321-17

Range Commanders Council

Range Safety Group

COMMON RISK CRITERIA STANDARDS FOR NATIONAL TEST RANGES

ABERDEEN TEST CENTER
DUGWAY PROVING GROUND
REAGAN TEST SITE
REDSTONE TEST CENTER
YUMA PROVING GROUND
WHITE SANDS MISSILE RANGE

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
NAVAL AIR WARFARE CENTER WEAPONS DIVISION
NAVAL UNDERSEA WARFARE CENTER DIVISION, KEYPORT
NAVAL UNDERSEA WARFARE CENTER DIVISION, NEWPORT
PACIFIC MISSILE RANGE FACILITY

30TH SPACE WING
45TH SPACE WING
96TH TEST WING
412TH TEST WING
ARNOLD ENGINEERING DEVELOPMENT COMPLEX

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

DISTRIBUTION A: APPROVED FOR PUBLIC RELEASE

DISTRIBUTION IS UNLIMITED

DOCUMENT 321-17

COMMON RISK CRITERIA STANDARDS FOR NATIONAL TEST RANGES

September 2017

Prepared by

Range Safety Group
Risk Committee

Published by

Secretariat
Range Commanders Council
US Army White Sands Missile Range,
New Mexico 88002-5110

Table of Contents

Table of Figures

Table of Tables

Changes to this Edition

This document is an updated version of RCC Document 321-16 (Common Risk Criteria for National Test Ranges). The following is a list of changes.

Note: The use of the word “supplement” used herein refers to the companion (supplemental) document to RCC Document 321.

a. Added a two-tiered risk management process for the protection of public infrastructure.
b. Included provisional acceptable risk criteria for public infrastructure.

This page intentionally left blank.

Preface

This is the foundational document that defines consensus standards for the range risk management process and risk criteria. The companion document[1] provides additional detailed information to assist in implementation of the standards. The standards in this document are not considered absolute; rather, this document and its supplement are intended to provide a baseline for defining acceptable risks for hazardous range operations and to assist the user in the development and implementation of robust risk assessments.

This document presents the results of an extensive cooperative effort by the Range Safety Group of the Range Commanders Council. Planned and unplanned hazardous events generated by flight operations present a safety concern for all test ranges. Each range has established its own set of criteria and analytical methods for protecting personnel, facilities, aircraft, and other assets from hazardous operations. Although these separate efforts have been very successful, the logical relationships among criteria used at the test ranges and across different hazards are often difficult to comprehend. The consensus standards presented in this document are intended to:

a. Promote a common set of safety standards and process among the ranges;

b. Promote valid, repeatable risk assessments;

c. Facilitate innovation to support challenging missions;

d. Nurture openness and trustworthiness among the ranges, range users, and the public;

e. Simplify the scheduling process;

f. Present common risk criteria that can reduce cost for users of multiple test ranges.

The RCC gives special acknowledgement for production of this document to:

Dr. Paul Wilde, Chairman, RSG Risk Committee
Deputy Chief Engineer, Federal Aviation Administration, AST-4
800 Independence Ave, SW. Rm 331
Washington, D.C. 20591
Phone (202) 267-5727
E-mail Paul.Wilde@faa.gov

Please direct any questions to:

Secretariat, Range Commanders Council
ATTN: CSTE-WS-RCC
1510 Headquarters Avenue
White Sands Missile Range, New Mexico 88002-5110
Phone (575) 678-1107, DSN 258-1107
E-mail usarmy.wsmr.atec.list.rcc@mail.mil

---

[1] Range Commanders Council. *Common Risk Criteria for National Test Ranges (Supplement)*. 321-10 (Supplement). December 2010. May be superseded by update. Retrieved 28 July 2016. Available to RCC members with Private Portal access at https://wsdmext.wsmr.army.mil/site/rccpri/Publications/321-10_Supplement_Common_Risk_Criteria_Standards_For_National_Test_Ranges/.

This page intentionally left blank.

Acronyms

AIS	abbreviated injury scale
COLA	collision avoidance
COP	critical operations personnel
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DSL	damage severity level
E_C	expected casualties
E_F	expected fatalities
FAA	Federal Aviation Administration
FTCA	Federal Tort Claims Act
FTS	flight termination system
GP	general public
JSpOC	Joint Space Operations Squadron
km	kilometer
MEP	mission-essential personnel
MRTFB	Major Range and Test Facility Base
nm	nautical mile
NOTMAR	Notice to Mariner
RC	Risk Committee
RCC	Range Commanders Council
RSG	Range Safety Group
UAV	unmanned aerial vehicle

This page intentionally left blank.

CHAPTER 1

Introduction

1.1 Purpose

This document provides a common set of range safety policies, risk criteria, and guidelines for managing risk to people and assets during manned and unmanned flight operations, excluding aviation operations. It establishes the following:

a. Acceptable risk criteria for both the general public (GP) (involuntary acceptance) and mission-essential personnel (MEP) (voluntary acceptance), excluding people in the launch or reentry vehicle;

b. Debris injury thresholds for unprotected people;

c. Debris hazard thresholds for aircraft and ships;

d. Vulnerability models for large commercial transport aircraft and business-class jets;

e. Approach for evaluating flight hazards to critical assets;

f. Provisional acceptable risk criteria for unoccupied or largely unoccupied public infrastructure.

1.2 Scope

The policies and criteria in this document are intended for use by members of the Department of Defense (DoD) national ranges and Major Range and Test Facility Bases (MRTFBs). These policies and criteria apply to launch and reentry hazards generated by endoatmospheric and exoatmospheric range activities, including both guided and unguided missiles and missile intercepts, space launches, and reentry vehicles. This does not include aviation operations or unmanned aerial vehicle (UAV) operations. The Range Commanders Council (RCC) document 323-99[2] provides criteria for UAVs.

1.3 Implementation

This document is an advisory document. Its content is based on the consensus positions held by the Risk Committee (RC) within the Range Safety Group (RSG), which is made up of a broad cross-section of the US range safety community. Therefore, the content of this document represents consensus standards. The main body of this document provides consensus standards with the highest levels of priorities while the supplement contains lower levels of priority requirements, guidelines, and example methods; however, precise language is used in both this document and the supplement in an attempt to capture the intent of the RC as follows.

- The words “must,” “shall,” and “will” indicate a requirement that is strongly recommended. Legitimate alternatives may exist, but each alternative shall demonstrate an equivalent level of safety or be granted a waiver.

---

[2] Range Commanders Council. *Range Safety Criteria for Unmanned Air Vehicles.* RCC 323-99. December 1999. May be superseded by update. Retrieved 6 April 2016. Available at http://www.wsmr.army.mil/RCCsite/Documents/323-99_Range_Safety_Criteria_Unmanned_Air_Vehicles_(Basic)/323-99.pdf.

- "Should" indicates an advisory requirement or a highly desirable procedure. When this standard uses "should," the committee intends that a range will achieve compliance to the maximum extent practical, but no waiver or equivalent level of safety will be required.
- "Can" and "may" permit a choice and express a guideline.

In order for a range to effectively implement this document, the range should evaluate the contents of this document and incorporate it accordingly into the local regulations and requirements.

1.4 Range Responsibilities

High-level authorizing documents, such as the Department of Defense Instruction (DoDI) 3200.18,[3] assign responsibility to each range commander[4] (or other launch/reentry decision authority for non-DoD facilities) for ensuring that all missions are conducted safely, consistent with operational requirements. Range flight operations typically involve some level of risk. Therefore, an important aspect of the range safety responsibility is to ensure that the risk is properly managed within prescribed limits. To accomplish this, each range commander (or designee) must perform the following.

a. Establish risk management procedures (including hazard containment) to implement the risk management process described herein.

b. Establish acceptable risk criteria appropriate to each type of mission flown in consideration of the guidance provided herein.

c. Accept any risks, including those that exceed the established risk criteria when warranted for a mission in consideration of the operational requirements and national need.

    (1) Make such decisions based on a thorough understanding of any additional risk that exceeds the risk criteria and the benefits to be derived from taking the additional risk.

    (2) Ensure such decisions are documented in a formal waiver process (or equivalent), preferably in advance of the mission.

d. Maintain related range policy and requirements documents.

e. Maintain records of risk assessments and waivers to established risk criteria.

f. For a mission involving more than one range:

    (1) coordinate with the other range(s) to clearly document safety responsibility for each phase of the mission;

    (2) develop and implement joint plans for controlling the mission risk due to all planned and unplanned events.

---

[3] Department of Defense. "Subject: Management and Operation of the Major Range and Test Facility Base (MRTFB)." 1 February 2010. May be superseded by update. Retrieved 6 April 2016. Available at http://www.dtic.mil/whs/directives/corres/pdf/320018p.pdf.

[4] This document uses "range commander" to refer to the duly authorized launch or reentry decision authority.

CHAPTER 2

Policies and Procedures

2.1 General Policy and Goals

In planning any operation, risk must be reduced to the extent that is practical in keeping with operational objectives. Safety should be balanced with operational objectives by cooperative interaction between the range and the range user. To maximize achievement of mission objectives within safety constraints, the range user should consider overall risk along with other factors that affect mission acceptability. These factors include criticality of mission objectives, protection of life and property, the potential for high-consequence mishaps, local political factors, and governing range or programmatic environmental requirements.

All ranges should strive to achieve complete containment of hazards resulting from both normal and malfunctioning flights. If a planned mission cannot be accomplished using a containment approach, a risk management approach may be authorized by the range commander or the designated representative. The risk management approach should conform to the guidelines presented in this document or otherwise demonstrate compliance with the objectives presented.

Range commanders should never regard events (such as injuries) as being routine or permissible. No adverse consequences are routinely acceptable; however, the probability is finite that range mishaps producing adverse consequences may occur. The term “acceptable risks” used in this document can be properly interpreted as “tolerable risks.” These are risks the range commander may tolerate to secure certain benefits from a range activity with the confidence that the risk is properly managed within prescribed limits.

Compliance with this document leads to defensible launch support and launch commit decisions. Employing a sound basis for accuracy and repeatability in risk assessments leads to consistent risk acceptance decisions, thereby fostering public confidence that the ranges are operated with appropriate regard for safety. Thus, individuals living or working at or near a range may go about their daily lives without concern for their proximity to range activities. Moreover, compliance with these guidelines provides assurance that flights near or over communities by space boosters or weapon systems does not significantly increase the risk to these communities. These goals have led to the policy objectives provided here.

In defining objectives for risk assessment and risk management, the RCC goals are to:

a. Create a common set of safety standards and processes among the ranges that will achieve the stated risk management goals;

b. Promote accurate, repeatable risk assessments by minimizing errors in estimating and ensuring their scientific validity;

c. Facilitate innovation to support challenging missions;

d. Nurture openness and trustworthiness among the ranges, range users, and the public.

2.2 Policy Objectives

2.2.1 General Public

The GP includes all people located on- and off-base that are not essential to a specific mission or nearby critical operation. This definition applies to all people regardless of whether they are in some mode of transportation (such as airplanes, ships, and busses), are within a structure, or are unsheltered. The GP should not be exposed, individually or collectively, to a risk level greater than the background risk in comparable involuntary activities, and the risk of a catastrophic mishap should be mitigated.

In the above context, the RCC considers "comparable involuntary activities" as those where the risk arises from manmade activities that:

a. Are subject to government regulations or are otherwise controlled by a government agency;

b. Are of vital interest to the US; and

c. Impose involuntary risk of serious injury or worse on the public.

2.2.2 Mission-Essential Personnel

A certain degree of risk is inherent in hazardous operations. The MEP may include persons in training to perform specific tasks that are part of the current operation. The range commander or mission director (or their designees) should identify the MEP in training and justify their designation as MEP. The MEP should not be exposed, individually or collectively, to a risk level greater than that found in comparable high-risk occupations, and the risk of a catastrophic mishap should be mitigated.

