RAI Volume 2, Chapter 2.1.1.3, First Set, Number 9: Second Supplemental Question:

Page 2, last paragraph: In its supplemental question which deals with distance from mishap initiation to crash, and hence with the cumulative distribution function F(r) in Equation 9 of reference BSC 2007c, the function F(r), as shown in Figure 5 of the reference is the distance of pilot ejection to crash. NRC does not understand how this can be conservative for the important subset of mishaps due to engine failures. About 25% of all military aircraft mishaps are engine failures. In such cases, pilots will not, in fact, eject immediately upon loss of engine. Instead, they are trained to attempt an engine restart. Their direction of travel should thus be assumed to be random from the initial engine failure point, and the travel distance should be the maximum glide distance. Such glide distances for typical F-16 situations are determined by the aircraft altitude, plus about 3000 ft for zoom, and the glide ratio of 8.4. Thus for aircraft even as low as 2000 ft, 2000 + 3000 × 8.4 is 8.4 miles. Aircraft operating at more typical altitude of 3 miles would travel about 25 miles. Thus, it appears that most of the engine failure crashes would have traveled more than the 5 mile restriction radius, far enough to reach from outside the restricted airspace to the target area, and hence should be mostly included in crashes estimated to occur within the target area without considering the restriction. Conversely, as can be seen for the F(r) plotted in Figure 5, distances from ejection to crash are almost always quite short. Thus, using the function from Figure 5 on distances from ejection to crash does not appear to be conservative for engine failure events. What appears to be needed for this separate piece of engine failures is an F(r) curve for distance from mishap initiation to crash.

1. SECOND SUPPLEMENTAL RESPONSE

The aircraft crash methodology documented in *Frequency Analysis for Aircraft Hazards for License Application* (BSC 2007) provides a conservative approach when taken in its entirety. The overall aircraft analysis provides a conservative estimate of expected aircraft crash probability that is well below the threshold for screening aircraft crash from consideration as an external hazard. The frequency analysis (BSC 2007) uses a uniform crash frequency density developed from crashes from flight activity that is typical of flight paths in the Test and Training Range and military operations areas indicated in Figure 1. Crash locations used to determine the uniform crash frequency density (BSC 2007, Table 8) are plotted in Figure 2. Comparing these figures shows that crash locations in Figure 2 coincide with the locations of flight paths in Figure 1, which are outside of a 30-mile radius from the repository. The selection of a 30-mile radius of interest was based on providing an areal basis for the analysis much more inclusive than that of *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants*, NUREG-0800 (NRC 1987). Further, the analysis conservatively applied the crash frequency density based on these more distant crashes within the 30-mile radius but outside of the flight-restricted area.

As discussed in the July 23, 2009, public call with the NRC, this response provides additional explanation of the DOE methodology and supplemental analyses. The information in this response accounts for the inhomogeneity (i.e., clustering) of the crash frequency density to demonstrate that the crash frequency density at the repository can be interpreted to be much less than that used in the analysis. The response also provides supplemental analyses demonstrating that the use of other methods, including removing $F(r)$ from the analysis, coupled with accounting for the actual inhomogeneity of crash frequency density, yields results comparable to the frequency analysis (BSC 2007).

This RAI concerns the portion of the frequency analysis (BSC 2007) that addresses military aircraft activity that takes place outside the Beatty Corridor and outside the flight-restricted airspace. The direction of travel of aircraft following a crash-initiating event is considered random in the frequency analysis (BSC 2007). With the use of a uniform crash frequency density and the assumption of no pilot action, the distance the aircraft travels while the pilot is in the aircraft is not required, and as such, an $F(r)$ based on that distance is not required. The uniform crash frequency density was determined from the location of the crash sites, not from the point of mishap initiation, as further discussed below.

1.1 FURTHER EXPLANATION OF CRASH FREQUENCY DENSITY

To address the military flight activity that takes place within a 30-mile radius of the North Portal that is not included in the evaluation of the 1,000 military overflights or the military aircraft traveling in the Beatty Corridor, a uniform crash frequency density was developed, similar to the value *C* in NUREG-0800 (NRC 1987, Section 3.5.1.6, Subsection III, (4)) based on crashes that were all beyond the 30-mile radius from the repository. A uniform crash frequency density is equivalent to an areal crash density. It is the total probability of an aircraft crash per year per square mile (crashes/yr/mi^2), regardless of pilot action. Because the uniform crash frequency density was determined from the location of the crash sites and not from the point of mishap initiation, the crash frequency density eliminates the need to have knowledge of the flight path, the distance the aircraft travels, or actions that a pilot may take following a mishap, such as to attempt an engine restart or direct the aircraft before ejection. All of these activities occur prior to aircraft impact; therefore, they are inherently accounted for in the uniform crash frequency density, which is based on the point of impact.

