Bruce Hamilton, Chairman
Jessie H. Roberson
Joyce L. Connery

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

November 6, 2019

The Honorable James Richard Perry
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Secretary Perry:

The Department of Energy (DOE) issued Standard 3014-2006, *Accident Analysis for Aircraft Crash into Hazardous Facilities*, in October 1996 to provide guidance for performing conservative and consistent analysis of a potential aircraft crash into a facility. In May 2006, DOE reaffirmed the use of this standard for preparing documented safety analyses for defense nuclear facilities. Since DOE Standard 3014's issuance in 1996, DOE has not made any modifications that include the most recent industry practices, lessons learned from over 20 years of implementation experience, or constructive feedback from users. The Defense Nuclear Facilities Safety Board (Board) conducted a thorough review of the contents of this standard and a limited review of its implementation across the defense nuclear complex.

The Standard, having been written in 1996, is outdated as it is inconsistent with updated DOE directives, and, as it does not call for periodic updates of aircraft crash accident analysis, the inputs used to screen the hazards are inadequate. In addition to the flaws in the Standard itself, the Standard is implemented inconsistently across the complex. As Standard 3014 is one of the supporting standards to the safe harbor methodologies in DOE's Nuclear Safety Management Rule, Title 10 Code of Federal Register Part 830, the technical credibility of its contents has a direct impact on ensuring adequate protection of the public.

Pursuant to 42 U.S.C. §2286a(a), the Board advises DOE to take action in accordance with DOE Order 251.1D, *Departmental Directives Program*, to revise Standard 3014 and address the identified safety issues enumerated in this report. This will ensure that pertinent hazard analyses are prepared in an adequate manner to support the documented safety analyses required for compliance with 10 CFR 830.

Yours truly,

Bruce Hamilton
Chairman

Enclosure

c: Mr. Joe Olencz

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Report

July 26 2019

Review of DOE Standard 3014, *Accident Analysis for Aircraft Crash into Hazardous Facilities*

Summary. Members of the Defense Nuclear Facilities Safety Board's (Board) staff reviewed Department of Energy (DOE) Standard 3014, *Accident Analysis for Aircraft Crash into Hazardous Facilities* [1]. DOE prepared the standard in 1996 in response to several Board correspondences, but has not revised or updated the standard since.

Standard 3014 is one of the supporting standards to the safe harbor methodologies in 10 CFR 830, *Nuclear Safety Management*. As a result, technical credibility of its contents has a direct impact on ensuring adequate protection of the public.

The Board's staff's review identified some weaknesses that should be corrected, as well as areas where DOE should provide additional guidance to improve the standard's contents:

- Parameters used in the standard for determination of the consequences to the public and collocated workers are outdated, inconsistent with current DOE methodologies, and do not provide the same level of protection as DOE's current methodologies. For example, using current DOE guidance for wind speed as provided in DOE Standard 3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, instead of Standard 3014 guidance would increase the dose consequences to the maximally exposed offsite individual by a factor of approximately two.

- The impact frequency evaluation methodology has weaknesses, including lack of consideration of the life of the facility, inadequate guidance on multi-building facilities, and ambiguous guidance on impact area definition and reductions associated with unoccupied space.

- The standard does not require periodic updates of contractors' aircraft crash accident analyses to ensure that conditions remain as reflected and adequately protect members of the public throughout the life of the facilities.

- Standard 3014 is inconsistent with the DOE's updated methodology for preparation of standards and does not differentiate between the requirements that must be met (i.e., "shall" statements) versus guidance and recommendations (i.e., "should" statements), resulting in inadequate analyses.

- Implementation of this standard in the complex varies from verbatim compliance to complete disregard of application of its recommended methodology and the use of its provided data.

Background. DOE prepared and issued Standard 3014 in response to Board correspondences (October 1, 1993 and May 2, 1995) identifying the lack of credible aircraft crash accident analyses at several defense nuclear facilities such as Pantex, Rocky Flats, and Los Alamos National Laboratory (LANL). DOE issued Standard 3014 in October 1996 to provide its contractors with a methodology for performing a conservative and consistent analysis of a potential aircraft crash into a facility.

