effects in the NUREG-0800 model, it is understandable that the U.S. Nuclear Regulatory Commission (NRC) implied a range of applicability of the model of two miles from the edge of an airway (NRC 1987, 3.5.1.6.II.1.c). The proposed Yucca Mountain facility will be several miles from the edge of an airway (Section 5.5.2), so edge effects are sure to be significant, and the NUREG-0800 model may be too conservative.

A straightforward extension of the NUREG-0800 model to take more credit for edge effects is possible. Consider an airway with straight-line flight paths running parallel to the centerline of the corridor (Assumption 3.7) along the length l of an arbitrarily long section of the airway (Figure 3). In keeping with the assumptions of the previous sections, the effective radius of the facility is assumed to be very small compared to the crash range: $r_{\mathrm{eff}} << r_{\mathrm{c}}$ (Assumption 3.4). Assume the flight paths are uniformly distributed across the width of the airway w_{f} (Assumption 3.8). The crash range r_{c} specifies the maximum distance at which aircraft are considered a threat to the facility. The annual frequency of crash initiation in the area A_{f} is $N\lambda l$. Only the fraction $A_{\mathrm{d}} / A_{\mathrm{f}}$ of the total crash frequency is a threat to the facility. Therefore, the crash frequency of concern to the facility is $[N\lambda l / (l w_{\mathrm{f}})]A_{\mathrm{d}} = (N\lambda / w_{\mathrm{f}})A_{\mathrm{d}}$. As in Figure 2, let A_{c} denote the area surrounding the crash-initiation point in which a crashing plane could hit the ground. Assuming that the crash impact points are distributed uniformly throughout the area within reach of the crashing aircraft A_{c} (Assumption 3.2), the fraction of the crashes in the area A_{d} that actually hit the facility is $A_{\mathrm{eff}} / A_{\mathrm{c}}$. Therefore, the total crash frequency into the facility is.

$$F = \frac{N\lambda}{w_{\mathrm{f}}} \frac{A_{\mathrm{d}}}{A_{\mathrm{c}}} A_{\mathrm{eff}} \quad . \qquad \text{(Eq. 7)}$$

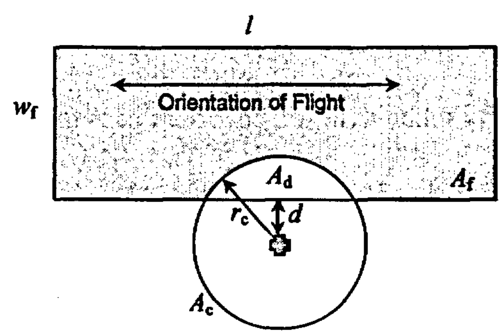

Figure 3. Example Surface Facility and Nearby Section of an Airway

Note that the NUREG-0800 formula (Equation 6) and the formula just developed (Equation 7) are the same except for the width variable and the ratio $A_{\mathrm{d}} / A_{\mathrm{c}}$. For the special case in which the facility is exactly on the edge of the airway, the definitions of the width variable are the same and the ratio $A_{\mathrm{d}} / A_{\mathrm{c}}$ is one-half, independent of the crash range. Thus, the edge-effect adjustment is one-half when the facility is located on the edge of the airway.

When the facility is located some distance d away from the edge of the airway, the computation of the ratio $A_{\mathrm{d}} / A_{\mathrm{c}}$ is more complicated. The area A_{d} as a function of the radius r_{c} and the distance d is (Beyer 1987, p. 125):

$$A_d = r_c^2 \cos^{-1}\left(\frac{d}{r_c}\right) - d\sqrt{r_c^2 - d^2} \quad . \qquad \text{(Eq. 8)}$$

The effect of increasing distance from the airway (as determined with the help of Equation 8) is illustrated in Table 1. The crash frequency depends on the crash range. However, if the crash range is not known, a conservative edge adjustment of 0.5 can be used whenever the facility lies outside the edge of the airway. An edge adjustment of 0.5 is conservative whenever the facility lies outside the airway because the adjustment does not take credit for the reduced crash risk afforded by the facility's distance from the edge of the airway. Equation 8 may also be used with Equation 7 to account for the edge effect inside an airway, but near the edge. The distance from the edge of the airway is negative whenever the facility is inside the airway. Note that when $d = -r_c$ (such that there is no edge effect), Equation 8 gives $A_d = \pi r_c^2$. Then, $A_d / A_c = 1$ in Equation 7 and the resulting special case is identical to the NUREG-0800 model as applied to a facility inside an airway.

Table 1. Edge Adjustments as a Function of Distance from the Airway

Distance d from Airway	Edge Adjustment for Equation 7 (A_d / A_c)	Example Edge Adjustment for NUREG-0800 Model[a]
$-1.0r_c$	1.000	1.000
$-0.9r_c$	0.981	1.000
$-0.8r_c$	0.948	1.000
$-0.7r_c$	0.906	1.000
$-0.6r_c$	0.858	1.000
$-0.5r_c$	0.804	1.000
$-0.4r_c$	0.748	1.000
$-0.3r_c$	0.688	1.000
$-0.2r_c$	0.626	1.000
$-0.1r_c$	0.564	1.000
$0.0r_c$	0.500	1.000
$0.1r_c$	0.436	0.909
$0.2r_c$	0.374	0.833
$0.3r_c$	0.312	0.769
$0.4r_c$	0.252	0.714
$0.5r_c$	0.196	0.667
$0.6r_c$	0.142	0.625
$0.7r_c$	0.094	0.588
$0.8r_c$	0.052	0.556
$0.9r_c$	0.019	0.526
$1.0r_c$	0.000	0.500

NOTE: [a]The example assumes that the width of the airway is equal to $2r_c$

The NUREG-0800 model has an edge adjustment if the facility is located outside the airway. Consider the edge adjustment defined as the ratio of crash frequency F (for a facility located outside the airway) to the frequency F_0 (for a facility located on the edge of the airway). Using Equation 6, it can be shown that the value of the ratio F/F_0 is w_0/w, where according to the NUREG-0800 model, w is the width of the airway plus twice the distance d to the facility from the edge of the airway and w_0 is simply the width of the airway (because $d = 0$ in this instance). The edge adjustment for the NUREG-0800 model depends on the width of the airway. To pick a concrete example that will allow a comparison with the model given by Equation 7, let the width of the airway be $2r_c$. According to the definition of the NUREG-0800 model $w_0 = 2r_c$ and $w = 2r_c + 2d$. Therefore the edge adjustment is $w_0/w = r_c / (r_c + d)$. Table 1 shows the effect on crash frequency of increasing distance from the edge of the airway. For the NUREG-0800 model, the crash frequency is not affected by proximity to the edge when the facility is inside the airway. When the facility is outside the airway, the calculated crash frequency falls off, but not as dramatically as for the model given by Equation 7.

2.3 HELICOPTER FLIGHTS

DOE Standard, Accident Analysis for Aircraft Crash into Hazardous Facilities (DOE-STD-3014-96, Section 5.3.2; Sanzo et al. 1996, Section 4.3.2.3) gives the following formula for estimating the crash frequency for helicopters that fly over a facility:

$$F = \frac{NP}{2Dv} A_{\text{eff}} \ , \qquad \text{(Eq. 9)}$$

where N is the annual frequency of helicopter overflights (y^{-1}), P is the probability of crash per flight, D is the average length of a flight (mi), v is the distance (mi) on either side of the helicopter flight path over which crashes are assumed to be uniformly distributed (Assumption 3.9). The formula has been rewritten to make it independent of units of measurement. The DOE standard prescribes a crash range of 0.25 mi (1320 ft) on either side of the intended flight path (DOE-STD-3014-96, pp. 45, 46).

Equation 9 applies for straight-line flights over the facility. For flights associated with security patrols, aerial site inspections, emergency response, or other operations in which the flight may not trace a straight path over the facility, the crash frequency may be estimated by Equation 2, with the flight area defined to be a circular area one-quarter mile in radius, centered on the facility: $A_f \equiv \pi(r_c)^2 = \pi(0.25 \text{ mi})^2 = 0.20 \text{ mi}^2$. A crash range of one-quarter mile is implied by Assumption 3.9. That the facility is negligibly small compared to the crash range (that is, $r_{\text{eff}} << r_c$) is not obviously true for helicopter analysis (Assumption 3.4). If the facility size, r_{eff}, were not neglected in Equation 2, the frequency estimated would be greater. Therefore, Assumption 3.4 would be nonconservative if Equation 2 were used to exclude the helicopter crash hazard from further consideration due to low frequency. On the other hand, the known bias in Assumption 3.4 is acceptable when using Equation 2 to justify prohibition of routine helicopter flights near radiological facilities (as in Section 5.6). That is, if prohibition of routine helicopter flights can be justified on the basis of a crash frequency that is biased downward, the prohibition could certainly be justified if the bias were removed.