A key point is that there have been no crashes in the geologic repository operations area, no crashes in the flight-restricted airspace, and no crashes within a 30-mile radius of the repository (outside of the Beatty Corridor), as shown in Figure 2. In search of nonzero data, the frequency analysis (BSC 2007) used crash information based on 18 crashes that have occurred in the Nevada Test and Training Range and military operations areas during a 16.5 year period to develop a uniform crash frequency density (7.5×10^{-5} crashes/yr/mi^2). The type of flight activity within the airspace of the Nevada Test and Training Range and military operations areas includes aggressive maneuvering activity typical of military training exercises (e.g., Red Flag), which is not permitted within the Nevada Test Site.

The absence of crashes within the 30-mile radius is not random. It results from a consistent pattern of flights as shown in Figure 1. Figures 1 and 2 provide support for the insight that the uniform crash frequency density within the 30-mile radius would be expected to be lower because the preponderance of flight paths and crashes are far from the repository (significantly further than the analogous flight path considerations in NUREG-0800). Notwithstanding that and even though the DOE currently allows only military transitory type flights through the Nevada Test Site, the uniform crash frequency density of 7.5×10^{-5} crashes/yr/mi^2 was conservatively applied to the area within 30 miles of the repository without reduction. The uniform crash frequency density is not applied to the area inside the flight-restricted radius because aircraft are not permitted to fly in the airspace below 14,000 ft mean sea level. It is also not applied to the aircraft activity above the flight-restricted airspace because the 1,000 overflights permitted above 14,000 ft mean sea level are in a different flight mode due to flight restrictions (straight and level versus military training activity). Thus, the 1,000 overflights are analyzed separately.

Figures 1 and 2 show that the flight activity occurred in the Nevada Test and Training Range and military operations areas, and the crash sites remained in the Nevada Test and Training Range and military operations areas. Because the crash frequency density is determined from the location of the crash sites, not from the point of mishap initiation, it could be assumed that with no flight activity occurring within the flight-restricted area below 14,000 ft mean sea level, any crash-initiating event that occurred outside the flight-restricted area, based on the crash frequency density, would also remain outside this area. However, a crash frequency from military training activity outside of the flight-restricted area is determined from this crash frequency density. The function $F(r)$ is used to extrapolate the uniform crash frequency density from outside the flight-restricted airspace to the vicinity of the surface facilities inside the flight-restricted radius. Given that the use of a uniform crash frequency density eliminates the need to have knowledge of the flight path, the distance the aircraft travels, or actions that a pilot may take following a mishap because it is based on crash impact points, the $F(r)$ is developed from information of aircraft behavior after the pilot leaves the plane.

1.2 ENGINE FAILURES AND PILOT ACTION

The RAI discusses actions that a pilot may take following an aircraft engine failure, and states that the direction of the aircraft following the engine failure should be random. Because of pilot training and the location of airports, the direction of flight after engine failure mishaps will not be random or uniformly distributed. Assumption 3.2.15 of the frequency analysis (BSC 2007) states that "No credit for pilot action is taken in this analysis." This assumption is implemented specifically to conservatively address actions that pilots are trained to take when their aircraft experiences abnormalities or failures. Pilots are trained to take specific actions to increase their likelihood of surviving and returning their aircraft safely to an airfield. For example, upon an engine failure a pilot would initially increase altitude and direct the aircraft to the closest emergency airfield while attempting to restart the engine. This practice is reflected in the mishap reports related to crashes. If the aircraft cannot reach an airfield and ejection from the aircraft is necessary, it is reasonable to assume that the pilot will look for open space before ejecting to reduce collateral damage caused by the plane. This action is part of pilot emergency training and reduces the probability of crash into repository facilities. For example, a reasonable conclusion is that, because the closest airfields are not in the direct path of Yucca Mountain from the areas in the Nevada Test and Training Range or military operations areas where military training occurs, a pilot attempting to reach an airfield would not choose a flight path that would take the ailing aircraft over Yucca Mountain. If the pilot did have to eject and the aircraft was in the vicinity of Yucca Mountain, the pilot would likely direct the aircraft to an unpopulated area away from structures, as indicated in many mishap reports. All of these actions would result in reducing the crash probability into Yucca Mountain facilities. However, predictions of these actions cannot be quantified, accurately analyzed, or numerically defended. As such, they are conservatively not relied upon in the analysis. No credit for pilot action is taken in the frequency analysis (BSC

2007, Section 3.2.15) and crashes are considered uniformly distributed (BSC 2007, Section 3.2.14).

