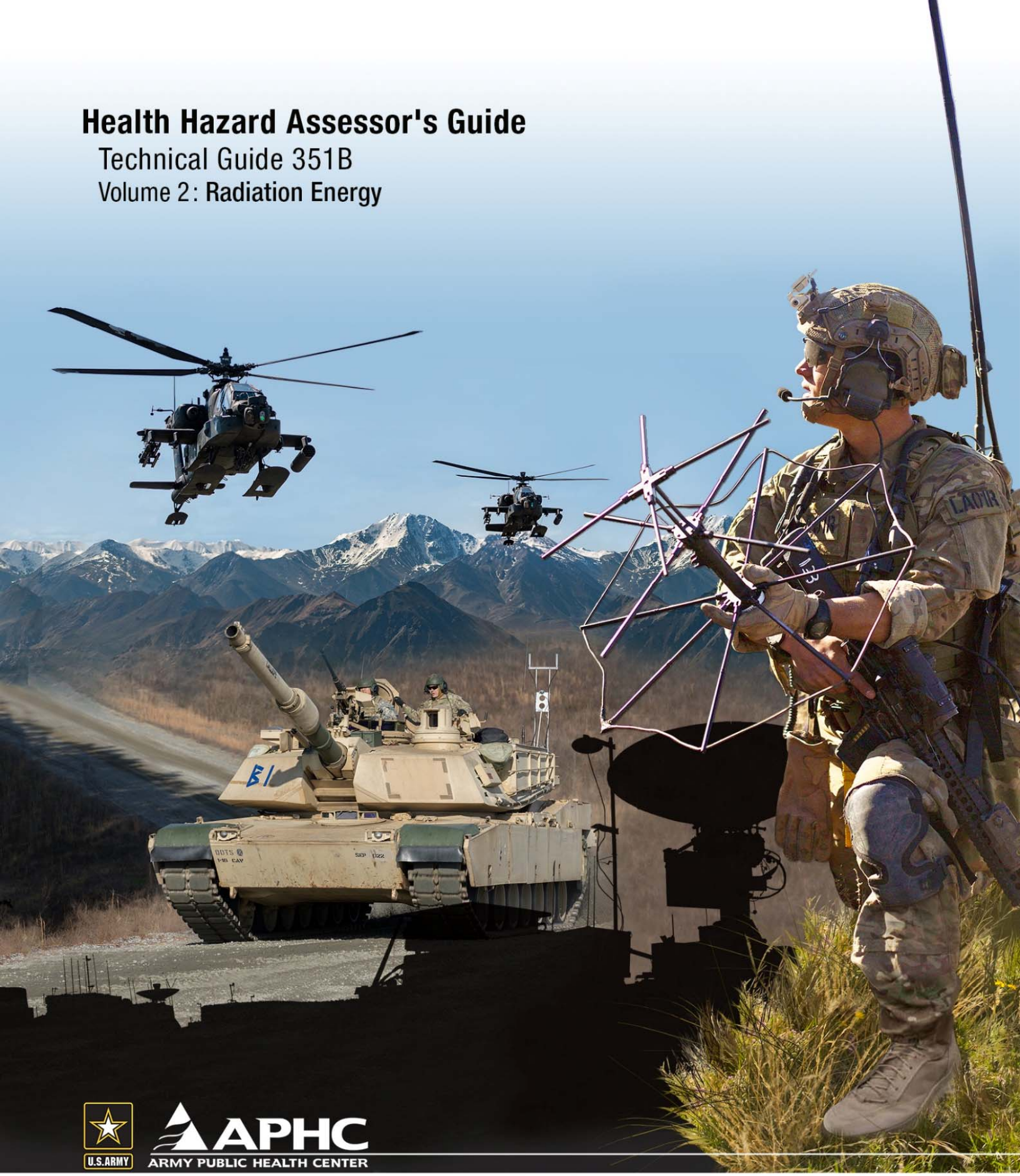
Health Hazard Assessor's Guide

Technical Guide 351B

Volume 2: Radiation Energy



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PREFACE

TG 351B, Volume 2: Radiation Energy, consists of guidelines for assessing health hazards related to radiation energy. Radiation energy is divided into two main categories, ionizing and nonionizing radiation, based on the wavelength/frequency of the source. This volume includes an introductory chapter, followed by three chapters presenting guidelines for conducting health hazard assessments of exposure to ionizing radiation, radio frequency radiation, and laser and optical radiation, respectively.

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1–1. Purpose

The Health Hazard Assessor's Guide consists of a series of chapters, each focusing on a health hazard category addressed in the current version of Army Regulation (AR) 40–10, *Health Hazard Assessment Program in Support of the Army Acquisition Process*. The purpose of this technical guide (TG) is to—

(1) Characterize health hazard categories and expand upon the Health Hazard Assessment (HHA) Program process as established in AR 40–10.

(2) Provide guidance on the process of conducting an HHA for each unique health hazard category in order to assign consistent risk assessment codes (RACs) and effectively communicate recommendations to the materiel developer (MATDEV) responsible for hazard mitigation. (Note: A category may comprise multiple sub-categories.)

(3) Provide a technical resource for U.S. Army Public Health Center (APHC) independent medical assessors (IMAs) and other personnel who identify and assess potential materiel system health hazards in support of the Army Acquisition Process. Chapter 1 serves as the reference for the remaining chapters as it contains key relevant definitions and general risk assessment processes that appear throughout the Guide.

1–2. Definitions of Key Terms

Capability developer (CAPDEV): A command or agency that formulates doctrine, concepts, organization, training, materiel requirements, and objectives. The CAPDEV represents the user community over the life cycle of the system.

Hazard probability (HP): An expression of the degree of likelihood that an exposure to a hazard/hazardous condition (physical, chemical, or biological) will produce an adverse health outcome to a materiel system user or maintainer. HP is based on an assessment of factors such as the affected population, the user scenario, and the duration and frequency of the exposure. See Table 1–1 for the HP levels.

Hazard severity (HS): An expression of magnitude of an adverse health outcome (occupational injury/illness) to a materiel system user or maintainer that will occur from exposure to a hazard/hazardous condition (physical, chemical, or biological) during normal use or maintenance of the materiel system. See Table 1–2 for the HS categories.

Health hazard: An existing or likely condition, inherent to the operation or use of materiel, that can cause personnel death, injury, illness, disability, and/or reduced job performance. It is important to distinguish between hazards inherent in the normal use and maintenance tasks and those hazards related to equipment failures, mishaps, or human errors. The scope of the HHA process includes assessment of inherent hazards

during normal use and maintenance while the hazards related to failures, mishaps, or human errors fall within the scope of the system's safety program.

Health Hazard Assessment (HHA): The application of biomedical knowledge and principles to document and quantitatively determine the health hazards of Army systems during normal system operation and maintenance. This assessment identifies, evaluates, and recommends controls to reduce risks to the health and effectiveness of personnel who test, use, or service Army systems. This assessment includes—

- The evaluation of HS, HP, risk assessment, consequences, and operational constraints.
- The identification of required precautions and protective devices.
- Training requirements.

Health protection criteria: Include applicable criteria and standards that have been adopted for use in assessing potential adverse effects associated with exposure to the identified hazards. The Department of Defense (DOD), Department of the Army (DA), and other governmental (Federal, state, and local) criteria and standards should be used as deemed practical. Other scientific and professional criteria and standards may be developed, and the HHA Program may adopt these consensus standards to be applicable to military-unique requirements. The type of criteria may differ depending on the specific hazard and available research (e.g. medical criteria, injury criteria, damage risk criteria, design criteria). When military design, specification, or deployment requirements render compliance with existing occupational health standards infeasible or inappropriate, or when no standard exists for military-unique applications, the Army will apply standards appropriate for the exposure scenario or use the health risk management process to develop military-unique occupational health standards.

Independent Medical Assessor (IMA): Personnel, independent of materiel and combat developers, who are tasked by the Army Medical Department (AMEDD) to provide the appropriate HHA support to Army materiel systems.

Initial risk: The first assessment of the potential risk of an identified hazard. Initial risk establishes a fixed baseline for the health hazard.

Life cycle: The life of a system from conception to disposal.

Materiel developer (MATDEV): The research, development, and acquisition command agency or office assigned responsibility for the system under development or being acquired. This term may be used generically to refer to the research, development, and acquisition community in the materiel acquisition process (counterpart to the generic use of combat developer).

Military-unique operations, equipment, or systems: Operations, equipment, or systems that are unique to the national defense, including combat and operation testing and maintenance of military-unique weapons, aircraft, ships, missiles, early warning

systems, ordnance, and tactical vehicles. Nonmilitary-unique operations are those Army operations that are generally comparable to those of the private sector (for example, repair and overhaul of weapons, vessels, aircraft, or vehicles).

Program, project, and product managers: Individuals who are chartered to conduct business on behalf of the Army. These managers report to and receive direction from either a program executive officer, the Army Acquisition Executive, or other MATDEV and are responsible for the centralized management of a specified acquisition program.

Residual risk: The risk remaining after hazard mitigation strategies and control measures have been implemented.

Risk: An expression of possible injury or illness in terms of HS and HP.

Risk assessment: A structured process for identifying and assessing health hazards in terms of HS and HP. A risk assessment also provides recommendations for eliminating or controlling hazards.

Risk assessment code (RAC): A unique combination of HS and HP alphanumeric values (e.g., 1A, 2B, 3B) that describe risk and correspond to a risk level. The use of RACs is a standard way of portraying risk by the two individual HS and HP components rather than by a single risk level. Because a single risk level may be correlated with several different RACs, expressing risk in terms of an alphanumeric combination provides more information about the nature of the risk. See the risk matrix in Table 1–3 for the corresponding risk levels of each RAC.

Risk level: The characterization of risk as either High, Serious, Medium, or Low. See the risk matrix in Table 1–3 for the corresponding risk levels of each RAC.

Subject matter expert/evaluator (SME): A person who has the knowledge, skills, abilities, and other characteristics required to perform a specific job and who maintains competency by taking continuing education classes, writing articles, or producing other products associated with the subject area of expertise. Based on their experience and knowledge, SMEs use their professional judgment to make decisions logically and appropriately.

System: A composite, at any level of complexity, of trained personnel, procedures, materials, tools, equipment, facilities, and software. The elements of this composite entity are used together in the intended operational or support environment to perform a given task or achieve a specific production, support, or mission requirement.

Test condition: A set of unique parameters established for testing a materiel system. Such parameters may include, but are not limited to, location of materiel; location and/or position of personnel; temperature (atmospheric and/or materiel); atmospheric pressure; wind direction and speed; number and type(s) of propellant, charges, and/or weapons

fired; quadrant elevation; azimuth; and/or materiel configuration changes (e.g., open/closed hatches).

1–3. Applicable References/Health Protection Criteria

Appendix 1A lists the references applicable to this Guide.

1–4. Objectives

As part of the overall HHA Program Strategy, the primary objectives of this Guide are to—

(1) Review and improve the process for assessing specific health hazards and interpreting their health and/or performance risks.

(2) Provide a consistent approach to estimate HS and HP.

(3) Document and improve current risk calculation methodologies.

(4) Instruct in the use of biomedical data to consistently assess identified health hazards against established health protection criteria and standards, and to identify HHA capability gaps and recommend system-specific medical research requirements.

(5) Improve HHA Program support to the Army Acquisition Community, including Army CAPDEVs, MATDEVs, and, ultimately, the Soldier.

1–5. Scope

(1) This Guide describes the processes for conducting HHAs for each unique health hazard category; therefore, this Guide falls within the scope of the HHA Process (detailed in section 1–7A).

(2) The target audience for this Guide comprises all personnel who support the completion of an HHA, including IMAs, SMEs, HHA project managers, and MATDEVs; as well as the HHA Report (HHAR) recipients. By explaining assessment processes and the derivation of RACs, this Guide enables those who support HHA completion to better interface with HHAR recipients.

1–6. Objectives of the Health Hazard Assessment Program

The primary objective of the HHA Program is to identify and assess health hazards associated with materiel system life cycle management and provide recommendations to CAPDEVs, MATDEVs, and training developers to eliminate or control the health hazards inherent in weapon platforms, munitions, equipment, clothing, training devices, and other materiel systems. The Army's effort to eliminate health hazards from materiel systems links the HHA Program with Army warfighting capabilities and performance.

(1) Specific HHA Program objectives include—

(a) Preserving and protecting the health of individual Soldiers.

(b) Reducing degradation of Soldier performance and enhancing system effectiveness.

(c) Removing health hazards from systems by design to eliminate the need for health hazard-based retrofits.

(d) Reducing the number of readiness deficiencies attributable to health hazards, thus reducing training or operational restrictions.

(e) Reducing personnel compensation claims by eliminating or reducing injury or illness caused by health hazards associated with the use and maintenance of Army systems.

(f) Reducing or eliminating occupational health hazards attributable to Army systems.

(g) Estimating costs avoided as a result of implementing HHA Program recommendations.

(2) The focus of the HHA is on potential health hazards resulting from training and combat scenarios; however, health hazard issues in any phase of the life cycle may be addressed. The HHAR documents the results of the evaluation of these issues. The HHAR provides developers, testers, evaluators, and users of new materiel with assessments and recommendations for controlling identified health hazards.

(3) The Army's HHA Program is continuously adapting to new dimensions of its mission and focusing on initiatives to protect and preserve the health of the Soldier and enhance the military mission. Since the inception of the *Health Hazard Assessment (HHA) Program Strategy and Action Plan* approved by Army Leadership in 1995, the HHA Program has continued to improve its structure and framework to support the Army in assessing evolving health hazard challenges.

1–7. Overview of the Health Hazard Assessment Process

A. Scope. Ensure the HHA is performed within the limits of normal use and maintenance of the system. The HHA and RACs describe the inherent hazards to which Soldiers who operate and maintain materiel may be exposed during normal use and maintenance. The maintenance assessment is limited in scope to operator-, crew-, and unit-level maintenance. Those individuals who are downrange are out of scope. Testing personnel are out of scope. Mishaps, accidents, equipment failures, and human error fall within the scope of the system's safety program and are not included in the HHA. Survivability, environmental, and human factor issues are also out of scope.

B. Health Hazard Identification and Categories. The first step in the HHA process is identifying potential health hazards. Hazard identification consists of analyzing specific hazardous conditions (chemical, physical, or biological) associated with the operation, maintenance, and operating environment of a system. The specific health hazard categories assessed include, but are not limited to, the following:

- Acoustic Energy
  - Steady-state Noise
  - Impulse Noise
  - Blast Overpressure
  - Ultrasonic Noise
- Biological Substances
  - Sanitation
  - Pathogenic Microorganisms
- Chemical Substances
  - Weapon Combustion Products
  - Fuel Combustion Products
  - Toxic Materials
- Radiation Energy
  - Ionizing Radiation
  - Nonionizing Radiation
    - Lasers
    - Radiofrequency Radiation
    - Optical Radiation
- Shock
  - Acceleration and Deceleration
  - Recoil
- Temperature Extremes
  - Heat Stress
  - Cold Stress
- Trauma
  - Blunt Trauma
  - Sharp Trauma
  - Musculoskeletal Trauma
- Vibration
  - Whole-body
  - Hand-arm
  - Multiple Shock (Jolt)
- Oxygen Deficiency
  - Crew/Confined Spaces
  - High Altitude
  - Ventilation

To aid in the identification of health hazards, data are obtained from sources such as—

- Previous systems.
- Safety assessments.
- Human factor assessments.
- Capability documents.
- Management documents.
- Test documents.
- User manuals.
- Field observations.

C. Exposure and Dose-Response Assessments. The exposure assessment is fundamental to the HHA process. The IMA reviews the available qualitative and quantitative information on the presence and magnitude of the health hazards, routes of exposure, duration of exposure, frequency of exposure, and population at risk. When available, quantitative data is preferred over qualitative data. Based on the exposure dose information, the physiological response and potential adverse health effects may be assessed.

(1) Exposure levels can be determined by taking direct readings of actual conditions during testing, training, or simulated combat situations. This data collection is not the responsibility of the HHA Program and is preferably conducted by the U.S. Army Test and Evaluation Command (ATEC) in accordance with the applicable Military

Standard (MIL–STD) and Test Operations Procedure (TOP). For some applications, modeling techniques can yield useful potential exposure data at less cost and in less time than actual testing and sampling. By applying experience and professional knowledge, as logical and appropriate, it is also possible to estimate the significance of the health hazard based on analogy with previous assessments.

(2) The way in which a hazard impacts human health depends on the route of the exposure. The routes of exposure for the chemical and biological health hazard categories include inhalation, dermal absorption, and ingestion. Routes of exposure for physical health hazards depend on the characteristics of the specific energy. The populations at risk are the Soldiers operating or maintaining Army materiel, including Soldiers in close proximity to the hazardous condition.

(3) The hazard's frequency and duration of exposure are determined based on the system's intended normal use during both training and combat scenarios. Combat scenarios are inherently risky and produce situations in which health hazards cannot be avoided. Health hazards related to training are, in most cases, easier to control.

D. Risk Assessment. Risk assessment of the health hazards combines the hazard identification information, exposure assessment, and health protection criteria to express the risk of possible death, injury, or illness in terms of HS and HP (within the scope). The estimated exposure to the identified hazard is compared with established health protection criteria, and a health hazard is assumed for any exposure at or above the criteria. Exposure that remains within the established criteria does not necessarily mean there is no hazard present but represents a permissible level for the specific hazard type. Therefore, this type of exposure is typically assigned either no risk level or a low risk level.

