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DOE STANDARD

ACCIDENT ANALYSIS FOR AIRCRAFT CRASH INTO HAZARDOUS FACILITIES

U.S. Department of Energy
Washington, DC 20585

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FOREWORD

1. This Department of Energy standard is approved for use by all DOE components and contractors.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data that may improve this document should be sent by letter or by using the pre-addressed Document Improvement Proposal (DOE F 1300.3), which is included with this document, to the

   Tony Eng
   Director, Office of Facility Authorization Bases
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   U. S. Department of Energy
   20300 Century Blvd
   Germantown, MD 20874

   Copies of this correspondence should also be sent to the Office of Nuclear Safety Policy and Standards (EH-31), U.S. Department of Energy, Washington, DC 20585.

3. DOE technical standards, such as this technical standard, do not establish requirements. However, all or part of the provisions in a technical standard can become requirements under the following circumstances:

   a. They are explicitly stated to be requirements in a DOE requirements document; or

   b. The organization makes a commitment to meet a standard in a contract or in a plan or program required by a DOE requirements document.

   Throughout this standard, the word "shall" is used to denote actions which must be performed if this standard is to be met. If the provisions in this technical standard are made requirements through one of the two ways discussed above, then the "shall" statements would become requirements.

4. 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. This information is contained in a series of detailed technical support documents, which have not been distributed with the standard, but which are available by request. The support documents are:

   a. Kimura, C.Y. et al. *Data Development Technical Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard*. UCRL-ID-124837. Lawrence Livermore National Laboratory, 1996.

   b. Sanzo, D. et al. *ACRAM Modeling Technical Support Document*. LA-UR-96-2460, TSA-11-95-R112. Los Alamos National Laboratory, 1996.

   c. Hossain, Q.A. et al. *Structures, Systems, and Components Evaluation Technical Support Document for the DOE Standard, Accident Analysis for Aircraft Crash into Hazardous Facilities*. UCRL-ID-123577. Lawrence Livermore National Laboratory, 1996.

   d. Everett, H.C. et al. *Background Information on Source Term and Atmospheric Dispersion Modeling for the Aircraft Crash Risk Assessment Methodology Standard.* SAIC/95-1193. Prepared for the United States Department of Energy. Science Applications International Corporation, June 1995.

   e. Everett, H.C. et al. *Screening for Potential Consequences of Accidental Releases of Radioactive and Chemical Materials to the Atmosphere.* SAIC/95-1192. Prepared for the United States Department of Energy. Science Applications International Corporation, June 1995.

We encourage interested individuals to request copies of the supporting documents by writing to:

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The membership of the Interagency Working Group (IWG) on Accident Analysis for Aircraft Crash into Hazardous Facilities changed several times during the course of this standard's development. The individuals listed below served as members of the IWG at some time during the development process.

Organization Represented	Name of Representative
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Defense Nuclear Agency	Capt. Brent Bredehoff
Westinghouse Savannah River Corporation	Michael Hitchler
United States Department of Energy, Office of Nuclear Safety Policy and Standards	David Pyatt
United States Department of Energy, Office of Nuclear Safety Policy and Standards	Richard Stark
Federal Aviation Administration	Charles Thorpe
United States Environmental Protection Agency .	Paul Tobin
United States Nuclear Regulatory Commission (Observer Status Only)	James Wing

The responsibility for the contents of the standard lies with the Interagency Working Group Chairman and the Expert Panel on Accident Analysis for Aircraft Crash into Hazardous Facilities. The Expert Panel had the following membership at the time this standard was prepared.

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1. INTRODUCTION

1.1 Scope. This standard provides the user with sufficient information to evaluate and assess the significance of aircraft crash risk on facility safety without expending excessive effort where it is not required. The implementation guidance provides a framework of step-wise increases in analytical sophistication aimed at eliciting only that amount of analysis needed to demonstrate that aircraft crash either does or does not exceed a risk level of concern equivalent to what is generally applied to other sources of risk from the operation of hazardous material facilities. This standard establishes an approach for performing a conservative analysis of the risk posed by a release of hazardous radioactive or chemical material resulting from an aircraft crash into a facility containing significant quantities of such material.[1] This approach can establish whether a facility has a significant potential for an aircraft impact, and, given an aircraft impact, whether a facility has the potential for an accident producing significant offsite or onsite consequences. The analysis is based on the structural properties of a facility and the inventory at a facility.

This approach contains several interrelated analytical modules: (1) a methodology for determining the frequency of aircraft impact into a facility, based upon a conservative simplified equation; (2) a methodology to determine the effect of an aircraft impact into a facility through the performance of structural response analysis; (3) a methodology to determine the frequency of a release from a facility, given the effect of an aircraft impact; and (4) a methodology for evaluating the exposure resulting from a release. Evaluation guidelines are provided to aid in determining the need to conduct each subsequent analytical step. The methodologies take into consideration items determined to be important to understanding the risk from aircraft crash into hazardous facilities. These items include number of aircraft operations/flights; crash probabilities; aircraft characteristics; crash kinematics; impacting missiles; local, global, and vibratory structural damage; structure characteristics; source terms; release energy; and meteorological conditions.

[1] The thresholds for what constitutes "significant quantities" of material are established in Section 1.3, “Applicability.”

The analysis approach is consistent with an accident analysis (as in a Safety Analysis Report) that defines an approximate level of risk, rather than a detailed risk assessment. Thus, it adopts the typical accident analysis practice of addressing uncertainty through the use of analytical margin (i.e., conservatism) instead of through a formal uncertainty analysis. The philosophy is not one of providing substantial margin in every parameter used in the approach, as the combination of these margins would yield a final result so conservative as to be totally useless. Instead, margin is provided in each parameter based on the standard development team's judgement of the level of uncertainty in the parameter and the level of margin needed to address the uncertainty. Adjustments were made to assure that the level of margin provided at each step and throughout the process as a whole is adequate and reasonable.

When applied as a complete approach, the methodologies in this standard will result in a technically justified, conservative analysis of the risk posed by releases resulting from aircraft crash. The risk will be defined at a sufficient level of detail to document the safety of the facility with respect to aircraft crash, and at the same level of detail as would be expected for other types of accident analyses. The standard will also be sufficient to support safety findings, decision making, and design, and will free the user from justifying the techniques and models used in the assessment. However, it is not the intent of this standard to imply that these are the only methodologies acceptable for such an assessment. Alternative methodologies that meet the intent of the standard may be proposed and used, but their acceptability needs to be assessed on a case-by-case basis.

1.2 Purpose. This is an analytical standard intended to provide a sound, technically justifiable, and consistent approach to analyzing the risk posed by an aircraft crash into a facility containing radioactive or hazardous chemical materials. The focus is on analyzing the risk posed to the health and safety of the public and onsite workers from a release of hazardous material following an aircraft crash. Thus, this is not a standard on aviation safety and does not consider the risk to the occupants of the aircraft; the risk to individuals inside a building affected by the crash itself; or the risk to other individuals on the ground, either inside or outside a facility boundary, who might be directly impacted by the crash. This focus forms the basis for the standard's assumptions about excluding the consideration of consequences within a certain distance from the hazardous material release point.

Another important consideration in the development of this standard is the focus on analyzing the risk, as opposed to estimating the risk. This may seem to be a purely semantic distinction, but it emphasizes that application of this standard is intended to provide an organization (whether it be the facility operator or some cognizant safety oversight organization) with sufficient information to make a decision about the extent to which releases following an aircraft crash are a safety concern. It is also intended to provide sufficient information to identify where the risk is coming from and to determine what actions, if any, would be prudent to reduce the frequency or to mitigate the consequences of an aircraft crash into the facility. In most cases, this does not require an accurate estimate of the risk. Rather, it is sufficient to determine that the risk (or the individual subelements of frequency and consequences) does not exceed a predetermined level of concern (i.e., it is not large compared to other risks).

This standard allows the analysis to proceed along a series of increasingly complex steps; the results at each step are used to determine whether it is necessary to proceed to the next step or whether sufficient information has been provided and the analysis can be stopped and documented. As one proceeds through the steps, the results will get closer to an actual estimate of the risk, but even after fully implementing this standard, the results will still be more conservative than would be expected from a best-estimate risk assessment. In summary, following this standard will, in the vast majority of cases, provide sufficient information to document facility safety and support sound decision making for addressing the effects of an aircraft crash in the context of facility safety. In those rare cases where additional analysis is considered necessary to achieve these goals, an organization may perform a more detailed analysis. This standard does not provide guidance on completing such an analysis.

A necessary corollary to the above discussion is that this is not a criterion-based standard. It does not provide any hard and fast rules prescribing what actions should be taken in response to the results; it does not even prescribe whether any action should be considered. It does provide quantitative guidelines against which the results for each step in the analysis can be measured; however, these are only for the purpose of determining whether further analysis should be performed. Meeting or not meeting these guidelines should not be interpreted as indicating that preventive or mitigative actions either are or are not required.

This standard does not include consideration of malicious acts (e.g., sabotage, terrorism, and war). The available data on aircraft crashes do not support assessment of such acts. Further, such acts are not unique to aircraft, nor are they initiated by failures and errors associated with aircraft. However, the parts of this standard that address structural response and exposure due to a release could be useful (to a limited extent) in assessing the effects of such an assault.

1.3 Applicability. This standard is applicable to all facilities containing significant quantities of radioactive or hazardous chemical materials. For the purposes of this standard, a facility contains significant quantities of such material if it meets one or more of the following conditions:

a. The facility contains radioactive material, and the inventory of such material would cause the facility to be classified as a Hazard Category 1 or Hazard Category 2 facility in accordance with the criteria established by the U.S. Department of Energy (DOE) (Reference 1); or

b. The facility contains hazardous chemicals in quantities that make it subject to the requirements of 29 Code of Federal Regulations (CFR) 1910.119 (Reference 2); or

c. The facility contains hazardous chemicals that make it subject to the requirements of the Environmental Protection Agency's (EPA's) Risk Management Program (Reference 3).

The conditions above specify the minimum circumstances under which this standard should apply. However, they do not preclude applying this standard or its parts to facilities that do not meet any of these conditions. Users are encouraged to consider whether there are special circumstances in which a particular facility should be subject to this standard even though none of the above conditions are met. Such special circumstances could include (1) the presence of large amounts of material that were excluded from the inventory due to their enclosure in Department of Transportation (DOT) Type B shipping containers or sealed sources, per recommendation by DOE (Reference 1), but which may be subject to release in an aircraft crash; (2) the presence of large quantities of other materials which are known to pose a hazard but are not covered under conditions b and c; (3) the close proximity of an unusually large number of members of the public; (4) the presence of environmental resources that are particularly susceptible to the materials in the facility (e.g., endangered species) or that can spread contaminants over long distances (e.g., waterways); or (5) other similar circumstances.

1.4 References.

1. United States Department of Energy. *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports.* DOE-STD-1027-92. December 1992.
2. Title 29 Code of Federal Regulations, Part 1910, Section 119, *Process Safety Management of Highly Hazardous Chemicals*. 1994.
3. Title 40 Code of Federal Regulations, Part 68. 1996.

2. DEFINITIONS.

The first step in the development of this standard was to identify and define several critical terms. The terms are listed here in alphabetical order, and, where possible, the source of the definition has been identified.

Air Carrier: As defined by the Federal Aviation Administration (FAA), the commercial system of air transportation consisting of certificated air carriers, air taxis (including commuters), supplemental air carriers, commercial operators of large aircraft, and air travel clubs.

Air Taxi: As defined by the FAA, a classification of air carriers that transports persons, property, and mail using small aircraft (under 30 seats or a maximum payload capacity of less than 3401 kg [7,500 lb]) in accordance with 14 CFR 135.

Airborne Release Fraction (ARF): The coefficient used to estimate the amount of radioactive material suspended in air as an aerosol and thus available for transport due to physical stresses from a specific accident.

Aircraft Accident: As defined by the National Transportation Safety Board (NTSB), an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, and in which any person suffers a fatal or serious injury as a result of being in or upon the aircraft or by direct contact with the aircraft or anything attached thereto, or in which the aircraft receives substantial damage.

Aircraft Category: The broadest, most general level of classification for aircraft and aviation used in this standard. There are three categories: (1) commercial aviation, (2) military aviation, and (3) general aviation.

Aircraft Crash: For the purpose of this standard, any aircraft accident that results in destruction of or substantial damage to the aircraft. Fatal or serious injury sustained as a result of the aircraft accident by itself, without related destruction or substantial damage to the aircraft, does not make an aircraft accident qualify as an aircraft crash.

Aircraft Subcategory: The most detailed level of classification used in this standard for aircraft and aviation. For use in performing the specified analyses, the aircraft categories are divided into subcategories that consist of aircraft types having similar physical characteristics and distributions of crash parameters.

Aircraft Type: As defined by the FAA and used in this standard, a specific make and basic model of aircraft.

Airport: As defined by the FAA, an area of land or water that is used or intended to be used for the landing and takeoff of aircraft. This includes any buildings or facilities on the area.

Airport Operation: As defined by the FAA, the number of arrivals and departures from the airport at which the airport traffic control tower is located. There are two types of airport operations, local and itinerant. Local operations are those performed by aircraft that (1) operate in the local traffic pattern or within sight of the airport; (2) depart for or arrive from flight in practice areas located within a 37-km (20-mile [assuming nautical miles]) radius of the airport; or (3) execute simulated instrument approaches or low passes at the airport. All aircraft operations other than local operations are itinerant operations.

ARTCC: Air Route Traffic Control Center.

Barrier: A building, structural component, or object (e.g., equipment) that has the potential to prevent a missile from impacting a target, or to mitigate the effects of a missile impacting a target.

Certificated Air Carrier: As defined by the FAA, an air carrier holding a Certificate of Public Convenience and Necessity issued by the U.S. Department of Transportation (DOT) to conduct scheduled services interstate. Nonscheduled or charter operations may also be conducted by these carriers. Certificated air carriers operate large aircraft (30 seats or more or a maximum payload of 3401 kg [7,500 lb] or more) in accordance with 14 CFR 121.

Commercial Aviation: For the purpose of this standard, any aircraft activity performed under 14 CFR Parts 121, 125, 127, and 135.

Crash: See the definition of an aircraft crash.

Crash Location Distribution: The normalized conditional probability distribution (i.e., given that the crash occurs) in terms of the x and y coordinates of a coordinate system centered at the relevant runway.

Damage Ratio: The fraction of material at risk (MAR) actually impacted by the accident-generated conditions.

Distance Inclusion Criteria: The specified distance between the facility of interest and the flight sources within which aircraft operations are assumed to have a measurable impact on the aircraft crash impact frequency and are to be included in the analysis.

ERPG-2 (Emergency Response Planning Guidelines - Level 2): The maximum airborne concentrations below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective actions.

ERPG-3 (Emergency Response Planning Guidelines - Level 3): The maximum airborne concentrations below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

Effective Area: 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.

Exposure Evaluation: A calculation of the predicted airborne dose, as a function of distance, to which an individual would be exposed as a result of the accidental release of hazardous chemical or radioactive materials in specified weather conditions.

Exposure Screening: A preliminary conservative estimate of the potential offsite effects from an aircraft crash impact that allows all identified hazardous chemical and radioactive materials to be released. Facilities meeting recommended guidelines do not have to be evaluated in terms of aircraft impact frequency analysis.

Facility: As used in this standard, 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 magazine complex. The facility should be defined as the collection of such structures that could be affected by a single aircraft impact.

Fatal Injury: As defined by the NTSB, any injury that results in death within 30 days after the accident.

Flight Phase: The portions of an aircraft flight that are distinctly different due to the configuration of the aircraft and/or the conditions under which the flight is taking place. In general, there are seven distinct phases per flight. These are: takeoff roll, initial climb, climb to cruise, cruise/in-flight, descent from cruise, approach, and landing roll. For this standard, the seven phases were grouped into three main flight phases:

1. Takeoff phase, which includes the takeoff roll and the initial climb;
2. In-flight phase, which includes the climb to cruise, cruise/in-flight, and the descent from cruise; and
3. Landing phase, which includes the landing approach and the landing roll.

Flight Source: An aircraft activity (e.g., either airport operations or nonairport operations) that is assumed to contribute to the overall aircraft crash impact frequency and, thus, is included in the analysis. This standard addresses two types of flight source: (1) airport operations and (2) in-flight or nonairport activities, including the special case of deliberate overflights involving observation and local operations aircraft. For example, if there are three airports within the distance inclusion criteria, then there are four flight sources to be included in the analysis (three airport sources and one nonairport source).

Frequency: The expected number of events that occur or are expected to occur over some measured interval, such as events per unit time or events per aircraft operation.

General Aviation: As defined by the NTSB in their compilation of accident data and as used in this standard, all operations involving U.S. registered aircraft that are not conducting air carrier revenue operations (i.e., not air carriers or air taxis).

Global Response: Response of the overall target structure, as measured by its state of strain or displacement, which may result in global structural failure due to collapse or excessive structural deformation. Global response may also result in the functional failure of SSCs.

Hazard: An inherent physical or chemical characteristic that has the potential for causing harm to people, property, or the environment. It is the combination of a hazardous material, an operating environment, and certain unplanned events that could result in an accident.

High Altitude (Jet) Route: The designated route between VOR (very high frequency omnidirection radio) or VORTAC stations for aircraft flying between 5486 m or 5.5 km (18,000 ft) mean sea level (MSL) and 13,716 m or 13.7 km (45,000 ft) MSL.

IFR Flight: As defined by the FAA, flight conducted in accordance with Instrument Flight Rules.

Immediately Dangerous to Life or Health (IDLH): The maximum concentration of a (chemical) substance in air from which healthy male workers can escape without loss of life or irreversible health effects under conditions of a maximum 30-minute exposure time.

Impact Frequency: The frequency, per unit time, of an aircraft impacting a facility of interest.

In-flight Flight Phase: Refer to “Flight Phase” for definition.

Jet Route: Same as high altitude route.

Landing Flight Phase: Refer to “Flight Phase” for definition.

Leakpath Factor: The fraction of the radionuclides in the aerosol transported through some confinement deposition of filtration mechanism.

Level of Concern: The concentration of an extremely hazardous substance in air above which there may be serious irreversible health effects or death as a result of a single exposure for a relatively short period of time.

Local Response or Damage: Penetration and spalling, scabbing, punching shear, and perforation of building structural components (e.g., a wall or floor) that may not result in the overall failure or collapse of the whole building structure.

Low Altitude (Victor) Route: The designated route between VOR or VORTAC stations for aircraft flying at or below 5486 m or 5.5 km (18,000 ft) MSL.

Material at Risk (MAR): The amount of radionuclides available to be acted on by a given physical stress.

Military Aviation: As used in this standard, the aircraft category pertaining to any aircraft activity performed by the U.S. Air Force (USAF), U.S. Navy (USN), U.S. Marine Corps (USMC), U.S. Army (USA), and the U.S. Coast Guard (USCG).

Missile: A general term used to denote both primary and secondary missiles. See also “primary missile” and “secondary missile.”

Near-Airport Analysis: The aircraft crash impact frequency analysis involving the airport flight phases (takeoff and landing) for aircraft using airports within specified distances from a facility.

Nonairport Analysis: The aircraft crash impact frequency analysis involving aircraft in the in-flight flight phase.

Pattern Side: A well-defined side of the runway at a military airport where the downwind leg of landings, touch-and-goes, etc. take place. A pattern side could also be present at a civilian airport if that airport is used for military aviation.

Penetration: A local damage that signifies displacement of the missile into the target and is a measure of the depth of crater formed at the zone of impact.

Perforation: A local damage that signifies that the missile fully penetrates the target or passes through the target.

Primary Missile: An aircraft or a detached part of an aircraft (e.g., engine) that can hit a target directly from the air or after skidding on the ground.

Probability: A unitless quantitative measure of the likelihood of a given event with a value ranging from 0 to 1.

Punching Shear: Local shear failure occurring in the immediate vicinity of the impacted zone. Punching shear may occur as part of the perforation process.

REM: Acronym of roentgen equivalent man.

Respirable Fraction (RF): The fraction of airborne radionuclides as particles that can be transported through air and inhaled into the human respiratory system. These are commonly assumed to include particles 10µm Aerodynamic Equivalent Diameter (AED) and less.

Respirable Release Fraction: Product of airborne release fraction and respirable fraction.

Risk: The measure of a potentially hazardous event in terms of its likelihood and the severity of its consequences. Risk can be determined following the release analysis for specified aircraft crash scenarios that have been evaluated for both impact and structural response likelihoods. Prior to this step, risk is evaluated: first by inventory screening (risk's severity parameter) and then by frequency (risk's likelihood parameter).

SSC Functionality: As used in this standard, the function that a structure, system, or component (SSC) performs to ensure that no significant threat to the general public (from release of hazardous material) results from an aircraft crash accident.

Scabbing: A local damage that signifies the peeling off (or ejection) of material from the back face of the target.

Scenario: A succession of specified events beginning with an initiating event, followed by other events (such as failures of structures or systems), and ending with the release of hazardous material.

Secondary Missile: A part of the breakaway aircraft segments or a facility SSC (e.g., a chimney structure) that becomes detached as a result of the impact of a primary missile on a facility.

Spalling: A local damage that signifies the ejection of target material from the front face of the target.

Structures, Systems, and Components (SSCs): Buildings; building components (e.g., a roof slab or wall); other structures (e.g., tanks, bunkers); mechanical or electrical systems (e.g., a heating, ventilating, and air conditioning [HVAC] system or a cable-tray system); and mechanical or electrical components or equipment (e.g., a motor control center or a pump). In this standard it is generally used to refer to SSCs whose failure as a result of aircraft crash could result in a release of hazardous material.

TACAN: Tactical Air Navigation, a military aviation navigational aid.

Takeoff Flight Phase: Refer to “Flight Phase” for definition.

Target: A facility, SSC, or other structure under evaluation that has the potential to be impacted by an aircraft or aircraft-generated missile where such impact could ultimately lead to a release of hazardous material.

Threshold Quantity (TQ): The quantity of a hazardous chemical below which exposure screening or evaluation is not necessary.

VFR Flight: As defined by the FAA, flight conducted in accordance with Visual Flight Rules.

VOR: As defined by the FAA, very high frequency omnidirection radio range. Used as a basis for navigation in the national airspace system.

VORTAC: As defined by the FAA, a navigation aid providing azimuth and distance measuring equipment at one site. A combination of VOR and TACAN navigational aids.

Victor Route: Same as low altitude route.

3. GENERAL IMPLEMENTATION GUIDANCE.

This chapter provides an overview of the approach described in this standard. The approach is summarized in the flowchart in Figure 1. The flowchart depicts an approach that provides maximum flexibility in implementing this standard. The components of the approach are modular, so they may be used in a different order and still be applicable. For example, a facility that is located relatively far from airports with limited operations may decide that the best route through the approach is to begin with impact frequency evaluation. Likewise, a facility with a low quantity of hazardous material may decide to start with exposure screening. In fact, the analyst is not limited to these selections and can start the implementation anywhere in the flowchart. The chronological order of activities presented in Figure 1 is believed to provide the most efficient method for implementing the approach.

As can be seen by the boxes in Figure 1, the approach consists of three distinct phases, which aim to answer the following three questions:

Phase I:	Does the total hazardous material in the facility pose a threat to the public?
Phase II:	Does aircraft crash impact pose a threat to the facility?
Phase III:	What is the extent of the threat posed to the facility and the public?

The steps in the first phase are intended to determine whether the facility in question contains sufficient inventory of hazardous radioactive or chemical material to pose a potential hazard if an aircraft crash could result in the release of the available material. If the steps in this phase indicate that the facility contains sufficient inventory to pose such a hazard, then the analysis moves to the second phase. The second phase is intended to demonstrate whether an aircraft crash poses a significant threat of release from the facility. This phase primarily considers whether the frequency of aircraft impact into the facility is significant and whether those aircraft that have a high impact frequency could actually do damage to the facility. If the steps in this phase indicate that aircraft crash poses a threat of release from the facility, the analysis moves to the third phase. The third phase comprises a “graded” analytical approach for assessing the extent of the damage to the facility, the extent of any release associated with the damage, and the exposures associated with the release. In this context, a “graded” analysis means performing the steps in this phase to the extent necessary to (1) understand the level of threat posed by an aircraft crash and (2) provide sufficient information to allow the facility operator to determine the need for (and type of) preventive and/or mitigative measures.

Another key aspect of the approach is that it must be integrated with the analysis of other potential facility safety hazards. While the adverse effects of aircraft impact on safety-related structures systems or components (SSCs) are being evaluated, the effect of the failure of nonsafety-related SSCs (due to aircraft impact) on the safety-related SSCs, if any, should also be evaluated.

The consideration of aircraft crash is not an independent safety assessment. This concept is illustrated in Figure 1 by the inputs to the various steps from facility design, operation, and safety documentation. The analysis of aircraft crash should not be addressed outside the context of this other information.

The individual steps in the analysis are briefly described in this section. Each subsection provides a list of inputs to and outputs from the analytical steps. The sources of inputs are identified as follows:

a. Available - Information that should be available in other documents describing the specific facility and its operation. Such information is generally not specific to aircraft crash analysis and can be readily located by an analyst. Whenever information is indicated as available, a potential source of that information is indicated.

b. Defined - Information that exists in this standard, its supporting documents, or a technical document referenced by this standard. Such information is generic in nature (i.e., it is not a function of the specific facility being analyzed) and is intended to be accepted as a given in the analysis (e.g., a constant to be used in an equation).

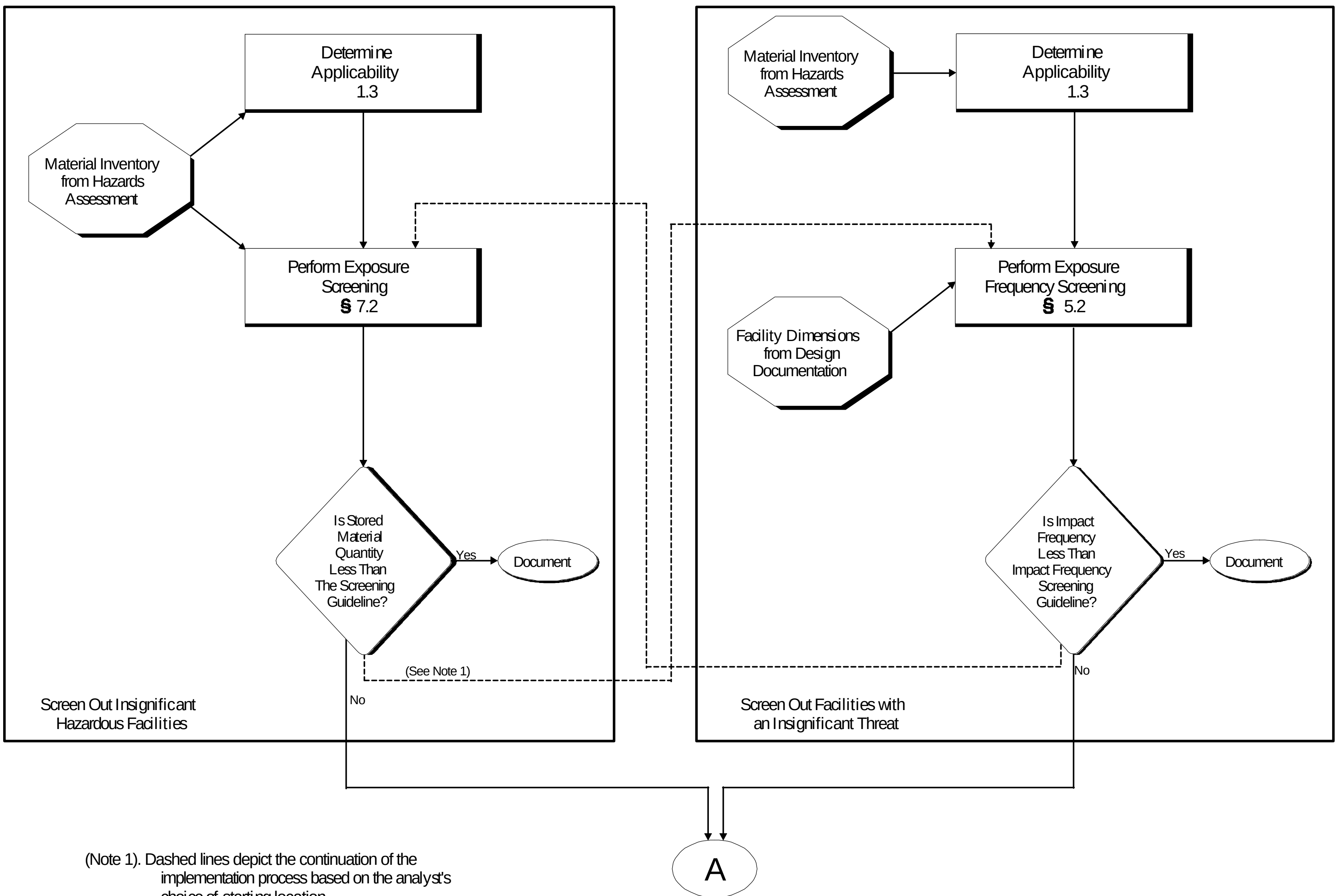

FIGURE 1. Flowchart implementing the standard

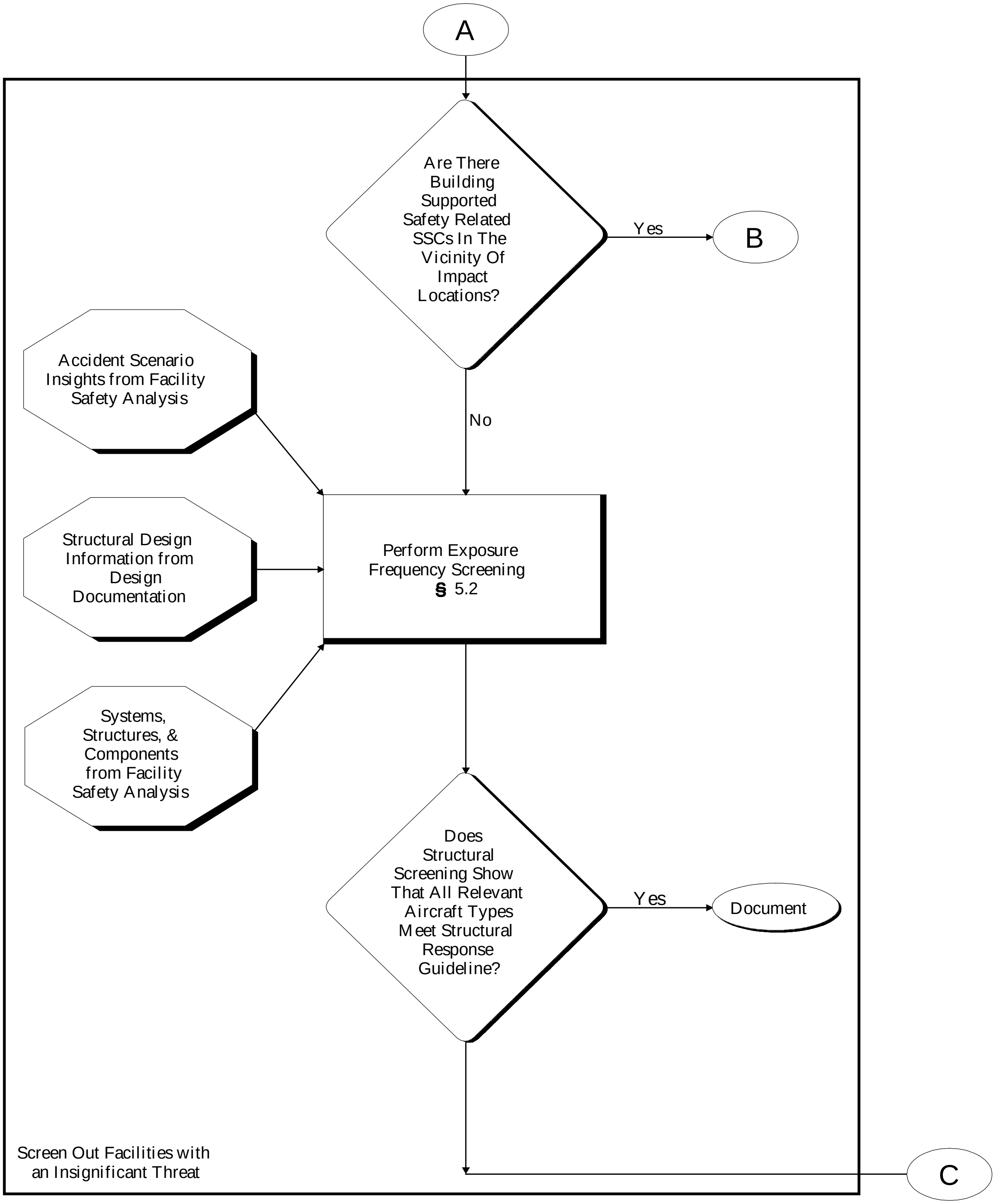

FIGURE 1. Flowchart implementing the standard

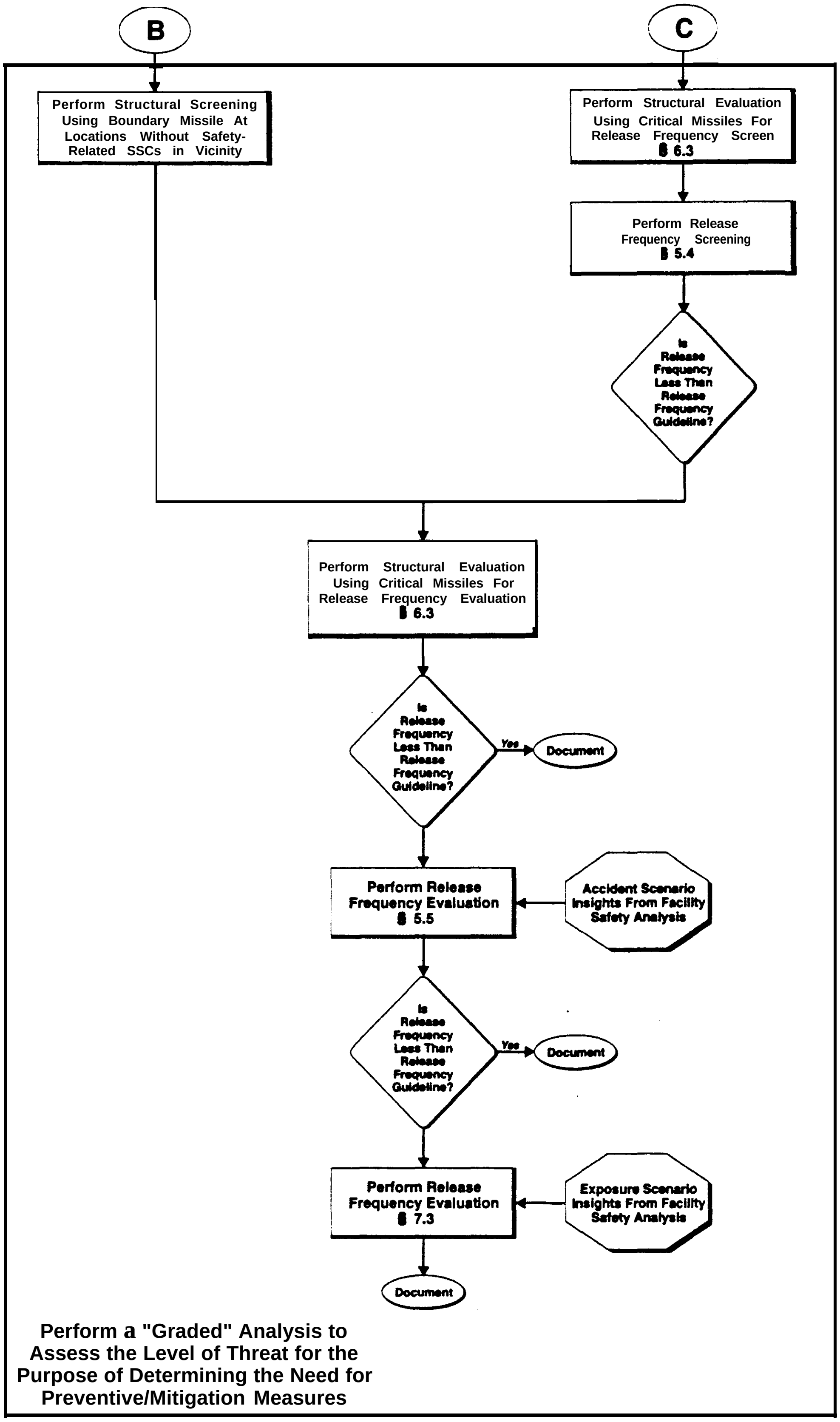

FIGURE 1. Flowchart implementing the standard

c. Data - Information that is specific to the facility being analyzed but is unlikely to have already been compiled in other documents. Such information is generally needed only for aircraft crash analysis and would therefore not be readily available unless a previous analysis has been performed.

d. Derived - Information that results from the application of this standard. Generally, a derived input was an output of one of the previous steps of the analysis.

3.1 Exposure Screening. Exposure screening consists of performing a simplified, conservative analysis of the potential hazardous material exposure to any member of the public resulting from an aircraft crash into a facility. For the purpose of this screening, it is assumed that the building is destroyed and all of the hazardous material available in the building is impacted; conservative values for the amount of material that can be transported and ingested are used, and it is assumed that the most direct and harmful path is taken to the site boundary. Exclusions of well-confined material from the hazardous materials inventory may be made, but should be justified on the basis of the robustness of the material containment in a postulated aircraft impact environment. The purpose of this step is to determine whether there is sufficient hazardous material inventory in the facility that the worst possible release could cause measurable harm to a member of the public (or, in certain cases, to a worker near the facility). The guidelines (given in Section 4.1) are expressed in terms of a dose (for radioactive materials) or a concentration (for chemical hazards) to the maximally exposed individual at or beyond the site boundary. The methodology for the analysis is provided in Section 7.2.

The result of the analysis allows the analyst to determine what amount of radioactive or hazardous chemical material would have to be present in the facility to exceed the guidelines at or beyond the site boundary (see Chapter 4). The analyst can then determine whether the facility inventory would exceed those guidelines. If the facility inventory does not exceed the thresholds, the risk is deemed to be small and the results are documented. If the facility inventory does exceed the thresholds, the analysis should proceed to the next step.

Inputs:

a. The exposure screening guidelines. (Defined)

b. The amount and form of hazardous material contained in the facility. (Available from existing facility design and operation documents)

c. The distance from the facility to the site boundary. (Available from existing facility site drawings)

Outputs:

a. The amount of material that would have to be present in the facility to create the potential for site boundary exposure guidelines to be exceeded.

3.2 Impact Frequency Evaluation. The impact frequency evaluation consists of performing a conservative assessment of the expected frequency per year of an aircraft impacting a facility of interest. This evaluation takes into account the site-specific and crash-specific parameters that affect aircraft impact frequency. No assessment is made of the severity of the postulated aircraft impact into the facility, nor are the specific aircraft types identified as part of the analysis. However, these data are available if, after this evaluation, structural response analysis is required. The results of the impact frequency evaluation are expressed in terms of the annual impact frequency for the facility of interest. The requirements for the impact frequency evaluation are provided in Section 5.3. The calculated total annual impact frequency (summed over all aircraft categories) is compared to the impact frequency evaluation guideline provided in Section 4.2. If the guideline is not exceeded, the results are documented. If the guideline is exceeded, the analysis should proceed to the next step.

