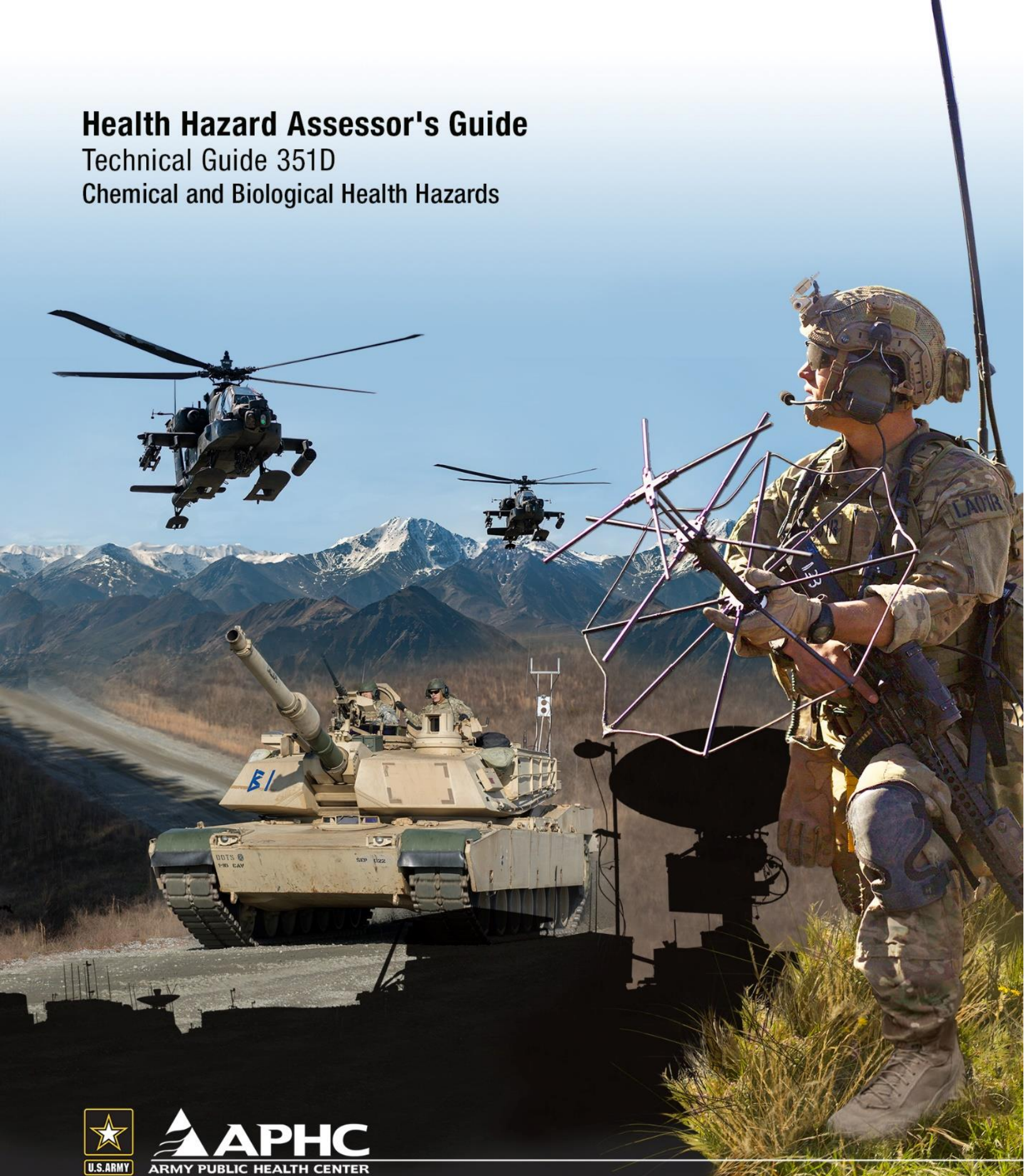


# Health Hazard Assessor's Guide

Technical Guide 351D

Chemical and Biological Health Hazards



Approved for public release; distribution unlimited.  
JULY 2021

## ACKNOWLEDGMENTS

Dr. Timothy A. Kluchinsky, Jr., Chief, Health Hazard Assessment Division, U.S. Army Public Health Center (APHC), extends appreciation to the following organizations and individuals for their assistance in creating Technical Guide (TG) 351D. Were it not for their unrelenting support and continued guidance, this volume would not have been possible.

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## PREFACE

TG 351D, *Chemical and Biological Health Hazards*, is the fourth volume of the *Health Hazard Assessor's Guide*. This volume includes an introductory chapter followed by three chapters presenting guidelines for conducting health hazard assessments of exposure to biological substances, chemical substances, and oxygen deficiency.

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# CHAPTER 1. INTRODUCTION TO THE HEALTH HAZARD ASSESSOR'S GUIDE



Source: Defense Visual Information Distribution Service (DVIDS)

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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 are 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 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. The 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<sup>1</sup>**

| 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:

<sup>1</sup>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.