Note that individual IMAs may conduct a specific health hazard risk assessment by using many different resources, ranging from gathering SME input, or using mathematical modeling, to conducting field evaluations. In those cases when critical data are incomplete or not available, a professional judgment or inference based on the assessor's experience and the system-specific situation may be necessary to complete the risk assessment.

The goal of the HHA Program is to identify potential hazards early in the life cycle and make recommendations to eliminate or control hazards. When health hazards cannot be eliminated, the HHA Program provides RACs (made up of HP and HS coordinates) to characterize the health risk and recommendations to control the hazard. MIL–STD–882E provides a standard practice to aid MATDEVs in the management of environmental, safety, and health risks encountered in the development, test, production, maintenance, use, and disposal of DOD systems. This standard practice includes a risk assessment matrix used in the HHA process to characterize assessed health hazards in terms that decision makers can prioritize and use in their overall risk management strategy.

(1) The HP is an expression of the degree of likelihood that an exposure to a hazard/hazardous condition (physical, chemical, or biological) will produce an adverse health outcome to a materiel system user or maintainer based on an assessment of factors such as affected population, user scenario, and exposure duration and frequency. Probability level F is used to document cases where the hazard is no longer present. No amount of doctrine, training, warning, caution, or personal protective equipment (PPE) can move an HP from levels A through E to level F.

Note that although the HP levels are derived from MIL–STD–882E, the HHA definition of HP varies from the MIL–STD–882E definition. MIL–STD–882E focuses on system safety and the probability of occurrence of a mishap, whereas the HHA Program assesses the probability of an exposure producing an adverse health outcome. The HP levels assigned by system safety representatives and the HHA Program may differ.

Table 1–1. Hazard Probability Levels[1]

Description	Level	Likelihood of Occurrence
Frequent	A	Likely to occur often.
Probable	B	Will occur several times.
Occasional	C	Likely to occur sometime.
Remote	D	Unlikely, but possible to occur.
Improbable	E	So unlikely it can be assumed occurrence may not be experienced.
Eliminated	F	Incapable of occurring. This level is used when potential hazards are identified and later eliminated.

Source: Adapted from MIL–STD–882E
Note:
[1]Degree of likelihood that an exposure will produce an adverse health outcome as a consequence of a Soldier's normal use of an item.

(2) The HS is an expression of magnitude of the adverse health outcome (occupational injury/illness) to a materiel system user or maintainer that will occur from exposure to a hazardous condition (physical, chemical, or biological) during normal use of the materiel system.

Table 1–2. Hazard Severity Categories

Description	Category	Result Criteria
Catastrophic	1	Could result in death or permanent total disability.
Critical	2	Could result in permanent partial disability, injuries, or occupational illness that may result in hospitalization.
Marginal	3	Could result in injury or occupational illness resulting in one or more lost work days.
Negligible	4	Could result in injury or occupational illness not resulting in a lost work day.

Source: Adapted from MIL–STD–882E

(3) Using the risk assessment matrix derived from MIL–STD–882E (Table 1–3), the assigned HP and HS are combined to determine the RAC and risk level. The RAC is the alphanumeric combination of the HS and HP. The risk level is determined by the intersection of the HS category and HP level, as shown in Table 1–3.

Table 1–3. Risk Assessment Matrix

SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)				

Source: MIL–STD–882E

E. Recommendations. Recommendations to eliminate or control health hazards are developed using the hierarchy of effectiveness of controls consistent with DOD Instruction (DODI) 6055.01, *DOD Safety and Occupational Health (SOH) Program* (Figure 1–1). The goal of the HHA Program is to identify potential hazards early in the life cycle in order to provide more efficient controls. An assessment may result in multiple recommendations, each with its own residual risk and RAC. The approving authority (in coordination with the MATDEV) makes the decision to implement the recommended controls or accept the risk based on cost, schedule, and mission requirements. Examples of the recommended hierarchy of effectiveness of controls are listed below in priority order:

(1) ***Elimination.*** Design and build systems that have no hazards under normal use and maintenance conditions. For example, a lifting procedure could potentially require numerous lifters in order to move a heavy piece of equipment. If the procedure could be accomplished using a mechanical lifting device, then the lifting hazard would be eliminated.

(2) ***Substitution.*** Substitute less hazardous materials, processes, operations, or equipment. For example, substitute a lead-free ammunition primer for a lead-based ammunition primer to minimize or prevent exposure to lead.

(3) ***Engineering Controls.*** Redesign systems to control hazardous conditions. For example, implement ventilation systems to control weapon combustion products in crew-occupied spaces or automatic lock-out systems to disengage high radio frequency beams before personnel enter a hazardous area.

(4) ***Warnings.*** Add warning devices, labels, and alarms that alert personnel of potential hazards. For example, emission indicators on a laser system may warn operators that the system is energized.

(5) ***Administrative Controls.*** Develop risk reduction work practices (e.g., exposure time limitations, work-rest cycles, and personnel rotations), medical surveillance programs, and training programs.

(6) ***PPE.*** PPE is the least effective control because the risk reduction is dependent on Soldiers consistently wearing their PPE and routinely following the applicable processes and procedures. PPE recommendations may be appropriate when the implemented engineering controls will not sufficiently reduce or eliminate exposure, or engineering controls are not feasible. PPE may include protection such as noise muffs, respirators, clothing, and/or gloves.

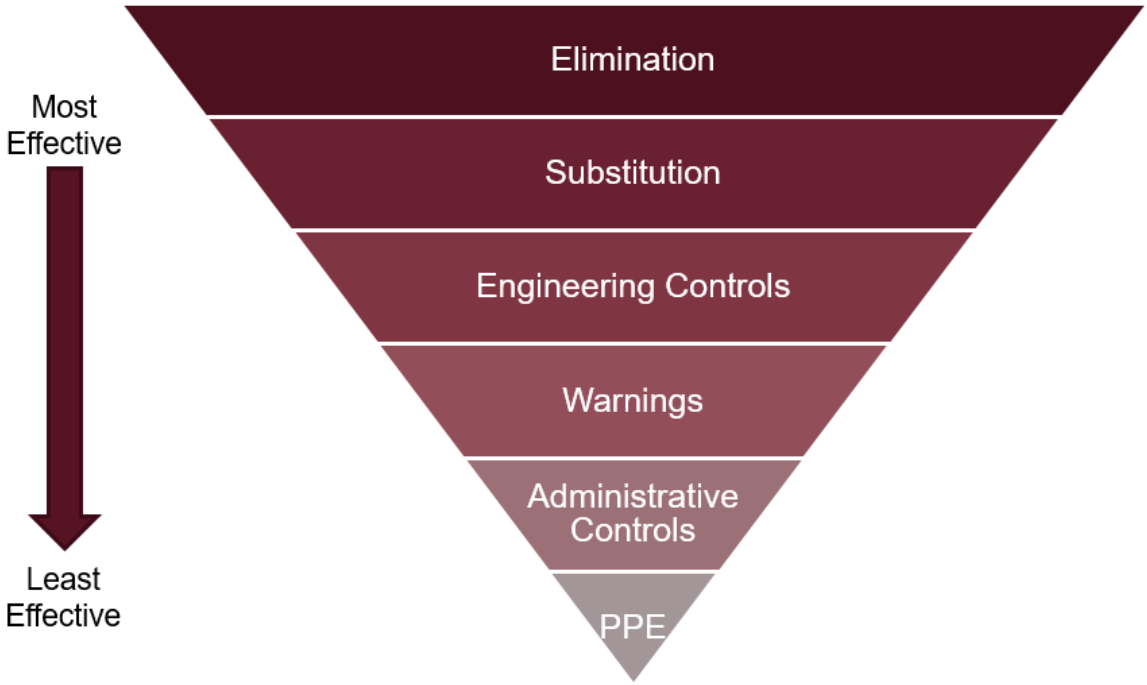

Figure 1–1. Hierarchy of Effectiveness of Controls
(Source: DODI 6055.01)

F. Health Hazard Assessment Report (HHAR). The HHAR presents the formal analysis and assessment of the health risks of materiel systems. The MATDEVs, Army Human Systems Integration (HSI) domain evaluator, and testers comprise the report's target audience. Information from the HHAR is incorporated into the programmatic environment, safety, and occupational health evaluation, a required DOD safety and occupational health, acquisition-related document. Guidance concerning type classification, materiel release, fielding, and transfer requirements is contained in AR 700–142.

(1) A complete HHAR will include the findings, conclusions, and recommendations resulting from the HHA for each applicable health hazard. This includes initial RACs, residual RACs, recommendations for eliminating or controlling the identified hazards, and descriptions of the methods used.

(2) During the early stages of development, sufficient information with which to develop a complete HHAR is not always available. Therefore, the HHA Program may prepare either an initial HHAR listing the identified hazards or a partial HHAR evaluating some identified hazards and requiring additional data for other hazards. These initial reports promote more efficient controls during the development of materiel. In addition, initial reports identify the areas from which data are needed, allowing for coordination of test plans with the ATEC to save time and money. A definitive HHAR is completed after all of the additional data identified in the initial HHAR become available and the materiel is further developed.

(3) Due to Army modernization, an increasing number of systems are undergoing Urgent Materiel Release and other types of rapid acquisition. Since time is of the essence, HHA coordination is typically limited to a review of the documentation provided and an email message from the HHA Program that briefly summarizes the materiel system's potential health hazards during its normal use and maintenance. This HHA input can help inform future data collection needs and the development of controls.

1–8. Format and Content of the Health Hazard Assessor's Guide

This TG is organized into chapters, each of which focuses on a health hazard category addressed by the Army's HHA Program, as outlined in AR 40–10. Each chapter in this Guide is organized as follows:

(1) ***Purpose.*** This section describes the health hazard category to be discussed or outlines the intent of the chapter. For example, the purpose of the chapter on whole-body vibration (WBV) is to provide guidelines for the risk assessment of WBV exposure during normal use and operation of materiel systems.

(2) ***Definitions of Key Terms.*** This section provides descriptive information characterizing the health hazard addressed in the chapter, thereby providing both a framework and specific guidance useful in identifying and assessing hazards and their sources. In addition, terms unique to hazard data collection, hazard assessment, or hazard-unique mitigation measures are defined. For example, definitions of terms such as "weighted root mean square" and "blast test device," or an explanation of the difference between auditory and non-auditory pressure wave effects, may be included. Chapter 1 includes definitions of the terms that are pertinent to all chapters.

(3) ***Applicable References/Health Protection Criteria.*** This section outlines the full range of applicable health protection criteria and standards used in assessing specific health hazards.

(4) ***Health Effects.*** This section includes information on the health effects associated with exposure to the specific health hazard.

(5) ***Pre-assessment Procedures.*** This section includes the collection of information required to support the assessment. Examples include identifying operational scenarios during anticipated Soldier exposures and data collection. The Operational Mode Summary or Mission Profile typically provides the type of exposure information necessary to support the assessment, particularly when the HP is being determined. This section also references the appropriate ATEC TOP to ensure data collected for the specific hazard type are accurate, precise, and usable. The data collection requirements should be sufficiently referenced to enable assessors, SMEs, and MATDEVs to clearly identify the appropriate data collection procedures.

(6) ***Risk Assessment Process.*** This section describes how to compare the collected data and any additional relevant information to the selected health protection

criterion. Based on that comparison and a review of the additional relevant information, a standardized methodology for deriving both the HS and HP is documented. That process should reflect the SME's assessment process and logic and should link each identified hazard with a RAC from the MIL–STD–882E RAC matrix. The goal is not only to document the HS and HP derivation logic to assist others in understanding it but to provide a repeatable process as well.

(a) The assigned RAC will consist of the HS and HP coordinates (3C, for example) and will correspond with the MIL–STD–882E risk levels of High, Serious, Medium, and Low for risk acceptance authority identification (i.e., the level of leadership authorized to accept the assigned risk level). As an outcome of the RAC assignment, the assessor generates recommendations corresponding with the identified HS and HP.

(b) Assigning risk is indeed subjective. Multiple assessors evaluating the same hazard may assign different RACs to it. This is to be expected; however, the goal is to assign risk as consistently as possible.

(c) Certain health hazards, when designed within the applicable design criteria, may have a maximum HS category that is deemed acceptable to the MATDEV. The MATDEV may decide not to collect additional data but assume the risk associated with the hazard exposure. SMEs should identify the maximum HS category capable of occurring under a normal use scenario for each health hazard category.

(7) ***Example Assessment Scenario.*** Because operating conditions may impact the process for deriving both the HS and HP, the final section of each chapter provides brief examples of operationally relevant assessments. For example, assessment of factors such as affected population, user scenario, and exposure duration and frequency may either decrease or increase a RAC. Based on the understanding that not all assessment factors can be documented, the examples provided document the typical health hazard category variables that may affect the RAC assignment.

(8) ***Limitations and Potential Future Work.*** This section further describes known limitations of the current assessment processes and possible ways forward to address these limitations and improve health hazard assessment capabilities.

APPENDIX 1A

CHAPTER 1 REFERENCES

Department of the Army (DA). 2020. Regulation 40–5, *Army Public Health Program.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN16450_R40_5_FINAL.pdf

DA. 2020. Regulation 700–142, *Type Classification, Materiel Release, Fielding, and Transfer.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN21122_R700_142_CC_FINAL.pdf

DA. 2017. Regulation 70–1, *Army Acquisition Policy.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN5631_R70_1_FINAL.pdf

DA. 2017. Regulation 385–10, *The Army Safety Program.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN16777_ARN16343_AR385_10_FINAL.pdf

DA. 2015. Regulation 602–2, *Human Systems Integration in the System Acquisition Process.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/r602_2.pdf

DA. 2007. Regulation 40–10, *Health Hazard Assessment Program in Support of the Army Acquisition Process.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/AR%2040-10.pdf

Department of Defense (DOD). 2020. Instruction 5000.2, *Operation of the Adaptive Acquisition Framework*. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2020-01-23-144114-093

DOD. 2014. Instruction 6055.01, *DOD Safety and Occupational Health (SOH) Program,* Change 2, July 14, 2020. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/605501p.pdf?ver=2018-11-19-110543-180

DOD. 2012. Military Standard 882E, *Department of Defense Standard Practice: System Safety.* https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=36027

Memorandum, Under Secretary of Defense, Acquisition, Technology, and Logistics, USD(AT&L), September 23, 2004; Subject: *Defense Acquisition System Safety*. https://www.dau.edu/policy/

U.S. Army Center for Health Promotion and Preventive Medicine (Provisional). 1995. *Program Strategy, U.S. Army Health Hazard Assessment.* Aberdeen Proving Ground, Maryland.

APPENDIX 1B

CHAPTER 1 GLOSSARY

APHC
U.S. Army Public Health Center

AR
Army Regulation

ATEC
U.S. Army Test and Evaluation Command

CAPDEV
capability developer

DA
Department of the Army

DOD
Department of Defense

DODI
Department of Defense Instruction

HHA
health hazard assessment

HHAR
Health Hazard Assessment Report

HP
hazard probability

HS
hazard severity

IMA
Independent Medical Assessor

MATDEV
materiel developer

MIL–STD
Military Standard

PPE
personal protective equipment

RAC
risk assessment code

SME
subject matter expert

SOH
safety and occupational health

TG
Technical Guide

TOP
Test Operations Procedure

WBV
whole-body vibration

CHAPTER 2. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO IONIZING RADIATION

Source: DVIDS

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2–1. Purpose

This chapter provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to ionizing radiation during the normal use and maintenance of materiel systems.

2–2. Definitions of Key Terms

Absorbed dose: Amount of energy deposited per unit mass by ionizing radiation, expressed in units of gray (Gy) (Système International (SI)) or rad (conventional). The term “radiation dose” is often used as shorthand for any amount of ionizing radiation energy received. The absorbed dose is the fundamental physical quantity in ionizing radiation dosimetry.

Activity: Instantaneous rate of transformation (disintegration) or decay of radioactive material (RAM), expressed in units of becquerel (Bq) (SI) or curie (Ci) (conventional). One Bq is equal to one transformation per second, and one Ci is equal to 3.7×10^{10} transformations per second.

Dose equivalent or equivalent dose: Measure of the risk of stochastic adverse health effects (e.g., cancer), expressed in units of roentgen equivalent man (rem) or sievert (Sv). Because these quantities are based on the concept of a reference person, they are sex- and age-averaged and do not apply to a specific individual. The dose equivalent or equivalent dose is calculated as the product of absorbed dose in tissue multiplied by a weighting or quality factor that depends on the type and energy of the radiation.

Effective dose equivalent or effective dose: Quantities used for radiation protection purposes that allow for the additions of external and internal radiation doses, expressed in units of rem or Sv. They are used mainly for prospective assessment of doses, optimization in radiation protection, and regulatory compliance. They are not meant for epidemiological investigations or as measures of risk for specific individuals. However, they do provide an estimate of the risk of stochastic adverse health effects. The quantities are calculated by summing the tissue-weighted dose equivalent or equivalent dose over all the appropriate tissues. The system of internal dosimetry used determines the particular tissues over which this summation occurs.