2.4 DROPPED OBJECTS

Consider a facility that is located within a convex area A (Assumption 3.6), for which the annual frequency of over-flights N is known. Let α be the average rate at which objects are unintentionally dropped per sortie, D be the average distance traveled per sortie, and A_{eff} be the effective area of the facility with respect to dropped objects. While the aircraft is within area A, its flight path is assumed to be a straight line (Assumption 3.5). Much of the distance traveled on each sortie may be done outside the area A. Therefore, while the total drop frequency for the flights that pass over area A is $N\alpha$, only a fraction of the drops will occur within area A. Assuming that the distribution of dropped objects along the flight path is uniform (Assumption 3.10), the fraction that occur in area A is the ratio of the mean chord l_m through area A to the average distance per sortie, D. According to Equation 3 the mean length of a chord through A is $\pi A / L$, where L is the perimeter of area A. Thus, the fraction of drops that occur over area A is $\pi A / (LD)$ and the frequency of drops over area A is $N\alpha\pi A / (LD)$. Of those, the fraction expected to hit the facility is A_{eff} / A. The frequency of objects expected to hit the facility, F, is the product of the frequency of drops over area A and the fraction expected to hit the facility. The area A cancels, giving:

$$F = \frac{N\alpha\pi}{LD} A_{eff} \quad . \tag{Eq. 10}$$

2.5 EFFECTIVE-AREA FORMULAS

The effective area A_{eff} depends on characteristics of the aircraft, the facility, and the site. Sanzo et al. (1996, Section 4.4) approximate a facility as a rectangular prism of length L_b, width W_b, and height H_b to derive a formula for effective area. Their 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). It is informative to calculate fly-in and skid areas separately. The fly-in area is the effective area of the facility, considering an airborne approach at an angle, and ignoring the possibility of hitting the ground and skidding into the facility:

$$A_{\text{fly-in}} = L_b W_b (1 + \frac{2G}{D_b}) + (G + D_b) H_b \cot\phi \quad , \tag{Eq. 11}$$

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

$$A_{\text{skid}} = (D_b + G)S \quad . \qquad \text{(Eq. 12)}$$

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

3. ASSUMPTIONS

3.1 Assumption: Crash-initiation events are uniformly distributed throughout the flight areas for the mathematical derivations in Sections 2.1 and 2.2. Rationale: This formal assumption is required for the mathematical derivations. The practical function of the assumption is to ensure that the crash-rate density within crash range of the facility is representative of the larger area for which the flight frequency is known. The use of Equation 5 in Section 5.5.1 maintains this representativeness, so that the function of the assumption is fulfilled, although it cannot be shown that the assumption is strictly true. As it pertains to the modified NUREG-0800 analysis (Sections 2.2 and 5.5.2), this assumption is implied by Assumption 3.8.

3.2 Assumption: Crash-impact points are uniformly distributed throughout the circular area defined by the crash range for the mathematical derivations in Sections 2.1 and 2.2. Rationale: This formal assumption is required for the mathematical derivations. It is not strictly true, but its use in this analysis is conservative. As demonstrated in Attachments I and II for general aviation accidents, crashes that occur many miles away from the accident-initiation point are possible but rare. The same is true for crashes involving military aircraft (BSC 2002c, Appendix G). It follows (contrary to the assumption) that crashes tend to be concentrated near the center of the crash range. The assumption may be conservative or nonconservative depending on the geographical relationships between the flight area, the facility, and the crash range. The assumption may be nonconservative in situations where the crash range is larger than the flight area, and the facility is inside or near the flight area, because the hazard from nearby flights would be given too little weight. The assumption is conservative in this analysis because the flight areas are larger than the crash ranges. This assumption is used in Sections 2.1 and 2.2.

3.3 Assumption: The crash frequency is taken to be proportional to the full effective area of the facility, not just the fraction of the effective area that is within range, when any part of the facility is within crash range of a potential crash-initiation point. This formal assumption applies to the mathematical derivations in Sections 2.1 and 2.2. Rationale: Using the full area is conservative because it results in a slightly greater estimated crash frequency.

3.4 Assumption: The Yucca Mountain surface facility is small compared to the crash range. Rationale: This formal assumption applies to the mathematical derivations in Sections 2.1 and 2.2. The crash ranges for fixed-wing aircraft are on the order of several miles (Assumptions 3.17, 3.21, and 3.18). The dimensions of the relevant buildings are on the order of a few hundred feet (Assumption 3.14), which is negligible compared to several miles. For helicopters, with an assumed crash range of 1320 ft (Section 2.3), the facility dimensions are smaller than the crash range, but perhaps not negligible. Therefore, this assumption should be applied carefully to helicopter analysis. This assumption is used in Sections 2.1.1, 2.1.2, 2.2, and 2.3.

3.5 Assumption: Flight paths are considered straight lines for the derivations in Sections 2.1.2 and 2.4. Rationale: Air Force aircraft use the NTS airspace, including airspace near the North Portal, as a shortcut between the northern areas of the NTTR and the southern areas and to reach the NTTR from the public airspace south of the NTS (BSC 2002c, Section 5.1.2.2). Flying the shortest distance between two points is the most efficient way to cross the NTS.

3.6 Assumption: The flight areas considered in the derivations in Section 2.1.2 and 2.4 are convex, as required by the formula for the mean length of a chord. Rationale: The 7 by 5.8 mile rectangular aircraft incursion area surrounding the North Portal (Section 5.5.1) is convex. The NTS is not convex; however, the area that has been defined to approximate the NTS for aircraft incursion counts (Section 5.5.1) is convex.

3.7 Assumption: Flight paths are considered straight lines parallel to the centerline of the flight corridor for the derivation in Section 2.2. Rationale: The graphical display of flight paths in Attachment IV and the other graphics provided by the FAA (Ragan 2002) show that the assumption is roughly accurate for the flight corridor to the southwest of Yucca Mountain.

3.8 Assumption: Flight paths are uniformly distributed across the width of the airway for the derivation in Section 2.2. Rationale: The radar tracks provided by the U.S. Federal Aviation Administration (FAA) (Attachment IV; Ragan 2002) show that flight paths are somewhat concentrated toward the center of the corridor, but that there is a reduction in flight density toward the edges. 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 with its southwestern edge at the Shoshone MOA exaggerates the crash rate density in the corridor and is therefore conservative.

3.9 Assumption: The crash-impact points for helicopter flights are uniformly distributed in a band extending 0.25 miles on either side of the intended flight path. Rationale: This is the assumption made in the DOE standard (DOE-STD-3014-96, pp. 45, 46; Sanzo et al. 1996, Section 4.3.2.3). This assumption is used in Section 2.3.

3.10 Assumption: The distribution of dropped objects along the flight path is assumed uniform in the derivation in Section 2.4. Rationale: There are reasons to expect that the drop rate per unit distance traveled would peak on or near the runway and fall with distance away from the runway. For example, objects falling from the landing gear would fall before the gear is withdrawn after takeoff or after it is extended before landing. Objects loosely attached or not attached at all would fall soon after the acceleration, vibration, and wind pressure associated with takeoff began. Therefore, it is conservative to assume a uniform distribution.

3.11 Assumption: Aircraft operating in small portions of R-64A, R-64-B, and R-64C (BSC 2002c, Figure 16) contribute a negligible fraction of the total hazard. Rationale: These airspace subdivisions are nearly 30 miles from the North Portal. For aircraft flying there to pose a hazard to the Yucca Mountain facilities would require that uncontrolled aircraft destined to crash travel nearly 30 mi before striking the ground. Such an outcome is difficult to imagine for the reasons set forth in *Identification of Aircraft Hazards* (BSC 2002c, Appendix G). The cited report examines the various events that could initiate a crash. For each event, it is shown that either (1) the plane is uncontrollable and crashes near the location of the initiating event, or (2) the pilot is in control to some degree and will either recover from the event completely or maneuver the aircraft to a suitable location and altitude for ejection and rescue. At preferred altitudes for ejection (below about 10,000 ft AGL), the maximum glide distance is less than about 16 miles. This assumption is used in Section 5.2.1.

3.12 Assumption: Aircraft missions in EC South and in the Caesar Corridor, which overlies part of EC South (USAF 1996, Section 1.24; USAF [n.d.]), are an extension in space of the missions over the NTS. Rationale: EC South is adjacent to the NTS to the west, so aircraft crossing the NTS near Yucca Mountain would also pass through EC South. EC South is at least 4 mi from the North Portal at its closest, and most of EC South is much farther away. (The coordinates of the North Portal are 36° 51' 8" north latitude and 116° 25' 35" west longitude [MO0004YMP00017.000]. Distance from the North Portal was measured by hand on a map [NIMA 2001] from the coordinates listed.) Because EC South is at least several miles from the North Portal, the aircraft crash hazard is insensitive to flight activity in EC South. The hazards from missions in EC South are treated by the conservative analysis in Section 5.5.1. (The contribution from VR-222 is addressed in Section 5.5.2.)

3.13 Assumption: A crash of a general aviation airplane in cruise mode that is not severe enough to cause a fatality would not do major damage to ground-based facilities. Rationale: A couple of different crash scenarios during cruise that do not result in fatal injury to the pilot may be imagined: (1) a crash landing and (2) a crash from low altitude at low speed. (1) A crash landing implies that the pilot is at least partially in control of the aircraft just before impact. The pilot in such a situation would steer away from mountainous areas and buildings, which makes a crash into Yucca Mountain facilities unlikely. (2) A crash from low altitude at low speed might not cause a fatality; in this case any impact to ground facilities would be limited to superficial damage. The same assumption in a similar context was accepted by the NRC (Delligatti 2001, pp. 5, 6). This assumption is used in Section 5.3.

3.14 Assumed dimensions of relevant buildings are given in Table 2. Rationale: The dimensions given for the transfer and remediation buildings conservatively represent the process areas of the facilities as described by Brown (2002, Figures 3-11, 3-15, and 3-17). Support areas are not included in the building designs shown, but this is appropriate for calculating effective areas because an impact into a support area would not jeopardize the integrity of the process areas. The figures cited reflect then current design concepts. Unless the basic design concept changes, the sizes of the process areas of the relevant buildings will not change drastically. As corroboration of this claim, consider more highly developed drawings of Dry Transfer Facility 1 (BSC 2002a and BSC 2002b). These drawings depict a facility with roofs at different levels. The highest roof is the same height (88 ft) as assumed in Table 2. The high-roofed portion of the building (including the cask transfer cell, the disposal container transfer cell, the welding cells, the waste-package-loadout room, and the spent fuel staging areas) measures 160 ft wide by 269 ft long. These dimensions are comparable to the dimensions assumed in Table 2. The dimensions for the Surface Aging Facility are based on the storage array shown in the *Site Development Plan for the Monitored Geologic Repository* (Williams 2002, Figure II-9) and the four-cask unit shown in the *Conceptual Design Report* (McDaniel 2002, Figure 11). The four-cask unit is 35 ft by 36 ft and 20 ft tall, and rows of units are separated by 35 ft. The storage array can be conservatively represented as two rows of four-cask units with 20 units in each row (for a total of 160 storage casks). The width of the array is 3×35 ft = 105 ft. The length is 20×36 ft = 720 ft. Transportation casks inside the Transporter Receipt Building or in transit between buildings, and waste packages in shielded transporters heading underground are not included because the effective area represented by such small targets is very small compared to the effective area of the facilities that are included. The Low-Level Waste Building, if any, will be appropriately considered when the design for license application is available. The design information presented in Table 2 is used in Section 5.4 to calculate effective areas with respect to aircraft hazards. The design of the surface facilities is still evolving. However, the sizes and shapes of the radiological facilities are not expected to change enough to affect the conclusions of the analysis. This assumption will be reexamined when more definite design information becomes available.