2.2.3 Critical Operations Personnel

Critical operations personnel (COP) include persons not essential to the specific operation or launch currently being conducted, but who are required to perform safety, security, or other critical tasks at the range. The critical operations range user (or manager) provides the number and justification of personnel required to conduct the critical operations. The range safety personnel will approve or determine the number and location of COP with the concurrence of the appropriate decision authority. The COP should be included in the same risk category as MEP.

2.2.4 Catastrophe Potential and Transportation Systems

People on aircraft, ships, and other modes of transportation and people on oilrigs and offshore platforms should be protected to a level commensurate with the background risk associated with those activities. The risk assessment should account for potential catastrophic consequences to all exposed people, and mitigations should be implemented to ensure that the risk from catastrophic events is consistent with the allowable risk given in Subsection 3.7.3 and Subsection 3.7.4.

Scenario-specific information should be considered in providing protection against catastrophic consequences. Combinations of factors that should be considered include the number of people who may be simultaneously injured, the risk of damage to high-value assets, the risk of a casualty, factors that may significantly impair the range's ability to perform its mission, and factors that may have national or international consequences.

Transportation systems include all modes of transportation such as airplanes, ships, trains, busses, and automobiles. People in transportation systems must be categorized following the same rules that apply to unsheltered people and people in fixed shelters (i.e., MEP, COP, or GP). Each individual in a transportation system must be protected to the level for his or her population category (MEP, COP, or GP). Collective risk must be assessed to include people in transportation systems. The collective risk to people in transportation systems must be added to the collective risk for unsheltered people and the collective risk for sheltered people. The numerical value defining the acceptability of the total collective risk must be based on the population category. Additional protection, such as defined in Section 3.7, must be applied to people in transportation systems in order to minimize the potential for catastrophic risk.

2.2.5 Spacecraft

Orbiting manned spacecraft will be protected to a level equivalent to that provided to mission-essential aircraft. When the planned missions involve vehicles or propagated hazards with altitude capability greater than 150 kilometers (km), ranges should coordinate with the Joint Space Operations Squadron (JSpOC) for conjunction assessment if needed. In addition, ranges should establish collision avoidance (COLA) periods in the launch window if there are any manned spacecraft within 50 km of, or lower than, the 3-sigma altitude capability of the launch vehicle, payloads, jettisoned objects, or debris cloud boundary.

The RC recognizes that protection for critical unmanned space systems should also be provided because orbital debris mitigation is a national policy goal. The most recent National Space Policy of the United States (dated June 28, 2010) states that “the United States will pursue the following goals in its national space programs …strengthening measures to mitigate orbital debris.”[5] While DoD Directive (DoDD) 3100.10[6] states that DoD activities are to be conducted “…in a safe and responsible manner that protects space systems…,” it does not specify which DoD activity, the launching agency (range user) or the range, has the responsibility for assuring this protection.[7] In the absence of clear direction, the RC recommends that the launching agencies and the ranges adopt the provisional standards specified in Section 3.6. In the case of the Air Force, the roles and responsibilities for COLA are documented in AFI 91-217.[8]

2.2.6 Critical Assets

Damage to range resources can have public safety and mission assurance implications. As a minimum, the decision authority should protect resources that could increase the risk to surrounding population centers if they were damaged or not available in the event of an emergency. Additionally, since national security is dependent on range resources, the decision

---

[5] Office of the President, United States of America. National Space Policy of the United States of America. 28 June, 2010. May be superseded by update. Retrieved 7 April 2016. Available at https://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf.

[6] Department of Defense. “Subject: Space Policy.” DoDD 3100.10. 18 October 2012. May be superseded by update. Retrieved 6 April 2016. Available at http://www.dtic.mil/whs/directives/corres/pdf/310010p.pdf.

[7] Historically, protection of unmanned systems has been addressed as part of mission assurance by the launching agency but only for DoD missions or highly valued NASA missions. In the commercial space industry, the launch operator must obtain liability insurance to cover such potential mishaps and has historically not required conjunction assessments for mission assurance or unmanned asset protection purposes.

[8] Department of the Air Force. “Space Safety and Mishap Prevention Program.” AFI 91-217. 11 April 2014. May be superseded by update. Retrieved 11 May 2016. Available at http://static.e-publishing.af.mil/production/1/af_se/publication/afi91-217/afi91-217.pdf.

authority should consider the protection of selected facilities and equipment necessary to conduct the range's mission.

In this standard, critical assets include property (typically government property) that is essential to protect the public health and safety, maintain the minimum operations of the range, or protect the national security or foreign policy interests of the United States. It includes property/infrastructure that must remain operational following a mishap, such as range facilities and equipment, as well as hospitals, and fire stations.

The criteria for protecting critical assets depend on the consequences of an impact. It can be influenced by the importance of the critical asset in terms of emergency response or continued range operations, the down time and cost of repairing the critical asset, and other considerations. Therefore, the individual ranges need to establish the protection criteria to meet the policy objective for their particular situation. Sample criteria are included in Chapter 4 of the supplement. The ranges may need to modify the criteria to fit the conditions at their particular range.

2.2.7 On-Base and Off-Base Public Infrastructure

The term "infrastructure" refers to equipment and facilities; it excludes mission-critical assets. Equipment and facilities that comprise part of an on- or off-base renewable energy system, such as wind turbine generation facilities and associated transmission lines, are examples of infrastructure for which the risk management process and provisional criteria specified in this standard should apply.

With the encroachment of public facilities (which may be either on or nearby base installations) that are large and/or include fragile subsystems critical for operations, missions conducted at MRTFB facilities may directly produce threats to the infrastructure that comprises those facilities; and likewise the actual or perceived impact of minimizing the risk to such infrastructure can (and has in the past) indirectly affect MRTFB activities by imposing holds or mission changes and/or cancellations.

In order to protect unoccupied or largely unoccupied public infrastructure, the initial standard focuses on proposed developments involving renewable power generation and electrical power distribution, with immediate consequences from MRTFB activities the central concern (consequences from latent and/or delayed damage are excluded). While consequences from latent and/or delayed damage are excluded, secondary public safety consequences are addressed due to the network-centric nature of public infrastructure. This is because these consequences could create a significant public safety impact, such as loss of electrical power in a city for an extended period or exposure to the release of hazardous material.

2.2.8 Environment

As part of environmental documentation preparation in compliance with federal and local regulations, launch and flight test hazards should be taken into account and mitigated as necessary. While safety is a factor in environmental compliance, environmental protection and regulation are beyond the scope of this standard.

2.3 Risk Management Process

Risk management is a systematic and logical process to identify hazards and control the risk they pose. This process should include the following elements (phases) described in Figure

2-1. Table 2-1 lists the phases and the subsections of this document that provide more detail for each.

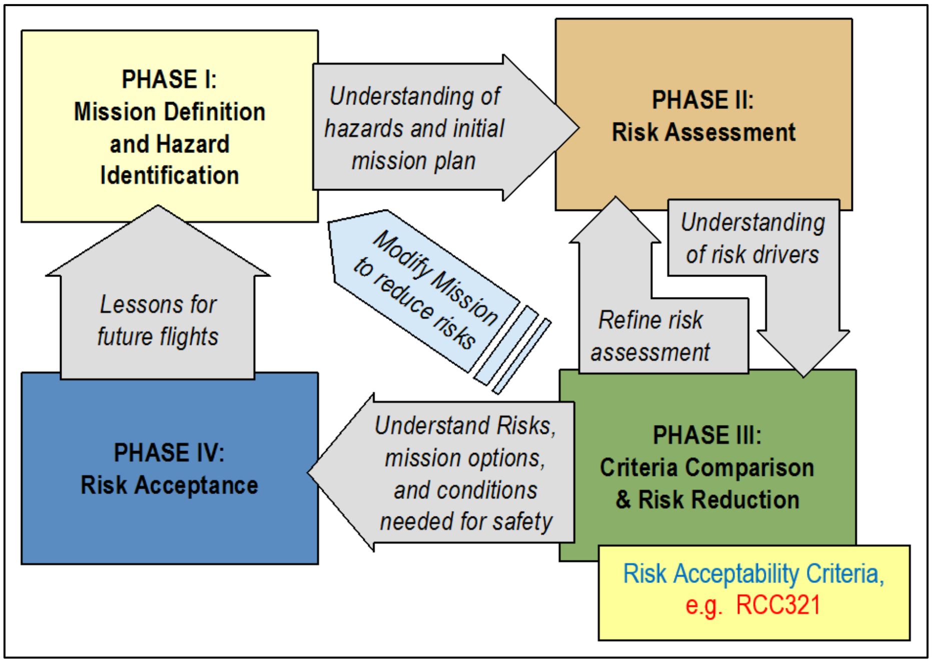

Figure 2-1. Risk Management Process

Table 2-1. Four Phases of Risk Management Process

Phase	Title	Subsection
I	Mission Definition and Hazard Identification	2.3.1
II	Risk Assessment	2.3.2
III	Criteria Comparison and Risk Reduction	2.3.3
IV	Risk Acceptance	2.3.4

The initial goals of the risk management approach are to contain the hazards and isolate them from populated areas wherever practical. An alternative to hazard isolation is to define hazard containment areas so as to minimize the population exposed or be able to evacuate persons not associated with the hazard-generating event. This is in accordance with the primary policy that no hazardous condition is acceptable if mission objectives can be attained from a safer approach, methodology, or position (i.e., minimizing the hazards and conducting the mission as safely as reasonably possible). When hazards cannot be contained or minimized to an insignificant level, refined assessments are performed to determine if the remaining risks are acceptable. An additional benefit of hazard containment is that this process is typically less costly than risk assessments and can be evaluated relatively quickly with straightforward assumptions and with less required data.

2.3.1 Phase I: Mission Definition and Hazard Identification

Phase I is the "problem definition" step of the process. Information is assembled to identify mission characteristics, objectives, and constraints. Potential hazard sources must be identified by evaluating the system to be flown and the range safety constraints. Information sources typically include:

a. range safety data packages;
b. system description documents;
c. MEP and COP locations;
d. surrounding population data to include public and commercial facilities and transportation assets (including aircraft corridors and shipping lanes);
e. seasonal meteorological data;
f. the range safety system used;
g. lessons learned on similar missions.

Further details of information sources are in Chapter 2 and Chapter 7 of the supplement to this document. The output of this step provides a basis for hazard analysis and risk assessment and for use in evaluating options for mitigating risks in ways that will minimize adverse mission impact.

2.3.2 Phase II: Risk Assessment

This step provides information needed to determine whether further risk reduction measures are necessary. Risk levels for identified hazards are expressed using qualitative and quantitative methods. This step produces basic measures of the risks posed by hazards. These hazards include direct hazards, such as inert, explosive, and flammable debris dispersions, explosive overpressure fields, exposure to toxic substances, and exposure to ionizing and non-ionizing radiation. They also include possible indirect hazards and derivative exposure to people that could arise from damage to infrastructure. In some cases, this step will provide sufficient information to support the decision making without further analysis.

A valid risk assessment must account for all potential hazards posed by the range activity to personnel, facilities, and other assets. The assessment must be based on accurate data, scientific principles, and an application of appropriate mathematics. The assessment must be consistent with the range safety control that is planned for the mission. Valid calculations to assess risk can be made using the methods presented in the supplement. These typically produce conservative estimates (i.e., they produce a scientifically plausible result that characteristically overestimates risk given existing uncertainties). In all cases, the analyst is responsible for ensuring that the application of the methods in the supplement produces reasonable results. This assessment leads to mitigation measures needed to protect individuals and groups of people. This topic is discussed more fully in Chapter 3.