Since the standard's publication in 1996, DOE has not revised the standard to improve its contents, to provide additional guidance based on the experience gained by its implementation, or to update any of the statistical crash data used in the standard. In May 2006, DOE reaffirmed the use of this standard for preparing documented safety analyses (DSA). The Board's staff provided some comments concerning certain areas for improvement to DOE's departmental representative in 2013 in a comment letter during the standard's proposed re-affirmation in 2013; however, DOE did not revise or reaffirm Standard 3014-2006 [2] as proposed. This staff report discusses a list of weaknesses that DOE should address in revision to the Standard 3014-2006.

The standard goes beyond "what" to prepare (as is contained in other DOE standards) and provides "how to" discussions that users should follow.

Discussion. Standard 3014 is one of the most comprehensive and detailed standards that DOE has issued. It took many scientists more than two years to prepare the first draft. As a result, the Foreword to the standard states the following:

> *This volume comprises the main body of the standard, including appendices, and is intended to provide sufficient information for the knowledgeable practitioner to conduct an aircraft crash safety analysis. The standard does not contain all of the details regarding the basis for the methodology or the detailed technical information required to fully understand how the standard was developed* [emphasis added].

The standard relies heavily on the knowledge of the analysts to understand the concepts presented, and to perform the described analyses. The Board's staff has observed inconsistencies in implementation of the standard throughout the DOE complex, and misinterpretation of its contents due to the lack of knowledge of some practitioners who use it. Additionally, the Board's staff has identified some technical weaknesses in the standard. The following describes the Board's staff's observations in reviewing the contents of the standard and implementation of the standard at defense nuclear facilities.

Outdated or Inconsistent Technical Guidance for Dose Consequence Evaluation—Standard 3014 contains technical guidance that is outdated or inconsistent with current DOE practices, examples of which are detailed below.

- The aircraft impact uses a standard wind speed of 2 m/s for its nomograph analysis and recommends site-specific analysis for dose consequence to the maximally exposed offsite individual (MOI). Current DOE requirements and guidance, such as DOE Standard 3009-2014, indicates that 1 m/s is the default wind speed chosen for DSA analysis: "If representative meteorological data is not available, Pasquill stability class F and one meter/second wind speed may be used for radiological dispersion...." [3]. DOE should provide additional justification for the use of 2 m/s wind speed, or align with current guidance. The plume dispersion analysis that determines the dose consequences is inversely proportional to the wind speed; therefore, a change from 2 m/s to 1 m/s would increase the consequences by a factor of approximately two. This indicates that Standard 3009-2014 is more conservative than Standard 3014-2006.

- The standard recommends a breathing rate of 3.0×10^{-4} cubic meters per second (m^3/s) for the dose consequence to the MOI, which is inconsistent with the breathing rate recommended by DOE Standard 3009-2014 of 3.3×10^{-4} m^3/s. The dose consequence to a receptor is directly proportional to the breathing rate. Consequently, using the updated breathing rate in DOE Standard 3009-2014 would increase dose consequences by 10 percent.

- To protect the "onsite workers located outside a facility" of concern (i.e., collocated workers), the standard prescribes criteria that are outdated and inconsistent with DOE's current practice. Standard 3014-2006 considers collocated workers to be located 300m from the facility, whereas Standard 3009-2014, which is a safe harbor in 10 CFR 830, *Nuclear Safety Management*, requires evaluating collocated workers at 100m from the source of a hazard or facility [4]. Furthermore, Standard 3014-2006 uses the facility inventory as the criterion and a threshold value of 25 times the amount identified by DOE as Hazard Category 2 threshold quantities. Standard 3009-2014 requires a 100 rem total effective dose threshold as the criterion for identification of safety-significant controls for co-located worker protection. Consequently, implementation of the methodology described in Standard 3014-2006 would lead to a level of protection of the workers that is non-conservative with respect to the methodology and criteria required by Standard 3009, a safe harbor in 10 CFR 830 for demonstrating adequate protection.

- Appendix D of Standard 3014-2006 states, "There is no 'officially approved' model for the atmospheric dispersion of hazardous chemical vapors." However, the DOE *Safety Software Quality Assurance - Central Registry* (developed subsequent to the 1996 issuance of Standard 3014) cites multiple chemical dispersion codes, including ALOHA by the National Oceanic and Atmospheric Administration and EPIcode by Homann Associates, Inc., which DOE has accepted as toolbox codes for use in safety analyses [5]. Use of these DOE approved methodologies should be recommended by the standard to yield "conservative and consistent" analyses across the complex.