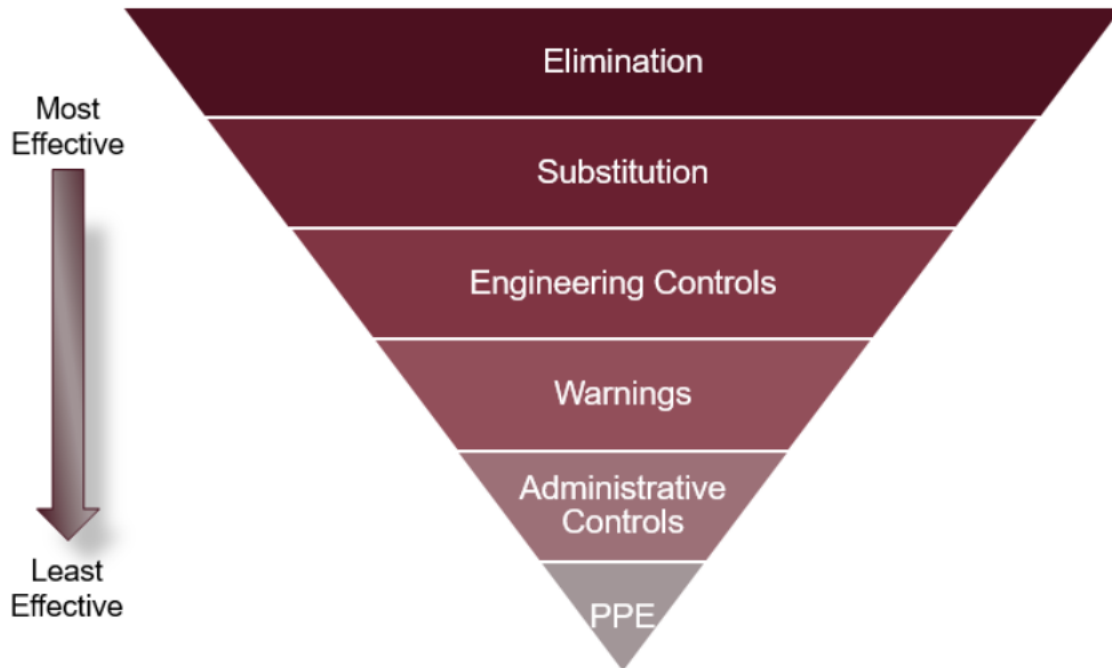
(3) **Engineering Controls.** Redesign systems to control hazardous conditions. For example, implement ventilation systems to control weapon combustion products in crew-occupied spaces or automatic lock-out systems to disengage high radio frequency beams before personnel enter a hazardous area.

(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.

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**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 BIOLOGICAL SUBSTANCES



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## 2-1. Purpose

This chapter of Technical Guide (TG) 351D provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to health hazards related to biological substances during the normal use and maintenance of materiel systems.

## 2-2. Definitions of Key Terms

**Biological substances:** Any material that contains or is reasonably expected to contain a microorganism (e.g., bacteria, viruses, rickettsiae, parasites, or fungi), human or animal products (e.g., blood, tissue, bodily fluids), insects, plants, or toxic compounds produced by microorganisms, plants, animals, or insects that can cause disease in humans or animals.

**Clean:** Free of visible soil, debris, and oily or chemical residues; the absence of objectionable odors.

**Disease:** An illness characterized by specific signs and symptoms.

**Disinfect:** To destroy or irreversibly inactivate microorganisms, except spores, on hard surfaces.

**Fomite:** Any nonliving object or substance that is capable of absorbing/carrying and transmitting the infecting organism of a disease to a new host that comes in contact with the object or substance.

**Foodborne illness:** Illness or injury caused by the consumption of food that is contaminated with disease-causing microorganisms (such as bacteria, viruses, parasites, or toxins deposited by these microorganisms), or by food that contains physical hazards such as glass, wood, or metal shavings.

**Host:** The human body that may be at risk of infection. May also be referred to as the susceptible host.

**Illness:** An interruption, cessation, or disorder of a body, system, or organ structure of function.

**Infection:** Invasion of the body by organisms that have the potential to cause disease.

**Mode of transmission:** The movement or the transmission of pathogens from a reservoir to a susceptible host. Once a pathogen has exited the reservoir, it needs a mode of transmission to the host through a route of entry.

- Direct contact is person-to-person transmission of pathogens through touching. Microorganisms can also be expelled from the body by coughing, sneezing, or talking.
- Indirect contact includes both fomite-borne and vector-borne contact.

**Pathogens:** Microorganisms capable of causing diseases or infections.

**Reservoir:** Any person, animal, arthropod, plant, soil, or substance (or combination of these) in which a pathogenic organism normally lives and depends upon for survival, and where it reproduces in such manner that it can be transmitted to a susceptible host.

- Animate reservoirs include people, insects, birds, and other animals.
- Inanimate reservoirs include fomites, soil, water, food, waste, bodily fluids, and equipment.

**Routes of entry:** The site through which microorganisms enter the susceptible host and cause disease/infection. Various routes include mucous membranes, the skin, and the respiratory and gastrointestinal tracts. The skin normally serves as a barrier to infection. However, any break in the skin invites the entrance of pathogens.

**Sanitize:** To reduce the number of microorganisms on a surface to levels considered safe, based on established parameters, without adversely affecting either the quality of the product or its safety.

**Supported population:** The military population that consumes the output or product(s) of the materiel system, such as with food feeding systems and water distribution systems. In rare occasions, personnel with incidental or collateral exposure due to downstream operations may be considered. For example, a human remains container can present a hazard to those transporting it as well as to the mortuary personnel recovering the remains.