The uniform crash frequency density used in the frequency analysis (BSC 2007) is based on 18 crashes that occurred in the Nevada Test and Training Range or military operations areas, which includes areas over 100 miles from the repository. Of these 18 crashes, only three crashes were a result of engine failure. However, the flight activity occurred in the Nevada Test and Training Range and military operations areas, and the crash sites remained in the Nevada Test and Training Range and military operations areas, as shown in Figure 2. As stated earlier, the uniform crash frequency density is based on crash locations, not the location of the mishap leading to the crash. Thus, the distance the aircraft travels while the pilot is attempting control of the aircraft is not relevant to the analysis, and as such, the $F(r)$ is not based on this distance. It is only after the pilot leaves the plane (i.e., the plane is falling out of the sky without any attempt to control its descent) that the distance of aircraft travel becomes a factor in order to extrapolate the uniform crash frequency density from outside the flight-restricted radius to inside the radius where the surface facilities are located. An evaluation in the next section removes this factor.

1.3 SUPPLEMENTAL ANALYSES

The response to the second supplemental question on RAI 2.2.1.1.3-002 evaluates the aircraft activity surrounding the Yucca Mountain repository using the three NUREG-0800, Section 3.5.1.6 acceptance criteria. Based on that evaluation, all three NUREG-0800 acceptance criteria are met such that a detailed evaluation of aircraft activity would not be required if this guidance were followed. Specifically, military aircraft activity outside the flight-restricted airspace would not need to be evaluated.

Several alternate evaluations of the military aircraft activity within 30 miles of the repository but outside the 5.6-mile radius of the flight-restricted area and Beatty Corridor are provided in this section. These evaluations are for the purpose of demonstrating that use of other methods provides results comparable to those of the frequency analysis (BSC 2007) method.

1.3.1 Other Analyses Including the Distribution $F(r)$

1.3.1.1 A Single Hypothetical Crash within the 30-mile Radius

If the analysis had restricted the use of flight crash data to data within 30 miles of the repository, the uniform crash frequency density would be zero. However, hypothetically using one crash within this 30-mile area, the crash frequency density is 4.3×10^{-5} crashes/yr/mi^2 (BSC 2007, Section 3.2.14), which is over 40% lower than the crash frequency density used in the frequency analysis (BSC 2007). Thus, the crash frequency contribution from this portion of the analysis decreases from 4.8×10^{-7} crashes/yr to 2.8×10^{-7} crashes/yr.

1.3.1.2 Engine Malfunctions Only

The RAI discussion focuses only on engine failures. Only three of the eighteen crashes that have occurred in the Nevada Test and Training Range and military operations areas have been engine failures. A uniform crash frequency density derived from the engine failures that have occurred in the Nevada Test and Training Range and military operations areas is 1.2×10^{-5} crashes/yr/mi^2. Using a cumulative distribution function derived from only engine failure events in the frequency analysis data set, the crash frequency decreases from 4.8×10^{-7} crashes/yr to 1.1×10^{-7} crashes/yr.

1.3.2 Bayesian Analysis Excluding the Distribution *F*(*r*)

One of the areas of discussion in the RAI concerned the use of the distribution $F(r)$, which represents the fraction of aircraft crashes within a radius of 30 miles of the site, excluding the flight-restricted area, that has the potential to impact in the flight-restricted area. The discussion centers on whether this distribution is appropriate given that some initiating events are engine mishaps for which a longer distance to crash than represented by $F(r)$ might occur if the pilot is attempting to restart the engine. The following discussion and analysis does not use $F(r)$; instead, it relies only on geographical and crash frequency density information. The approach of removing $F(r)$ altogether, which is equivalent to $F(r) = 1$, is more conservative than the approach suggested in the RAI of developing an alternate $F(r)$ based on the distance from crash initiation to crash site.

The fundamental question for this analysis is "given the aircraft crash frequency density derived from data outside the 30-mile radius, what is the crash frequency density in the flight-restricted airspace?"

1.3.2.1 Inhomogeneity of Crash Frequency Density

The uniform crash frequency density used in the analysis is derived from military flights that occur in a region outside of a 30-mile radius of the repository. The lack of crashes within the 30-mile radius is not random but results from a consistent pattern of flights, as shown in Figure 1, which is from one day in the date range of flight data used in the analysis (BSC 2007). Figure 2 plots the 18 crashes that have occurred on the Nevada Test and Training Range and military operations areas (BSC 2007, Table 8). Figures 1 and 2 provide support for the insight that the crash frequency density within the 30-mile radius would be expected to be lower because the preponderance of flight paths and crash sites are far from the repository.

More quantitative support for this insight is provided in Figure 3, which presents the distance from any pixel on the diagram to the nearest crash. Iso-distance lines are also shown on the figure. The North Portal is located in a yellow to light green region in the lower left of the figure indicating that there is at least 40 miles between the Yucca Mountain site and the nearest crash. Another important feature of this figure is that it indicates a geographical (or spatial) clustering of the crashes which coincides reasonably well with the flight path information in Figure 1. If the crashes were strictly random, they would be more uniformly distributed over the entire region leading to more uniformity in coloration. Thus, Figure 3 shows that the crashes are not uniformly distributed, but are indeed clustered in defined areas.