These weaknesses as described above would lead to inconsistent or less conservative exposure evaluations than if current DOE requirements and guidance were used. However, the Board's staff noted that many facilities' aircraft crash analyses across the complex do not follow the exposure evaluation guidance in Standard 3014-2006, even if those facilities exceeded the preceding Standard 3014-2006 frequency thresholds. Instead, many facilities that perform exposure calculations follow requirements and guidance in Standard 3009 rather than Standard 3014-2006. As a result, the Board's staff believes that DOE should reevaluate the benefit of including exposure evaluation guidance in Standard 3014-2006, because DOE has adequate and updated dose consequence evaluation directives (e.g., Standard 3009, Standard 5506) that already contain this type of requirements and guidance. Additionally, because most facilities that are required to perform this exposure evaluation already use Standard 3009 requirements and guidance, the effect on individual facilities from removing such exposure evaluation guidance from Standard 3014-2006 should be minimal.

Limitations of Annual Frequency-based Crash Risk to Facility—The second screening step in implementing the standard is to determine if the aircraft crash frequency is greater than 1E-06 per year. Frequency based risk assessments are a common practice in nuclear safety analysis. However, the Board's staff observes that the crash risk over the anticipated life of the defense nuclear facility may be more meaningful for the purposes of assessing adequacy of controls. The risk of an aircraft impacting a facility during the life of the defense nuclear facility is the annual impact frequency multiplied by the anticipated defense nuclear facility life. The Board's staff believes that an impact screening criterion based on this facility lifetime risk would be more appropriate.

Additionally, the annual frequency-based evaluation is based on annualized aircraft crash statistics, and does not address intensified, localized air traffic scenarios such as aerial firefighting campaigns, which may significantly increase crash probabilities for a given defense nuclear facility. While statistical data on aircraft crash probabilities incorporate historical crashes from aerial firefighting campaigns, these probabilities would not be representative of actual crash probabilities for facilities known to experience large fires in the facility vicinity. This is true because the crash probabilities [6] for aerial firefighting campaigns are significantly higher than the national averages for similar aircraft (e.g., aerial firefighting is a higher risk activity than general aviation). Also, during aerial firefighting campaigns near a defense nuclear facility, the number of flights during the campaign would be much higher than the number given by the general statistical data for the same period of time. Further, aerial firefighting activities are not usually monitored or directed by airport control towers or air traffic controllers, and these activities pose an unpredictable crash risk. Hence for facilities with the potential for large fires in the vicinity, or other intensified aerial activities, incorporating an additional crash probability associated with these anticipated activities near the facility is appropriate.

Deficiencies in the Guidance for Computing Facility Effective Target Area—DOE Standard 3014-2006 provides an approach for computing the aircraft crash frequency into a facility containing radioactive or hazardous chemical materials. The approach prescribes the computation of the crash frequency per square mile using tables in the standard. This is multiplied by the "facility effective target area" to obtain the annual impact frequency. The analyst computes the facility's effective target area[1] by following the guidance in the standard. The Board's staff found several deficiencies associated with the guidance for computing the facility effective target area, which are discussed below.

The standard defines "facility" as "an area of interest for the purpose of performing aircraft crash impact analysis involving either individual structures or buildings; portions of structures or buildings (such as critical structures, systems, and components [SSCs]); or a multibuilding or multistructure conglomeration such as a storage tank farm or munition

1 The area of a potential target that is vulnerable to an aircraft crash. This area is a planar, or "horizontal," mapping of areas that an aircraft could crash into. It is derived as a function of physical target characteristics (width, length, and height), as well as aircraft and flight characteristics such as wing span, impact angle, and heading.

magazine complex. The facility should be defined as the collection of such structures that could be affected by a single aircraft impact."

The standard does not provide any guidance on how such multistructures should be accounted for in calculating the "effective target area" prescribed by the standard. As a result, the contractors for some nuclear facilities have had a difficult time interpreting the prescribed methodology for proper application and preparation of their safety basis documents. Further, the standard does not provide any guidance on how to assess the risk of an aircraft crash into outside storage of containers that are not in a building or structure.