**Vector:** An animal or arthropod that plays a part in the transmission of pathogens.

**Waterborne disease:** A condition caused by pathogenic microorganisms that are transmitted in water. Waterborne illness may occur after exposure to contaminated water through skin contact, inhalation of aerosolized water particles, or ingestion.

## 2–3. Applicable References/Health Protection Criteria

Aspects of design (e.g., structure, materials, space allowance, ventilation, temperature controls, cross-contamination prevention, pest control, and industry standards) will be considered in comparison to the established public health standards. Appendix 2A lists the references applicable to this chapter. The methods and references described in Chapter 1 of this Guide also apply to this chapter.

## 2–4. Health Effects of Biological Substances Exposure

The health effects of exposure to biological substances vary according to many different factors including, but not limited to, the specific pathogen or agent of concern, the route of entry, and the susceptibility of the person exposed. Due to the disease process, health effects resulting from biological substances differ from those of other hazards (e.g., chemical substances). Effects of biological substances predominantly result from the infectious nature of the causative agents. Health effects due to biological substance exposure include, but are not limited to, the following:

- Malaise
- Fever
- Dizziness
- Headache
- Body aches
- Stiffness/soreness
- Nausea/vomiting
- Diarrhea
- Respiratory congestion
- Skin irritations
- Muscle weakness/ataxia
- Paralysis
- Hemorrhage
- Pneumonia
- Toxemia
- Sepsis

Populations usually considered highly susceptible to such health effects are the elderly, the very young, the immuno-compromised, and the pregnant; however, deployed Soldiers can also be considered to have a higher susceptibility. Soldiers become more susceptible to illness and injury when placed in high-stress situations for extended periods of time, coupled with significant climatic changes, interrupted sleep periods or sleep deprivation, and irregular meals. Extended periods of time in the field and prolonged deployments in austere environments place tremendous stress on the human body. These stressors can negatively impact the body's natural defense mechanisms and weaken its ability to efficiently protect against disease.

## 2–5. Pre-assessment Procedures

**A. Early Involvement.** Recognizing a health hazard related to biological substances as early as possible in the materiel system's development is important to identify potential engineering changes that could have the most useful impact in mitigating the health hazard. Subject matter experts (SMEs) within the U.S. Army Public Health Center (APHC) should be consulted when a potential biological substances health hazard has been identified, regardless of which acquisition life cycle phase the materiel system is in.

**B. Assessor Qualifications.** The assessor should be a qualified SME in the field of sanitation and environmental health. In particular, they should have expertise in sanitation and hygiene standards, public health regulations, and disease transmission. The following APHC divisions provide SME support and guidance on the listed areas of expertise during assessments of biological substances:

(1) ***Veterinary Services and Public Health Sanitation Directorate, Food Protection and Public Health Sanitation Division.*** General sanitation considerations include—

- Cleanability of surfaces and components based on the types of materials used and the design, construction, and installation of the equipment or system. This includes the cleanability of porous substances, such as fabrics.
- Engineering controls to prevent release of infectious biological substances as a result of operating the equipment/system, or to prevent entry of biological substances from the environment that could adversely affect the operator or supported population.
- Specified operational controls for proper management and maintenance of the equipment/system to further control potential health hazards.

(2) ***Environmental Health Sciences and Engineering Directorate, Environmental Health Engineering Division.*** Water resources, field and drinking water quality, and air quality considerations include—

- Surface water and groundwater quality protection (from wash and rinse wastewater).
- Air quality protection from burning or detonating material, and from exterior discharge of air exhaust.
- Field and drinking water quality for potable and hygienic purposes.
- Controls for the use of hygienic, non-toxic, non-absorbent, corrosion-resistant equipment and materials, which can be adequately cleaned and disinfected and are suitable to support production, storage/bottling, and distribution of potable water for drinking or sanitary use.
- Implementation of cross-contamination controls within equipment and at connections between equipment to prevent the introduction of infectious biological substances into the finished potable water.
- Procedures and operations controls to ensure free chlorine residual is maintained during production, storage, and distribution of drinking water to prevent infectious biological substances from developing.
- Documented operational procedures for the proper management and maintenance of the equipment/system to ensure continuous control of potential biological health hazards.
- Biological substance field sampling to include drinking water, wastewater, and debris/surfaces.

(3) ***Environmental Health Sciences and Engineering Directorate, Environmental Health Sciences Division.*** Waste management considerations include—

- Waste generation during normal operation and maintenance, to include wastes resulting from the use of cleaning products, lubricants, and other maintenance applications.
- Waste generation during end-of-life/disposal processes.
- Demilitarization (demil) in end-of-life/disposal procedures.
- Biological substance waste management guidance to include personal protective equipment (PPE), collection, storage, transportation, treatment, and disposal.

(4) ***Environmental Health Sciences & Engineering Directorate, Environmental Health Risk Assessment Division.*** Environmental health risk information and analyses considerations include—

- Supporting health readiness and deployment health missions by providing exposure and health risk assessments and consultations for force health protection personnel.
- Supporting environmental health and health readiness through health risk assessments and consultations for cleanup programs, demilitarization programs, training range sustainment, and installation response to environmental hazards, all with an emphasis on human and ecological health risk assessments.
- Supporting health readiness, force health protection, risk management, and capability development by providing specialized health risk assessment (HRA) capabilities and advancing HRA concepts, methods, tools, and guidance to address current and emerging biological health hazards (occupational environmental health and chemical biological radiological and nuclear) found in garrison and field operating environments.