Exposure: In common usage, the scenario under which personnel are exposed to ionizing radiation or RAM. An older quantity also known as “exposure” refers to the measurement of electric charge produced in air. Exposure in that sense is a measure of the mean total charge of one sign produced per unit mass of dry air (e.g., coulombs per kilogram ($C\ kg^{-1}$)).

External radiation dose: Radiation dose received from sources outside the body.

Gray (Gy): The SI unit for the quantity absorbed dose. One Gy equals one joule per kilogram of energy deposited in matter (1 Gy = 100 rad).

Internal radiation dose: Radiation dose received from RAM taken into the body, usually via inhalation, ingestion, or through a wound. In general, inhalation is the most significant route of intake. The calculation of internal radiation dose and subsequent health outcomes is a complex endeavor that should be undertaken by a qualified expert. See the definition of a “qualified expert” below.

Ionizing radiation: Charged, subatomic particles and ionized atoms with kinetic energies greater than 12.4 electronvolts (eV), electromagnetic radiation with photon energies greater than 12.4 eV, and all free neutrons and other uncharged subatomic particles (except neutrinos and antineutrinos). When ionizing radiation passes through material, it can deposit enough energy to produce ions by breaking molecular bonds and displacing (or removing) electrons from atoms or molecules.

Occupational dose: As defined in Department of the Army Pamphlet (DA Pam) 385−24, “The dose received by an individual in the course of employment in which the individual’s assigned duties involve exposure to radiation or to RAM [radioactive material] from regulated and unregulated sources of radiation, whether in the possession of the employer or another person. Occupational dose does not include dose received from background radiation; from any medical administration the individual has received; from exposure to patients administered RAM and released in accordance with applicable regulations; from voluntary participation in medical research programs; or as a member of the public. Workplace exposure to naturally occurring RAM, such as radon, considered background radiation by NRC [U.S. Nuclear Regulatory Commission] may be considered an occupational exposure by OSHA [Occupational Safety and Health Administration] and regulated under 29 CFR [Code of Federal Regulations] 1910.1096” (p. 56).

Qualified expert: As defined in DA Pam 385−24, “A person who, by virtue of training and experience, can provide competent, authoritative guidance on specific aspects of radiation safety. Being a qualified expert in one aspect of radiation safety does not necessarily mean that a person is a qualified expert in a different aspect” (p. 56).

Rad: The conventional unit of absorbed dose. The rad is equal to 0.01 Gy (conversely, 1 Gy = 100 rad).

Radiation dose: A context-dependent, simplifying term for the quantities absorbed dose, equivalent dose, dose equivalent, effective dose, and effective dose equivalent. For example, if acute radiation syndrome (ARS) is the endpoint of concern, then the absorbed dose (Gy or rad) is the radiation dose (quantity) of interest. However, if the endpoint of concern is the overall risk of dying from cancer, then the effective dose or effective dose equivalent is likely the quantity of interest.

Roentgen (R): The traditional unit for the quantity exposure. One R is equal to 0.000258 C kg^{-1} produced in dry air. For external, photon, whole-body irradiation, it is often assumed that 1 R ≈ 1 rad ≈ 1 rem ≈ 0.01 Gy ≈ 0.01 Sv.

Roentgen equivalent man (rem): The traditional unit for equivalent dose, dose equivalent, effective dose, and effective dose equivalent.

Sievert (Sv): The SI unit for equivalent dose, dose equivalent, effective dose, and effective dose equivalent.

2–3. Applicable References/Health Protection Criteria

A. References. Appendix 2A lists the references applicable to this chapter. The methods and references listed in Chapter 1 of this Guide also apply to this chapter.

B. Ionizing Radiation Protection Standards. Several regulatory criteria and standards apply to the acquisition, use, and control of, and the exposure to, ionizing radiation. The overarching goal of the Army Radiation Safety Program, established by Army Regulation (AR) 385−10, is to keep radiation exposures as low as reasonably achievable (ALARA).

(1) ***The Army Radiation Safety Program.*** The details of the Army Radiation Safety Program are found in DA Pam 385−24, the use of which is prescribed by AR 385−10. In general, the Army is required to comply with NRC regulations, NRC licenses, Army reactor permits, Army Radiation Authorizations (ARA), and Army Radiation Permits. Any occupational radiation exposure not governed by the NRC is governed by OSHA regulations.

To control ionizing radiation sources that are not regulated by the NRC (including radiation-generating devices (RGDs)), the Army uses ARA with a few exceptions. The ARA program is similar to the NRC's licensing program whereby the Army applies NRC regulations and guidance, modified as needed to meet the needs of the Army. Except for exempt quantities of RAMs, an NRC license or ARA must be in place to support acquisition activities regardless of the type of acquisition cycle or the point at which the source of radiation enters the acquisition process. Table 2–1 summarizes the Army's personnel ionizing radiation standards. Refer to DA Pam 385–24 for details.

Table 2–1. Summary of the Army's Ionizing Radiation Standards

Category	Annual Limit[a]	Comments
Member of the general public	1 mSv[b] (100 mrem)	Total of internal and external radiation dose
Occupational exposure of adults	50 mSv (5 rem)	
Lens of the eye	150 mSv[c] (15 rem)	
Individual organ	500 mSv (50 rem)	
Skin or extremity	500 mSv (50 rem)	
Occupational exposure of minors under age 18[d]	5 mSv (500 mrem)	
Fetus/embryo of occupationally exposed declared pregnant women[d]	5 mSv (500 mrem)	Not to exceed 0.5 mSv (50 mrem) per month over the course of the pregnancy

Legend:
mrem = milliroentgen equivalent man
mSv = millisievert
rem = roentgen equivalent man
Notes:
[a]Unless otherwise noted.
[b]The dose in any unrestricted area from external sources, exclusive of the dose contributions from patients administered radioactive material and released in accordance with applicable regulations, will not exceed 0.02 mSv (2 mrem) in any one hour.
[c]The Occupational Safety and Health Administration (OSHA) standard for occupational exposure of adults and the lens of the eye is 15 mSv (1.5 rem) in a calendar quarter. The OSHA standard for skin of the whole body is 75 mSv (7.5 rem) in a calendar quarter. The OSHA standard for hands and forearms; feet and ankles is 187.5 mSv (18.75 rem) in a calendar quarter.
[d]Population not considered within the scope of health hazard assessments. Refer to Army Regulation 40−502 for more information about exposures during pregnancy.

(2) ***Life Cycle Management (LCM).*** AR 385−10 states, "Organizations involved in RDT&E [research, development, test, and evaluation] and in acquisition of equipment (including COTS [commercial off-the-shelf] equipment) that emits radiation or contains radioactive material will develop management and quality control processes to—

- Identify hazards and controls and incorporate protection measures or identify operational restrictions before fielding.
- Process residual risks for acceptance per AR 70–1 before fielding materiel.
- Ensure that radiological concerns have been addressed in the fielding, training, and life cycle management of commodities containing radioactive material or that produce radiation.
- Ensure that proponents of technical publications include radiation safety requirements about siting, operation, training, and maintenance of commodities and systems that contain radioactive material or emit radiation" (p. 52).

The goal of LCM is to provide oversight of the RAMs and RGDs the Army needs to accomplish its mission. DA Pam 385–24 states, “Acquisition of material containing radioactive material is covered in AR 70–1 and DA Pam 70–3. Provided below are a few considerations for the acquisition community when considering the use of radioactive materials:

- Separate national stock numbers that use radioactive material from non-radioactive versions.
- Serial numbers should be used to identify each radioactive source.
- Propose not procuring radioactive items if non-radioactive items are available.
- Require life cycle costs to be covered (for example, disposal, leak/wipe testing, training, dummy device for training procurement, and inspections).
- Plan for disposal, one for one replacement, cost versus benefit analysis, and a tracking system” (pp. 14–15).

Any item containing RAM that is covered by an existing NRC license must be approved by the Army NRC license holder before the item can be acquired. Furthermore, an NRC license or ARA must be in place to support acquisition except for exempt RAM. Materiel developers (MATDEVs) must work with the Army Test and Evaluation Command, Army Materiel Command, and/or Army Futures Command to ensure support for the item. Refer to DA Pam 385–24, Table 6–1 for a listing of Army Materiel Command NRC commodity license radiation safety officers (RSOs).

2–4. Health Effects of Ionizing Radiation Exposure

Biologically, ionizing radiation causes injury by breaking molecules into electrically charged fragments or free radicals and producing chemical reactions that may lead to permanent cellular damage. There are three outcomes at the cellular level: (1) repair with no residual damage; (2) death with cellular replacement; and (3) incorrect repair and subsequent changes in the cell’s life cycle. Changes at the cellular level can manifest themselves as chronic (late or stochastic), acute (immediate or tissue reactions), or teratogenic (fetal/embryonic) effects. Special units of measurement are used to quantify exposure to ionizing radiation, address the magnitude of the exposure and the biological risk, and allow for comparison of different exposure types (refer to section 2–3). The preferred system of units is the extended SI.

A. Stochastic Effects. Stochastic effects in a population exposed to ionizing radiation are effects randomly distributed in a population, assumed not to have a threshold, and whose severity does not increase with increasing dose. Cancer is the stochastic effect of most concern for ionizing radiation exposure. Because cancers begin to appear roughly 5 to 7 years after exposure for leukemia and up to 60 years after exposure (latent period) for other types of cancer, they are also known as late or chronic effects. No biomarkers have been identified that can definitively link a given cancer to radiation exposure. At the radiation doses likely to be received by users of Army materiel, the adverse health effect of concern is cancer.

For radiation doses less than about 100 millisievert (mSv) (10 rem) in humans, the effects are not well understood. However, for relatively low doses (less than 100 mGy (10 rad) delivered in a short time) and dose rates (less than 5 milligray (mGy) per hour (0.5 rad per hour)), the NCRP recommends use of a linear no-threshold model "as a prudent and practical approach for the system of protection, recognizing that the underlying biological processes have great variability and there remains considerable uncertainty at the low absorbed doses and low absorbed-dose rates of interest" (p. 40).

The estimated (theoretical) risk of fatal cancer on which the system of radiation protection rests is about 0.05 Sv^{-1} (0.0005 rem^{-1}). That is, about 50 excess cancers are hypothesized to occur in a mixed-aged population of 100,000 exposed to 10 mSv (1 rem) of external radiation. Roughly 40,000 cancers would occur in a comparable population with no radiation exposure. Adverse health effects at radiation doses on the order of 1 mSv (0.1 rem) have not been seen in humans. Other organizations, such as the Health Physics Society, recommend against numerical estimates of risks at low radiation doses.

B. Tissue Reactions. Tissue reactions in a population generally have a threshold, and the reactions increase in severity as the dose increases (e.g., induction of skin erythema or the various phases of ARS). Regarding radiation protection, tissue reactions are also known as deterministic or acute effects. HHAs rarely consider the onset of ARS because of the typically low normal-use exposure levels of the systems assessed. ARS manifests similarly to an acute, viral illness resulting from an acute, whole-body (or nearly whole-body) external radiation exposure.

At acute doses of about 0.1 to 0.2 Gy (10 to 20 rad), chromosome aberrations in lymphocytes can be detected and, in fact, are used as a biological dosimeter. As the dose increases to about 0.5 Gy (50 rad), hematopoietic effects can be seen. The International Commission on Radiological Protection (ICRP) states, "…acute doses up to approximately 0.1 Gy [10 rad] produce no functional impairment of tissues…After acute or accumulated doses of >0.5 Gy [50 rad], the risk of tissue reactions (deterministic effects) becomes increasingly important…" (p. 23).

As the acute doses increase, the probability and severity of tissue reactions increase with a threshold of about 0.5 Gy (50 rad), as per the ICRP, for a reduction in the activity of blood forming tissues. Anno reports that in the dose range of 0.5 to 1 Gy (50–100 rad), about 5 to 50% of a population will experience mild symptoms of nausea, vomiting, and anorexia in addition to hematopoietic effects within about one day after an exposure. In the range of 1 to 2 Gy (100 to 200 rad), larger portions (30 to 90%) of the population will show signs and symptoms of acute radiation exposure; death might occur in up to 5% of the population without medical intervention. The Armed Forces Radiobiology Research Institute reports about 100% survival without treatment up to 2 Gy (200 rad). Army Techniques Publication 4−08.23 states that in the dose range of 0 to 0.35 Gy (0 to 35 rad), no signs or symptoms would be evident in a population of Soldiers. As the dose increases to about 0.75 Gy (75 rad), some Soldiers may become

nauseated and have mild headaches. In both dose ranges, no restriction of duty would be required.

C. Summary. When conducting an HHA of exposure to ionizing radiation at doses less than 0.2 Sv (20 rem), the health outcome of concern is fatal cancer, and the risk per unit dose is about 0.05 Sv^{-1} (0.0005 rem^{-1}). At doses greater than 0.2 Sv (20 rem), tissue reactions may be of concern as well; however, the risk of fatal cancer will be significant and might outweigh the risk of tissue reactions in the final risk assessment.

2–5. Pre-assessment Procedures

A. Assessor Qualifications. The assessor should be a qualified subject matter expert (SME) in the field of radiation protection (health physics). In particular, they should have expertise in external and internal radiation dosimetry and be familiar with the biological effects of radiation exposure. The U.S. Army Public Health Center (APHC) Health Physics Division (HPD) has health physicists on staff to estimate radiation doses and make recommendations on mitigating ionizing radiation risks.

B. Information Required for a Health Hazard Assessment. For all materiel that may be a source of ionizing radiation, obtain the following information from the MATDEV:

- Detailed description of how the system will be used, including the expected duration and frequency of exposure during normal use and maintenance.
- Types, quantities, and the physical and chemical forms of all RAM in the system.
- Types and radiological characteristics of ionizing RGDs in the system.
- Personnel locations and expected radiation dose rates during normal use and maintenance of the system.
- Expected intakes or uptakes of RAM, or expected or acceptable leakage of RAM.

Sources of the required information may include manufacturer data, safety assessments, capability documents, user manuals, or experimental studies. The data and measurement quality must meet the objectives of the HHA. If necessary, the HPD may design and perform an experiment to obtain data that are not available from other sources.

C. Identifying Sources of Ionizing Radiation. It is expected that the MATDEV will provide all information needed to conduct the HHA, including the fact that the item contains a source of ionizing radiation. APHC Technical Guide (TG) 238 includes information on identifying items containing sources of ionizing radiation.

The Army RSO website, https://cecom.aep.army.mil/gstaff/ds_user/rso/default2.aspx, is a useful resource for materiel/commodity information, NRC license information, and technical information about radiation sources in the Army.

Certain sources of nonionizing radiation such as klystrons, magnetrons, and high-power vacuum tubes can be sources of inadvertent (stray) ionizing radiation and are generally subject to Food and Drug Administration (FDA) regulations. When assessing a source of nonionizing radiation, obtain data from the MATDEV on the potential for the production of stray ionizing radiation.

All items containing RAM should be labeled. Typically, these labels contain the words “Caution” and “Radioactive Material.” In the United States, the labels might also contain the trefoil radiation symbol. Figure 2–1 shows example RAM labels from TG 238.

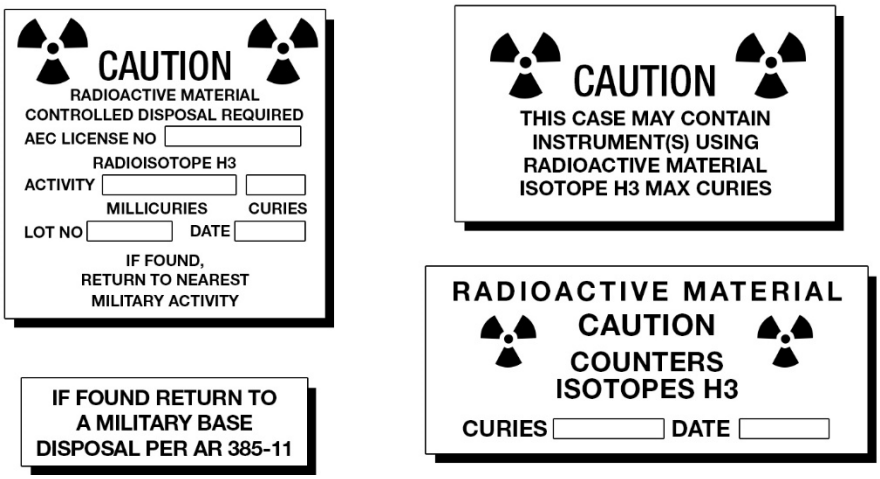

Figure 2–1. Examples of Radioactive Material Labels

The FDA requires labeling of radiation-emitting electronic products unless RAM is the source of the emitted ionizing radiation. The FDA regulations state that “Tubes designed for x-radiation must bear a warning that the device produces X-rays when energized” (p. 4). This warning applies to products with cold-cathode gas discharge tubes (the source of x rays in an x-ray machine). Cabinet x-ray systems must be labeled with the following warnings:

- **“**CAUTION: X RAYS PRODUCED WHEN ENERGIZED” (p. 6) at the location of any controls which can be used to initiate x-ray generation.
- **“**CAUTION: DO NOT INSERT ANY PART OF THE BODY WHEN SYSTEM IS ENERGIZED—X-RAY HAZARD” (p. 6) at each port.