In general, risk is expressed as the product of the probability of occurrence of an event and the consequences of that event. Total risk is the combination of the products, over all possible events, of the probability of each event and its associated consequence. The probability of an event is always between zero and one; however, the consequences of that event can be any value. Risk can be relatively high if the probability is high, or the consequence is great, or a combination of the two.

Simple risk models are often employed to make an initial determination of risk. They are also used when the identified hazards are known to result in low risks and the analyst is assured that the estimated risk is conservative. For example, simple models can be used when only inert debris occurs and the debris is fairly limited in size and weight with relatively low values of kinetic energy or ballistic coefficients and shelters would provide protection from debris. These models are generally less costly, minimize schedule impacts, and have the following characteristics.

a. Simplified application of input parameters and assumptions.
b. Simplified measures of population estimation utilized.
c. A basic injury model and associated casualty areas.
d. Conservative assumptions of debris fragmentation and survivability.

If the resulting risk estimate is conservative and well within acceptable limits, then models that are more costly and time-consuming, more complex, or of higher fidelity will not be necessary.

When the identified hazards are significant or the initial risk estimate shows that acceptance criteria are, or may be, exceeded, then more complex risk models are typically used. Use of these models may be more costly, be time-consuming to execute, and require a higher fidelity and more sophisticated application of input data and assumptions. The assessment may require detailed population and sheltering models, more complex human vulnerability models, and more realistic debris fragmentation and survivability models. This may require input parameters and assumptions to be supported by empirical evidence or expert elicitation and quantification of the impact of uncertainty in the risk model and model parameters. Complex risk assessment models are typically used when significant size debris or explosive debris impacts are present that could compromise shelters and the associated population.

2.3.3 Phase III: Criteria Comparison and Risk Reduction

Risk measures are compared with criteria to determine the need or desirability for risk reduction. If the risk is initially unacceptable, measures should be considered to eliminate or mitigate it. Elimination is achieved by design or system changes that remove the hazard source, such as replacing a hazardous material with a non-hazardous one or moving a trajectory to achieve containment. Mitigation is achieved by reducing the consequences of an event or the probability of an event happening. For example, increasing system reliability of a launch vehicle or test article will increase the probability of success, thereby lowering risk. Alternatively, designing a mission to avoid flight over densely populated areas will decrease consequences of casualties and thereby reduce the risk. Mitigation measures may include elements in the operation plan that reduce risk and are consistent with operational objectives, flight termination systems (FTSs), containment policies, evacuation, sheltering, and other measures to protect assets from the hazards. Flight termination criteria and mission rules should be reviewed to assure that the risks induced, should they be exercised, are tolerable. To evaluate the effectiveness of mitigation measures, risk must be reassessed assuming they have been implemented. These risk reduction procedures should be followed until risk levels are as low as reasonably practical.[9] See, for example, the waiver of debris containment requirements for launch granted by the Federal Aviation Administration (FAA) as documented in the Federal Register.

2.3.4 Phase IV: Risk Acceptance

Presentations to the decision authority must be sufficient to support an informed decision. The presentations should include all range-mandated risk control measures, residual risks, measures of catastrophic loss potential (such as collective risk given a flight termination action, collective risk given failure of an FTS, and risk profiles), key analysis assumptions, the size and impact of uncertainties in the analysis, and the protective measures that have been considered and implemented and their effectiveness. The decision authority must approve proposed mission rules and should compare the operational risk to the criteria defined in this document and to other applicable mission requirements. When local agreements are in place and the range has adequately communicated the content and rationale of this document to the representatives of local government, local agreements should govern. This shall not be interpreted as overriding any federal or state laws or regulations. The three-tiered hierarchy of requirements is:

a. Federal and state laws and regulations;
b. Local agreements;
c. This document.

In general, higher-risk operations require a higher level of approval. The range commander may tolerate risk levels within criteria given herein to secure certain benefits from a range activity with the confidence that the risk is properly managed and consistent with best practices. The outcome of these presentations to the decision authority is the acceptance of operational risks by a properly informed decision authority. This acceptance includes a determination that the residual operational risk is within tolerable limits. By doing so, it avers/ justifies that the proposed conditions for allowing the operation to be initiated and the rules to allow the mission to continue to completion comply with best practices for ensuring that the risk is less than accepted/tolerable levels.

The terms of this acceptance and required implementation conditions must be documented. The responsible safety office should document a risk assessment to demonstrate compliance with the risk management policy applied.

2.3.5 Risk Management for Public Infrastructure[10]

The risk management process described in the previous subsections is maintained for public infrastructure; however, it is accomplished using the two-tiered methodology shown in Figure 2-2 because, in contrast to injury to people, damage to infrastructure must be evaluated at both the unit component level and, following that, at the system level. The colors of the steps in

---

[9] Federal Aviation Administration. “Waiver of Debris Containment Requirements for Launch.” Notice of Waiver. Federal Register, Vol. 81, No. 7. 12 January 2016. Available at https://www.federalregister.gov/articles/2016/01/12/2016-00444/waiver-of-debris-containment-requirements-for-launch.

[10] Some of the details in this subsection may be moved to the supplement when it is updated.

Figure 2-2 correspond to the colors used in Figure 2-1 for the phases of the risk management process.

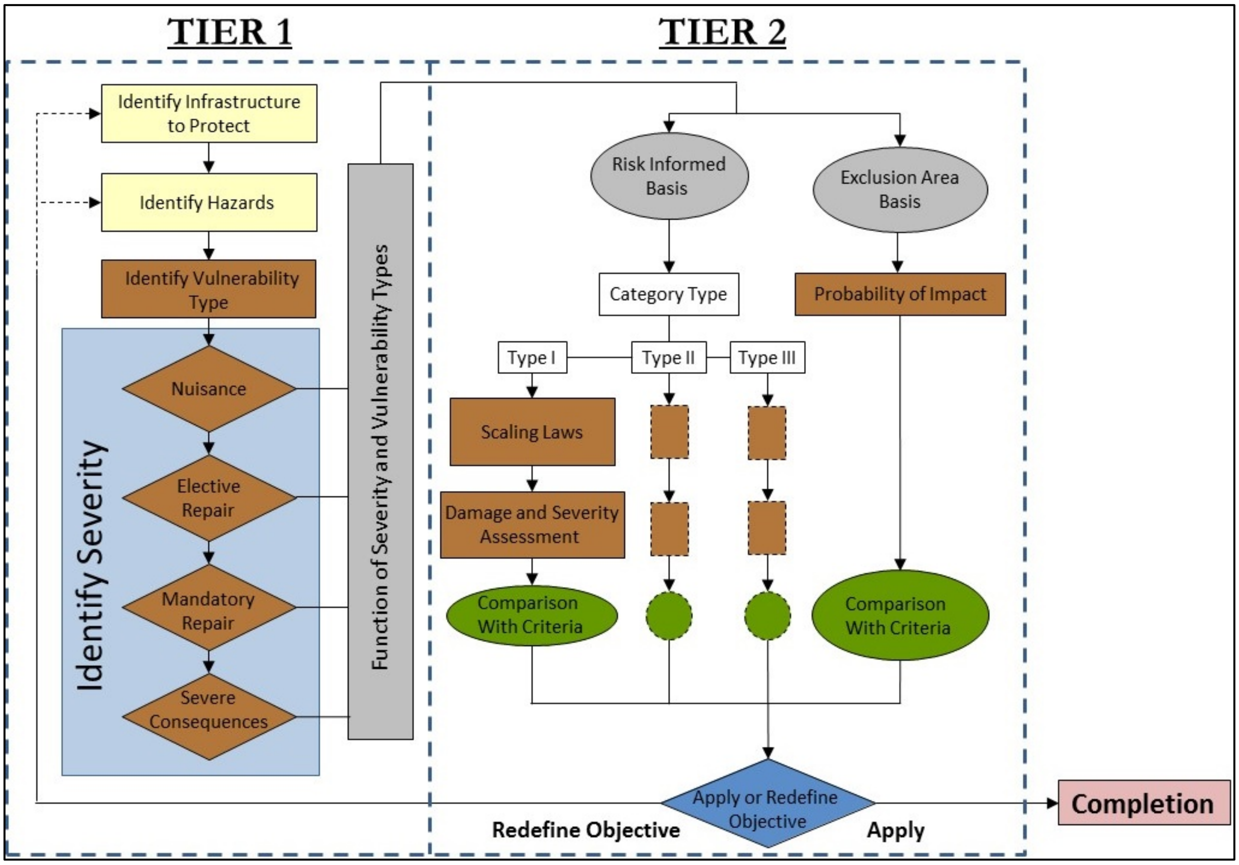

Figure 2-2. Two-Tiered Risk Management Process for Infrastructure

a. Tier 1 Consequence Assessment. A Tier 1 consequence assessment is an initial, and largely qualitative, assessment performed to achieve three objectives:

(1) Enumerating the items and categories of public infrastructure to which a mission constitutes a realistic threat;

(2) Specifying the type and number of unit components of each item of infrastructure for possible vulnerability;

(3) Identifying the criticality of unit component functionality to the larger system-level functionality and possible derivative exposure that could result from nominal or off-nominal mission occurrences.

The Tier 1 consequence assessment should be performed using Table 3-2 in order to ascertain which of the four possible maximum-consequence severity classes could result from a nominal or off-nominal mission.

b. Tier 2 Consequence Assessment. A Tier 2 consequence assessment follows the Tier 1 assessment. The Tier 2 assessment is a quantitative assessment of the probable effects of damage to the set of public infrastructure unit components and system networks identified as requiring protection in Tier 1. The Tier 2 assessment uses the appropriate vulnerability flowcharts, damage severity thresholds, and models of the threats to estimate the acceptability criteria identified in the Tier 1 assessment process for each of the applicable infrastructure types.

2.3.6 Conditional Risk Management

Flight termination action is a good example of a risk-mitigating safety intervention that induces a conditional risk that should be managed. A conditional risk management process should be implemented to assure that mission rules and flight termination criteria do not induce unacceptable levels of risk when they are implemented.[11] This review process is outlined in the supplement in Chapter 2. Figure 2-3 shows the relationship between the risk management process just outlined and the conditional risk management process.