**C. Information Required for a Health Hazard Assessment.** For all materiel that may be a source of biological substances, obtain the following information from the materiel developer (MATDEV):

- Description of the system design, to include function and structure.
  - Diagrams with dimensions and major components.
  - Description of material used for construction.
  - Industry standards applied for or obtained.
- Detailed description of how the system will be used.
  - Operational Mode Summary/Mission Profile outlining the length of time for operations.
  - Capacity of the system (e.g., number of people supported).
  - Set-up configurations.
  - Maintenance procedures.
- Testing information for performance requirements (e.g., water temperature, swatch testing, and filtration performance) for those aspects that involve biological hazards.

The required information may be sourced from documents such as manufacturer data, safety assessments, capability documents, user manuals, and test reports.

## 2–6. Risk Assessment Process

**A. Scope.** Biological substances can present a health hazard to the operators of the equipment/system as well as to the end user or population that the system services. The primary focus population for an HHA are the operators and maintainers; however, in some situations the risk to the Soldiers supported by the system may need to be considered (refer to the definition for “supported population” in section 2–2). An HHA only considers normal use, which includes operational information, regulatory requirements, operational guidance, standard operating procedures, and user manuals.

**B. Hazard Identification.** Recognizing the source, type, and mode of transmission of potential biological substances is important when assessing the system for risk of health effects due to hazards associated with biological substances. Aspects of the equipment/system and its use/operation must be reviewed and analyzed to ensure that a mode of transmission of pathogens is not supported. Table 2–1 lists common examples of equipment/systems and the characterization of biological substances for each.

**Table 2–1. Examples of Health Hazard Assessment Characterization of Biological Substances**

| Equipment/System                                   | Biological Substance Source                       | Biological Substance Type                          | Mode of Transmission  |
|--|---|--|---|
| Field food service (kitchen, sanitation center)    | Food, water, hands, pests (insects/rodents)       | Bacteria, viruses, parasites, fungi (mold), toxins | Ingestion (food), fomites (food-contact surfaces, equipment, utensils)                                |
| Hygiene facilities (shower; hand wash)             | Grey water, people (skin contact, bodily fluids)  | Bacteria, viruses, fungi                           | Inhalation (water vapor/aerosols), direct dermal/ocular, incidental ingestion, fomites (skin contact) |
| Field laundry                                      | Soiled/contaminated fabrics, grey water           | Bacteria, viruses, parasites, mold, plant toxins   | Inhalation, dermal/ocular, incidental ingestions, fomites (skin contact), insect vectors              |
| Drinking water (production, storage, distribution) | Untreated (raw) water, cross-connection, people   | Bacteria, viruses, parasites, fungi, toxins        | Ingestion   |
| Human waste (toilets, collection systems, storage) | Black water, people (skin contact, bodily fluids) | Bacteria, viruses, fungi                           | Fomites (fecal-oral), aerosols, dermal/ocular   |
| Kennels  | Animal excreta, environment                       | Bacteria, viruses, parasites, fungi                | Fomites, animal contact, insect vectors   |
| Ambulances, medical transport                      | Bodily fluids                                     | Bacteria, viruses                                  | Fomites   |

| Equipment/System                            | Biological Substance Source          | Biological Substance Type                   | Mode of Transmission                                 |
|---|--------------------------------------|---|--|
| Field living areas (tents and shelters)     | Environment, human activities, pests | Bacteria, viruses, fungi                    | Fomites, inhalation (aerosolization), insect vectors |
| Mortuary affairs (human remains containers) | Human remains                        | Bacteria, viruses                           | Fomites, inhalation (aerosolization), dermal         |
| Clothing items                              | Environment, bodily fluids           | Bacteria, viruses, parasites, fungi, toxins | Dermal/ocular, inhalation                            |

**C. Hazard Severity.** The expected impact on adverse health or medical outcomes for operators and supported populations (as applicable) from potential hazards associated with biological substances, presented by the system, determines its hazard severity (HS). The HS is a composite of multiple factors regarding the biological substances (e.g., pathogen, length of exposure, mode of transmission) and requires knowledge of the adverse health effects resulting from exposure. The HS has a temporal element in that adverse health effects may be realized acutely or at a future time after exposure. Additionally, HS may be dependent on whether the exposure is acute or chronic. For some biological substances, it may be necessary to consult with other appropriate SMEs such as a preventive medicine physician, internal medicine physician, epidemiologist, microbiologist, infectious disease specialist/physician, occupational/environmental medicine physician, public health nurse, or entomologist to assess the severity of associated health effects.