In addition to the above labels, Title 21, Part 1020.40 of the U.S. Code of Federal Regulations (CFR) requires cabinet x-ray systems to have other indicators of x-ray production, such as audible and visible signals that activate before x rays are generated.

2–6. Risk Assessment Process

A. Hazard Identification. Describe the type(s) of ionizing radiation source or ionizing RGD, including chemical and physical forms of any radionuclide or operating parameters for any electronic device. When evaluating RAM, quantify the activity and any shielding present in the system. When evaluating an RGD, identify the maximum operating potential or energy, current radiation levels, and duration of exposure while radiation is produced. Give particular attention to any non-developmental ionizing radiation sources purchased "off-the-shelf" for use as individual radioactive commodities or for incorporation into developmental items. These non-developmental sources may pose unique radiation hazards when used in the military environment.

B. Dose Estimation. Information gathered in the process of identifying the ionizing radiation hazard is used to quantify the dose of each radioactive source or RGD. The dose rate of the radiation source, the potential routes of exposure (both external and internal exposure), the exposure duration, the frequency of exposure, and the population at risk are all factors for consideration and may affect the initially assigned hazard probability (HP).

Determine the exposure duration and frequency by reviewing the intended normal use of the system, the procedures used to train Soldiers, and the maintenance requirements (operator-, crew-, and unit-level). Consider the route of exposure. Ionizing RGDs (external exposure only) and RAM (both external and internal contamination from possible inhalation, ingestion, wounds, or absorption through the skin) present different considerations. Estimate the total radiation dose or dose rate (internal and external) to the user.

C. Hazard Severity Determination. Based on the biological effects of ionizing radiation exposure, there are two categories of injury that must be considered: fatal cancer and tissue reactions (i.e., acute damage to tissues and organs such as cataracts and death from ARS). The hazard severity (HS) for tissue reactions can fall into any of the categories; however, tissue reactions have a threshold and will be limited to doses greater than 0.2 Sv (20 rem). Death is a possible outcome of all non-zero doses. ***Therefore, assign Catastrophic (HS 1) for all ionizing radiation HHAs.***

D. Hazard Probability Determination.

(1) ***Stochastic Effects.*** Consider the likelihood of fatal cancer during the lifetime of the user of the system. For ionizing radiation, the HP is the product of the probability of being exposed to ionizing radiation (including having an intake of RAM) and the probability of fatal cancer. Conservatively, it is assumed that probability of exposure while a radiation source is present is 1, and the probability of a fatal cancer is based on a nominal risk of 0.05 Sv^{-1} (0.0005 rem^{-1}). To relate the HP and radiation dose, use the quantitative estimates of probability from Military Standard 882E (shown in Table 2−2), as shown in Equation 2−1.

$$dose_{HP} = \frac{HP}{nominal\ risk} \quad \text{(Equation 2−1)}$$

Where:
HP = quantitative hazard probability estimate from Military Standard 882E
nominal risk = 0.05 Sv^{-1} (estimated risk of fatal cancer)

For example, calculate the radiation dose range corresponding to HP level D (Remote) for stochastic effects, as shown below.

$$dose_{HP,lower} = \frac{10^{-6}}{0.05\ Sv^{-1}} = 2 \times 10^{-5}\ Sv = 2\ mrem$$

$$dose_{HP,upper} = \frac{10^{-3}}{0.05\ Sv^{-1}} = 0.02\ Sv = 2\ rem$$

(2) ***Tissue Reactions.*** At doses less than 0.2 Sv (20 rem), there are no tissue reactions; that is, the HP is limited to levels A and B (Frequent and Probable) (Table 2−2). Because death from ARS is assumed to be possible at all doses above the 0.2 Sv (20 rem) threshold (refer to section 2–4B), it is the only health outcome considered for tissue reactions (i.e., assign an HS 1).

(3) ***Summary.*** The HP levels for fatalities caused by exposure to ionizing radiation can be combined into a single table for assigning a risk assessment code (RAC). For radiation doses less than 0.2 Sv (20 rem), the risk is death from cancer; above the threshold, the risks are death from cancer or complications of ARS. Table 2–2 summarizes the HP levels and resultant risk levels for ionizing radiation exposure.

Table 2–2. Hazard Probability Levels Based on Ionizing Radiation Dose

Description and Level		Likelihood of Fatal Cancer	Tissue Reaction Notes	Radiation Dose Range	Risk Level*
Frequent	A	Probability of occurrence greater than or equal to 10^{-1}. (>10%)	>2 Gy, 5 to 99% fatalities	>2 Sv *(>200 rem)*	High
Probable	B	Probability of occurrence less than 10^{-1} but greater than or equal to 10^{-2}. (1 to 10%)	1 to 3 Gy, ≤5 to 10% fatalities	≥0.2 Sv to ≤2 Sv *(≥20 rem to ≤200 rem)*	High
Occasional	C	Probability of occurrence less than 10^{-2} but greater than or equal to 10^{-3}. (0.1 to 1%)	None	≥20 mSv to <0.2 Sv *(≥2 rem to <20 rem)*	High
Remote	D	Probability of occurrence less than 10^{-3} but greater than or equal to 10^{-6}. (0.0001 to 0.1%)	None	≥20 µSv to <20 mSv *(≥2 mrem to <2 rem)*	Serious
Improbable	E	Probability of occurrence less than 10^{-6}. (<0.0001%)	None	<20 µSv *(<2 mrem)*	Medium
Eliminated	F	Incapable of occurring. This level is used when potential hazards are identified and later eliminated.	N/A	N/A	N/A

Legend:
Gy = gray
µSv = microsievert
mrem = milliroentgen equivalent man
mSv = millisievert
N/A = not applicable
rem = roentgen equivalent man
Sv = sievert
Note:
*Assumes a hazard severity of Catastrophic (1) due to the risk of death from cancer or acute radiation syndrome complications.

E. Risk Mitigation. Because the policy of the Army Radiation Safety Program is to reduce levels of radiation exposure to ALARA, control measures must be considered and evaluated regardless of the RAC. To achieve reductions in radiation exposure, the basic principles of “time, distance, and shielding” are used. These principles are expanded into methods to reduce the duration of an exposure, lengthen the distance from the source, and use shielding consistent with the specific needs of the Army.

The fundamental goal of a radiation safety program is to ensure that regulatory limits are not exceeded. In the evaluation of risk mitigation alternatives, the overarching goal is to keep the total radiation dose ALARA. Doing so entails balancing the risk of harm against the expected operational benefits of using a source of radiation so the greatest operational benefit is obtained for the smallest acceptable level of risk. In addition, the

system should meet the requirements of AR 385−10, DA Pam 385−24, and if applicable, the NRC license (refer to section 2−3B).

Risk mitigation is a holistic process, taking into account that recommendations to reduce risk from one hazard might increase risk from another. Radiological risk should not be reduced in isolation from other hazards. According to Department of Defense Instruction 6055.01, there is a preferred hierarchy of effectiveness of controls that should be considered: (1) elimination, (2) substitution, (3) engineering controls, (4) warnings, (5) administrative controls, and (6) personal protective equipment (PPE). Refer to section 2−5C for the required labeling of RAM. The HP may be lowered based on the type of control and its effectiveness, resulting in residual risk.

If the expected radiation dose is in the range of 5 to 50 mSv (0.5 to 5 rem) in a year, then the usage of the system requires extra scrutiny as this radiation dose would likely require a personal monitoring program (i.e., issuing personal radiation dosimeters to individuals) and could result in a radiation dose greater than occupational dose limits. At radiation doses approaching the occupational limit, the risk should be mitigated in all but the most extenuating circumstances. Regardless of the mitigation measures used, the assessment must be thoroughly documented.

If the expected radiation doses are in the range of 0.01 to 5 mSv (0.001 to 0.5 rem) in a year, then mitigation measures commensurate with the risk should be considered. The Army Radiation Safety Program requires monitoring if it is likely that an individual would receive a radiation dose greater than 10% of the applicable limit. For adults (excluding those who have declared in writing that they are pregnant), this dose is 5 mSv (0.5 rem).

If the radiation dose is expected to be about 0.01 mSv (0.001 rem), then measures to reduce the radiation dose might not be necessary. This radiation dose is about equal to the radiation dose corresponding to the lower limit of the range of acceptable risk under the Environmental Protection Agency’s National Contingency Plan, found in 40 CFR 300.430.

2–7. Example Assessment Scenario

The APHC received a request to assess the ionizing radiation exposure associated with a heavy armor package for a tank. This armor package is covered by an NRC license.

Step 1. Gather relevant radiological information about the system. It is known from previous studies that the heavy armor contains RAM in the form of depleted uranium (DU). It is assumed that this heavy armor is similar to that in previous studies. This information was provided by the license holder for DU commodities.

The HPD has conducted a radiation dose assessment for similar armor. The results of the assessment were as follows:

- <0.5 mrem per hour (h^{-1}) on contact.
- ~0.1 mrem h^{-1} at 30 centimeters (cm) from the surface.
- ~0.06 mrem h^{-1} at 1 meter from the surface.
- ~0.03 mrem h^{-1} background dose equivalent rates.

It was noted that the dose equivalent rate inside the crew compartment was less than outside background measurements.

Step 2. Gather relevant information on the normal use of the system. During normal use, the armor package does not release DU nor is any work performed on the armor that would uncover DU; therefore, there is no possibility for intakes of RAM. Only external radiation exposure needs to be considered.

No information on either the proximity of individuals to the armor or the duration of potential exposures is available.

Step 3. Estimate the expected radiation dose. Because no proximity or exposure duration information is available, make conservative assumptions based on typical use scenarios of tanks. Assume the population will spend 2000 hours per year working at about 30 cm from the armor package.

Step 4. Calculate the expected annual dose. Use the equation below to calculate the annual dose that could be received in the population of interest.

$$Annual\ exposure\ duration\ \times (dose\ rate - background\ dose\ equivalent\ rate)$$
$$= 2000\ hours \times ((0.1 - 0.03)\ mrem\ hr^{-1}) = 140\ mrem = 1.4\ mSv$$

Step 5. Determine the HP. Compare the annual dose (140 mrem) to Table 2–2. The result for this dose is HP D (Remote).

Step 6. Assign the HS. Assign an HS 1 (Catastrophic) because the expected health outcome of concern is fatal cancer.

Step 7. Determine the RAC. Based on the HS and HP determined in steps 5 and 6, assign a risk level of Serious (RAC: HS 1, HP D).

Step 8. Recommendations. It is impossible to completely eliminate potential exposure to ionizing radiation from this source during normal use. The range of estimates of the risk of adverse health effects includes zero. There are no recommendations other than to keep exposure ALARA, follow procedures to ensure that the armor remains intact during normal use, and ensure that Soldiers are trained regarding the presence of DU (ionizing radiation) in the armor. Consult Technical Bulletin 9-1300-278. The residual risk level is also Serious.

At this expected dose, it is unlikely that any individual would receive an annual dose greater than 10% of the applicable limit; therefore, a personnel dosimetry program is not

required. However, the NRC license may require a dosimetry program.

When comparing to other risks, consider that despite a final risk of Serious, the risk of dying at doses less than about 100 mSv (10 rem) is hypothetical, and the numerical estimates of risk used here are highly uncertain and include zero.

2–8. Limitations and Potential Future Work

An attractive alternative to a dose assessment is a cancer morbidity and mortality risk assessment using the data in Federal Guidance Report (FGR) 13 (most recent version). The morbidity and mortality risk coefficients of FGR 13 are limited to ingestion and inhalation intakes and external radiation exposures from submersion, a ground plane, or infinitely deep soil. The risk coefficients in FGR 13 are intended for use when the dose rate is less than 0.1 milligray per minute (10 millirad per minute) or when acute doses are less than 0.2 Gy (20 rad). More sophisticated analyses might be able to (1) account for the large uncertainties in the estimates of radiological risks at low doses and (2) incorporate more current cancer risk models that account for both age at exposure and time since exposure to estimate the risks of adverse health effects.

APPENDIX 2A

CHAPTER 2 REFERENCES

Armed Forces Radiobiology Research Institute, Military Medical Operations. 2013. *Medical Management of Radiological Casualties, Fourth Edition.* https://www.usuhs.edu/afrri/productsandpublications

Anno GH, SJ Baum, HR Withers, and RW Young. 1989. Symptomatology of acute radiation effects in humans after exposure to doses of 0.5–30 Gy, *Health Phys* 56(6):821–838. https://doi.org/10.1097/00004032-198906000-00001

Code of Federal Regulations (CFR). 2018. Title 21, Section 1020.20, Cold-cathode gas discharge tubes. https://www.ecfr.gov/cgi-bin/text-idx?SID=83e7409dda2abc0266a69b8cdefc2dd5&mc=true&node=se21.8.1020_120&rgn=div8

CFR. 2015. Title 10, Part 20, STANDARDS FOR PROTECTION AGAINST RADIATION. https://www.ecfr.gov/cgi-bin/text-idx?SID=8bc87bbf39f2deb20fbe46ee9592a42a&mc=true&tpl=/ecfrbrowse/Title10/10cfr20_main_02.tpl

CFR. 1996. Title 29, Section 1910.1096, Ionizing radiation. https://www.ecfr.gov/cgi-bin/text-idx?SID=3d28290528bc0985dea13450b5cc30e6&mc=true&node=se29.6.1910_11096&rgn=div8

CFR. 1990. Title 40, Section 300.430, Remedial investigation/feasibility study and selection of remedy. https://www.ecfr.gov/cgi-bin/text-idx?SID=8bc87bbf39f2deb20fbe46ee9592a42a&mc=true&node=se40.30.300_1430&rgn=div8

CFR. 1974. Title 21, Section 1020.40, Cabinet x-ray systems. https://www.ecfr.gov/cgi-bin/text-idx?SID=6bea2d151abedb33dbd6d92999246461&mc=true&node=pt21.8.1020&rgn=div5#se21.8.1020_140

Department of the Army (DA). 2019. Regulation 40–502, *Medical Readiness.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN8680_AR40_502_FINAL_WEB.pdf

DA. 2018. Pamphlet 70–3, *Army Acquisition Procedures.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN11426_DAPam70-3_FINAL.pdf

DA. 2015. Pamphlet 385−24, *The Army Radiation Safety Program*. https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/p385_24.pdf

DA. 2014. Techniques Publication 4-02.83, *Multiservice Tactics, Techniques, and Procedures for Treatment of Nuclear and Radiological Casualties*. https://armypubs.army.mil/ProductMaps/PubForm/Details.aspx?PUB_ID=104161

DA. 2012. Pamphlet 385−25, *Occupational Dosimetry and Dose Recording for Exposure to Ionizing Radiation*. https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/p385_25.pdf

DA. 1996. Technical Bulletin 9-1300-278, *Guidelines for Safe Response to Handling, Storage, and Transportation Accidents Involving Army Tank Munitions or Armor which Contain Depleted Uranium*. https://armypubs.army.mil/ProductMaps/PubForm/Details.aspx?PUB_ID=63047

Department of Defense. 2009. Instruction 6055.08, *Occupational Ionizing Radiation Protection Program*, incorporating change 2, August 31, 2018. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/605508p.pdf?ver=2019-04-04-095236-493

Hall EJ and AJ Giaccia. 2019. *Radiobiology for the Radiobiologist*, 8th Edition. Philadelphia, Pennsylvania: Wolters Kluwer.

Health Physics Society. 2019. Position Statement PS010-4, *Radiation Risk in Perspective.* http://hps.org/documents/radiationrisk.pdf

International Commission on Radiological Protection (ICRP). 2012. ICRP publication 118: ICRP statement on tissue reactions and early and late effects of radiation in normal tissues and organs – threshold doses for tissue reactions in a radiation protection context. *Ann ICRP* 41(1-2):1–322. doi: 10.1016/j.icrp.2012.02.001

ICRP. 2007. ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection. *Ann ICRP* 37(2-4):1–332. doi: 10.1016/j.icrp.2007.10.003

National Council on Radiation Protection & Measurements (NCRP). 2018. *Management of Exposure to Ionizing Radiation: Radiation Protection Guidance for the United States (2018).* NCRP Report No. 180. Bethesda, Maryland.

National Research Council. 2006. *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. Washington, DC: The National Academies Press. https://doi.org/10.17226/11340.

Thun MJ, MA Linet, JR Cerhan, CA Haiman, and D Schottenfeld. 2018. *Cancer Epidemiology and Prevention*, 4th Edition. New York: Oxford University Press.