A quantitative indication of the inhomogeneity in crash frequency density associated with the clustering represented in Figure 3 may be gained. This is done by fitting the spatial crash distribution using a two-dimensional quadratic formulation whose coefficients are derived using the maximum likelihood method. Figure 4 is the result of this two-dimensional quadratic formulation. The crash frequency density in the dark blue area of Figure 4 at and around the North Portal is significantly lower than most of the areas associated with the flight paths when comparing this figure to Figure 1. If the crash frequency density were uniform, this figure would be one solid color. However, the quadratic formulation indicates a crash frequency density at least an order of magnitude lower than the value that is derived from a randomly distributed set of crashes. This information is used in the Bayesian analysis shown in Attachment 1.

1.3.2.2 Bayesian Analysis

A Bayesian analysis is shown in Attachment 1 to estimate the crash frequency density inside the 30-mile radius of the repository, given that there have been no crashes within this 30-mile radius. The crash frequency density developed with the Bayesian analysis is then used to determine the crash frequency at the repository without the use of the factor $F(r)$. Attachment 1 shows that the crash frequency is below the Category 2 event sequence screening threshold of 2×10^{-6} events/yr.

1.4 SUMMARY

A significant conservatism in the frequency analysis (BSC 2007) is the use of a uniform crash frequency density derived from military flights in a region outside of a radius of 30 miles from the repository (excluding the Beatty Corridor) but applied within that 30-mile radius. The information provided demonstrates a significant inhomogeneity in the crash frequency density, which leads to estimates of military aircraft crash frequency density within 30 miles of the repository much lower than the crash frequency density used in the frequency analysis (BSC 2007). In addition, a supplemental Bayesian analysis, accounting for this inhomogeneity in the crash frequency density and removing the $F(r)$ factor, shows that the crash frequency for this aircraft activity is below the Category 2 event sequence screening threshold.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2007. *Frequency Analysis of Aircraft Hazards for License Application*. 000-00C-WHS0-00200-000-00F. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070925.0012.

NRC (U.S. Nuclear Regulatory Commission) 1987. *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants*. NUREG-0800. LWR Edition. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 203894.