Inputs:

a. The impact frequency evaluation guideline. (Defined)

b. A list of the applicable flight sources within specified distances from the facility. (Data)

c. A list of aircraft categories/subcategories for each applicable flight source. (Data)

d. The estimated number of operations per year at each source, for each candidate aircraft category/subcategory, and flight phase. (Data)

e. The representative crash probability for each candidate aircraft category/subcategory and flight phase. (Defined)

f. The crash location probability for each candidate aircraft category/subcategory and flight phase. (Defined)

g. The mean of the cotangent of the impact angle for each candidate aircraft category/subcategory and flight phase. (Defined)

h. The mean skid length for each candidate aircraft category/subcategory and flight phase. (Defined)

i. The facility/site dimensions. (Available from existing facility and site design documents)

j. Crash location expected frequency of an in-flight crash for each candidate aircraft category/subcategory. (Defined)

Outputs:

a. The annual impact frequency for each candidate aircraft category/subcategory.

b. The total annual impact frequency for all candidate aircraft categories/subcategories.

c. A list of aircraft categories/subcategories that contribute to exceeding the impact frequency evaluation guideline (if any).

3.3 Structural Screening and Evaluation.

3.3.1 Structural Screening. Structural screening consists of simplified but conservative structural evaluation of the facility using two bounding missiles, one for building local damage evaluation and the other for building collapse evaluation (Section 6.2). If this evaluation indicates that the building components meet the structural screening guidelines (Section 4.3) for all impact locations and if there is no safety-related equipment supported from the building structure in the vicinity of the postulated impact, the risk is deemed small and the results are documented. If the guidelines are exceeded for any impact location or if there is any safety-related equipment in the vicinity of the postulated impact, the analysis should proceed to the next step.

Inputs:

a. The structural screening guideline. (Defined)
b. Mass (for aircraft and aircraft engine) and speed data for the candidate aircraft categories/subcategories identified in Section 3.2. (Defined partially in References 1 and 2 of Chapter 5)
c. Structural design information for the facility. (Available from existing facility design documents)
d. A list of building-supported equipment whose failure could result in a release (safety-related equipment) and its locations. (Available from existing facility safety analyses)
e. The location of hazardous material within the facility and accident scenario information. (Available from existing facility design, operation, and safety analysis documents)

Outputs:

a. A list of impact locations and/or aircraft categories/subcategories that can be screened out from further evaluation.

3.3.2 Structural Evaluation. The structural response evaluation step consists of determining the type and extent of damage (local damage, excessive structural deformation, and/or SSC functional failure due to vibration) to the facility when subjected to impacts from aircraft subcategories that were identified in the previous step as contributing to an annual impact frequency greater than the frequency guideline. The results of the response analysis are reported as the damage status for systems and structures, including confinement barriers, meaning the level of damage an aircraft causes. In the case of individual components, the damage status is limited to operable/nonoperable. Each aircraft subcategory may be represented by a surrogate aircraft design for the purpose of structural response evaluation. This surrogate aircraft design provides design parameters such as aircraft mass, mass distribution, impact velocity, crosssectional area of missile, and impact angle. These parameters reasonably represent the important characteristics of the aircraft types that are included in the subcategory. Alternatively, one or more critical aircraft may be selected, considering all contributing aircraft subcategories for the particular site. Guidelines for selecting these critical aircraft are provided in Chapter 6, along with guidelines for selecting critical impact locations and impact angles. Interactions between safety and nonsafety systems, structures, and components are also considered. If the structural response evaluation indicates that the facility (including any equipment supported by the structure) meets the structural response evaluation guidelines (Section 4.3) for all impact locations of all aircraft subcategories considered, the risk is deemed small and the results are documented. If the guidelines are exceeded for any impact location and for any of the aircraft subcategories considered, the analysis should proceed to the next step.

Inputs:

a. The structural response evaluation guideline. (Defined)
b. Design information for the representative aircraft used as a surrogate for the aircraft types contained in the aircraft subcategory (mass, speed, angle of impact, mass distribution, etc.). (Defined)
c. A list of aircraft subcategories that contribute to exceeding the impact frequency evaluation guideline. (Derived)
d. Structural design information for the facility. (Available from existing facility design documents)
e. A list of, and design information about, SSCs whose failure could result in a release. (Available from existing facility safety analyses)
f. The location of hazardous material within the facility and accident scenario information. (Available from existing facility design, operation, and safety analysis documents)

Outputs:

a. A list of aircraft types or subcategories whose impact into the facility could result in facility damage (if any) potentially leading to a release.

b. For each of these aircraft types or subcategories, the impact locations that could result in such facility damage.

c. For each such impact location, the level of damage that would result from an impact, including (1) location and depth of penetration, (2) identification of structural failures, (3) path and final location of missiles, (4) post-crash location of fuel tanks, and (5) damage status of SSCs of concern.

3.4 Release Frequency Screening. The release frequency screening is a simple, conservative calculation. For this analysis, an aircraft category is considered to have no effect on a facility only if no impact results in structure damage (i.e., damage does not exceed the structural response guideline). Thus, if any impact from a given aircraft subcategory will cause a release, then it is assumed that all impacts from that aircraft subcategory will result in a release. Any aircraft subcategory considered to have no effect on the facility is deleted from further consideration in the analysis. The release frequency is calculated by summing the impact frequencies for all remaining aircraft subcategories. Note that this calculation includes the impact frequencies of any aircraft subcategories that have not been subject to a structural response analysis, unless it can be documented that they will not cause sufficient damage to cause a release. The methodology for the analysis is provided in Section 5.4. This result is compared to the release frequency screening guideline provided in Section 4.4. If the guideline is not exceeded, the results are documented. If the guideline is exceeded, the analysis should proceed to the next step.

Inputs:

a. The release frequency screening guideline. (Defined)

b. A list of aircraft subcategories subjected to structural response analysis. (Derived)

c. The annual aircraft impact frequency for all aircraft subcategories. (Derived)

d. Accident scenario information. (Available from existing facility safety analysis documents)

Outputs:

a. The total annual impact frequency for those aircraft categories/subcategories that have not been shown to have no effect on the facility, i.e., those aircraft subcategories that could result in facility damage affecting hazardous material or its confinement (i.e., the initial release frequency)

3.5 Release Frequency Evaluation. The release frequency evaluation step is a refinement that takes into account the fact that not all impacts from aircraft subcategories that damage the facility will necessarily result in a release. This process considers how much of the facility is damaged, whether the hazardous material available in the facility is impacted or affected through secondary mechanisms, and (to a limited extent) what release mechanisms impact the material. For each impact location that results in damage, the structural analysis has already provided the extent of that damage (the "damage level"). Each of these damage levels would now be converted into an event scenario to determine whether a release could actually occur. For each scenario, the frequency of the aircraft impact would be modified to account for the fraction of the overall facility area to which that level of damage applies. The release frequency is calculated by summing the event scenario frequencies for all event scenarios that are determined to lead to an actual release. The methodology for the analysis is provided in Section 5.5. This result is compared to the release frequency evaluation guideline provided in Section 4.5. If the guideline is not exceeded, the results are documented. If the guideline is exceeded, the analysis should proceed to the next step.

Inputs:

a. The release frequency evaluation guideline. (Defined)

b. The list of aircraft subcategories whose impact into the facility could result in facility damage potentially leading to a release. (Derived)

c. The annual impact frequency for each such aircraft subcategory. (Derived)

d. For each of these subcategories, the impact locations that could result in such facility damage. (Derived)

e. For each such impact location, (1) the extent of local and global damage and depth of penetration, (2) identification of structural failures, (3) path and final location of missiles, (4) location of fuel, and (5) damage status of safety-class SSCs. (Derived)

f. Accident scenario information. (Available from existing facility safety analysis documents)

Outputs:

a. Release scenarios for each of the aircraft subcategory impact locations that could result in damage that could lead to a release (or a finding that no release would actually occur).

b. For each release scenario, the fraction of the facility area and/or skid area where the aircraft impact could lead to the scenario.

c. The annual frequency of each such release scenario and the total of all such frequencies (i.e., the final release frequency).

d. A list of the release scenarios that contribute to the total annual release frequency exceeding the release frequency evaluation guideline (if any).

3.6 Exposure Evaluation. Exposure evaluation consists of performing a detailed but still conservative analysis of the potential hazardous material exposure to any member of the public (and, where appropriate, to onsite workers) resulting from an aircraft crash into the facility. The results of the release frequency evaluation (for those scenarios that could result in a material release) are used to define the specific source term and exposure scenarios. This process considers how much of the facility is damaged, how much of the hazardous material available in the facility is affected, what release mechanisms affect the material, how much of the material is converted into a form that can be absorbed into the body and do harm, and what energy is associated with the release. The result of this analysis is expressed as a dose (for radioactive materials) or a concentration (for chemical hazards) to the maximally exposed individual at or beyond the site boundary. The methodology for the analysis is provided in Section 7.3. Once this step is accomplished, the analysis required under this standard is complete and the results are documented.

Inputs:

a. The list of the release scenarios that contribute to the total release frequency exceeding the release frequency evaluation guideline. (Derived)

b. The frequency of each such release scenario. (Derived)

Outputs:

a. The hazardous material source term for each of the listed release scenarios.

b. The exposure level to the maximally exposed individual at or beyond the site boundary for each of the listed release scenarios.

3.7 Further Analysis. No further analysis is envisioned by this standard. In the vast majority of cases, analysis taken to this point should provide sufficient information and insights upon which to base decisions regarding the need for preventive or mitigative actions to reduce risk from aircraft crash. However, the standard recognizes that this may not always be the case, and therefore does not preclude further analysis. Such an analysis would likely be a formal probabilistic risk assessment incorporating features such as evaluation of crash/impact/release frequencies and structural response by specific aircraft type (rather than subcategory), development of probabilistic fragility curves for structural response, and quantification of distributions representing the analyst's state of knowledge concerning total population exposures, health effects, and cleanup area associated with the release scenarios. Guidance on the methods for performing such additional analysis is beyond the scope of this standard.

4. SCREENING AND EVALUATION GUIDELINES.

This chapter provides the numerical screening and evaluation guidelines referred to in Chapter 3. These guidelines are used to determine at what stage in the approach the analysis is sufficient. It is extremely important to note that these guidelines were developed in full consideration of and integration with the analytical requirements and methodologies presented in this standard. Thus, they are only valid when used in conjunction with those requirements and methodologies (e.g., the atmospheric conditions specified in this standard should be used). In order to utilize the guidelines in this standard to apply a graded approach to accident analysis, the conservatisms embedded in alternative approaches should be equivalent to those in the standard; otherwise, the guidelines do not provide a valid comparison with the results of the alternative approach.

4.1 Exposure Screening Guidelines. The results of the exposure screening step will be compared to the following guidelines for exposure to the maximally exposed offsite individual:

a. Radiological exposure - 25 rem (0.25 Sv) committed effective dose equivalent (CEDE);

b. Hazardous material exposure - Emergency Response Planning Guidelines - Level 2 (ERPG-2), as established by the American Industrial Hygiene Association (AIHA); or

c. Hazardous material exposure where ERPG-2 has not been established - the Level of Concern established by the U.S. Environmental Protection Agency (EPA) specified in the 1987 EPA *Technical Guidance on Hazards Analysis* (or a successor document).

Generally, dose to the maximally exposed offsite individual is deemed to be a sufficient measure of potential hazard from aircraft crash. However, there may be special circumstances in which exposure to onsite workers located outside the facility needs to be considered (see discussion in Appendix A, Section A.1). In those rare cases, the following additional screening guidelines may be applied:

d. Radiological exposures - the facility inventory exceeds 25 times the Hazard Category 2 threshold quantities provided in DOE-STD-1027-92;[2]

e. Hazardous material exposure - Emergency Response Planning Guidelines - Level 3 (ERPG-3), as established by the AIHA to the maximally exposed worker located at or beyond 300 m (984 ft) from the facility; or

f. Hazardous material exposure where ERPG-3 has not been established - the Immediately Dangerous to Life and Health (IDLH) criteria specified in the latest National Institute of Occupational Safety and Health (NIOSH) recommendation (or a successor document) to the maximally exposed worker located at or beyond 300 m (984 ft) from the facility.

4.2 Impact Frequency Evaluation Guideline. The results of the impact frequency evaluation step will be compared to the following guideline for the frequency of aircraft impact:

a. Frequency of aircraft impact into a facility from all types of aircraft - 1E-6/y.

4.3 Structural Screening and Evaluation Guideline. The results of the structural response calculation will be compared to the following guidelines for various types of damage:

a. Local damage to reinforced concrete targets:

1. scabbing - to prevent scabbing, required wall thickness is 110 percent of the predicted scabbing thickness;

[2] Threshold quantities for criticality are not used for comparison to the facility inventory, since the comparison is based on dose.

2. perforation - to prevent perforation, required wall thickness is 120 percent of the predicted perforation thickness;

3. punching shear - to prevent punching shear failure, the predicted punching shear stress should not exceed four times the square root of the compressive strength of concrete (f'_c) at the perimeter one-half the effective depth away from the load, unless higher values can be justified using Long's formula given in Appendix C, Section C.6.3.2.1.3.

b. Local damage to steel targets:

1. penetration - to prevent perforation of a steel target, the minimum wall thickness required is at least 125 percent of the predicted penetration depth.

c. Excessive structural deformation or collapse:

1. for concrete structural components - permissible ductility ratios as specified in American Concrete Institute (ACI) Code 349;

2. for steel structural components - permissible ductility ratios as specified in section Q1.5.8 of American Institute of Steel Construction (AISC) Nuclear Specifications, American National Standards Institute (ANSI) N690.

d. Structure, system, and component (SSC) functionality:

1. for evaluation by analysis - up to code allowable acceptance criteria given in American Society of Civil Engineers (ASCE-4), American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Institute of Electrical and Electronic Engineers (IEEE)-344, and NUREG-0800, as specified for safety-related SSCs;

2. for evaluation by testing - using the instructure spectra generated from transient response analysis, following the methods described in IEEE-344.

4.4 Release Frequency Screening Guideline. The results of the release frequency screening step will be compared to the following guideline for the frequency of hazardous material release:

a. Frequency of hazardous material release due to an aircraft impact into a facility from all types of aircraft - 1E-6/y.

4.5 Release Frequency Evaluation Guideline. The results of the release frequency evaluation step will be compared to the following guideline for the frequency of hazardous material release:

a. Frequency of hazardous material release due to an aircraft impact into a facility from all types of aircraft - 1E-6/y.

5. METHODOLOGY FOR EVALUATING AIRCRAFT CRASH IMPACT AND RELEASE FREQUENCY

5.1 Introduction. This chapter establishes a set of guidelines and methods for calculating and analyzing the impact frequency of aircraft crashes into a facility and the release frequency for radioactive and/or hazardous materials. The approach to analyzing frequency is divided into three parts:

a. Impact Frequency Evaluation: The fundamental analysis, based on estimating the frequency of aircraft crashes into a facility. This provides basic frequencies for subsequent screening and evaluation analyses.

b. Release Frequency Screening: An analysis based on including the structural response evaluation in the impact frequency evaluation.

c. Release Frequency Evaluation: An analysis based on developing release scenarios from the time of an aircraft crash until the time exposure occurs due to the release of hazardous material.

The method used to estimate the frequency in each part is based on the same technical principle; however, each part consists of varying degrees of complexity and conservatism. After each part is completed, the results are compared with the guideline value given in Chapter 4. If the result exceeds the guideline value, then additional analyses are performed; otherwise, no further work is required beyond documenting the analysis.

The technical information provided in this chapter covers only the basic guidelines for implementing the three parts, along with a description of the frequency estimation models and the corresponding important input parameters for each model. Further technical information required to perform the analysis is provided in Appendix B.

Detailed technical evaluations that support the development of each frequency model are provided in the modeling and data technical support documents (References 1 and 2). These support documents should be consulted if additional information on the specifics of each method is needed. Neither this standard nor the modeling and data technical support documents contain site-specific information; rather, they provide guidance on what site-specific information is necessary and how to develop it.

Aircraft crash frequencies are estimated using a "four-factor formula" which considers (1) the number of operations, (2) the probability that an aircraft will crash, (3) given a crash, the probability that the aircraft crashes into a 1-square-mile area where the facility is located, and (4) the size of the facility. In this standard, the four-factor formula is implemented in two different ways, depending on the flight phase:

a. For near-airport activities, which consist of takeoffs ($i=1$) and landings ($i=3$), the four-factor formula is implemented through a combination of site-specific information and data obtained by the user of the standard, and a set of tables (whose origins are discussed in Reference 2) provided in Appendix B of this standard.

b. For nonairport activities ($i=2$), DOE site-specific values, as well as reasonable estimates applicable throughout the continental United States, for the expected number of crashes per square mile per year in the vicinity of the sites (i.e., the value of the product NPf(x,y)) are provided in Appendix B of this standard; the four-factor formula is implemented by combining these with the facility effective areas to assess frequencies.

Mathematically, the four-factor formula is:

$$F = \sum_{i,j,k} N_{ijk} \cdot P_{ijk} \cdot f_{ijk}(x,y) \cdot A_{ij} \qquad (5\text{-}1)$$

where:

F = estimated annual aircraft crash impact frequency for the facility of interest (no./y);

N_{ijk} = estimated annual number of site-specific aircraft operations (i.e., takeoffs, landings, and in-flights) for each applicable summation parameter (no./y);

P_{ijk} = aircraft crash rate (per takeoff or landing for near-airport phases and per flight for the in-flight (nonairport) phase of operation for each applicable summation parameter;

$f_{ijk}(x,y)$ = aircraft crash location conditional probability (per square mile) given a crash evaluated at the facility location for each applicable summation parameter;

A_{ij} = the site-specific effective area for the facility of interest that includes skid and fly-in effective areas (square miles) for each applicable summation parameter, aircraft category or subcategory, and flight phase for military aviation (see Appendix B);

i = (index for flight phases): i=1, 2, and 3 (takeoff, in-flight, and landing);

j = (index for aircraft category or subcategory): j=1, 2,..., 11;

k = (index for flight source): k=1, 2,..., K (there could be multiple runways, and nonairport operations);

$\sum_{ijk}$ = $\sum_k \sum_j \sum_i$; = site-specific summation over flight phase, i; aircraft category or subcategory, j; and flight source, k.

It should be noted that there is uncertainty associated with the frequency estimates produced using the four-factor formula, caused by the need to model complex physical processes using parameters that are based upon limited historical data. Experience-based judgements have been made as needed to supplement historical data, introducing additional uncertainties. This standard does not provide a quantitative estimate of the uncertainties involved; rather, the mathematical formulations and supporting parameter estimates have been made so as to provide a reasonable point estimate of the frequency of aircraft crash impacts into specified facilities.

5.2 Methodology for Impact Frequency Screening. Although the desirability of a simple impact frequency screen based on the number of operations at nearby airfields was recognized, the high value of the maximum expected frequency of an in-flight mishap resulting in an aircraft impacting an arbitrary square mile in the continental United States precluded the development of a useable impact frequency screening methodology.

5.3 Methodology for Impact Frequency Evaluation. This section describes the approach for implementing the impact frequency evaluation, using the four-factor formula as given in Equation 5-1. The following guidance provides a set of steps for calculating impact frequency. Steps 1 through 6 are for determining the impact frequency from airport operations; Steps 7 through 19 are for determining the impact frequency from nonairport operations (Steps 7-8 for general aviation, Steps 9-12 for commercial aviation, Steps 13-16 for military aviation; and Steps 17-19 for helicopters); and Steps 20 and 21 are for comparing the results with the guidelines.

An example of the use of these steps is included as Section B.5 of Appendix B.

5.3.1 Impact Frequency from Airport Operations.

Step 1. Identify the flight sources affecting the facility. To do this, identify any airports that can be located within the boundaries of the aircraft crash location probabilities (Tables B-2 through B-13). Contact these airports to get an estimate of the annual number of takeoffs and landings, N, for each aircraft category or subcategory. This information can usually be provided by the airport on a category basis. If the airport can only provide total operations and is not able to discriminate between operation activities, assume that one-half (50 percent) of the operations are takeoffs and one-half (50 percent) are landings. This assumption will result in very conservative numbers because total operations include activities other than takeoff and landing, such as an aircraft contacting the tower for a change of vector. Finally, have the airport identify the pattern side of the runway for military aviation, if applicable.

Step 2. For each flight source, determine the orthonormal distance (Cartesian distance, both x and y coordinates) from the facility, measured from the facility's closest point, to the center of each runway at the flight source (for guidance on determining the orthonormal distance see Appendix B, Section B.3.1, and the example in Section B.5).

Step 3. Given the orthonormal distance of the facility from each flight source, obtain the generic aircraft crash location probability per square mile, i.e., f(x,y), for takeoff and landing for each aircraft category/subcategory. This information is included in Appendix B as Tables B-2 through B-13. If the orthonormal distance of a facility falls outside the boundaries of these tables, the corresponding f(x,y) is assumed to be zero (a noncontributor).

Step 4. Obtain the aircraft takeoff and landing crash rates, P, for each aircraft category or subcategory. This information is provided in Table B-1 of Appendix B.

Step 5. Calculate the effective area, A, for each aircraft category or subcategory. The calculation of the effective area consists of two components: the aircraft can crash into the structure either by skidding or by flying directly into it. To calculate the effective area, assume that the aircraft skids or flies into the structure in the direction that produces the largest area, i.e., crashing in a direction perpendicular to the largest diagonal of the building. The formula for calculating the skid- and fly-in areas of an aircraft crashing into a facility are provided as Equations B-3 through B-5 in Section B.4 of Appendix B. The effective area is a function of the cotangent of the impact angle, wingspan, and skid distance of the crashing aircraft. Values of these parameters are given in Section B.4 of Appendix B.

Step 6. Multiply the values for N, P, f(x,y), and A for each combination of flight source, flight phase, and aircraft category/subcategory. Sum over flight sources and flight phases to calculate an impact frequency for each aircraft category/subcategory. (Do not sum the categories yet; this will be included in a later step.)

5.3.2 Impact Frequency from Nonairport Operations. Even though the expected frequency of aircraft crashes into a facility due to mishaps occurring during the in-flight phase of operation, is expected to be lower than the frequency associated with airport operations, the expected frequency cannot be shown to be a noncontributor to the overall frequency for all facilities. Thus, nonairport operations must be considered in the impact frequency analysis.

The analysis of the nonairport operations impact frequency for all categories of aircraft is based on the same four-factor formula (Equation 5-1) as is used for airport operations; i.e., the frequency, F_j, for the class of aircraft, j, is

$$F_j = N_j \cdot P_j \cdot f_j\,(x,y) \cdot A_j \qquad (5\text{-}2)$$

where the product NP represents the expected number of in-flight crashes per year; f(x,y) is the probability, given a crash, that the crash occurs in a 1-square-mile area surrounding the facility of interest; and A is the effective area of the facility. Ideally, values for NP and f(x,y) would be provided for any location within the continental United States (CONUS), similar to those provided for airport operations. However, this is impractical because of the large area of the CONUS. For this standard, values of the product NPf(x,y) applicable to selected DOE sites are provided in Tables B-14 and B-15. Also included are minimum, U.S. average, and maximum values, which can be used for facilities at other locations within the CONUS, for each category of aircraft.

Development of the values in the tables is based on an analysis of the locations of past aircraft crashes within the CONUS. For general aviation, this record is substantial (over 1000 crashes) while the available data for other aircraft categories/subcategories, e.g., air carrier and large military, are very limited. Discussion of the bases of the values in Tables B-14 and B-15 and an outline of the analysis steps follow.

a. <u>General Aviation</u>. The distribution of general aviation (GA) aircraft crashes throughout the CONUS is based on GA aircraft flying under both VFR and IFR conditions. Except for certain restrictions, e.g., restricted airspace, a GA aircraft can fly almost anywhere in the CONUS. In addition, once an in-flight mishap does occur, with an eventual loss of control, there is nothing to prevent a disabled aircraft from crashing into any location, even within a restricted airspace area. Thus, it is reasonable to assume that GA aircraft can crash anywhere in the CONUS.

Crash location probabilities for GA aircraft are based on the assumption that future levels of GA aircraft activity and flight patterns will be similar to the historical record. The model for estimating the distribution of GA aircraft crash locations uses historical locations as the most likely but assumes that future locations will deviate within some area about the historical locations.

Several models of the variation of future crash locations based on different hypotheses formed the basis for conducting a parametric study of the product NPf(x,y). The models and the associated sensitivity studies are discussed in Reference 1. The DOE site-specific values provided in Table B-14 of Appendix B represent reasonably conservative estimates obtained through a collective consideration of the sensitivity study results.

Step 7. Refer to Appendix B, Table B-14, and obtain the appropriate site-specific or generic value for NPf(x,y).

Step 8. Multiply the value of NPf(x,y) by the corresponding value for A determined in Step 5. This is the estimated GA nonairport impact frequency.

b. Commercial and Military Aviation. Nonairport commercial and military impact frequency calculations are based on the assumption that the aircraft will fly point to point under the new FAA regulations rather than in specific airways. The values of NPf(x,y) in Table B-15 are derived from values developed for the ARTCC spanning the CONUS. The model assumes that the traffic density within an ARTCC is uniform and, given a crash in the ARTCC, the location of the crash is random.

For commercial and large military aviation, crashes are assumed to occur at random throughout the CONUS, and the variation in traffic volume is reflected by the variation in the number of aircraft handled in each ARTCC. For small military aviation, the number of crashes varies among the ARTCCs. Thus, the expected number of crashes per year is estimated for each ARTCC based on the distribution of crash locations in the historical record.

Table B-15 in Appendix B provides reasonable estimates of NPf(x,y) for selected DOE sites, as well as estimates of a minimum, average, and maximum value applicable for facilities at other locations within the CONUS.

It is important to recognize that the in-flight analysis for military aviation given below only applies to normal in-flight operations outside military operations areas and low level flight ranges. For facilities at or near these latter types of areas, it is necessary to perform a site-specific assessment of the impact frequencies associated with activities in these areas.

The analyses for each of the commercial and military subcategories are as follows:

1. Commercial Aviation Air Carrier.

Step 9. Refer to Appendix B, Table B-15, and obtain the appropriate site-specific or generic value of NPf(x,y).

Step 10. Multiply the value of NPf(x,y) by the A value determined for air carriers in Step 5.

2. Commercial Aviation Air Taxi.

Step 11. Refer to Appendix B, Table B-15, and obtain the appropriate site-specific or generic value for NPf(x,y).

Step 12. Multiply the value NPf(x,y) by the A value determined for air taxis in Step 5.

3. Large Military Aviation.

Step 13. Refer to Appendix B, Table B-15, and obtain the appropriate site-specific or generic value for NPf(x,y).

Step 14. Multiply the value NPf(x,y) by the takeoff effective area value, A, determined for large military takeoff in Step 5. The takeoff effective area, A, is used because it more closely represents in-flight crashes.

4. Small Military Aviation.

Step 15. Refer to Appendix B, Table B-15, and obtain the appropriate site-specific or generic value for NPf(x,y).

Step 16. Multiply the value NPf(x,y) by the takeoff effective area value, A, determined for small military takeoff in Step 5. The takeoff effective area, A, is used because it more closely represents in-flight crashes.

c. Helicopter Aviation. Based on an analysis of historical helicopter crash data, the contribution to impact frequencies associated with nonlocal helicopter overflights is insignificant and need not be considered in the impact frequency calculations. However, it is necessary to consider local overflights, either planned overflights associated with the facility operations, e.g., security flights, or flights associated with area operations, e.g., spraying flights. Thus, the calculation of in-flight helicopter impact frequencies is a site-specific calculation. For application of this standard, each facility needs to obtain (1) the expected number, N, of helicopter local overflights per year; (2) the average length, L, in miles, of the flights corresponding to the site-specific overflights; and (3) the effective area for helicopter in-flight crashes, using Equation B-4, assuming an impact angle of 60 degrees, i.e., cotϕ = 0.58 (note skid length is assumed to be 0). For these calculations, as shown in Equation 5-3, the lateral variations in crash locations for a helicopter are conservatively assumed to be one-quarter a mile on the average from the centerline of its flight path.

The analysis for helicopter impact frequency calculations is as follows:

Step 17. Obtain N_H, the expected number of local helicopter overflights per year, and L_H, the average length of a flight.

Step 18. Compute the effective area, A_H, using Equation B-4.

Step 19. Using the values of the probability of a helicopter crash per flight, P_H, in Table B-1 in Appendix B, compute the helicopter impact frequency, F_H.

$$F_H = N_H \cdot P_H \cdot \frac{2}{L_H} \cdot A_H \tag{5-3}$$

5.3.3 Calculated Impact Frequency.

Step 20. Sum the calculated impact frequency for airport and nonairport operations for each aircraft category or subcategory. For example, add up all the general aviation impact frequencies calculated in Steps 6 and 8. Rank the impact frequencies for all aircraft categories/subcategories in decreasing order. Sum the impact frequencies over the aircraft categories/subcategories to get the total impact frequency for the facility of interest.

Step 21. If the total impact frequency is below the guideline value, the safety risk is below the level of concern; stop the analysis and document the results. If the total impact frequency is greater than the guideline value, it is necessary to identify the aircraft categories/subcategories to be used for the structural response and release frequency analyses. A certain amount of judgment is required in making this selection. It is recommended that the analyst interact with the facility structural engineers and/or analysts to identify a subset of those aircraft categories/subcategories that are significant contributors to the impact frequencies.

5.4 Methodology for Aircraft Crash Release Frequency Screening. The assessment of impact frequency, as evaluated above, assumes that all impacts will lead to facility damage and a possible release of radioactive or hazardous chemical material. This assumption is due to the lack of information about the response of the structure to impact during the impact frequency stage of the analysis. Following completion of the structural analysis, as described in Chapter 6, it is possible to determine the initial release frequency, which is the total impact frequency minus the impact frequencies of the aircraft categories/subcategories shown to have little or no effect on the facility, i.e., will not lead to a release. This section explains the process of calculating the initial release frequency using results from the structural analysis.

The approach for the initial release frequency analysis is to exclude those aircraft categories/subcategories that are known and/or shown by the structural response analysis to inflict little or no damage should they impact the facility. The major assumption in this analysis is that if any of the impact locations analyzed in the structural response analysis for a particular aircraft category/subcategory can be shown to cause sufficient damage to lead to release, then all impact locations will lead to a release. This simplifies the analysis. The screening is performed in the following steps:

Step 1. From the structural response analysis results, identify the aircraft categories/subcategories whose impact into the facility would result in little or no damage to the facility, i.e., would not result in a release.

Step 2. From the list of impact frequencies compiled for the impact frequency evaluation, delete the impact frequencies corresponding to the aircraft categories/subcategories identified in Step 1.

Step 3. Sum the impact frequencies for the remaining aircraft categories/subcategories. The calculated sum is the release frequency screening value.

Step 4. Compare the release frequency screening value to the guideline. If the guideline is met, the safety risk associated with aircraft impact is below the level of concern and no further analysis is needed; document the results. If the guideline is exceeded, proceed to the release frequency evaluation (Section 5.5).

5.5 <u>Methodology for Aircraft Crash Release Frequency Evaluation</u>. The release frequency screening does not take into account the fact that, even if a particular aircraft category or subcategory can cause damage that could potentially lead to a release, only certain impact locations will have that effect. By making better use of the structural analysis and the impact frequency calculations, the analyst can define specific release scenarios and estimate the frequency associated with those scenarios. This makes it possible to determine the extent to which the actual release frequency may be lower than the initial release frequency. This section addresses the evaluation process for making this determination.

For each impact location which is determined in the structural response analysis to exceed the structural response guideline, a release scenario associated with the level of damage resulting from the impact should be developed. The intent is to specify the most realistic conditions that can be justified. The scenario selected should be physically possible and rational within the physical constraints of the level of damage incurred (including the occurrence of process accidents as a result of system failures). Once it has been determined that a release can occur, the overall facility dimensions used to assess the impact frequency are replaced with a partial facility dimension representing the impact location (a new effective area) for the specific release scenario. The new effective area is input into the four-factor formula (Equation 5-1) for the appropriate aircraft subcategory, resulting in a revised impact frequency specific to the impact location being evaluated.

This process is performed on each of the impact locations that exceeds the structural response guidelines, following the steps listed below.

Step 1. From the results of the structural analysis, take the description of the level of damage. This description will provide a conservative estimate of the structural damage that has occurred, including the path and location of penetrators; the damage state of walls, barriers, and equipment; the location of the aircraft fuel; and other pertinent information, as described in Chapter 6.

Step 2. Assume that all available fuel burns, as well as any other combustibles that are in the path of the penetrators. Assume also that any high explosive material undergoes a high explosive violent reaction (HEVR). High explosive material includes such things as TNT, ion exchange resins, and the like, but not highly flammable materials that are subject to burning (i.e., prompt thermal releases) rather than true explosion (e.g., aircraft fuel, hydrogen gas). Note that this assumption pertains only to combustibles and explosives that are directly affected by the penetrators; that is, they are in areas or compartments that are actually breached by the penetrators.

Step 3. Evaluate the extent to which secondary effects cause the scenario to spread beyond the area directly damaged by the crash. Comprehensive guidance cannot be provided for this step because situations will vary greatly from facility to facility. However, these are some questions to consider:

- Is there sufficient combustible material to breach additional barriers and spread further through the facility? Remember that fire can also spread through ducts and along wiring conduits. Credit can be taken for the existence of fire barriers and breaks, if they have not been damaged by the crash. The basis for taking credit (e.g., short duration of the fire) should be documented. Therefore, a characterization of fire duration will almost certainly be required, although the level of detail will depend on how much sophistication is required to determine the duration of the fire relative to the capability of the fire barriers. Due to the difficulty of demonstrating that active systems can function following a crash, credit should not be allowed for fire suppression systems unless an explicit analysis shows that they will remain effective.

- Is the force of any explosion capable of causing further barriers to be damaged or destroyed? Can it cause additional fires and/or explosions in the facility? Again, credit can be taken for the dissipation of explosive energy by existing barriers, if they have not been damaged by the crash. Credit can also be taken for diversion of the explosive force through breaches caused by the crash, thus reducing the shock to intact barriers. The basis for taking credit should be documented. Again, characterization of the explosive force generated relative to barrier strength and the force transmitted to collocated explosives is required to justify the credit.

Step 4. Based on the findings of the previous step, determine if a release could occur, given the scenario as defined. Again, specific guidance cannot be provided, but the following questions should guide the analyst's thinking:

- Could any of the material at risk in the facility be impacted by any release mechanism (e.g., shock, fire, explosion) as a result of the scenario? The answer to this question should be “yes” if there is any material that is not separated from the energy available from the release mechanism by an intact barrier capable of dissipating that energy.

- Could the primary confinement around any of that material be breached as a result of the scenario? The answer to this question should be “yes” if the structural integrity of the primary confinement is degraded below that required under accident conditions and if there is a driving force capable of causing the material to migrate through the breach.

- Could a path to the atmosphere result from the scenario? The answer to this question should be “yes” if there are no longer any intact barriers between the material and the atmosphere, assuming that the primary confinement is failed and that there is a driving force capable of causing the material to migrate along the path.

In this context, the word "could" should be taken to mean "is it mechanistically possible, given the level of damage." The possibility that failures occurring away from the material could cause system failures resulting in process accidents should also be considered. Therefore, intersystem dependencies and support system interactions should be explicitly evaluated. If there is any doubt about the answer to any of the three questions listed in this step, the answer should be assumed to be “yes.” If, for the given crash location, the answer to any of these questions is “no,” the scenario can be designated as a nonrelease scenario and eliminated from further consideration.

Step 5. If the scenario has not been eliminated (i.e., the analysis has shown that it could lead to a release), calculate the impact frequency by rerunning the four-factor formula for the appropriate aircraft subcategory, using facility dimensions specific to the impact location associated with the scenario. The analyst will need to better define the location as an area (rather than just a single point) where impact could result in the release scenario. This requires judgement and consultation with the analyst(s) who conducted the structural response evaluation. Use this information to develop a set of "scenario facility dimensions" that represents what the target would look like if it encompassed an area equal to the target area associated with the release scenario being evaluated. Credit should be taken for shielding effects from other facilities to further reduce the scenario facility dimensions (Appendix B, Section B-4). The development of the scenario facility dimensions should be well justified and documented in detail. Once these dimensions have been established, run the appropriate four-factor formula to calculate the scenario release frequency.

Step 6. Repeat Steps 1 through 5 for all of the impact locations that exceed the structural response guidelines. Adding together the scenario release frequencies from each pass through Step 5 gives the final release frequency for the evaluation step.

Step 7. Compare the final release frequency value to the guideline. If the guideline is met, no additional analysis of aircraft impact is required. If the guideline is not met, a more detailed analysis of the exposure associated with each release scenario needs to be performed in accordance with Section 7.3 of this standard. For the purpose of that analysis, each scenario that contributes to the release frequency exceeding the guideline should be fully documented. In particular, a full description of the damage state of the facility should be provided, including details about what parts of the facility are subject to each of the release mechanisms considered (e.g., fire, explosion, and crush/impact).

5.6 References.

1. Sanzo, D. et al. *ACRAM Modeling Technical Support Document*. LA-UR-95-X, TSA-11-95-R112. Los Alamos National Laboratory, 1996.

2. Kimura, C.Y. et al. *Data Development Technical Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard*. UCRL-ID-124837. Lawrence Livermore National Laboratory, 1996.

6. METHODOLOGY FOR EVALUATING THE INTEGRITY OF STRUCTURES, SYSTEMS, AND COMPONENTS SUBJECTED TO AIRCRAFT IMPACT

6.1 Purpose. This chapter establishes a methodology for deterministically evaluating the structural integrity of targets (or barriers) and the functionality of safety-related structures, systems, and components (SSCs) in a facility that may be subjected to impact from one or more subcategories of aircraft with frequencies greater than frequency guidelines. It also provides the technique for selecting critical missiles from the site-specific list of aircraft that may potentially impact the facility.

The design/evaluation procedures in this chapter are generally conservative and consistent with nuclear power industry practices. However, the use of a more precise and detailed methodology is not precluded if the intent of this chapter is satisfied. Alternative methods and technical discussions are provided in Appendix C, and the justification for these recommended methods and examples is provided in Reference 1.

6.1.1 Adverse Effects. The following potential adverse effects of a missile impact on a target should be considered:

a. Local Structural Damage: A missile may hit a target, causing excessive local damage (i.e., penetration and spalling, scabbing, perforation).

b. Global Structural Damage: When subjected to the impact from a missile, a target may undergo excessive structural deformation or displacement (without collapse) or may structurally collapse or overturn.

c. Functional Failure of SSCs: When a building structure is impacted, attached SSCs in close proximity to the impact location may be subjected to shock and vibration, resulting in their functional failure.

An outline of the structural evaluation process to analyze the adverse effects of an aircraft impact is provided in Figure 2. The process allows for some initial screening prior to performing a detailed structural evaluation. The amount of screening depends on the existence of building supported safety-related structures, systems, and components (SSCs) in the vicinity of the potential impact locations. If no safety-related SSCs are present in the vicinity of potential impact locations, optional structural and release frequency screening is possible prior to performing a detailed structural evaluation. If safety-related SSCs are present, the structural screening, although it cannot be used to screen out entire structures, is still useful for identifying nonsafety-related SSC locations, which can be screened out from further structural response analysis.