The Board's staff notes that for facilities with multiple buildings or structures, the overall facility impact frequency is the sum of the impact frequencies for the individual buildings or structures. For example, consider a facility with two buildings, each with a computed impact frequency of 5E-7 per year. The probability of either one or the other of the two buildings being impacted by an aircraft crash would be the sum of the two individual probabilities, or 1E-6 per year. If the two buildings together are considered to be a defense nuclear facility and share a common DSA, then the combined impact frequency may be more appropriate as a screening criteria for assessing the need for additional controls. This can also be effectively accomplished by summing the areas of the individual buildings when computing the target area.

The definition of facility in Standard 3014-2006 includes the statement: "The facility should be defined as the collection of such structures that could be affected by a single aircraft impact." The Board's staff has observed cases where this statement has led contractors to limit the "facility effective target area" to a subset of structures that could be damaged by a single aircraft. This interpretation requires the contractor to estimate the extent of damage from an impact into multistructures, essentially defining the effective target area as the area that is damaged by the aircraft. This approach conflates the impact frequency screening with a structural assessment and neglects the larger target area of the facility that could be impacted by a given aircraft crash.

The standard provides that the facility's effective target area may be reduced by considering "critical areas," which are "locations in a facility that contain hazardous material and/or locations that, once impacted by a crash, can lead to cascading failures, e.g., a fire, collapse, and/or explosion that would impact the hazardous material." The standard states, "This knowledge is important for reducing the unnecessary conservatism that is likely to be introduced if the facility's dimensions are used blindly. For example, if the critical area dimensions are small fractions of the overall facility dimensions, this must be reflected in the analysis."

The standard does not discuss the meaning of "small fractions of the overall facility area" nor does it discuss how the spatial distribution of hazardous material within the facility affects target area reduction. This has led some contractors to significantly reduce the effective target area without an adequate justification, resulting in reduction of the impact frequency below the screening threshold.

Appendix A of this report presents examples of implementation inconsistencies and difficulties due to the lack of adequate guidance by the standard. DOE should provide additional clarification and guidance to the users for consistent and appropriate implementation.

Annual Update—10 CFR 830 requires contractors to update their safety bases annually and submit the updates to DOE for approval. The contractors may have prepared an analysis to comply with Standard 3014-2006 years ago and continue to report their results in their DSAs. The use of outdated information has resulted in declarations of a potential inadequacy in the safety analysis at some DOE sites when safety analysts revisited the aircraft crash analysis. Standard 3014-2006 does not contain any requirements for periodic review of site-specific input data to ensure that the analyses remain up to date. However, the purpose of annual update is to ensure DOE approves a safety basis that provides adequate protection.

With the expansion of general aviation, the types of planes and their frequency of flying into and out of local municipal airports may have changed over the years. For example, in 2017 the Tennessee Department of Transportation appropriated $15 million to build a new airport at Heritage Center, the former K-25 site in west Oak Ridge near the Y-12 National Security Complex. Appendix A includes an example of an analysis that was performed in 1999, and continues to be used by the contractor, Consolidated Nuclear Security, LLC, even though the nearby airport activities have increased by 50 percent. DOE should ensure the aircraft crash accident analyses are reevaluated at a minimum of once every 10 years[2], to ensure the risk remains the same and to determine whether it needs to take additional precautions.

Outdated Terminology—Standard 3014-2006 contains terminology that is outdated or inconsistent with current DOE practices. The standard contains few “shall” statements, and instead uses imprecise words like “will.” For example, the standard states: “High explosive detonations involving nuclear weapons and associated assemblies *will* use a value for the fraction of material released and respirable equal to 2E-1.” Lack of specific “shall” statements to highlight the nuclear safety requirements of the standard has led to deviation from, or lack of compliance with, the prescribed methodology. Appendix A presents some examples of how such deviations have resulted in non-conservative analysis and potentially less than adequate protection of the public. To be more aligned with current DOE terminology, the “will” should be replaced with “may”, “should,” or “shall,” depending on the importance of the guidance in meeting the intent of the standard.