U.S. Army Public Health Center. 2020. Technical Guide 238, *Radiological Sources of Potential Exposure and/or Contamination*. https://phc.amedd.army.mil/PHC%20Resource%20Library/TG238_RadSourcesofPotentialExposure.PDF

U.S. Environmental Protection Agency (EPA). 2017. *Radiation Health Effects*. https://www.epa.gov/radiation/radiation-health-effects

EPA. 1999. EPA 402-R-99-001, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides.* Federal Guidance Report No. 13. https://www.epa.gov/radiation/federal-guidance-report-no-13-cd-supplement

U.S. Food and Drug Administration. 2018. *Labeling Requirements for Radiation Emitting Devices and Products*. https://www.fda.gov/medical-devices/device-labeling/labeling-requirements-radiation-emitting-devices-and-products#top

U.S. Nuclear Regulatory Commission. 2017. *Backgrounder on Biological Effects of Radiation*. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.html

APPENDIX 2B

CHAPTER 2 GLOSSARY

ALARA
as low as reasonably achievable

APHC
U.S. Army Public Health Center

AR
Army Regulation

ARA
Army Radiation Authorizations

ARS
acute radiation syndrome

Bq
becquerel

C kg^{-1}
coulombs per kilogram

Ci
curie

CFR
Code of Federal Regulations

DA Pam
Department of the Army Pamphlet

DU
depleted uranium

EPA
Environmental Protection Agency

eV
electronvolts

FDA
Food and Drug Administration

FGR
Federal Guidance Report

Gy
gray

HHA
health hazard assessment

HP
hazard probability

HPD
Health Physics Division

HS
hazard severity

ICRP
International Commission on Radiological Protection

LCM
life cycle management

MATDEV
materiel developer

NCRP
National Council on Radiation Protection & Measurements

NRC
Nuclear Regulatory Commission

OSHA
Occupational Safety and Health Administration

R
roentgen

RAC
risk assessment code

RAM
radioactive material

rem/mrem
roentgen equivalent man/milliroentgen equivalent man

RGD
radiation-generating device

RSO
radiation safety officer

SI
Système International

SME
subject matter expert

Sv/mSv
sievert/millisievert

TG
Technical Guide

CHAPTER 3. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO RADIO FREQUENCY RADIATION

Source: DVIDS

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3–1. Purpose

This chapter provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to radio frequency radiation (RFR) during the normal use and maintenance of materiel systems. RFR is nonionizing radiation.

3–2. Definitions of Key Terms

Directional antennas: Antennas that emit RFR in a preferred direction (Figure 3–1). Examples of directional antennas are Yagi-Uda, log-periodic, helical, horn, parabolic reflector, and array. The hazardous areas are usually in the main beam of the antenna and/or between the feed and reflector for reflector antennas. The main beam is characterized by the antenna gain, which is one of the key parameters of the antenna. The larger the antenna gain, the more directional the main beam is. Some of the more powerful sources have hazardous zones outside the main beam.

Figure 3–1. Directional Antennas

Duty factor: The ratio of pulse duration to the pulse period of a periodic pulse train. Duty factor is sometimes expressed as a percentage. A duty factor of 1.0 (100%) corresponds to continuous-wave operation.

Exposure reference level (ERL): Another term for maximum permissible exposure (MPE).

Far field: The region far from an antenna where the electromagnetic field has a largely plane-wave character. In the far field, the power per unit area decreases with the square of the range.

Frequency: The rate of oscillation of a varying electric and/or magnetic field, expressed in units of hertz (Hz). Frequency is inversely related to the wavelength.

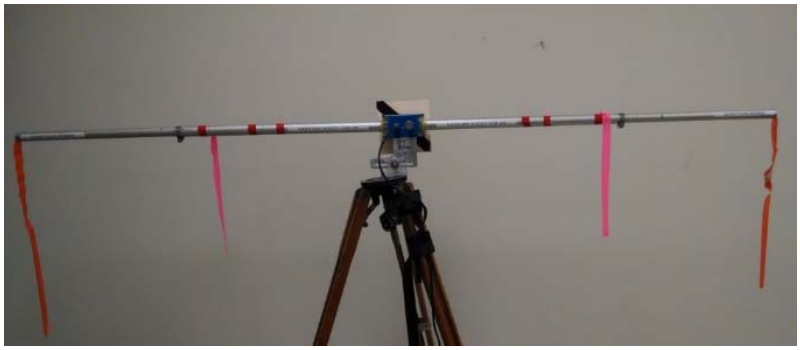
Maximum permissible exposure (MPE): The highest electric or magnetic strengths, power densities, or induced and contact currents to which a person may be exposed without incurring an adverse health effect and with an acceptable margin of safety. The

MPEs are expressed in terms of electric field strength in volts per meter, magnetic field strength in amperes per meter, plane-wave equivalent power densities in either milliwatts per square centimeter or watts per square meter (W/m^2), or induced and contact currents in amperes. While this term is widely used, other terms include ERL, permissible exposure limit, and reference levels.

Near field: A region, generally close to an antenna or radiating element, where the electric and magnetic fields (1) do not have plane-wave characteristics and (2) fluctuate considerably.

Omnidirectional antennas: Antennas that transmit equally in all directions (Figure 3–2). Antennas are either exposed metal or sheathed to prevent direct contact. The risks associated with these antennas are direct electrical contact and being located nearer to the antenna than the calculated RFR safe standoff distance (SSD).

Monopole



Dipole

Figure 3–2. Omnidirectional Antennas

Power density: Power per unit area normal to the direction of propagation. Maximum near field power density may be calculated as shown in Equation 3−1, commonly expressed in units of W/m^2.

$$S_{nf} = \frac{4P}{A} \qquad \text{(Equation 3−1)}$$

Where:
S_{nf} = near field power density
P = output power
A = area of the antenna

The power density at a specified range in the far field may be calculated using Equation 3–2, as shown.

$$S_{ff} = \sqrt{\frac{P \times G}{4\pi \times r}} \quad \text{(Equation 3–2)}$$

Where:
S_{ff} = far field power density
P = output power
G = antenna gain
r = distance from the antenna

Radio frequency radiation (RFR): Nonionizing, electromagnetic radiation with a wavelength from about 1 millimeter (about 300 gigahertz (GHz)) to static fields (0 Hz). Figure 3–3 shows the approximate range of RFR in the electromagnetic spectrum.

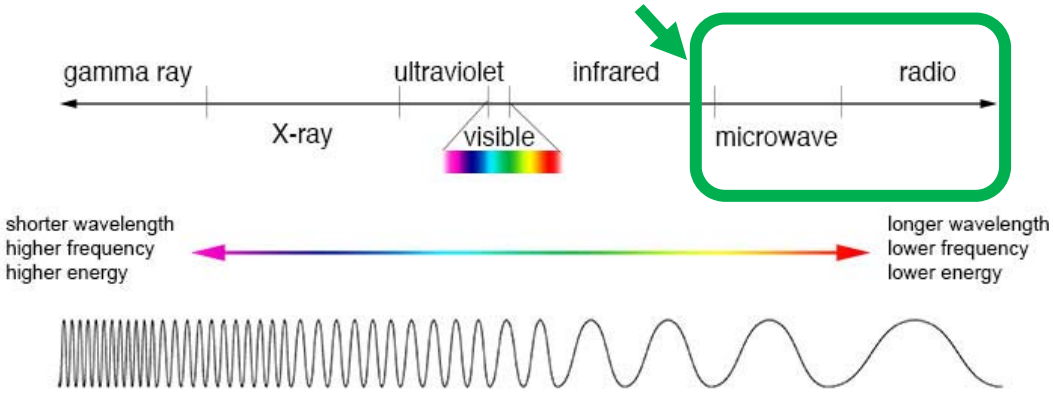


Figure 3–3. Approximate Range of Radio Frequency Radiation in the Electromagnetic Spectrum
(Adapted from the National Aeronautics and Space Administration)

Radio frequency radiation (RFR) safe standoff distance (SSD): The minimum distance, hereafter referred to as SSD, at which the RF emitter must be kept away from personnel in order to ensure that the MPE is not exceeded.

Wavelength: The distance between adjacent crests of a wave. RFR is usually discussed in terms of frequency and is inversely related to the wavelength.

3–3. Applicable References/Health Protection Criteria

A. References. Appendix 3A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

B. Health Protection Criteria. The RFR guidance pertaining to personnel protection may be found in Department of Defense (DOD) Instruction (DODI) 6055.11. This Instruction directs the use of the following Institute of Electrical and Electronics

Engineers (IEEE) C95 series of standards as guidance for protection of personnel to exposure from electromagnetic fields from 0 to 300 GHz:

- C95.1–2005, Exposure levels from 3 kHz to 300 GHz.
- C95.2–1999, Warning Sign Formats.
- C95.3–2002, Measurement Procedures and Techniques.
- C95.6–2002, Exposure levels from 0 to 3 kHz.
- C95.7–2005, Recommended Practice for RF Safety Programs.

Note: A pending update to DODI 6055.11 (expected in early 2021) will direct the use of the newer C95 series of standards, which will apply when the DODI 6055.11 revision is published.

3–4. Health Effects of Radio Frequency Radiation Exposure

A. Health Effects of Exceeding the Maximum Permissible Exposure (or Exposure Reference Level). The primary effect of absorbed RF energy is increased tissue temperature. A large tissue temperature increase may cause tissue damage. The established effects of human exposure to electromagnetic fields (EMFs) in the 0 to 3 kilohertz (kHz) range include the following short-term reactions: aversive or painful stimulation of sensory or motor neurons, muscle excitation that could lead to injury while doing potentially hazardous activities, change of synaptic activity within the brain, cardiac excitation, and adverse effects associated with rapidly moving charges within the body (such as in blood flow). The current DOD standard for protecting personnel from EMFs and RFR in the 3 kHz to 300 GHz frequency spectrum is based on the IEEE C95.1−2005 standard, which is based on established adverse health effects and specifies the MPE limits for the protection of personnel. ***There are no expectations that any adverse health effects result from exposures that are below the MPE limits, even under repeated or long-term exposure conditions.*** A minimum safety factor of 10 is incorporated into the MPE limits, and additional safety factors need not be applied. These MPEs are also assessed with reference to spatial and temporal averaging.

The threshold for the exposure limits is defined by absorption of RF fields which cause a subsequent tissue temperature rise of 1.0 degrees Celsius (°C); this approximately correlates to a whole-body exposure of 10 times the MPE. Individuals engaged in lightly physical work can tolerate a 1.0 °C rise in tissue temperature, but larger increases may cause adverse effects. For that reason, this level is used as a basis for exposures. After the source of the exposure has been removed, or the individuals have left its area of influence, their temperatures will return to normal, usually with no indications of exposure.

B. Shock and Burn Hazards. RFR shock and burn conditions exist when personnel are in direct contact with a conducting surface present with RF energy. Shock and burn hazards may exist even if the RF energy is below the MPE. IEEE C95.1−2005 states that at certain frequencies, the touch contact limit may be exceeded at 6% of the MPE,

and the induced current limit may be exceeded at 16% of the MPE. Depending on multiple factors (e.g., frequency, open circuit voltage, grounding, insulation), the health effects of these hazards may vary from a heating effect to severe RF burns.

The conducting surface may be the bare metal element-type (monopole whip, dipole, log periodic) antenna itself or passively coupled in free space. Traditionally, bare metal antennas are seen in the high frequency spectrum and lower frequency regime. Passively coupled conductive sources, however, are only seen near a high power, low frequency radio transmitter, such as an amplitude modulation (AM) radio station tower. Guy wires that support the antenna structure itself are an example of a passively coupled conducting surface at this location. Currents and voltages may be present on guy wire cables that are not properly grounded or terminated. Today, most element antennas are covered (plastic coating or fiberglass sheath); however, the base of the antenna may still be exposed metal, such as a spring mount in a vehicle configuration.

3–5. Pre-assessment Procedures

Identify all potential sources of RFR within the system being assessed. Sources of RFR include— but are not limited to— radars, radios, electronic countermeasures, and satellite communication terminals. These sources use transmitters or transceivers to generate electromagnetic energy and antennas to radiate (or emit) this energy.

Obtain all available emitter specification information from the materiel developer (MATDEV), such as the following:

- Emitter name, model, and serial number
- Frequency
- Average output power
- Antenna gain
- Duty factor
- Beam width
- Aperture area

Note: Emitter information can be obtained from DD Form 1494 Request for Frequency Allocation (required for use of all RF emitters) or from the manufacturers' technical manuals. Many commercially available systems might also have reports on file with the Federal Communications Commission.

Based on user information, identify the concept of normal use and operation of the emitter, particularly in a theater and/or training environment. Include, for example, the following: when the emitter will be used; where Soldiers (if any) will be located nearby; control of the emitter (on/off); whether or not Soldiers will wear the emitter; and antenna height. The field of effect (cone/path) of directional RF emitters should also be determined. Understanding the operation of the emitter helps determine the areas around the emitter affected, whether or not personnel will be present, and whether or not these areas can be controlled.

Other considerations include multi-source systems, proper design of waveguides, and maintenance tasks. RFR from multiple emitters within a system must be treated as a cumulative effect. Therefore, all emitters in any given configuration must be included in the determination of the RFR exposure. Verify that waveguide integrity is addressed during test and evaluation. Unterminated/broken waveguides can emit very high levels of RFR. Determine how the system will be routinely maintained by Soldiers (if at all) at operator, crew, and unit levels.

The Nonionizing Radiation Division (NRD) performs a Nonionizing Radiation Protection Study (NRPS) on military sources of RFR. Safety input for an NRPS differs from an HHA in that an NRPS considers mishaps and accidents while an HHA only considers normal use. An NRPS also considers testing and repair cycles involving maximum RF output power. Requests for an NRPS for an RF emitter may be submitted here: https://usaphcapps.amedd.army.mil/MSRV_mvc

The completion of the NRPS is not a substitute for the HHA since the NRPS has a different focus. The NRPS may be prepared as input to the safety assessment reports, safety releases, safety confirmations, and/or HHAs. The NRD and HHA Program may collaborate to ensure both documents are completed for applicable Army materiel undergoing the acquisition process.

3–6. Risk Assessment Process

A. Maximum Permissible Exposure Determination. Refer to DODI 6055.11 for the current MPE standards (IEEE C95 series). First, consider the frequency of the emitted RFR. Decide which of the two tiers of MPEs to consider for possible exposures. The lower tier applies when exposures to the general public are expected, and the upper tier applies to people in controlled environments. Most military systems conform to the upper tier of MPEs because they expose personnel who are aware of the hazards.

Consider the area of the body where exposure is expected. Often, the MPEs given are applicable to whole-body exposures, but such exposures might not be possible for certain systems. For systems where only a partial-body exposure is anticipated (e.g., only the top half of a gunner's body is exposed), another set of MPEs (found in the IEEE C95 standards) applies; these "relaxed" MPEs are known as localized, or local, exposures.

B. Safe Standoff Distance Calculation. The safe standoff distance (SSD) is based on the MPE, and equal to:

$$SSD = \sqrt{\frac{P \times G}{4\pi \times MPE}} \qquad \text{(Equation 3–3)}$$

Where:
P = power fed to the antenna
G = gain of the antenna in ratio form

MPE = maximum permissible exposure

Note: The above SSD is only applicable in the far field region of the antenna.

C. Hazard Severity Determination. The hazard severity (HS) is assigned based on potential exposure to RFR above the MPE limits. Table 3–1 serves as a guideline for determining the HS category and possible recommended mitigations. Refer to section 3−6E for more information about control measures to reduce the HS.

Table 3–1. Hazard Severity Categories for Radio Frequency Radiation (3 Kilohertz to 300 Gigahertz)

Category and Description		Criteria	Possible Control Measures
1	Catastrophic	>>10x MPE	Engineering (physical barriers with interlocks or verified engineering changes)
2	Critical	>10x MPE	
3	Marginal	5x MPE to 10x MPE	
4	Negligible	MPE to <5x MPE	Administrative (training, warnings, and labels)
None		< MPE*	None

Legend:
MPE = maximum permissible exposure
Note:
*The potential for shock and burn hazards may be present below the MPE and needs to be evaluated separately.

Systems categorized as HS 1 (Catastrophic) are rare and require a thorough evaluation by a subject matter expert with consideration of factors outside of a typical HHA. An exposure in this category could result in death or permanent total disability. While catastrophic injuries from EMF exposures are possible, a clear delineation of where this occurs is not known due to varying injury mechanisms and frequency dependence.

The HS determination for RF shock and burn hazards differs from Table 3−1. The HS for shock and burn hazards is typically limited to HS 3 (Marginal) or HS 4 (Negligible) based on the nature of the injuries. A potential for shock and burn may exist even if no HS is assigned based on Table 3−1. The overall risk should be based on the type of hazard resulting in the most conservative risk assessment code (RAC) (i.e., either the RF energy compared to the MPEs, or the potential for shock and burn).