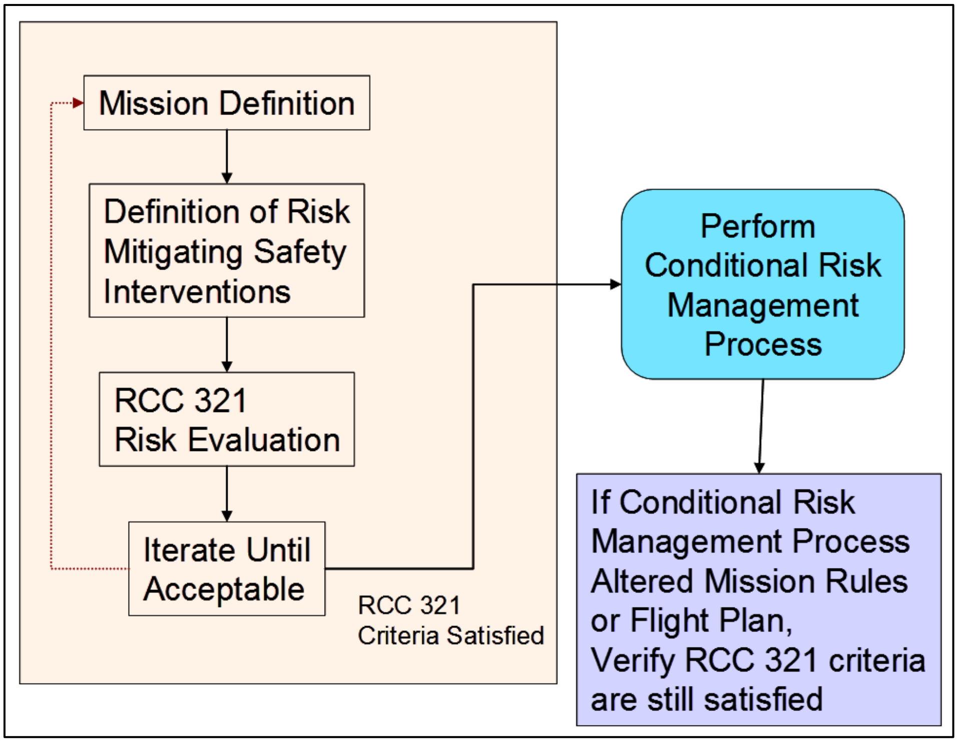

Figure 2-3. Relationship Between Conditional Risk Management and Basic Risk Management

2.4 Uncertainty in the Computed Risk

The RSG RC recognizes that there is significant uncertainty in the computed risks of rocket launches. Confidence bounds of 90% describing the uncertainty in the computed risk can have a range of several orders of magnitude. For this reason, uncertainty cannot be ignored; however, it is not necessary to deal with uncertainty if the estimate of the expected casualties (E_C) or expected fatalities (E_F) is so small that even with a large uncertainty the true risk is unlikely to challenge the acceptability criterion. The RC has introduced a process whereby the uncertainty does not have to be considered if the computed risk is less than one-third of the

---

[11] The FAA referenced this in the waiver of debris containment requirements for launch it as documented in the Federal Register Vol. 81, No. 7, 12 January 2016, p.1470

primary aggregated collective risk criterion.[12] On the other hand, if the risk level does not pass this test, the range should compute the uncertainty to assure that a launch is not allowed that would violate the criterion based on best estimates that account for uncertainty. The decision process regarding risk acceptability under uncertainty is shown in the flowchart in Figure 2-4.

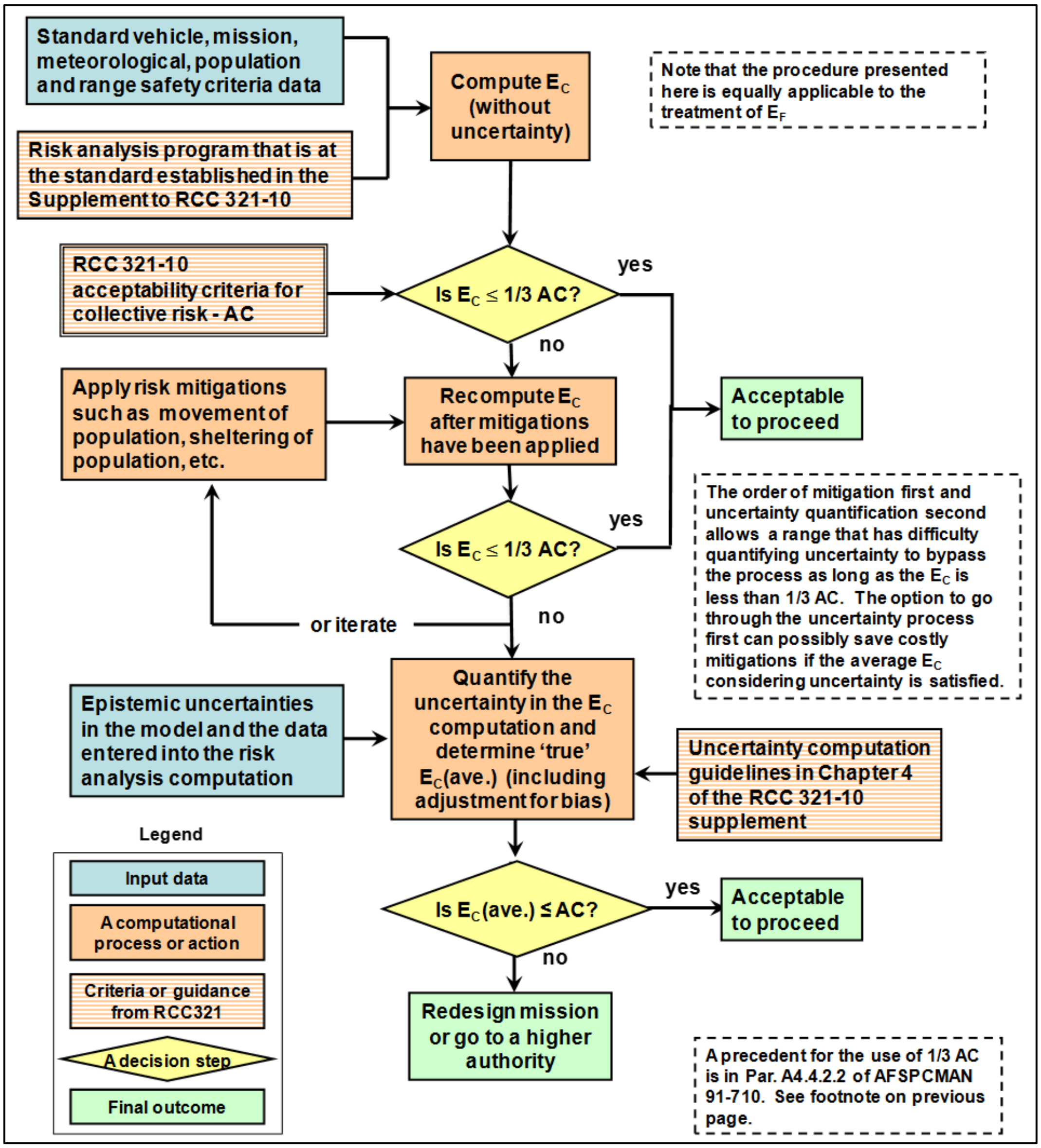

Figure 2-4. Flow Diagram for the Launch Risk Acceptability Process Considering Uncertainty

---

[12] The choice of 1/3 is consistent with the recommendation in AFSPCMAN 91-710VI, 1 July 2004, which uses 30×10^{-6} as the acceptability criterion for casualty expectation. In the range between 10 and 30×10^{-6} (equivalent to one third of the risk criterion), AFSPCMAN 91-710V1, Attachment 4, page 11 states "A4.4.2.2. Hazard Risks >10 through 30 in 1,000,000 ($E_C > 10\times10^{-6}$ through 30×10^{-6}). This level of risk may require the Range User to take additional measures to protect personnel and resources. Examples include fix/ correct/improve existing noncompliances, improve risk analyses to reduce the level of uncertainty, require day-of-launch risk analyze, establish disaster aversion criteria. Range Safety is the approval authority for risks >10 through 30 in 1,000,000 ($E_C > 10\times10^{-6}$ through 30×10^{-6})."

This page intentionally left blank.

CHAPTER 3

Acceptable Risk Criteria

This chapter defines acceptable risk criteria for people, aircraft, ships, and spacecraft that may be exposed to hazards associated with range flight operations. It also includes provisional acceptable risk criteria for public infrastructure. Hazard thresholds for people, aircraft, and ships are provided in Chapter 6 of the supplement.

There are two major components of the risk acceptability criteria: a set of performance standards for establishing and implementing appropriate risk criteria at a range, followed by a set of quantitative standards. The quantitative risk criteria contained in this chapter prescribe limits on a per-mission and an annual basis. The per-mission requirements are intended to apply separately to launch and reentry missions as defined in the glossary. Chapter 4 of the supplement provides guidelines for establishing a risk budget for complex missions, such as those that involve multiple launches or distinct phases of flight. Chapter 4 also provides guidelines for implementation of these criteria, including annual risk management, catastrophe aversion, and protection of ships, aircraft, and manned spacecraft.

3.1 Performance Standards

Each range must perform the following.

a. Assess the risk to all people from launch and reentry activities in terms of hazard severity and mishap probability. Note: Hazardous operations that can be contained within a controlled area may not require a risk assessment.

b. Estimate[13] the E_C associated with each activity that falls within the scope of this document. Additional risk measurements may be useful for range operations that are dominated by fatality to ensure fatality risks do not exceed acceptable limits.

c. Document its measure(s) of risk and risk acceptability policy in local requirements and policy documentation.

d. Maintain documentation to demonstrate that its risk measures provide a complete and accurate assessment of the risks, to include documentation needed to demonstrate that its risk measures:

    (1) clearly convey the risk for decision makers;

    (2) are consistent with the measures used by other scientific or regulatory communities involved in “comparable involuntary activities” (as described in Subsection 2.2.1).

e. Estimate the risk on a per-mission basis, except under special conditions where risk management on an annual basis is justified as described below.

f. Periodically conduct a formal review to ensure that its activities and its mission risk acceptability policy are consistent with the annual risk acceptability criteria.

---

[13] The overall process is a risk assessment, but a particular value (i.e., a point estimate) is referred to as an estimate.

3.2 Personnel Protection

3.2.1 General Public

a. Individual Risk Criteria. Individuals must not be exposed to a probability of casualty greater than 1E−6 for any single mission.[14] If fatality risks are also incorporated into the risk management process, then individuals must not be exposed to a probability of fatality greater than 0.1E−6 (1E−7) for any single mission.

b. Collective Risk Criteria. Collective risk for the GP must not exceed a casualty expectation of 100E−6 (1E−4) for any single mission.[14] If annual risk is measured, collective risk for the GP should not exceed a casualty expectation of 3000E−6 (3E−3) on an annual basis.[15] Risk management using only an annual measure of collective risk is only justified for range operations that occur frequently and pose low[16] risk on a per-mission basis. If fatality risks are also incorporated into the risk management process, then the collective risk for the GP must not exceed 30E−6 (3E−5) E_F for any single mission. If risk management using only annual risks is justified, and fatality risks are also incorporated into the risk management process, then the collective risk for the GP must not exceed 1000E−6 (1E−3) E_F on an annual basis.

c. Catastrophic Risk Criteria. Catastrophic risk for the GP[17] should not exceed the provisional[18] criteria outlined in Subsection 3.7.3.

3.2.2 Mission-Essential and Critical Operations Personnel

a. Individual Risk Criteria. Individual MEP and individual COP must not be exposed to a probability of casualty greater than 10E−6 (1E−5) for any single mission. If fatality risks are also incorporated into the risk management process, then individual MEP and COP must not be exposed to a probability of fatality greater than 1E−6 for any single mission.

b. Collective Risk Criteria. Collective risk for MEP and COP must not exceed a casualty expectation of 300E−6 (3E−4) for any single mission. If annual risk is measured, collective risk for MEP and COP must not exceed a casualty expectation of 30000E−6 (3E−2) on an annual basis.[15] Risk management using only an annual measure of collective risk is only justified for range operations that occur frequently and pose low[16] risk on a per-mission basis. If fatality risks are also incorporated into the risk management process, then collective risk for MEP and COP must not exceed an expected number of fatalities of 300E−6 (3E−4) for any single mission. If risk management using only annual risks is justified, and fatality risks are also incorporated into the risk management process, then the collective risk for MEP and COP should not exceed 10000E−6 (1E−2) E_F on an annual basis.

---

[14] If a flight operation creates a toxic risk, then the range must separately ensure the allowable level of risk enforced by them does not exceed other standards for toxic exposure limits for the public when appropriate mitigations are in place. Chapter 8 of the supplement provides an approach for implementing this requirement.

[15] Chapter 4 of the supplement provides guidelines to assist in the implementation of annual risk management.

[16] In this context, “low risk” means approximately two orders of magnitude below the per-flight criteria for collective and individual risks.