**Table 2–2. Hazard Severity Categories for Biological Substances**

| Category | Description  | Consequences of Hazard  |   |
|----------|--------------|---|---|
|          |              | Operator  | Supported Population  |
| 1        | Catastrophic | Death or permanent total disability   | Mission failure (inability to complete mission due to number of Soldiers incapacitated)                                       |
| 2        | Critical     | Permanent partial disability; includes chronic (long-term) health effects without acute onset, or severe injury or illness resulting in lost duty days or inability to perform assigned tasks | Hospitalization of at least 3 personnel, or 2 or more lost duty days (without hospitalization) of 10% or more of unit members |
| 3        | Marginal     | Minor injury or illness resulting in lost duty days   | Minor injury or illness resulting in 1–2 lost duty days of less than 10% of unit members                                      |
| 4        | Negligible   | Minimal injury/illness; First Aid or minor medical treatment (no lost duty days)  | Minimal injury/illness; First Aid or minor medical treatment (no lost duty days) in unit members                              |



**D. Hazard Probability.** The expected likelihood of adverse health or medical outcomes for operators and supported populations (as applicable) from potential hazards associated with biological substances, presented by the system, determines its hazard probability (HP). A key consideration in determining the HP is the effectiveness of the controls to reduce or prevent the transmission of biological substances.

**Table 2–3. Hazard Probability Levels for Biological Substances**

| Level | Description | Definition  |
|-------|-------------|---|
| A     | Frequent    | The transmission of biological substances is likely to occur often because the design and construction allow for the growth or spread of biological substances. There are no engineering controls in place. Administrative controls and PPE cannot mitigate the hazard.                               |
| B     | Probable    | The transmission of biological substances will occur several times because the design, construction, or use allows for the growth or spread of the biological substances. Engineering controls are in place but need to be improved. Administrative controls and PPE are required to mitigate hazard. |
| C     | Occasional  | The transmission of biological substances is likely to occur at times because of how the equipment/system is used. Adequate engineering controls are in place. Administrative controls are in place but need to be improved. PPE is required.   |
| D     | Remote      | The transmission of biological substances is unlikely but possible to occur because of how the equipment/system is used. Adequate engineering controls are in place. Adequate administrative controls are in place. PPE is required.  |
| E     | Improbable  | The transmission of biological substances is so unlikely it can be assumed occurrence may not be experienced. Adequate engineering controls are in place. Adequate administrative controls are in place. No PPE is required.  |
| F     | Eliminated  | The transmission of biological substances is incapable of occurring. This level is used when potential hazards are identified and later eliminated.   |

Legend:

PPE = personal protective equipment

## E. Risk Assessment Procedures.

(1) **General Guidelines.** The general risk assessment process includes the following steps:

- a. Identify the hazard associated with biological substance(s) and the affected population (operator, supported population, or both). For some equipment/systems, it may be appropriate to conduct a separate risk assessment for each impacted group: system operators and the supported population.
- b. Based on the existing condition/control(s), characterize the hazard to the operator and/or supported population, and determine the initial risk level for the identified deficiencies.

- c. Identify recommended control(s) for the deficiencies, and determine the residual risk level to the operator and/or supported population.
- d. In the case of multiple initial or residual risk levels, assign the highest (i.e., most conservative) risk level to the hazard.

A risk assessment tool, shown in Table 2–4, was developed using key assessment questions and “if-then” logic to guide the SME through the risk assessment procedure. The tool is designed to be used in conjunction with Tables 2–2 and 2–3 when assigning the HS and HP. Additionally, there are specific considerations for system/equipment design, construction, assembly, and use that need to be taken into account when the HS and HP are determined. These considerations are listed in section E(2), following Table 2–4.

**Table 2–4. Biological Substances Risk Assessment Tool**

| Focus                                  | Key Assessment Questions   | If                         | Then   |
|--|--|----------------------------|--|
| Identification of Biological Substance | Does operating the equipment/system produce new biological substances or create the potential for biological substances to spread and present a health risk? | Yes                        | Identify the biological substance(s), source(s), and mode(s) of transmission.  |
| Operator Exposure                      | Is the equipment/system operator at risk due to exposure during normal use?  | Yes                        | Define the potential exposure.   |
|  | Is the system designed and/or constructed to prevent operators from being exposed? <sup>a</sup>  | No                         | Describe the deficiencies. Assign initial HS <sup>b</sup> based on potential exposure. Assign initial HP <sup>c</sup> based on controls. |
|  | Would engineering controls be feasible to prevent or reduce operator exposure?   | Yes                        | Provide recommended engineering controls. Assign residual HS <sup>b</sup> and/or HP <sup>c</sup> based on the recommendations.           |
|  |  | No                         | No change in the HS or HP.   |
|  | Are there administrative controls and/or personal protective equipment available to prevent or reduce operator exposure?                                     | Yes                        | Provide recommendations. Assign residual HP <sup>b</sup> based on all recommendations.   |
| No                                     |  | No change to the HS or HP. |  |
| Supported Population Exposure          | Does the equipment/system as designed/operated present a biological substances risk to the supported population?   | Yes                        | Define the potential exposure.   |
|  | Is the system designed and/or constructed to prevent supported population from being exposed? <sup>1</sup>   | No                         | Describe the deficiencies. Assign initial HS <sup>b</sup> based on potential exposure. Assign initial HP <sup>c</sup> based on controls. |
|  | Would engineering controls be feasible to prevent or reduce supported population exposure?   | Yes                        | Provide recommended engineering controls. Assign residual HS <sup>b</sup> and/or HP <sup>c</sup> based on the recommendations.           |
| No                                     |  | No change in the HS or HP. |  |

| Focus | Key Assessment Questions   | If  | Then   |
|-------|--|-----|--|
|       | Are there reasonable/feasible administrative controls and/or personal protective equipment to prevent or reduce population exposure? | Yes | Provide recommendations. Assign residual HP <sup>b</sup> based on all recommendations. |
|       |  | No  | No change to the HS or HP.   |

Legend:

HP = hazard probability

HS = hazard severity

Notes:

<sup>a</sup> Include questions from section 2-6F(2), Specific Considerations for Design, Construction, Assembly, and Use.