6.2 Structural Screening. Given that the frequency of aircraft impact from all types of aircraft in the Impact Frequency Evaluation (Section 5.3) exceeds the guideline (see Section 4.2), the first step in the structural evaluation analysis, as an option, is to perform a structural screening prior to undertaking a more detailed structural response evaluation. If there are no building supported safety-related SSCs in the vicinity of the impact locations and if the entire structure passes the structural response guideline in Section 4.3, no further analysis and evaluation will be needed. The structural screening assumes that the various types of aircraft applicable to the structure under consideration are identified and their mass and an estimate of maximum speed are available for estimating maximum kinetic energy. These data, along with the data/information listed as inputs in Section 3.3.1, will be used to perform structural screening, which consists of the following steps:

Step 1. Identify locations for screening. Based on the location of hazardous materials within the facility, accident scenario information, the location of safety-related equipment, and the facility layout, prepare a list of potential aircraft impact locations. Identify those locations where building-supported safety-related SSCs are present. These impact locations cannot be screened out from further evaluation. The structural screening is performed on the remaining locations.

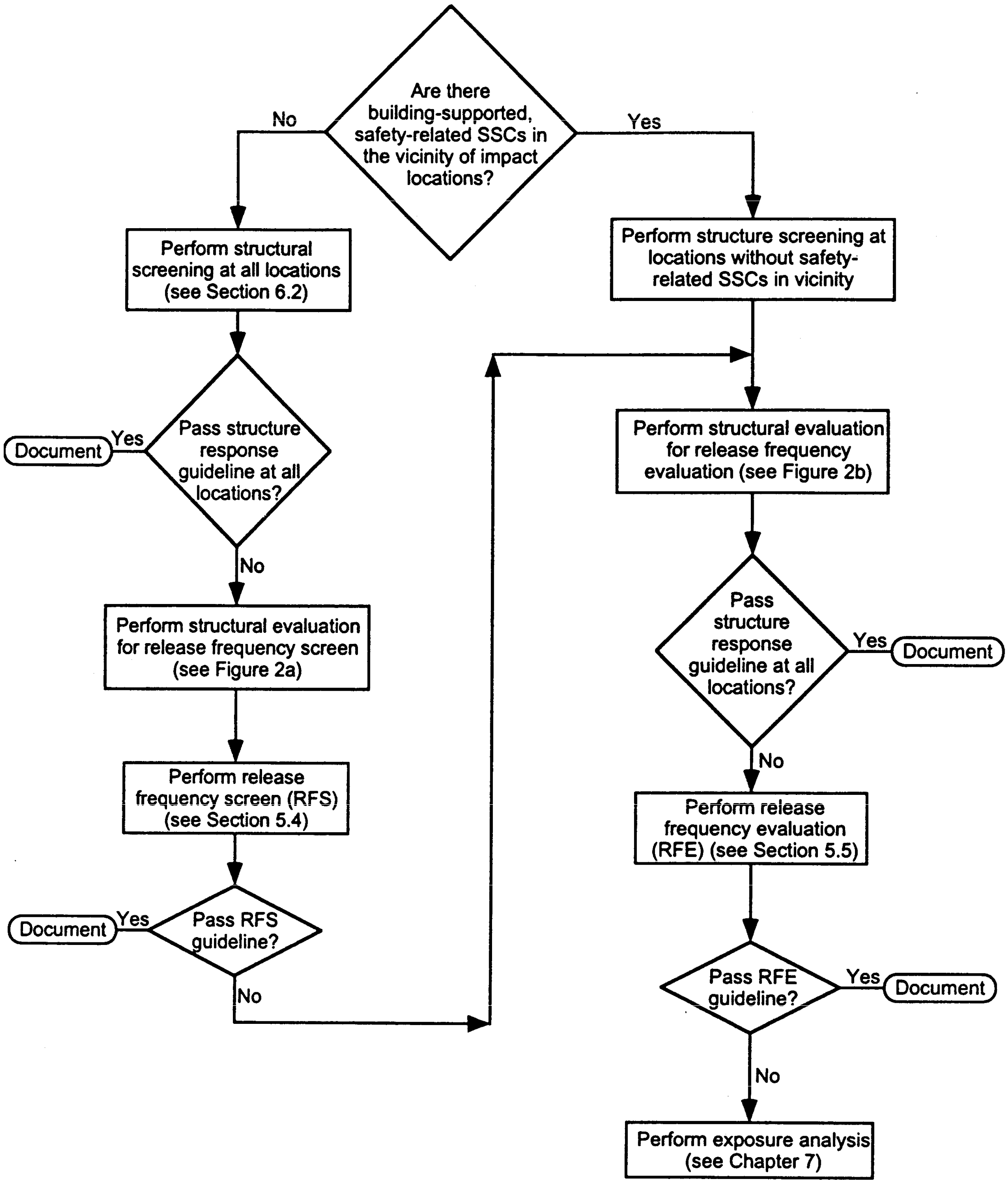

Figure 2: Structural Evaluation Outline

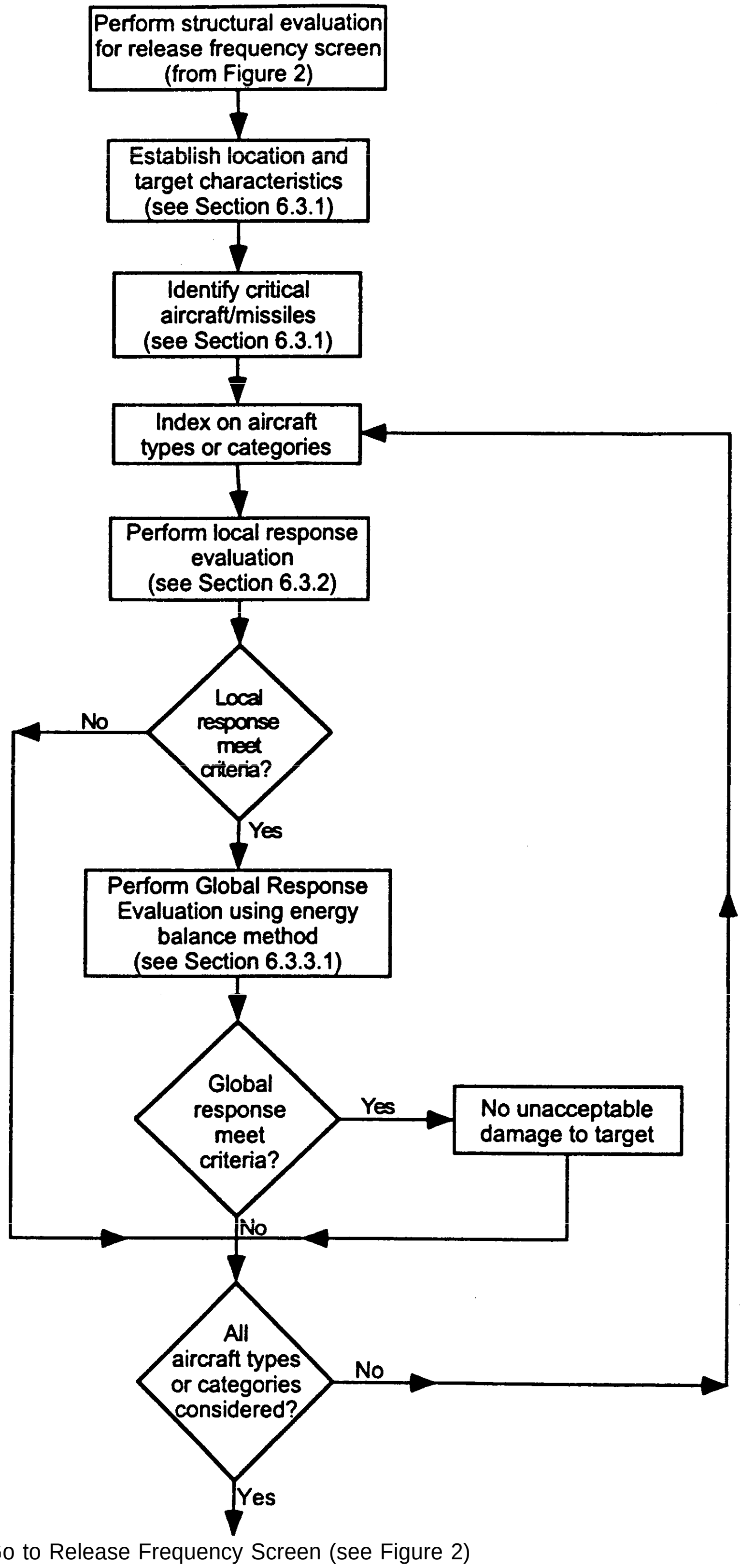

Figure 2a: Structural Evaluation for Release Frequency Screen

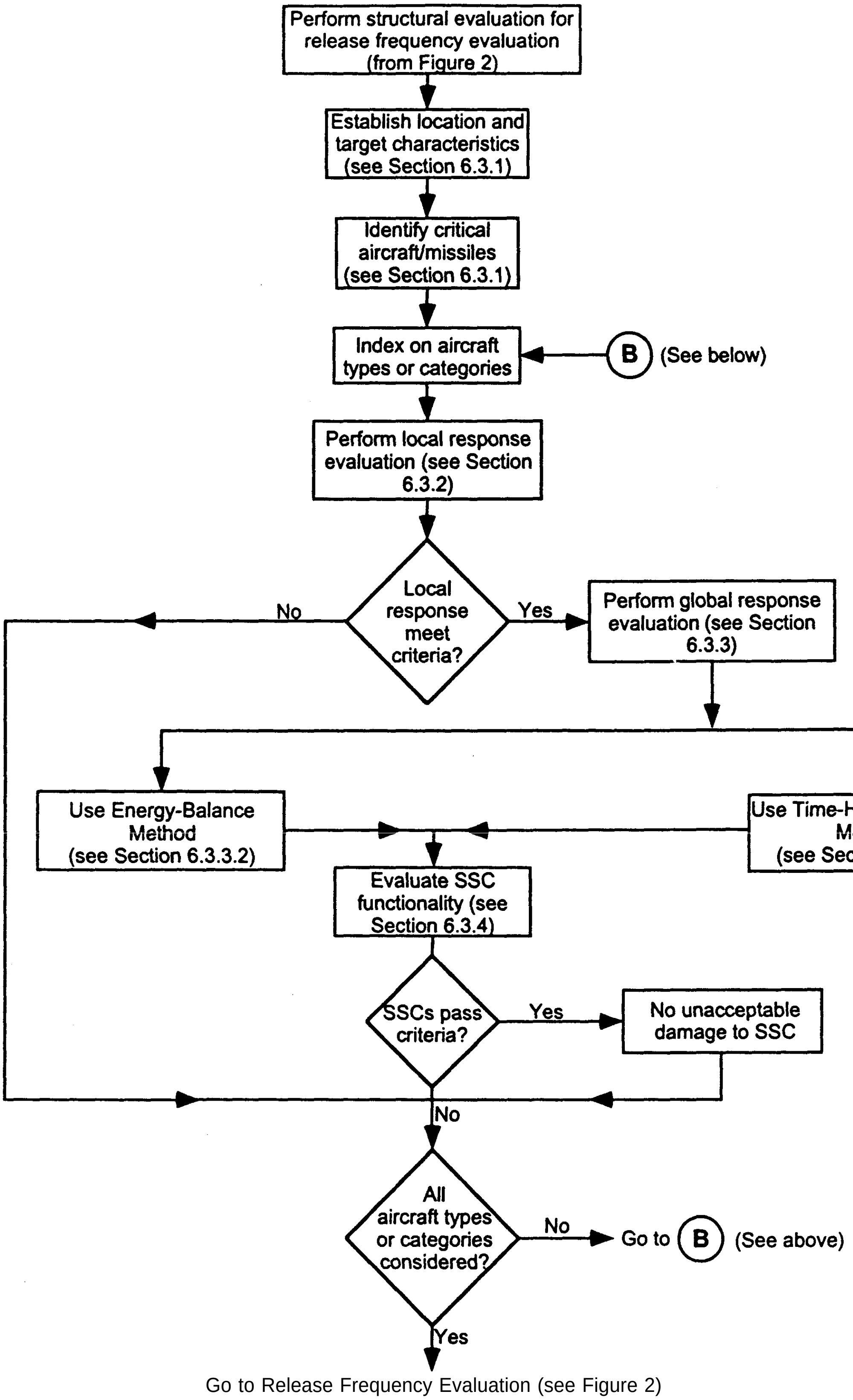

Figure 2b: Structural Evaluation for Release Frequency Evaluation

Step 2. Identify critical missiles. Identify a set of missiles to be used for local and global structural response evaluations by either (1) performing a site-wide basis aircraft hazard analysis (see Section 2.1 of Reference 1) or (2) as follows:

> Select two bounding missiles considering all applicable categories/subcategories and types of aircraft, one for structural local damage evaluation and the other for structural collapse evaluation. The bounding missile for local damage evaluation will be the aircraft engine (or any of the nearly rigid and compact components) having the highest kinetic energy (i.e. one-half the engine mass times the square of the impact velocity). The bounding missile for structural collapse evaluation will be the aircraft having the highest kinetic energy of impact (i.e. one-half the total aircraft mass times the square of the impact velocity). Reasonable estimates of horizontal and vertical velocities to be used for assessing bounding kinetic energy values are the highest velocity values (corresponding to probability 0.0075) given, for each aircraft subcategory, in Table 2-1 of Reference 1.

Step 3. Perform structural response evaluations. Perform a building local damage evaluation in accordance with Section 6.3.2. If the local damage evaluation results meet the guideline provided in Section 4.3, perform a building collapse evaluation using the energy balance method in accordance with Section 6.3.3. If standardized charts, tables, or nomographs are available, they can be used for structural screening if they are developed using conservative criteria and methods equivalent to those described in Section 6.3.

Step 4. Identify locations meeting guidelines. Identify the structure locations meeting the guidelines in Section 4.3, i.e., identify the structure locations that are not susceptible to significant local and global structure damage when impacted by a crashing aircraft. Note that in the vicinity of these locations, there must not be any building-supported safety-related SSCs.

Step 5. Test if structure meets guidelines. If there are no building-supported safety-related SSCs in the vicinity of impact locations, evaluate if all locations within the structure meet the structural response guidelines of Section 4.3. If yes, the analysis should be terminated and the results documented. Otherwise, go to the Structural Evaluation for Release Frequency Screening (see Section 6.3).

If there are safety-related SSCs in the vicinity of impact locations, identify the nonsafety-related SSC locations which are not vulnerable to aircraft impacts. These locations need not be further evaluated. Go to the Structural Evaluation for Release Frequency Evaluation (see Section 6.3).

6.3 Structural Evaluation. If there are building-supported safety-related SSCs in the vicinity of the impact locations, or if the entire structure does not meet the structural response guidelines for Structural Screening, a more detailed structural evaluation is necessary. The structural evaluation is performed leading up to either a Release Frequency Screening or Release Frequency Evaluation. Outlines of the structural evaluation for Release Frequency Screening and Release Frequency Evaluation are given in Figures 2a and 2b, respectively. Details for implementing the evaluation are given in this section.

The structural evaluation process involves the following steps:

Step 1. Identify locations for evaluation. Prepare a list of potential aircraft impact locations (see Section 6.2 Step 1). Include locations associated with building-supported safety-related equipment, but delete any location that has been screened out by the Structural Screening.

Step 2. Identify critical missiles. Identify a set of missiles to be used for the structural response evaluation for Release Frequency Screening by either (1) performing category/subcategory aircraft hazard analyses (see Situation 1, Section 2.1 of Reference 1) for all applicable aircraft categories/subcategories as identified in the impact frequency evaluation (see Section 5.3), or (2) selecting appropriate aircraft as discussed in Section 6.3.1, keeping in mind that a pair of bounding aircraft types must be identified for each applicable aircraft category/subcategory.

For the Release Frequency Evaluation, the identification of a set of missiles to be used for the structural evaluation can be done by either (1) selecting a set of aircraft types for each category/subcategory as outlined above, (2) performing a site-wide basis aircraft hazard analysis (see situation 2, Section 2. i of Reference 1) to identify a set of aircraft types to represent all applicable categories/subcategories of aircraft, or (3) selecting appropriate aircraft types as discussed in Section 6.3.1.

Step 3. Perform structural response evaluations. Sequentially perform structural local response, global response and SSC functionality evaluations as outlined in Figures 2a and 2b and discussed in Sections 6.3.2, 6.3.3, and 6.3.4, respectively, at all locations except those previously screened out from consideration. Additional analysis should be consistent with the analyses associated with the Release Frequency Screening and Release Frequency Evaluation methods as described in Sections 5.4 and 5.5 respectively. For Release Frequency Screening, SSC functionality is not evaluated, and global response is based on the Energy Balance Method discussed in Section 6.3.3.1. For Release Frequency Evaluation, global response evaluations for locations related to building-supported safety-related SSCs are based on the Time-History Analysis Method, discussed in Section 6.3.3.2.

Step 4. Identify categories/subcategories of aircraft. For the Release Frequency Screening, identify the aircraft categories/subcategories meeting the structural response guidelines in Section 4.3. These are the aircraft categories/subcategories which inflict insignificant structural damage upon impact.

For the Release Frequency Evaluation, identify the locations within the facility at which the impact of a crashing aircraft will inflict insignificant damage and need not be considered in assessing the effective area of the facility in evaluating impact frequencies.

Step 5. Proceed to the Release Frequency Screening or Evaluation. See Sections 5.4 and 5.5, respectively.

6.3.1 Missile and Target Selection.

6.3.1.1 Selection and Characterization of Critical Missiles.

a. Aircraft subcategories identified in the site-specific hazard study (see Chapter 5) should be considered as sources of missiles for the facility being evaluated. The mass, velocity, and stiffness characteristics and configuration of these aircraft subcategories and their major heavy and rigid components should be used to select the critical missiles.

b. Nondeformable missiles are the rigid and heavy components (e.g., landing gear, engine shaft) of the aircraft. Deformable missiles are relatively soft components (e.g., wings, fuselage). As evidenced in some recent tests, aircraft engines deform significantly upon impact with rigid barriers and hence can be considered as deformable. Critical missiles should be selected by considering the three adverse effects listed in Section 6.1.1. The local damage evaluation should be performed using relatively nondeformable components of the aircraft as the candidate missiles. Typically, the aircraft as a whole is critical for global response evaluation. For SSC functionality evaluation, the whole aircraft and its rigid and heavy components can be critical.

c. In selecting critical missiles, consideration should also be given to the relative location, orientation, and configuration of SSCs and their barriers at the facility.

d. When more than one missile can potentially impact a target, select the missile with the maximum kinetic energy as the critical missile for global response evaluation. For local response, also consider the penetration characteristics of the missiles (Reference 1). For evaluating SSC functionality (discussed in detail in Section 6.3.4), in addition to the kinetic energy of the impacting aircraft, the mass and stiffness characteristics of the missiles should also be considered because these are likely to affect the frequency content of the vibration resulting from the impact.

e. For evaluating local response, the selection of critical missiles should be based on the postulated aircraft impact velocity and the relative sizes and weights of the heaviest rigid-type components, considering all candidate aircraft subcategories. Consideration should also be given to the mode of local damage (see Section 6.3.2). One aircraft component may not be critical for all modes of local damage. Also, for each mode of local damage, more than one missile may need to be selected unless one particular missile's combination of velocity, size, and weight is clearly more critical than that of other candidate missiles.

f. A representative weight and velocity for the aircraft in each subcategory should be established based on the review of aircraft subcategory data in the *Data Development Technical Support Document for the Aircraft Crash Risk Analysis Methodology Standard* (Reference 2) and the results of the site-specific hazard study performed in accordance with the guidance given in Chapter 5 of this standard. The analyst should consider the representative aircraft weights and velocities associated with both takeoff and landing scenarios.

g. Mass distribution of the aircraft along the length of the fuselage can be obtained from Reference 2, from the aircraft manufacturer, or by calculation based on the weights and locations of major components and fuel, which can be obtained from published literature on the same type of aircraft.

h. The variation of load capacity due to fuselage buckling or crushing (whichever is lower) as the crushing length progresses from the aircraft nose toward the rear can be obtained from the manufacturer or calculated using pertinent data from published literature on the same type of aircraft.

i. When an aircraft impacts a target, the potential for damage from secondary missiles should be considered in order to evaluate the adequacies of safety-related SSCs in the vicinity of the primary impact area.

j. The velocity of the secondary missiles at the instant of detachment from the main body of the aircraft can be calculated by methods that are well established in the industry, such as the method developed by Riera (Reference 3). Alternatively, it should be conservative to assume that the initial velocity of such secondary aircraft missiles is equal to the impact velocity of the primary aircraft missile.

6.3.1.2 Selection of Target SSCs, Angle, and Location of Impact.

a. The list of target SSCs and their barriers that should be evaluated for adverse effects (listed in Section 6.1.1) from aircraft missile impacts can be based on available facility safety analyses. The selection of these targets is a joint activity of the structural engineer and the facility safety analyst. Using insights derived from any existing safety analysis, the safety analyst should provide the structural engineer with lists of potential targets whose failure could lead to the release of hazardous material, the location of the affected material, and the failure modes that could lead to the release.

b. For each target SSC or its barrier selected above, more than one impact location should be considered so that the worst adverse effects can be determined. It is possible that the impact location that produces the worst global response is different from the location that produces the worst local damage or SSC functional failure.

c. The angle of impact should be based on the orientation of the SSC or barrier being evaluated, the worst impact angle from SSC/barrier vulnerability considerations, and the most probable angle of impact for the aircraft subcategory to which the critical missile belongs.

6.3.2 Local Response Evaluation. The local response of the target will be initiated with spalling and subsequently result in penetration, scabbing of target material from the back face of the target, and the eventual perforation of the target, transporting the missile through the target (Figure 3).

Empirical formulas validated by tests have been used to predict these local responses for predominantly rigid (nondeformable) missiles (see Table I). Empirical formulas are for the case of normal (90-degree) impact. When the impacting missile strikes normal to the target face, the local responses are maximized. The angle of strike can substantially influence the extent of local damage and should be appropriately considered. For further guidance see the technical support document for SSC evaluation (Reference 1).

Typically, spalling is not of any safety concern, and it is sufficient to evaluate safety-related targets against only scabbing and perforation (i.e., full penetration) using the methods provided herein. If the results of such evaluation do not meet Section 4.3 guidelines, it is not necessary to perform global response or building collapse evaluation, and the evaluation should proceed to consequence analysis in accordance with Chapter 7.

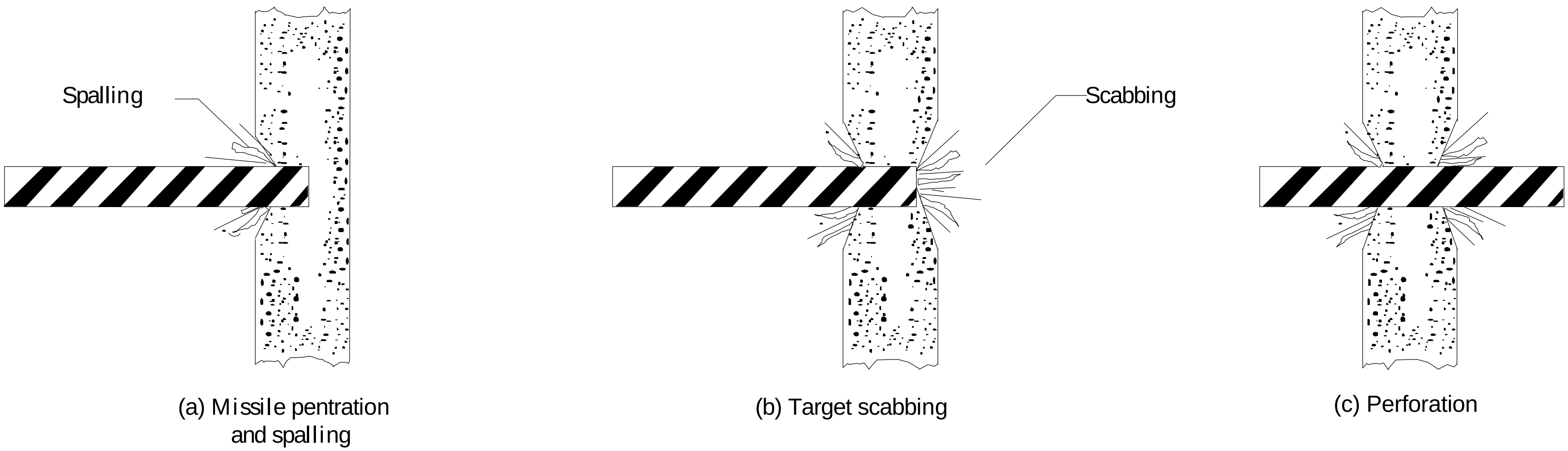

FIGURE 3. Sequence of local target response to missile impact

6.3.2.1 Evaluation of Reinforced Concrete Targets.

6.3.2.1.1 Scabbing Thickness. The scabbing thickness (t_s) is defined as the panel thickness that is just large enough to prevent the peeling off of the back face of the panel opposite to the face of impact. In 1981, Chang (Reference 4) proposed an empirical formula based on lower velocity missiles (less than about 500 ft/sec [152 m/s]) to predict mean scabbing thickness for reinforced concrete panels subjected to a cylindrical rigid (nondeformable) steel missile impact:

$$t_s = 1.84 \left(\frac{U}{V}\right)^{0.13} \frac{(MV^2)^{0.4}}{D^{0.2} \, (f_c^{/})^{0.4}} \qquad (6\text{-}1)$$

where:

U	=	reference velocity = 200 ft/sec;
V	=	missile impact velocity (ft/sec);
M	=	mass of the missile = W/g,
where:		W = missile weight (lb),
		g = 32.2 ft/sec^2;
D	=	effective missile diameter (ft);
$f^{/}_c$	=	ultimate compressive strength of concrete (lb/ft^2).
t_s	=	scabbing thickness (ft)

To prevent scabbing, minimum concrete thickness, t_d, should be $\geq 1.1t_s$, where t_s is given by the above formula. Other formulas, as listed in Table I and discussed in Appendix C, may also be used if the missile and target characteristics (missile size, velocity, and deformability, and target rigidity and thickness) are comparable to those used in the formula above.

TABLE I.* Empirical formulas for local response evaluation of reinforced concrete targets (see Note 1).

DAMAGE MODE	RIGID (NONDEFORMABLE) MISSILE	SOFT (DEFORMABLE) MISSILE (See Note 2)
Penetration (x)[3]	-Modified NDRC	50% of Rigid
Scabbing (t_s)[4]	- Modified NDRC - Bechtel - Chang[7] - CRIEPI	60% of Rigid or - Stone & Webster
Perforation (t_p)[5]	- Modified NDRC - CEA - EDF - Degen - Chang[7] - CRIEPI	70% of Rigid
Punching Shear[6]		- ACI[7] - Long

NOTES:

1. For a typical example using these empirical formulas and a discussion of their relative merits, please refer to Section 3 of the technical support document (Reference 1) and Table A-1 therein. These formulas are not applicable to unreinforced concrete or masonry structures.

2. The reduction factors for deformable missiles acknowledge the fact that they produce relatively less local damage, and the impact forces do not exceed the crushing strength of these missiles. They are based on recent aircraft engine missile tests and comparison of various empirical formulas and their agreement with the actual test results, as reported by Sugano (Reference 5).

3. Penetration (x) is computed to determine t_s and t_p (Modified NDRC and Degen formulas only).

4. To prevent scabbing, minimum required thickness t_d should be $\geq 1.1\ t_s$.

5. To prevent perforation, minimum required thickness t_d should be $\geq 1.2\ t_p$.

6. Punching shear considerations for small nondeformable missiles are implicit in the formulas for penetration and perforation.

7. Recommended formula (see Section 6.3.2.1). References for all other formulas are given in Appendix C.

*All of the formulas presented in this table are based on data for lightly reinforced (0.3 percent - 1.5 percent each way) concrete targets. Application to heavily reinforced targets would give a conservative estimate of local response.

6.3.2.1.2 Perforation Thickness. The perforation thickness (t_p) is defined as the panel thickness that is just great enough to allow a missile to pass through the panel without any exit velocity. The mean perforation thickness, t_p (ft), for reinforced concrete panels subjected to a cylindrical rigid (nondeformable) steel missile impact, based on Reference 4, is:

$$t_p = \left(\frac{U}{V}\right)^{0.25} \left(\frac{MV^2}{Df_c'}\right)^{0.5} \qquad (6\text{-}2)$$

The parameters U, V, M, D, and f_c' are the same as those defined in Equation 6-1. To prevent perforation, minimum concrete thickness, t_d, should be $\geq$ 1.2 t_p, where t_p is given by the above formula. Other formulas, as listed in Table I and discussed in Appendix C, may also be used if applicable.

For further discussion and an example using these formulas, refer to the technical support document for Chapter 6 (Reference 1).

6.3.2.1.3 Punching Shear. Missile impact on a concrete wall or slab can induce shear failure, either near the periphery of the impact area or at the edge of the wall or slab. The former is called punching shear failure, and the latter is known as the reaction shear failure. The following punching shear criterion is applicable for this standard. For design against punching shear, capacity is limited by the diagonal tension failure in the concrete adjacent to the load. The ACI 318 and ACI 349 Codes (References 7 and 8) limit the punching shear stress (psi) to

$$4\sqrt{f_c'}$$

(where f'_c = ultimate compressive strength of concrete in psi) at the perimeter, one-half the effective depth away from the load. This criterion is very conservative compared to recent test results, but may be used conservatively for structural screening purposes and for cases where punching shear is not likely to be critical. For marginal or critical cases, the alternative formula in Appendix C of this standard can be used as applicable. For punching shear evaluation, the dynamic increase factor, strength reduction factor, and ultimate load factors are given in Appendix C of ACI 349.

6.3.2.2 Evaluation of Steel Targets. A widely accepted formula for predicting penetration of steel targets is the Ballistic Research Laboratory (BRL) formula:

$$T^{1.5} = \frac{0.5MV^2}{17{,}400K_sD^{1.5}} \tag{6-3}$$

where:

T	=	predicted thickness to just perforate a steel plate (in.);
M	=	W/g missile mass (lb-sec^2/ft);
V	=	missile impact velocity (ft/sec);
K_s	=	constant depending on the grade of steel (usually $\approx$ 1);
D	=	missile diameter (in.).

The range of test data parameters used in developing this formula and their scope of applicability are not defined. However, the formula is independent of target size or support conditions. It should be used only to predict local perforation of steel structures by small rigid missiles. To prevent perforation of steel targets, the minimum thickness, t_d, should be > 1.25T.

Alternative formulas such as the Stanford Research Institute (SRI) formula and the Hagg-Sankey formula can be used as applicable.

6.3.3 Global Response Evaluation.

a. The objective of the global response evaluation is to determine if the impact of the aircraft results in the excessive deformation or collapse of the target structure. A localized collapse evaluation (i.e., the collapse of a segment, a component, or a portion of the structure) may be sufficient if it can be demonstrated that such a localized collapse would not adversely affect the structure’s function or the function of any systems or components. Global response evaluation of a building or a structure typically involves characterization of the nonlinear behavior of both the aircraft and the target, including soil-structure interaction.

b. Global response evaluation can be performed by either the energy-balance method or the time-history analysis method. The energy-balance method discussed in Section 6.3.3.1 can be used for global response or collapse evaluation if the following conditions are met: (1) there are no safety-related SSCs supported by the target in the vicinity of the impact; (2) the configuration of the target is simple, such that the overall dynamic characteristics of the structure can be adequately represented by a single-degree-of-freedom (SDOF) nonlinear energy-absorbing system; and (3) the resulting response of the SDOF system would be compatible with the strength and ductility limits of the various components and supports of the impacted structure. If these conditions are not met, then the time-history analysis method described in Section 6.3.3.2, or in Appendix C, Section C.6.3.3.2, should be used to evaluate the global response.

6.3.3.1 Energy-Balance Method.

a. The objective of the energy-balance method of global response evaluation is to determine whether the target structure can absorb the energy that is imparted to it without deforming excessively. This method uses the principles of conservation of energy and conservation of momentum, and requires that the energy absorption capability (SE) of the target be greater than the kinetic energy imparted to it (E_a). It recognizes that, since a significant portion of the impact energy is dissipated in deforming the aircraft body, the effective missile mass is less than the total mass of the aircraft but more than the mass of the rigid components, such as the engines. The effective missile mass for calculating the total kinetic energy of impact (E_i) will depend on the mass of the engines and the relative rigidity of the aircraft body.

b. To calculate E_i, the effective missile mass (m) can be conservatively estimated based on Chelapati (Reference 10):

1. For small aircraft with airframes that are flexible relative to the target structure, m=2 times the combined mass of the engines.

2. For large aircraft, m=8 times the combined mass of the engines. However, m should not be less than 30 percent, nor more than the total mass of the aircraft.

c. To calculate E_a, the effective target mass (M_e) may conservatively be taken as the mass of the target structure that is included within d/2 of the periphery of the impact interface, where d is the thickness of the target in the direction of missile travel. On the basis of the predicted deformed shape of the target, less conservative but practical values may be used if justified. However, M_e need not be less than one-tenth of the total mass of the target structure panel (Reference 10).

d. If the coefficient of restitution between the aircraft and the target (e) can be estimated, the portion of the total impact kinetic energy (E_i) that will be transmitted to the target structure (E_a) can be computed as follows.

$$E_a = \frac{1}{2} M_e V_t^2, \ when \ \frac{m}{M_e} \leq e \qquad (6\text{-}4)$$

or

$$E_a = \frac{1}{2} M_e V_t^2 + \frac{1}{2} m V_m^2, \ when \ \frac{m}{M_e} > e \qquad (6\text{-}5)$$

where:

E_a = kinetic energy imparted to the target;
M_e = target effective mass (represents inertial resistance);
V_m = velocity of missile after impact.
V_t = velocity of target after impact;

and

$$V_m = \frac{V_o \left[\frac{m}{M_e} - e \right]}{1 + \frac{m}{M_e}} \qquad (6\text{-}6)$$

$$V_t = \frac{m/M_e}{1 + (m/M_e)} [V_o (1 + e)] \qquad (6\text{-}7)$$

where:

m = effective missile mass;

e = coefficient of restitution $= \frac{V_t - V_m}{V_o}$; (6-8)

V_o = velocity of missile before impact.

For the entire aircraft impact (which is relatively deformable) on hard structures, e is between 0 (plastic impact) and 1 (elastic impact). The value of e is estimated based on the relative mass and stiffness of the target and the missile. If the value of e cannot be easily estimated, the lower and upper bounds of E_a can be calculated as in Paragraphs e and f below.

e. Lower Bound E_a: A lower bound E_a can be obtained by assuming a plastic impact (i.e., the aircraft moves along with the target after impact), for which e equals zero and is less than m/M_e. For such cases,

$$E_a = \left(\frac{1}{2} m V_o^2\right)\left(\frac{m/M_e}{1 + m/M_e}\right) \quad . \tag{6-9}$$

f. Upper Bound E_a: An upper bound E_a can be obtained by assuming an elastic impact (i.e., the aircraft and the target velocities after impact are different), for which e=1. For such cases,

$$E_a = \left(\frac{1}{2} m V_0^2\right)\left(\frac{4m/M_e}{(1+m/M_e)^2}\right) \qquad (6\text{-}10)$$

$$when\ m/M_e \leq 1,$$

and

$$E_a = \frac{1}{2} m V_0^2 \qquad when\ m/M_e >> 1. \qquad (6\text{-}11)$$

g. The energy absorption capability (SE) of the target structure is determined as

$$SE = R_m X_e (\mu - 0.5). \qquad (6\text{-}12)$$

The ductility ratio (μ) may then be computed as

$$\mu_{min} = \frac{E_a}{R_m X_e} + 0.5 \qquad (6\text{-}13)$$

where:

R_m = static collapse load;

X_e = effective yield displacement.

The static collapse load, R_m, can be computed by methods discussed in standard handbooks and structural analysis/design texts and references. It is a function of the ultimate capacity of the structural member and varies for different end support configurations. The "effective yield" point is found by extending the initial elastic deformation line to its intersection with the limit or collapse load line.

The permissible ductility ratio, μ, is defined as the ratio between maximum permissible deflection of a structural system and the deflection at the effective yield for the system (see Section 6.3.3.3).

6.3.3.2 Time-History Analysis Method. A time-history response analysis method of evaluating the global response or collapse of the target structure uses the inertial and stiffness characteristics of both the aircraft and the target structure (including its foundation flexibility). One of the acceptable methods that has been extensively used is outlined below.

This method, called the force time-history analysis method, consists of two major steps. The first step is to determine impact force time-history based on the aircraft mass distribution, crushing/buckling characteristics, impact velocity, aircraft length, and other aircraft structural data, and conservatively assuming that the target structure is rigid. Impact force time-history is determined using the momentum principle, similar to the method developed by Riera (Reference 3) and modified by Muto et al. (Reference 9). Accordingly, the impact force, F(t), acting on the rigid fixed target at time, t, is expressed as

$$F(t) = P_c[x(t)] + \alpha m[x(t)][v(t)]^2 \qquad (6\text{-}14)$$

where:

P_c	=	load necessary to crush or buckle the fuselage;
x(t)	=	distance from the nose of the aircraft to the point up to which crushing has progressed at time, t;
m	=	longitudinal mass per unit length of the uncrushed aircraft;
v(t)	=	velocity of the uncrushed portion of the aircraft at time, t;
α	=	empirical correlation factor (use a value of 0.9 unless justified otherwise).

When necessary data for the given aircraft are not available, an approximate method given in Appendix C may be used to determine F(t), by scaling available impact force time-histories of other similar aircraft (see Reference 1).

The second step is to develop a structural model of the impacted structure and perform a dynamic analysis using the impact force time-history computed in the first step or the one obtained from Reference 1.

6.3.3.3 Structural Evaluation Criteria. Deformation responses computed for various target structural components by either the energy-balance method or the time-history analysis method are then used to compute the ductility ratio (the ratio of computed displacement to elastic displacement). Computed ductility ratios are then compared to the permissible ductility ratios specified below to determine if the component would deform excessively or collapse under impact loads.

a. For concrete structural components, the permissible ductility ratios shall be as specified in ACI Code 349, Appendix C, Section C-3. For beam columns, walls, and slabs carrying axial compression loads, the provisions of Paragraph C 3-8 of ACI Code 349, Appendix C, shall be followed.

b. For steel structural components, the permissible ductility ratios shall be as specified in Section Q1.5.8 of AISC Nuclear Specifications, ANSI-N690 (Reference 11). For plate structures, the permissible ductility ratio of 10 is recommended.

Potential loss of SSC safety functions resulting from structural deformation and degradation due to aircraft impact should also be evaluated.

6.3.4 SSC Functionality Evaluation.

a. SSCs that are supported by target structures should be evaluated for aircraft impact-related vibratory loads. Such an evaluation consists of (1) generation of instructure vibratory motion at SSC support locations resulting from impact force time-history; (2) structural evaluation of SSC supports, including anchorage; and (3) evaluation of the SSC functionality. Both support and SSC functionality evaluation can be performed either by analysis or by testing.

b. For evaluation by analysis, the SSCs can be modeled, analyzed, and evaluated in accordance with the applicable industry-accepted dynamic analysis methods and acceptance criteria for safety-related SSCs, such as those given in ASCE-4, ASME Boiler and Pressure Vessel Code, IEEE-344, and NUREG-0800 (References 12, 13, 14, and 15), recognizing that impact of some aircraft may generate vibratory loads with more high frequency contents than those from typical seismic loads.

c. For evaluation by testing, the SSCs can be subjected to shake table testing, using the instructure spectra generated from transient response analysis as input spectra and following the methods described in IEEE-344.