Conclusion. Historically, DOE periodically reviewed (about every five years) its directives to ensure consistency with the most recent industry practices, to include lessons learned from implementation of those directives, and to incorporate constructive feedback from its users through the review and comment (RevCom) process. DOE, however, has not submitted Standard 3014 for RevCom revision since it was issued in 1996. Recently, DOE has used a prioritization process to prioritize and schedule revisions of its directives as described in DOE Order 251.1D [8]. Accordingly, the Board’s staff concludes DOE should revise Standard 3014-2006. The Board’s staff concludes that it is prudent for DOE to collect lessons learned from implementation of this standard, update some of the outdated input data, and provide additional

2 It should be noted that DOE Order 420.1C, *Facility Safety*, contains similar requirements for periodic review and update of Natural Phenomena Hazards.

guidance where ambiguity or lack of information may have caused less than satisfactory implementation of this standard. Standard 3014-2006 is one of the supporting standards to the safe harbor methodologies of 10 CFR 830, and as such, technical credibility of its contents has a direct impact on providing adequate protection of the public.

Additionally, Appendix A of this report describes some of the Board's staff's observations in assessing the analyses provided by the contractors to address this hazard in their safety basis documents for DOE review and approval. The detail of these analyses is rarely provided in the safety basis documents and may not be apparent to the DOE review team unless specifically requested. The findings and observations of the Board's staff's review, therefore, may be worthy of sharing with DOE officials so that they can take appropriate action to correct the deficiencies and weaknesses in the future.

References

[1] Department of Energy, *Accident Analysis for Aircraft Crash into Hazardous Facilities*, DOE-STD-3014-2006, May 2006.

[2] Daniel B. Bullen, Defense Nuclear Facilities Safety Board directives lead, letter, to Mari-Jo Campagnone, HS-1.1, April 18, 2013.

[3] Department of Energy, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis,* DOE-STD-3009-2014, November 2014.

[4] Department of Energy, *Nuclear Safety Management*, 10 CFR 830, January 2001.

[5] Department of Energy, *Safety Software Quality Assurance – Central Registry*, Office of Environment, Health, Safety and Security, accessed May 1, 2018.

[6] "Developing an Aviation Exposure Index to Inform Risk-Based Fire Management Decisions," *Journal of Forestry*, Vol 112 (6), pp 581-590, November 2014.

[7] Department of Energy, *Preparation of Safety Basis Documents for Transuranic (TRU) Waste Facilities,* DOE-STD-5506-2007, April 2007.

[8] Department of Energy, Departmental Directives Program, DOE Order 251.1D, January 2017.

Appendix A: An Assessment of Implementation of Standard 3014 at Defense Nuclear Facilities

The Defense Nuclear Facilities Safety Board's (Board) staff has evaluated the technical adequacy of the analyses that several contractors performed to implement the methodology prescribed in Standard 3014-2006. The contractors reported the results of these analyses in the safety basis documents for Department of Energy (DOE) review and approval in compliance with the requirements of 10 CFR 830, *Nuclear Safety Management*, and its safe harbor, Standard 3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, or Standard 3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*.

Transuranic (TRU) Waste Facility (TWF) Project at the Los Alamos National Laboratory (LANL)—The TWF facility design comprises several storage buildings that are separated by a distance of less than 50 feet. The analysis performed by the contractor, Los Alamos National Security, LLC (LANS), [1] estimated the probability of a crash into a bounding area of buildings to be 2.46E-06 per year. This estimated probability exceeded the DOE screening threshold criterion of 1E-6 per year. LANS then adjusted the result by taking credit for "unoccupied space," retaining walls, and vehicle barriers. With these adjustments the crash probability was reduced to 9.08E-7, which is below the DOE screening threshold.

To determine the bounding area, LANS estimated that an aircraft could damage two waste storage buildings. It rounded this estimate up to three buildings for conservatism. In considering the extent of damage, the contractor used the aircraft class with the highest probability of impact: general aviation aircraft (5000lb). The standard states that "the facility should be defined as the collection of such structures that could be affected by a single aircraft impact." The contractor did not consider the number of buildings that could be impacted by the largest aircraft. Evaluating larger aircraft would likely have increased the number of buildings impacted, and subsequently increased the target area and impact frequency.

LANS also reduced the impact area by approximately 39 percent to account for "unoccupied space" by considering non-material-at-risk (MAR) areas. The standard states "if the critical area [locations with MAR] dimensions are small fractions of the overall facility dimensions, this must be reflected in analysis." While the standard does not define the meaning of "small fraction," considering a fraction of 0.39 to be a small fraction would appear to be a highly favorable interpretation of the standard. Further, LANS did not present the technical basis for the size and spatial distribution of the non-MAR areas relative to potential aircraft damage paths.