[17] This includes people in any transportation system, such as ships and aircraft, as described in Chapter 4 of the supplement.

[18] The RC intends to investigate this further and the criteria are subject to change in the future.

c. Catastrophic Risk Criteria. Catastrophic risk for MEP and COP should not exceed the provisional criteria outlined in Subsection 3.7.4.

3.3 Aircraft Protection[19]

3.3.1 Non-Mission Aircraft Criteria

a. Non-Mission Aircraft Hazard Volumes. Non-mission aircraft will be restricted[20] from hazard volumes of airspace where the cumulative probability of impact of debris capable of causing a casualty on an aircraft[21] exceeds 0.1E−6 (1E−7) for all non-mission aircraft. As an alternative to protecting against a probability of impact, non-mission aircraft will be restricted from hazard volumes that exceed the individual risk criteria given in a of Subsection 3.2.1 and the catastrophe criterion given in Subsection 3.7.3.[22]

b. Non-Mission Aircraft Risk Criteria. The individual and collective risks posed to the GP in any aircraft must comply with the criteria given in Subsection 3.2.1.

3.3.2 Mission-Essential Aircraft Criteria

a. Mission-Essential Aircraft Hazard Volumes. Mission-essential aircraft will be restricted[20] from hazard volumes of airspace where the cumulative probability of impact of debris capable of causing a casualty on an aircraft exceeds 1E−6 for all mission-essential aircraft. As an alternative to protecting against a probability of impact, mission-essential aircraft will be restricted from hazard volumes that exceed the individual risk criteria given in a of Subsection 3.2.2 and the catastrophe criterion given in Subsection 3.7.4.

b. Mission-Essential Aircraft Risk Criteria. The individual and collective risks posed to MEP in any aircraft must comply with the criteria given in Subsection 3.2.2.

3.3.3 Aircraft Hazard Volumes for Planned Debris Releases

The range must confirm that Notices to Airmen are issued that encompass the volume and duration necessary to protect aircraft from debris capable of causing an aircraft accident due to all planned events.[23]

---

[19] Chapter 4 of the supplement provides important guidelines on the proper implementation of aircraft protection measures.

[20] In this context restricted from means that the range will: (1) ensure that appropriate warnings/restrictions are issued through the FAA; and (2) not proceed with the hazardous activity if the range has knowledge that any aircraft hazard volume is violated.

[21] Chapter 6 of the supplement provides threshold values to help define such debris.

[22] The supplement explains how hazard areas can be defined using probability of impact values and demonstrate compliance with Subsection 3.3.1 for non-mission aircraft or Subsection 3.3.2 for mission-essential aircraft. A range may prefer to use other methods that demonstrate compliance with the individual and collective risk criteria. In any case, the individual and collective risk criteria requirements always apply to all people, regardless of transportation mode.

[23] Planned debris releases include intercept debris, jettison stages, nozzle covers, fairings, inter-stage hardware, etc.

NOTE

Federal law[24] defines an aircraft accident as "an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage." As described in the glossary, federal law also defines death, serious injury, and substantial damage for the purposes of accident reporting.

3.3.4 Mishap Response

The range must coordinate with the FAA to ensure timely notification[25] of any expected air traffic hazard associated with range activities. In the event of a mishap, the range must immediately inform the FAA of the volume and duration of airspace where an aircraft hazard is predicted.

3.4 Ship Protection[26]

The term "ship" includes boats and watercraft of all sizes.

3.4.1 Non-Mission Ship Criteria

a. Ship Warning Areas. Notices to Mariners (NOTMARs) shall be issued to warn non-mission ships of regions defined by one of the following approaches:[27]

(1) where the probability of debris capable of causing a casualty impacting on or near a vessel exceeds 10E−6 (1E−5), accounting for all relevant hazards; or

(2) the union of the areas where the individual probability of casualty for any person onboard exceeds the criteria in a of Subsection 3.2.1, the collective casualty expectation for an individual ship would exceed the criterion in b of Subsection 3.2.1, and the catastrophic risk for an individual ship would exceed the provisional criteria outlined in Section 3.7.

In some situations, warnings may be optional when expected ship traffic in the affected area is low and adequate observation will be performed.

b. Non-Mission Ship Risk Criteria. People on observed non-mission ships shall be included[28] in the determination of compliance with collective risk criteria in b of Subsection 3.2.1 and provisional catastrophic criteria in c of Subsection 3.2.1. Observation to locate non-mission ships is an acceptable method to ensure compliance, provided that suitable observation techniques are used to include the region(s):

(1) where the individual probability of casualty exceeds the criteria in a of Subsection 3.2.1; and

---

[24] 49 C.F. R. 830.2. 1 October 2011.

[25] This may be accomplished through preflight analyses and coordination as described in Chapter 4 of the supplement.

[26] Chapter 4 of the supplement provides important guidelines on the proper implementation of ship protection measures.

[27] The warning area may be expanded to provide additional mitigation so that risk criteria (3.2.1) are met, as discussed in Chapter 4 of the supplement.

[28] Mission risk shall include all members of the GP on land, on ships, and on aircraft.

(2) where the collective casualty expectation or provisional catastrophic risk criteria (b or c of Subsection 3.2.1, respectively) would be exceeded given a conservative estimate of typical ship traffic.

3.4.2 Mission-Essential Ship Criteria

a. Mission-Essential Ship Hazard Areas. Mission-essential ships will be restricted from hazard areas defined by either:

(1) the region where the probability of debris capable of causing a casualty impacting on or near a vessel exceeds 100E−6 (1E−4), accounting for all relevant hazards; or

(2) The union of the areas where the individual probability of casualty for an exposed person onboard exceeds the criteria in a of Subsection 3.2.2, the collective risk criteria in b of Subsection 3.2.2, or the catastrophic risk criteria in c of Subsection 3.2.2.

b. Mission-Essential Ship Risk Criteria. Ship-board MEP shall be included in the assessment of compliance with the collective risk criteria in b of Subsection 3.2.2 and catastrophic risk criteria in c of Subsection 3.2.2.

3.4.3 Ship Hazard Areas for Debris Releases

The range must confirm that NOTMARs are issued for each planned debris release event that encompasses the areas and durations necessary to satisfy the risks as described in a of Subsection 3.4.1 or contain, with 99% probability of containment, all resulting debris impacts capable of causing a casualty.[29]

3.4.4 Mishap Response

The range must coordinate with the United States Coast Guard or other appropriate authorities to ensure timely notification of any ship traffic hazard associated with range activities. In the event of a mishap, the range must promptly inform the appropriate authority(s) of the area and duration of navigable waters where a ship hazard is predicted.

3.5 Infrastructure Protection

3.5.1 Mission-Essential Infrastructure Criteria

Mission-essential infrastructure (such as radar equipment) is treated separately as critical assets.

3.5.2 Non-Mission Public Infrastructure Criteria[30]

Damage severity for infrastructure is currently defined beginning at the *unit component* level, for all types of infrastructure according to the definitions in Table 3-1.[31]

---

[29] This 99% probability of containment region corresponds to a 3-sigma dispersion region for a single impact if the impact uncertainty can be characterized by a bivariate normal impact probability distribution.

[30] Some of the details in this subsection may be moved to the supplement when it is updated.

[31] A unit component is the minimal set or collection of equipment that is necessary to fulfill the basic functions required of the infrastructure to be protected. As an example, for a wind turbine farm, the unit component would be a single wind turbine. A unit component can be considered analogous to a single person (individual).

Table 3-1. Severity Level Definitions

Damage Level	Definitions	Associated Damage Index
No Damage	Component functions without repair	0
Regular Repair	Item can be repaired by a "reasonable competent mechanic" working with "basic set of tools"	1 Onset of regular repair 2 Regular repair damage assured ("significant" repair time is required)
Special Repair Damage	Item can be repaired by "specially trained mechanic" working with a "special set of tools"	3 Onset of specialized repair damage 4 Specialized repair damage assured
Total Damage	Item is beyond repair	5 Total damage

There are two operational severity categories of interest in Table 3-1: damage severity level (DSL) 2 and DSL 5. Protection to infrastructure is achieved by limiting the probability of DSL 2 to unit components and the cumulative probability to a critical number of unit components being damaged at this level or greater.[32] In addition, higher-fidelity analyses will consider a systematic assessment of the severity of the maximum system-level consequences that could plausibly result due to unit component damage along with cascading damage to secondary infrastructure or possibly derivative exposure to people.

Table 3-2 lists provisional[33] protection criteria for public infrastructure located on or nearby base installations. The criteria are a function of the level of consequences to the infrastructure system. Four consequence categories are defined for Tier 1 assessment depending on the severity and spatial extent of the damage. Risk-informed criteria are proposed for less-severe consequences, while physical separation of the protected assets from a hazard containment area is recommended for events with more severe consequences, where the hazard containment area is defined by the allowable probability of impact contour.

a. Risk-Informed Criteria

(1) Nuisance to infrastructure should be protected on a *unit component* basis to ensure the probability of DSL 2 is less than or equal to 1000E−6 (1E−3), unless a hazard containment criterion is applied.[34]

(2) Elective repair to infrastructure should be protected on a *unit component* basis to ensure the probability of DSL 2 is less than or equal to 100E−6 (1E−4), unless a hazard containment criterion is applied.[35]

---

[32] These two categories may be qualitatively interpreted as analogous to human casualty and fatality.

[33] The RC intends to investigate this further and the criteria are subject to change in the future.

[34] Nuisance includes damage comparable in terms of maximum severity of consequences to normal background damaging events (such as lighting, malicious vandalism from firearms) that can be repaired as part of the routine maintenance program for the infrastructure.

[35] Elective repair includes damage that does not preclude the operation of the infrastructure and can be repaired as part of the routine maintenance program for the infrastructure; however operation may be on a reduced schedule or capacity, and on-going monitoring is generally required.

(3) Mandatory repair to infrastructure should be protected on a *unit component* basis to ensure the probability of DSL 2 is less than or equal to 10E−6 (1E−5), unless a hazard containment criterion is applied.[36]

(4) Severe system consequences would normally be protected using the hazard containment criteria in b of Subsection 3.5.2; however, if warranted, a risk-informed criterion can be used, provided protection on a *unit component* basis ensures the probability of DSL 2 is less than or equal to 1E−6.

b. Hazard Containment Criteria

(1) Nuisance to infrastructure should be protected on an exclusion-area basis such that the cumulative probability of DSL 2 or greater to the *critical number* of unit components is less than or equal to 1000E−6 (1E−3), unless the risk-based criterion in a of Subsection 3.5.2 is applied.

(2) Elective repair to infrastructure should be protected on an exclusion-area basis such that the cumulative probability of DSL 2 or greater to the *critical number* of unit components is less than or equal to 100E−6 (1E−4), unless the risk-based criterion in a of Subsection 3.5.2 is applied.

(3) Mandatory repair to infrastructure should be protected on an exclusion-area basis such that the cumulative probability of DSL 2 or greater to the *critical number* of unit components is less than or equal to 10E−6 (1E−5), unless the risk-based criterion in a of Subsection 3.5.2 is applied.

(4) Severe system consequences to infrastructure should be protected on an exclusion-area basis such that the cumulative probability of DSL 2 or greater to the *critical number* of unit components is less than or equal to 1E−6, unless the risk-based criterion in a of Subsection 3.5.2 is applied.

---

[36] Mandatory repair includes damage that precludes the operation of a complete unit component or infrastructure system and requires an unscheduled and generally immediate maintenance action to repair it.