<sup>b</sup> Refer to Table 2-2.

<sup>c</sup> Refer to Table 2-3.

### (2) **Specific Considerations for Design, Construction, Assembly, and Use.**

Review the following questions when assessing a system/equipment for hazards related to biological substances. Apply these questions in conjunction with those in Table 2-4 to consider unique aspects of the system/equipment. Negative responses to the questions below will be used to identify and weight deficiencies that may affect the initial HS and HP assigned to the system/equipment.

- Do the design and construction of the equipment/system facilitate proper cleaning to remove the biological substance?
- Are materials that are exposed to the biological substance durable, smooth, and nonporous?
- Are joints, seams, and gaps appropriately sized to prevent accumulation of debris that may harbor the biological substance, or to allow proper access to component areas that need to be cleaned?
- Can the equipment/system be easily disassembled or moved to allow proper cleaning?
- Are engineering controls such as heating/cooling, ventilation, or filters in place to control biological substances or the conditions that could contribute to the growth or spread of the biological substances?
- Have the engineering controls been evaluated for proper size, capacity, and performance under expected operational conditions?
- Does configuration of the system (e.g., placement of equipment in the supporting structure) prevent conditions that may render other controls ineffective?

**F. Risk Mitigation Strategies.** Risk mitigation is a holistic process, taking into account that recommendations to reduce risk from one hazard might increase risk from another. Recommendations, therefore, should not be made in isolation from other hazards but should consider the system and its use as a whole. Mitigation strategies for biological substances will vary widely depending on the use scenario and source.

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) PPE. Some examples of biological substance controls follow (in priority order):

(1) **Elimination.** Remove the potential for personnel exposure to biological substances. Elimination is not often feasible, however, as it would likely alter the system's purpose and its use scenario.

(2) **Substitution.** Replace porous surfaces with nonporous surfaces to improve cleanability, or change the materials of a clothing item to improve the item's ability to be laundered in temperatures required for proper cleaning.

(3) **Engineering Controls.** Add a high-efficiency particulate air (HEPA) filter to a ventilation system to prevent cross-contamination to food contact surfaces in field kitchens, or add a drain to the floor of a food sanitation system to prevent standing water and allow for better cleaning.

(4) **Warnings.** Use internal thermometers in warewashing operations (i.e., the process of washing and sanitizing utensils and food preparation equipment) to alert Soldiers when specific temperature conditions are met.

(5) **Administrative Controls.** Provide cleaning and sanitizing instructions for waste containment and management of field latrines, showers, or laundry systems. Label water storage containers for designated use (e.g., raw, potable, or gray).

(6) **PPE.** Require rubber gloves, eye protection, a face shield, and Tyvek (or similar disposable suit) to prevent exposure to biological substances during handling of human remains and the cleaning and disinfection of human remains transport cases.

## 2–8. Example Assessment Scenarios

Details for the example assessments have been abbreviated to provide a simple illustration of the HHA process using the general risk assessment guidelines outlined in this chapter, along with the biological substances risk assessment tool. The SME may exercise professional judgment as required, which may lead to a slight variation in the assigned risk assessment code (RAC).

### A. Example 1: Human Remains Transport Case

**Step 1.** *Gather relevant information about the system.* The MATDEV provided the following information:

The Human Remains Transport Case (HRTC) protects human remains and maintains an optimal temperature while the remains are transported from the area of operation to the servicing mortuary. The case includes a visible means of ensuring the internal

temperature of the case is maintained during transit. HRTC components include insulation, a temperature sensor, cooling apparatus, and a radio frequency identification tag. The outer shell of the HRTC is aluminum; the inner shell is durable plastic. In place of insulation, vacuum-insulated panels and foam are between the two shells. The HRTC surfaces are designed to be cleaned and disinfected after use. The built-in refrigeration unit can be operated by 24 Volt (V) direct current or 120 V alternating current electrical sources, or by onboard rechargeable nickel-metal hydride batteries when the unit is not connected to an external power source. The unit includes a temperature indicator and status lights, which can be viewed without opening the case.

**Step 2.** *Gather relevant information on the normal use of the system, to include the supported population.* The MATDEV provided the following information:

The HRTC is reusable, stackable, and able to be loaded onto an aircraft pallet. The goal of this system is for a Soldier’s remains to arrive at the receiving mortuary without being subject to advanced decomposition. Human remains are placed in a “body bag” referred to as a Human Remains Pouch (HRP). Accompanying documents, as well as personal effects found on the remains, are also placed inside the transfer case. While the HRP is leak-resistant, bodily fluids may leak from it, thus contaminating the HRTC. The HRTC is maintained by mortuary affairs personnel who are responsible for preparing human remains before their placement in the HRTC and for proper cleaning and disinfection of the HRTC after the human remains have been removed. Disinfection procedures prescribe the use of chlorine bleach at a 5% strength, which represents an undiluted concentration of standard household bleach that is equivalent to 50,000 parts per million. A pressure washer or hose is used to rinse disinfected HRTCs.