Table 2. Assumed Dimensions of Relevant Surface Facilities

	Dry Transfer Facility 1	Dry Transfer Facility 2	Remediation Building	Surface Aging Facility
Length (ft)	240	370	272	720
Width (ft)	200	206	87	105
Height (ft)	88	88[a]	85	20

NOTES: [a]Taken to be the same as the height of Dry Transfer Facility 1

3.15 Assumption: The military aircraft on the NTTR flying near enough to Yucca Mountain to pose a hazard to proposed surface facilities are assumed to be small attack, fighter, or trainer aircraft, such that the corresponding crash rate (Section 5.3) and the corresponding characteristics for computing effective areas (Section 5.4) may be used. This assumption is used in Section 5.5.1. Two aspects of this assumption require a rationale:

First, the crash rate used must be justified despite the fact that its implied mix of small aircraft types does not correspond exactly to the mix of small aircraft used on the NTTR near Yucca Mountain. The crash rate corresponding to all attack, fighter, and trainer aircraft (1.84×10^{-8} mi^{-1}), is less than the crash rate for F-16s (3.86×10^{-8} mi^{-1}), but greater than that for F-15s (6.25×10^{-9} mi^{-1}) (Kimura et al. 1996, Table 4.8). F-15s and F-16s, among other fighter and attack aircraft with crash rates somewhere between those two extremes, are commonly used in exercises on the NTTR (BSC 2002c, Section 5.1.3.1), so the intermediate value used is reasonable.

Second, the use of effective areas for small aircraft 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 area of the facility (see Equation 5, for example). Although the effective facility area seen by small aircraft is about a factor of two less than that seen by large aircraft (Section 5.4), the net effect of using the smaller effective areas is conservative regardless of the actual distribution of aircraft because the crash frequency for small aircraft is about a factor of ten higher than that of large aircraft (Section 5.3).

3.16 Assumption: The aviation corridor to the southwest of Yucca Mountain is defined to be the band, with edges parallel to the Nevada-California border, passing between the edge of Shoshone MOA and passing within 8 mi of the North Portal at its closest. Rationale: The entire width between R-2508 and R-4808/R-4807 is used as a flight corridor (BSC 2002c, Section 5.6.2; Shively 2002). This width (measured as the closest distance between the Shoshone MOA to R-4808N) is approximately 26 miles (NACO 2002). If the edge of the flight corridor were assumed to follow the border between R-4808S and R4808N and then angle slightly northward in a straight line to the western edge of R-4808N, then the closest distance to the North Portal at Yucca Mountain would be about 6 miles (NACO 2002). It is apparent that R-4808S is not heavily used by civilian air traffic (Ragan 2002, graphics from 3/30/02 through 4/5/02). Furthermore, the air traffic near and within R-4808S tends toward the VORTAC (very high frequency omnidirectional range and tactical air navigation station) south of Beatty (NIMA 2001), rather than more northeasterly, which would take it closer to Yucca Mountain. A line drawn from the eastern corner of R-4808S to the Beatty VORTAC is, at its closest, about 8 mi from the North Portal. A few flights may venture north of this line daily; at some distance south of the line, flights appear to be rather uniformly distributed, so 8 mi is a reasonable, conservative estimate of the distance between the North Portal and the northeast boundary of the flight corridor.

Defining the corridor so that its closest approach to the North Portal is 8 mi (rather than 6) shaves the corridor's width to about $w_f = 24$ mi (rather than 26). This assumption is used in Section 5.5.2 and Attachment I.

3.17 Assumption: The crash range is 25 mi for air carriers and 30 mi for military aircraft in the flight corridor southwest of Yucca Mountain. Rationale: *Identification of Aircraft Hazards* (BSC 2002c, Section 6.2.4) uses a criterion zone of 25 miles to screen out hazards from crashes of air carriers on federal airways and jet routes and concludes that "selecting a criterion zone that extends 25 miles from the North Portal at Yucca Mountain will ensure that any airways screened out will have no impact on the cumulative crash probability." The same report (BSC 2002c, Section 6.2.2.3) screens out hazards from military aircraft crashes on military aircraft training activities beyond 30 mi. Using the criterion zones as crash ranges is conservative because the screening criteria are conservative enough to remove distant hazards from further consideration without detailed analysis. This assumption is used in Section 5.5.2.

3.18 Assumption: The crash range for general aviation aircraft and air taxis flying above 10,000 ft MSL is assumed to be 10 miles. A rationale for this assumption is provided in Attachment II. This assumption is used in Section 5.5.2.

3.19 Assumption: The record of flights that were tracked through the aviation corridor to the southwest of Yucca Mountain (Attachment IV) is representative of an entire year of flights. Rationale: Brent Shively, the FAA representative who provided the flight records, stated that the week in question is representative of an entire year of flights through the corridor (Ragan 2002). The results of the analysis are not sensitive to the precise frequencies of flights through the corridor because incrementally increasing (even doubling) the flight frequencies in Section 5.5.2 would not cause the total crash hit frequency in Section 6 to exceed the frequency-screening threshold defined in Section 5.1. This assumption is used in Section 5.5.2.

3.20 Assumption: Civilian aircraft flying at 1200 ft above ground level (AGL) or below and military flights on military training routes and low-altitude tactical navigation areas pose a negligible hazard to the Yucca Mountain facilities. A rationale for this assumption is provided in Attachment I. This assumption is used in Section 5.5.2.

3.21 Assumption: Civilian aircraft flying below 10,000 ft above mean sea level (MSL) and above 1200 ft AGL will not pose a hazard to proposed repository facilities at the North Portal. A rationale for this assumption and is provided in Attachment I. This assumption is used in Section 5.5.2.

3.22 Assumption: The heliport associated with repository surface facilities will be located far enough away from radiological facilities that helicopter flights to and from the surface facilities could be routed to render a helicopter crash into radiological facilities beyond Category 2 as defined in Section 5.1. According to the model presented in Section 2.3, a distance of at least one-quarter mile (1320 ft) would be sufficient.

Furthermore, it is assumed that routine helicopter flights within one-quarter mile horizontally of radiological facilities will be prohibited. Rationale: There is no apparent operational need for routine flights to and from the site to fly over radiological facilities and little if any benefit to having the heliport nearer than one-quarter mile from radiological facilities. It is only prudent to avoid this source of unnecessary risk by siting the heliport at some distance from radiological facilities and by prohibiting helicopter flight within one-quarter mile horizontally from radiological facilities. The latest site development plan (Williams 2002, Figures II-8 and II-9) shows the heliport located at approximately one-quarter mile from the nearest radiological facility (Dry Transfer Facility 2). This assumption is used in Sections 5.6 and 6.

3.23 Assumption: Air Force helicopters crossing R-4808 and DOE helicopters not on a repository-related flight will not fly within one-quarter mile horizontally from the radiological facilities at the North Portal. Rationale: According to the model presented in Section 2.3, a separation of at least one-quarter mile (1320 ft) would be sufficient to remove helicopter crashes from further consideration. There is no obvious reason why Air Force helicopters or DOE helicopters not on repository business would need to fly near the North Portal. The DOE controls its helicopters, and could keep those that are not on repository business away from surface facilities. Agreement with the Air Force could presumably be reached whereby its helicopters would be similarly restricted. This assumption is used in Sections 5.6 and 6.

4. USE OF SOFTWARE

4.1 SOFTWARE APPROVED FOR QUALITY ASSURANCE (QA) WORK

None used.

4.2 COMMERCIAL OFF-THE-SHELF SOFTWARE USED

Microsoft Excel 97 SR-2, a commercially available spreadsheet software package, was used to calculate results. Excel is appropriate because simple mathematical expressions and operations that are standard in Excel were used to derive the results.

5. ANALYSIS

5.1 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). "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). Event sequences that have been shown to be less likely are considered beyond Category 2 and need not be considered further. Stating the frequency-screening threshold operationally 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 repository environmental impact statement projected that the emplacement period could last from 24 to 50 years (DOE 2002, Figure 2-9). Allowing one chance in 10,000 over 24 y gives a frequency of $(1 / 10{,}000) / (24\ y) = 4 \times 10^{-6}\ y^{-1}$. Similarly, a 50-y emplacement period gives a frequency of $2 \times 10^{-6}\ y^{-1}$. For the purposes of this analysis, the frequency-screening threshold is conservatively set to $10^{-6}\ y^{-1}$, which generously allows emplacement and other handling operations to last up to 100 y. This approach is consistent with the discussion in the *Preclosure Safety Analysis Guide*, on aircraft crashes (BSC 2002d, Section 10.6.2.3) and objects dropped from aircraft (BSC 2002d, Section 10.6.3.6).

5.2 HAZARDS CONSIDERED

The hazards considered in this analysis are listed in *Identification of Aircraft Hazards* (BSC 2002c, Section 8). This section maps the identified hazards to the sections in this analysis that treats them.

5.2.1. Small Military Aircraft

- Aircraft that enter and exit the R-4808N airspace are treated in Section 5.5.1.
- Aircraft operating in small portions of R-64A, R-64-B, and R-64C nearly 30 miles from the North Portal are addressed in Assumption 3.11.
- Aircraft that conduct missions in EC South are addressed in Section 5.5.1.
- Aircraft flying the military training routes (MTRs) IR-286, VR-222, and VR-1214 are addressed in Section 5.5.2.
- Aircraft flying in the low altitude tactical navigation (LATN) area to the southwest of Yucca Mountain are addressed in Section 5.5.2.

5.2.2. Large Military Aircraft

Large military aircraft are considered, as appropriate to their location, in Sections 5.5.1 for those in R-4808N and 5.5.2 for those in the aviation corridor to the southwest of Yucca Mountain.