6.3.5 Evaluation of Earth-covered Structures.

a. Penetration of a rigid missile into earth media can be determined using analytical or empirical formulas, which provide good agreement with test data. Because most of the tests have been performed using ballistic missiles, care should be exercised in applying the formulas to aircraft missiles.

b. If the earth cover exceeds 1.2 times the penetration depth calculated by assuming a rigid missile, the missile should be assumed not to directly impact the structure. The resistance force developed by the penetrating missile may be used to determine the response of the buried structures.

c. If the earth cover does not meet the requirements in b, above, the missile should be assumed to impact the structure. In these instances, the structure may be evaluated for missile impact using techniques similar to those given in Sections 6.3.2 and 6.3.3.

d. Forcing functions developed for aircraft impact on rigid barriers may be used as a conservative estimate of the missile impact loading for earth-covered structures.

6.3.6 Structural Evaluation Results. If there are no adverse effects as listed in Section 6.1.1, then no further analysis is necessary, and the structural evaluation results should be documented. However, if there are any adverse effects, then further analysis, as described in Chapter 7, should be performed.

6.4 References.

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7. METHODOLOGY FOR EVALUATING EXPOSURE DUE TO AIRCRAFT IMPACT

7.1 Purpose. This chapter provides the methodology for evaluating exposure resulting from aircraft impact on a facility. The methodology by which exposure is assessed can be divided into two broad areas: exposure screening and exposure evaluation.

7.2 Exposure Screening. The purpose of exposure screening is to determine, on the basis of overall facility inventory and generic expected release mechanisms associated with aircraft impact (e.g., fuel fire, missile impact shock, building collapse), whether a facility has the potential for significant onsite or offsite exposure, given an aircraft impact.

7.2.1 Applicability. Exposure screening will be performed for all facilities subject to the provisions of this standard.

7.2.2 Hazard Identification. Hazard identification will be performed to identify and inventory hazardous materials and energy sources (in terms of quantity, form, and location) associated with the facility processes or related operations. Standard industrial hazards will be identified only to the degree that they may exacerbate a postulated aircraft impact on the facility. Well-confined material may be excluded from the hazardous materials inventory, but such exclusions should be justified based on the robustness of the material containment in a postulated aircraft impact environment (i.e., such assumptions should be shown to be valid for the class of accidents being evaluated). References 1 and 2 may be used in performing hazard identification.

7.2.3 Radioactive Materials. This section summarizes the screening approach for radioactive materials. More detail is provided in a separate report, *Screening for the Potential Consequences of Accidental Releases of Radioactive and Chemical Materials to the Atmosphere* (Reference 3).

7.2.3.1 Radioactive Material Source Term Determination. A bounding source term will be developed based upon an assumed loss of containment for all hazardous radioactive material associated with the facility, except the material excluded from the hazardous material inventory, as discussed in Section 7.2.2 of this document. Facility segmentation (as discussed in DOE-STD-1027-92) or other means of demonstrating the lack of facility-wide release potential may be used, as appropriate, to reduce the inventory for direct comparison with guidelines. In all cases, however, such reductions should be justified in terms of the unavailability of common-cause release mechanisms stemming from aircraft impact.

7.2.3.2 Radioactive Material Offsite Exposure Determination. The exposure to the maximally exposed individual at or beyond the site boundary will be estimated in terms consistent with the screening guidelines presented in Section 4.1.

Source term values will be based upon a bounding release consistent with the following assumptions:

a. All material in close proximity to high explosives present at the facility will be assumed to be subjected to the energetics associated with high explosive detonation.

b. No credit will be taken for mitigation, either passive or active, including ventilation, fire suppression, building confinement, and rubble effects.

c. The fraction of radioactive material assumed to be driven airborne and respirable will be based on Table II, which is derived from DOE-HDBK-3010-94 and explained in Reference 8.

TABLE II. Fraction of radioactive material released and respirable.

Material Form	Fraction Released and Respirable
Gases/Vapors	1.0
Liquids:	
Aqueous	2E-3
Combustible Organic	1E-2
Subject to Explosive Stress	TNT Equivalent Mass*
Solids:	
Pyrophoric Metals	3E-4
Uranium	1E-3
Subject to Explosive Stress	TNT Equivalent Mass*,**
Powders	2E-3
Surface Contamination	
Combustible Solids	1E-2
Noncombustible Solids	1E-3
Other	1E-3
HEPA Filters	1E-2

* The amount of material released and respirable will be equivalent to the TNT equivalent mass of the explosive, except where the TNT equivalent mass exceeds the total mass of the material at risk, in which case the amount of material released and respirable will be the total mass of the material at risk.

** 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. Additional discussion of airborne release resulting from such detonations can be found in DOE-HDBK-3010-94, Section 4.1 (Reference 5).

7.2.3.2 Radioactive Material Offsite Exposure Determination. The exposure to the maximally exposed individual at or beyond the site boundary will be estimated in terms consistent with the screening guidelines presented in Section 4.1. For radioactive material releases, Reference 3 contains a series of nomographs for common radioactive materials that provide dose estimates under various conditions relevant to aircraft crash scenarios. These nomographs may be used to provide a screening value for the site boundary dose for the materials and conditions specified. Using the nomographs to calculate doses should account for the additive property of dose over all isotopes of concern, so that isotopes are evaluated cumulatively, as opposed to individually, against guidelines. If a particular facility has materials or conditions not covered by the nomographs provided, the simple Gaussian dispersion equation that was used to develop the nomographs will be used to estimate the dose at the site boundary, using the shortest distance to the site boundary as the evaluation point and an atmospheric stability of F, with a wind speed of 2 m/s, as explained in Reference 8. For releases that are potentially buoyant, the buoyancy will be ignored for the purposes of screening calculations. The centerline dose can be estimated using the following equation:

$$Dose = \sum_{i=1}^{n} \frac{Q_i \cdot SA_i \cdot CEDE_i \cdot BR}{\pi \cdot \sigma_y \cdot \sigma_z \cdot u} \qquad (7\text{-}1)$$

where:

Dose = dose (sievert [rem]) - CEDE;
Q = material released and respirable (i.e., source term) (g);
SA = specific activity (Curies/gram [Ci/g], [Bq/g]);
CEDE = committed effective dose equivalent (rem/Ci [Sv/Bq] inhaled assuming a 1-µm activity median aerodynamic diameter particle size);
BR = breathing rate (3E-4 m^3/s);

σ_y = crosswind concentration standard deviation for F stability at 2 m/s ($\sigma_y = 0.067\ d^{0.9}$, where d = distance to site boundary);

σ_z = vertical concentration standard deviation for F stability at 2 m/s ($\sigma_z = 0.057\ d^{0.8}$, 100m < d 500m, d = distance to site boundary; $\log_{10}\sigma_z = -1.91 + 1.37 \log_{10}d - 0.119 \log_{10}^2 d$, 500m < d < 10^4m, d = distance to site boundary);

u = wind speed (2 m/s);

i = a unique designator for each material/form found in the facility.

7.2.3.3 Radioactive Material Onsite Exposure Determination. In the rare instance when assessment of exposure to onsite personnel outside the facility is desired (see discussion in Appendix A, Section A.1.2), the exposure to the maximally exposed individual at 300 m (984 ft) should be estimated in a manner consistent with the assumptions used in DOE-STD-1027-92, Attachment 1, for the calculation of Category 2 radiological thresholds, but with a dose threshold of 25 rem (0.25 Sv) instead of the 1 rem (0.01 Sv) used in this standard. Equivalently, the Category 2 radiological thresholds identified in DOE-STD-1027-92 can be used as the basis for exposure determination, using the following equation.

$$X = \sum_i \left(\frac{MAR_i}{25 \cdot Thresh_i} \right) \tag{7-2}$$

where:

MAR = material at risk (g or Ci);

Thresh = DOE-STD-1027-92 Category 2 threshold (g or Ci)[3];

i = a unique designator for each isotope found in the facility.

If X exceeds unity, the threshold has been exceeded.

7.2.4 Hazardous Chemicals. This section summarizes the screening approach for hazardous materials. More detailed information is provided in Reference 3.

7.2.4.1 Hazardous Chemical Material Source Term. The source term value will be based on a bounding release consistent with the following assumptions:

a. No credit will be taken for mitigation, either passive or active, including ventilation, fire suppression, building confinement, and rubble effects.

b. All materials will be released to the environment as a result of the impact.

c. The state and form of the release will be determined as follows:

1. For gases liquefied under pressure (e.g., chlorine, ammonia, propane), the entire contents of the vessel will be assumed to become airborne as a puff. The same will apply to wholly gaseous releases.

2. For liquids with a boiling point above ambient and storage temperatures at ambient, the material will be assumed to spill

[3] Exposure determination will not use the criticality lists for ^{233}U, ^{235}U, and ^{239}Pu, since these values are unrelated to onsite receptor dose.

instantaneously onto the ground and either spread to a depth of 1 cm (0.4 in.) or cover a well-defined diked area if there is one. The rate of evaporation will then be calculated using standard formulas such as those provided by the Center for Chemical Process Safety (CCPS) (Reference 6).

3. For refrigerated liquids, the material will likewise be assumed to spill onto the ground and either spread to a depth of 1 cm (0.4 in.) or cover a well-defined diked area. The rate of evaporation will again be calculated using standard formulas such as those provided by CCPS.

4. For a pipeline rupture, the complete contents of the pipeline up to the nearest undamaged isolation valve(s) will be assumed to be released as a puff.

5. For materials that can burn and form toxic products of combustion, the burning will be assumed to be instantaneous, with 100 percent efficient production of the toxic products.

In the above determinations, the respirable fraction will be assumed to be 100 percent. For releases that are potentially buoyant, the buoyancy will be ignored for the purposes of the screening calculation.

7.2.4.2 Hazardous Material Offsite Exposure Determination. Reference 3 contains a series of nomographs for common hazardous chemicals that provide dosage estimates under various conditions relevant to aircraft crash scenarios. These nomographs serve to guide analysts and simplify the screening process. They can be used to provide a screening value for the site boundary Level of Concern for the materials and conditions specified. If a particular facility has materials or conditions not covered by the nomographs, an acceptable technique is given by the U.S. Environmental Protection Agency's (EPA's) TSCREEN Code

(Reference 7), which does a range of calculations and selects the worst case. Alternatively, Reference 3 contains a simplified screening approach.

7.2.4.3 Hazardous Material Onsite Exposure Determination. In the rare instance when assessment of exposure to onsite personnel outside the facility is desired (see discussion in Appendix A, Section A.1.2), the onsite evaluation guideline, per Section 4.1, is that individuals should not be exposed to a concentration in excess of ERPG-3 (or an equivalent measure) at a distance of 300 m (984 ft) in Atmospheric Dispersion Category D with a windspeed of 4.25m/s (14 ft/sec). Reference 3 contains a tabulation of release rates for various chemicals that will just meet this criterion.

7.2.5 Other Methods. For both radioactive and chemical releases, other techniques may be proposed and will be evaluated for sufficiency on a case-by-case basis by the cognizant safety authority.

7.2.6 Comparison to Guidelines. The exposure to the maximally exposed individual at or beyond the site boundary will be compared to the exposure screening guidelines. If the exposure screening guidelines are met, no additional analysis of aircraft impact is required. If the exposure screening guidelines cannot be met, a more detailed analysis will be performed, based on both an assessment of the aircraft impact frequency (Chapter 5) and an evaluation of the structural response of the facility/operation subjected to aircraft impact (Chapter 6), in accordance with the approach described in Chapter 3.

7.3 Exposure Evaluation. The purpose of exposure evaluation is to determine, based on the specific level of damage and phenomenology associated with a spectrum of aircraft crashes into the subject facility, the extent to which individual members of the public and/or site workers may be exposed to a release of radioactive or hazardous chemical material. This section provides an overview of the evaluation approach. Further details are provided in Appendix D.

7.3.1 Applicability. Exposure evaluation will be performed for all facilities for which the frequency of release has been shown to exceed the release frequency evaluation guideline.

7.3.2 Application Guidance. Exposure evaluation will be based on the results of the structural response analysis performed in accordance with Chapter 6 and the scenario development part of the release frequency evaluation performed in accordance with Section 5.5. For each scenario considered, exposure evaluation will consist of translating facility damage into a source term and exposure, based on the interaction between the energy generated during the accident and the facility hazardous material inventory. Exposures should be analyzed for receptors corresponding to the exceeded guidelines, but need not be evaluated for receptors for which the corresponding guidelines are met. Therefore, for cases in which offsite guidelines are met, exposure evaluation may be restricted to onsite impacts only.

7.3.2.1 Source Term Guidance for Radioactive Material Releases: Building source term (BST) development for exposure evaluation for radioactive material releases will be consistent with the guidance provided in DOE-HDBK-3010-94 (Reference 5), which is based on a five-component linear equation:

$$BST = \sum_{i=1}^{n} \sum_{j=1}^{m} MAR_i \cdot DR_{ij} \cdot ARF_{ij} \cdot RF_{ij} \cdot LPF_{ij} \tag{7-3}$$

where:

MAR = material at risk - the amount of radionuclides available to be acted on by a given physical stress;

DR	=	damage ratio - the fraction of MAR actually impacted by the accident-generated conditions;
ARF	=	airborne release fraction - the coefficient used to estimate the amount of radioactive material suspended in air as an aerosol and thus available for transport due to a physical stress from a specific accident;
LPF	=	leakpath factor - the fraction of the radionuclides in the aerosol transported through some confinement deposition of filtration mechanism;
RF	=	respirable fraction - the fraction of airborne radionuclides as particles that can be transported through air and inhaled into the human respiratory system and is commonly assumed to include particles 10-µm Aerodynamic Equivalent Diameter (AED) and less;
i	=	a unique designator for each particular material and form found in the facility;
j	=	a unique designator for each release mechanism acting upon a given material and form found in the facility (e.g., j=1 for crush/impact, j=2 for fire, j=3 for explosion).

For valid application, the source term calculation should be based on the development of aircraft impact scenarios at a level of detail that allows for the specification of appropriate values for the above parameters. However, as discussed in DOE-STD-3009-94 (Reference 2), a graded approach should be applied to scenario development to ensure that the level of effort required to perform the analysis does not divert resources from areas where effort could be spent more appropriately. Further information on the development of radioactive material source terms is provided in Appendix D, Section D.1.

7.3.2.2 Source Term Guidance for Hazardous Chemical Releases. Source term development for exposure evaluation for hazardous chemical releases will be consistent with the guidance provided in Appendix D, Section D.2.

7.3.3 Exposure Calculation. Once a refined source term has been developed based on the structural response of the facility to the postulated aircraft impact, onsite and offsite exposures can be reassessed in accordance with Section 7.2, "Exposure Screening." If the offsite screening guideline (and the onsite screening guideline when deemed necessary) is met by the refined source term, no additional analysis of aircraft impact (i.e., meteorological dispersion and consequence assessment) is required. If the offsite screening guideline (and the onsite screening guideline when deemed necessary) cannot be met, additional analysis will be performed to assess the consequences of the release. Additional guidance is provided in Appendix D, Section D.1 (for radioactive material) and Section D.2 (for hazardous chemicals) to aid the analyst in defining the release scenarios and selecting the appropriate dispersion models and parameters. Notwithstanding the guidance provided, credit will not be taken for evacuation or medical treatment of receptors, or for passive or active mitigation due to building confinement and rubble effects.

7.4 References.

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5. United States Department of Energy, *Recommended Values and Technical Bases for*

Airborne Release Fractions/Rates and Respirable Fractions at DOE Non-Reactor Nuclear Facilities. DOE-HDBK-3010-94. 1994.

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7. United States Environmental Protection Agency, *Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants* (revised). 1992.
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APPENDIX A

BASIS FOR SCREENING AND EVALUATION GUIDELINES

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Scope. Chapter 4 presents the numerical screening and evaluation guidelines used in this standard to determine at what stage in the approach the analysis of aircraft crash is sufficient. This appendix presents the basis for the selection of these guidelines.

A.1 Exposure Screening Guidelines. Protecting the health and safety of the public is a primary concern when considering the risk from releases of hazardous material resulting from aircraft crash. This standard establishes three screening criteria for determining whether a particular facility poses a potential threat to the public. These criteria set exposure levels below which there are unlikely to be any significant health effects, even to the maximally exposed individual in the offsite population. Each of these criteria is listed below, along with the basis for its selection. Note that the criteria reflect a consistent approach toward the selection of radiological and chemical exposure guidelines, as opposed to an attempt to provide directly comparable guidelines. It would be ideal if there were total consistency between the guidelines for radioactive exposures and chemical exposures. However, given that chemicals act in different ways upon the human body, and given that regulation of hazardous chemicals and radioactive materials has historically never sought consistency (and given the desire to make as much use as possible of already established regulatory precedents), it is too much to expect that total consistency could be achieved here.

A.1.1 Exposure Screening Guidelines for Exposures Evaluated at the Site Boundary.

a. Radiological exposure - 25 rem (0.25 sievert [Sv]) committed effective dose equivalent (CEDE).

Basis: First, note the distinction between committed effective dose equivalent (CEDE) and total effective dose equivalent (TEDE). The former is the accumulated dose over 50 years following inhalation or ingestion of radionuclides. The latter includes, in addition, the dose resulting from external irradiation.

A TEDE of 25 rem (0.25 Sv) at the site boundary has precedent as a siting criterion, referenced in DOE Order 6430.1A, *General Design*

Criteria. A whole body dose of 25 rem (0.25 Sv) is generally accepted as a dose that will not cause early health effects (that is, health effects that manifest themselves within a few hours or days of irradiation).

The use of CEDE instead of TEDE may be nonconservative because it does not include external irradiation, if any. However, the predominant means of potential exposure at most U.S. nuclear facilities (i.e., nonreactor facilities) is through the inhalation of long-lived alpha emitters, from which there is a very small contribution to external irradiation. In general, therefore, the use of CEDE is approximately equivalent to the use of TEDE.

b. Hazardous material exposure - Emergency Response Planning Guideline Level 2 (ERPG-2), as established by the American Industrial Hygiene Association (AIHA).

<u>Basis</u>: The ERPG-2 is "The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action." This guideline has clearly been developed as a threshold for emergency response and has been used in a number of regulatory situations (e.g., by agencies that administer the State of California's Risk Management and Prevention Program). The use of ERPG-2 also has precedent in DOE's *Emergency Management Guide for Hazards Assessment*, where it is chosen as a protective action guideline.

c. Hazardous materials where ERPG-2 has not been established - the Level of Concern (LOC) as established by the U.S. Environmental Protection Agency (EPA), as specified in the 1987 EPA *Technical Guidance on Hazards Analysis* (or a successor document).

Basis: Currently, ERPGs have only been defined for 35 chemicals. In Appendix A of *Technical Guidance on Hazards Analysis*, the EPA discusses the options that are available for the definition of the LOC. For most chemicals, the Immediately Dangerous to Life and Health (IDLH) is tabulated. The IDLH has been developed by the National Institute for Occupational Safety and Health (NIOSH) and is defined as "The maximum concentration of a substance in air from which healthy male workers can escape without loss of life or irreversible health effects under conditions of a maximum 30-minute exposure time." EPA recommends 10 percent of the IDLH as an LOC. If neither the IDLH nor the ERPG is available, it is recommended that the analyst consult an expert toxicologist.

Occasionally, the question arises as to whether worker exposure limits such as the Threshold Limit Value (TLV) could be used as LOCs in emergencies involving the public. The TLV has been developed by the American Conference of Government Industrial Hygienists (ACGIH) to limit workplace exposure. ACGIH explicitly advises against using or applying TLVs outside the workplace.

A.1.2 Onsite Exposure Screening Guidelines. Much thought went into the issue of whether additional guidelines were required specifically to address the risk to onsite workers. That is, could there be cases in which more detailed analysis of aircraft crash scenarios would be desirable even if there no risk to the public? It was felt that, in the main, there would be no need for guidelines related to worker safety. The basis for this conclusion is the nature of aircraft crash itself. An aircraft crash violent enough to cause a release from a facility will result in death to the occupants of the aircraft with near certainty. Further, the level of damage at the facility itself would also, with high probability, result in death or serious injury to occupants of the facility or neighboring areas directly affected by the crash and associated debris. When one considers these high probability consequences, exposure to hazardous material release is very unlikely to add significantly to the workers' overall risk from the accident. In fact, the insights developed from further analysis could prove to be misleading, since actions might be taken to protect workers from hazardous material release when the true risk is from the crash itself. For these reasons, this standard takes the position that incremental risk to the offsite public is the appropriate metric for determining whether the additional analysis of aircraft crash release scenarios is warranted.

It is recognized, however, that there may be unique cases for which consideration of the impact of releases on onsite workers may be useful in the absence of any impact on the offsite public. Specifically, one could envision a situation where there is an unoccupied (or lightly occupied) facility containing very large amounts of hazardous material in close proximity to a large concentration of workers (but not close enough that these workers could be directly impacted by the same crash that would cause the release) and where the closest offsite member of the public is a great distance away. In such a case, it is possible that the offsite exposure guideline would not be exceeded, but the greatest risk to the workers would be from a hazardous material release.

To address such rare circumstances, three onsite exposure guidelines were established. The basis for these guidelines is provided below.

a. Radiological exposure - the facility inventory exceeds 25 times the Hazard Category 2 threshold quantities provided in DOE-STD-1027-92.

   Basis: DOE-STD-1027-92 contains a table of radionuclides, showing the maximum number of curies that could be released and cause a CEDE of 1 rem (0.01 Sv) at a distance of 300 m (984 ft) in atmospheric stability Category D with a wind speed of 4.5 m/s (14.8 ft/sec). These curie quantities are the thresholds for defining a facility as Hazard Category 2. Clearly, 25 times these quantities would lead to a radiation dose of 25 rem (0.25 Sv) CEDE at 300 m (984 ft) and, as noted above, 25 rem (0.25 Sv) CEDE is being taken as a surrogate threshold for 25 rem (0.25 Sv) to the whole body, which is a threshold for early injury.

Since the precedent has already been established in an existing DOE standard, it is reasonable to take 25 times the DOE-STD-1027-92 Hazard Category 2 thresholds as limiting inventories, above which there would be potential injuries to workers at a distance of 300 m (984 ft) in the above-specified weather conditions.

b. Hazardous material exposure - Emergency Response Planning Guideline Level 3 (ERPG-3) as established by the AIHA, to the maximally exposed individual beyond 300 m (984 ft) from the facility.

Basis: The ERPG-3 is "The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life threatening health effects." In spirit, the ERPG-3 seems to be closer to the IDLH than does the ERPG-2, so it is reasonable to choose it as a guideline for the impact on workers.

c. Hazardous material exposure where ERPG-3 has not been established - the IDLH, as established by the NIOSH, to the maximally exposed individual beyond 300 m (984 ft) from the facility.

Basis: As noted above, the IDLH is "The maximum concentration of a substance in air from which healthy male workers can escape without loss of life or irreversible health effects under conditions of a maximum 30-minute exposure time." Thus, the IDLH has been specifically defined with worker protection in mind.

The analyst is warned against creating more work than is necessary by pursuing evaluation against the onsite screening guidelines when the circumstances do not warrant it. As discussed above, these guidelines are provided to address specific, unique cases in which special consideration of worker exposure resulting from aircraft crash would provide meaningful additional insights. The default position is that the onsite guidelines are not needed. Thus, the analyst's obligation is to justify why they should be used in a specific case, not why they are not being used. In particular, it should be noted that, because of the differences between the offsite and onsite guidelines and the way the exposure calculations are performed, the onsite guidelines are totally useless when the site boundary is within 300 m (984 ft) of the facility and are very likely to be useless when the site boundary is within 1000 m (3280 ft) of the facility.

A.1.3 Potential Contamination to the Environment Exposure Screening Guidelines. The final topic considered in developing the exposure screening guidelines was potential contamination of the environment. In most cases, it was felt that exposure to the general public was a sufficient surrogate for offsite environmental contamination. Similarly, if onsite contamination were an issue, then exposure to onsite workers was considered a sufficient surrogate. Although it was recognized that this may not always be the case, there was no obvious set of accidental contamination guidelines readily available for incorporation into this standard. This is in large part due to the fact that there are many different types of environmental receptors (as opposed to only one, a human, for health and safety), and these receptors vary in their sensitivity to different hazards. For this reason, providing specific guidelines for environmental contamination was felt to be impractical. As stated in Section 1.3, "Applicability," it is left to the analyst to determine whether special conditions exist that would warrant a specific evaluation of environmental impacts in those cases where such analysis is not warranted by health and safety concerns. Again, the default position is that such analyses are not needed, and the burden is on the analyst to justify their inclusion.

A.2 Frequency Screening Guidelines. The DOE has issued a standard, DOE-STD-3009-94 (Reference 1), providing guidance for the preparation of Safety Analysis Reports (SARs). This standard states that an external event should be analyzed as a design basis accident (DBA) if its frequency of occurrence exceeds 1E-6/y conservatively estimated, or 1E-7/y, realistically estimated. Aircraft crash impacts are human-caused external events, and this standard's methodology has been developed in a conservative manner. Therefore, the DOE has provided the 1E-6/y screening value for aircraft crash impact accidents in terms of design basis considerations. DOE-STD-3009-94 also states that the use of this cutoff frequency represents a unique case, based on established NRC precedents for human-caused external events, such as aircraft crash.

There are no universally accepted definitions of either risk acceptance criteria or screening values. It is impossible to use a "zero risk" philosophy because, short of terminating a program, there are always residual risks. In fact, terminating a program could actually result in higher risks because of the spreading of risks from one program area to another. Because of these and other difficulties, risk frequency screening as used in this standard has, as its primary objective, efficient resource allocation. The screened out scenarios are considered safe enough, for the purpose of this standard, that additional resources do not have to be expended in further analyzing them. However, those postulated accident scenarios that are screened out because they are located in the "risk acceptance" region of the risk curve or matrix can still be evaluated by reviewers.

The FDA, EPA, DOE, NRC, and ANSI (References 1 through 8) have documented precedents that exclude events from further analysis if they have postulated accident frequencies less than 1E-6/y. DOE has further restricted this interpretation to apply only to external events, such as aircraft crash impact accident sequences. Only the FDA and EPA have attempted to codify a quantitative "incredible" cutoff frequency. The FDA assumed that "one in a million" is considered safe enough in terms of developing cancer. In the 1990 revised *National Contingency Plan,* EPA used accident frequencies of 1E-6/y as a point of departure, below which regulatory consideration is not warranted, and recognized that the acceptable risk frequency range could in fact be several orders of magnitude greater.

This standard uses 1E-6/y as a benchmark for resource allocation. In other words, when postulated aircraft crash impact frequencies fall below the 1E-6/y cutoff frequency, this standard implies that, for the purpose of resource allocation, these scenarios can be regarded as "safe enough," and no further resource expenditures are necessary for analyzing the scenarios and implementing risk reduction recommendations. This by no means implies that postulated accident scenarios that have frequencies less than 1E-6/y are acceptable risks because they lie below the boundary between risk rejection and risk acceptance. This standard uses the screening cutoff frequency in terms of the sum of all aircraft crash impact frequencies, which are also the initiating event frequencies. All individual aircraft type initiating event frequencies and subsequent accident sequences will have frequencies less than the cutoff. This criterion applies to the frequency screening, frequency evaluation, and damage assessment stages of the process. In all three stages, the sum of the applicable initiating event frequencies is determined and the same 1E-6/y screening value is applied.

A.3 Structural Response Screening Guidelines. The basis for the structural response guidelines is predominantly the industry norms that are prescribed and uniformly accepted by structural engineering professionals through the national and consensus codes.

For local damage to reinforced concrete structures, it was felt that some degree of conservatism would be achieved by increasing the penetration thickness by 10 and 20 percent for scabbing and perforation, respectively. The rationale behind this increase is to account for any uncertainty; and because these are empirical formulas, in some cases validated by test results, a nominal increase would ensure consistency and lend some degree of assurance that failure would be prevented if these requirements were met. Similarly, for steel targets, an increase of 25 percent over the penetration depth was recommended to prevent any failure.

As for excessive structural deformation/collapse and the SSCs' functionality, the national consensus codes were recommended to be consistent with the analysis/design evaluation for structures subjected to any other such accidental or abnormal load.

A.4 References.

1. United States Department of Energy. *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports.* DOE-STD-3009-94. July, 1994.

2. American Nuclear Society. *American National Standard Guidelines for Combining Natural and External Man-made Hazards at Power Reactor Sites*. ANSI/ANS-2, 12-1978. 1978.

3. American Nuclear Society. *American National Standard Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants*. ANSI/ANS-51.1-1983. 1983.

4. United States Environmental Protection Agency. *EPA Watch*, Vol. 3, No. 17. The DeWeese Publishing Company, 1995.

5. United States Environmental Protection Agency. (1990 *National Contingency Plan*.) "National Oil and Hazardous Pollution Prevention Plan. Final Rule," *Federal Register*, 8670-8852, March 8, 1990.

6. National Safety Council. Annual published data. 1990.

7. Travis, C.C. *Environmental Science and Technology*. 1991.

8. United States Department of Energy. *Nuclear Safety Policy*. SEN-35-91. September 9, 1991.

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APPENDIX B

GUIDANCE AND DATA FOR IMPACT FREQUENCY CALCULATION

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This appendix provides the information and guidance necessary to implement the frequency calculation methods described in Chapter 5 of the standard.

B.1 Determination of Number of Operations. The first factor in determining the aircraft impact frequency, F, is the number of annual aircraft flight activities, N, near the site under consideration. Because of the different ways in which flight operations are conducted, aircraft flight activities are tabulated differently for the airport environment and the nonairport environment.

In the airport environment, aircraft flight activities may be tabulated in terms of aircraft operations or airport operations. The analyst may have to use data concerning either aircraft operations or airport operations or both to derive a value for N. Aircraft operations, as defined by the Federal Aviation Administration (FAA), include the arrivals at and departures from an airport at which an airport traffic control tower is located. Airport operations are defined as either local or itinerant. Local airport operations are flights in which the aircraft flies to a nearby airport or performs simulated approaches to the airport. Also classified as local operations are those which include aircraft that (1) operate in the local traffic pattern or within sight of the airport, (2) are known to be departing for or arriving from practice areas located within a 22-mile radius of the airport, or (3) execute simulated instrument approaches or low passes at the airport. All other airport operations are classified as itinerant operations. Itinerant operations are basically flights which land at the airport after a trip from somewhere else, or take off from the airport for a trip elsewhere. For both itinerant and local airport operations, each takeoff, landing, or approach without landing is an operation. For historical data on airport operations at airports with FAA control towers, the analyst should obtain the document, *FAA Air Traffic Activity,* distributed by the FAA Office of Aviation Policy, Plans and Management Analysis each fiscal year.

For the nonairport environment, values for the NPf(x,y) product have been determined. If additional information is needed, the analyst should consult the *ACRAM Modeling Technical Support Document* (Reference 1) and the *Data Development Technical*

Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard (Reference 2) for further information.

B.2 Aircraft Crash Rates. Generic crash rates for each aircraft category and subcategory were calculated based on a review of accident reports published by FAA and/or the National Transportation Safety Board (NTSB) for civilian aircraft, and by the United States military for military aircraft. The evaluation techniques used to estimate specific crash rates for each aircraft category or subcategory are documented in Reference 2. See this document for more information on the databases and evaluation techniques. Table B-1 provides the generic crash rates for each aircraft category (and subcategory as available).

B.3 Crash Location Probability. Crash location probabilities per square mile in the vicinity of a runway were calculated based on a review of accident reports published by FAA and/or NTSB for civilian aircraft, and by the United States Air Force for military aircraft. The probability values are given in a tabular format for commercial, general aviation, and military aircraft categories (or subcategories as available). The probability values are a function of distance from an intended runway. Each probability value reflects the conditional probability that, given a crash, the crash will occur within a specific one-square-mile bin in the vicinity of an airport. The data and calculations used to determine the probability values are provided in Reference 2.

Since the crash location probabilities are a function of distance from a runway, it is important that the coordinate convention specified in this standard be used. Using this convention, the analyst will determine the facility's location coordinates (x and y distances) and find the appropriate probability value for the facility.

TABLE B-1. Aircraft crash rates by category, subcategory, and flight phase.[1]

AIRCRAFT	CRASH RATE (P)	
	Takeoff (per takeoff)	Landing (per landing)
General Aviation		
1. Fixed Wing Single Engine Reciprocating	1.1E-5	2.0E-5
2. Fixed Wing Multiengine Reciprocating	9.3E-6	2.3E-5
3. Fixed Wing Turboprop	3.5E-6	8.3E-6
4. Fixed Wing Turbojet	1.4E-6	4.7E-6
Representative Fixed Wing	1.1E-5	2.0E-5
Representative Helicopter[2]	2.5E-5	See Note 2
Commercial		
1. Air Carrier	1.9E-7	2.8E-7
2. Air Taxi	1.0E-6	2.3E-6
Military		
1. Large Aircraft [3]	5.7E-7	1.6E-6
2. Small Aircraft [4]	1.8E-6	3.3E-6

Notes:

[1] Reference 1 provides additional information, such as the crash rate per mile for these aircraft categories.

[2]Helicopter crashes are considered on a per-flight basis and are reported under takeoff for convenience.

[3]Large military aircraft includes bombers, cargo aircraft, and tankers.

[4]Small military aircraft includes fighters, attack aircraft, and trainers.

B.3.1 Coordinate Convention. At an airport, each runway is designated by two numbers (one for each end). Each number designation is approximately one-tenth of the angle that the extended runway direction makes with magnetic north. For example, depending on its direction of use, a runway may be called Runway 4 or Runway 22. An aircraft departing Runway 4 flies an approximate course of 40 degrees with respect to magnetic north; similarly, an aircraft landing on Runway 4 also flies an approximate course of 40 degrees prior to touchdown. Use of Runway 22 sets the flight course at 220 degrees with respect to magnetic north. Parallel runways receive similar numbers with right (R) and left (L) designations.

To define aircraft crash locations relative to airfield runways and facilities, it is necessary to establish a location coordinate system. This standard uses the Cartesian coordinate convention with the following characteristics:

1. The origin of the coordinate system is at the center of the relevant runway.

2. The x axis coincides with the extended runway centerline; the positive direction is the direction of flight.

3. The y axis is perpendicular to the x axis with the positive direction created by a 90-degree counterclockwise rotation of the positive x axis.

The coordinate system is depicted in Figure B-1.

This figure is used for determining f(x,y) for:

Commercial Aircraft Takeoff - Table B-2
Commercial Aircraft Landing - Table B-3
General Aviation Takeoff - Table B-4
General Aviation Landing - Table B-5

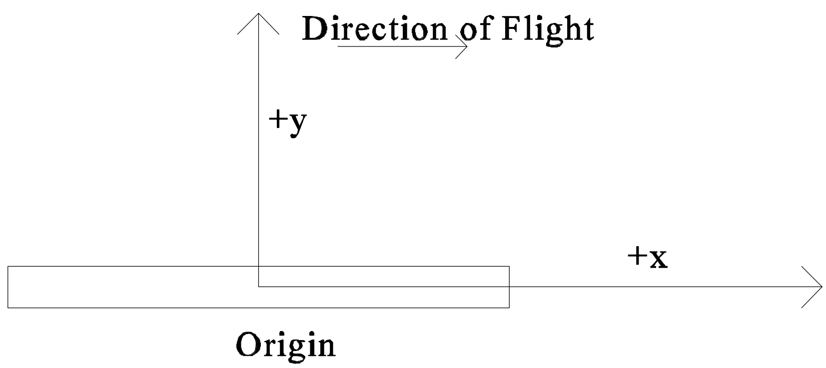

FIGURE B-1. Coordinate convention for use with crash location probability tables for commercial and general aviation

Often, the location of a facility is expressed in terms of the distance, R, and bearing, θ, from the facility to the airfield. For purposes of this standard, it is appropriate to assume that these measurements represent the distance and bearing from the corner of the facility closest to the runway to the center of the relevant runway. To determine the x,y values of the facility in the specified coordinate system, apply Equations B-1 and B-2.

$$x = -R \cos(\theta - \phi) \tag{B-1}$$

and

$$y = R \sin(\theta - \phi) \tag{B-2}$$

where:

R	=	distance from the facility (miles);
θ	=	bearing from the facility to the airport;
ϕ	=	runway bearing as an angle with respect to magnetic north (this equals the runway number times ten).

B.3.2 Pattern Side for Military Aviation. For military aviation, a landing often involves an initial approach over the runway followed by a turn to a downwind leg parallel to the runway, a base leg turn, and a final approach to a full-stop landing. This flight pattern is usually performed on a specified side of the runway, referred to as the pattern side. All local operations, e.g., touch-and-goes, also involve pattern side flight. This concentration of traffic on the pattern side of the runway is reflected in the crash locations, thus influencing crash location probabilities. In other words, there tends to be a bias toward the pattern side. To accommodate this, separate tables of crash location probabilities are provided for cases when the pattern side is to the left of the direction of flight and cases when it is to the right of the direction of flight. The pattern side is shown in Figure B-2

This figure is used for determining f(x,y) for:

A. Pattern side to the right of the direction of flight
Large Military Aircraft Takeoff - Table B-6
Large Military Aircraft Landing - Table B-8
Small Military Aircraft Takeoff - Table B-10
Small Military Aircraft Landing - Table B-12

B. Pattern side to the left of the direction of flight
Large Military Aircraft Takeoff - Table B-7
Large Military Aircraft Landing - Table B-9
Small Military Aircraft Takeoff - Table B-11
Small Military Aircraft Landing - Table B-13

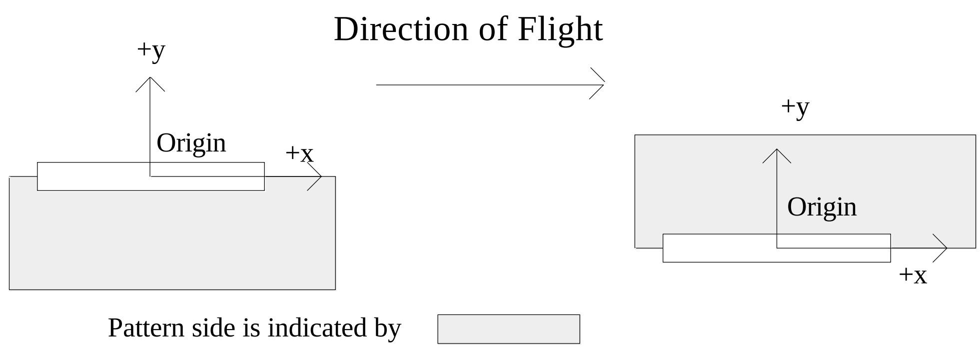

FIGURE B-2. Coordinate convention and effect of pattern side, for use with crash location probability tables for military aviation

B.3.3 Crash Location Probabilities for Near-airport Operations. Tables B-2 through B-13 provide crash location probabilities for near-airport operations. Each entry in the tables represents the conditional probability that, given an aircraft crash, the aircraft will crash in the one-mile-square area defined by the 1-mile x direction and 1-mile y direction intervals in the horizontal and vertical headings of the table. Tables B-2 and B-3 are for commercial aviation and are relevant to both air carriers and air taxis.