D. Hazard Probability Determination. The hazard probability (HP) is a subjective determination based on factors such as accessibility to the radiation source, duty factor, safety features, and the manner in which the source is used. Assign the HP based on the probability of exposure (P(E)) to an RF source. Some of the factors that affect P(E) include antenna height, antenna duty factor, scanning rate, and beam elevation angle (calculations shown in Equations 3−5 through 3−8). This list is not all-inclusive; other

factors may be considered when assigning the overall HP. Use these factors to estimate P(E) as shown in Equation 3−4.

$$Probability\ of\ Exposure\ (P(E)) = P(E|H) \times P(E|D) \times P(E|S) \times P(E|A) \times P(E|O)$$
(Equation 3–4)

Where:
P(E|H) = probability of exposure given antenna height
P(E|D) = probability of exposure given duty factor
P(E|S) = probability of exposure given scanning directed energy emitter
P(E|A) = probability of exposure given minimum elevation angle of the main beam
P(E|O) = probability of exposure based on other factors as applicable

The probability of exposure given antenna height (P(E|H)) is equal to:

$$P(E|H) = \begin{cases} \left(\frac{SSD}{H-2}\right)^n & \text{if} \quad SSD < H-2 \\ 1 & \text{if } SSD \geq H-2 \ or \ H \leq 2 \end{cases}$$
(Equation 3–5)

Where:
n = 2 when antenna gain is <10
n = 3 when antenna gain is ≥10
H = height of the antenna centerline above ground in meters (m)
SSD = safe standoff distance

The probability of exposure given duty factor (P(E|D)) is equal to:

$$P(E|D) = \begin{cases} \left(\frac{T}{480}\right)^2 & \text{if} \quad T < 480 \\ 1 & \text{if } T \ is\ unknown \ or \ T \geq 480 \end{cases}$$
(Equation 3–6)

Where:
T = total time in minutes that the system is transmitting during an 8-hour period

The probability of exposure given scanning directed energy emitter (P(E|S)) is equal to:

$$P(E|S) = \begin{cases} 1.5\left(\frac{\theta}{\varphi}\right) & \text{if } \theta \leq 270 \ and \ \varphi \neq 0 \\ 1 & \text{if } \varphi = 0 \ or \ \theta > 270 \end{cases}$$
(Equation 3–7)

Where:
θ = half power beam width angle in degrees
φ = sector scan angle in degrees

The probability of exposure given minimum elevation angle of the main beam (P(E|A)) is equal to:

$$P(E|A) = \begin{cases} 10^{-(\Psi/20)} & \text{if } 0 \le \Psi \le 90 \\ 1 & \text{if } \Psi < 0 \end{cases} \quad \text{(Equation 3–8)}$$

Where:
ψ = minimum elevation angle, in degrees, of the antenna main beam from horizontal

Table 3–2 shows the HP assignments based on P(E) as calculated in Equation 3–4.

Table 3–2. Hazard Probability Levels for Radio Frequency Radiation

Level and Description		Probability of Exposure (P(E))*
A	Frequent	0.1 ≤ P(E) ≤ 1.0
B	Probable	0.01 ≤ P(E) < 0.1
C	Occasional	0.001 ≤ P(E) < 0.01
D	Remote	0.000001 ≤ P(E) < 0.001
E	Improbable	P(E) <0.000001
F	Eliminated	P(E)=0 Hazard Engineered Out

Note:
*Probability of exposure is calculated based on exposure factors such as antenna height, duty factor, emitter scanning, and elevation angle of the main beam.

Additional HP considerations (e.g., proximity of the energized elements to personnel, use scenario, recommended SSD) may be required for RF shock and burn hazards related to bare metal element-type antennas. For example, systems requiring an SSD of greater than 1 m do not present a risk of shock and burn during normal use because no one is nearby to touch energized elements. The HP associated with a potential shock and burn hazard is determined on a case-by-case basis based on the system's normal use and the controls in place. The overall risk should be based on the type of hazard resulting in the most conservative RAC.

E. Residual Risk. A residual risk may remain after the implementation of risk mitigations and recommendations. If the recommended controls are implemented, reevaluate the P(E) using Equation 3−4 and the HP levels in Table 3−2 to assign a residual risk. The HS typically remains the same. According to DODI 6055.01, there is a preferred hierarchy of effectiveness of controls that should be considered: (1) elimination, (2) substitution, (3) engineering controls, (4) warnings, (5) administrative controls, and (6) personal protective equipment (PPE). Examples of RFR controls in priority order include the following:

(1) ***Elimination.*** An RFR hazard may be eliminated by reducing output power to below the MPE.

(2) ***Substitution.*** Substitute the hazard for a lesser one, such as substituting Class 1 Light Detection and Ranging (LIDAR) for radar.

(3) ***Engineering Controls.*** Implement recommended engineering controls (where applicable) to reduce the risk of injury, such as physical barriers; interlocks; elevation or azimuth emitter shutdown zones; emitter power and frequency zone inhibitors; and automatic shutoff during maintenance operations.

(4) ***Warnings.*** Inform users that the RFR source is present or active. Examples include displaying warning lights when the system is transmitting.

(5) ***Administrative Controls.*** Publish instructions in manuals, and periodically train the operators/maintainers regarding procedures. Post the appropriate RFR signage (refer to IEEE C95 standards) on or near antennas to alert personnel to the hazard and SSD, if applicable. Antennas presenting a shock and burn hazard also require an RF caution label indicating the potential hazard of RF shock or burn from direct contact while the system is transmitting.

(6) ***PPE.*** Using PPE for reducing RF exposures is not recommended unless controls 1 through 5 above are not possible. DODI 6055.11 states, “Protective clothing is not authorized for routine use as a means of protecting personnel from EMF overexposure. PPE, such as electrically insulated gloves and shoes for protection against EMF-induced shock and burn or for insulation from the ground plane, is authorized where necessary for compliance with the induced current limits. Personal EMF monitors are not approved for routine use as a means of personal protection from EMF exposure.”

3–7. Example Assessment Scenario

The APHC received a request to assess a new Groundstation low power satellite dish.

Step 1. Obtain the emitter specifications from the MATDEV. The specifications should include emitter name, model, serial number, frequency, average power, antenna gain, and duty factor. The average output power is 500 watts, the frequency of transmission is 6 GHz, the antenna gain is 40 decibels relative to isotropic, and the antenna diameter is 2.0 m. The antenna is mounted 1 m above the ground, and the dish transmits a maximum of 5 minutes each hour. The minimum elevation angle of the main beam is 10 degrees from horizontal.

Step 2. Obtain the normal use scenario information from the MATDEV. The information provided should include the platform, safety features, anticipated exposures to nearby Soldiers, required maintenance and who is expected to perform it, antenna height, duty factor, and, if the emitter is directional, the field of effect (cone/path).

Step 3. Coordinate with the NRD for data collection and completion of an NRPS.

Step 4. Find the appropriate MPE in IEEE C95 standards, taking into account the exposure area and exposure time. Table 3−3 provides the applicable MPE for this example.

Table 3–3. Example of Whole-body Maximum Permissible Exposure (MPE)

Frequency Range (megahertz)	MPE in Terms of RMS Power Density (W/m^2)	Averaging Time (minutes)
3000–30000	100	$19.63/f_G^{1.079}$

Legend:
f_G = frequency in gigahertz
RMS = root mean square
W/m^2 = watts per square meter

Note:
*The values for this table are from IEEE C-95 standards and are specific to this scenario. Refer to IEEE C95 for additional scenarios.

Step 5. Determine the SSD using Equation 3–3, as shown. The SSD for the Groundstation low power satellite dish (a directional antenna) is 63 m.

$$SSD = \sqrt{\frac{P \times G}{4\pi \times MPE}} = \sqrt{\frac{500\ W \times 40\ dBi}{4\ \pi\ \times 100\ W/m^2}} = \sqrt{\frac{500\ W \times 10000}{4\ \pi\ \times 100\ W/m^2}} = 63\ m$$

Where:
P = power fed to the antenna
G = gain of the antenna in ratio form
MPE = maximum permissible exposure

Based on the large SSD, shock and burn is not a potential hazard for the Groundstation during normal use.

Step 6. Estimate the maximum near field power density using Equation 3–1, as shown.

$$S_{nf} = \frac{4P}{A} = \frac{4 \times 500\ W}{\pi\left(\frac{2\ meters}{2}\right)^2} = 636\ W/m^2$$

Where:
S_{nf} = near field power density
P = output power
A = area of the antenna

Step 7. Determine the HS. Because the MPE is 100 W/m^2 (Table 3–3) and the power density is 636 W/m^2 (step 6), the Soldiers' exposure to RF energy from this system is

6.4 times the MPE. Compare the ratio by which the system exceeds the MPE (6.4x) to the criteria in Table 3–1 to obtain the HS. The result for this scenario is HS 3 (Marginal).

Step 8. Calculate the P(E) using the equations in section 3–6D.

Step 8a. To factor in the probability of exposure due to the antenna height, calculate the P(E|H) using Equation 3–5. The antenna height centerline above the ground is the height mounted above the ground (1 m) plus the radius of the antenna (1.5 m). The antenna height is 2.5 m, and the SSD is 3 m. Because the SSD is greater than the antenna height minus 2, the P(E|H) is equal to:

$$P(E|H) = \begin{cases} \left(\frac{SSD}{H-2}\right)^n & \text{if} \quad SSD < H-2 \\ \mathbf{1} & \textbf{if } \boldsymbol{SSD \geq H-2 \; or \; H \leq 2} \end{cases} = 1$$

Where:
n = 2 when antenna gain is <10
n = 3 when antenna gain is ≥10
H = height of the antenna centerline above ground in meters (m)
SSD = safe standoff distance

Step 8b. To factor in the duty factor's probability of exposure, calculate the P(E|D) using Equation 3–6. The total time that the Groundstation is transmitting (T) is 5 minutes each hour, or 40 minutes in an 8-hour period. Since the total time is less than 480 minutes, the P(E|D) is equal to:

$$P(E|D) = \begin{cases} \left(\frac{\boldsymbol{T}}{\mathbf{480}}\right)^{\mathbf{2}} & \textbf{if} \quad \boldsymbol{T < 480} \\ 1 & \text{if } T \; is \; unknown \; or \; T \geq 480 \end{cases} = \left(\frac{40}{480}\right)^2 = 0.00694$$

Where:
T = total time in minutes that the system is transmitting during an 8-hour period

Step 8c. To factor in the probability of exposure based on scanning, calculate the P(E|S) using Equation 3–7. The Groundstation dish does not scan an area, so the sector scan angle (ϕ) is equal to zero, and the P(E|S) is equal to:

$$P(E|S) = \begin{cases} 1.5\left(\frac{\theta}{\varphi}\right) & \text{if } \theta \leq 270 \; and \; \varphi \neq 0 \\ \mathbf{1} & \textbf{if } \boldsymbol{\varphi = 0 \; or \; \theta > 270} \end{cases} = 1$$

Where:
θ = half power beam width angle in degrees
φ = sector scan angle in degrees

Step 8d. To factor in the probability of exposure based on the elevation angle of the main beam, calculate the P(E|A) using Equation 3–8. The minimum elevation angle is 10 degrees. Because the minimum elevation angle is between 0 and 90 degrees, the P(E|A) is equal to:

$$P(E|A) = \begin{cases} \mathbf{10^{-(\Psi/20)}} & \mathbf{if\ 0 \le \Psi \le 90} \\ 1 & \text{if } \Psi < 0 \end{cases} \quad = 10^{-(10/20)} = 0.316228$$

Where:
ψ = minimum elevation angle, in degrees, of the antenna main beam from horizontal

Step 8e. There are no other probabilities to consider for the Groundstation's P(E). Using the probabilities calculated in steps 8a through 8d, calculate the P(E) using Equation 3–4, as shown.

$$P(E) = P(E|H) \times P(E|D) \times P(E|S) \times P(E|A) = 1 \times 0.00694 \times 1 \times 0.316228 = 0.00219$$

Where:
P(E|H) = probability of exposure given antenna height
P(E|D) = probability of exposure given duty factor
P(E|S) = probability of exposure given scanning directed energy emitter
P(E|A) = probability of exposure given minimum elevation angle of the main beam

Step 9. Compare the P(E) to Table 3–2 to determine the HP. The P(E) of 0.00219 is associated with HP C (Occasional).

Step 10. Determine the RAC and risk level. Using the HS and HP determined in Steps 7 and 9 above, assign the Groundstation a risk level of Medium (RAC: HS 3, HP C).

Step 11. Identify mitigation recommendations and the residual risk. Some possible controls that may be applied to the Groundstation system are interlocked physical barrier, SSD (step 5), appropriate signage and labels, and hazard control training for operators. Assign a residual risk level of Medium (RAC: HS 3, HP D) for compliance with all of the following recommendations:

- Require personnel to observe a 63 m SSD from the Groundstation antenna.
- Post RFR caution signs on or near the antenna alerting personnel to maintain an SSD of 63 m from the antenna when it is transmitting.
- Include these instructions in all training materials, operator/technical manuals, and materiel fielding plans.

3–8. Limitations and Potential Future Work

(1) DODI 6055.11 dictates which IEEE C95.1 standard revision to use. The currently approved standard is C95.1-2005, but the pending update to DODI 6055.11 (expected in early 2021) will direct the use of C95.1−2345 2014, which includes MPEs

for the full 0- to 300-GHz region in a single standard. The C95.1−2345 2014 standard also updates the terminology from MPEs to ERLs and adds exposure “Zones,” which are tiers of exposure limits.

(2) A quantitative risk assessment methodology needs to be developed for potential shock and burn hazards and for RFR exceeding 10 times the MPE.

(3) Newly developed, high-power microwave systems require specialized evaluation through a working group and would not be addressed in an HHA based on the guidance provided in this chapter.

(4) The exposure limits for high-peak power-pulsed fields are prescribed by North Atlantic Treaty Organization Standardization Agreement 2345, not the IEEE C95 standards.

(5) Individuals fitted with metallic implants or certain medical devices (e.g., pacemakers, defibrillators, insulin pumps) should be aware that the MPEs are not necessarily protective against interference. Such persons should consult with their physician if they operate or are often near RF devices.

APPENDIX 3A

CHAPTER 3 REFERENCES

Department of Defense (DOD). 2010. Military Standard 464C, *Department of Defense Interface Standard, Electromagnetic Environmental Effects Requirements for Systems*. https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=35794

DOD. 2009. Instruction 6055.11, *Protecting Personnel from Electromagnetic Fields.* Incorporating Change 2, August 31, 2018. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/605511p.pdf?ver=2019-04-04-095225-447

Federal Communications Commission (FCC). 2020. *Equipment Authorization Approval Guide.* https://www.fcc.gov/oet/ea/fccid

FCC. 1997. Office of Engineering & Technology (OET) Bulletin 65, *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields.* Edition 97-01. https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet65/oet65.pdf

Institute of Electrical and Electronics Engineers (IEEE). 2018. Standard C95.2−2018, *Radio-Frequency Energy and Current-Flow Symbols, 3 kHz to 300 GHz.* https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

IEEE. 2014. Standard C95.1−2345−2014, *Military Workplaces--Force Health Protection Regarding Personnel Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.* https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

IEEE. 2014. Standard C95.7−2014, *Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz.* https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

IEEE. 2006. Standard C95.1−2005, *Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*. https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

IEEE. 2005. Standard C95.7−2005, *Recommended Practice for Radio Frequency Safety Programs*, *3 kHz to 300 GHz.* https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

IEEE. 2002. Standard C95.3−2002, *Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz-300 GHz.* https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

IEEE. 2002. Standard C95.6−2002, *Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz.* https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

IEEE. 1999. Standard C95.2−1999, *Radio-Frequency Energy and Current-Flow Symbols, 3 kHz to 300 GHz.* https://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=82

APPENDIX 3B

CHAPTER 3 GLOSSARY

AM
amplitude modulation

°C
degrees Celsius

DOD
Department of Defense

DODI
Department of Defense Instruction

EMF
electromagnetic field

ERL
exposure reference level

GHz
gigahertz

HHA
health hazard assessment

HP
hazard probability

HS
hazard severity

Hz
hertz

IEEE
Institute of Electrical and Electronics Engineers

kHz
kilohertz

LIDAR
light detection and ranging

MATDEV
materiel developer

MPE
maximum permissible exposure

NRD
Nonionizing Radiation Division (U.S. Army Public Health Center)

NRPS
Nonionizing Radiation Protection Study

P(E)
probability of exposure

P(E|A)
probability of exposure given minimum elevation angle of the main beam

P(E|D)
probability of exposure given duty factor

P(E|H)
probability of exposure given antenna height

P(E|S)
probability of exposure given scanning directed energy emitter

PPE
personal protective equipment

RAC
risk assessment code

RF
radio frequency

RFR
radio frequency radiation

SSD
safe standoff distance

W/m^2
watts per square meter

CHAPTER 4. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO LASER AND OPTICAL RADIATION

Source: DVIDS

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4–1. Purpose

This chapter provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to light amplification by stimulated emission of radiation (laser) and optical radiation during normal use and training operations of materiel systems. Laser and optical radiation are types of nonionizing radiation.

4–2. Definitions of Key Terms

Accessible emission limit (AEL): The maximum accessible emission level permitted within a particular class. The AEL is usually represented in units of joules (J) or watts (W) and is equal to:

$$AEL = MPE \times A_{Limiting\ Aperture} \qquad \text{(Equation 4–1)}$$

Where:
AEL = accessible emission limit
MPE = maximum permissible exposure
$A_{Limiting\ Aperture}$ = area of the limiting aperture

Continuous wave output: A laser, such as a laser pointer, that constantly emits laser radiation.

Designated Service Laser Hazard Agency: The military service agency designated by the appropriate authority to perform independent laser hazard evaluations.

Diffuse reflections: Reflections that result when surface irregularities scatter light in all directions (Figure 4–1). A diffuse surface is defined as having a surface roughness greater than the wavelength of the incident light. A very rough surface is not specular to visible light but might be specular to infrared (IR) radiation of 10.6 micrometers (μm) from a carbon dioxide laser.

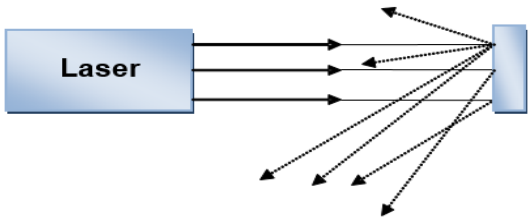

Figure 4–1. Diffuse Reflection

Divergence: The full angle spread of laser beam diameter as the beam propagates. In laser safety, the divergence is measured at the 1/*e* point (1 divided by the unitless mathematical constant *e*, which is about 37% of the peak power).