5.2.3. DOE Aircraft

DOE helicopters are treated in Section 5.6.

5.2.4. Dropped Objects

Objects inadvertently dropped from aircraft are addressed in Section 5.7.

5.2.5. Civilian Aircraft

Aircraft that fly on J-92, J-86, V-105, and V-135 are treated in Section 5.5.2.

5.3 CRASH-RATE STATISTICS

Statistics for crash rates of fixed-wing aircraft in the present analysis (Table 3, Table 4, and Table 5) are based on *Data Development Technical Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard* (Kimura et al. 1996). An adjustment was made to the crash rates in Table 4 to discount crashes in which there were no fatalities, the assumption being that a general aviation crash that is not severe enough to cause a fatality would not do major damage to ground-based facilities (Assumption 3.13). The adjustment is made by multiplying the raw crash rate by the ratio of the numbers of fatal to total crashes.

A representative helicopter crash rate per flight is given as 2.5×10^{-5} per flight (DOE-STD-3014-96, Table B-1). 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, Table 3.34). Military helicopters crash at a rate of about 9.9×10^{-6} h^{-1} (12 crashes / 1,209,057 h) for crashes in which the helicopter is destroyed (Kimura et al. 1996, Table 4.6).

Table 3. Crash Rates for Military Aircraft

Military Aircraft Type	Cruise or Normal-Flight Crash Rate (mi^{-1})	Specific References from Kimura et al. 1996
Single and multiple engine attack, fighters, and trainers	1.84E-08	Table 4.8
Large (including all cargo aircraft)	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})	Number of Fatal Accidents[a]	Total Number of Accidents[b]	Fatal Accident Rate (mi^{-1})	Specific References from Kimura et al. 1996
Total fixed wing	1.510E-07	1028	3790	4.10E-08	Tables 3.33, 3.5
Single engine, piston	2.233E-07	849	3386	5.60E-08	Tables 3.29, 3.1
Multi-engine, piston	9.238E-08	145	326	4.11E-08	Tables 3.30, 3.2
Turboprop	3.557E-08	27	65	1.48E-08	Tables 3.31, 3.3
Turbojet	3.067E-09	7	13	1.65E-09	Tables 3.32, 3.4

NOTES: [a]Number of fatal accidents during climb, cruise, and descent phases (excluding takeoff and landing).
[b]Total number of accidents during climb, cruise, and descent phases (excluding takeoff and landing).

Table 5. Crash Rates for Commercial Aviation

Commercial Aviation Aircraft Type	Cruise or Normal-Flight Crash Rate (mi^{-1})	Specific Reference from Kimura et al. 1996
Air Carrier	3.094E-10	Table 2.15
Air Taxi	1.553E-08	Table 2.21

5.4 EFFECTIVE-AREA CALCULATIONS

The effective area of the facility depends on characteristics of the site and of aircraft. Aircraft characteristics recommended by DOE-STD-3014-96 for effective-area calculations are provided in Table 6. As of this writing, the design of the surface facilities is not final; assumed dimensions of relevant surface facilities are used (Assumption 3.14). Table 7 gives calculated effective areas for the relevant facilities. Effective areas were calculated according to the formulas in Section 2.5. The shadow areas for the separate buildings may overlap, but this has not been accounted for in the analysis due to the preliminary nature of the design. Neglecting the overlap is conservative because it results in a greater total effective area.

Table 6. Aircraft Characteristics Used for Effective-Area Calculations

Aircraft Type	Wingspan[a], G (ft)	Skid Length[b], S (ft)	Impact Angle, ϕ (degrees)	Cot(ϕ)[c] (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
Helicopter	50	0	59.9	0.58
Commercial Aviation				
Air Carrier	98	1440	5.6	10.2
Air Taxi	59	1440	5.6	10.2
Military Aviation				
Large	223	780	7.7	7.4
Small Fighter, Attack, and Trainer	78	246	6.8	8.4
Other Small	110	246	6.8	8.4
Dropped Object[d]	0	0	59.9	0.58

SOURCES: [a]DOE-STD-3014-96, Table B-16
[b]DOE-STD-3014-96, Table B-18
[c]DOE-STD-3014-96, Table B-17
[d]Like helicopter, but no wingspan.

Table 7. Effective Areas (A_{eff}) for Relevant Facilities

	General Aviation				Commercial Aviation		Military Aviation			
	Piston	Turboprop	Turbojet	Helicopter	Air Carrier	Air Taxi	Large	Small, High Performance	Small, Low Performance	Dropped Object
Dry Facility 1										
Fly-in	0.012	0.013	0.012	0.003	0.016	0.014	0.017	0.013	0.014	0.002
Skid	0.001	0.001	0.001	0.000	0.021	0.019	0.015	0.003	0.004	0.000
Sum	0.012	0.013	0.012	0.003	0.037	0.034	0.032	0.016	0.018	0.002
Dry Faciity 2										
Fly-in	0.016	0.017	0.016	0.004	0.021	0.019	0.021	0.017	0.018	0.004
Skid	0.001	0.001	0.001	0.000	0.027	0.025	0.018	0.004	0.005	0.000
Sum	0.017	0.018	0.017	0.004	0.048	0.044	0.039	0.021	0.023	0.004
Remediation Facility										
Fly-in	0.008	0.008	0.008	0.003	0.009	0.009	0.009	0.008	0.009	0.003
Skid	0.002	0.002	0.002	0.000	0.043	0.041	0.027	0.007	0.007	0.000
Sum	0.009	0.010	0.009	0.003	0.052	0.050	0.036	0.015	0.016	0.003
Surface Aging Facility										
Fly-in	0.010	0.010	0.010	0.002	0.013	0.012	0.014	0.011	0.012	0.001
Skid	0.001	0.001	0.001	0.000	0.020	0.018	0.014	0.003	0.003	0.000
Sum	0.010	0.011	0.010	0.002	0.033	0.030	0.028	0.014	0.015	0.001
Total	0.049	0.052	0.049	0.012	0.170	0.157	0.134	0.067	0.072	0.010

NOTE: Effective areas in mi^2. Greater precision was used for the calculations than is shown in the table. Therefore, entries in the table may not add to the indicated sums.

5.5 FIXED-WING CRASH-FREQUENCY ANALYSES BY FLIGHT AREA

5.5.1. Nevada Test Site

Monthly flight counts are currently being kept for a rectangular incursion area that approximates the NTS and for a much smaller rectangular incursion area roughly centered on the North Portal of the Yucca Mountain site (Table 8). The coordinates of the YMP 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 (Monette 2002). The resulting YMP rectangle is about 7 mi long north and south, 5.8 mi wide east and west, and roughly centered on the North Portal (MO0004YMP00017.000, NIMA 2001). The NTS incursion area is composed of three separate areas: a triangle and two rectangles (Takenaka 2002), 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.

Equation 4 provides a formula for estimating the areal crash-rate density F / A_{eff}. For the NTS incursion area, take the flight frequency N to be the annual average from the last row of Table 8, 19,035 y^{-1}. The crash rate for large military planes is about a factor of ten smaller than that of small planes (Table 3). To be conservative, take the crash rate for small military aircraft, 1.84×10^{-8} mi^{-1} (Assumption 3.15). The perimeter of the NTS incursion area is about 133 mi (NACO 2002). The site is near the edge of the NTS, so Equation 4 with an edge effect somewhat greater than 0.5 applies. In lieu of taking credit for the edge effect, a conservatively estimated crash-rate density for the NTS may be calculated from Equation 5: (19,035 $y^{-1} \times 1.84 \times 10^{-8}$ $mi^{-1} \times \pi$ / 133 mi) = 8.27×10^{-6} $y^{-1}mi^{-2}$. Using Equation 5 is equivalent to conservatively assuming that the facility is completely surrounded by the flight area, and not near any edge. Thus, if the missions in EC South are essentially a spatial continuation of the missions over the NTS (Assumption 3.12) then this conservative treatment of the NTS flights includes flights in EC South.

For the smaller region surrounding the North Portal, the average flight frequency is 1,689 y^{-1} (Table 8) and the perimeter is 25.6 mi. Again apply Equation 5. The estimated crash-rate density for the YMP region is 1,689 $y^{-1} \times 1.84 \times 10^{-8}$ $mi^{-1} \times \pi$ / 25.6 mi = 3.81×10^{-6} $y^{-1}mi^{-2}$.

The smaller region is more representative of the immediate vicinity of the site, so the lower crash-rate density for the smaller region, 3.81×10^{-6} $y^{-1}mi^{-2}$, is used to calculate the crash hit frequency. Although the crash-rate density is calculated for the YMP incursion area, which is mostly inside the NTS or the NTTR, applying Equation 5 implies that the same density extends at least as far as the crash range in every direction. This is conservative because the quadrant to the southwest of the North Portal is mostly outside the NTS and the NTTR. Taking the product of the crash-rate density and the effective area for small fighter, attack, and trainer aircraft from Table 7, 0.067 mi^2, the estimated crash frequency for fixed-wing military aircraft flying over the NTS is calculated to be about 2.6×10^{-7} y^{-1}. The distribution of military aircraft between small and large (for those flying near Yucca Mountain) is not known. Assuming that all aircraft flying near Yucca Mountain are small (Assumption 3.15) is conservative due to the offsetting effects of the effective areas and crash rates. Although the effective area for small aircraft is about a factor of two less than that for large aircraft, the net effect is conservative regardless of the actual distribution of aircraft because the crash frequency for small aircraft is a factor of ten higher than that of large aircraft.