**Step 3.** *Identify the hazard associated with the biological substance(s).* Table 2–5 displays the biological substance characterizations for the system.

**Table 2–5. Example 1: Identification of Biological Substances**

| Key Assessment Question  | If         | Then  | Biological Substances Characterization   |
|--|------------|---|--|
| Does operating the equipment/system produce new biological substances or create the potential for biological substances to spread and present a health risk? | <b>Yes</b> | Identify the biological substance(s), source(s), and mode(s) of transmission. | Chronic infectious hazards, including hepatitis B virus, hepatitis C virus, human immunodeficiency virus; enteric pathogens; Mycobacterium tuberculosis. <b>Hazards from unique environments:</b> acute or “epidemic-causing” infections; biological warfare agent. <b>Transmission mode:</b> fomites, aerosolized liquids, inhalation |

**Step 4.** *Characterize the hazard to operator and/or supported population based on the existing condition/control(s).* The HRTC presents a biological substances-associated hazard to both the operator and the supported population. The exposure characterization for the operator and the supported population of the HRTC is displayed in Tables 2–6 and 2–7, respectively.

**Table 2–6. Example 1: Exposure Characterization for the Operators**

| Key Assessment Question   | If         | Then   | Operator Characterization  |
|---|------------|--|--|
| Is the equipment/system operator at risk due to exposure during normal use? | <b>Yes</b> | Define the potential exposure.   | Operators include any person involved with processing the human remains or handling the HRTC, such as medical, mortuary affairs, and escort personnel. |
| Potential Exposure Characterization   |            | <p>Human remains typically pose a limited health threat after death because the body temperature drops rapidly, resulting in the corresponding death of most bacteria and viruses. However, this may not be true in hot climates where ambient temperatures are near or above body temperature. Human remains located in high-temperature environments allow microorganisms to continue to grow and multiply, increasing the health threat to personnel handling the remains. The exposure risk also increases if, after the remains have been processed and placed in the HRTC, cold temperature control within the HRTC is not maintained between the case’s initial point of processing and its final destination. Use of the prescribed chlorine bleach concentration to disinfect the HRTC will likely corrode the exposed evaporator assembly over time, which may result in a refrigeration failure of the HRTC during use, thus increasing the microbial hazard risk.</p> <p>Potential exposure:</p> <ul style="list-style-type: none"> <li>• Fomites. Contact with contaminated surfaces/items inside the case if there is leakage of bodily fluids from the human remains pouch (HRP).</li> <li>• Draining liquids. The evaporator assembly for the refrigeration system is not sealed from the interior of the HRTC, which could result in condensation pooling inside the case. The condensate is subject to contamination from any liquids leaked from the HRP. A manually operated recessed drain in the bottom section of the HRTC, located next to the evaporator assembly, is used to drain liquids (including cleaning and disinfecting liquids) to minimize contamination. The drain is operated by a valve on the outside of the container and can be fitted with a tube for draining into a receptacle.</li> <li>• Aerosols. Release of airborne bacteria, viruses, and other pathogens and aerosolized liquids containing biological substances from inside the HRTC. The case is designed with a vent that allows pressure release when the HRTC is being transported inside an aircraft. There is no filter on the vent to prevent escape of biological substances when there is a pressure differential between the inside and outside of the container.</li> </ul> |  |

Legend:  
 HRP = Human Remains Pouch  
 HRTC = Human Remains Transport Case

**Table 2-7. Example 1: Characterization for the Supported Population**

| Key Assessment Question  | If         | Then  | Supported Population Characterization  |
|--|------------|---|--|
| Does the equipment/system as designed/operated present a biological substances risk to the supported population? | <b>Yes</b> | Define the potential exposure.  | The supported population in this situation consists of any personnel who have no direct responsibility for handling the HRTC but are in close proximity to the HRTC during or immediately following air transport. Personnel may include the flight crew, flight passengers, and cargo grounds crew. |
| <b>Potential Exposure Characterization</b>   |            | <b>Aerosols.</b> Release of airborne bacteria, viruses, and other pathogens and aerosolized liquids containing biological substances from inside the HRTC. The HRTC pressure release vent is not equipped with a filter to prevent biological substances from escaping during or immediately following air transport. |  |

Legend:

HRTC = Human Remains Transport Case

**Step 5.** Determine the **initial** risk level (RAC: HS, HP) to the operator and supported population for the deficiencies identified. If multiple deficiencies are identified, a RAC is assigned for each, and the most conservative RAC is assigned for the hazard. Table 2-8 displays the initial risk for the deficiencies identified for the HRTC, which apply to both the operators and supported population.