High-intensity optical sources (HIOS): Non-laser sources of high-intensity ultraviolet (UV), visible, and IR radiation that may pose a hazard to the eyes and skin. Examples of HIOS include welding and cutting torches, non-lethal weapons, high-intensity lamps, and explosive devices used in training.

Laser designator: A device that illuminates a spot on a target with coded IR energy so that a seeker in a guided projectile can hone in on that spot (e.g., AN/PED-1 Lightweight Laser Designator Rangefinder).

Laser illuminator: A device with a large divergence for illuminating a target or area, similar to a flashlight. Most laser illuminators operate in the IR spectrum between 800 and 950 nanometers (nm) where night vision goggles are most sensitive and would be required for viewing the laser spot. Short-wave infrared (SWIR) pointers work with SWIR imagers for target identification and handoff.

Laser pointer: A device that illuminates a spot on a target. Laser pointers have a small divergence and are typically used for aiming or for pointing out an area or object of interest. Some laser pointers operate in the IR spectrum between 800 and 950 nm, where night vision goggles are most sensitive and are required for viewing the laser spot. SWIR pointers work with SWIR imagers for target identification and handoff. Visible laser pointers are also available; these most commonly produce light in the red or green spectrum although commercial-off-the-shelf wavelength selection is broad.

Laser rangefinder: A device that measures distance to an object, typically by measuring the amount of time in which a pulsed laser beam traverses some distance, known as time-of-flight (e.g., AN/PED-3 Target Locator Module).

Maximum permissible exposure (MPE): The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. MPE limits are based on biological injury data and include a safety factor, usually represented in units of joules per square centimeter (J/cm^2) or watts per square centimeter (W/cm^2).

Military-specific laser: A laser or laser system developed for or sold to the Department of Defense (DOD) for use in combat, combat training, or for a purpose that is classified in the interest of national security.

Nominal ocular hazard distance (NOHD): The distance along the axis of the unobstructed beam from a laser to the human eye, beyond which the irradiance or radiant exposure during operation is not expected to exceed the appropriate ocular (eye) MPE; that is, the safe ocular hazard distance from the laser.

Nominal ocular hazard distance with magnifying optics (NOHD–M): The NOHD when a laser beam is viewed with optical aids. The standard used for calculating NOHD–M is viewing with common 7x50 binoculars.

Nominal skin hazard distance (NSHD): The distance along the axis of the unobstructed beam from a laser to the skin, beyond which the irradiance or radiant exposure during operation is not expected to exceed the appropriate skin MPE; that is, the safe skin hazard distance from the laser.

Optical density (OD): The logarithmic amount of attenuation provided by laser eye protection (LEP). Appropriate LEP is required for intrabeam viewing of the laser from within the NOHD or NOHD–M.

Optical radiation: Nonionizing, electromagnetic radiation at wavelengths in the ranges representing UV radiation, visible light, and IR radiation (i.e., wavelengths that affect the eye). Potential sources of optical radiation include lasers and HIOS. Figure 4–2 shows the approximate range of optical radiation in the electromagnetic spectrum.

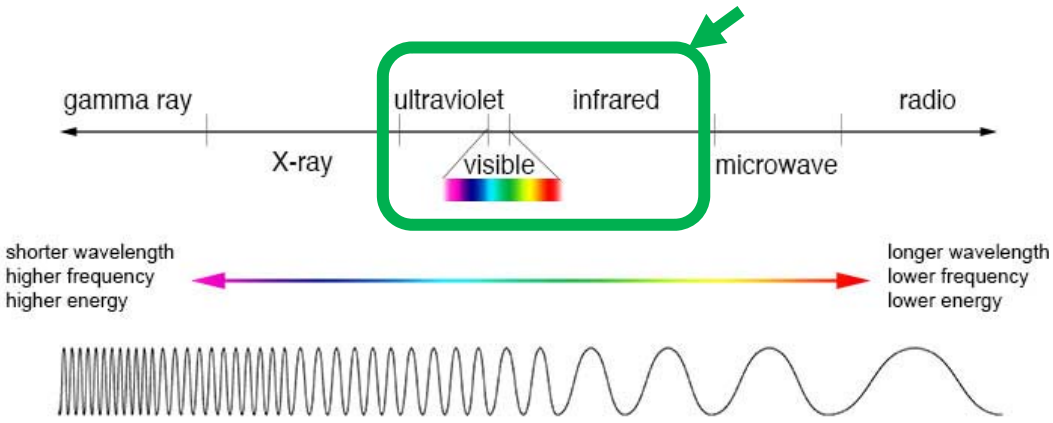

Figure 4–2. Approximate Range of Optical Radiation in the Electromagnetic Spectrum
(Adapted from the National Aeronautics and Space Administration)

Output power: The rate at which energy is emitted from a laser exit aperture, usually represented in units of W.

Platform: A system designed with an integrated laser. Common platforms are weapon-mounted, vehicle-mounted, gimbal-mounted, or handheld.

Pulsed output: Output of a pulsed laser turns on and off repetitively, using a variety of different methods. Some pulsed lasers are also coded, such as the Multiple Integrated Laser Engagement System (MILES).

Shade number: A number that indicates the intensity of light radiation allowed to pass through the filter lens of welding eye protection (e.g., face shields, welding helmets, safety goggles). Higher shade numbers indicate darker filters and less light radiation passing through to the eyes. The 29 Code of Federal Regulations (CFR) 1910.133 provides minimum shade number requirements for eye protection for various welding processes. The American National Standards Institute (ANSI) Z49.1 provides higher shade numbers to allow for comfortable viewing.

Specular reflections: Mirror-like reflections that can reflect nearly 100% of the incident light (Figure 4–3). Flat surfaces will not change a fixed beam's diameter or divergence, only its direction. Convex surfaces will cause a beam to spread; concave surfaces will cause it to focus. A specular surface is defined as having a surface roughness less than the wavelength of the incident light.

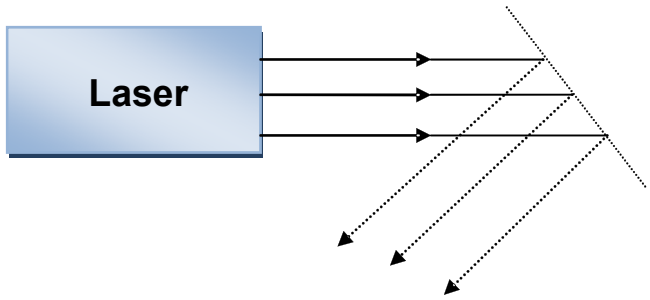

Figure 4–3. Specular Reflection

Training device: A system such as the MILES, which uses pulsed lasers and blank cartridges to simulate the live fire of a weapon. It functions similarly to laser tag.

Wavelength: The distance between adjacent crests of a wave. General wavelength ranges for optical radiation are shown below. There are no precise limits for the visible spectral range, typically defined as 400–700 nm (see note in Table 4–1). It varies depending on the amount of radiant power reaching the retina and the responsivity of the observer.

- ***UV (180–400 nm):*** UV radiation is absorbed in the anterior segments of the eye, primarily the cornea, with the longer UV (around 300 nm) penetrating into the lens. Minimal UV corneal lesions heal within a few days; more severe lesions may scar. UV radiation exposure over an 8 hour day is additive.

- ***Visible (400–700 nm):*** Visible radiation is primarily absorbed within the retina. An ideal eye can focus a collimated visible laser beam by as much as 100,000 times. The aversion response time, which includes the blink reflex, eye movement, pupillary constriction, and movement of the head to avoid an exposure, is approximately 0.25 seconds.

- ***Near IR (700–1400 nm):*** Near IR radiation is primarily absorbed within the retina. This portion of the spectrum is very dangerous because the eye focuses the radiation and the light is not visible; consequently, there is no resulting aversion response.

- ***Mid/far IR (1400 nm–1 millimeter (mm)):*** Mid/far IR radiation primarily affects the cornea. Radiation with wavelengths longer than 1 mm falls into the radiofrequency (RF) portion of the electromagnetic spectrum (see Chapter X(RF) for RF guidelines).

4–3. Applicable References/Health Protection Criteria

A. References. Appendix 4A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply.

B. Laser Standards. DOD Instruction 6055.15 and Army Regulation (AR) 385–10 require Army laser systems to comply to the greatest extent possible with the provisions of the Radiation Safety Performance Standards issued by the U.S. Food and Drug Administration (FDA) 21 Code of Federal Regulations (CFR) Subchapter J. FDA Laser Notice No. 56 also allows for the use of International Electrotechnical Commission (IEC) 60825-1 standards.

C. Military-Exempt Lasers. Some laser products are military-exempt, meaning they are specifically exempted from one or more FDA requirements due to military mission need. To be declared DOD-exempt, a military laser product must be used in combat/combat training or classified in the interest of national security. The manufacturer must obtain an exemption letter from the authorized MATDEV. The laser system must include alternate controls to eliminate or control hazards in accordance with the performance requirements in MIL–STD–1425A. Military-exempt lasers are classified in accordance with ANSI Z136.1. For more information about military-exempt lasers, refer to APHC Technical Information Paper 24-108-0420.

4–4. Health Effects of Laser and Optical Radiation Exposure

Lasers and HIOS can present eye and skin hazards. Lasers emit a collimated, monochromatic beam of optical radiation. Optical radiation (UV, visible, and IR) is termed nonionizing radiation to distinguish it from ionizing radiation (e.g., x rays and gamma rays), which is known to cause biological effects that differ from those associated with nonionizing radiation (although x-ray lasers are under development, they are limited to a few specialized laboratories). When a system produces hazardous

laser radiation, the health hazard is limited to specularly reflected beam exposure, diffusely reflected beam exposure, or direct intrabeam exposure within the NOHD, NOHD–M, or NSHD. Diffuse reflection hazards, if present, typically occur only a few meters from the target. A reflected beam is not hazardous if the user is outside the NOHD. Note that not all laser systems are hazardous. The following is a summary of laser and HIOS biological effects to the eyes and skin.

A. Eye Hazards. Acute exposure may result in corneal and/or retinal burns (depending upon wavelength), corneal or lenticular opacities (cataracts), or retinal injury. The cornea is vulnerable to mid/far IR and shorter UV wavelength radiation. The lens, similar to the cornea, is vulnerable to longer UV wavelength radiation and, to a lesser extent, near IR wavelength radiation. The retina is vulnerable to visible and near IR wavelength radiation. Visible laser radiation at or below the MPE level may appear extremely bright to the observer. Such an exposure may temporarily impair an individual's immediate functional capability if he or she is performing a vision-critical task; however, the exposure will not result in retinal injury. Near IR radiation may cause eye injury even if the beam is not detected by the eye. Exposure to UV radiation, from a laser or otherwise, is additive throughout an 8-hour day and has the potential to result in injuries. Some injuries from UV radiation are acute, such as photokeratitis (welder's flash) or retinopathy, but symptoms may appear hours after exposure. Many acute injuries are reversible, depending on the severity of the exposure. Some effects from UV radiation, such as cataracts and pterygium ("eye web"), are chronic.

B. Skin Hazards. Because of its large surface, skin is readily available for accidental and/or repeated exposures to optical radiation. The biological significance of irradiation of the skin by lasers operating in the visible and IR regions is considerably less than that of exposure to the eye and requires more power. Skin damage is often repairable or reversible. Effects may vary from a mild reddening of the skin (erythema) to blisters and charring. Depigmentation, ulceration, and scarring of the skin, as well as damage to underlying organs, may result from exposure to extremely high-powered laser systems. If within the NSHD, exposed skin should be covered with a closely-woven fabric to protect it from lower-power UV exposure. Avoiding exposure within the NSHD is recommended for all wavelengths. Exposure to UV radiation, from a laser or otherwise, is additive throughout an 8-hour day and has the potential to result in injuries that are similar to sunburn.

4–5. Pre-assessment Procedures

Obtain all available laser system specification information from the MATDEV, such as the following:

- System name, model, and serial number.
- Wavelength.
- Average and/or maximum power or energy.
- Divergence.
- Initial beam diameter.

- Pulse information (if applicable):
  - Pulse width.
  - Pulse repetition frequency.
  - Energy per pulse.

Based on user information, identify the concept of normal use and maintenance of the laser system, especially in a theater and/or training environment. Include, for example, how the system will be used, where Soldiers (if any) will be located nearby, control of the system (on/off), safety features, how the system will be mounted (e.g., on small arms or a vehicle), and how the system will be routinely maintained at the operator-, crew-, and unit-levels. Most laser systems are designed and used in a manner that does not expose operators to the hazard during normal use. Laser maintenance is typically performed by manufacturers, not Soldiers.

The APHC Nonionizing Radiation Division (NRD) performs a Nonionizing Radiation Protection Study (NRPS) on every Army laser system (including military-exempt lasers), as well as many commercial-off-the-shelf systems. The NRPS, which is routinely requested by the program offices that are developing or purchasing the lasers, is often requested by test centers as well. Based on direct measurements, the NRPS provides the laser hazard classification, hazard distances (NOHD, NOHD–M, NSHD), OD requirements for LEP, and regulatory compliance recommendations. Laser safety input for an NRPS differs from an HHA because the study considers mishaps and accidents, while the HHA considers normal use only. Normal use of most laser systems precludes operator exposure to laser beams. Requests for a laser study may be submitted here: https://usaphcapps.amedd.army.mil/MSRV_mvc

The completion of the NRPS may not necessarily preclude completion of the HHA since the NRD has a different focus; however, the NRD's measurements and results are needed for the HHA. The NRD and the HHA Program should collaborate to ensure both required documents are completed for all Army materiel undergoing the acquisition process.

4–6. Risk Assessment Process

A. High-intensity Optical Sources. HIOS hazards are evaluated and assigned risk assessment codes (RACs) on a case-by-case basis. Specific or measured HIOS optical radiation emissions are compared to limits published by the American Conference of Governmental Industrial Hygienists (ACGIH®). Army Regulation 40–5 and Department of the Army Pamphlet (DA Pam) 40–506 require that welding eye protection be selected according to ANSI Z49.1. In addition, some welding equipment can emit radiofrequency radiation (RFR) that may interfere with the functioning of implanted medical devices. Refer to Chapter 3 for information about RFR.

The remainder of section 4−6 describes guidelines for assessing lasers, not HIOS.

B. Laser Classification. The NRD documents a laser system's classification by publishing an NRPS. The NRP studies are performed and documented in accordance with (IAW) the FDA (21 CFR Subchapter J) or IEC 60825-1 for non-exempt lasers, and ANSI Z136.1 for military-exempt lasers. Lasers are classified as either Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, or Class 4.

The laser classification is based on a comparison of the emitting power or energy to the AEL. The AEL found in the laser safety standards (FDA, IEC 60825-1, or ANSI Z136.1) is based on known hazardous effects from laser exposures. Exposures below the AEL and within the exposure duration are not expected to result in adverse health effects. AEL calculations are based on several system parameters, including wavelength, output power, size, divergence, exposure duration, pulsed timing, etc. More information on the laser classification process can be found in Technical Bulletin, Medical (TB MED) 524. The NRPS provides laser classification, mitigating steps, and general safety measures and limitations to be adhered to during Soldier operation of the laser system. Safe operation of enclosed lasers is also discussed in NRD studies.

The laser classes include the following:

- ***Class 1:*** Class 1 lasers emit any wavelength radiation at levels that are not hazardous under any viewing conditions. They are exempt from most control measures; however, as a matter of good safety practice, intrabeam viewing should be avoided. Technically, Class 1 lasers cannot emit *accessible* radiation in excess of the AEL. A laser with an internal beam that is above the Class 1 AEL may still be considered Class 1 if that beam is not accessible during regular use; therefore, maintenance personnel may require the use of controls for what is otherwise considered a Class 1 device.

- ***Class 1M:*** Class 1M lasers emit radiation at levels that are not hazardous under normal, unaided, viewing conditions but could be hazardous when intrabeam viewing through magnifying optics occurs. Class 1M lasers emit radiation in the IR, visible, or UV portions of the electromagnetic spectrum. Classification considers magnified viewing as viewing through 7x50 binoculars; specific classifications can be assigned when viewing with other optical systems is expected. The laser's radiation output cannot exceed the Class 3B AELs for optically aided viewing.

- ***Class 2:*** Class 2 lasers emit radiation in the visible portion of the electromagnetic spectrum (400–700 nm) and are potentially hazardous to the eye only when prolonged intrabeam viewing occurs. The aversion response, including the blink reflex, would normally prevent overexposure by limiting the exposure to 0.25 seconds or less.

- ***Class 2M:*** Class 2M lasers emit visible laser wavelengths and are not hazardous for short exposure durations (0.25 seconds) of unaided intrabeam viewing. However, these lasers could be hazardous for intrabeam viewing through magnifying optics. Classification considers magnified viewing as viewing through 7x50 binoculars; specific classifications can be assigned when viewing with other optical systems is

expected. The laser output cannot exceed the Class 3B AELs for optically aided viewing.

- ***Class 3R:*** Class 3R lasers exceed the Class 1 or Class 2 AEL by not more than five times. These lasers emit radiation in the IR, visible, or UV portions of the electromagnetic spectrum and are hazardous for both direct intrabeam and specular reflection viewing. Diffuse reflections are not normally hazardous.