Tables B-4 and B-5 are for general aviation and are applicable to all fixed wing general aviation aircraft. Separate tables are provided for large and small military aircraft and for the pattern side to the right and to the left of the runway. Tables B-6 and B-8 are for large military aircraft with the pattern side to the right of the runway; Tables B-7 and B-9 are for large military aircraft with the pattern side to the left of the runway; Tables B-10 and B-12 are for small military aircraft with the pattern side to the right of the runway; and Tables B-11 and B-13 are for small military aircraft with the pattern side to the left of the runway.

Note that the commercial aviation takeoff and landing crash location probability values are symmetric about the x axis (the extended runway centerline), i.e., $f(x,y)=f(x,-y)$. In addition, the crash locations are concentrated along the x axis, which is to be expected, since commercial aircraft are always flown under instrument flight rules and follow a precise directional approach during takeoff and landing operations. Also note that, consistent with the coordinate convention system used, all takeoff crash locations are in the positive x direction occurring beyond the end of the runway (see Table B-2). The landing crashes have negative values for the x distance, because during landing the aircraft approaches the runway from a negative x value and heads towards the origin.

Tables B-4 and B-5 provide the estimated crash location probability values for fixed wing general aviation takeoff and landing crashes, respectively. The estimated probability values are based on the crash location classifications and distances provided in the NTSB database. The probability values indicate more widely spread crash locations, as expected, since general aviation aircraft are frequently used for training and takeoff and landing practice, and they are usually flown under visual flight rules.

For military aviation, two sets of crash location probability values are provided for each aircraft subcategory. Each set identifies the pattern side, the side of the runway where the majority of flight activities take place. For large military aircraft, the estimated crash location probability values for takeoff and landing crashes are provided in Tables B-6 and B-8 when the pattern side is on the right side of the runway, and in Tables B-7 and B-9 when the pattern side is on the left side of the runway. For small military aircraft, the estimated crash location probability values for takeoff and landing crashes are provided in Tables B-10 and B-12 when the pattern side is on the right side of the runway, and in Tables B-11 and B-13 when the pattern side is on the left side of the runway.

A comparison of the military aviation tables with those for commercial aviation indicates significant differences between the areas where takeoff and landing crashes are expected to occur. In commercial aviation, landing crashes end just about a mile from the origin (center of the runway). In military aviation, landing crashes are more widespread and extend up to 10 miles beyond the end of the runway. These differences are driven by the assumptions made in the classification of crashes. For military crashes, takeoffs are defined as the instant the aircraft lifts from the runway until the time it transitions to climb to cruise altitude. If an aircraft crashes after takeoff with no control capability, it is considered a takeoff crash. However, if an aircraft gets into trouble during takeoff and the pilot is able to turn the aircraft for an attempted emergency landing but crashes prior to a successful landing, it is considered a landing crash. Therefore, an aircraft which has taken off from one end of the runway could crash miles away from that end of the runway but still be classified as a landing crash. This is why the takeoff crash location probability values for military aviation are concentrated along the extended centerline of a runway, and those for the landing crashes are spread out. In addition, because the downwind leg is parallel to, but some distance away from, the runway, the landing probability values would not necessarily monotonically decrease with increasing values of y, as is the case for commercial aviation. Since the identification of crashes used to estimate the crash rates and location probability values is consistent within each of the categories, military and commercial, differences in the shape of the location distributions for military and commercial aviation are realistic and do not affect the overall impact frequency calculations.

The crash location probability values represent the conditional probability, given a crash, of a crash into an area of one square mile. The analyst would use the facility's coordinates (Cartesian distances) that fall within a bin identified in Tables B-2 through B-13 to find the corresponding crash location probability value. For example, if a facility's coordinate with respect to a runway is (x= -4.7, y=3.2), the analyst would take, from the appropriate table, the crash location probability value that is given for the bin at the intersection of (-5, -4) for the x value and (3, 4) for the y value. If the facility's coordinate falls outside the boundaries of any of the tables or falls in a bin where no value is given, the corresponding probability value is assumed to be zero.

B.3.4 Expected Number of Crashes Per Square Mile Per Year for Nonairport Operations. Because of the limited number of historical in-flight crashes, particularly for commercial and large military aircraft, frequency calculations for nonairport operations are based on modeling the number of crashes per square mile per year, i.e., the product NPf(x,y), and combining this with the facility effective area.

Table B-14 presents values of NPf(x,y), i.e., the expected number of crashes per square mile per year, for general aviation applicable to selected DOE sites, as well as maximum, minimum, and average values applicable to an arbitrary one-square-mile area within the CONUS. These values have been derived from an analysis of the locations of historical general aviation crashes. If site-specific information is required and not presented here, further information is provided in Reference 2.

Table B-15 presents the maximum, minimum, average CONUS, and selected DOE site values of NPf(x,y) (i.e., number of crashes per square mile per year) for commercial and military aviation nonairport operations. These values have been derived from an analysis of the historical locations of commercial and military aircraft combined with the distribution of the activity levels in various ARTCCs. If site-specific information is required and not presented here, further information is provided in Reference 2.

For military aviation, the values provided are based on 'normal' military aircraft in-flight crashes, which are not associated with special maneuvering and low level operations at military operations areas (MOAs) and training ranges. Analysts at facilities in the proximity of such areas must take into consideration the effects these types of operations have on their facilities. It is expected that future revisions of Reference 2 will provide additional information about this situation.

TABLE B-2. Crash location probability f(x,y) for commercial aircraft takeoff.

X⇒ Y⇓	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12
13,14							1.1E-5	1.1E-5					
12,13						1.0E-5	1.4E-5	1.3E-5	1.0E-5				
11,12						1.4E-5	1.7E-5	1.6E-5	1.2E-5				
10,11					1.1E-5	1.9E-5	2.2E-5	1.9E-5	1.4E-5				
9,10					1.7E-5	2.6E-5	2.8E-5	2.4E-5	1.6E-5				
8,9				1.1E-5	2.6E-5	3.7E-5	3.7E-5	2.9E-5	1.9E-5	1.1E-5			
7,8				2.0E-5	4.0E-5	5.3E-5	5.0E-5	3.7E-5	2.3E-5	1.3E-5			
6,7			1.1E-5	3.7E-5	6.6E-5	7.8E-5	6.8E-5	4.8E-5	2.9E-5	1.6E-5			
5,6			2.6E-5	7.3E-5	1.1E-4	1.2E-4	9.6E-5	6.3E-5	3.6E-5	1.9E-5			
4,5		1.1E-5	6.8E-5	1.6E-4	2.1E-4	1.9E-4	1.4E-4	8.6E-5	4.7E-5	2.4E-5	1.1E-5		
3,4		4.5E-5	2.0E-4	3.7E-4	4.1E-4	3.3E-4	2.2E-4	1.2E-4	6.4E-5	3.1E-5	1.4E-5		
2,3		2.3E-4	7.3E-4	1.0E-3	9.2E-4	6.4E-4	3.7E-4	1.9E-4	9.2E-5	4.2E-5	1.9E-5		
1,2	1.0E-4	1.8E-3	3.9E-3	3.8E-3	2.6E-3	1.5E-3	7.5E-4	3.5E-4	1.5E-4	6.5E-5	2.8E-5	1.2E-5	
0,1	2.6E-2	1.8E-1	1.5E-1	7.1E-2	2.8E-2	1.1E-2	3.9E-3	1.5E-3	5.5E-4	2.1E-4	8.0E-5	3.1E-5	1.2E-5
-1,0	2.6E-2	1.8E-1	1.5E-1	7.1E-2	2.8E-2	1.1E-2	3.9E-3	1.5E-3	5.5E-4	2.1E-4	8.0E-5	3.1E-5	1.2E-5
-2,-1	1.0E-4	1.8E-3	3.9E-3	3.8E-3	2.6E-3	1.5E-3	7.5E-4	3.5E-4	1.5E-4	6.5E-5	2.8E-5	1.2E-5	
-3,-2		2.3E-4	7.3E-4	1.0E-3	9.2E-4	6.4E-4	3.7E-4	1.9E-4	9.2E-5	4.2E-5	1.9E-5		
-4,-3		4.5E-5	2.0E-4	3.7E-4	4.1E-4	3.3E-4	2.2E-4	1.2E-4	6.4E-5	3.1E-5	1.4E-5		
-5,-4		1.1E-5	6.8E-5	1.6E-4	2.1E-4	1.9E-4	1.4E-4	8.6E-5	4.7E-5	2.4E-5	1.1E-5		
-6,-5			2.6E-5	7.3E-5	1.1E-4	1.2E-4	9.6E-5	6.3E-5	3.6E-5	1.9E-5			
-7,-6			1.1E-5	3.7E-5	6.6E-5	7.8E-5	6.8E-5	4.8E-5	2.9E-5	1.6E-5			
-8,-7				2.0E-5	4.0E-5	5.3E-5	5.0E-5	3.7E-5	2.3E-5	1.3E-5			
-9,-8				1.1E-5	2.6E-5	3.7E-5	3.7E-5	2.9E-5	1.9E-5	1.1E-5			
-10,-9					1.7E-5	2.6E-5	2.8E-5	2.4E-5	1.6E-5				
-11,-10					1.1E-5	1.9E-5	2.2E-5	1.9E-5	1.4E-5				
-12,-11						1.4E-5	1.7E-5	1.6E-5	1.2E-5				
-13,-12						1.0E-5	1.4E-5	1.3E-5	1.0E-5				
-14,-13							1.1E-5	1.1E-5					

TABLE B-3. Crash location probability f(x,y) for commercial aircraft landing.

X⇒ Y⇓	-16,-15	-15,-14	-14,-13	-13,-12	-12,-11	-11,-10	-10,-9	-9,-8	-8,-7	-7,-6	-6,-5	-5,-4	-4,-3	-3,-2	-2,-1	-1,0	0,1
5,6					1.2E-5	1.2E-5											
4,5			1.0E-5	1.4E-5	1.9E-5	2.1E-5	2.1E-5	1.6E-5									
3,4			1.4E-5	2.2E-5	3.1E-5	4.0E-5	4.6E-5	4.4E-5	3.4E-5	2.0E-5							
2,3		1.2E-5	2.0E-5	3.4E-5	5.4E-5	7.9E-5	1.1E-4	1.3E-4	1.3E-4	1.1E-4	7.1E-5	3.3E-5					
1,2		1.6E-5	3.1E-5	5.6E-5	1.0E-4	1.7E-4	2.8E-4	4.2E-4	5.8E-4	7.1E-4	7.5E-4	6.5E-4	4.3E-4	1.9E-4	5.1E-5		
0,1	1.4E-5	2.9E-5	5.9E-5	1.2E-4	2.5E-4	5.0E-4	1.0E-3	2.1E-3	4.3E-3	8.6E-3	1.7E-2	3.4E-2	6.3E-2	1.1E-1	1.5E-1	9.9E-2	6.9E-3
-1,0	1.4E-5	2.9E-5	5.9E-5	1.2E-4	2.5E-4	5.0E-4	1.0E-3	2.1E-3	4.3E-3	8.6E-3	1.7E-2	3.4E-2	6.3E-2	1.1E-1	1.5E-1	9.9E-2	6.9E-3
-2,-1		1.6E-5	3.1E-5	5.6E-5	1.0E-4	1.7E-4	2.8E-4	4.2E-4	5.8E-4	7.1E-4	7.5E-4	6.5E-4	4.3E-4	1.9E-4	5.1E-5		
-3,-2		1.2E-5	2.0E-5	3.4E-5	5.4E-5	7.9E-5	1.1E-4	1.3E-4	1.3E-4	1.1E-4	7.1E-5	3.3E-5					
-4,-3			1.4E-5	2.2E-5	3.1E-5	4.0E-5	4.6E-5	4.4E-5	3.4E-5	2.0E-5							
-5,-4			1.0E-5	1.4E-5	1.9E-5	2.1E-5	2.1E-5	1.6E-5									
-6,-5					1.2E-5	1.2E-5											

TABLE B-4. Crash location probability f(x,y) for general aviation aircraft takeoff.

X⇒ Y⇓	-4,-3	-3,-2	-2,-1	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8
3,4				1.2E-5	1.8E-4	4.2E-4	1.7E-4	1.4E-5				
2,3			1.1E-5	1.6E-4	1.1E-3	2.2E-3	9.1E-4	4.1E-4	1.1E-3	6.7E-4	6.5E-5	
1,2		1.7E-5	6.2E-4	8.4E-3	1.5E-2	1.0E-2	4.0E-3	2.0E-3	3.2E-3	1.9E-3	2.1E-4	
0,1		3.5E-4	7.1E-3	1.5E-1	2.0E-1	7.2E-2	2.2E-2	5.9E-3	4.6E-3	4.6E-3	1.5E-3	1.7E-4
-1,0	1.1E-5	4.9E-4	8.4E-3	1.5E-1	1.9E-1	6.6E-2	2.1E-2	6.2E-3	4.4E-3	4.5E-3	1.5E-3	1.7E-4
-2,-1		6.1E-5	1.1E-3	9.2E-3	1.3E-2	5.9E-3	2.1E-3	5.2E-4	2.8E-4	3.9E-4	1.4E-4	1.0E-5
-3,-2			1.7E-5	1.0E-4	1.7E-4	4.6E-4	1.0E-3	5.2E-4	8.0E-4	1.7E-3	6.1E-4	3.7E-5
-4,-3					2.6E-5	4.4E-4	1.2E-3	5.8E-4	2.0E-4	3.4E-4	1.3E-4	
-5,-4						1.5E-5	4.3E-5	2.0E-5				

TABLE B-5. Crash location probability f(x,y) for general aviation aircraft landing

X→ Y⇓	-16, -15	-15, -14	-14, -13	-13, -12	-12, -11	-11, -10	-10,-9	-9,-8	-8,-7	-7,-6	-6,-5	-5, -4	-4,-3	-3,-2	-2,-1	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8
5,6													1.5E-5	6.3E-5	1.9E-4	3.5E-4	3.5E-4	1.9E-4	6.2E-5	1.5E-5				
4,5												4.3E-5	1.9E-4	4.3E-4	6.1E-4	6.8E-4	6.0E-4	4.9E-4	3.8E-4	2.4E-4	1.7E-4	8.7E-5	2.0E-5	
3,4										3.3E-5	1.1E-4	2.7E-4	5.2E-4	8.3E-4	9.7E-4	7.6E-4	5.0E-4	3.9E-4	3.7E-4	4.8E-4	4.8E-4	2.3E-4	4.4E-5	
2,3			5.6E-5	2.0E-4	3.3E-4	2.9E-4	1.6E-4	7.1E-5	9.9E-5	3.1E-4	5.0E-4	4.5E-4	7.5E-4	1.5E-3	1.7E-3	1.1E-3	6.0E-4	4.0E-4	4.5E-4	7.1E-4	7.1E-4	3.3E-4	6.0E-5	
1,2		7.2E-5	2.8E-4	5.2E-4	6.1E-4	5.6E-4	4.5E-4	4.5E-4	6.5E-4	8.8E-4	8.7E-4	6.6E-4	1.1E-3	3.0E-3	5.8E-3	1.2E-2	1.1E-2	4.4E-3	1.5E-3	7.0E-4	5.3E-4	3.3E-4	8.9E-5	
0,1	1.2E-5	1.0E-4	3.5E-4	5.3E-4	5.0E-4	5.8E-4	7.4E-4	9.5E-4	1.6E-3	2.9E-3	4.0E-3	4.3E-3	7.2E-3	1.8E-2	3.9E-2	1.6E-1	1.6E-1	2.9E-2	1.1E-2	3.9E-3	2.6E-3	1.7E-3	5.6E-4	6.8E-5
-1,0		7.3E-5	3.1E-4	6.0E-4	6.3E-4	6.0E-4	6.5E-4	6.7E-4	1.1E-3	2.2E-3	3.3E-3	3.8E-3	6.8E-3	1.7E-2	3.7E-2	1.6E-1	1.6E-1	2.8E-2	1.0E-2	4.0E-3	3.0E-3	2.1E-3	6.5E-4	7.7E-5
-2,-1			5.8E-5	1.9E-4	3.0E-4	3.9E-4	3.7E-4	2.1E-4	2.5E-4	3.5E-4	5.1E-4	7.4E-4	1.0E-3	2.3E-3	4.9E-3	1.1E-2	1.0E-2	3.8E-3	1.6E-3	8.2E-4	6.0E-4	4.0E-4	1.2E-4	1.4E-5
-3,-2			4.6E-5	1.6E-4	2.1E-4	1.5E-4	1.0E-4	7.8E-5	1.9E-4	3.2E-4	3.9E-4	5.3E-4	6.8E-4	1.1E-3	1.4E-3	1.2E-3	9.4E-4	6.8E-4	4.7E-4	4.2E-4	3.7E-4	1.6E-4	2.7E-5	
-4,-3								5.2E-5	1.6E-4	2.0E-4	2.5E-4	6.0E-4	8.3E-4	5.8E-4	3.6E-4	3.9E-4	3.3E-4	1.4E-4	1.4E-4	2.8E-4	2.4E-4	8.1E-5		
-5,-4								4.8E-5	1.5E-4	1.7E-4	1.8E-4	3.5E-4	4.8E-4	3.8E-4	2.5E-4	3.3E-4	3.1E-4	1.2E-4	1.2E-4	2.6E-4	2.2E-4	6.8E-5		
-6,-5												1.3E-5	1.6E-5	2.5E-5	1.1E-4	3.0E-4	3.0E-4	1.1E-4	3.5E-5	5.3E-5	4.5E-5	1.4E-5		

TABLE B-6. Crash location probability f(x,y) for large military aircraft takeoff with the pattern side to the right of the direction of flight.

X⇒ Y⇓	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12	12,13
1,2	4.3E-4	9.6E-4	1.5E-3	1.7E-3	1.3E-3	6.9E-4	2.4E-4	5.5E-5						
0,1	2.3E-2	5.0E-2	7.4E-2	7.7E-2	5.6E-2	2.8E-2	9.7E-3	2.4E-3	6.2E-4	2.2E-4	7.9E-5	2.0E-5		
-1,0	3.4E-2	7.1E-2	1.0E-1	1.0E-1	7.0E-2	3.9E-2	2.5E-2	2.3E-2	2.1E-2	1.3E-2	5.1E-3	1.3E-3	2.1E-4	2.1E-5
-2,-1	1.7E-2	2.7E-2	2.8E-2	1.9E-2	9.8E-3	7.1E-3	1.1E-2	1.6E-2	1.6E-2	9.8E-3	3.9E-3	9.8E-4	1.6E-4	1.6E-5
-3,-2	4.4E-4	6.8E-4	6.7E-4	4.3E-4	1.8E-4	7.8E-5	8.7E-5	1.2E-4	1.2E-4	7.3E-5	2.9E-5			

TABLE B-7. Crash location probability f(x,y) for large military aircraft takeoff with the pattern side to the left of the direction of flight.

X→ Y⇓	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12	12,13
2,3	4.4E-4	6.8E-4	6.7E-4	4.3E-4	1.8E-4	7.8E-5	8.7E-5	1.2E-4	1.2E-4	7.3E-5	2.9E-5			
1,2	1.7E-2	2.7E-2	2.8E-2	1.9E-2	9.8E-3	7.1E-3	1.1E-2	1.6E-2	1.6E-2	9.8E-3	3.9E-3	9.8E-4	1.6E-4	1.6E-5
0,1	3.4E-2	7.1E-2	1.0E-1	1.0E-1	7.0E-2	3.9E-2	2.5E-2	2.3E-2	2.1E-2	1.3E-2	5.1E-3	1.3E-3	2.1E-4	2.1E-5
-1,0	2.3E-2	5.0E-2	7.4E-2	7.7E-2	5.6E-2	2.8E-2	9.7E-3	2.4E-3	6.2E-4	2.2E-4	7.9E-5	2.0E-5		
-2,-1	4.3E-4	9.6E-4	1.5E-3	1.7E-3	1.3E-3	6.9E-4	2.4E-4	5.5E-5						

TABLE B-8. Crash location probability f(x,y) for large military aircraft landing with the pattern side to the right of the direction of flight.

X→ Y⇓	-12,-11	-11,-10	-10,-9	-9,-8	-8,-7	-7,-6	-6,-5	-5,-4	-4,-3	-3,-2	-2,-1	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11
6,7												1.1E-5	1.2E-5	1.0E-5									
5,6				1.0E-5	2.2E-5	3.6E-5	4.3E-5	4.2E-5	4.0E-5	5.0E-5	7.2E-5	9.6E-5	1.0E-5	8.6E-5	5.2E-5	2.3E-5							
4,5			2.0E-5	6.2E-5	1.4E-4	2.3E-4	2.9E-4	3.0E-4	3.1E-4	3.8E-4	5.0E-4	6.1E-4	6.1E-4	4.7E-4	2.8E-4	1.2E-4	3.8E-5						
3,4		1.8E-5	8.0E-5	2.6E-4	5.9E-4	1.0E-3	1.3E-3	1.4E-3	1.6E-3	2.0E-3	2.4E-3	2.7E-3	2.5E-3	1.8E-3	1.0E-3	4.4E-4	1.4E-4	3.5E-5					
2,3		4.7E-5	2.1E-4	7.0E-4	1.7E-3	2.9E-3	4.0E-3	4.7E-3	5.5E-3	6.9E-3	8.2E-3	8.3E-3	7.1E-3	4.8E-3	2.7E-3	1.2E-3	3.9E-4	1.1E-4	2.4E-5				
1,2	1.3E-5	8.3E-5	3.8E-4	1.3E-3	3.1E-3	5.6E-3	8.2E-3	1.0E-2	1.3E-2	1.7E-2	1.9E-2	1.8E-2	1.4E-2	9.3E-3	5.0E-3	2.3E-3	8.6E-3	2.8E-4	7.2E-5	1.6E-5			
0,1	1.5E-5	9.6E-5	4.5E-4	1.5E-3	3.9E-3	7.5E-3	1.2E-2	1.6E-2	2.1E-2	2.6E-2	3.0E-2	2.7E-2	2.1E-2	1.3E-2	7.2E-3	3.6E-3	1.6E-3	5.8E-4	1.8E-4	4.9E-5	1.2E-5		
-1,0	1.1E-5	7.4E-5	3.6E-4	1.3E-3	3.4E-3	6.8E-3	1.1E-2	1.6E-2	2.2E-2	2.8E-2	3.1E-2	2.8E-2	2.1E-2	1.4E-2	8.0E-3	4.4E-3	2.2E-3	9.9E-4	4.0E-4	1.5E-4	5.0E-5	1.4E-5	
-2,-1		3.8E-5	1.9E-4	7.1E-4	2.0E-3	4.2E-3	7.4E-3	1.1E-2	1.6E-2	2.1E-2	2.2E-2	2.0E-2	1.5E-2	1.0E-2	6.6E-3	4.2E-3	2.6E-3	1.5E-3	8.6E-4	4.3E-4	1.7E-4	5.0E-5	1.1E-5
-3,-2		1.4E-5	7.1E-5	2.7E-4	8.0E-4	1.8E-3	3.4E-3	5.4E-3	7.8E-3	9.9E-3	1.1E-2	9.8E-3	7.7E-3	5.6E-3	4.2E-3	3.3E-3	2.8E-3	2.3E-3	1.7E-3	9.7E-4	4.1E-4	1.2E-4	2.6E-5
-4,-3			2.3E-5	9.1E-5	2.7E-4	6.3E-4	1.2E-3	1.9E-3	2.7E-3	3.3E-3	3.6E-3	3.3E-3	2.7E-3	2.3E-3	2.1E-3	2.4E-3	2.9E-3	3.1E-3	2.5E-3	1.5E-3	6.5E-4	2.0E-4	4.2E-5
-5,-4			2.7E-5	1.0E-4	2.7E-4	5.2E-4	7.9E-4	9.8E-4	1.1E-3	1.2E-3	1.1E-3	9.5E-4	7.7E-4	7.4E-4	1.0E-3	1.7E-3	2.6E-3	3.1E-3	2.6E-3	1.6E-3	6.8E-4	2.1E-4	4.4E-5
-6,-5		1.3E-5	6.7E-5	2.4E-4	6.3E-4	1.2E-3	1.6E-3	1.8E-3	1.7E-3	1.5E-3	1.2E-3	7.9E-4	4.3E-4	3.1E-4	4.9E-4	1.0E-3	1.7E-3	2.1E-3	1.8E-3	1.1E-3	4.6E-4	1.4E-4	3.0E-5
-7,-6		2.3E-5	1.2E-4	4.4E-4	1.1E-3	2.1E-3	2.9E-3	3.3E-3	3.2E-3	2.9E-3	2.3E-3	1.4E-3	6.5E-4	2.6E-4	2.3E-4	4.4E-4	7.4E-4	9.1E-4	7.9E-4	4.8E-4	2.1E-4	6.3E-5	1.4E-5
-8,-7		2.7E-5	1.4E-4	5.2E-4	1.3E-3	2.5E-3	3.5E-3	4.0E-3	4.1E-3	3.8E-3	3.0E-3	1.9E-3	8.5E-4	2.9E-4	1.1E-4	1.3E-4	2.2E-4	2.6E-4	2.3E-4	1.4E-4	6.0E-5	1.8E-5	
-9,-8		2.1E-5	1.1E-4	4.0E-4	1.0E-3	1.9E-3	2.8E-3	3.2E-3	3.4E-3	3.3E-3	2.6E-3	1.6E-3	7.5E-4	2.4E-4	6.5E-5	3.2E-5	4.1E-5	5.0E-5	4.3E-5	2.6E-5	1.1E-5		
-10,-9		1.1E-5	5.4E-5	2.0E-4	5.2E-4	9.8E-4	1.4E-3	1.7E-3	1.8E-3	1.8E-3	1.5E-3	9.4E-4	4.3E-4	1.4E-4	3.3E-5								
-11,-10			1.8E-5	6.4E-5	1.7E-4	3.2E-4	4.7E-4	5.8E-4	6.5E-4	6.6E-4	5.6E-4	3.5E-4	1.6E-4	5.2E-5	1.2E-5								
-12,-11				1.4E-5	3.6E-5	6.8E-5	1.0E-4	1.3E-4	1.5E-4	1.6E-4	1.3E-4	8.5E-5	3.9E-5	1.2E-5									
-13,-12							1.4E-5	1.9E-5	2.3E-5	2.5E-5	2.1E-5	1.3E-5											

TABLE B-9. Crash location probability f(x,y) for large military aircraft landing with the pattern side to the left of the direction of flight.

X→ Y⇓	-12,-11	-11,-10	-10,-9	-9,-8	-8,-7	-7,-6	-6,-5	-5,-4	-4,-3	-3,-2	-2,-1	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11
12,13							1.4E-5	1.9E-5	2.3E-5	2.5E-5	2.1E-5	1.3E-5											
11,12				1.4E-5	3.6E-5	6.8E-5	1.0E-4	1.3E-4	1.5E-4	1.6E-4	1.3E-4	8.5E-5	3.9E-5	1.2E-5									
10,11			1.8E-5	6.4E-5	1.7E-4	3.2E-4	4.7E-4	5.8E-4	6.5E-4	6.6E-4	5.6E-4	3.5E-4	1.6E-4	5.2E-5	1.2E-5								
9,10		1.1E-5	5.4E-5	2.0E-4	5.2E-4	9.8E-4	1.4E-3	1.7E-3	1.8E-3	1.8E-3	1.5E-3	9.4E-4	4.3E-4	1.4E-4	3.3E-5								
8,9		2.1E-5	1.1E-4	4.0E-4	1.0E-3	1.9E-3	2.8E-3	3.2E-3	3.4E-3	3.3E-3	2.6E-3	1.6E-3	7.5E-4	2.4E-4	6.5E-5	3.2E-5	4.1E-5	5.0E-5	4.3E-5	2.6E-5	1.1E-5		
7,8		2.7E-5	1.4E-4	5.2E-4	1.3E-3	2.5E-3	3.5E-3	4.0E-3	4.1E-3	3.8E-3	3.0E-3	1.9E-3	8.5E-4	2.9E-4	1.1E-4	1.3E-4	2.2E-4	2.6E-4	2.3E-4	1.4E-4	6.0E-5	1.8E-5	
6,7		2.3E-5	1.2E-4	4.4E-4	1.1E-3	2.1E-3	2.9E-3	3.3E-3	3.2E-3	2.9E-3	2.3E-3	1.4E-3	6.5E-4	2.6E-4	2.3E-4	4.4E-4	7.4E-4	9.1E-4	7.9E-4	4.8E-4	2.1E-4	6.3E-5	1.4E-5
5,6		1.3E-5	6.7E-5	2.4E-4	6.3E-4	1.2E-3	1.6E-3	1.8E-3	1.7E-3	1.5E-3	1.2E-3	7.9E-4	4.3E-4	3.1E-4	4.9E-4	1.0E-3	1.7E-3	2.1E-3	1.8E-3	1.1E-3	4.6E-4	1.4E-4	3.0E-5
4,5			2.7E-5	1.0E-4	2.7E-4	5.2E-4	7.9E-4	9.8E-4	1.1E-3	1.2E-3	1.1E-3	9.5E-4	7.7E-4	7.4E-4	1.0E-3	1.7E-3	2.6E-3	3.1E-3	2.6E-3	1.6E-3	6.8E-4	2.1E-4	4.4E-5
3,4			2.3E-5	9.1E-5	2.7E-4	6.3E-4	1.2E-3	1.9E-3	2.7E-3	3.3E-3	3.6E-3	3.3E-3	2.7E-3	2.3E-3	2.1E-3	2.4E-3	2.9E-3	3.1E-3	2.5E-3	1.5E-3	6.5E-4	2.0E-4	4.2E-5
2,3		1.4E-5	7.1E-5	2.7E-4	8.0E-4	1.8E-3	3.4E-3	5.4E-3	7.8E-3	9.9E-3	1.1E-2	9.8E-3	7.7E-3	5.6E-3	4.2E-3	3.3E-3	2.8E-3	2.3E-3	1.7E-3	9.7E-4	4.1E-4	1.2E-4	2.6E-5
1,2		3.8E-5	1.9E-4	7.1E-4	2.0E-3	4.2E-3	7.4E-3	1.1E-2	1.6E-2	2.1E-2	2.2E-2	2.0E-2	1.5E-2	1.0E-2	6.6E-3	4.2E-3	2.6E-3	1.5E-3	8.6E-4	4.3E-4	1.7E-4	5.0E-5	1.1E-5
0,1	1.1E-5	7.4E-5	3.6E-4	1.3E-3	3.4E-3	6.8E-3	1.1E-2	1.6E-2	2.2E-2	2.8E-2	3.1E-2	2.8E-2	2.1E-2	1.4E-2	8.0E-3	4.4E-3	2.2E-3	9.9E-4	4.0E-4	1.5E-4	5.0E-5	1.4E-5	
-1,0	1.5E-5	9.6E-5	4.5E-4	1.5E-3	3.9E-3	7.5E-3	1.2E-2	1.6E-2	2.1E-2	2.6E-2	3.0E-2	2.7E-2	2.1E-2	1.3E-2	7.2E-3	3.6E-3	1.6E-3	5.8E-4	1.8E-4	4.9E-5	1.2E-5		
-2,-1	1.3E-5	8.3E-5	3.8E-4	1.3E-3	3.1E-3	5.6E-3	8.2E-3	1.0E-2	1.3E-2	1.7E-2	1.9E-2	1.8E-2	1.4E-2	9.3E-3	5.0E-3	2.3E-3	8.6E-3	2.8E-4	7.2E-5	1.6E-5			
-3,-2		4.7E-5	2.1E-4	7.0E-4	1.7E-3	2.9E-3	4.0E-3	4.7E-3	5.5E-3	6.9E-3	8.2E-3	8.3E-3	7.1E-3	4.8E-3	2.7E-3	1.2E-3	3.9E-4	1.1E-4	2.4E-5				
-4,-3		1.8E-5	8.0E-5	2.6E-4	5.9E-4	1.0E-3	1.3E-3	1.4E-3	1.6E-3	2.0E-3	2.4E-3	2.7E-3	2.5E-3	1.8E-3	1.0E-3	4.4E-4	1.4E-4	3.5E-5					
-5,-4			2.0E-5	6.2E-5	1.4E-4	2.3E-4	2.9E-4	3.0E-4	3.1E-4	3.8E-4	5.0E-4	6.1E-4	6.1E-4	4.7E-4	2.8E-4	1.2E-4	3.8E-5						
-6,-5				1.0E-5	2.2E-5	3.6E-5	4.3E-5	4.2E-5	4.0E-5	5.0E-5	7.2E-5	9.6E-5	1.0E-5	8.6E-5	5.2E-5	2.3E-5							
-7,-6												1.1E-5	1.2E-5	1.0E-5									

TABLE B-10. Crash location probability f(x,y) for small military aircraft takeoff with the pattern side to the right of the direction of flight.

X⇒ Y⇓	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12	12,13
5,6								1.0E-5	2.1E-5	2.5E-5	1.7E-5			
4,5							4.4E-5	1.6E-4	3.3E-4	4.0E-4	2.7E-4	1.1E-4	2.4E-5	
3,4	1.1E-4	1.6E-4	1.5E-4	8.6E-5	4.5E-5	5.7E-5	2.3E-4	8.0E-4	1.7E-3	2.0E-3	1.4E-3	5.3E-4	1.2E-4	1.5E-5
2,3	1.8E-3	2.8E-3	2.6E-3	1.7E-3	9.2E-4	6.0E-4	6.6E-4	1.4E-3	2.7E-3	3.2E-3	2.2E-3	8.6E-4	1.9E-4	2.4E-5
1,2	1.3E-2	1.9E-2	1.9E-2	1.3E-2	7.9E-3	5.0E-3	3.2E-3	2.2E-3	2.1E-3	2.0E-3	1.3E-3	4.9E-4	1.1E-4	1.4E-5
0,1	3.4E-2	5.3E-2	5.4E-2	4.0E-2	2.6E-2	1.8E-2	1.2E-2	7.0E-3	4.2E-3	2.7E-3	1.4E-3	4.6E-4	9.3E-5	1.1E-5
-1,0	3.5E-2	5.6E-2	5.9E-2	4.6E-2	3.4E-2	2.5E-2	1.8E-2	1.2E-2	9.2E-3	6.9E-3	3.7E-3	1.3E-3	2.5E-4	2.9E-5
-2,-1	1.3E-2	2.2E-2	2.5E-2	2.2E-2	2.0E-2	1.7E-2	1.3E-2	9.9E-3	9.4E-3	7.9E-3	4.4E-3	1.5E-3	2.9E-4	3.3E-5
-3,-2	1.9E-3	3.6E-3	4.9E-3	5.7E-3	6.4E-3	6.1E-3	4.8E-3	4.3E-3	4.8E-3	4.1E-3	2.2E-3	7.0E-4	1.3E-4	1.4E-5
-4,-3	1.6E-4	4.3E-4	1.0E-3	2.0E-3	3.2E-3	3.7E-3	3.2E-3	2.2E-3	1.5E-3	1.0E-3	4.8E-4	1.4E-4	2.5E-5	
-5,-4	1.2E-4	5.9E-4	1.9E-3	4.2E-3	6.5E-3	7.5E-3	6.2E-3	3.5E-3	1.2E-3	3.1E-4	6.7E-5	1.3E-5		
-6,-5	2.2E-4	1.0E-3	3.0E-3	5.5E-3	7.4E-3	7.9E-3	6.4E-3	3.5E-3	1.2E-3	2.4E-4	2.8E-5			
-7,-6	1.5E-4	6.8E-4	1.8E-3	3.0E-3	3.6E-3	3.6E-3	2.8E-3	1.6E-3	5.2E-4	1.0E-4	1.2E-5			
-8,-7	3.5E-5	1.5E-4	4.0E-4	6.3E-4	6.9E-4	6.3E-4	4.9E-4	2.7E-4	9.1E-5	1.8E-5				
-9, -8		1.1E-5	2.8E-5	4.4E-5	4.6E-5	4.0E-5	3.0E-5	1.6E-5						

TABLE B-11. Crash location probability f(x,y) for small military aircraft takeoff with the pattern side to the left of the direction of flight.

X⇒ Y⇓	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8	8,9	9,10	10,11	11,12	12,13
8,9		1.1E-5	2.8E-5	4.4E-5	4.6E-5	4.0E-5	3.0E-5	1.6E-5						
7,8	3.5E-5	1.5E-4	4.0E-4	6.3E-4	6.9E-4	6.3E-4	4.9E-4	2.7E-4	9.1E-5	1.8E-5				
6,7	1.5E-4	6.8E-4	1.8E-3	3.0E-3	3.6E-3	3.6E-3	2.8E-3	1.6E-3	5.2E-4	1.0E-4	1.2E-5			
5,6	2.2E-4	1.0E-3	3.0E-3	5.5E-3	7.4E-3	7.9E-3	6.4E-3	3.5E-3	1.2E-3	2.4E-4	2.8E-5			
4,5	1.2E-4	5.9E-4	1.9E-3	4.2E-3	6.5E-3	7.5E-3	6.2E-3	3.5E-3	1.2E-3	3.1E-4	6.7E-5	1.3E-5		
3,4	1.6E-4	4.3E-4	1.0E-3	2.0E-3	3.2E-3	3.7E-3	3.2E-3	2.2E-3	1.5E-3	1.0E-3	4.8E-4	1.4E-4	2.5E-5	
2,3	1.9E-3	3.6E-3	4.9E-3	5.7E-3	6.4E-3	6.1E-3	4.8E-3	4.3E-3	4.8E-3	4.1E-3	2.2E-3	7.0E-4	1.3E-4	1.4E-5
1,2	1.3E-2	2.2E-2	2.5E-2	2.2E-2	2.0E-2	1.7E-2	1.3E-2	9.9E-3	9.4E-3	7.9E-3	4.4E-3	1.5E-3	2.9E-4	3.3E-5
0,1	3.5E-2	5.6E-2	5.9E-2	4.6E-2	3.4E-2	2.5E-2	1.8E-2	1.2E-2	9.2E-3	6.9E-3	3.7E-3	1.3E-3	2.5E-4	2.9E-5
-1,0	3.4E-2	5.3E-2	5.4E-2	4.0E-2	2.6E-2	1.8E-2	1.2E-2	7.0E-3	4.2E-3	2.7E-3	1.4E-3	4.6E-4	9.3E-5	1.1E-5
-2,-1	1.3E-2	1.9E-2	1.9E-2	1.3E-2	7.9E-3	5.0E-3	3.2E-3	2.2E-3	2.1E-3	2.0E-3	1.3E-3	4.9E-4	1.1E-4	1.4E-5
-3,-2	1.8E-3	2.8E-3	2.6E-3	1.7E-3	9.2E-4	6.0E-4	6.6E-4	1.4E-3	2.7E-3	3.2E-3	2.2E-3	8.6E-4	1.9E-4	2.4E-5
-4,-3	1.1E-4	1.6E-4	1.5E-4	8.6E-5	4.5E-5	5.7E-5	2.3E-4	8.0E-4	1.7E-3	2.0E-3	1.4E-3	5.3E-4	1.2E-4	1.5E-5
-5,-4							4.4E-5	1.6E-4	3.3E-4	4.0E-4	2.7E-4	1.1E-4	2.4E-5	
-6,-5								1.0E-5	2.1E-5	2.5E-5	1.7E-5			

TABLE B-12. Crash location probability f(x,y) for small military aircraft landing with the pattern side to the right of the direction of flight.