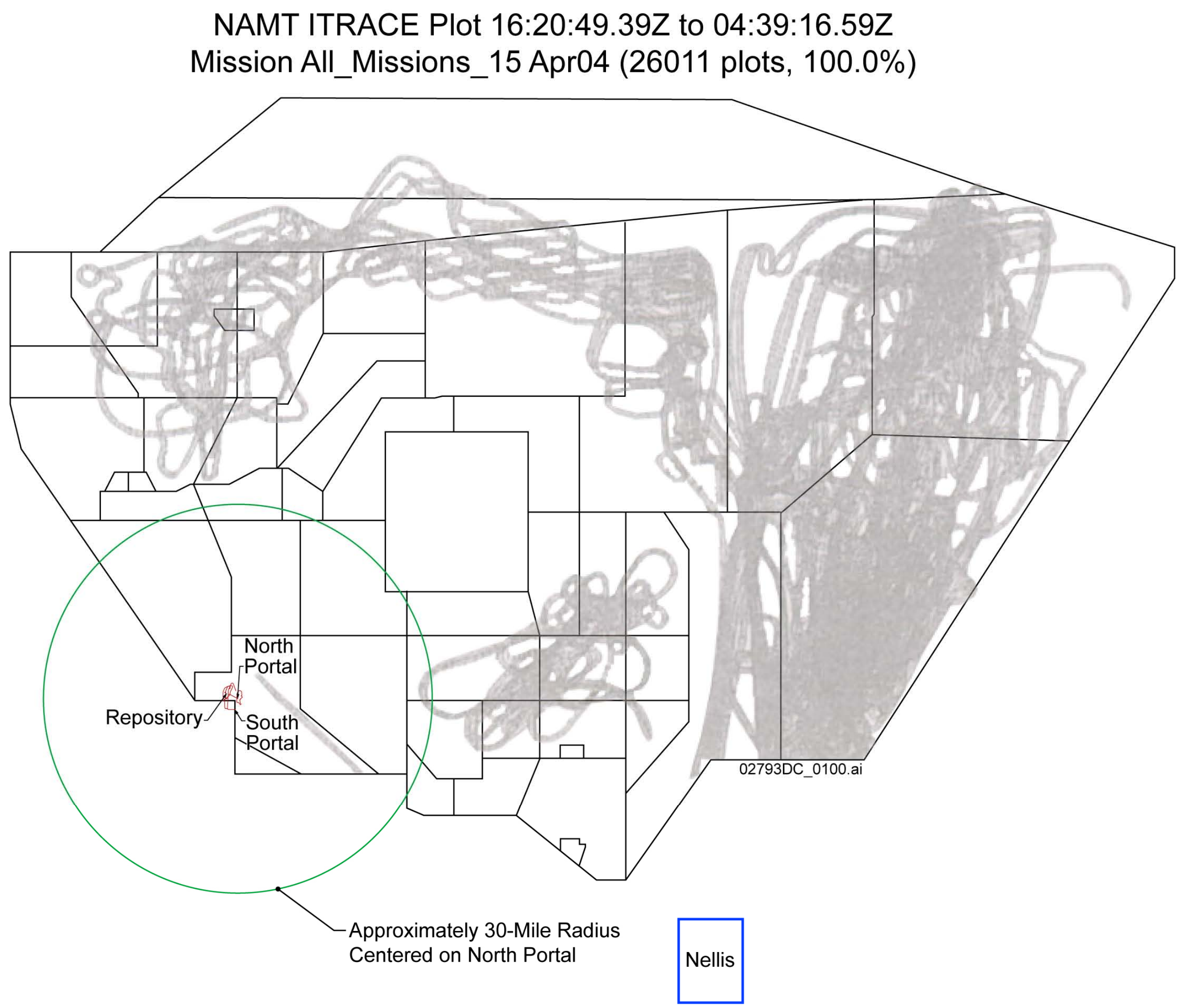

Figure 1. April 15, 2004, Military Aircraft Trace Plots on the Nevada Test and Training Range and Military Operations Areas provided by U.S. Air Force