Table 8. Aircraft Incursion Counts for NTS and YMP Incursion-Count Areas

Month or Quarter	Numbers of Incursions in Specified Month or Quarter by Year									
	1998	1999		2000		2001		2002		Average or Sum	
	NTS	NTS	YMP	NTS	YMP	NTS	YMP	NTS	YMP	NTS	YMP
JAN	-	1241	-	-	-	824	76	1079	61	1048	69
FEB	-	1710	-	-	-	1091	102	1907	269	1569	186
MAR	-	1407	95	-	-	1722	192	1336	79	1488	122
APR	-	1955	165	-	-	1858	234	1807	162	1873	187
MAY	-	1833	143	-	-	2257	403	2199	208	2096	251
JUN	-	1711	53	-	-	1241	132	1586	83	1513	89
JUL	-	1389	83	1097	72	904	80	1088	50	1120	71
AUG	-	2498	103	2105	165	1651	88	1063	74	1829	108
SEP	917	1653	88	1560	89	951	67	1240	113	1264	89
OCT	1611	-	-	1681	174	2597	238	-	-	1963	206
NOV	1037	-	-	2322	204	2346	227	-	-	1902	216
DEC	788	-	-	1534	176	1060	105	-	-	1127	141
Q1	-	-	-	3780	328	-	-	-	-	3780	328
Q2	-	-	-	6465	648	-	-	-	-	6465	648
Q3	-	-	-	-	-	-	-	-	-	-	-
Q4	-	5625	424	-	-	-	-	-	-	5625	424
Sum	4353	21022	1154	20544	1856	18502	1944	13305	1099	77726	6053
# Months	4	12	10	12	12	12	12	9	9	49	43
Monthly	1088	1752	115	1712	155	1542	162	1478	122	1586	141
Annual	13059	21022	1385	20544	1856	18502	1944	17740	1465	19035	1689

SOURCES: Monette 2001, Monette 2002.

NOTE: Counts were sometimes provided monthly, sometimes quarterly. Monthly counts are listed here as available; quarterly counts are listed otherwise. Monthly or quarterly counts in the YMP box are first available for March 1999. Counts for the NTS box are first available for September 1998.

5.5.2. Unrestricted Airspace to the Southwest

The modified airways model (Equation 7) is appropriate for estimating crash frequencies from air traffic passing through the aviation corridor in unrestricted airspace to the southwest of Yucca Mountain. For this analysis, the aviation 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 8 mi of the North Portal at its closest (Assumption 3.15). Civilian aircraft that fly on J-92, J-86, J-110, V-105, and V-135 and military aircraft flying in the LATN southwest of Yucca Mountain and the MTRs IR-286, VR-222, and VR-1214 are included in the corridor as defined. The width of the aviation corridor is approximately $w_f = 24$ miles (Assumption 3.15).

The crash range is taken to be 25 mi for air carriers and 30 mi for military aircraft (Assumption 3.17). In light of the difficulty imagining realistic scenarios in which a fixed-wing airplane that is out of control and destined to crash would fly 25 or 30 miles before striking the ground, the crash ranges appear to be very conservative. However, owing to the low in-flight crash rates for air carriers and the relatively low frequency of military flights in the flight corridor, exaggerating the crash ranges does not introduce excessive conservatism. In contrast, general aviation and air-taxi flights are frequent and have comparatively high in-flight crash rates. To avoid excessive conservatism for general aviation aircraft and air taxis, their crash range is set to 10 mi for flights above 10,000 ft MSL (Assumption 3.18). Table 9 gives the flight history for a representative week in the spring of 2002 (Assumption 3.19). Civilian aircraft flying at 10,000 ft MSL or below and military flights on military training routes and low-altitude tactical navigation areas are assumed to pose a negligible hazard to the Yucca Mountain facilities (Assumptions 3.20 and 3.21). The remaining parameters needed for Equation 7 are the crash rates λ from Table 3, Table 4, and Table 5, and the effective areas from Section 5.4. Table 10 gives results of the crash frequency calculations based on the equivalent annual frequencies for the representative week.

Table 9. Flight Counts and Average Frequencies in the Aviation Corridor Southwest of Yucca Mountain

Aircraft Type	Date of 24-hour Count[a]							Average Daily	Equivalent Annual[b]
	3/30/02	3/31/02	4/01/02	4/02/02	4/03/02	4/04/02	4/05/02		
Commercial									
Air carrier	219	236	246	182	218	272	254	232.43	84895
Air taxi	28	37	42	34	32	36	44	36.14	13201
General Aviation									
Turbojet	40	33	40	35	32	56	54	41.43	15132
Turboprop	25	8	16	9	9	20	14	14.43	5270
Piston	7	16	19	14	13	19	21	15.57	5687
Military									
Small	10	2	4	5	12	8	22	9.00	3287
Large	1	1	2	3	3	5	1	2.29	835
Totals									
All	330	333	369	282	319	416	410	351.29	128307

NOTES: [a]The flight counts do not thoroughly cover the airspace below 10,000 ft MSL, where an undetermined number of general aviation flights are conducted (Ragan 2002), as well as military flights on military training routes (BSC 2002c, Section 5.2.2). General aviation flights below 10,000 ft MSL and flights on the MTRs and LATN areas do not pose a hazard to Yucca Mountain facilities (Assumptions 3.20 and 3.21). See Attachment IV for the categorization scheme used to produce the counts in this table.

[b]365.25 times average daily. Computed at higher precision than that shown in the Average Daily column.

SOURCE: See Assumption 3.19.

Table 10. Crash Frequencies for the Unrestricted Airspace to the Southwest of Yucca Mountain

Aircraft Type	Flight Frequency N (y^{-1})	Linear Crash Rate λ (mi^{-1})	Crash Range (mi)	Edge Adjustment (unitless)	Effective Area A_{eff} (mi^2)	Crash Hit Frequency (y^{-1})
Air carrier	84895	3.09E-10	25	0.300	0.170	5.6E-08
Air taxi	13201	1.55E-08	10	0.052	0.157	7.0E-08
Turbojet	15132	1.65E-09	10	0.052	0.049	2.7E-09
Turboprop	5270	1.48E-08	10	0.052	0.052	8.8E-09
Piston	5687	5.60E-08	10	0.052	0.049	3.4E-08
Small military	3287	1.84E-08	30	0.332	0.067	5.6E-08
Large military	835	1.90E-09	30	0.332	0.134	2.9E-09
Sum	128307	N/A	N/A	N/A	N/A	2.3E-07

5.6 HELICOPTER CRASHES

Helicopter flights that are directly associated with repository operations could pose a crash hazard. On an hourly basis, helicopter crash rates are on the order of 10^{-5} h^{-1} or greater (Section 5.3). Solving Equation 2 for T [with $\beta = 10^{-5}$ h^{-1}, $A_f = 0.20$ mi^2 (Section 2.3), and $A_{eff} = 0.012$ (Section 5.4)], it can be shown that the frequency of helicopter crash into the radiological facilities would be greater than 10^{-6} y^{-1} if the helicopter flying time within one-quarter mile of the facilities exceeded about 1.7 h/y. Thus, prohibition of routine flights within a quarter mile of radiological facilities (measured horizontally), possibly with an exception for emergencies, will be necessary to screen out the hazard from helicopter crashes. If the repository heliport is located at least one-quarter mile (1320 ft) from radiological facilities, rules could be established whereby routine flights would not approach closer than one-quarter mile of the site (Assumption 3.22). Some closer flights for emergency response or other limited purposes might be allowed.

According to Section 2.3, helicopters farther than one-quarter mile from the facility (measured horizontally) do not pose a crash hazard to the facility. Therefore, helicopters in the flight corridor to the southwest of Yucca Mountain need not be considered. Military helicopters crossing R-4808 and DOE helicopters that are not on a repository-related flight will likewise pose no hazard, provided that they do not fly within one-quarter mile of the radiological facilities at the North Portal (Assumption 3.23). Therefore, flights within one-quarter mile of the radiological surface facilities (measured horizontally) by helicopters not directly associated with repository operations should be prohibited, possibly with an exception for emergencies.

5.7 DROPPED OBJECTS

A request to the Air Force Safety Center for detailed information on objects unintentionally dropped from aircraft by aircraft associated with Nellis Air Force Base produced a comprehensive list of 13 dropped objects in the 12 years from fiscal year 1991 through fiscal year 2002 (Alley 2002), or 1.08 drops/y. Conservatively taking the lower end of the estimated range of annual frequency of sorties over the period in question of 40,000 sorties/y (Takenaka 2003) yields (1.08 drops/y) / (40,000 sorties/y) = 2.7×10^{-5} drops/sortie. Using Equation 10, an estimate of the frequency of dropped objects hitting radiological facilities can be calculated. For the YMP aircraft-incursion area, the average annual frequency of overflights for the period from 1999 through 2002 is $N = 1{,}689\ y^{-1}$ (Table 8), and the perimeter of the corresponding flight area is $L = 25.6$ mi (Section 5.5.1). A conservatively low estimate of the distance flown per sortie is $D = 90$ mi, the approximate distance to the Nellis landing strip from the North Portal (NIMA 2001, MO0004YMP00017.000). The effective area for dropped objects from Table 7 is $A_{eff} = 0.010\ mi^2$. The resulting frequency is conservatively estimated to be about $6 \times 10^{-7}\ y^{-1}$, which is below the frequency-screening threshold of $10^{-6}\ y^{-1}$.

6. RESULTS

The frequency of fixed-wing aircraft crashes into the radiological surface facilities associated with the proposed Yucca Mountain repository has been conservatively estimated. Because different degrees of conservatism have been used for estimating the various components of the total crash frequency, the frequency estimates by aircraft type and by flight area do not necessarily indicate relative risks. For flights within the NTS, the calculated crash hit frequency is $2.6 \times 10^{-7}\ y^{-1}$. For flights in the corridor to the southwest of Yucca Mountain, the calculated frequency is $2.3 \times 10^{-7}\ y^{-1}$. The total crash frequency is estimated as the sum of the two component crash frequencies: about $5 \times 10^{-7}\ y^{-1}$. This conservatively estimated frequency is a factor of 2 less than the conservatively defined frequency-screening threshold, $10^{-6}\ y^{-1}$. Therefore, this preliminary calculation screens fixed-wing aircraft crash into radiological surface facilities at Yucca Mountain from further consideration. This conclusion will be revisited after more-nearly-final design information becomes available. At that time, any developments with respect to flight frequencies near Yucca Mountain including projections of future activity will also be taken into account.