X→ Y⇓	-22, -21	-21, -20	-20, -19	-19, -18	-18, -17	-17, -16	-16, -15	-15, -14	-14, -13	-13, -12	-12, -11	-11, -10	-10,-9	-9,-8	-8,-7
7, 8											1.0E-5				
6,7							1.6E-5	4.4E-5	9.2E-5	1.4E-4	1.7E-4	1.4E-4	9.2E-5	4.4E-5	1.6E-5
5,6						1.7E-5	6.4E-5	1.8E-4	3.8E-4	5.9E-4	6.8E-4	5.9E-4	3.8E-4	1.8E-4	6.4E-5
4,5						2.1E-5	7.0E-5	1.9E-4	4.0E-4	6.3E-4	7.2E-4	6.3E-4	4.0E-4	2.0E-4	7.8E-5
3,4			1.1E-5	2.8E-5	5.4E-5	8.1E-5	1.0E-4	1.2E-4	1.5E-4	2.0E-4	2.3E-4	2.2E-4	2.0E-4	2.0E-4	2.4E-4
2,3		2.2E-5	7.6E-5	2.0E-4	3.9E-4	5.7E-4	6.3E-4	5.4E-4	4.0E-4	3.1E-4	3.3E-4	4.8E-4	7.6E-4	1.2E-3	1.6E-3
1,2		4.3E-5	1.6E-4	4.2E-4	8.6E-4	1.3E-3	1.6E-3	1.5E-3	1.3E-3	1.2E-3	1.2E-3	1.6E-3	2.3E-3	3.2E-3	4.3E-3
0,1		2.9E-5	1.1E-4	3.2E-4	7.1E-4	1.2E-3	1.7E-3	2.0E-3	2.2E-3	2.3E-3	2.5E-3	3.1E-3	4.0E-3	5.2E-3	6.8E-3
-1,0			4.2E-5	1.5E-4	4.1E-4	9.0E-4	1.6E-3	2.2E-3	2.6E-3	3.0E-3	3.3E-3	4.0E-3	5.0E-3	6.1E-3	7.4E-3
-2,-1			4.2E-5	1.5E-4	4.3E-4	9.2E-4	1.5E-3	2.1E-3	2.3E-3	2.3E-3	2.4E-3	2.9E-3	3.6E-3	4.4E-3	5.1E-3
-3,-2		1.8E-5	7.7E-5	2.4E-4	5.8E-4	1.1E-3	1.5E-3	1.6E-3	1.4E-3	1.1E-3	1.1E-3	1.5E-3	2.1E-3	2.7E-3	3.0E-3
-4,-3		1.7E-5	6.9E-5	2.1E-4	4.6E-4	7.7E-4	9.6E-4	9.1E-4	6.7E-4	4.4E-4	3.8E-4	5.3E-4	8.1E-4	1.1E-3	1.3E-3
-5,-4			2.1E-5	5.9E-5	1.3E-4	2.1E-4	2.5E-4	2.2E-4	1.5E-4	9.1E-5	7.9E-5	1.4E-4	3.1E-4	6.3E-4	1.1E-3
-6,-5			2.2E-5	4.5E-5	7.1E-5	8.5E-5	7.7E-5	5.3E-5	3.0E-5	2.7E-5	7.3E-5	2.3E-4	6.0E-4	1.2E-3	1.9E-3
-7,-6	1.4E-5	5.0E-5	1.4E-4	2.8E-4	4.2E-4	4.8E-4	4.0E-4	2.5E-4	1.2E-4	5.8E-5	9.1E-5	2.7E-4	6.7E-4	1.3E-3	1.9E-3
-8,-7	2.4E-5	8.7E-5	2.4E-4	4.9E-4	7.3E-4	8.3E-4	6.9E-4	4.3E-4	2.0E-4	8.1E-5	7.5E-5	2.1E-4	5.5E-4	1.1E-3	1.7E-3
-9,-8	1.1E-5	3.9E-5	1.1E-4	2.2E-4	3.3E-4	3.7E-4	3.1E-4	2.0E-4	9.1E-5	3.7E-5	3.9E-5	1.1E-4	3.1E-4	6.2E-4	9.5E-4
-10,-9			1.2E-5	2.5E-5	3.8E-5	4.3E-5	3.6E-5	2.3E-5	1.1E-5			2.2E-5	5.9E-5	1.2E-4	1.8E-4
-11,-10															

X→ Y⇓	-7,-6	-6,-5	-5,-4	-4,-3	-3,-2	-2,-1	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8
7, 8															
6,7															
5,6	1.7E-5														
4,5	3.6E-5	3.6E-5	5.3E-5	7.2E-5	7.9E-5	6.9E-5	4.9E-5	2.9E-5	1.5E-5						
3,4	3.1E-4	3.9E-4	5.0E-4	6.0E-4	6.5E-4	6.0E-4	4.8E-4	3.3E-4	1.9E-4	8.7E-5	3.2E-5				
2,3	2.0E-3	2.2E-3	2.2E-3	2.3E-3	2.4E-3	2.4E-3	2.1E-3	1.6E-3	9.7E-4	4.9E-4	2.0E-4	6.4E-5	1.6E-5		
1,2	5.5E-3	6.7E-3	8.4E-3	1.1E-2	1.2E-2	1.3E-2	1.1E-2	8.1E-3	4.7E-3	2.2E-3	8.3E-4	2.6E-4	6.6E-5	1.4E-5	
0,1	9.3E-3	1.4E-2	2.1E-2	3.2E-2	4.1E-2	4.4E-2	3.8E-2	2.7E-2	1.5E-2	6.7E-3	2.5E-3	7.9E-4	2.1E-4	4.9E-5	
-1,0	9.6E-3	1.4E-2	2.2E-2	3.3E-2	4.3E-2	4.6E-2	4.1E-2	2.9E-2	1.7E-2	8.0E-3	3.5E-3	1.3E-3	4.1E-4	1.1E-4	2.5E-5
-2,-1	5.8E-3	7.0E-3	9.5E-3	1.3E-2	1.6E-2	1.7E-2	1.5E-2	1.1E-2	7.1E-3	4.2E-3	2.3E-3	1.1E-3	4.4E-4	1.4E-4	3.3E-5
-3,-2	3.1E-3	3.1E-3	3.3E-3	3.7E-3	4.1E-3	4.0E-3	3.5E-3	2.9E-3	2.3E-3	1.7E-3	1.1E-3	5.8E-4	2.4E-4	7.7E-5	1.9E-5
-4,-3	1.5E-3	1.7E-3	1.8E-3	1.9E-3	1.7E-3	1.4E-3	1.1E-3	7.9E-4	5.9E-4	4.3E-4	2.6E-4	1.3E-4	5.2E-5	1.6E-5	
-5,-4	1.5E-3	1.8E-3	1.8E-3	1.4E-3	1.0E-3	6.6E-4	3.7E-4	1.9E-4	9.1E-5	4.7E-5	2.4E-5	1.0E-5			
-6,-5	2.3E-3	2.3E-3	1.7E-3	1.0E-3	5.1E-4	2.1E-4	8.1E-5	2.8E-5							
-7,-6	2.2E-3	1.9E-3	1.3E-3	6.5E-4	2.6E-4	7.8E-5	1.9E-5								
-8,-7	1.9E-3	1.6E-3	1.0E-3	4.9E-4	1.8E-4	4.8E-5									
-9,-8	1.1E-3	9.1E-4	5.8E-4	2.7E-4	9.5E-5	2.5E-5									
-10,-9	2.0E-4	1.7E-4	1.1E-4	4.9E-5	1.7E-5										
-11, -10	1.0E-5														

TABLE B-13. Crash location probability f(x,y) for small military aircraft landing with the pattern side to the left of the direction of flight.

X→ Y⇓	-22, -21	-21, -20	-20, -19	-19, -18	-18, -17	-17, -16	-16, -15	-15, -14	-14, -13	-13, -12	-12, -11	-11, -10	-10,-9	-9,-8	-8,-7
10,11															
9,10			1.2E-5	2.5E-5	3.8E-5	4.3E-5	3.6E-5	2.3E-5	1.1E-5			2.2E-5	5.9E-5	1.2E-4	1.8E-4
8,9	1.1E-5	3.9E-5	1.1E-4	2.2E-4	3.3E-4	3.7E-4	3.1E-4	2.0E-4	9.1E-5	3.7E-5	3.9E-5	1.1E-4	3.1E-4	6.2E-4	9.5E-4
7,8	2.4E-5	8.7E-5	2.4E-4	4.9E-4	7.3E-4	8.3E-4	6.9E-4	4.3E-4	2.0E-4	8.1E-5	7.5E-5	2.1E-4	5.5E-4	1.1E-3	1.7E-3
6,7	1.4E-5	5.0E-5	1.4E-4	2.8E-4	4.2E-4	4.8E-4	4.0E-4	2.5E-4	1.2E-4	5.8E-5	9.1E-5	2.7E-4	6.7E-4	1.3E-3	1.9E-3
5,6			2.2E-5	4.5E-5	7.1E-5	8.5E-5	7.7E-5	5.3E-5	3.0E-5	2.7E-5	7.3E-5	2.3E-4	6.0E-4	1.2E-3	1.9E-3
4,5			2.1E-5	5.9E-5	1.3E-4	2.1E-4	2.5E-4	2.2E-4	1.5E-4	9.1E-5	7.9E-5	1.4E-4	3.1E-4	6.3E-4	1.1E-3
3,4		1.7E-5	6.9E-5	2.1E-4	4.6E-4	7.7E-4	9.6E-4	9.1E-4	6.7E-4	4.4E-4	3.8E-4	5.3E-4	8.1E-4	1.1E-3	1.3E-3
2,3		1.8E-5	7.7E-5	2.4E-4	5.8E-4	1.1E-3	1.5E-3	1.6E-3	1.4E-3	1.1E-3	1.1E-3	1.5E-3	2.1E-3	2.7E-3	3.0E-3
1,2			4.2E-5	1.5E-4	4.3E-4	9.2E-4	1.5E-3	2.1E-3	2.3E-3	2.3E-3	2.4E-3	2.9E-3	3.6E-3	4.4E-3	5.1E-3
0,1			4.2E-5	1.5E-4	4.1E-4	9.0E-4	1.6E-3	2.2E-3	2.6E-3	3.0E-3	3.3E-3	4.0E-3	5.0E-3	6.1E-3	7.4E-3
-1,0		2.9E-5	1.1E-4	3.2E-4	7.1E-4	1.2E-3	1.7E-3	2.0E-3	2.2E-3	2.3E-3	2.5E-3	3.1E-3	4.0E-3	5.2E-3	6.8E-3
-2,-1		4.3E-5	1.6E-4	4.2E-4	8.6E-4	1.3E-3	1.6E-3	1.5E-3	1.3E-3	1.2E-3	1.2E-3	1.6E-3	2.3E-3	3.2E-3	4.3E-3
-3,-2		2.2E-5	7.6E-5	2.0E-4	3.9E-4	5.7E-4	6.3E-4	5.4E-4	4.0E-4	3.1E-4	3.3E-4	4.8E-4	7.6E-4	1.2E-3	1.6E-3
-4,-3			1.1E-5	2.8E-5	5.4E-5	8.1E-5	1.0E-4	1.2E-4	1.5E-4	2.0E-4	2.3E-4	2.2E-4	2.0E-4	2.0E-4	2.4E-4
-5,-4						2.1E-5	7.0E-5	1.9E-4	4.0E-4	6.3E-4	7.2E-4	6.3E-4	4.0E-4	2.0E-4	7.8E-5
-6,-5						1.7E-5	6.4E-5	1.8E-4	3.8E-4	5.9E-4	6.8E-4	5.9E-4	3.8E-4	1.8E-4	6.4E-5
-7,-6							1.6E-5	4.4E-5	9.2E-5	1.4E-4	1.7E-4	1.4E-4	9.2E-5	4.4E-5	1.6E-5
-8,-7											1.0E-5				

X→ Y⇓	-7,-6	-6,-5	-5,-4	-4,-3	-3,-2	-2,-1	-1,0	0,1	1,2	2,3	3,4	4,5	5,6	6,7	7,8
10,11	1.0E-5														
9,10	2.0E-4	1.7E-4	1.1E-4	4.9E-5	1.7E-5										
8,9	1.1E-3	9.1E-4	5.8E-4	2.7E-4	9.5E-5	2.5E-5									
7,8	1.9E-3	1.6E-3	1.0E-3	4.9E-4	1.8E-4	4.8E-5									
6,7	2.2E-3	1.9E-3	1.3E-3	6.5E-4	2.6E-4	7.8E-5	1.9E-5								
5,6	2.3E-3	2.3E-3	1.7E-3	1.0E-3	5.1E-4	2.1E-4	8.1E-5	2.8E-5							
4,5	1.5E-3	1.8E-3	1.8E-3	1.4E-3	1.0E-3	6.6E-4	3.7E-4	1.9E-4	9.1E-5	4.7E-5	2.4E-5	1.0E-5			
3,4	1.5E-3	1.7E-3	1.8E-3	1.9E-3	1.7E-3	1.4E-3	1.1E-3	7.9E-4	5.9E-4	4.3E-4	2.6E-4	1.3E-4	5.2E-5	1.6E-5	
2,3	3.1E-3	3.1E-3	3.3E-3	3.7E-3	4.1E-3	4.0E-3	3.5E-3	2.9E-3	2.3E-3	1.7E-3	1.1E-3	5.8E-4	2.4E-4	7.7E-5	1.9E-5
1,2	5.8E-3	7.0E-3	9.5E-3	1.3E-2	1.6E-2	1.7E-2	1.5E-2	1.1E-2	7.1E-3	4.2E-3	2.3E-3	1.1E-3	4.4E-4	1.4E-4	3.3E-5
0,1	9.6E-3	1.4E-2	2.2E-2	3.3E-2	4.3E-2	4.6E-2	4.1E-2	2.9E-2	1.7E-2	8.0E-3	3.5E-3	1.3E-3	4.1E-4	1.1E-4	2.5E-5
-1,0	9.3E-3	1.4E-2	2.1E-2	3.2E-2	4.1E-2	4.4E-2	3.8E-2	2.7E-2	1.5E-2	6.7E-3	2.5E-3	7.9E-4	2.1E-4	4.9E-5	
-2,-1	5.5E-3	6.7E-3	8.4E-3	1.1E-2	1.2E-2	1.3E-2	1.1E-2	8.1E-3	4.7E-3	2.2E-3	8.3E-4	2.6E-4	6.6E-5	1.4E-5	
-3,-2	2.0E-3	2.2E-3	2.2E-3	2.3E-3	2.4E-3	2.4E-3	2.1E-3	1.6E-3	9.7E-4	4.9E-4	2.0E-4	6.4E-5	1.6E-5		
-4,-3	3.1E-4	3.9E-4	5.0E-4	6.0E-4	6.5E-4	6.0E-4	4.8E-4	3.3E-4	1.9E-4	8.7E-5	3.2E-5				
-5,-4	3.6E-5	3.6E-5	5.3E-5	7.2E-5	7.9E-5	6.9E-5	4.9E-5	2.9E-5	1.5E-5						
-6,-5	1.7E-5														
-7,-6															
-8,-7															

TABLE B-14. DOE site-specific values and maximum, minimum, and average CONUS values of NPf(x,y) for general aviation (GA) nonairport operations (in crashes per square mile, per year, centered at the site).

Site	GA Airplanes
Maximum	3E-3
Minimum	1E-7
Average CONUS	2E-4
Argonne National Laboratory	3E-3
Brookhaven National Laboratory	5E-4
Hanford	1E-4
Idaho National Engineering Laboratory	9E-5
Kansas City	6E-4
Los Alamos National Laboratory	2E-4
Lawrence Livermore National Laboratory	1E-4
Mound	4E-4
Nevada Test Site	8E-5
Oak Ridge National Laboratory	2E-3
Pantex	7E-5
Pinellas	3E-4
Rocky Flats	2E-3
Sandia National Laboratories	1E-3
Savannah River Site	2E-4

TABLE B-15. DOE site-specific values and maximum, minimum, and average CONUS values of NPf(x,y) for commercial and military aviation nonairport operations (in crashes per square mile, per year, centered at the site).

Site	Air Carrier	Air Taxi	Large Military	Small Military
Maximum	2E-6	8E-6	7E-7	6E-6
Minimum	7E-8	4E-7	6E-8	4E-8
Average CONUS	4E-7	1E-6	2E-7	4E-6
Argonne National Laboratory	7E-7	4E-6	9E-8	8E-7
Brookhaven National Laboratory	2E-6	8E-6	7E-7	2E-7
Hanford	1E-7	1E-6	1E-7	4E-8
Idaho National Engineering Laboratory	7E-8	4E-7	9E-8	7E-7
Kansas City	4E-7[1]	1E-6[1]	2E-7	1E-6
Los Alamos National Laboratory	2E-7	3E-6	1E-7	5E-6
Lawrence Livermore National Laboratory	5E-7	2E-6	2E-7	3E-6
Mound	6E-7	3E-6	1E-7	2E-6
Nevada Test Site	5E-7	2E-6	2E-7	6E-6
Oak Ridge National Laboratory	6E-7	2E-6	1E-7	6E-7
Pantex	2E-7	3E-7	1E-7	5E-6
Pinellas	4E-7	1E-6	2E-7	4E-6
Rocky Flats	2E-7	6E-7	9E-8	9E-7
Sandia National Laboratories	2E-7	3E-7	1E-7	5E-6
Savannah River Site	6E-7	2E-6	1E-7	6E-7

[1]The Average CONUS was used for these sites.

B.4 Effective Area Calculations.

The effective area represents the ground surface area surrounding a facility such that if an unobstructed aircraft were to crash within the area, it would impact the facility, either by direct fly-in or skid into the facility. The effective area depends on the length, width, and height of the facility, as well as on the aircraft's wingspan, flight path angle, heading angle relative to the heading of the facility, and the length of its skid. The effective area consists of two parts, the fly-in area and the skid area. The former represents the area corresponding to a direct fly-in impact and consists of two parts, the footprint area and the shadow area. The footprint is the facility area that an aircraft would hit on its descent even if the facility height were zero. The shadow area is the facility area that an aircraft hits on its descent, but which it would have missed if the facility height were zero.

For this standard, the facility is represented by a bounding rectangle, and the heading of the crashing aircraft with respect to the facility is assumed to be perpendicular to the diagonal of the bounding rectangle, as shown in Figure B-3. These assumptions provide a conservative approximation to the true effective area.

The formula for calculating the skid and fly-in areas for an aircraft crashing into a rectangular building is given in Equations B-3 to B-5. Details are provided in Reference 1. Table B-16 provides typical wingspans for commercial, general aviation, and military aircraft. Table B-17 provides values for the mean of the cotangent of the impact angle. Table B-18 provides mean skid distances for each aircraft category. Values of wingspans for selected aircraft, values of marginal cumulative distribution functions for the impact angle, and aircraft subcategory skid distances are provided in Reference 2.

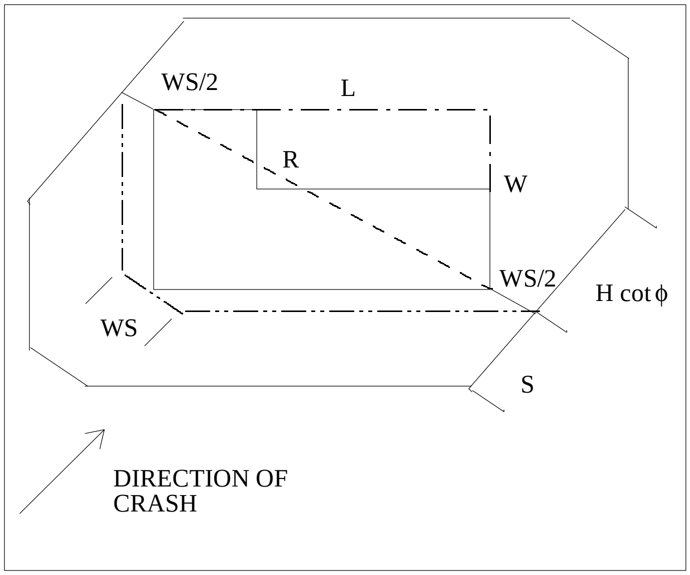

FIGURE B-3. Rectangular facility effective target area elements

$$A_{eff} = A_f + A_s \tag{B-3}$$

where:

$$A_f = (WS + R) \cdot H \cot\Phi + \frac{2 \cdot L \cdot W \cdot WS}{R} + L \cdot W \tag{B-4}$$

and

$$A_S = (WS + R) \cdot S \tag{B-5}$$

where:

A_f	=	effective fly-in area;
A_s	=	effective skid area;
WS	=	aircraft wingspan, provided in Table B-16;
R	=	length of the diagonal of the facility, = $(L^2 + W^2)^{0.5}$

H	=	facility height, facility-specific;
cotΦ	=	mean of the cotangent of the aircraft impact angle, provided in Table B-17 (for in-flight crashes use the takeoff mean of the cotangent of the impact angle, if available);
L	=	length of facility, facility-specific;
W	=	width of facility, facility-specific;
S	=	aircraft skid distance (mean value), provided in Table B-18 (for in-flight crashes use the takeoff skid length, if available).

TABLE B-16. Representative wingspans (WS) for commercial, general aviation, and military aircraft.

General Aviation	Piston Engine	Turboprop	Turbojet	Helicopters
50 ft	50 ft	73 ft	50 ft	50 ft

Commercial Aviation	Air Carrier	Air Taxi
	98 ft	59 ft

Military Aviation	Large Aircraft	Small Aircraft High Performance [1]	Small Aircraft Low Performance [2]
	223 ft	78 ft	110 ft

Notes:
[1]Includes fighters, attackers, and trainers.
[2]Includes other small aircraft.

For more information on aircraft wingspans please see Reference 2.

TABLE B-17. Values of the mean of the cotangent of the impact angle (cotΦ).

Aircraft Category	Commercial Aviation	General Aviation	Helicopters	Military Aviation			
				Large Aircraft		Small Aircraft	
				Takeoff	Landing	Takeoff	Landing
Mean (cotΦ)	10.2	8.2	0.58	7.4	9.7	8.4	10.4

TABLE B-18. Mean skid distances (s) for each aircraft category.

Aircraft Category	Commercial Aviation	General Aviation	Helicopters	Military Aviation			
				Large Aircraft		Small Aircraft	
				Takeoff	Landing	Takeoff	Landing
Mean Skid Distance, ft	1440	60	0	780	368	246	447

In calculating an effective area, the analyst needs to be cognizant of the "critical areas" of the facility. Critical areas 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. 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. In addition, the analyst needs to consider the facility's layout and its location in relation to other facilities when determining the facility input parameters. Information about critical areas and potential aircraft heading angles may eliminate or change the need for further analysis. Otherwise, the conservatism in the analysis might unnecessarily overburden the evaluations.

In addition, there may exist conditions and physical attributes that could affect the evaluation of the effective target areas. For example, there could be nearby barriers that have sufficient structural integrity to resist impact from the categories (or subcategories) of aircraft under investigation. Examples of barriers are robust structures (e.g., munition storage bunkers and seismically qualified process and storage buildings), extremely rocky terrain, soft soil, dense forests, ravines, and canyons. These special conditions could permit the analyst to reconsider the angle of impact and the skid length for the aircraft of interest. If, for example, the nearby robust structure is tall with respect to the facility, the angle of impact might be considerably larger than the mean value recommended, resulting in a substantially smaller effective target area. The higher angle of impact may result in a reduced or negligible skid length, which could also reduce the effective target area. In addition, if the facility is surrounded by other buildings, the skid distance will not be greater than the largest distance between these buildings and the facility.

B.5 Sample Problem. The following sample problem will take the reader through the steps described in Section 5.3 of the standard. A facility with three airports within a 22-mile radius will be considered, as shown in Figure B-4.

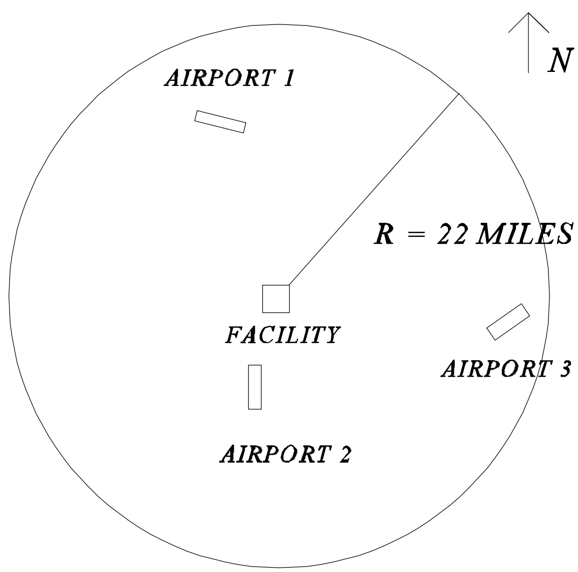

FIGURE B-4. Pictorial representation of sample facility and airport locations

TABLE B-19. Airport Information for sample facility.

	Distance from Facility to the Airport (mi)	Direction from the Facility to the Airport (degrees)	Number of Airstrips at Airport [1]	First Runway Number	Second Runway Number
Airport 1	8	350	1	10	28
Airport 2	9	185	1	0	18
Airport 3	19	95	1	4	22

[1]There are two runway headings in opposite directions for each physical airstrip.

First, the analyst will need to ascertain the impact frequency from airport operations (see Section 5.3 of the standard). Begin by compiling a set of questions prior to contacting each airport. Typical questions include, but are not limited to, the following:

1. What categories of aircraft fly in and out of the airport (general aviation, commercial aviation, or military aviation)?

2. For each category of aircraft, how many operations does the airport have in a year?

3. Does the airport break the operations down by subcategory? (If so, request the break-down.)

4. How many airstrips does the airport have?

5. What are the runway numbers?

6. Which side of the runway is considered the pattern side (for military aircraft)?

7. Is one runway used more than the others? If so, what percentage of the operations occur on each runway?

For this sample problem, the analyst should obtain information from the three nearby airfields. The results are provided in Table B-20.

During the interview, the analyst determined that Airport 2 has a pattern side to the west of the runway. Also, a helicopter flies around the facility once a day to perform surveillance.

Once the information is accumulated, the data should be organized by filling out Table B-21 for each runway. Tables B-22 through B-27 show how Table B-21 would be filled out for this example.

TABLE B-20. Information from the local airports.

	Number of Airstrips at Airport	Runway Numbers	Aircraft Categories that Use the Airport	Operations Per Year	Can the Operations be Broken Down into Sub-Categories	Sub-Categories	Operations Per Year for Each Sub-Category	Preferred Runway	Percentage of Operations on Preferred Runway
Airport 1	1	10, 28	GA	2,000	No			10	75
Airport 2	1	0, 18	Commercial	60,000	Yes	Air Carrier	46,000	18	56
						Air Taxi	14,000	18	56
			Military	120,000	Yes	Large Military	100,000	18	56
						Small Military	20,000	18	56
			GA	20,000	No			18	56
Airport 3	1	4, 22	GA	6,000	No			22	85

TABLE B-21. Data collection table.

Airport Name ___________ Runway Number_________ Pattern Side __________

	Number of Operations Per Year (Operations)	x distance, mi	y distance, mi	f(x,y) value (Probability of Crash per sq mile) [from Tables B2-B13]	P, Crash Rate (Crashes per Operation) [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency (Crashes/yr)
General Aviation Takeoff							
General Aviation Landing							
Commercial Aviation Air Carrier Takeoff							
Commercial Aviation Air Carrier Landing							
Commercial Aviation Air Taxi Takeoff							
Commercial Aviation Air Taxi Landing							
Military Aviation Large Aircraft Takeoff							
Military Aviation Large Aircraft Landing							
Military Aviation Small Aircraft Takeoff							
Military Aviation Small Aircraft Landing							

TABLE B-22. Data collection table for Airport 1 Runway 10.

Airport Name AIRPORT 1 | Runway Number 10 | Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation [B-3]	Impact Frequency
General Aviation Takeoff	750						
General Aviation Landing	750						
Commercial Aviation Air Carrier Takeoff	0						
Commercial Aviation Air Carrier Landing	0						
Commercial Aviation Air Taxi Takeoff	0						
Commercial Aviation Air Taxi Landing	0						
Military Aviation Large Aircraft Takeoff	0						
Military Aviation Large Aircraft Landing	0						
Military Aviation Small Aircraft Takeoff	0						
Military Aviation Small Aircraft Landing	0						

TABLE B-23. Data collection table for Airport 1 Runway 28.

Airport Name AIRPORT 1 | Runway Number 28 | Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B 2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	250						
General Aviation Landing	250						
Commercial Aviation Air Carrier Takeoff	0						
Commercial Aviation Air Carrier Landing	0						
Commercial Aviation Air Taxi Takeoff	0						
Commercial Aviation Air Taxi Landing	0						
Military Aviation Large Aircraft Takeoff	0						
Military Aviation Large Aircraft Landing	0						
Military Aviation Small Aircraft Takeoff	0						
Military Aviation Small Aircraft Landing	0						

TABLE B-24. Data collection table for Airport 2 Runway 18.

Airport Name AIRPORT 2 Runway Number 18 Pattern Side West

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B1]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	5600						
General Aviation Landing	5600						
Commercial Aviation Air Carrier Takeoff	12880						
Commercial Aviation Air Carrier Landing	12880						
Commercial Aviation Air Taxi Takeoff	3920						
Commercial Aviation Air Taxi Landing	3920						
Military Aviation Large Aircraft Takeoff	28000						
Military Aviation Large Aircraft Landing	28000						
Military Aviation Small Aircraft Takeoff	5600						
Military Aviation Small Aircraft Landing	5600						

TABLE B-25. Data collection table for Airport 2 Runway 0.

Airport Name AIRPORT 2 Runway Number 0 Pattern Side West

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	4400						
General Aviation Landing	4400						
Commercial Aviation Air Carrier Takeoff	10120						
Commercial Aviation Air Carrier Landing	10120						
Commercial Aviation Air Taxi Takeoff	3080						
Commercial Aviation Air Taxi Landing	3080						
Military Aviation Large Aircraft Takeoff	22000						
Military Aviation Large Aircraft Landing	22000						
Military Aviation Small Aircraft Takeoff	4400						
Military Aviation Small Aircraft Landing	4400						

TABLE B-26. Data collection table for Airport 3 Runway 22.

Airport Name AIRPORT 3 Runway Number 22 Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	2550						
General Aviation Landing	2550						
Commercial Aviation Air Carrier Takeoff	0						
Commercial Aviation Air Carrier Landing	0						
Commercial Aviation Air Taxi Takeoff	0						
Commercial Aviation Air Taxi Landing	0						
Military Aviation Large Aircraft Takeoff	0						
Military Aviation Large Aircraft Landing	0						
Military Aviation Small Aircraft Takeoff	0						
Military Aviation Small Aircraft Landing	0						

TABLE B-27. Data collection table for Airport 3 Runway 4.

Airport Name AIRPORT 3 Runway Number 4 Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2	Impact Frequency
General Aviation Takeoff	450						
General Aviation Landing	450						
Commercial Aviation Air Carrier Takeoff	0						
Commercial Aviation Air Carrier Landing	0						
Commercial Aviation Air Taxi Takeoff	0						
Commercial Aviation Air Taxi Landing	0						
Military Aviation Large Aircraft Takeoff	0						
Military Aviation Large Aircraft Landing	0						
Military Aviation Small Aircraft Takeoff	0						
Military Aviation Small Aircraft Landing	0						

The next step is to determine the orthonormal distance from the airport to the facility.

The first method is to use Equations B-1 and B-2. A second, graphical method is illustrated below using Airport 2. Begin by placing the origin in the center of the runway. Next, draw a line splitting the runway in half lengthwise. This line represents the x axis. Draw a line from the facility that is perpendicular to and intersects the x axis, as shown in Figure B-5.

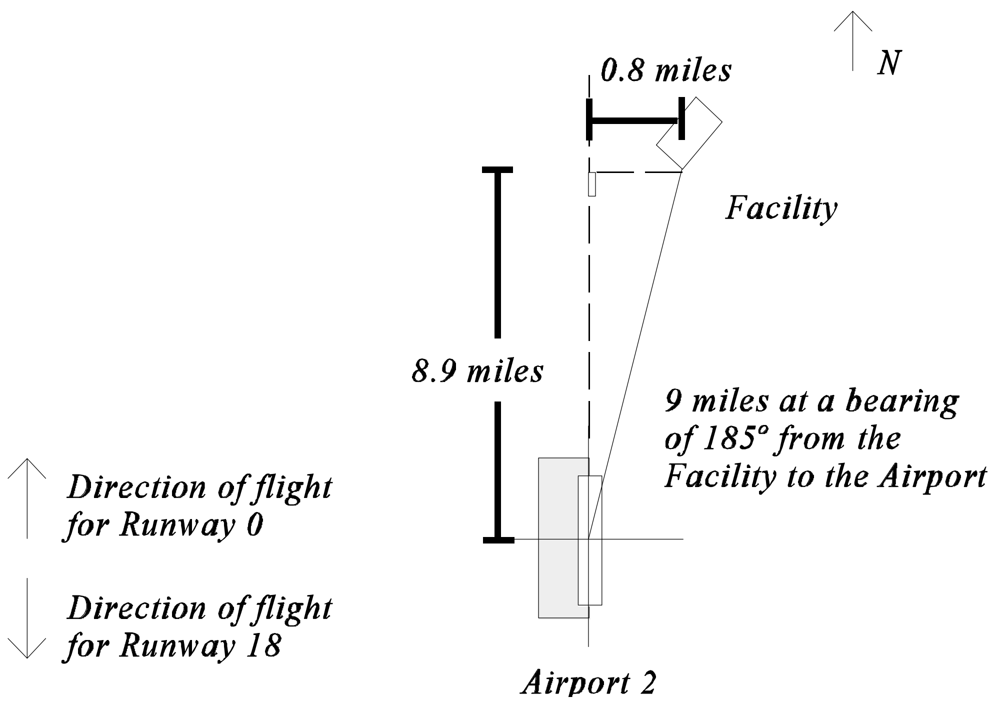

FIGURE B-5. Orthonormal distance from Airport 2 to facility

The analyst should then measure the distance along the x axis from the center of the airport to the intersection point. This is the magnitude of x. If the direction of flight is toward the facility, x is positive; if the direction of flight is away from the facility, x is negative. Then measure from the intersection point to the facility. This is the magnitude of y. If the facility is to the left of the positive x axis (direction of flight), y is positive; if the facility is to the right of the positive x axis (direction of flight), y is negative. In this example, the orthonormal distance for Airport 2, Runway 0, is (8.9, - 0.8), and the orthonormal distance for Airport 2, Runway 18, is (-8.9, 0.8).

The next step is to determine the crash location probability f(x, y) for each category of aircraft and flight phase at each airport. For commercial and general aviation, this is straightforward; the analyst reads the value defined by the coordinates determined above. For military aviation, the analyst first needs to determine the pattern side with respect to the direction of flight and then use the correct table. For example, for Airport 2, Runway 0, the pattern side is to the left, and the analyst should use Tables B-7, B-9, B-11, and B-13. For Airport 2, Runway 18, the pattern side is to the right of the direction of flight, and the analyst should use Tables B-6, B-8, B-10, and B-12.

The analyst should then enter the crash rates from Table B-1 into the data collection tables. After this is completed for all the airports, the data collection tables (based on Table B-21) should look like Tables B-28 through B-33.

TABLE B-28. Updated data collection table for Airport 1 Runway 10 showing f(x,y) value and crash rate.

Airport Name AIRPORT 1 | Runway Number 10 | Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi2 [from EquationB-3]	Impact Frequency
General Aviation Takeoff	750	2.7	-7.5	0	1.1E-5		
General Aviation Landing	750	2.7	-7.5	0	2.0E-5		
Commercial Aviation Air Carrier Takeoff	0	N/A	N/A		2.0E-7		
Commercial Aviation Air Carrier Landing	0	N/A	N/A		2.6E-7		
Commercial Aviation Air Taxi Takeoff	0	N/A	N/A		1.0E-6		
Commercial Aviation Air Taxi Landing	0	N/A	N/A		2.3E-6		
Military Aviation Large Aircraft Takeoff	0	N/A	N/A		5.7E-7		
Military Aviation Large Aircraft Landing	0	N/A	N/A		1.6E-6		
Military Aviation Small Aircraft Takeoff	0	N/A	N/A		1.8E-6		
Military Aviation Small Aircraft Landing	0	N/A	N/A		3.3E-6		

TABLE B-29. Updated data collection table for Airport 1, Runway 28 showing f(x,y) value and crash rate.

Airport Name AIRPORT 1 | Runway Number 28 | Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	250	-2.7	7.5	0	1.1E-5		
General Aviation Landing	250	-2.7	7.5	0	2.0E-5		
Commercial Aviation Air Carrier Takeoff	0	N/A	N/A		2.0E-7		
Commercial Aviation Air Carrier Landing	0	N/A	N/A		2.6E-7		
Commercial Aviation Air Taxi Takeoff	0	N/A	N/A		1.0E-6		
Commercial Aviation Air Taxi Landing	0	N/A	N/A		2.3E-6		
Military Aviation Large Aircraft Takeoff	0	N/A	N/A		5.7E-7		
Military Aviation Large Aircraft Landing	0	N/A	N/A		1.6E-6		
Military Aviation Small Aircraft Takeoff	0	N/A	N/A		1.8E-6		
Military Aviation Small Aircraft Landing	0	N/A	N/A		3.3E-6		

TABLE B-30. Updated data collection table for Airport 2 Runway 18 showing f(x,y) value and crash rate.

Airport Name AIRPORT 2 Runway Number 18 Pattern Side Right

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	5600	-8.9	0.8	0	1.1E-5		
General Aviation Landing	5600	-8.9	0.8	9.5E-4	2.0E-5		
Commercial Aviation Air Carrier Takeoff	12880	-8.9	0.8	0	2.0E-7		
Commercial Aviation Air Carrier Landing	12880	-8.9	0.8	2.1E-3	2.6E-7		
Commercial Aviation Air Taxi Takeoff	3920	-8.9	0.8	0	1.0E-6		
Commercial Aviation Air Taxi Landing	3920	-8.9	0.8	2.1E-3	2.3E-6		
Military Aviation Large Aircraft Takeoff	28000	-8.9	0.8	0	5.7E-7		
Military Aviation Large Aircraft Landing	28000	-8.9	0.8	1.5E-3	1.6E-6		
Military Aviation Small Aircraft Takeoff	5600	-8.9	0.8	0	1.8E-6		
Military Aviation Small Aircraft Landing	5600	-8.9	0.8	5.2E-3	3.3E-6		

TABLE B-31. Updated data collection table for Airport 2 Runway 0 showing f(x,y) value and crash rate.

Airport Name AIRPORT 2 Runway Number 0 Pattern Side Left

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	4400	8.9	-0.8	0	1.1E-5		
General Aviation Landing	4400	8.9	-0.8	0	2.0E-5		
Commercial Aviation Air Carrier Takeoff	10120	8.9	-0.8	2.1E-4	2.0E-7		
Commercial Aviation Air Carrier Landing	10120	8.9	-0.8	0	2.6E-7		
Commercial Aviation Air Taxi Takeoff	3080	8.9	-0.8	2.1E-4	1.0E-6		
Commercial Aviation Air Taxi Landing	3080	8.9	-0.8	0	2.3E-6		
Military Aviation Large Aircraft Takeoff	22000	8.9	-0.8	2.2E-4	5.7E-7		
Military Aviation Large Aircraft Landing	22000	8.9	-0.8	1.2E-5	1.6E-6		
Military Aviation Small Aircraft Takeoff	4400	8.9	-0.8	2.7E-3	1.8E-6		
Military Aviation Small Aircraft Landing	4400	8.9	-0.8	0	3.3E-6		

TABLE B-32. Updated data collection table for Airport 3 Runway 22 showing f(x,y) value and crash rate.