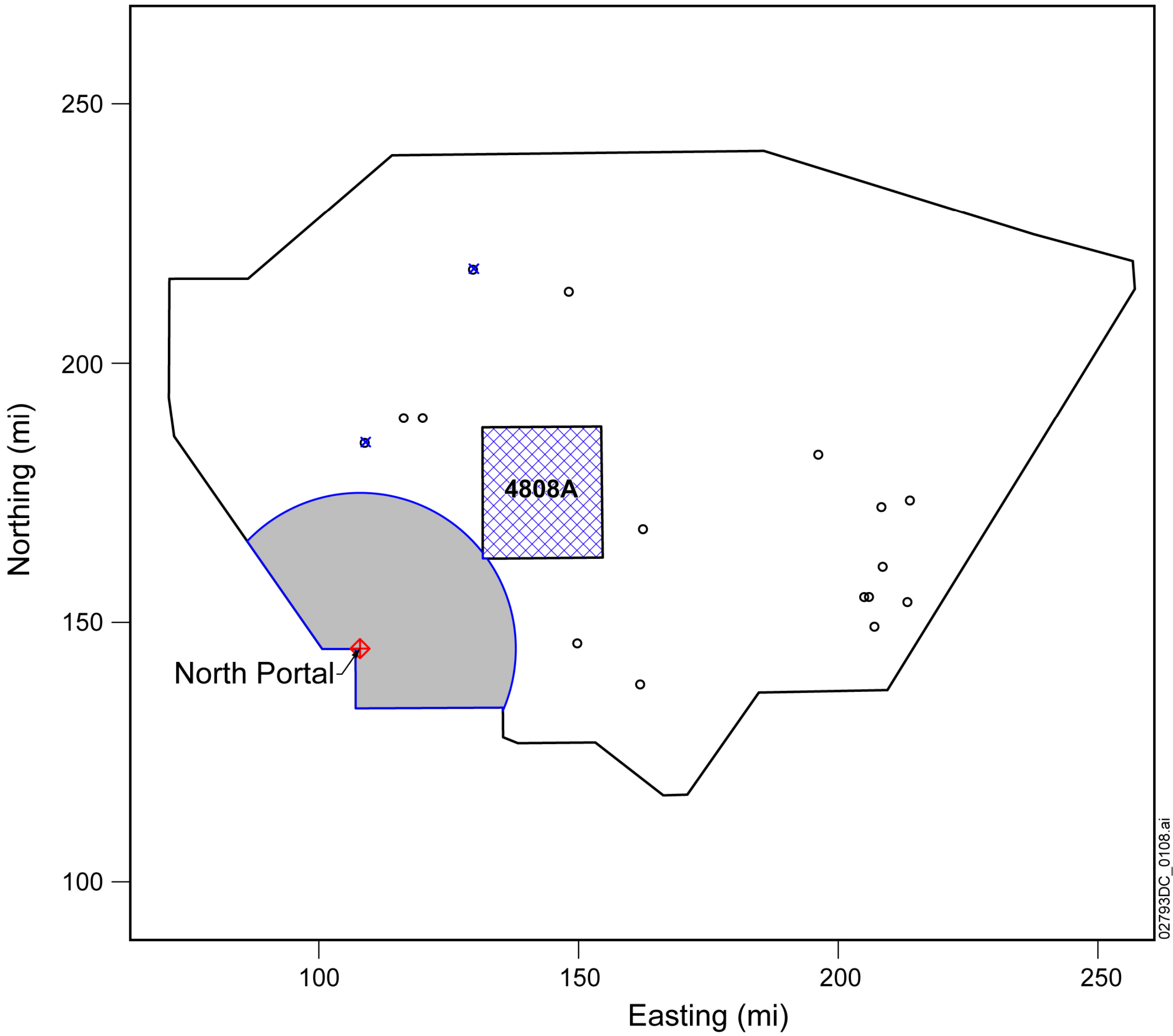

Figure 2. Nevada Test and Training Range and Military Operations Areas

NOTE: Small circles indicate locations of crashes listed in Table 8 of *Frequency Analysis of Aircraft Hazards for License Application* (BSC 2007). Small circles with an "x" indicate the site of mid-air collisions involving loss of both aircraft. Gray area indicates 30-mile radius centered at the North Portal. Military training flights are not permitted in the 4808A area; therefore, it is not included in the area used to determine the crash frequency density.

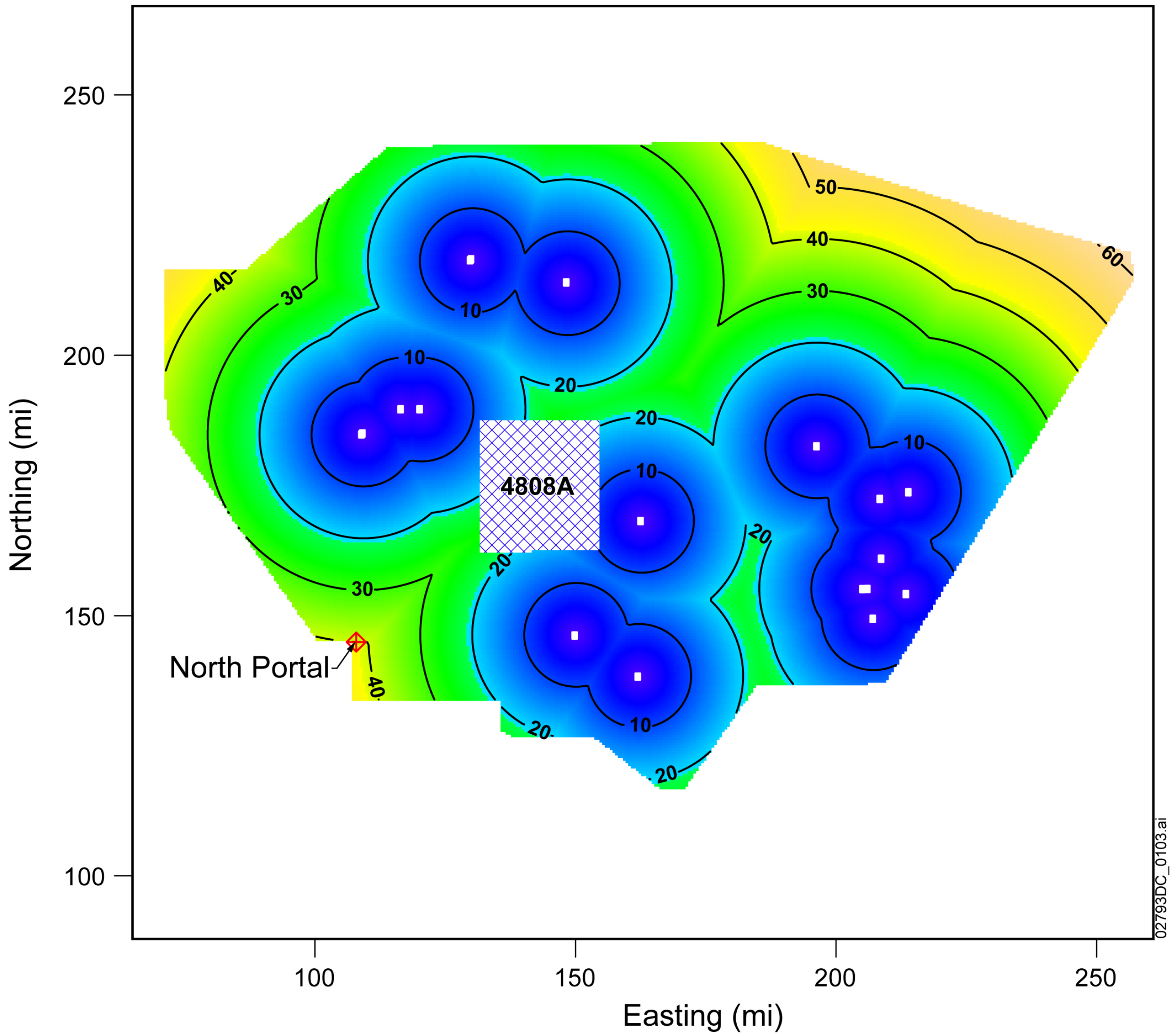

Figure 3. Iso-Distance Lines Indicating Distance to Nearest Crash Site in Miles

NOTE: Military training flights are not permitted in the 4808A area; therefore, it is not included in the area used to determine the crash frequency density.