Helicopter crashes can also be screened from further consideration provided that the following prohibitions on their operations are maintained:

1. Military helicopters must not fly within one-quarter mile (measured horizontally) of the surface facilities at the North Portal (Assumption 3.23). Exceptions for emergencies could be accommodated.

2. DOE helicopters, whether on repository business or not, and other helicopters that DOE allows to approach the surface facilities at the North Portal must not fly within one-quarter mile (measured horizontally) of the radiological surface facilities at the North Portal (Assumptions 3.23 and 3.22, Section 5.4). Exceptions for emergencies could be accommodated.

The second prohibition will require that the heliport associated with the North Portal operations area be located at least one-quarter mile from surface radiological facilities (Assumption 3.22).

This preliminary analysis indicates that objects unintentionally dropped from aircraft are unlikely to strike repository radiological facilities. Because the estimated strike frequency is below the frequency-screening threshold, the remote possibility that objects unintentionally dropped from aircraft could strike Yucca Mountain surface facilities and lead to a radiological release need not be considered further.

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7.3 SOURCE DATA LISTED BY TRACKING NUMBER

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ATTACHMENT I.

HAZARD POSED BY AIRCRAFT BELOW 10,000 FT MSL ON THE FLIGHT CORRIDOR TO THE SOUTHWEST OF YUCCA MOUNTAIN

The record of flight activity from the FAA (Ragan 2002) does not count all of the flights below 10,000 ft MSL, where an undetermined number of general aviation flights are conducted. Of these, some are below 1200 ft AGL in uncontrolled Class G airspace. At this altitude above the valley floor to the west or southwest of Yucca Mountain (NIMA 2001) at Crater Flat (elevation up to 4000 ft), an airplane would still be below the crest of Yucca Mountain (around 4800 ft). Therefore, there is no hazard to the Yucca Mountain facilities from general aviation aircraft below 1200 ft to the west or southwest.

The elevation of the Yucca Mountain facilities is about 3700 ft (NIMA 2001, MO0004YMP00017.000). Five or more miles to the south of the North Portal in the southwest corner of the test site (R-4808S), there is an area around Fortymile Wash (elevation up to 3000 ft) where aircraft flying at 1200 ft AGL could be higher in altitude and possibly in view of the Yucca Mountain facilities. However, civilian use of R-4808S is not permitted below FL200 (that is, below about 20,000 ft MSL) (USAF 1996, Section 1.27; USAF [n.d.]). Therefore, civilian air traffic below 10,000 ft MSL in the lower reaches of Fortymile Wash is at least 11 mi from the North Portal (NIMA 2001, MO0004YMP00017.000). Moreover, there are a number of obstructions, such as Busted Butte to the south of the North Portal (elevation 4266) and Little Skull Mountain to the southeast of the North Portal (elevation 4666) that would prevent a straight-line path into the facilities from the lower reaches of Fortymile Wash (elevation below about 2800 ft). North of Busted Butte and south of the North Portal, Fran Ridge runs north and south at about 3800 ft elevation and provides additional protection from aircraft to the southeast of the site. The great distance and topographical obstructions that separate the southern reaches of Fortymile Wash from the Yucca Mountain site make it difficult to imagine that an accident initiated there at an altitude below 1200 ft AGL could terminate in a crash into the Yucca Mountain facilities.

Of course, civilian flight is not permitted in R-4808N (USAF 1996, Section 1.1; USAF [n.d.]). While civilian flight is technically permitted in EC South under limited circumstances (USAF 1996, Sections 1.1, 1.24; USAF [n.d.]), in practice, there is very little if any civilian traffic there (Attachment IV). In conclusion, the hazard posed by general aviation aircraft below 1200 ft AGL near Yucca Mountain is negligible.

Military flights below 10,000 ft MSL are conducted on military training routes VR-222, VR-1214, and IR-286 (BSC 2002c, Section 5.2.2). They are normally flown between 500 ft and 1000 ft AGL (BSC 2002c, Section 5.2.2). This places them low enough that the topographic barriers discussed above will severely limit any hazard they might otherwise pose to Yucca Mountain surface facilities.

For general aviation above 1200 ft AGL, the topological features mentioned in the previous paragraph have considerably reduced protective effect. However, the following analysis of general aviation accidents in Nevada indicates that a deviation of several miles off course after the initiation of an accident sequence is unlikely. Of the 49 fatal accidents involving general aviation aircraft in Nevada since 1992 (NTSB 2002a), 20 occurred in cruise or in-flight mode (not in takeoff, landing, or special maneuvers). Sixteen of these (80 percent) were caused primarily by adverse weather conditions. Table I-1 examines each of the weather-related accidents. Three of the 20 (15 percent) were caused in part by mountainous terrain. The remaining one was caused by a loss of cabin pressure combined with the pilot's heart condition.

Table I-2 examines the non-weather-related in-flight accidents.

The history of the weather-related general aviation crashes in Nevada (Table I-1) prominently features two variations on a theme: a pilot attempts to fly by visual flight rules (VFR) into instrument meteorological conditions (IMC), is unable to cope, and either (1) loses control of the aircraft and crashes near the point of loss of control or (2) maintains control, but crashes into obscured mountainous terrain. In either case, the crash occurs near the point where a crash became inevitable. The one exception to the general theme is described in Item 16 in Table I-1. In that case the pilot became disoriented and flew erratically for 5 minutes before crashing into the ground. There is no way to know how far off course the plane traveled in the final 5 minutes. Several miles off course is possible. The non-weather-related crashes (Table I-2) all occurred near the point where trouble first became apparent.

The fact that a disoriented pilot flying in adverse weather conditions below 10,000 ft MSL in the unrestricted airspace to the southwest of Yucca Mountain could fly many miles off course before crashing deserves further analysis. A disoriented pilot may be in control of the aircraft and able to maintain altitude and direction, or may have also lost control. A disoriented pilot who has also lost control of the aircraft would either crash soon after losing control or, if the flight altitude were high enough, regain control of the aircraft, recover from disorientation, and avoid a crash altogether. A disoriented pilot who maintains control of the aircraft could crash into obscured terrain if the flight altitude is low enough. In that case, the topographical barriers discussed above would prevent a crash into Yucca Mountain surface facilities. On the other hand, if the plane were at a high enough altitude to avoid obscured terrain, the disoriented pilot might (1) recover from disorientation and avoid a crash altogether, or (2) continue travelling off course before crashing into higher terrain elsewhere. This leaves the possibility that a disoriented pilot, who is initially in control of the aircraft, veers several miles off course into the airspace near Yucca Mountain surface facilities, then loses control of the aircraft. Assuming the aircraft is high enough to avoid a crash into obscured terrain, and low enough that the pilot does not regain control, the aircraft crashes near the point where the pilot lost control, possibly into Yucca Mountain surface facilities. This scenario first requires adverse weather conditions, which are not as frequent in the desert as elsewhere. Given adverse weather conditions, it requires the pilot to fly into the adverse weather conditions, which the instinct for self-preservation discourages. Having flown into adverse weather conditions, the pilot must become disoriented. The disoriented pilot then must fly several miles off course in the direction of Yucca Mountain surface facilities. After the aircraft nears Yucca Mountain surface facilities, an appropriately timed event must occur to cause the pilot to lose control and crash. Thus, while a crash by a disoriented pilot into Yucca Mountain surface facilities is possible, it appears so unlikely that this scenario may be neglected.

The pattern that emerges from the crash history is that almost all general aviation accidents occur near the point where trouble first appears. Rarely, the airplane may survive the conditions that precipitated the crash long enough to fly many miles off course before crashing. In such cases, it has been shown that a crash into Yucca Mountain surface facilities is unlikely. Of course, the initial altitude above ground level is important. Pilots at lower altitude have less room for error, less time to recover from mistakes, and less chance of flying way off course before crashing. Given these observations, and the fact that the edge of the aviation corridor to the southwest of the North Portal is approximately 8 miles away from the site of the proposed Yucca Mountain facilities (Section 5.5.2, Assumption 3.15), it is reasonable to conclude that general aviation flights under 10,000 ft do not pose a hazard to the proposed facilities at the North Portal (Assumption 3.21).

Table I-1. Analysis of Fatal In-Flight Weather-Related General Aviation Accidents in Nevada Since 1992

Date and Location	NTSB ID	Aircraft Type (number and type of engines and weight class)
1. October 30, 2001; Mt. Charleston, NV	**LAX02FA018**	**Cessna P210N (1P/S[a])**
The accident occurred along the route between Beatty and Boulder City, which would have taken the aircraft past Yucca Mountain. The airplane had initially been cruising at 16,000 ft and requested clearance to descend to 15,000 ft due to downdrafts. Shortly after beginning its descent, the airplane's heading changed from northwest to southeast then back to northwest again and its ground speed decreased from 150 to 60 knots. Between 3:11:02 and 3:12:48, the airplane descended to 8,800 ft. At this rate of descent (about 4000 ft/min) the plane could not have been airborne for much longer. The crash must have occurred a very short distance from the location where trouble first became apparent.		
2. October 23, 2000; Stateline (Primm), NV	**LAX01FA023**	**Mooney M-207J**
The pilot attempted to turn around after picking up ice in the clouds. Shortly after indicating his intention to turn around, radar contact was lost. The wreckage was found in mountainous terrain at 4,650 ft MSL. It appears that the aircraft could not have crashed far from the location where trouble first became apparent.		
3. August 29, 2000; Las Vegas, NV	**LAX00FA320**	**Cessna 182N (1P/S)**
During cruise flight, the pilot failed to climb rapidly enough to clear mountainous terrain under poor visibility. The wreckage was found at 7450 ft elevation. Due to the location of Yucca Mountain facilities primarily behind topographical obstructions (as demonstrated above), this kind of accident is unlikely to result in a crash into the Yucca Mountain facilities.		
4. August 10, 1999; Boulder City, NV	**LAX99FA266**	**Cessna 177 (1P/S)**
The pilot flew into a box canyon where he encountered strong gusty winds and terrain-induced turbulence likely to contain wind shear conditions. Under such conditions, the aircraft could not have traveled far from the location where trouble first became apparent.		
5. October 29, 1998; Nixon, NV	**LAX99FA020**	**Cessna 182Q (1P/S)**
After encountering adverse weather conditions, the aircraft abruptly entered a descending spiral and disappeared from radar near the accident site. Clearly, the aircraft could not have crashed far from the location where trouble first became apparent.		