Table 3-2. Provisional Risk Assessment Matrix for Public Infrastructure

Severity **Vulnerability**	Severe System Consequences • Significant cost to repair, or • Potential derivative exposure, and • External authority involvement • Potential cascading consequences	Mandatory Repair with • Minimal social/political consequences, and • Local authority involvement, and • Consequences are confined	Elective Repair with • Minimal social/political consequences, and • No accident/environmental assessments • Consequences are confined	Nuisance to • Infrastructure, people or range ops • Consequences are confined and acceptable to government & developers/operators
• Prompt easily assessed damage, or • Immediate derivative exposure to people	🟥 $P_r(UC_i \geq DSL\ 2) \leq 1\ x\ 10^{-6}$, or exclude infrastructure from the region where the cumulative probability of DSL 2 or greater to the critical number of unit components is greater than 1 x 10^{-6}	🟨 $P_r(UC_i \geq DSL\ 2) \leq 1\ x\ 10^{-5}$, or exclude infrastructure from the region where the cumulative probability of DSL 2 or greater to the critical number of unit components is greater than 1 x 10^{-5}	🟨 $P_r(UC_i \geq DSL\ 2) \leq 1\ x\ 10^{-4}$, or exclude infrastructure from the region where the cumulative probability of DSL 2 or greater to the critical number of unit components is greater than 1 x 10^{-4}	🟨 $P_r(UC_i \geq DSL\ 2) \leq 1\ x\ 10^{-3}$, or exclude infrastructure from the region where the cumulative probability of DSL 2 or greater to the critical number of unit components is greater than 1 x 10^{-3}

🟥 Exclusion area risk criteria 🟨 Risk informed acceptance criteria

3.6 Spacecraft Protection

Manned spacecraft and those on route to, and in support of, manned missions shall be protected by: (1) not exceeding a probability of impact greater than 1E−6 per spacecraft; or (2) ensuring an ellipsoidal miss-distance of 200 km in-track and 50 km cross track and radially; or (3) ensuring a spherical miss-distance of 200 km. A spacecraft is considered manned if it is currently occupied, or on route to, and in support of manned missions.

These three protection options are listed in the order of preference, with Option 1 providing the highest level of protection. Option 1 requires a covariance matrix as input to JSpOC while the other two options use the nominal trajectories.

The second option of an ellipsoidal miss-distance is preferred over a spherical miss-distance because the largest uncertainty is in the in-track dimension.

For objects (including launch vehicle, payload, jettisoned components, or planned debris) launched into a sustainable orbit, the duration of the conjunction assessment required for manned and active spacecraft protection shall be applied from launch through orbit insertion plus an appropriate number of revolutions to account for: (1) the type orbit the vehicle or component is injected into, operating in, or passing through; (2) the altitudes where manned spacecraft may be in orbit and the appropriate miss-distance; and (3) a sufficient time for the object to be catalogued. This time shall not be less than 3 hours after liftoff without prior coordination with the JSpOC to allow an earlier time for the object to be catalogued. Besides the launch vehicle and payload, conjunction assessments must include all components jettisoned during the launch and intentionally propagated debris.

Advisory Requirement: Active spacecraft other than manned spacecraft should be protected by one of the following criteria (listed in the order of preference): (1) not exceeding a probability of impact greater than 1E–4 per spacecraft; or (2) ensuring an ellipsoidal miss-distance of 25 km in-track and 7 km cross track and radially; or (3) ensuring a spherical miss-distance of 25 km.

The vulnerability of the spacecraft must be accounted for in the risk assessment and the minimum debris size hazardous to the spacecraft ascertained from the spacecraft operator whenever practicable. Otherwise, the spacecraft should be considered vulnerable to the current minimum debris size of 1 millimeter or greater.

3.7 Catastrophic Risk Protection

Catastrophic[37] risk criteria are designed to protect against scenarios involving numerous casualties. The following provisional catastrophic risk criteria are suggested guidelines to supplement the collective and individual risk criteria given in Section 3.2. Catastrophic risk assessments are especially useful for pre-flight analyses intended to evaluate and mitigate potentially catastrophic outcomes.

---

[37] The term catastrophic refers to multiple casualties with a minimum ranging from 5 to 10 depending upon the particular regulation. The criterion presented here is "risk averse," a term that is used in the academic literature and applies to all values of *N* above one. Thus the term catastrophe averse is a subset of the term risk averse. Another expression that could also be used is aversion to increasing numbers of casualties.

3.7.1 General

Missions must be permitted only when the catastrophic risks are consistent with the policy objectives given in Section 2.2.

3.7.2 Ship and Aircraft Hazard Areas

If ships and aircraft are excluded from the hazard areas designed to protect against excessive probability of impact limits provided in Section 3.3 and Section 3.4 in accordance with the guidelines set in Chapter 4 of the supplement, then the catastrophic risks to ships and aircraft are consistent with the policy objectives given in Section 2.2.

3.7.3 General Public Criteria

Catastrophic risks for the GP should not exceed the following provisional criteria.

$$P[\geq N] \leq \frac{1\times 10^{-4}}{N^{1.5}} \qquad \text{(Equation 3-1)}$$

where

$P[\geq N]$ is the cumulative probability of all events capable of causing N or more casualties.

N is number of casualties, based on the occupant load as defined in Table 3-3.

10^{-4} is the maximum acceptable E_C as defined in b of Subsection 3.2.1.

Table 3-3. Definitions Used to Define Tolerable Catastrophic Risks

Population Type	Catastrophic Outcome	Occupant Load (*N*)
Public Aircraft	An occurrence resulting in multiple fatalities[38], usually with the loss of the airplane[39]	Maximum occupancy
Mission-Essential or Critical Aircraft	An occurrence resulting in multiple fatalities, usually with the loss of the airplane	Expected occupancy
Public Ship	An occurrence resulting in multiple casualties, usually with loss of the ship	Maximum occupancy
Mission-Essential or Critical Ship	An occurrence resulting in multiple casualties, usually with loss of the ship	Expected occupancy
Public Land Vehicle	An occurrence resulting in multiple casualties, usually with loss of the vehicle	Maximum occupancy
Mission-Essential or Critical Land Vehicle	An occurrence resulting in multiple casualties, usually with loss of the vehicle	Expected occupancy
Public Train	An occurrence resulting in multiple casualties, usually with loss of the train	Maximum occupancy
Mission-Essential or Critical Train	An occurrence resulting in multiple casualties, usually with loss of the train	Expected occupancy

---

[38] The FAA also has a formal definition for "severe consequence:" forced landing (which is also formally defined), loss of aircraft while occupants are on-board, serious injuries (as formally defined), or fatalities.

[39] Federal Aviation Administration. "Subject: Continued Airworthiness Assessments of Powerplant and Auxiliary Power Unit Installations of Transport Category Airplanes." AC 39-8. 8 September 2003. Available at http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC39-8.pdf.

Public Gatherings[40]	An occurrence resulting in multiple casualties	Maximum credible occupancy
Mission-Essential or Critical Personnel Gathering	An occurrence resulting in multiple casualties	Expected occupancy

Figure 3-1 shows the relationship between *P* and *N* for the public that satisfies this criterion.

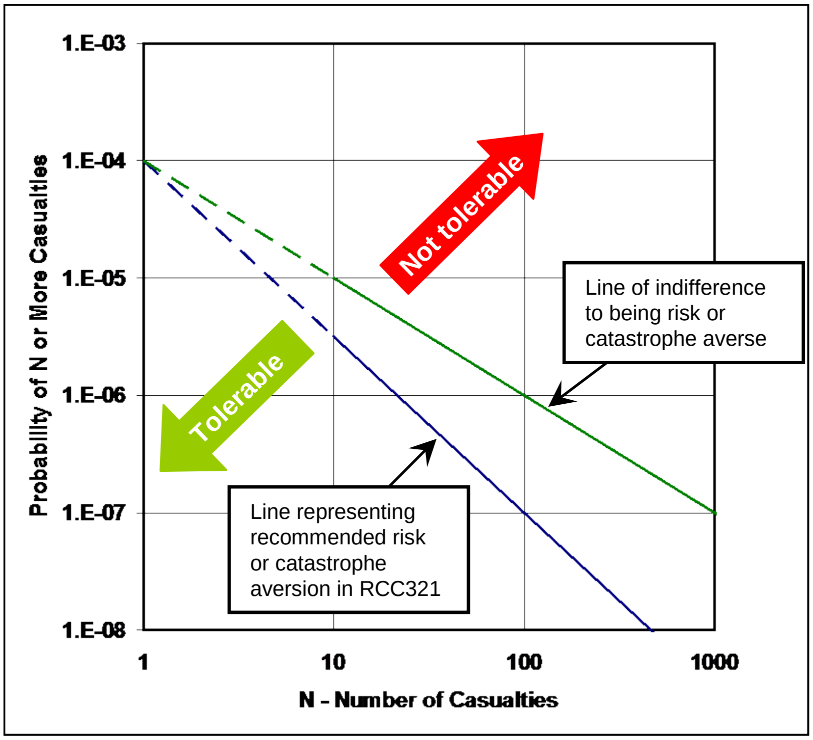

Figure 3-1. Tolerable Catastrophic Risks for the Public

3.7.4 Mission-Essential and Critical Operations Personnel Criteria

Catastrophic risks for MEP and COP should not exceed the following provisional criteria.

$$P[\geq N] \leq \frac{3\times10^{-4}}{N^{1.5}} \qquad \text{(Equation 3-2)}$$

where

P[≥N]	is the cumulative probability of all events capable of causing N or more casualties.
N	is number of casualties, based on the occupant load as defined in Table 3-3.
3×10^{-4}	is the maximum acceptable E_C as defined in b of Subsection 3.2.2.

---

[40] Public gathering places subject to catastrophic accidents include any locations where population concentrations may occur, such as schools, hospitals, stadiums, beaches, etc.

3.8 Criteria Summary

Table 3-4 summarizes the go/no-go criteria defined by this document; Table 3-5 presents the protection criteria for spacecraft. All of the criteria are considered mandatory requirements except those highlighted by a footnote, which are advisory requirements that may be considered mandatory under certain circumstances (as explained in Chapter 4 of the supplement).

Table 3-4. Summary of Commonality Criteria

	General Public		**Mission-Essential and Critical Operations Personnel**	
	Max. Acceptable	**Undesired Event**	**Max. Acceptable**	**Undesired Event**
Per Mission	1E−6[b]	Individual Probability of Casualty	10E−6	Individual Probability of Casualty
	100E−6[b]	Expected Casualties	300E−6	Expected Casualties
	0.1E−6[a]	Individual Probability of Fatality	1E−6[a]	Individual Probability of Fatality
	30E−6[a]	Expected Fatalities	300E−6[a]	Expected Fatalities
Annual	3000E−6	Expected Casualties	30000E−6	Expected Casualties
	1000E−6[a]	Expected Fatalities	10000E−6[a]	Expected Fatalities

[a] Advisory Requirements.

[b] If a flight operation creates a toxic risk, then the range must separately ensure the allowable level of risk enforced by them does not exceed other standards for toxic exposure limits for the GP when appropriate mitigations are in place. Chapter 8 of the supplement provides an approach for implementing this requirement.

Table 3-5. Summary of Commonality Criteria For Spacecraft

	Type of Spacecraft	**Max. Acceptable**	**Undesired Event**
Per Mission	Manned	1E−6	Individual Probability of Collision
		Ellipsoidal miss distance of 200 km in track and 50x50 cross-track and radial	Collision
		Spherical Miss Distance 200 km	Collision
	Active Satellites[a]	1E−4	Individual Probability of Collision
		Ellipsoidal miss distance of 25 km in track and 7x7 cross track and radial	Collision
		Spherical miss distance 25 km	Collision

[a] Provisional requirements

Appendix A

Glossary

3-sigma: Three times the standard deviation, typically referenced to the mean value.