LANS further reduced the effective area of impact by considering retaining walls and vehicle barriers. In doing so, it took weighted averages of the results for the different sides of the building, rather than taking the most conservative result.

The Board's staff concludes that the lack of adequate guidance and clear requirements in Standard 3014-2006 may have led to an analysis that does not meet the intent of the Standard.

Savannah River Site (SRS)—SRS personnel performed a generic site aircraft crash accident analysis to demonstrate that the probability of such a crash into a facility at the site is less than the DOE screening threshold criterion of 1E-6 per year [2].

In addition to the general aviation and commercial aircraft activities described in Standard 3014-2006 to be considered, there are other activities at the site that are ignored in the analysis by crediting administrative procedures used for their operation. These include flight activities by the US Forest Service and US Army for training soldiers. DOE's accident analysis methodologies do not allow crediting any administrative controls in the unmitigated analysis.

The SRS analysis deviates from using the aircraft crash probabilities presented in Standard 3014-2006. The analysis states:

> *The SRS General Aviation (GA) aircraft crash density (crashes/yr/square mile) can be reduced from the value in the DOE Standard (2.0x10-4 crashes/mi^2/yr) to 5.0 x10^{-5} crashes/mi^2/yr. The Savannah River Site is approximately 310 square miles. The site has existed for over 65 years (SRS Site selection in 1950 Reference 53). However, during that time span there has not been an aircraft crash on SRS. This is significant given the large land area as well as the long time span. If the crash density specified in the DOE Standard were applied, SRS should have seen 3-4 aircraft crashes over this time period. This indicates that there is significant conservatism in the values specified in the standard.*

The Board's staff concludes that using the revised and reduced crash probabilities resulted in SRS screening out the event as a potential hazard for all defense nuclear facility at the site. The rationale provided for reducing the crash probabilities is flawed since it relies on past history at a site as a justification for future predictions. This approach is not consistent with probabilistic risk analysis methodologies, and is not aligned with the DOE recommended methodology in Standard 3014-2006 for producing "conservative and consistent" analyses throughout the complex.

Y-12 National Security Complex (Y-12)—In 1999, Lockheed Martin Energy Systems performed a generic analysis [3] that estimated the probability of a crash into a facility with a variety of dimensions for Y-12 facilities. Each facility at Y-12 has used this analysis to derive its pertinent aircraft crash probabilities using its facility-specific dimensions. The generic analysis ignores the fact that Y-12 is a very congested site with buildings adjacent to each other or without much separation distance. Consequently, estimating the probability of a crash as if each building or facility is a stand-alone would not correctly characterize the risk of such an external event at the site, or the potential consequences to the public or the workers. Additionally, the close proximity of the facilities to each other would increase the probability of an aircraft crash into a nuclear facility, independent of the specific building being analyzed individually, due to the overlapping of their "effective area" as discussed above for the TWF project at LANL.

Furthermore, Lockheed Martin performed the generic analysis in 1999 using the number of flights in the nearby airports available at the time. More recent data [4] show that the number of flights into and out of one nearby airport, McGhee Tyson in Knoxville, TN, has increased by about 50 percent averaging over the last 10 years (from 73,000 annual airport activities in 1999 to 106,000 averaged over 2008 to 2017). This significant increase in one airport's operational activities would warrant a new estimate of the probabilities; however, the two-decade old analysis continues to be the basis for preparation of safety basis documents at Y-12.

The Board's staff concludes that the aircraft crash accident analysis, supporting the documented safety analyses at the Y-12 site, may be outdated and not reflect the current hazards posed by this event.

References

[1] Los Alamos National Security, LLC, *TRU Waste Facility – Aircraft Impact Frequency Estimates for Storage Buildings*, SBD-CALC-12-009, Rev.5, August 30, 2016.

[2] Norkus, J.K, *Aircraft Impact Frequencies for SRS Facilities*, S-CLC-G-00278, Rev. 2, June 15, 2015.

[3] Walker, D.A., *Estimated Total Annual Aircraft Crash Frequency for Generic Y-12 Building (U)*, DAC-SSE-921500-A002, March 1999.

[4] Airport Statistics, McGhee Tyson Airport, http://flyknoxville.com/airport-statistics/#1445357287695-5c6da99a-1599/, accessed 6/13/2018.