Table I-1. Analysis of Fatal In-Flight Weather-Related General Aviation Accidents in Nevada Since 1992 (continued)

6. September 26, 1998; Hawthorne, NV	**LAX98FA306**	**Beech 95-B55 (2P/S)**
After encountering significant icing conditions and a convective cell, the pilot lost control of the airplane and descended at a rate of 2000 ft per minute. Clearly, the aircraft could not have crashed far from the location where trouble first became apparent.		
7. September 25, 1997; Sandy Valley, NV	**LAX97FA331**	**Cessna 172K (1P/S)**
The pilot mistakenly flew in the wrong direction (south instead of north) from Sky Ranch airport near Sandy Valley, NV. Visibility was poor to the south. After he had been in the air for some time, the pilot radioed a witness at the Sandy Valley airport of his intent to descend and land in what he thought was a private airport near Pahrump, NV (many miles in the opposite direction). The aircraft soon collided into steep mountainous terrain at about 3,900 ft AGL about 9 miles southeast of the departure point. In this accident, the pilot had a mistaken notion of his heading and traveled many miles away from his intended course. Nevertheless, the immediate cause of the accident was flying by visual flight rules in inappropriate conditions. The aircraft apparently crashed not far from the point where a crash became inevitable.		
8. July 23, 1997; Gabbs, NV	**LAX97FA334**	**Navion G**
The non-instrument-rated pilot attempted to fly by visual flight rules into poor weather conditions. The probable cause of the accident is that the pilot became spatially disoriented due to poor visibility and lost control of the aircraft. Under these conditions, the aircraft could not have crashed far from the location where trouble first became apparent.		
9. December 24, 1994; Searchlight, NV	**LAX95LA060**	**Piper PA-28R-180 (1P/S)**
The pilot attempted VFR flight into IFR conditions. He was following US Highway 95 south and trying to stay below 5000 ft MSL at the time of the crash. The accident site is located about one-half mile east of the intended flight path (US Highway 95) near Searchlight, NV.		
10. May 18, 1994; Elko, NV	**FTW94FA165**	**Cessna 340 (2P/S)**
The non-instrument-rated pilot flew into poor visibility, icing, and turbulence in mountainous terrain near Elko, NV. Elko residents reported that a thunderstorm was in the area at the time of the crash. The wreckage was found at about 6100 ft elevation about 10 nautical miles (about 12 mi) southwest of Elko. The pilot was still in control as of the last radio communication, which occurred 14 miles south of Elko. The aircraft apparently crashed a few miles or less from the point where a crash became inevitable.		
11. June 6, 1993; Eureka, NV	**LAX93LA244**	**Beech K-35 (1P/S)**
The pilot attempted to fly VFR into adverse weather conditions including icing, low ceilings, mountain obscuration, rain or snow, fog, and turbulence. The pilot radioed several times that his plane was icing and requested a new heading. About ten minutes after reporting icing, the pilot lost control and the airplane disappeared from radar. The aircraft apparently crashed not far from the point where the pilot lost control.		
12. June 4, 1993; Lovelock, NV	**LAX93FA246**	**Beech S-35**
The pilot attempted to fly VFR north from Las Vegas into adverse weather conditions including moderate turbulence; occasional mountain obscuration; occasional moderate rime or mixed icing; and some ceilings below thousand feet and visibility below three miles. The aircraft crashed against an 80-degree slope of a mountain at about 8000 ft elevation. There was no radio communication from the aircraft at any time after the pilot departed the Las Vegas area.		
13. October 29, 1992; Ely, NV	**LAX93FA045**	**Beech D50A**
The pilot attempted to fly VFR into instrument meteorological conditions which included mountain obscuration and severe mixed icing. The airplane hit a mountain at about 8300 ft MSL in a near-vertical attitude at great speed. There was no radio communication from the aircraft at any time. The pilot lost control of the aircraft, probably due to a stall induced by severe airframe icing. The aircraft apparently crashed not far from the point where the pilot lost control.		
14. October 3, 1992, Elko, NV	**LAX93FA004**	**Bellanca 17-31ATC**
The pilot flew into adverse weather conditions, including turbulence, icing, rain, and mountain obscuration. According to the investigation, the aircraft descended vertically out of an overcast ceiling and collided with mountainous terrain. The aircraft apparently crashed not far from the point where the pilot lost control.		

Table I-1. Analysis of Fatal In-Flight Weather-Related General Aviation Accidents in Nevada Since 1992 (continued)

15. January 28, 1992; Austin, NV	**LAX92LA105**	**Cessna 170B (1P/S)**
The pilot was flying VFR following a highway over a 7500-ft mountain pass at an altitude of about 300 ft AGL in instrument meteorological conditions, including a ceiling at about 500 ft AGL, snow, and icing. The pilot attempted to turn around and probably stalled due to a loss of airspeed. The aircraft crashed not far from the point where the pilot lost control.		
16. January 11, 1992; Las Vegas, NV	**LAX92FA090**	**Cessna 425 (2T/S)**
The pilot flew into unfavorable weather conditions, including turbulence, show, rain, and mountain obscuration. He requested IFR clearance only after takeoff. The pilot apparently became spatially disoriented and erratically changed heading by as much as 180 degrees and altitude between 4500 ft MSL to 11500 ft MSL a number of times in the 5 minutes prior to the crash. During the erratic last 5 minutes of the flight, the aircraft could have traveled tens of miles. However, due to the random nature of the flight during this period, the distance off course was no doubt considerably less than the distance traveled.		

NOTES: [a]Number & type of engines/weight class as available from Order 7110.65 *Air Traffic Control* (FAA O 7110.65N, Change 1. 2002, Appendix A). Engine type: P=piston, T=jet/turboprop, J=jet. Weight class: H=heavy, >255,000 lbs.; L=large, >41,000 lbs.; S=small, <41,000 lbs.

SOURCE: NTSB 2002a.

Table I-2. Fatal In-Flight Non-Weather-Related General Aviation Accidents in Nevada Since 1992

Date and Location	NTSB ID	Aircraft Type (number and type of engines and weight class)
1. April 24, 2000; Austin, NV	**LAX00FA171**	**Cessna 152 (1P/S[a])**
The pilots flew into the airspace above mountainous terrain at inadequate altitude and were unable to climb fast enough to clear the mountains. The aircraft crashed during an attempt to turn around. The airplane crashed near the point where trouble first became apparent.		
2. August 8, 1998; Baker, NV	**LAX99FA260**	**Piper PA-31-T1 (2P/S)**
The pilot had been flying at 27,000 ft MSL when he reported a loss of cabin pressurization. He soon received clearance to descend to 15,000 ft. Shortly after the pilot acknowledged the lower altitude, radio communication deteriorated and the aircraft began a shallow descent with slight heading changes, then made a rapid descent into desert terrain. The investigation found that the pilot had exceeded a 12,500-ft altitude restriction, which had been imposed due to unresolved oxygen system issues, and that the pilot had severe coronary artery disease. This crash occurred while the plane was essentially on course shortly after trouble became apparent.		
3. July 30, 1993; Dayton, NV	**LAX93LA309**	**Cessna 182P (1P/S)**
The drunken pilot failed to maintain a sufficient altitude and crashed the stolen airplane into mountainous terrain. The accident apparently did not occur far from the point where an accident became inevitable.		
4. August 17, 1992; Incline Village, NV	**LAX92FA356**	**Piper PA-18-150 (1P/S)**
The pilot apparently lost control of the aircraft and crashed into mountainous terrain near 8000 ft elevation due to incapacitation related to heart disease. The airplane was found in near vertical attitude with its engine about 4 ft below ground level. The airplane apparently struck the ground nearly vertical at great speed, which indicates a rapid descent from the point at which trouble became apparent.		

NOTES: [a]Number & type of engines/weight class from Order 7110.65 *Air Traffic Control* (FAA O 7110.65N, Change 1. 2002, Appendix A). Number of engines: 1=single engine, 2=twin engine. Engine type: P=piston, T=jet/turboprop, J=jet. Weight class: H=heavy, >255,000 lbs.; L=large, >41,000 lbs.; S=small, <41,000 lbs.

SOURCE: NTSB 2002a.

ATTACHMENT II.

CRASH RANGE FOR GENERAL AVIATION FLIGHTS ABOVE 10,000 FT MSL

The National Transportation Safety Board (NTSB) reports that 361 US registered general aviation aircraft were involved in fatal accidents in 1997 (NTSB 2001, p. 1). Table II-1 summarizes the accidents and identifies the initiating event (NTSB 2001, Chart 9). NTSB investigations identify one or more occurrences that describe an accident sequence. The NTSB (NTSB 2001, p. 3) refers to the initiating event in the accident sequence as the "first occurrence." The analysis is limited to fatal crashes because crashes in which there were no fatalities presumably occurred either with the pilot in partial control of the aircraft and able to avoid crashing into buildings or originated from low altitudes and speeds that would not pose a hazard to Yucca Mountain facilities. The information from the NTSB report was examined to make inferences about the crash range of general aviation flights. The conclusions from the examination are taken as applicable to general aviation flights tracked by the FAA in the aviation corridor to the southwest of Yucca Mountain.

The most common category of initiating event identified by the NTSB was "noncollision in flight," with loss of control being the most common single initiating event and accounting for 28 percent of the accidents. Loss of control means that the aircraft is no longer flying level and on course. Unless control is restored quickly, a collision with the ground will occur soon after loss of control, and normally not far from the point at which control was lost. Accounting for about 10 percent of accidents, encounters with weather were the next most common initiating event. As the event sequences described in Table I-1 vividly showed, when an encounter with adverse weather conditions leads to a crash, it usually does so soon after the encounter begins, and leaves the wreckage not far from the point where trouble initially became apparent. Airframe, component, or system failures or malfunctions account for about 6 percent of accidents. Because the accidents under examination were fatal, it is likely that the aircraft in question were not controllable after the failure or malfunction and plummeted to the ground near the point where the initiating event occurred. The remaining noncollision initiating events accounted for only a small fraction of the accidents.