Abbreviated Injury Scale (AIS): An anatomically based, consensus derived, global severity scoring system that classifies each injury in every body region according to its relative importance on a 6-point ordinal scale.

Acceptable Risk: A predetermined criterion or standard for a maximum risk ceiling that permits the evaluation of cost, national priority interests, and number of tests to be conducted.

Accumulated Risk: The combined collective risk to all individuals exposed to a particular hazard through all phases of an operation. Guidance Information is as follows:

- For the flight of an expendable orbital launch vehicle, risk should be accumulated from liftoff through orbital insertion.
- For the flight of a suborbital launch vehicle, risk should be accumulated from liftoff through the impact of all pieces of the launch vehicle, including the payload.

Aggregated Risk: The accumulated risk due to all hazards associated with a flight. Guidance Information is that, for a specified launch, aggregated risk includes, but is not limited to, the risk due to debris impact, toxic release, and distant focusing of blast overpressure.

As Low As Reasonably Practical: That level of risk that can be lowered further only by an increment in resource expenditure that cannot be justified by the resulting decrement in risk. Often identified or verified by formal or subjective application of cost-benefit or multi-attribute utility theory.

Background Risk: risks voluntarily accepted in the course of normal activities.

Best Practice: There are two definitions.

- A management idea that asserts there is a technique, method, process, activity, or incentive (or reward) that is more effective at delivering a particular outcome than any other technique, method, process, etc. The idea is that with proper processes, checks, and testing, a project can be rolled out and completed with fewer problems and unforeseen complications.
- An acceptable level of effort that represents the best choice available given the circumstances.

Casualty: A serious injury or worse, including death, for a human. For the purposes of this standard, serious injury is defined as AIS Level 3 or greater except where prior general practice at the range has been to protect to a lesser level of injury than AIS level 3, such as eardrum protection.

Casualty Expectation: See *Expected Casualties*

Catastrophe: Any event that produces a large number (possibly five or ten or more) casualties or has a severe impact on continued range operations. See also definition of risk averse

Clearance Zone: An area or volume from which objects at risk (people, ships, aircraft, etc.) are to be restricted or eliminated in order to control the risks.

Collective Risk: The total risk to all individuals exposed to any hazard from an operation. Unless otherwise noted, collective risk is the mean number of casualties (E_C) predicted to result from all hazards associated with an operation. Collective risk is specified as either for a mission or per year. The collective risk should include the aggregated and accumulated risk.

Collision Avoidance (COLA): The process of determining and implementing a course of action to avoid potential on-orbit collisions with manned objects or with other specified orbiting objects. The process includes the determination of wait periods in either the launch window or spacecraft thrust firings based on validated conjunction assessments or risk analyses and accounts for uncertainties in spatial dispersions and arrival time of the orbiting objects and/or launch vehicle.

Conjunction Assessment: The process of determining the point of closest approach of two orbiting objects, or between a launch vehicle and an orbiting object, in association with a specified miss-distance screening criteria or the corresponding probability of collision. Associated with the closest approach assessment is the closest approach distance, the times of launch or orbital firing that would result in the closest approach, and meeting the miss-distance or collision probability criteria.

Conservatism: As used in risk analysis conservative modeling, conservatism is a set of modeling assumptions that overstates the risk by overstating event probabilities, hazard probabilities, or consequences. Conservatism refers to the degree of overstating risk.

Containment: The launch safety strategy/process of minimizing risk to the maximum extent practical by keeping hazardous operations within defined hazard areas that are unpopulated or where the population is controlled and adequate protection can be provided to highly valued resources; to stop, hold, or surround a hazard.

Critical Asset: A resource requiring protection. It normally includes property/ infrastructure that is essential to protect the public health and safety, maintain the minimum operations of the range, or protect the national security or foreign policy interests of the United States.

Critical Operations Personnel: Persons not essential to the specific operation or launch currently being conducted, but who are required to perform safety, security, or other critical tasks at the range. To be treated as COP they must be notified of a neighboring hazardous operation and either trained in mitigation techniques or accompanied by a properly trained escort. The COP does not include individuals in training for any job or individuals performing routine activities such as administrative, maintenance, or janitorial. The COP may occupy safety clearance zones and hazardous launch areas and may not need to be evacuated with the GP. The COP should be included in the same risk category as MEP.

Damage Severity: This term refers primarily to the extent of the adverse consequences of hazards to infrastructure. In contrast to injury to people, injury to infrastructure must be evaluated at both the unit component level and, following that, at the system-level. The recommended infrastructure protection process accommodates this process using a two-tiered approach.

Decision Authority: The range commander or senior official designated by the range commander to make risk decisions on his or her behalf.

Distant Focusing: An atmospheric phenomenon that can produce greatly enhanced overpressures at a distance from the acoustic (or explosive) source due to sonic velocity gradients with respect to altitude

Endoatmospheric: Within the Earth's atmosphere; generally considered to be those altitudes below 100 km.

Exoatmospheric: Outside the Earth's atmosphere; generally considered to be those altitudes above 100 km.

Expected Casualties: The mean number of casualties predicted to occur as a result of an operation if the operation were to be repeated many times. This risk is expressed with the following notation: $1E-7 = 10^{-7}$ = 1 in ten million.

Expected Fatalities: The mean number of fatalities predicted to occur as a result of an operation if the operation were to be repeated many times. This risk is expressed with the following notation: $1E-7 = 10^{-7}$ = 1 in ten million.

Fatal Injury: any injury that results in death within 30 days of the accident.

Fragmentation: The breakup of an in-flight vehicle into fragments (components of the vehicle, pieces of the structure, chunks of solid propellant, miscellaneous hardware, etc.) due to explosive loads, aerodynamic and inertial loads, activation of an FTS, intercept with another vehicle, or impact on a surface.

Federal Tort Claims Act (FTCA).[41] A statute that limits federal sovereign immunity and allows recovery in federal court for tort damages caused by federal employees, but only if the law of the state where the injury occurred would hold a private person liable for the injury.

Fidelity: The accuracy of the representation when compared to the real world.

Flight Termination System (FTS): The airborne portion of the flight safety system. An FTS ends the flight of a vehicle and consists of the entire system on an airborne vehicle used to receive, decode, and execute the ground signals. It includes all wiring, power systems, and methods or devices (including inadvertent separation destruct systems) used to terminate flight.

General Public: People who are not declared/identified as MEP or COP. This includes the public plus range personnel not essential to a mission, visitors, press, and personnel/dependents living on the base/ facility.

Hazard: Any real or potential condition that can cause injury, illness, or death of personnel, or damage to or loss of equipment or property.

Hazard Threshold: The lowest level at which adverse outcomes are expected to appear.

Hazard Area: A geographical or geometrical surface area that is susceptible to a hazard from a planned event or unplanned malfunction.

Hazard Volume: A geographical or geometrical volume of airspace that is susceptible to a hazard from a planned event or unplanned malfunction.

Hazardous Operation: Those activities that, by their nature, expose personnel or property to dangers not normally experienced in day-to-day actions.

---

[41] Tort Claims Procedure. 28 U.S.C. § 2671-2680.

Impact: The impingement of a fragment on a surface, a structure, a person, or a vehicle.

Inadvertent Separation Destruct System: a specialized form of ADS located on vehicle components that automatically activates when inadvertent separation of the component from the main vehicle is sensed. There is often a built-in delay included, in hope that the separated component will be sufficiently displaced at charge activation to preclude damage to the main vehicle.

Individual Risk: The risk that a person will suffer a consequence. Unless otherwise noted, individual risk is expressed as the probability that an individual will become a casualty due to all hazards from an operation at a specific location. Guidance information is that as follows.

- If each person in a group is subject to the same individual risk, then the collective risk may be computed as the individual risk multiplied by the number of people in the group.
- In the context of this document, individual risk refers to the probability that the exposed individual will become a casualty as a result of all hazards from a mission.

Informed Decision: Principle that is used in tort claims against the US Government. The FTCA enjoins the U.S. court system from second-guessing decisions made by properly authorized government officials in determining the acceptability of operational risks. A key test under the FTCA requires that the decision-making official be fully advised and informed of the known risks. Failure to fully advise the decision-making authority of known risks can result in liability of the US Government or its officials.

Involuntary Activity: No choice was made by the person affected that placed them in a position of increased risk; or the activity participated in or the item used was one that is generally done or used by more than 99% of the population. Examples: bathing, using coins, or drinking from glasses.

Launch Mission: For the purposes of flight safety analyses, a launch mission begins with lift-off, ends at orbital insertion, and includes impacts from all planned debris released prior to orbital insertion (or final impact for a suborbital mission). A launch mission includes any flight of a suborbital or orbital rocket, guided or unguided missile, and missile intercepts. See the supplement Subsection 4.2.5 for details on defining a launch mission for risk assessment.

Lift-off: For the purposes of flight safety analyses, lift-off occurs during a launch countdown with any motion of the launch vehicle with respect to the launch platform (that includes a carrier aircraft), including any intentional or unintentional separation from the launch platform.

Manned Spacecraft: a spacecraft that is either currently occupied or intended to be occupied. Includes spacecraft en route to, and in support of, manned missions.

Mishap: An unplanned event or series of events resulting in death, injury, occupational illness, or damage to or loss of equipment or property or damage to the environment.

Mission-Essential: Those persons and assets necessary to safely and successfully complete a specific hazardous operation or launch. The mission-essential individuals may include persons in training to perform the specific mission currently being conducted, but excludes those in training for other critical tasks. The MEP are informed of the hazards associated with the operation and trained in mitigation techniques appropriate to the hazard level. The range commander or mission director (or their designees) should identify the MEP in training and justify their designation as mission-essential.

Mission Rules: Rules that define safety constraints and conditions and establish the boundaries within which the safety team operates. The lead safety organization develops the mission rules and briefs the range user to ensure a complete understanding of the intent and application of them. Mission rules are documented and become part of the range safety plan.

Orbital Insertion: Orbital insertion occurs when the vehicle achieves a minimum 70-nautical mile (nm) perigee based on a computation that accounts for drag.

Overpressure: The pressure caused by an explosion over and above normal atmospheric pressure. It can be significantly affected by the atmospheric conditions, particularly the temperature and wind profiles.

Probability of Casualty: The likelihood that a person will suffer a serious injury or worse, including a fatal injury, from a hazardous event. This risk is expressed with the following notation: $1\text{E}{-7} = 10^{-7}$ = 1 in ten million.

Probability of Fatality: The likelihood that a person will die from a hazardous event. This risk is expressed with the following notation: $1\text{E}{-7} = 10^{-7}$ = 1 in ten million.

Prudent Person: See *Reasonable Person*

Public Infrastructure: Infrastructure that is owned by the public or is for public use. It is generally distinguishable from private or generic infrastructure in terms of policy, financing, or purpose.

Range Safety System: The ground-based portion of the flight safety system. *See also Flight Safety System* and *Flight Termination System*

Reasonable Care: As a test of liability for negligence, the degree of care that a prudent and competent person engaged in the same line of business or endeavor would exercise under similar circumstances - also termed due care; ordinary care; adequate care; proper care.