Airport Name AIRPORT 3 Runway Number 22 Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	2550	10.9	-15.6	0	1.1E-5		
General Aviation Landing	2550	10.9	-15.6	0	2.0E-5		
Commercial Aviation Air Carrier Takeoff	0	N/A	N/A		2.0E-7		
Commercial Aviation Air Carrier Landing	0	N/A	N/A		2.6E-7		
Commercial Aviation Air Taxi Takeoff	0	N/A	N/A		1.0E-6		
Commercial Aviation Air Taxi Landing	0	N/A	N/A		2.3E-6		
Military Aviation Large Aircraft Takeoff	0	N/A	N/A		5.7E-7		
Military Aviation Large Aircraft Landing	0	N/A	N/A		1.6E-6		
Military Aviation Small Aircraft Takeoff	0	N/A	N/A		1.8E-6		
Military Aviation Small Aircraft Landing	0	N/A	N/A		3.3E-6		

TABLE B-33. Updated data collection table for Airport 3 Runway 4 showing f(x,y) value and crash rate.

Airport Name AIRPORT 3 Runway Number 4 Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	450	-10.9	15.6	0	1.1E-5		
General Aviation Landing	450	-10.9	15.6	0	2.0E-5		
Commercial Aviation Air Carrier Takeoff	0	N/A	N/A		2.0E-7		
Commercial Aviation Air Carrier Landing	0	N/A	N/A		2.6E-7		
Commercial Aviation Air Taxi Takeoff	0	N/A	N/A		1.0E-6		
Commercial Aviation Air Taxi Landing	0	N/A	N/A		2.3E-6		
Military Aviation Large Aircraft Takeoff	0	N/A	N/A		5.7E-7		
Military Aviation Large Aircraft Landing	0	N/A	N/A		1.6E-6		
Military Aviation Small Aircraft Takeoff	0	N/A	N/A		1.8E-6		
Military Aviation Small Aircraft Landing	0	N/A	N/A		3.3E-6		

The next step in the near-airport frequency calculation is to determine the effective area of the facility. The example chosen is an L-shaped facility with a height of 20 feet and other dimensions as shown in Figure B-6.

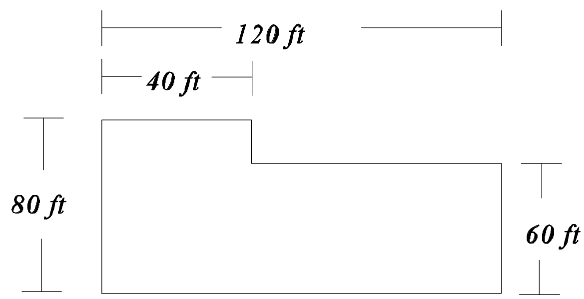

FIGURE B-6. Dimensions of sample facility

The bounding rectangle for this facility would be 120 ft x 80 ft. Using Equations B-3 through B-5, the effective areas would be those shown in Table B-34:

TABLE B-34. Results of effective area calculations.

	General Aviation	Helicopters	Commercial Aviation		Military Aviation			
			Air Carrier	Air Taxi	Large T/O	Large Land	Small T/O	Small Land
WS (from Table B-16), ft	50	50	98	59	223	223	78	78
R, ft	144.2	144.2	144.2	144.2	144.2	144.2	144.2	144.2
H, ft	20	20	20	20	20	20	20	20
cot ϕ	8.2	0.58	9.6	9.6	7.4	9.7	8.4	10.4
L, ft	120	120	120	120	120	120	120	120
W, ft	80	80	80	80	80	80	80	80
S, ft	68	0	1570	1570	780	368	246	447
A_f, sq. miles	1.73E-3	3.2E-4	2.48E-3	2.03E-3	3.35E-3	3.96E-3	2.05E-3	2.37E-3
A_s, sq. miles	4.74E-4	0	1.36E-2	1.14E-3	1.03E-2	4.85E-3	1.96E-3	3.56E-3
A, sq. miles	2.2E-3	3.2E-4	1.61E-2	3.17E-3	1.34E-2	8.81E-3	4.01E-3	5.93E-3

WS = wingspan
R = diagonal of facility
H = facility height
L = facility length
W = facility width
S = aircraft skid distance

After the effective area is determined for all applicable aircraft categories and subcategories, the analyst should update the data collection tables, as shown in Tables B-35 through B-40. The data collection tables now contain enough information to determine the aircraft impact frequency for near-airport operations, using Equation 5-1 in the standard. The results are shown in Tables B-35 through B-40.

TABLE B-35. Completed data collection table for Airport 1 Runway 10.

Airport Name AIRPORT 1 | Runway Number 10 | Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	750	2.7	-7.5	0	1.1E-5	2.1E-3	0
General Aviation Landing	750	2.7	-7.5	0	2.0E-5	2.1E-3	0
Commercial Aviation Air Carrier Takeoff	0	N/A	N/A		2.0E-7	1.5E-2	
Commercial Aviation Air Carrier Landing	0	N/A	N/A		2.6E-7	1.5E-2	
Commercial Aviation Air Taxi Takeoff	0	N/A	N/A		1.0E-6	1.3E-2	
Commercial Aviation Air Taxi Landing	0	N/A	N/A		2.3E-6	1.3E-2	
Military Aviation Large Aircraft Takeoff	0	N/A	N/A		5.7E-7	1.4E-2	
Military Aviation Large Aircraft Landing	0	N/A	N/A		1.6E-6	8.8E-3	
Military Aviation Small Aircraft Takeoff	0	N/A	N/A		1.8E-6	4.0E-3	
Military Aviation Small Aircraft Landing	0	N/A	N/A		3.3E-6	5.9E-3	

TABLE B-36. Completed data collection table for Airport 1 Runway 28.

Airport Name AIRPORT 1 | Runway Number 28 | Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	250	-2.7	7.5	0	1.1E-5	2.1E-3	0
General Aviation Landing	250	-2.7	7.5	0	2.0E-5	2.1E-3	0
Commercial Aviation Air Carrier Takeoff	0	N/A	N/A		2.0E-7	1.5E-2	
Commercial Aviation Air Carrier Landing	0	N/A	N/A		2.6E-7	1.5E-2	
Commercial Aviation Air Taxi Takeoff	0	N/A	N/A		1.0E-6	1.3E-2	
Commercial Aviation Air Taxi Landing	0	N/A	N/A		2.3E-6	1.3E-2	
Military Aviation Large Aircraft Takeoff	0	N/A	N/A		5.7E-7	1.4E-2	
Military Aviation Large Aircraft Landing	0	N/A	N/A		1.6E-6	8.8E-3	
Military Aviation Small Aircraft Takeoff	0	N/A	N/A		1.8E-6	4.0E-3	
Military Aviation Small Aircraft Landing	0	N/A	N/A		3.3E-6	5.9E-3	

TABLE B-37. Completed data collection table for Airport 2 Runway 18.

Airport Name AIRPORT 2 | Runway Number 18 | Pattern Side Right

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	5600	-8.9	0.8	0	1.1E-5	2.1E-3	0
General Aviation Landing	5600	-8.9	0.8	9.5E-4	2.0E-5	2.1E-3	2.3E-7
Commercial Aviation Air Carrier Takeoff	12880	-8.9	0.8	0	2.0E-7	1.5E-2	0
Commercial Aviation Air Carrier Landing	12880	-8.9	0.8	2.1E-3	2.6E-7	1.5E-2	1.1E-7
Commercial Aviation Air Taxi Takeoff	3920	-8.9	0.8	0	1.0E-6	1.3E-2	0
Commercial Aviation Air Taxi Landing	3920	-8.9	0.8	2.1E-3	2.3E-6	1.3E-2	2.4E-7
Military Aviation Large Aircraft Takeoff	28000	-8.9	0.8	0	5.7E-7	1.4E-2	0
Military Aviation Large Aircraft Landing	28000	-8.9	0.8	1.5E-3	1.6E-6	8.8E-3	5.9E-7
Military Aviation Small Aircraft Takeoff	5600	-8.9	0.8	0	1.8E-6	4.0E-3	0
Military Aviation Small Aircraft Landing	5600	-8.9	0.8	5.2E-3	3.3E-6	5.9E-3	5.7E-7

TABLE B-38. Completed data collection table for Airport 2 Runway 0.

Airport Name AIRPORT 2 | Runway Number 0 | Pattern Side Left

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	4400	8.9	-0.8	0	1.1E-5	2.1E-3	0
General Aviation Landing	4400	8.9	-0.8	0	2.0E-5	2.1E-3	0
Commercial Aviation Air Carrier Takeoff	10120	8.9	-0.8	2.1E-4	2.0E-7	1.5E-2	6.4E-9
Commercial Aviation Air Carrier Landing	10120	8.9	-0.8	0	2.6E-7	1.5E-2	0
Commercial Aviation Air Taxi Takeoff	3080	8.9	-0.8	2.1E-4	1.0E-6	1.3E-2	8.2E-9
Commercial Aviation Air Taxi Landing	3080	8.9	-0.8	0	2.3E-6	1.3E-2	0
Military Aviation Large Aircraft Takeoff	22000	8.9	-0.8	2.2E-4	5.7E-7	1.4E-2	3.9E-8
Military Aviation Large Aircraft Landing	22000	8.9	-0.8	1.2E-5	1.6E-6	8.8E-3	3.7E-9
Military Aviation Small Aircraft Takeoff	4400	8.9	-0.8	2.6E-3	1.8E-6	4.0E-3	8.6E-8
Military Aviation Small Aircraft Landing	4400	8.9	-0.8	0	3.3E-6	5.9E-3	0

TABLE B-39. Completed data collection table for Airport 3 Runway 22.

Airport Name AIRPORT 3 | Runway Number 22 | Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	2550	10.9	-15.6	0	1.1E-5	2.1E-3	0
General Aviation Landing	2550	10.9	-15.6	0	2.0E-5	2.1E-3	0
Commercial Aviation Air Carrier Takeoff	0	N/A	N/A		2.0E-7	1.5E-2	
Commercial Aviation Air Carrier Landing	0	N/A	N/A		2.6E-7	1.5E-2	
Commercial Aviation Air Taxi Takeoff	0	N/A	N/A		1.0E-6	1.3E-2	
Commercial Aviation Air Taxi Landing	0	N/A	N/A		2.3E-6	1.3E-2	
Military Aviation Large Aircraft Takeoff	0	N/A	N/A		5.7E-7	1.4E-2	
Military Aviation Large Aircraft Landing	0	N/A	N/A		1.6E-6	8.8E-3	
Military Aviation Small Aircraft Takeoff	0	N/A	N/A		1.8E-6	4.0E-3	
Military Aviation Small Aircraft Landing	0	N/A	N/A		3.3E-6	5.9E-3	

TABLE B-40. Completed data collection table for Airport 3 Runway 4.

Airport Name AIRPORT 3 | Runway Number 4 | Pattern Side NA

	Number of Operations Per Year	x distance, mi	y distance, mi	f(x,y) value [from Tables B2-B13]	P, Crash Rate [from Table B-1]	A, mi^2 [from Equation B-3]	Impact Frequency
General Aviation Takeoff	450	-10.9	15.6	0	1.1E-5	2.1E-3	0
General Aviation Landing	450	-10.9	15.6	0	2.0E-5	2.1E-3	0
Commercial Aviation Air Carrier Takeoff	0	N/A	N/A		2.0E-7	1.5E-2	
Commercial Aviation Air Carrier Landing	0	N/A	N/A		2.6E-7	1.5E-2	
Commercial Aviation Air Taxi Takeoff	0	N/A	N/A		1.0E-6	1.3E-2	
Commercial Aviation Air Taxi Landing	0	N/A	N/A		2.3E-6	1.3E-2	
Military Aviation Large Aircraft Takeoff	0	N/A	N/A		5.7E-7	1.4E-2	
Military Aviation Large Aircraft Landing	0	N/A	N/A		1.6E-6	8.8E-3	
Military Aviation Small Aircraft Takeoff	0	N/A	N/A		1.8E-6	4.0E-3	
Military Aviation Small Aircraft Landing	0	N/A	N/A		3.3E-6	5.9E-3	

The next step of the process is to ascertain the impact frequency from nonairport operations (see Section 5.3.2 of the standard). First, determine the aircraft crash frequency from general aviation nonairport operations. To do this, the analyst first obtains the generic maximum value of NPf(x,y) for general aviation nonairport operations from Table B-14. The general aviation nonairport crash frequency is shown in Table B-41.

TABLE B-41. General aviation nonairport crash frequency.

	Generic Maximum Value for NPf(x,y)	A, sq. miles	Generic Maximum Nonairport Crash Frequency
GA Aircraft	3E-3	2.1E-3	6E-6

The next step is to determine the commercial and military aviation in-flight crash frequency, following Steps 9 through 16 of Chapter 5. To do this, the analyst obtains the maximum NPf(x,y) for these aircraft categories from Table B-15. The commercial and military aviation nonairport crash frequencies are shown in Table B-42.

TABLE B-42. Commercial and military nonairport crash frequencies.

	Generic Maximum Value for NPf(x,y)	A, sq.miles	Generic Maximum Nonairport Crash Frequency (per year)
Commercial Aviation Air Carrier	2E-6	1.5E-2	3E-8
Commercial Aviation Air Taxi	8E-6	1.3E-2	1E-7
Military Aviation Large Aircraft	7E-7	1.4E-2	1E-8
Military Aviation Small Aircraft	6E-6	4.0E-3	2E-8

The next step is to determine the impact frequency from intentional overflight of helicopters. First, determine the number of operations. Earlier in the problem this was defined as 365/y (or 1/day). Next, get the effective area from Table B-34. The helicopter crash frequency is shown in Table B-43.

TABLE B-43. Helicopter Crash Frequency.

	Number of Operations	Crash Rate/Operation	A, Sq. Miles	Average Length of Flight (mi)	Frequency
Helicopter	365	2.5E-5	6.6E-4	37	3.3E-7

The next set of steps calculates the total impact frequency (see Section 5.3.3 of the standard). The analyst begins by adding the near-airport and in-flight results for each category/subcategory. The results are shown in Table B-44.

TABLE B-44. Total impact frequencies by category/subcategory.

Category/Subcategory	Impact Frequency (per year)
General Aviation	6.2E-6
Commercial Aviation Air Carrier	1.5E-7
Commercial Aviation Air Taxi	3.5E-7
Military Aviation Large Aircraft	6.4E-7
Military Aviation Small Aircraft	6.8E-7
Helicopters	3.3E-7
Total (all aircraft)	8.4E-6

Next, the analyst sums up the category/subcategory totals to find the total frequency of aircraft impact into the facility. This equals 8.4E-6, so the facility does not pass the impact frequency evaluation guideline in Section 4.2. Therefore, the analyst must decide which categories to forward to the structural analyst.

In this case, it is suggested that the analyst forward aircraft categories/subcategories of concern, including military aviation large aircraft, military aviation small aircraft, and general aviation.

B.6 References.

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APPENDIX C

GUIDANCE FOR STRUCTURAL RESPONSE EVALUATION

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Note: This appendix provides further explanation of the methods described in Chapter 6. It also describes alternative evaluation approaches that are acceptable.

Section and subsection numbers below correspond to those in Chapter 6.

C.6.1 Purpose.

Aircraft takeoff and landing weights, crash impact velocities, and angle of impact data for various types of aircraft have been provided on a generic basis in the *Data Development Technical Support Document* (TSD) for Chapter 5 (Reference 1) and the technical support document for Chapter 6 (Reference 2). When a site-specific aircraft hazard study is performed, there is a likelihood that all aircraft types applicable to that site may not be found in Reference 1. To determine the critical aircraft missile characteristics, it may be necessary to use both generic data from Reference 1 and data from the site-specific aircraft impact hazard study (see also Section C.6.3.1.1a). The use of site-specific hazard study results would permit exclusion of those aircraft types, subcategories, or even categories that are not applicable to the site.

C.6.1.1 Adverse Effects.

Most safety-related SSCs of a facility are within a building or are located so that barriers may protect them from direct impact from aircraft missiles. For such SSCs, aircraft impact evaluation essentially consists of determining the structural adequacy of these buildings and barriers against local damage and excessive global deformation. After the buildings and barriers are assessed to be structurally adequate, it must be established that the vibratory loads resulting from aircraft impact would not adversely affect the safety function of the SSCs that are within the building, behind the barriers, or supported from the building/barriers.

C.6.3.1 Missile and Target Selection.

This section provides more detailed guidance on the selection of missles and targets for the structural analysis. The most important part of this process is the identification of a representative aircraft for each subcategory to be used for the impact analysis. Since each subcategory may contain aircraft of different sizes, masses, numbers of engines, locations of engines, fuel loads, wingspans, and other key parameters, an envelope must be created to conservatively encompass these parameters. While it would be convenient to simply provide a composite aircraft, this could prove to be wildly conservative in many cases. Therefore, some judgment will be required. Specific guidance cannot be provided because of the multitude of possible situations, but some of the critical parameters to consider are given below as examples.

- If certain aircraft types within a subcategory are not expected to be using the airport, they should be eliminated from consideration. For example, if an airport has commercial flights but is not suitable for wide-body aircraft, these aircraft would not need to be considered in developing the representative aircraft.

- Aircraft types that are clearly less damaging than others within the subcategory do not have to be specifically considered. For example, if a large twin engine jet and a small twin engine turbo-prop both use an airport, it is permissible to state that the large aircraft bounds the smaller aircraft with respect to the structural response of the target.

- Do not feel constrained to pick a particular existing aircraft type to represent a subcategory. Features of various aircraft types (e.g., the fuel load of one type, the engine mass of another type, the number of engines of a third type, etc.) can be combined into a surrogate representative aircraft.

- Do not feel constrained to use only one representative aircraft. If certain parameters cannot be enveloped by a single representation, multiple structural response calculations may be performed. For example, if one type of aircraft has wing mounted engines and another has tail mounted engines, it may not be obvious which one will cause the most damage. In this case, the damage can be assessed for both and the worst case used for release scenario development.

Whatever representation is used, the basis for the assumptions that led to that selection must be fully documented.

C.6.3.1.1 Selection and Characterization of Critical Missiles.

a. Since the aircraft categories and subcategories in Reference 1 are not based on specific consideration of mass, stiffness, and velocity, which determine the impact force time-history, selection of critical aircraft missiles should be based on an assessment of all aircraft identified as potential missiles in the site-specific hazard study. However, if a site-specific hazard study shows that aircraft of only certain categories or subcategories are potential missiles, the critical missile selection should be based on these categories or subcategories. If no site-specific hazard study is performed, critical missiles can be selected based on generic aircraft properties given in References 1 and 2.

b. The use of impact kinetic energy as the sole parameter for selecting the critical missile for evaluating global structural deformation is approximate. It assumes that even though the peak force to which the target may be subjected depends on missile and target mass, stiffness, and strength characteristics, the target damage potential is essentially input energy-dependent since some ductility is permitted. However, if the kinetic energies of the missiles are comparable but their stiffness and strength characteristics are known to be significantly different, these differences should be considered.

c. References 1 and 2 provide impact velocity distributions for many aircraft subcategories based on subcategory-specific crash data. If the site-specific hazard study identifies an aircraft as a potential missile, and this aircraft belongs to one of the subcategories for which an impact velocity distribution is available in References 1 or 2, this distribution can be considered in establishing the impact velocity and selecting the critical missiles.

d. If the mass distribution of the aircraft along the length of the fuselage (M_d) cannot be obtained or calculated by any of the means outlined in Section 6.3.1.1, it can be estimated as follows:

    1. From published literature, obtain the mass distribution curve of a category or subcategory of aircraft, the shape and configuration of which are similar to the subject aircraft.

2. Multiply the ordinate of this curve (i.e., mass per unit length) by the following,

$$\alpha = \frac{W_a}{W_b}\frac{L_b}{L_a} \qquad \text{(C 6-1)}$$

where:

W_a = total weight of the subject aircraft;

W_b = total weight of the similar class aircraft;

L_a = length of the subject aircraft;

L_b = length of the similar class aircraft.

3. Make the necessary adjustments to this curve based on the known differences between the weights of major components and segments of the two aircraft, but keep the total weight of the subject aircraft W_a unchanged.

e. If P_c (fuselage buckling or crushing load) cannot be obtained from the aircraft manufacturer, it can be estimated as follows:

1. From published literature, obtain the P_c distribution and the crush interface area (A) distribution of a similar category or subcategory of aircraft, the shape and configuration of which have some similarity to the subject aircraft.

2. Multiply the ordinate of this curve (i.e., crushing strength) by the following factor, which varies with the distance, x, from the nose to the crush interface:

$$\beta(x) = \frac{t_a(x)d_a(x)\sigma_a}{t_b(x)d_b(x)\sigma_b} \qquad \text{(C 6-2)}$$

where:

a and b refer to the subject aircraft and the similar class aircraft, respectively;

$t_a(x), t_b(x)$	=	skin thickness at x;
$d_a(x), d_b(x)$	=	crush interface equivalent diameter at x;
σ_a, σ_b	=	crushing strength of the skin material.

C.6.3.1.2 Selection of Target SSCs, Angle, and Location of Impact.

a. The list of target SSCs need not include those that are protected by other structures at the site that act as barriers against aircraft missiles. However, the list should include SSCs that are not themselves safety-related, but whose failure may adversely affect safety-related SSCs.

b. The angle and location of aircraft impact on the target shall be determined from the following considerations:

1. Flight path of the aircraft and/or probability distribution of impact angle for the aircraft subcategory (if available from Reference 1).

2. Location and orientation of the target relative to other structures at the site that may act as effective barriers.

3. Potential for impact from a skidding aircraft.

4. Location of vibration-sensitive equipment or systems supported from the target.

Refer to Reference 2 for further discussion.

C.6.3.2 Local Response Evaluation.

C.6.3.2.1.1 Scabbing Thickness.

Modified National Defense Research Committee (NDRC) Formula (1976) (Reference 4).

In the local response sequence, the phenomenon of penetration is initiated by spalling or chipping off of the concrete from the front face. Penetration is the displacement of the missile into the target. The Modified NDRC formula predicts the penetration depth, x, of an equivalent solid circular cylindrical missile:

$$x = \sqrt{4KNWD\left(\frac{V}{1000D}\right)^{1.8}} \qquad \text{(C 6-3)}$$

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

$$x = \left[KNW\left(\frac{V}{1000D}\right)^{1.8}\right] + D \qquad \text{(C 6-4)}$$

$$for\ \frac{x}{D} > 2.0$$

where:

x	=	penetration depth of missile (in.);
K	=	concrete penetrability factor = $[180/(f'_c)^{1/2}]$;
f'_c	=	ultimate compressive strength of concrete (lb/in.^{2});

N	=	missile shape factor = 0.72 for flat-nosed bodies, 0.84 for blunt-nosed bodies, 1.00 for average bullet-nosed (spherical end) bodies, and 1.14 for very sharp-nosed bodies;
W	=	missile weight (lb);
D	=	effective missile diameter (in.);
V	=	missile impact velocity (ft/sec).

For noncircular or irregular shaped missiles, D is computed as the equivalent diameter of the contact area. The formula is only applicable when the target is sufficiently thick to prevent scabbing. Scabbing would lead to more penetration than would be predicted by the formula. The penetration depth, x, is used to predict scabbing and perforation thickness.

The NDRC formula was derived from impact data for missile velocities greater than 500 ft/sec or 340 mph (152 m/s) and missile diameters ranging from 1 in. to 16 in. (2.54 cm to 40.6 cm). The testing conditions included ratios of target thickness to missile diameter equal to or greater than 3. However, because it was based on the theory of penetration, it can be extrapolated beyond the range of available test data. The effects of reinforcing are inherently included.

In a properly designed reinforced concrete structural member with adequate longitudinal and transverse reinforcing steel in each direction, the spreading of the radial cracks produced by the impact will be inhibited by the rebars, and the amount of concrete that spalls off the front face will be limited.

The missile velocities from an aircraft crash event are typically less than 500 ft/sec or 340 mph (152 m/s), and the missile diameters are greater than 12 in. (30.5 cm). Missiles impacting the structures are also mostly deformable. Because of these factors, the Modified NDRC formula shall only be used to predict local penetration of the reinforced concrete structures. For further details on limitations, see Reference 2.

A few of the other formulas, such as the Modified Petry, Ammann and Whitney, and Army Corps of Engineers formulas, suffer from limitations in the range of available test data.

As discussed above, the Modified NDRC formula gives the penetration depth, x, using Equation C 6-3 or C 6-4 as applicable. Once this is known, the scabbing thickness, t_s, of a barrier is given by:

$$\frac{t_s}{D} = 2.12 + 1.36 \frac{x}{D} \qquad for\ 0.65 \le \frac{x}{D} \le 11.75 \tag{C 6-5}$$

or

$$\frac{t_s}{D} = 7.91 \left(\frac{x}{D}\right) - 5.06 \left(\frac{x}{D}\right)^2 \qquad for\ \frac{x}{D} \le 0.65 \tag{C 6-6}$$

To prevent scabbing, minimum concrete thickness, t_d, shall be $\geq 1.1t_s$.

C.6.3.2.1.2 Perforation Thickness.

As discussed earlier in Section C.6.3.2.1.1, the Modified NDRC formula gives the penetration depth, x, using Equation C 6-3 or C 6-4 as applicable. Once this is known, the perforation thickness, t_p, of a barrier is given by:

$$\frac{t_p}{D} = 1.32 + 1.24\ \frac{x}{D}$$

$$for\ 1.35 \le \frac{x}{D} \le 13.5 \qquad \text{(C 6-7)}$$

or

$$\frac{t_p}{D} = 3.19\left(\frac{x}{D}\right) - 0.718\left(\frac{x}{D}\right)^2$$

$$for\ \frac{x}{D} \le 1.35 \qquad \text{(C 6-8)}$$

To prevent perforation, minimum concrete thickness, t_d, shall be $\geq$ 1.2 t_p.

Bechtel Formula (1975)[1]

Based on full-scale tests, an empirical formula for predicting scabbing thickness of concrete targets struck by solid steel missiles with velocities less than 500 ft/s or 300 mph (152 m/s) was developed by Bechtel Corporation (Reference 5). The scabbing thickness, t_s, is given by:

$$t_s = \frac{15.5}{\sqrt{f_c^{/}}}\left(\frac{W^{0.4}V^{0.5}}{D^{0.2}}\right) \qquad \text{(C 6-9)}$$

where:

[1]The Bechtel and Stone & Webster formulas are presented here only to provide a historical perspective. Due to their limited applications they are not recommended for use in aircraft impact evaluation.

f'_c	=	ultimate compressive strength of concrete (lb/in.^{2});
D	=	missile nominal diameter (in.);
W	=	missile weight (lb);
V	=	missile impact velocity (ft/sec).

Stone & Webster Formula (1976)[1]

Based on an extensive series of quarter-scale tests, using hollow steel pipe missiles, Stone & Webster (Reference 6) developed an empirical formula where the scabbing thickness, t_s, is:

$$t_s = \left(\frac{WV^2}{C} \right)^{\frac{1}{3}} \qquad \text{(C 6-10)}$$

where:

C	=	coefficient based on ratio 2T/D;
T	=	missile wall thickness (in.);
D	=	missile outside diameter (in.);
W	=	missile weight (lb);
V	=	missile impact velocity (ft/sec).

The formula is limited to the following range:

$$0.06 \le \frac{2T}{D} \le 1.0$$

$$1.0 \le \frac{t_s}{D} \le 3 \; ; \qquad 75 fps \le V \le 250 fps$$

A ratio of 2T/D of unity corresponds to a solid steel missile.

CEA-EDF Formula (1977).

Based on an empirical fit to data from 52 tests with solid cylindrical missiles impacting at velocities greater and less than the critical perforation velocity, the CEA-EDF formula (Reference 7) was developed in France and presented in 1977. It gives the perforation velocity, $V_{p,}$ as:

$$V_p = 1.43 \left[f_c^{/} \left(\frac{D t_p^2}{W} \right)^{\frac{4}{3}} \right]^{\frac{1}{2}} \qquad \text{(C 6-11)}$$

Later, tests by CEA-EDF indicated that a realistic residual velocity is given by using a factor of 1.29 instead of 1.43 in Equation C 6-11. Thus, for reinforced concrete with a density of 156 lb/ft^3 (2500 Kg/m^3), the perforation thickness (t_p) is given by:

$$t_p = 0.765 \ (f_c^{/})^{-3/8} \left(\frac{W}{D} \right)^{1/2} (V)^{3/4} \qquad \text{(C 6-12)}$$

where:

$f^{/}_c$	=	ultimate compressive strength of concrete (lb/in^2);
D	=	missile nominal diameter (in.);
W	=	missile weight (lb);
V	=	missile impact velocity (ft/sec).

To prevent perforation, minimum concrete thickness, t_d, shall be $\geq$ 1.2 t_p.

Degen Formula (1980)

Based on experimental investigations, Peter Degen (Reference 8) proposed a partial revision to the Modified NDRC formula (Reference 4). The basic penetration depth, x, computed by the Modified NDRC can be used to compute the perforation thickness as follows:

$$\frac{t_p}{D} = 0.69 + 1.29\frac{x}{D} \quad \text{for } 2.65 \le \frac{t_p}{D} \le 18 \qquad \text{(C 6-13)}$$

or

$$\frac{t_p}{D} = 2.2\frac{x}{D} - 0.3\left(\frac{x}{D}\right)^2 \quad \text{for } \frac{x}{D} \le 1.52 \qquad \text{(C 6-14)}$$

To prevent perforation, minimum concrete thickness, t_d, shall be $\ge$ 1.2 t_p.

CRIEPI Formula (1985)

The Central Research Institute of the Electric Power Industry (CRIEPI) of Japan (Reference 9) conducted impact testing focusing on low velocity missiles and proposed the CRIEPI formula, which amended the Modified NDRC formula and the Chang formula (Reference 3). Thus, the scabbing thickness (t_s) and the perforation thickness (t_p) are given by:

$$t_s = 1.75 \left(\frac{U}{V} \right)^{0.13} \frac{(MV^2)^{0.4}}{D^{0.2} \, (f_c^{\prime})^{0.4}} \qquad \text{(C 6-15)}$$

and

$$t_p = 0.90 \left(\frac{U}{V} \right)^{0.25} \left(\frac{MV^2}{Df_c^{\prime}} \right)^{0.5} \qquad \text{(C 6-16)}$$

Parameters are as defined in Equation 6-1.

C.6.3.2.1.3 Punching Shear.

Punching shear stress (psi) calculated on the basis of

$$4\sqrt{f_c^{\prime}}$$

as given in Section 6.4.1.3 of this standard, provides very conservative results for two-way slabs when compared to recent test results. Long's formula given below provides more realistic results as it considers the beneficial effects of flexural stress and reinforcing strength. According to this formula, punching shear capacity, P_v, is the lesser of:

$$P_v = \frac{20(c+d)d(100\rho)^{0.25}}{\left(0.75 + 4\frac{c}{L} \right)} \sqrt{f_c^{\prime}} \qquad \text{(C 6-17)}$$

or

$$P_v = \frac{\rho f_y d^2 \left(1 - 0.59 \frac{\rho f y}{f_c^{/}}\right)}{\left(0.2 - 0.9 \frac{c}{L}\right)} \qquad \text{(C 6-18)}$$

where:

P_v	=	punching shear load (lb);
c	=	side length of the loaded area (in.) (= square root of loaded area);
d	=	effective depth of the section (in.);
ρ	=	reinforcement ratio;
f'_c	=	concrete compressive strength (psi);
L	=	distance between adjacent loads acting on the same panel (may be taken as infinity for typical aircraft engine impact, unless more than one engine are postulated to impact a given panel simultaneously);

and where f_y = yield strength of reinforcement.

C.6.3.3 Global Response Evaluation.

C.6.3.3.2 Time-History Analysis Method.

a. Determination of Force Time-History by Scaling

Impact force time-histories for a number of actual aircraft types have been developed using methods which are similar or identical to Riera's method (Reference 10) outlined in Section 6.3.3.2. These are shown in Reference 2. In the absence of sufficient data on a specific aircraft, its impact forcing function can be approximated by scaling one of the forcing functions given in Reference 2. The aircraft type selected should be one whose characteristics are closest to the aircraft being considered as a potential missile. The scaling method is outlined below.

1. Compute the scaling factor with which the ordinate (force) of the force time-history curve of the selected Reference 2 aircraft shall be multiplied.

$$S_f = \frac{w_1 V_1^2 P_1}{w V^2 P} \qquad \text{(C 6-19)}$$

where:

V_1, w_1, P_1	=	impact velocity, maximum weight per unit length, and maximum fuselage crushing strength of the aircraft being considered as a potential missile;
V, w, P	=	impact velocity, maximum weight per unit length, and maximum fuselage crushing strength of the selected Reference 2 aircraft.

2. Adjust the abscissa (time) of the above scaled force time-history curve such that, for the area under the curve,

$$A_1 = \frac{A(W_1 V_1)}{WV} \qquad \text{(C 6-20)}$$

where:

A	=	area under the force time-history curve for the selected Reference 2 aircraft with total weight W and impact velocity V;

W_1, V_1= total weight and impact velocity of the aircraft being considered as a potential missile.

b. Missile-Target Interaction Analysis

Global response analysis of the target can also be performed by considering the interaction between the missile and the target instead of using the two-step method described in Section 6.3.3.2. In this method, the impacting aircraft (missile) is explicitly modeled with the building structure (target). The aircraft model shall consist of several mass points interconnected by several nonlinear stiffness springs, and all mass points shall have an initial velocity equal to the postulated impact velocity. Similarly, the building model shall consist of several mass points and nonlinear springs, including massless soil springs representing the foundation flexibility. Depending on the data available, the aircraft and the building structure can also be represented by detailed finite elements, instead of lumped masses and equivalent stiffness springs. Also, in either model, the interface between the aircraft and the target, including the local stiffness and crushing properties, can be represented in detail. Alternatively, an equivalent nonlinear interface spring element can be developed from a separate detailed finite element model and inserted into the overall missile-target interface model.

The response of the above missile-target interface model can be determined using one of several nonlinear finite element computer codes available in the industry as an initial velocity problem. The predicted deformation or strain in the various target elements shall then be compared against the permissible values (see Section 6.3.3.3) to assess if the target structure can withstand the impact without excessive deformation or collapse.

c. Target Structure Modeling Guidelines

The type of analytical models used for performing global response evaluations by the time-history analysis method should depend on the purpose of the analysis and the level of detail necessary. Generally, an equivalent lumped mass and spring model is adequate to compute the overall building deformation levels to determine if the building would collapse under impact. But a detailed finite element model is necessary to determine if localized collapse needs to be evaluated.

If the model is also used to compute instructure shock spectra to evaluate the functionality of SSCs supported by the target structure, the structural components that support these SSCs should be explicitly represented by separate mass and stiffness elements. Also, the discretization of mass and stiffness should be refined enough that the high frequency content of the impact force is appropriately reflected in the generated instructure spectra.

C.6.3.3.3 Structural Evaluation Criteria.

a. Even if one or more structural components fail (i.e., the computed ductility ratio is more than the permissible value), the building or the structure as a whole may not collapse unless a mechanism (i.e., no resistance to additional load) is formed due to the failure of these components. To determine if collapse would occur, a nonlinear analysis (having both geometric and material nonlinearity) can be performed in which the stiffness of the structural components shall be set approximately to zero as soon as the deformation reaches the ductility limit. If the structure can withstand the impact force without forming a mechanism, no structural collapse will occur.

For certain target structures, their deformation, displacement, or strain may be required to remain within some specified limits well below those associated with the permissible ductility ratios given in Section 6.3.3.3. Examples of such structures are (1) concrete structures or vaults that must perform a confinement function and therefore are allowed only infinitesimal cracks, and (2) structures that must not deform excessively to avoid pounding on adjacent safety-related systems or structures. Permissible deformation or strain limits for these structures shall be based on their performance requirements.

C.6.3.5 Evaluation of Earth-covered Structures.

Aircraft missiles impacting earth media will, to varying degrees, disintegrate and/or penetrate the ground, depending on the characteristics of the missile (such as impact velocity, size, shape, weight, rigidity, and material properties) and the earth medium (clay, rock, etc.). A missile can directly impact an earth-covered structure if the earth cover is not sufficient to stop it. Such missiles also generate a pressure pulse, which is propagated through the earth media and acts on the buried structures.

Analysis and experiments performed to evaluate missile penetration into earth media and reported in the literature primarily deal with rigid or nondeformable missiles (e.g., ballistic). On the other hand, aircraft impact forcing functions reported in the literature have all been derived assuming a deformable missile impacting a rigid barrier. In the case of aircraft crash, two types of missiles impacting the ground can potentially be generated. First, the fuselage, which is a hollow, stiffened, thin shell structure, deforms upon impacting the ground. Second, the engines and other solid components, which are relatively rigid, essentially act as nondeformable missiles, although engines have been shown to deform on impact with rigid barriers (Reference 11).

In the case of nondeformable missiles, the primary concern for buried structures is direct impact if the depth of the earth is insufficient to stop the missile. The depth of penetration will depend on the missile characteristics (shape, weight, velocity, material properties, etc.) and the resistance offered by the ground. For the various classes of aircraft under consideration (i.e., general aviation, commercial aviation, and military aircraft), their impact velocities, and the strengths of the earth media (stiff soil, sand, clay, etc.), a set of conservative bounding earth media depths can be determined. Structures embedded beyond these depths will not be impacted by the rigid aircraft missiles.

Penetration of a rigid missile into an earth medium has been addressed empirically (References 12 and 13) and analytically (Reference 14). Equations derived from such studies have been compared with a limited number of tests performed with ballistic-type projectiles. Formulas have also been presented (Reference 14) to calculate the velocity decay and the resistance force mobilized as the missile penetrates the earth medium. Penetration equations (Reference 12) also provide techniques for treating missiles of shapes other than ballistic.

A finite element method has been used to determine the response of buried structures subject to aircraft impact (References 15-17). Other simplified and less rigorous methods can also be used where appropriate.

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APPENDIX D

ADDITIONAL GUIDANCE FOR EXPOSURE EVALUATION

TABLE OF CONTENTS

D.1. Nuclear Exposure Evaluation. The following guidance is intended to assist the analyst (post-structural) in modeling aircraft crashes in terms of appropriate parameter assumptions in dispersion modeling and consequence assessment.

D.1.1 Parameter Assumptions. A set of conservative parameter assumptions is made as follows:

a. MAR_i - The material at risk is considered to be the inventory of hazardous materials for the i^{th} material form, as discussed in Section 7.2.2.

b. DR_{ij} - The damage ratio is generated as follows. With respect to the phenomenon of crush/impact, the damage ratio is equal to the fraction of MAR within areas directly impacted by aircraft debris (i.e., all areas in the path of the penetrators, as established by the structural analysis) and other areas of the facility determined to collapse as a result of the penetration (as established by the structural analysis). This damage ratio may be reduced for material in robust containment for which it can be established that not all the material will be exposed. For instance, it may be possible to use geometrical or energy-balance considerations to estimate a maximum number of cans, pails, or drums with which a given aircraft fragment might interact during impact.

With respect to the phenomenon of fire, the damage ratio is equal to the fraction of MAR within areas directly impacted by aircraft debris and, given the presence of combustible loading to support the propagation of fire, any adjacent areas within the same fire zone (i.e., up to the next intact fire boundary). Further, if it is determined that the available combustible loading will support a fire of a duration in excess of the rating of the next intact fire boundary, the damage ratio is adjusted to include any MAR in the adjacent fire zones. Mitigating factors may be evaluated. However, given the difficulty of demonstrating that any available fire suppression systems would remain functional following an aircraft impact, credit for these systems should not be taken unless it can be clearly supported by analyses.