Table II-1. Initiating Events for Fatal General Aviation Accidents in 1997

Initiating Event (or First Occurrence)	Percent of Aircraft
Collision, in-flight	**33.0**
Midair collision between aircraft	5.8
Collision with object	12.2
Collision with terrain or water	14.4
Undershoot	0.6
Noncollision, in-flight	**46.3**
Encounter with weather	10.2
Loss of control	28.0
Abrupt maneuver	1.1
Airframe, component, system failure or malfunction	6.1
Forced landing	0.3
Uncontrolled altitude deviation	0.6
Noncollision, on-ground or on-water	**0.6**
Power-related accident	**16.6**
Propeller failure or malfunction	0.3
Rotor failure or malfunction	0.3
Loss of engine power	6.6
Total loss from mechanical failure or malfunction	*1.7*
Partial loss from mechanical failure or malfunction	*0.6*
Total loss from nonmechanical failure or malfunction	*5.8*
Partial loss from nonmechanical failure or malfunction	*1.4*
Landing gear related accident	**0.3**
Miscellaneous accident	**1.7**
Initiating event not determined	**1.7**

The second most common category of initiating event leading to fatal crashes was "in-flight collision." A collision with terrain or water was the most common at about 14 percent of accidents. Combined with collisions with objects, normally a tree (NTSB 2001, Chart 12) these two categories account for about 27 percent of the accidents. When collision with terrain or an object on the ground is identified as the initiating event, it means that there was no loss of control or disorientation due, for example, to an encounter with weather that precipitated the collision. Therefore, it may be surmised that these events are mostly related to landing or takeoff, and are therefore not applicable to normal flight past the Yucca Mountain facilities. Midair collisions between aircraft are the next most common initiating event, accounting for about 6 percent of accidents. Because the accidents under examination were fatal, it is likely that the aircraft in question were not controllable after the midair collision and plummeted to the ground near the point where the midair collisions occurred. The remaining in-flight-collision initiating events accounted for only a small fraction of the accidents.

"Power-related accident" is the next most common category. Here, the main culprit is total loss of engine power from nonmechanical failure or malfunction. Presumably, this means an electrical failure. Apparently, the pilot was unable to restart the engine and either had to rely on his ability to glide the plane unpowered to a forced landing, or was also unable to control the aircraft due to the electrical failure. One can be sure that a pilot passing southwest of the Yucca Mountain facilities who had some measure of control over the aircraft would not steer the aircraft into the mountains to attempt a landing, but would try to land on the valley floor near US Highway 95. A pilot unable to control the aircraft at all would probably enter an uncontrolled dive and crash near the point where control was lost. The remaining power-related initiating events accounted for only a small fraction of the accidents.

None of the remaining categories account for a significant fraction of the accidents. It is clear from the summary of accident sequences that fatal general aviation crashes that occur many miles off course must be rare. Assigning a generous crash range of 10 miles to general aviation crashes originating above 10,000 ft MSL is therefore conservative.

ATTACHMENT III.

CRASH RANGE FOR AIR TAXIS

The National Transportation Safety Board (NTSB) reports that there were 15 fatal accidents involving US registered air taxis in 1997 (NTSB 2002b, p. 35). Air taxis are unscheduled aircraft operating in accordance with 10 CFR 135, which regulates commuter airlines and on-demand air taxi operators (NTSB 2002b, p. 1). Over the ten-year period from 1987 to 1996, there were 26.3 fatal air taxi accidents per year, on average (NTSB 2002b, Table 53). Table II-1 summarizes the accidents over the ten-year period from 1987 to 1996 and identifies the initiating events (or "first occurrences"). Individual initiating events that account for less than 2 percent of accidents are omitted from Table II-1 and the following discussion. The analysis is limited to fatal crashes because crashes in which there were no fatalities presumably occurred either with the pilot in partial control of the aircraft and able to avoid crashing into buildings or originated from low altitudes and speeds that would not pose a hazard to Yucca Mountain facilities. The conclusions from the examination are taken as applicable to air taxis tracked by the FAA in the aviation corridor to the southwest of Yucca Mountain.

Table III-1. Initiating Events for Fatal Air Taxi Accidents between 1987 and 1996

Initiating Event (or First Occurrence)[a]	Percent of Aircraft
In-flight collision with terrain	22.1
Loss of control, in flight	17.1
In-flight encounter with weather	13.3
Airframe, component, or system failure or malfunction	9.5
In-flight collision with object	7.6
Total loss of engine power due to mechanical failure or malfunction	6.1
Loss of engine power	3.4
Midair collision	3.0
Fire	2.7
Partial loss of engine power due to mechanical failure or malfunction	2.3
Total loss of engine power due to non-mechanical cause	2.3
Total	89.4

NOTES: [a]Individual initiating events that account for less than 2 percent of accidents are omitted. Therefore, the total does not equal 100 percent.
[b]Source: NTSB 2002b, Table 53.

The most common initiating event identified by the NTSB was in-flight collision with terrain, which accounted for about 22 percent of accidents. When collision with terrain is identified as the initiating event, it means that there was no loss of control or disorientation due, for example, to an encounter with weather that precipitated the collision. Therefore, it may be surmised that these events are mostly related to landing or takeoff, and are therefore not applicable to normal flight past the Yucca Mountain facilities.

Loss of control is the second most common initiating event, accounting for about 17 percent of the accidents. Loss of control means that the aircraft is no longer flying level and on course. Unless control is restored quickly, a collision with the ground will occur soon after loss of control, and normally not far from the point at which control was lost.

Accounting for about 13 percent of accidents, encounters with weather were the next most common initiating event. As the event sequences described in Table I-1 vividly showed, when an encounter with adverse weather conditions leads to a crash, it usually does so soon after the encounter begins and leaves the wreckage not far from the point where trouble initially became apparent.

Airframe, component, or system failures or malfunctions account for about 10 percent of accidents. Because the accidents under examination were fatal, it is likely that the aircraft in question were not controllable after the failure or malfunction and plummeted to the ground near the point where the initiating event occurred.

The next most common initiating event leading to fatal crashes was in-flight collision with object (a tree or wires, etc. NTSB 2002b, Table 55). When collision with an object is identified as the initiating event, it means that there was no loss of control or disorientation due, for example, to an encounter with weather that precipitated the collision. Therefore, it may be surmised that these events are mostly related to landing or takeoff, and are therefore not applicable to normal flight past the Yucca Mountain facilities.

Total loss of engine power due to mechanical failure or malfunction accounts for about 6 percent of initiating events leading to fatal accidents. Other partial and total losses of power account for another 8 percent of accidents. In these accidents, apparently, the pilot was unable to restore power and either had to rely on his ability to glide the plane unpowered (or with little power) to a forced landing, or was unable to control the aircraft after the failure or malfunction. Obviously, a pilot passing southwest of the Yucca Mountain facilities who had some measure of control over the aircraft would not steer the aircraft into the mountains to attempt a landing, but would try to land on the valley floor near US Highway 95. A pilot unable to control the aircraft at all would probably enter an uncontrolled dive and crash near the point where control was lost.

Midair collision and fire together account for almost 6 percent of accidents. Because the accidents under examination were fatal, it is likely that the aircraft in question were not controllable after the midair collision or fire and plummeted to the ground near the point where the initiating event occurred.

None of the remaining categories account for a significant fraction of the accidents. It is clear from the summary of accident sequences that fatal air taxi crashes that occur many miles off course must be rare. Assigning a generous crash range of 10 miles to air taxi crashes is therefore conservative.

ATTACHMENT IV.

A WEEK IN THE LIFE OF THE AVIATION CORRIDOR SOUTHWEST OF YUCCA MOUNTAIN

In response to a request for information, Brent Shively, a representative of the FAA, provided a record of flights that the FAA tracked through the aviation corridor to the southwest of Yucca Mountain (Ragan 2002). Mr. Shively provided tabular and graphical information. The tabular information consists of records of each flight tracked from 3/30/02 to 4/5/02, including information such as the type of aircraft, its engine type, weight class, and whether the flight is general aviation, air carrier, air taxi, or military. The graphical information shows each day's flights on a background of the airspace divisions of the NTTR and the R-2508 Range complex. Note that the airspace divisions are simplified so that subdivisions that may be shown on other maps are not shown.

Figure IV-1 is a grayscale negative of the scanned image of the hardcopy that was provided by the FAA. The scanned image has been modified to indicate the locations of R-2505 on the R-2508 Range complex, R-2508N, and R-2508S. It shows the flights that passed through the corridor on Thursday, April 4, 2002 as gray traces. This particular day's flights are shown here as an example because they illustrate certain features of interest for the analysis. First, note that flights are concentrated between the two restricted airspace complexes in what could be considered a flight corridor. R-4808N covers most of the NTS, though the southwest corner of the NTS is beneath the triangular R-4808S. Next, note that while some flights cross R-4808S, it does not appear to be heavily used, especially near the border with R-4808N. Figure IV-1 shows two flights that happened to cross R-4808N that day. These are included in the counts provided by the FAA. Such flights would also be counted elsewhere in the analysis as flights over the NTS or through the 5.8 by 7 mi area around the North Portal. For the total crash-frequency estimate, this slight double counting is conservative.

For this analysis, it is useful to separately count air carriers and air taxis; general aviation turbojets, turboprops, and reciprocating-piston aircraft; and small and large military aircraft. After a few minor enhancements and error corrections, as described in the next paragraph, the counts were performed as follows. Air carriers and air taxis 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 lbs) 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 Table 9.

The information provided by Shively 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), which is manufactured by IAI and was delivered to the first customer in January 2000 (Jackson et al. 2001, 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 information provided by Shively. The first is resolved by noting that the aircraft type "T210" probably corresponds to Cessna C210, which has one reciprocating-piston engine (Schuster 2002). 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). 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). This change affected one record.

Figure IV-1. Flights Recorded on 4/4/02