Reasonable Person: A hypothetical person used as a legal standard, especially to determine if someone acted with negligence. The reasonable person acts sensibly, does things without serious delay, and takes proper but not excessive precautions. Also termed *Reasonable Man* or *Prudent Person.*

Reentry Mission: Reentry missions include both controlled and uncontrolled reentries. In this context, a controlled reentry mission begins with the final commitment to enter the atmosphere from orbit (or otherwise from outer space) and ends when all vehicle components associated with the reentry come to rest on the Earth (or are otherwise secured). For example, a controlled reentry mission could begin with the final command to commit the vehicle (or object) to a perigee below 70 nm and end when all vehicle components come to rest on the Earth. An uncontrolled reentry mission begins when the object naturally decays to a perigee below 70 nm and ends when all vehicle components associated with the reentry come to rest on the Earth. The reentry of upper stages and payloads are separate reentry missions per the US Government

Orbital Debris Mitigation Standard Practices[42] and DoDI 3100.12.[43] In this context, reentry missions do not occur during suborbital flights because a reentry mission separate from the launch mission can occur subsequent to orbital insertion only. See the supplement Chapter 4 for details on defining a reentry mission for risk assessment.

Risk: A measure that accounts for both the probability of occurrence and the consequence of a hazard to a population or installation. Unless otherwise noted, risk to people is measured in casualties and expressed as individual risk or collective risk.

Risk Analysis: A study of potential risk under a given set of conditions. Risk analysis is an activity that includes the complete array of tasks from data gathering, identification of hazards, estimation of associated risks, and verification of results.

Risk Averse: An aversion to increasing numbers of casualties that makes a single event having, for example, two casualties more than twice as undesirable as a single event having one casualty. This is exactly equivalent to the term catastrophe averse when the number of casualties is large. The term “large” could be 10 in some definitions.

Risk Management: A systematic and logical process to identify hazards and control the risk they pose.

Risk Profile: A plot that shows the probability of N or more casualties (vertical axis) as a function of the number of casualties, N (horizontal axis). It is discrete (not fractional) and is the complementary cumulative distribution of the histogram representing the aleatory uncertainty of number of casualties. The mean of the histogram is the E_C. In addition, the sum of the values of the $P[\geq N]$ over all N is equal to the E_C.

Safety: Relative protection from adverse consequences.

Serious Injury: Any injury that meets one or more of the following:

- requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received;
- results in a fracture of any bone (except simple fractures of fingers, toes, or nose);
- causes severe hemorrhages, nerve, muscle, or tendon damage;
- involves any internal organ;
- involves second degree or third degree burns, or any burns affecting more than 5 percent of the body surface.

Ship Accident: A “ship accident” occurs if the vessel is involved in an accident that results in loss of life, personal injury that requires medical treatment beyond first aid, or complete loss of the vessel. This definition is consistent with the level of protection afforded people involved in a “boat accident” as defined in current regulations.

Sigma: Standard deviation.

---

[42] United States Federal Government. *US Government Orbital Debris Mitigation Standard Practices*. Retrieved 28 July 2016. Available at http://orbitaldebris.jsc.nasa.gov/library/usg_od_standard_practices.pdf.

[43] Department of Defense. “Subject: Space Support.” DoDI 3100.12. 14 September 2000. May be superseded by update. Retrieved 6 April 2016. Available at http://www.dtic.mil/whs/directives/corres/pdf/310012p.pdf.

Suborbital Mission: Any flight of a launch vehicle, rocket, or missile that does not achieve orbital insertion. The per-mission requirements for launch are intended to apply from lift-off until landing or final impact for a suborbital mission, including all planned debris impacts.

Suborbital Rocket: A rocket-propelled vehicle intended to perform a suborbital mission whose thrust is greater than its lift for the majority of the rocket-powered portion of its flight.

Substantial Damage: Relating to aircraft vulnerability means damage or failure that adversely affects the structural strength, performance, or flight characteristics of the aircraft and that would normally require major repair or replacement of the affected component.

Toxic Substance: A chemical or mixture that may present an unreasonable risk of injury to health or the environment.

Toxics: A generic term for the toxic propellants and combustion by-products resulting from a nominal launch vehicle flight or catastrophic launch abort.

Uncertainty: The absence of perfectly detailed knowledge. Uncertainty includes incertitude (the exact value is unknown) and variability (the value is changing). Uncertainty may also include other forms such as vagueness, ambiguity, and fuzziness (in the sense of borderline cases).

Unit Component: The minimal set or collection of equipment that is necessary to fulfill a basic function required of public infrastructure. Basic functions generally include generation, storage, and routing of energy in some form. Damage to a unit component will have a measurable adverse impact upon the functionality of the larger system to which the unit component belongs. For example, a single wind turbine is a unit component of a wind turbine farm. A photovoltaic power module is a unit component of a photovoltaic installation. Conceptually, unit components can frequently be sub-divided further; however, from the standpoint of infrastructure protection, the critical demarcation is with respect to the system-level functionality that is of concern to stakeholders. As an example, a photovoltaic module in a modern solar facility is itself composed of several hundred or more individual solar panels. The individual panels are not considered unit components since the impairment to the functionality of the photovoltaic module due to damage of a single panel is negligible. On the other hand, hazards sufficient to cause damage to the functionality at the module level represent a non-negligible impairment in the absence of mitigation to the functionality (i.e., normal and expected operation) and output of a solar farm.

Variability: Observed differences attributable to true heterogeneity or diversity. Variability is the result of natural random processes and is usually not reducible by further measurement or study (although it can be better characterized).

Verification: refers to the set of activities that ensure that software correctly implements a specific function. The verification process determines whether a computer simulation code for a particular problem accurately represents the solutions of the mathematical model. Evidence is collected to ascertain whether the numerical model is being solved correctly. This process ensures that sound software-quality practices are used and the software codes themselves are free of defects and errors. It also checks that the code is correctly solving the mathematical equations in the algorithms and verifies that the time and space steps or zones chosen for the mathematical model are sufficiently resolved.

Voluntary Activity: The person affected made a choice that placed him or her in an increased position of risk compared to the rest of the population. This includes career and job choices. Examples include repetitive motion injuries, recreational boating, etc.

This page intentionally left blank.

Appendix B

Citations

49 C.F.R. 830.2. 1 October 2011.

Department of the Air Force. “Space Safety and Mishap Prevention Program.” AFI 91-217. 11 April 2014. May be superseded by update. Retrieved 11 May 2016. Available at http://static.e-publishing.af.mil/production/1/af_se/publication/afi91-217/afi91-217.pdf.

Department of Defense. “Subject: Management and Operation of the Major Range and Test Facility Base (MRTFB).” DoDI 3200.18. 1 February 2010. May be superseded by update. Retrieved 6 April 2016. Available at http://www.dtic.mil/whs/directives/corres/pdf/320018p.pdf.

———. “Subject: Space Policy.” DoDD 3100.10. 18 October 2012. May be superseded by update. Retrieved 6 April 2016. Available at http://www.dtic.mil/whs/directives/corres/pdf/310010p.pdf.

———. “Subject: Space Support.” DoDI 3100.12. 14 September 2000. May be superseded by update. Retrieved 6 April 2016. Available at http://www.dtic.mil/whs/directives/corres/pdf/310012p.pdf.

Federal Aviation Administration. “Subject: Continued Airworthiness Assessments of Powerplant and Auxiliary Power Unit Installations of Transport Category Airplanes.” AC 39-8. 8 September 2003. Available at http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC39-8.pdf.

———. “Waiver of Debris Containment Requirements for Launch.” Notice of Waiver. Federal Register, Vol. 81, No. 7. 12 January 2016. Available at https://www.federalregister.gov/articles/2016/01/12/2016-00444/waiver-of-debris-containment-requirements-for-launch.

Office of the President, United States of America. *National Space Policy of the United States of America.* 28 June, 2010. May be superseded by update. Retrieved 7 April 2016. Available at https://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf.

Range Commanders Council. *Common Risk Criteria for National Test Ranges (Supplement)*. 321-10 (Supplement). December 2010. May be superseded by update. Retrieved 28 July 2016. Available to RCC members with Private Portal access at https://wsdmext.wsmr.army.mil/site/rccpri/Publications/321-10_Supplement_Common_Risk_Criteria_Standards_For_National_Test_Ranges/.

———. *Range Safety Criteria for Unmanned Air Vehicles*. RCC 323-99. December 1999. May be superseded by update. Retrieved 6 April 2016. Available at http://www.wsmr.army.mil/RCCsite/Documents/323-99_Range_Safety_Criteria_Unmanned_Air_Vehicles_(Basic)/323-99.pdf.

Tort Claims Procedure. 28 U.S.C. § 2671-2680.

United States Federal Government. *US Government Orbital Debris Mitigation Standard Practices*. Retrieved 28 July 2016. Available at http://orbitaldebris.jsc.nasa.gov/library/usg_od_standard_practices.pdf.

Appendix C

References

Department of Defense. “Range Laser Safety.” MIL-HDBK-828B. 5 May 2011. May be superseded by update. Retrieved 11 May 2016. Available at http://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=110720.

———. “Subject: DoD Safety and Occupational Health (SOH) Program.” DoDI 6055.01. 14 October 2014. May be superseded by update. Retrieved 6 April 2016. Available at http://www.dtic.mil/whs/directives/corres/pdf/605501p.pdf.

———. “Subject: Environment, Safety, and Occupational Health (ESOH).” DoDD 4715.1E. 19 March 2005. May be superseded by update. Retrieved 11 May 2016. Available at http://www.dtic.mil/whs/directives/corres/pdf/471501p.pdf.

Department of the Air Force. “Integrated Life Cycle Management.” AFPD 63-1. 3 July 2012. May be superseded by update. Retrieved 11 May 2016. Available at http://static.e-publishing.af.mil/production/1/saf_aq/publication/afpd63-1/afpd63-1.pdf.

———. “Risk Management.” AFI 90-802. 11 February 2013. Updated 8 March 2016. May be superseded by update. Retrieved 11 May 2016. Available at http://static.e-publishing.af.mil/production/1/af_se/publication/afi90-802/afi90-802.pdf.

———. “Risk Management (RM) Guidelines and Tools.” AFPAM 90-803. 11 February 2013. May be superseded by update. Retrieved 11 May 2016. Available at http://static.e-publishing.af.mil/production/1/af_se/publication/afpam90-803/afpam90-803.pdf.

Department of the Army. “The Army Safety Program.” AR 385-10. 27 November 2013. May be superseded by update. Retrieved 5 April 2016. Available at http://armypubs.army.mil/epubs/pdf/R385_10.PDF.

———. “Risk Management.” ATP 5-19. April 2014. May be superseded by update. Retrieved 11 May 2016. Available at http://armypubs.army.mil/doctrine/DR_pubs/dr_a/pdf/atp5_19.pdf.

Department of the Navy. “Operational Risk Management.” OPNAVINST 3500.39C. 2 July 2010. May be superseded by update. Retrieved 11 May 2016. Available at http://www.public.navy.mil/airfor/nalo/Documents/SAFETY/OPNAVINST%203500.39C%20OPERATIONAL%20RISK%20MANEGEMENT.pdf.

Environmental Protection Agency. “Risk Characterization Handbook.” EPA 100-B-00-002. December 2000. May be superseded by update. Retrieved 11 May 2016. Available at https://www.epa.gov/sites/production/files/2015-10/documents/osp_risk_characterization_handbook_2000.pdf.

National Aeronautics and Space Administration. “Subject: Range Flight Safety Program.” NPR 8715.5A. Effective 17 September 2010; expires 17 January 2017. Retrieved 11 May 2016. Available at http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8715&s=5A.

Range Commanders Council. *Flight Termination Systems Commonality Standard*. RCC 319-14. September 2014. May be superseded by update. Retrieved 6 April 2016. Available at http://www.wsmr.army.mil/RCCsite/Documents/319-14_Flight_Termination_Systems_Commonality_Standard/.

Secretary of the Air Force. “Safety Programs.” AFPD 91-2. 24 July 2012. May be superseded by update. Retrieved 6 April 2016. Available at http://static.e-publishing.af.mil/production/1/af_se/publication/afpd91-2/afpd91-2.pdf.