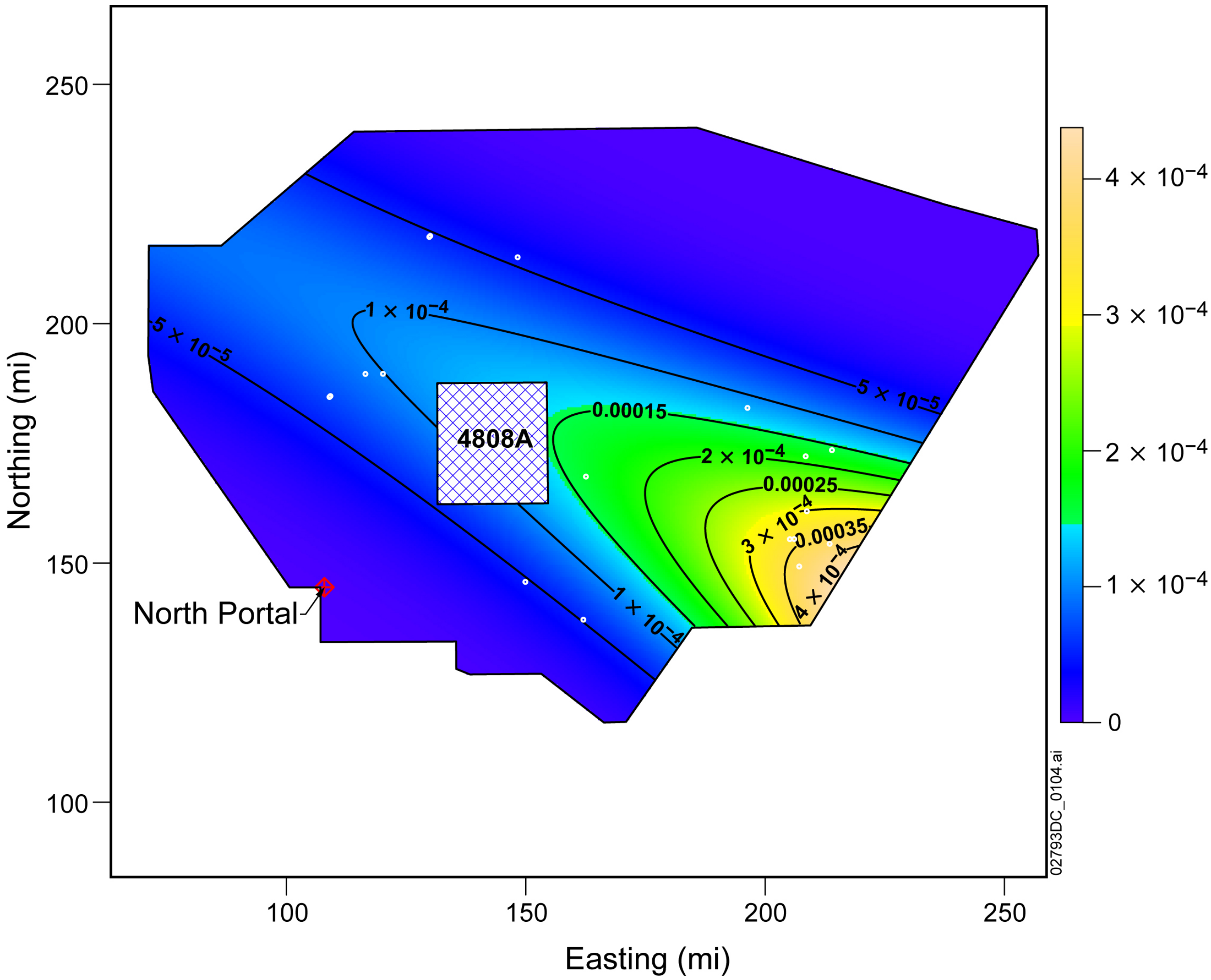

Figure 4. Inhomogeneous Poisson Log-quadratic Frequency Density

NOTE: Military training flights are not permitted in the 4808A area; therefore, it is not included in the area used to determine the crash frequency density.

ATTACHMENT 1

BAYESIAN ANALYSIS

The following Bayesian analysis estimates the crash frequency density within a 30-mile radius of the repository associated with military flights outside of the Beatty Corridor.