- ***Class 3B:*** Class 3B lasers exceed the Class 1 and Class 2 AEL by more than five times but emit less radiation than Class 4 lasers. Class 3B high-power lasers emit radiation in the IR, visible, or UV portions of the electromagnetic spectrum. Some Class 3B lasers are a hazard to the skin and may also be diffuse reflection hazards.

- ***Class 4:*** Class 4 high-power lasers emit radiation in the IR, visible, or UV portions of the electromagnetic spectrum and are hazardous for direct intrabeam exposure and specular exposure. Some can produce a hazard from diffuse reflections. Class 4 lasers may also produce fire, material damage, laser-generated air contaminants, and hazardous plasma radiation. Many Class 4 lasers are also a hazard to the skin.

C. Hazard Distance Calculations. The NOHD, NOHD–M, and NSHD are calculated using the system parameters and the MPE or AEL. The NOHD, NOHD–M, and NSHD are the distances from the output aperture at which the beam irradiance or radiant exposure equals the appropriate AEL. In other words, exposures at distances beyond the NOHD, NOHD–M, and NSHD are not expected to result in adverse health effects. Permanent eye injury may result from an exposure within the NOHD even when the exposure is short. NRD calculates the NOHD, NOHD–M, and NSHD by determining where the power is equal to the AEL, or where the beam irradiance is equal to the MPE.

D. Risk Assessment. Laser hazards are assessed IAW Table 4–1 and Table 4–2. The assessment is based on the laser's classification, wavelength, AEL, and pointing accuracy. The RAC is a function of the wavelength, AEL, NOHD–M, and platform. The risk is based on *direct* hazards, including reflections. Secondary effects from laser exposure are not within the scope of the HHA (e.g., aircraft crashes caused by temporary blindness).

Actual laser systems that present a health hazard according to the HHA criteria are rare because of the highly directional and localized nature of the laser beam and the fact that mishaps are excluded from consideration. In other words, the nature of the laser beam makes it very easy to design a system such that the operators and maintainers are not exposed to a potential hazard during normal use conditions. In an unusual case, downrange personnel may be considered in an HHA if they are also U.S. Army Soldiers and are expected to be intentionally within the NOHD (e.g., the MILES). In a situation such as this, the normal use conditions may result in personnel occupying the laser's danger zone.

E. Hazard Severity Determination. The HS is a function of the laser system's output power or energy with respect to its AEL. The AEL is a function of the laser's wavelength and temporal characteristics (e.g., pulse repetition frequency, pulse width). Table 4–1 contains the guidelines for determining a laser's HS category.

Table 4–1. Hazard Severity Based on Laser Classification and Accessible Emission Limit

Description	Category	Visible Wavelengths* (400–700 nm)	Other Wavelengths
Catastrophic	1	Large beam capable of bilateral eye exposure at range AND Class 3B or 4 AND ≥25x Class 2 AEL	Large beam capable of bilateral eye exposure at range AND Class 3B or 4 AND ≥60x Class 1 AEL
Critical	2	Class 3B or 4 AND ≥25x Class 2 AEL	Class 3B or 4 AND ≥60x Class 1 AEL
Marginal	3	Class 3B AND <25x Class 2 AEL	Class 3B AND <60x Class 1 AEL
Negligible	4	Class 3R	Negligible
		Class 1M or 2M with NOHD–M ≥25m	
No hazard	N/A	Class 1 or Class 2	No hazard
		Class 1M or 2M with NOHD–M <25m	

Legend:
AEL = Accessible Emission Limit; m = meter; N/A = not applicable; nm = nanometer; NOHD–M = Nominal Ocular Hazard Distance with Magnifying Optics
Note:
*The general range of visible spectrum is 400–700 nm; however, the International Commission on Illumination defines "visible radiation" as "any optical radiation capable of causing a visual sensation directly," and also notes that "There are no precise limits for the spectral range of vision since they depend upon the amount of radiant power reaching the retina and the responsivity of the observer." The lower limit is generally between 360 and 400 nm, and the upper limit is generally between 760 and 830 nm.

F. Hazard Probability Determination. The laser system's platform and controls are the primary (but not the only) considerations when the HP is evaluated. As the pointing accuracy of the platform decreases, the probability of a hazardous exposure occurring increases. Table 4–2 summarizes the broad categories of platforms and their associated HP levels. For most HHAs, there is no risk under normal use because there is no potential for exposure. Most normal-use scenarios limit the exposure durations; hence, the HP level of A (Frequent) is not typically assigned. Constant exposure to low

power sources, such as infrared eye scanners, is not considered since the energy is not sufficient to produce a hazard.

Table 4–2. Hazard Probability Levels Based on Laser Platform (Pointing Accuracy)

Description	Level	Laser Platform
Frequent	A	System precludes operator control of hazardous beams or does not meet the MIL–STD–1425A requirements.
Probable	B	Any platform housing a laser that may emit irregular beam(s) emissions to include spontaneous firing, unnecessary secondary or focused beams, unwanted hotspots, collateral radiation or secondary wavelengths, unintentional self-oscillation, mode-locking, or double pulsing.
Occasional	C	Handheld laser without sighting optics (beam itself is aiming device).
Remote	D	Handheld with sighting optics, or weapon-mounted and boresighted; or systems (manned or unmanned) without stabilizing optics.
Improbable	E	Stable platform or active stabilization (manned or unmanned), laser with separate sighting laser system aligned on target before lasing, laser boresighted to camera. Laser on tank, on viscous damped tripod, on systems (manned or unmanned) with stabilizing optics.
Eliminated	F	Laser is Class 1, 1M, 2, or 2M, with NOHD–M of < 25 meters (any platform).

The HP levels in Table 4–2 assume that the laser meets either the FDA performance requirements for non-exempt lasers or the engineering controls of MIL–STD–1425A for exempt lasers. Lasers that do not meet federal or DOD requirements for safety should assume a higher probability of risk.

The independent medical assessor should consider the consequences of underdeveloped or inadequate controls (e.g., systems lacking labels and/or training plans, rapid fielding items lacking engineering controls) when assigning the HP for an HHA. The NRPS will include some risk mitigation information such as the labels that were present when the system was evaluated, and recommendations on permanent proper labels (if required). If adequate controls are not included in the system, consider increasing the HP and recommending risk mitigation strategies.

G. Risk Mitigation. After the implementation of risk mitigations and recommendations, a residual risk may remain. According to Department of Defense Instruction (DODI) 6055.01, a preferred hierarchy of effectiveness of controls should be considered: (1) elimination, (2) substitution, (3) engineering controls, (4) warnings, (5) administrative controls, and (6) personal protective equipment (PPE). Required controls

for all lasers are stated in 21 CFR 1040.10. MIL–STD–1425A provides additional required control measures for military-exempt lasers. Examples of laser and optical radiation controls, in priority order, include the following:

(1) ***Elimination.*** Enclosing the laser such that the only accessible radiation is below the AEL may allow a laser system to become Class 1. The enclosure should be permanent or very difficult to remove.

(2) ***Substitution.*** Substituting a less hazardous developed laser reduces the risk of injury. The laser that produces the lowest output power required to accomplish the mission should be used. Substituting reflective surfaces for non-reflective surfaces also reduces the risk of injury.

(3) ***Engineering Controls.*** Required engineering controls include the elimination of secondary laser emissions; laser emission “watchdog” timers to prevent inadvertent long-term lasing; beam attenuators; scan failure shutter which stops the lasing if a scanning laser stops scanning; required passcode for activating high-power modes; and remote interlock connector use for maintenance procedures.

(4) ***Warnings.*** Federal regulations require warning labels for lasers above Class 1. Laser safety standards such as IEC 60825-1 and ANSI Z136.1 include descriptions of the formatting for laser warning labels. When applicable, systems should also include warnings such as visual light indicators to show when the laser is turned on.

(5) ***Administrative Controls*****.** Examples of administrative controls that may reduce risk include adjusting the use scenario to outside the NOHD, using standard operating procedures, and training users.

(6) ***PPE.*** PPE for optical radiation includes skin and eye protection (e.g., LEP, welding face shields, welding helmets, safety goggles, tightly woven clothing). Minimum shade numbers for various welding processes are required by 29 CFR 1910.133. LEP is classified by the OD, a unitless logarithmic function, which is calculated to reduce any exposures to the Class 1 AEL. Such eyewear is assigned an OD at a specified wavelength and does not protect against all wavelengths. Higher ODs and higher shade numbers provide greater protection. LEP is not required for the laser operator unless reflections are possible, or intrabeam exposures are expected. The ANSI Z49.1 standard provides requirements for appropriate protective clothing.

LEP may not be practical when laser systems are used in a combat or combat training environment. The use of LEP is required during training when personnel are expected to be exposed to the laser beam within the NOHD. LEP is not always readily available to Soldiers, and individual spectacles or goggles, which are specified for specific wavelengths, will not provide protection across all wavelengths.

4–7. Example Assessment Scenario

The APHC received a request to assess a new military-exempt laser system.

Step 1. Obtain the laser specifications from the MATDEV. The information provided includes the system name, model, serial number, wavelength, average power or energy, divergence, initial beam diameters, and pulse information (e.g., pulse width, pulse repetition frequency, energy per pulse). The laser has a wavelength of 532 nm and is continuous-wave with an average power output of 150 milliwatts (mW). The entire laser beam passes through an aperture with a diameter of 7mm, so assume the exposure through the pupil and onto the retina will be the entire 150 mW.

Step 2. Obtain the normal use scenario information from the MATDEV. The information provided should include the platform, safety features, anticipated exposures to nearby Soldiers, required maintenance, and who is responsible for performing the maintenance. The laser is vehicle-mounted with a separate (Class 1) sighting laser that is used before firing. The laser is attached to the exterior of a vehicle that has a place for a gunner. The laser is contained inside a gimbal, thus allowing it to fire at any point along a 360-degree arc. This configuration potentially places the gunner inside the hazard distance associated with the laser under normal use. The operator's manual contains the laser warnings, and the system has a permanent warning label.

Step 3. Coordinate with the NRD for data collection and completion of an NRPS.

Step 4. Use ANSI Z136.1 to determine the military-exempt laser's AEL based on the system parameters (e.g., wavelength, size, pulse information) and expected exposure duration. The AELs for this laser are shown in Table 4–3.

Table 4–3. Example Accessible Emission Limits

Class	Exposure Duration (s)	MPE (W/cm^2)	Limiting Aperture (mm)	AEL (mW)
Class 1	0.25	1.0×10^{-3}	7	0.39
Class 2	10	2.6×10^{-3}	7	1.0
Class 3R	10	1.3×10^{-2}	7	5.0
Class 3B	10	N/A	7	500

Legend:
AEL = Accessible Emission Limit; mm = millimeter; mW – milliwatt; N/A = not applicable; s = seconds; W/cm^2 = watts per square centimeter

Step 5. Compare the emitted, accessible power of the laser (150 mW) to the AELs in Table 4–3 to determine the laser classification. Therefore, the laser's power exceeds the Class 1 AEL, Class 2 AEL, and the Class 3R AEL (5 times the Class 2 limit) but does not exceed the Class 3B limit. The laser is classified as a Class 3B laser.

Step 6. Calculate the hazard distance using the system parameters and the AEL. Determine the NOHD, NOHD-M, and NSHD by calculating the distance at which the

accessible power equals the AEL. The NOHD and NOHD–M are 40 m and 265 m, respectively. The gunner is expected to operate the system within these hazard distances during normal use; consequently, there is a risk of injury.

Step 7. To assign the HS, use Table 4–1 to compare the class (Class 3B) and the degree to which the output energy exceeds the AELs. Use the visible wavelengths column because the wavelength of 532 nm falls within the visible range. Based on the class, the laser is at least an HS 3 (Marginal) or above. The 7-mm beam diameter is too small to be capable of bilateral eye exposure. The output power is 30 times the AEL (150 mW output/5 mW AEL = 30). Assign an HP 2 (Critical) based on Table 4–3 because the output energy is greater than 25 times the Class 2 AEL, and bilateral eye exposure is not a concern.

Step 8. To assign the HP, compare the known controls and platform information to Table 4–2. The system has a sighting laser system and some controls (e.g., training manuals, labels). However, because the military-exempt laser does not meet the MIL–STD–1425A requirements, the HP levels in Table 4–2 do not apply. MIL–STD–1425A requires that operators are not exposed above the Class 1 limit. Due to the potential for operator exposure to a 3B laser, the HP is C (Occasional).

Step 9. Using the HS and HP determined in Steps 7 and 8 above, the laser is assigned a risk level of Medium (RAC: HS 2, HP C).

Step 10**.** The potential for injury exists due to the 360-degree arc that may place the gunner within the hazard distance. As a risk mitigation, recommend the rotation be limited to a 180-degree arc to eliminate the potential for gunner exposure. Since these controls would eliminate the exposure, their implementation would eliminate the risk (RAC: HS 2, HP F).

4–8. Limitations and Potential Future Work

The HIOS risk assessment process will be established as additional health protection criteria are established for HIOS. Currently, HIOS are assessed on a case-by-case basis only.

APPENDIX 4A

CHAPTER 4 REFERENCES

American Conference of Governmental Industrial Hygienists (ACGIH). 2020. *Threshold Limit Values and Biological Exposure Indices.* Cincinnati, Ohio.

American National Standards Institute (ANSI). 2014. ANSI Z136.1-2014, *Safe Use of Lasers,* Laser Institute of America: Orlando, Florida.

ANSI. 2012. Z49.1-2012, *Safety in Welding, Cutting, and Allied Processes.* American Welding Society: Miami, Florida.

Department of the Army (DA). 2015. Pamphlet 385–24, *The Army Radiation Safety Program.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/p385_24.pdf

DA. 2009. Pamphlet 40–506, *The Army Vision Conservation and Readiness Program.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/p40_506.pdf

DA. 2006. Technical Bulletin Medical 524, *Occupational and Environmental Health: Control of Hazards to Health from Laser Radiation.* https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/tbmed524.pdf

Department of Defense (DOD). 2017. Military Handbook 828C, *Range Laser Safety.* https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=110720

DOD. 2007. Department of Defense Instruction 6055.15, *DOD Laser Protection Program.* https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/605515p.pdf

DOD. 1991. Military Standard 1425A, *Department of Defense Design Criteria Standard: Safety Design Requirements for Military Lasers and Associated Support Equipment*. Notice 1, 29 March 2010. https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=36858

International Electrotechnical Commission (IEC). 2014. IEC 60825-1:2014, *Safety of laser products – Part 1: Equipment classification and requirements.* https://www.iecee.org/dyn/www/f?p=106:49:0::::FSP_STD_ID:3587

U.S. Army Public Health Center. 2020. Technical Information Paper 24-108-0420, *Military Laser Exemption from U.S. Food and Drug Administration Requirements*. Aberdeen Proving Ground, Maryland. https://phc.amedd.army.mil/PHC%20Resource%20Library/military_laser_exemption_from_fda_requirements.pdf

U.S. Food and Drug Administration (FDA). 2020. Code of Federal Regulations. Title 21, Subchapter J, Radiological Health. https://www.ecfr.gov/cgi-bin/text-idx?SID=2c1469324e2260bd8063e93152a8a791&mc=true&tpl=/ecfrbrowse/Title21/21CIsubchapJ.tpl

FDA. 2019. *Laser Products – Conformance with IEC 60825-1 Ed. 3 and IEC 60601-2-22 Ed. 3.1 (Laser Notice No. 56).* https://www.fda.gov/regulatory-information/search-fda-guidance-documents/laser-products-conformance-iec-60825-1-ed-3-and-iec-60601-2-22-ed-31-laser-notice-no-56

FDA. 2002. *Guidance on the Department of Defense Exemption from the FDA Performance Standard for Laser Products (Laser Notice No. 52).* https://www.fda.gov/media/71322/download

FDA. 1976. FDA Exemption No. 76EL-01DOD, *Certain Military Lasers Exempt from 21 CFR 1040.10 & .11 (Laser Notice 9)*. https://www.fda.gov/media/73777/download

APPENDIX 4B

CHAPTER 4 GLOSSARY

ACGIH
American Conference of Governmental Industrial Hygienists

AEL
accessible emission limit

ANSI
American National Standards Institute

APHC
U.S. Army Public Health Center

AR
Army Regulation

CFR
Code of Federal Regulations

DA
Department of the Army

DOD
Department of Defense

FDA
U.S. Food and Drug Administration

HHA
health hazard assessment

HIOS
High-intensity optical sources

HP
hazard probability

HS
hazard severity

IEC
International Electrotechnical Commission

IR
infrared

LEP
laser eye protection

MATDEV
materiel developer

MILES
Multiple Integrated Laser Engagement System

MIL–STD
Military Standard

mm
millimeter

MPE
maximum permissible exposure

µm
micrometer

mW
milliwatt

N/A
not applicable

nm
nanometer

NOHD
nominal ocular hazard distance

NOHD–M
nominal ocular hazard distance with magnifying optics

NRD
Nonionizing Radiation Division (APHC)

NRPS
Nonionizing Radiation Protection Study

NSHD
nominal skin hazard distance

OD
optical density

RAC
risk assessment code

RFR
radiofrequency radiation

SWIR
short-wave infrared

UV
ultraviolet

W
watt

W/cm^2
watts per square centimeter