It is not expected that an explosion will occur except in the case of systems having an existing explosive potential, such as an ion exchange column or weapons components. Where such systems exist and are subject to events with the potential to act as initiators, an explosion will be assumed to occur. Such explosions may serve as initiators for subsequent releases beyond those expected from the aircraft crash itself, particularly in cases where kinetic energy released from an explosion has the potential to impact material that otherwise would not be impacted (e.g., material not within areas directly impacted by aircraft debris). Therefore, postulating an explosion requires a re-evaluation of damage ratio assumptions, since explosions may disable barriers otherwise assumed to function, and may produce secondary energetic effects (e.g., due to shrapnel or collapsing structural members). For example, fire barriers on robust containments that would otherwise remain intact may be breached or compromised.

c. $ARF_{ij}/ARR_{ij}/RF_{ij}$ - Bounding values for nuclear materials are based on guidance developed by the U.S. Department of Energy (Reference 1). The use of bounding values, as opposed to best estimates, is specified due to the variability and limited quantity of experimental data from which analytically useful values can be derived. In addition, due to the limited data available, the variety of experimental conditions from which individual bounding values are derived, and the general lack of precise correspondence between experimental conditions and conditions assumed for analysis, statistical analysis is not considered appropriate when using data from DOE-HDBK-3010-94 for the purpose of aircraft crash evaluations. Specific applications considered inappropriate include the use of best estimate values or the development of ARF/ARR/RF distributions based on the experimental data for the purpose of statistical sampling.

During the measurement of ARFs and RFs, precise correspondence between event conditions and experimental conditions is not generally found. For conservative analysis, the data are applicable if the measurement conditions exceed those calculated for the event (e.g., if the fall distances for spilled powders or liquids with characteristics like the materials used in the experiments are equal to or less than the experimental distance). In most cases, extrapolation beyond the domain of experimental data is valid to a limited extent (a factor of 2 to 5, depending on the slope of the experimental data and the range of conditions covered in the experimental study). Models are available for the calculation of ARFs, ARRs, and RFs for some phenomena. Care should be used in any extrapolation, however, to avoid producing inappropriate results.

d. LPF_{ij} - The use of leakpath factors is generally most advantageous when taking credit for deposition within a building under quasi-static conditions, such as after an earthquake that causes cracks in the structure and a loss of ventilation. For aircraft impact, the leakpath factor is 1.0 for all affected material, given the possible extent of facility structural damage.

D.1.2 Dispersion Modeling and Consequence Assessment. Once the source term has been developed, it is necessary to translate the quantity of hazardous material released into dose to the maximally exposed individual at the site boundary. The specifics of the calculation will depend upon the definition of the evaluation guidelines, in terms of the precise parameter being measured and the conditions (e.g., meteorological) under which the evaluation guidelines are developed. In general, however, the modeling of material transport from the source to the receptor is necessary, and should be performed at a calculational level of detail commensurate with the balance of the analysis. In most cases, it should be possible to demonstrate that the evaluation guidelines have been met using simple, straight-line Gaussian dispersion modeling. Guidance on the use of this and other models can be found in the literature (Reference 2). In addition, computer codes may be used for modeling material transport and assessing consequences. Where they are used, their appropriateness should be justified on a case-by-case basis, recognizing that different codes tend to have different domains of applicability (e.g., puff releases, explosive releases). Examples of computer codes that may be appropriate under certain analytical conditions include the MELCOR Accident Consequence Code System (MACCS) (Reference 3) and the Explosive Release Atmospheric Dispersion Code (ERAD) (Reference 4).[1]

D.2. Chemical Exposure Evaluation. A wide variety of chemical releases may potentially occur as a result of an aircraft crash. One of the most critical tasks is to select the vapor dispersion model that is most appropriate for the accident scenario. Guidance for characterizing many of the most common types of accident scenarios and for performing the exposure modeling is provided in References 5 and 6.

D.2.1 Definition of Source Terms. The series of flowcharts in Figure D-1 is intended to help the analyst clearly define the accident scenario to be modeled. Beginning on page D-7 of Figure D-1, the analyst should identify which case is most applicable to the accident scenario being investigated. Page D-7 directs the analyst to go to another page of Figure D-1 and proceed to identify sections of references (such as References 5 or 6) or seek expert advice. On subsequent pages of Figure D-1, the scenarios are broken down into more classes, after which the analyst is directed to other sections of appropriate references, where he/she will either find advice on how to model the scenario of interest or be advised to seek expert advice. Clearly, Figure D-1 is a simple, paper-based expert system. It can readily be modified to include

[1]These computer codes have been listed as examples only. Their identification here does not represent endorsement of the codes, individually or collectively, nor does it imply blanket acceptance of the codes that may be used in meeting the requirements of this standard.

additional scenarios, if needed, or be updated as better information about certain models becomes available (e.g., aerosolization).

To illustrate the use of Figure D-1, let us assume that an airplane has crashed into a vessel containing acetone at ambient temperature. This corresponds to the top scenario on page D-7 of Figure D-1. The analyst is then directed to page D-8 of Figure D-1, where a number of variations are displayed. The boiling point of acetone is ~330 K (~594° R), which is typically well above the ambient temperature. The temperature on a hot day might be 305 K (~549° R). Therefore, the upper branch on page D-8 of Figure D-1 should be selected. The next question is whether the acetone is under its own static head (i.e., the pressure is due to its own weight) or under additional pressure from another source.

A typical condition in which acetone could be under its own static head only is storage in a vessel at atmospheric pressure. In this case, the analyst is directed to go to page D-9 of Figure D-1, where the choice is between spillage into a diked or an undiked area. The analyst is then directed to Section 5.1 or 5.3 of Reference 6) for spillage into a diked area or to Section 5.6.2 of Reference 6 for spillage into an undiked area. Section 5.1, for example, gives a detailed analysis of how to calculate the rate of evaporation of acetone spilled into a diked area and how to prepare inputs for the Dense Gas Atmospheric Dispersion model (DEGADIS) (Reference 7) and SLAB (Reference 8). Section 5.6.2 of Reference 6 gives guidance on how to model a spreading pool that is unconfined.

Returning to page D-8 of Figure D-1, the acetone may be under high pressure, for example, if the vessel is padded with an inert gas. In this case, the analyst should proceed through the lower portion of page D-9 of Figure D-1 and on to various sections of Reference 6, as illustrated for the case above. On page 3, the top branch differs from the lower branch only by the presence of high pressure. This means that the liquid will be driven out of the vessel at a higher rate than it would be if it were under static head only.

Figure D-2 is included to help the reader visualize the scenarios that are the end points of the flowchart on Figure D-1. Figure D-2 contains more information about important phenomena that must be addressed.

D.2.2 Dispersion Models. There is no “officially approved” model for the atmospheric dispersion of hazardous chemical vapors. The two listed above, DEGADIS (Reference 7) and SLAB (Reference 8), are in the public domain. The EPA has developed a computer model, TSCREEN, that is suitable for several applications in this area (Reference 9). Hanna et al. (Reference 10) evaluated 11 models using data from nine field experiments. The EPA (Reference 11) and Touma et al. (Reference 12) have also compared a number of heavy vapor models. Each of the models mentioned in these references has various strengths and weaknesses. The analyst must choose an appropriate model and justify its use.

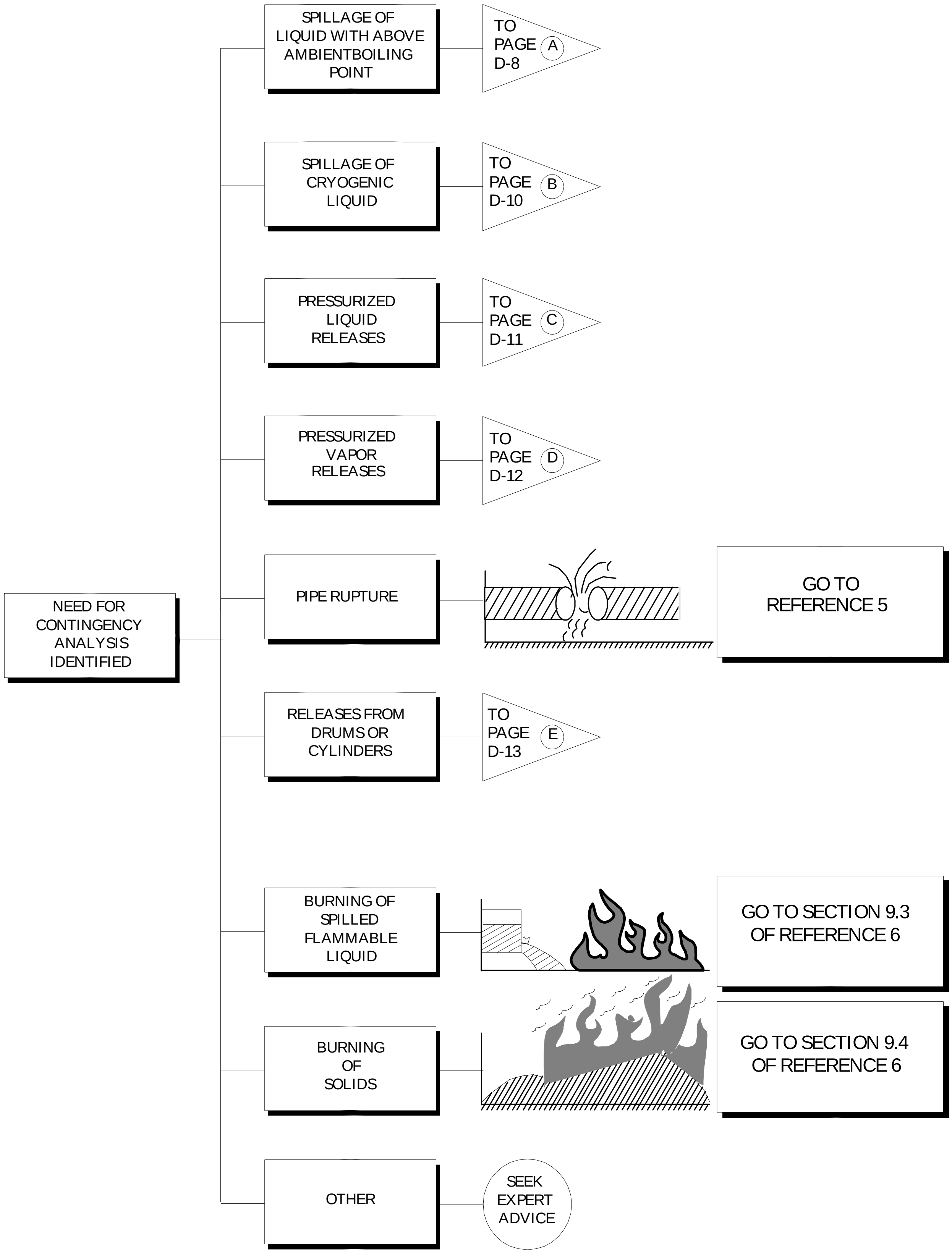


FIGURE D-1 Scenario identification flowchart

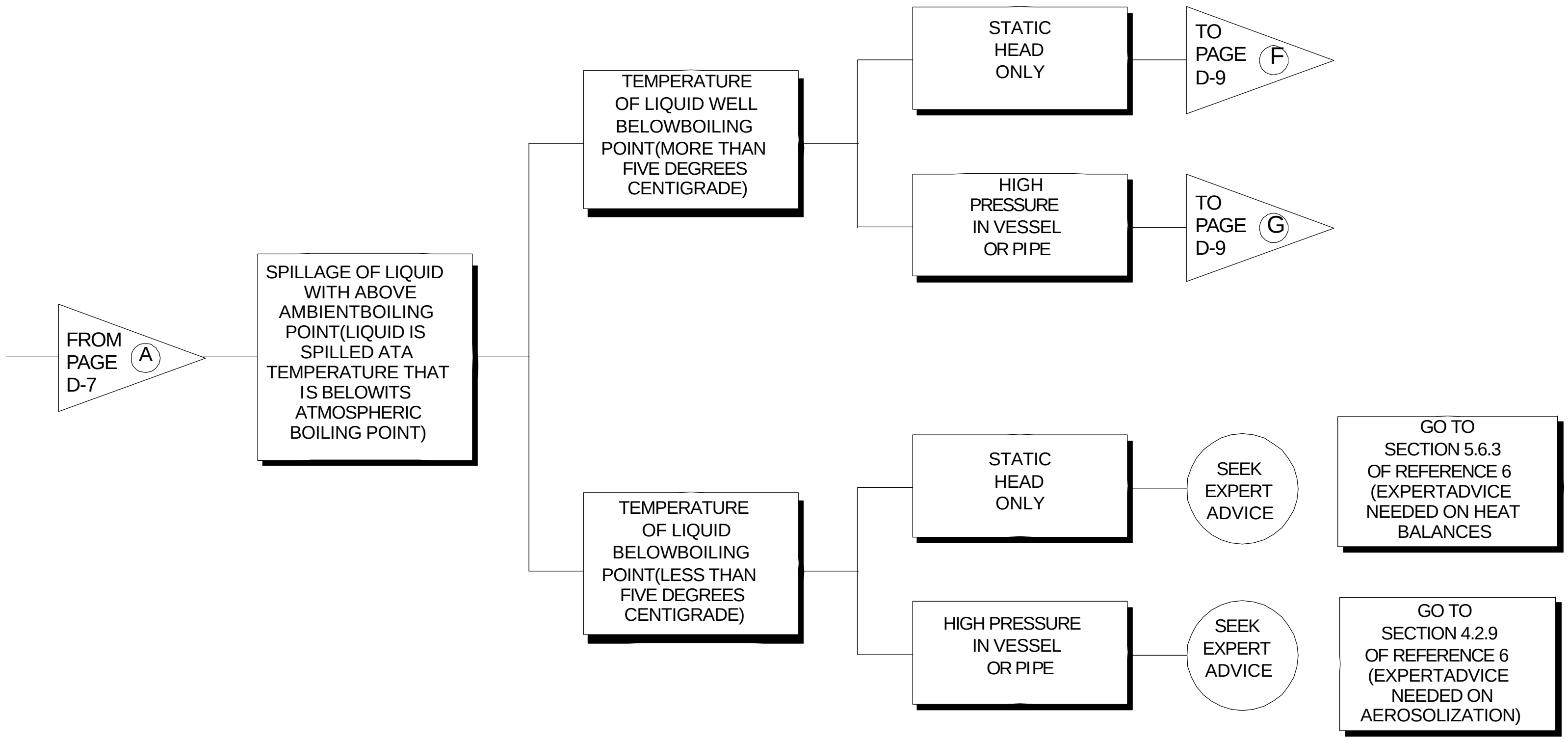
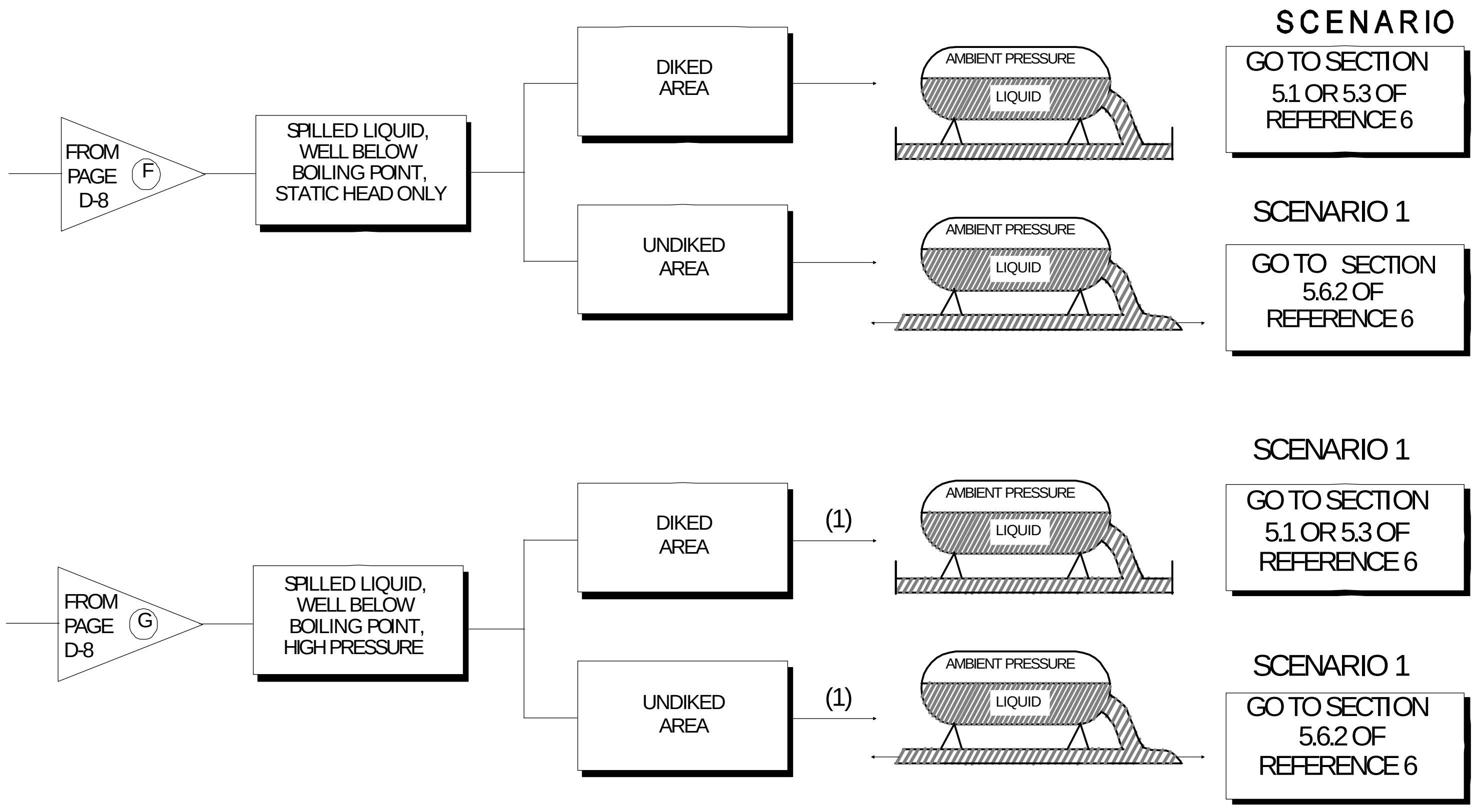
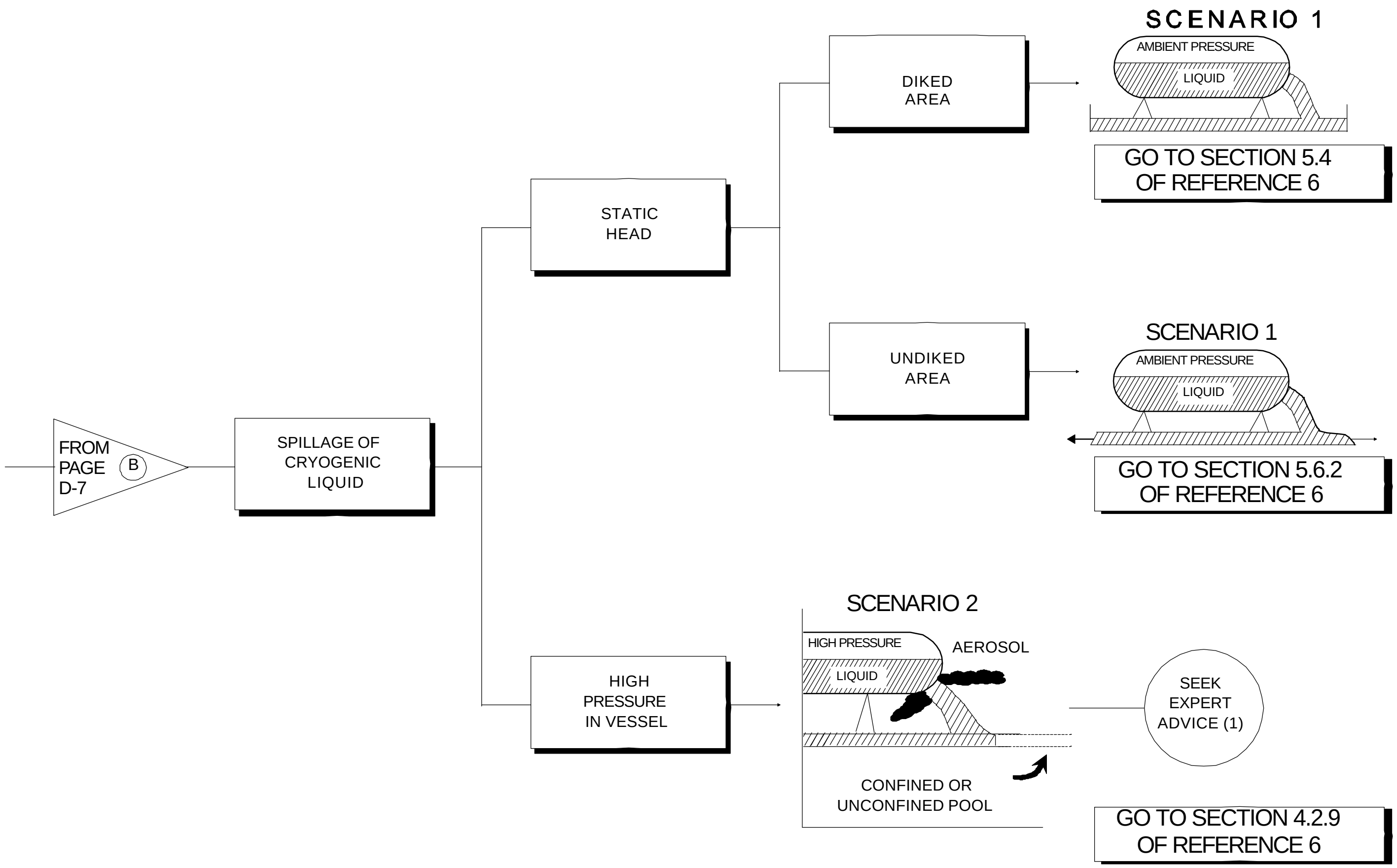


Figure D-1. Scenario identification flowchart - (continued)



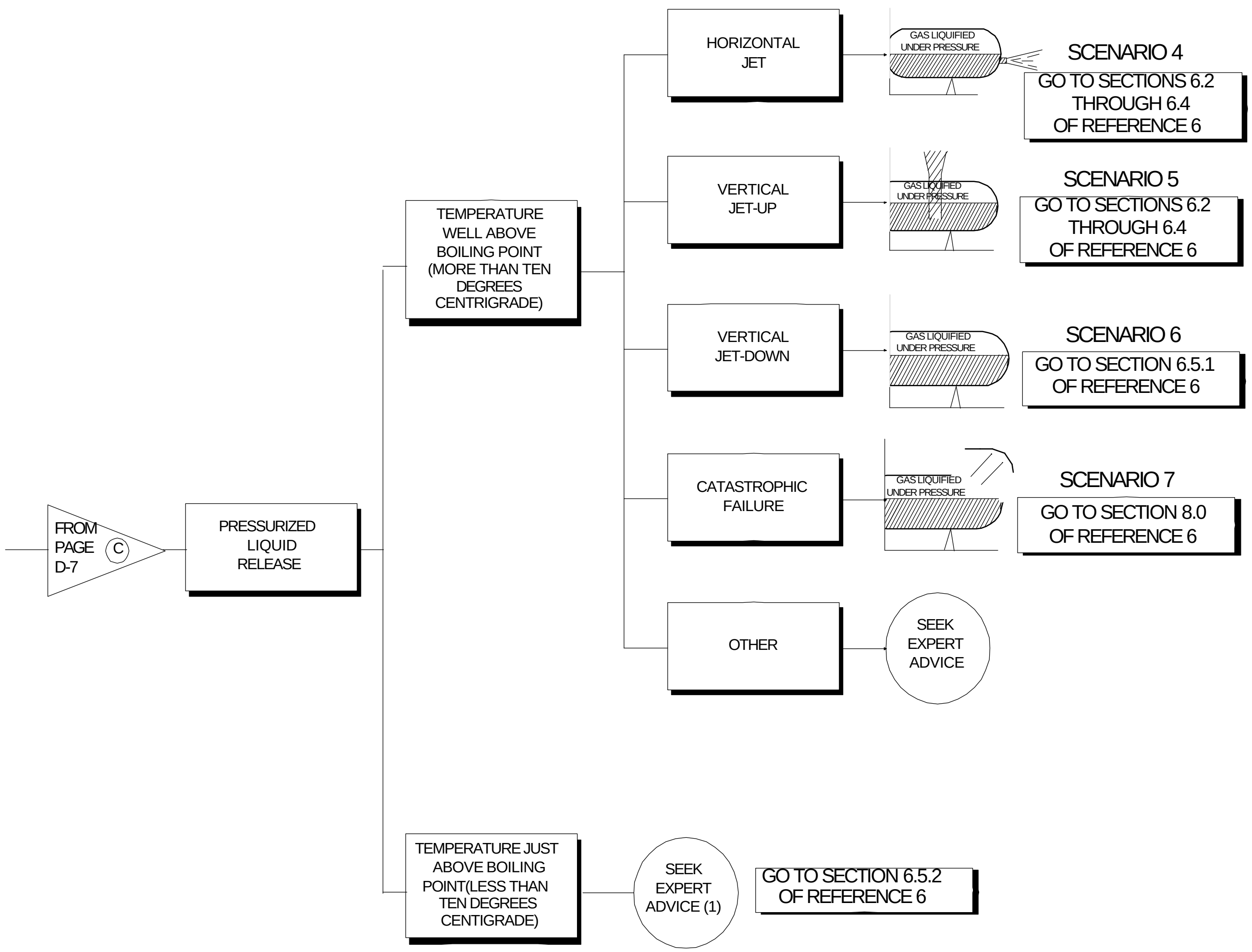
(1) Key assumption: high pressure causes little or no aerosolization when temperature of liquid is well below boiling point.

FIGURE D-1. Scenario identification flowchart (continued)



(1) Expert advice required on aerosolization

FIGURE D-1. Scenario identification flowchart (continued)



(1) Expert advice needed on aerosolization

FIGURE D-1. Scenario identification flowchart (continued)

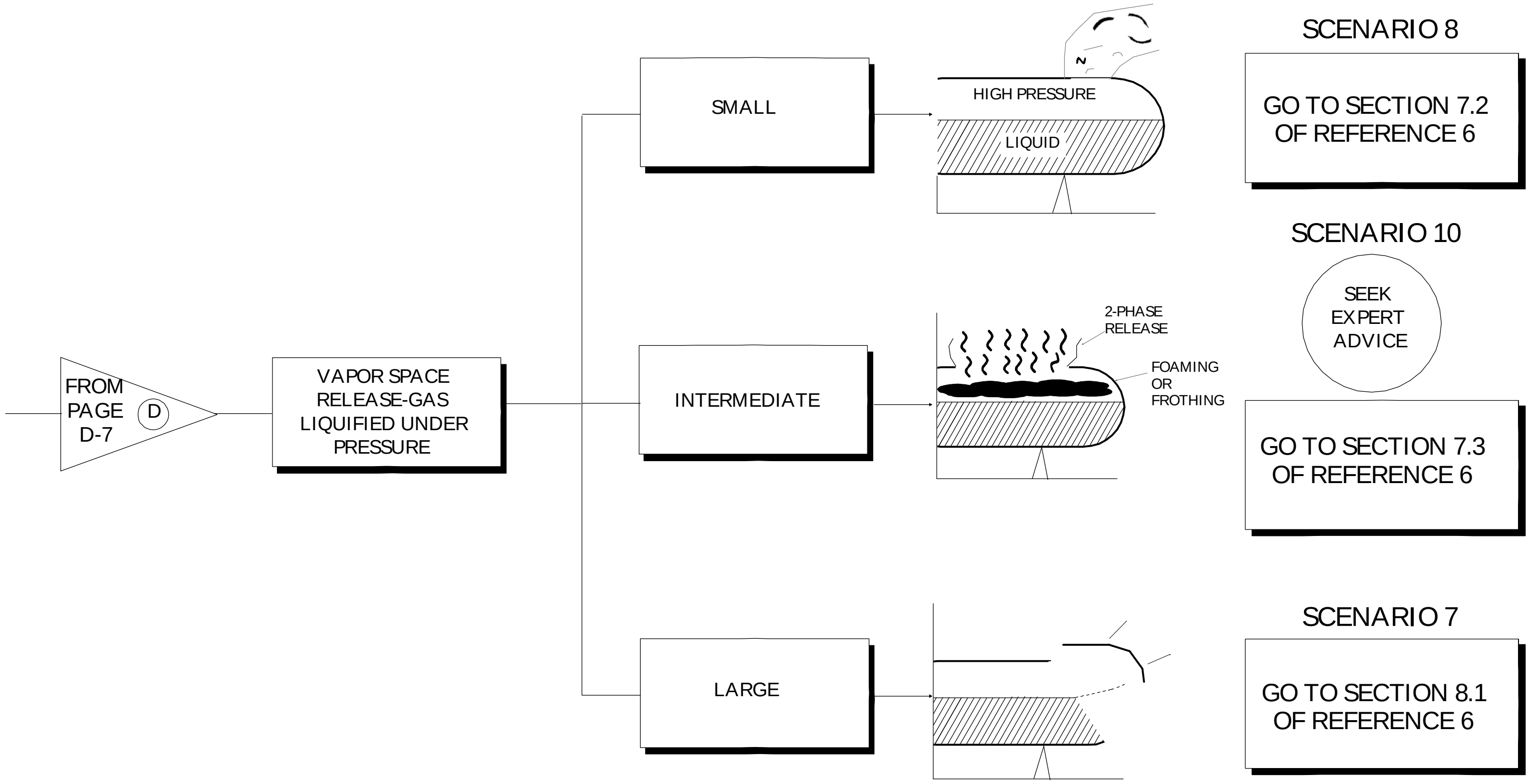


FIGURE D-1. Scenario identification flowchart (continued)

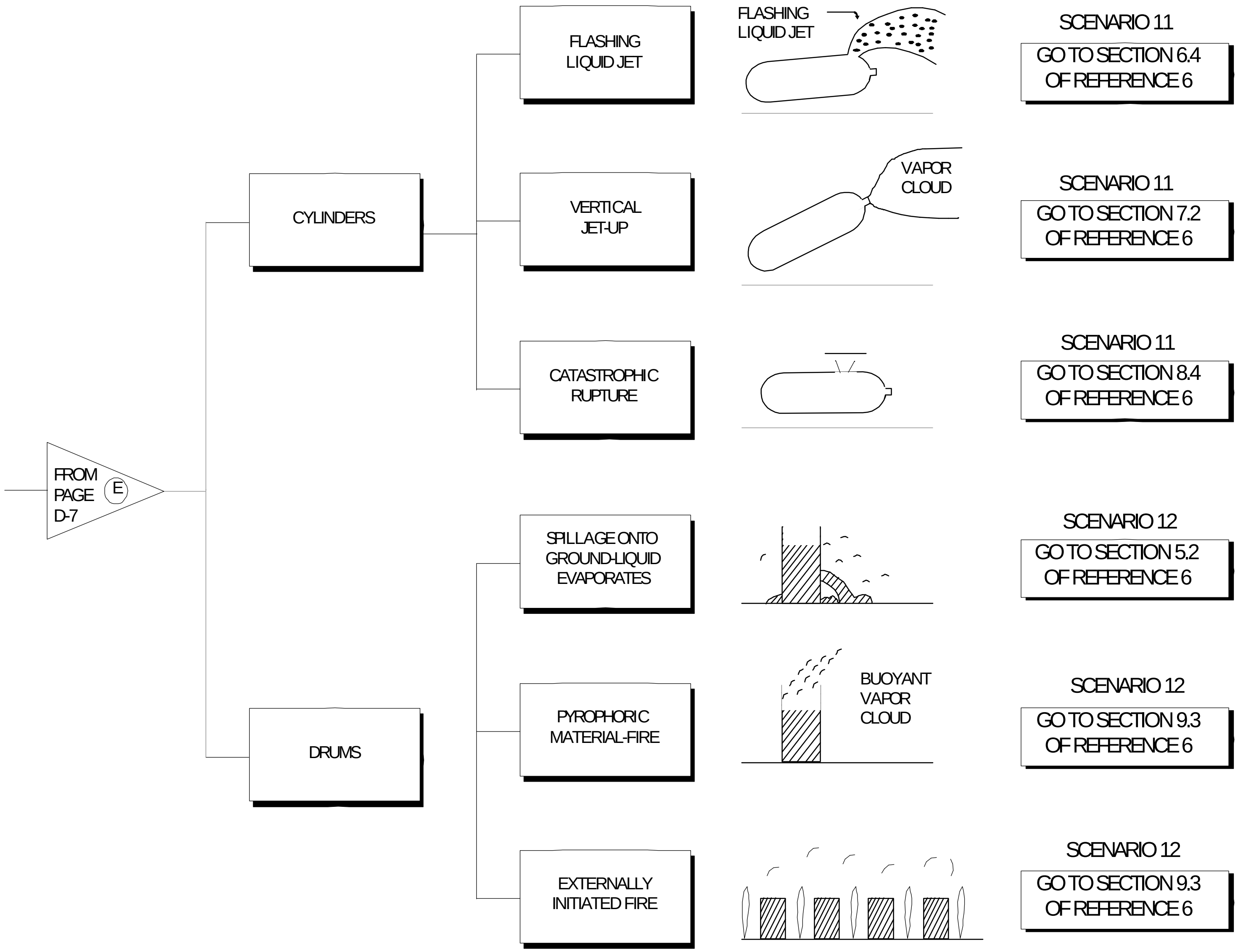


FIGURE D-1. Scenario identification flowchart (continued)

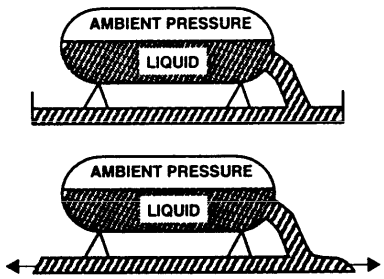
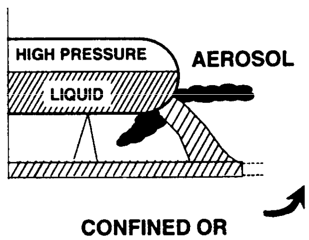
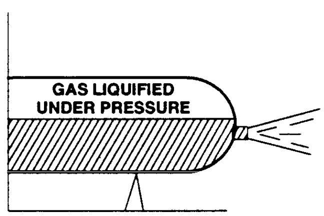
Description of Release Scenario	Visualization	Phenomena/Issues Addressed
1. Rupture of vessel containing liquid with above ambient boiling point at low pressure		Calculation of evaporation rates from a confined or an unconfined pool
2. Rupture in vessel containing liquid with above ambient boiling point at high pressure		Definition of cases in which pressure drive release can form aerosols by mechanical fragmentation
3. Rupture in vessel containing refrigerated liquids same as 1 and 2	Same as above	Calculation of the rate of evaporation of cryogens spilled onto ground
4. Liquid release from wall of vessel containing gas liquified under pressure		• Rate of release of liquid driven by high pressure • Flashing • Flashing-driven aerosolization • Momentum effects

FIGURE D-2. Visualization of scenarios

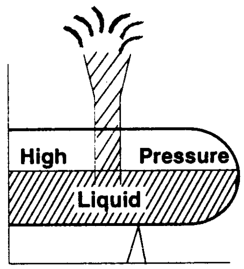
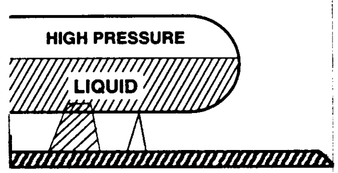
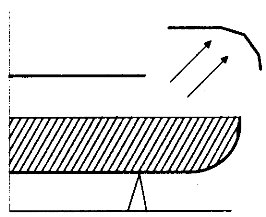
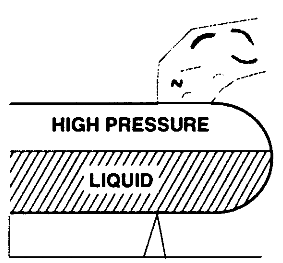
Description of Release Scenario	Visualization	Phenomena/Issues Addressed
5. Release of gas liquified under pressure from long pipe		• **Flashing in pipe** • **Rate of release of two phase mixture**
6. Liquid release of gas liquified under pressure-impingement onto surface		• **Droplet recovery, pool formation** • **Evaporation rates from unconfined pool**
7. Catastrophic failure of vessel containing gas liquified under pressure or castrophic failure in vapor space		• **Definition of characteristics of puff sources** • **Potential for explosion if flammable material is involved**
8. Small hole in vapor space of pressurized vessel		**Vapor jet releases**

FIGURE D-2. Visualization of scenarios - (continued)

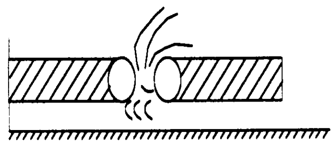
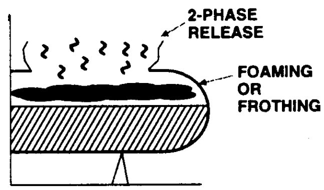
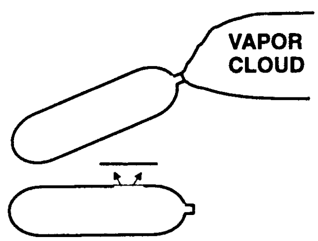
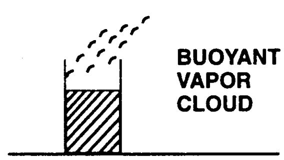
Description of Release Scenario	Visualization	Phenomena/Issues Addressed
9. Pipe ruptures		• Rates of discharge from pipeline • Potential for explosions if gases are flammable
10. "Intermediate" sized hole in the vapor space of vessel containing gas liquified under pressure		Two phase flow requires (bubbly flow, churn trubulent flow, droplet flow)
11. A cylinder is punctured or ruptured		Various possible modes of release from small containers
12. Contents of drum or vessel burn		• Rate of release of vapor cloud resulting from the combustion of contents of the drum or vessel • Buoyant plant

FIGURE D-2. Visualization of scenarios - (continued)

Description of Release Scenario	Visualization	Phenomena/Issues Addressed
13. Burning of spilled liquid pools		• Rate of release of vapor cloud resulting from the combustion of pool material • Buoyant plumes • Burning of pools
14. Burning of solids		• Release of combustion gaseous product • Buoyant plumes • Rate of release of heat from burning solids • Momentum effects

FIGURE D-2. Visualization of scenarios - (continued)

D.3 References.

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12. Touma, J.S. et al. "Performance Evaluation of Air Toxics Dispersion Models for Simulating Heavier-than-Air Releases," *Proceedings of the 1991 International Conference and Workshop on Modeling and Mitigating the Consequences of Accidental Releases of Hazardous Materials, New Orleans, LA.* New York: Center for Chemical Process Safety of the American Institute of Chemical Engineers, 1991.
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Concluding Material

Review Activities:

DOE
DP
EM
ER
FE
FM
LM
NE

Preparing Activity:

DOE-DP-31

Project Number:

SAFT-0030