Consider a crash frequency density within a 30-mile radius of the repository. This crash frequency density is a fraction, f_c, of the crash frequency density outside the 30-mile radius developed from 18 crashes over a 16.5 year period. The exact value of f_c is uncertain and can be represented by a prior distribution $p(f_c)$. This fraction must have a value between zero and one. Based on the information in Section 1.3.2.1 on the inhomogeneity of the crash frequency density, the distribution that represents prior knowledge would have a mean value that is less than or equal to 0.1 with extreme values (zero and one) much less than the mean. The information in Section 1.3.2.1 strongly suggests that $f_c = 1$ would not be credible because a unity value would contradict the insight of inhomogeneity. In addition, there is little support for a value of f_c less than ~0.001. These characteristics suggest a beta function as a prior distribution with parameters (α, β) greater than one in order to obtain the desired convex shape. By using a conservative mean of 0.1 and a confidence (i.e., probability) that there is less than a 1% chance that f_c would be below 0.001, the parameters $\alpha = 1.1$ and $\beta = 10$ are appropriate.

With the evidence, E_{0in18}, of 18 crashes over 16.5 years outside the 30-mile radius and zero crashes within a 30-mile radius, a likelihood function, $L(E_{0in18}| f_c)$, is defined as the probability that zero crashes would have been observed given a postulated value of f_c. A binomial distribution gives the probability of occurrence of 0 of 18 crashes given a postulated fraction f_c. The parameters of this binomial distribution are $r = 0$ occurrences, $n = 18$ trials, and $q = f_c$ per trial.

The posterior probability distribution, $p(f_c| E_{0in18})$, is defined as the probability of each value of f_c given the evidence E_{0in18}. The posterior distribution is represented by Equation 1 according to Bayes' Theorem.

$$p(f_c \mid E_{0in18}) = \frac{p(f_c)L(E_{0in18} \mid f_C)}{\int p(f_c)L(E_{0in18} \mid f_C)df_C} \qquad \text{(Eq. 1)}$$

Because beta and binomial distributions are a conjugate pair, the posterior mean value of f_c, $\overline{f_c}$, is developed using Equation 2.

$$\overline{f_c} = \frac{\alpha + r}{\alpha + \beta + n} \qquad \text{(Eq. 2)}$$

Substitution of the relevant inputs yields:

$$\overline{f_c} = \frac{1.1+0}{1.1+10+18} = 0.038 \qquad \text{(Eq. 3)}$$

This model yields an expected value of the crash frequency density within a 30-mile radius of the repository of 3.8% of the crash frequency density in the area in which 18 crashes have been observed. Thus, the crash frequency density within the 30-mile radius is estimated using this Bayesian method as 0.038 × (7.5 × 10^{-5} crashes/yr/mi^2) = ~3 × 10^{-6} crashes/yr/mi^2. With an effective target area of the surface facilities of 0.33 mi^2 (BSC 2007, Section 6.4), the crash frequency, without the use of $F(r)$, is ~1 × 10^{-6} crashes/yr, which is less than the Category 2 event sequence screening threshold of 2 × 10^{-6} events/yr for a 50-year preclosure period.

The likelihood function used in Equation 2, however, treats all crashes as equivalent. In recognition that engine failures may be a failure mode involving a different likelihood, Equation 4 provides the appropriate formulation for the posterior probability distribution, $p(f_c^{'} \mid E_{0in18})$, that discriminates between engine failure modes and other failure modes within the crash data.

$$p(f_c^{'} \mid E_{0in18}) = p(f_c^{e} \mid E_{0in3}) f_e + p(f_c^{o} \mid E_{0in15}) f_o \qquad \text{(Eq. 4)}$$

where

$p(f_c^{e} \mid E_{0in3})$	=	probability distribution of f_c due to engine failure modes
$p(f_c^{o} \mid E_{0in15})$	=	probability distribution of f_c due to other failure modes
f_e	=	fraction of crashes due to engine failure modes = 3/18
f_o	=	fraction of crashes due to other failure modes = 15/18

Using the same prior distribution for both, Equation 2 may be applied to $p(f_c^{e} \mid E_{0in3})$ and $p(f_c^{o} \mid E_{0in15})$ in Equation 4 to obtain:

$$\overline{f_c^{'}} = \frac{1.1+0}{1.1+10+3}\left(\frac{3}{18}\right) + \frac{1.1+0}{1.1+10+15}\left(\frac{15}{18}\right) = 0.048 \qquad \text{(Eq. 5)}$$

This formulation yields an expected value of the crash frequency density within a 30-mile radius of the repository of 4.8% of the crash frequency density in the area in which 18 crashes have been observed. Thus, the crash frequency density within the 30-mile radius can be estimated as 0.048 × (7.5 × 10^{-5} crashes/yr/mi^2) = ~4 × 10^{-6} crashes/yr/mi^2. With an effective target area of 0.33 mi^2, the crash frequency, without the use of $F(r)$ and discriminating between engine and other failures, is ~1 × 10^{-6} crashes/yr, which is less than the Category 2 event sequence screening threshold of 2 × 10^{-6} events/yr.