**Table 2-8. Example 1: Deficiencies and Initial Risk**

| Key Assessment Questions   | If        | Then  | Deficiencies  | HS | HP | Risk Level (RAC)   |
|--|-----------|---|---|----|----|--------------------|
| Is the system designed and/or constructed to prevent operators/supported populations from being exposed? | <b>No</b> | Describe the deficiencies.                            | No mechanism to prevent or contain leakage from the HRP or to prevent liquid wastes from contaminating the interior of the HRTC.  | 2  | C  | <b>High (2, B)</b> |
|  |           | Assign <b>initial</b> HS based on potential exposure. | Evaporation assembly is not enclosed/separate from possible liquid and airborne contamination. The assembly is subject to corrosion from use of excessive bleach concentration during disinfection, which may result in mechanical refrigeration failure. | 2  | B  |                    |
|  |           | Assign <b>initial</b> HP based on controls.           | No filter mechanism for the HRTC pressure release vent.   | 2  | B  |                    |

Legend:

HP = hazard probability

HRP = Human Remains Pouch

HRTC = Human Remains Transport Case

HS = hazard probability  
 RAC = risk assessment code

**Step 6.** Provide recommended control(s) for deficiencies; determine the **residual** risk level (RAC: HS, HP) to the operator and supported population.

The recommendations and residual risk provided in Table 2–9 are for the system design and operator of the system; the engineering controls and corresponding residual risk (Low (RAC: 4, D)) apply to the supported population. There are no recommended administrative controls for the supported population.

**Table 2–9. Example 1: Recommendations and Residual Risk**

| Key Assessment Questions   | If  | Then   | Recommendations   | HS | HP | Risk Level (RAC) |
|--|-----|--|---|----|----|------------------|
| Would engineering controls be feasible to prevent or reduce operator exposure?           | Yes | Provide recommended engineering controls.  | Enclose the HRP in a secondary layer that is completely sealed, or add an absorbent gel material to contain any liquid leakage.   | 4  | D  | Low (4, D)       |
|  |     | Assign <b>residual</b> HS and/or HP <b>based on the recommendations.</b>                             | Encase the evaporation assembly so it is protected from possible contamination and corrosion from disinfectants.  | 4  | F  |                  |
|  |     |  | Equip the pressure release valve with a HEPA filter to capture any aerosolized pathogens.   | 4  | E  |                  |
| Are administrative controls and/or PPE available to prevent or reduce operator exposure? | Yes | Provide recommendations.<br><br>Reassign the <b>residual</b> HP <b>based on all recommendations.</b> | <ul style="list-style-type: none"> <li>• Vaccinations for hepatitis B and tuberculosis.</li> <li>• PPE when handling remains/ cleaning and disinfecting the HRTC: Eye protection, face shield, Tyvek or similar disposable suit, rubber gloves.</li> <li>• Proper hand hygiene after handling remains and conducting cleaning and disinfection tasks.</li> <li>• Replace the corrosive bleach disinfectant with a noncorrosive disinfectant if the evaporator assembly is not modified to protect it from contamination.</li> <li>• Training: PPE use; cleaning and disinfection procedures; hand hygiene; bloodborne pathogens.</li> </ul> | 4  | E  | Low (4, E)       |



## Legend:

HEPA = high-efficiency particulate air

HP = hazard probability

HRP = Human Remains Pouch

HRTC = Human Remains Transport Case

HS = hazard severity

PPE = personal protective equipment

RAC = risk assessment code

## B. Example 2: Improved Physical Training Uniform

**Step 1.** *Gather relevant information about the system.* The MATDEV provided the following information:

The Improved Physical Training Uniform (IPTU) consists of shorts, t-shirt, jacket, pants, and knit cap. The shorts and t-shirt are designed using high-performance fabrics that are characterized as lightweight, breathable, moisture-wicking, and fast-drying. Garment laundering instructions presented on the manufacturer's label state, "hand wash, or machine wash delicate; tumble dry low."

**Step 2.** *Gather relevant information on the normal use of the system to include supported population.* The MATDEV provided the following information:

The IPTU is the official uniform worn by military personnel during physical fitness training in the garrison setting. The IPTU also serves as an alternate uniform worn during field training and in deployment settings when Soldiers are not on duty or required to wear the Army Combat Uniform or other prescribed uniform. Based on the activities and environments in which the IPTU is worn, the fabric is subject to contamination from bodily fluids, environmental soils, toxic plant residues, insect and arthropods, and parasites (e.g., lice). During field training exercises and deployments, Soldiers have limited access to showers and laundry, which typically results in their wearing the same uniform for multiple days. Field/deployment laundry services are provided by the Army Quartermaster utilizing systems that only employ a hot-water wash and high-heat drying, and/or a logistics contract, which also uses a hot-water wash and high-heat drying.

**Step 3.** *Identify the hazard associated with biological substance(s).* The biological substance characterization for the IPTU is displayed in Table 2-10.

**Table 2–10. Example 2: Identification of Biological Substances**

| Key Assessment Question  | If  | Then  | Biological Substance Characterization  |
|--|-----|---|--|
| Does operating the equipment/system produce new biological substances or create the potential for biological substances to spread and present a health risk? | Yes | Identify the biological substance(s), source(s), and mode(s) of transmission. | Microbial contaminants: bacteria, viruses, fungi; parasites (lice); insects and arthropods (ticks, fleas, lice); plant toxins (poison ivy/oak) |

**Step 4.** Characterize the hazard to operator and/or supported population based on the existing condition/control(s). For the IPTU, the operators and the supported population are the same. Table 2–11 displays the exposure characterization for both.

**Table 2–11. Example 2: Exposure Characterization for the Operators**

| Key Assessment Questions  | If  | Then   | Operator Characterization   |
|---|-----|--|---|
| Is the equipment/system operator at risk due to exposure during normal use? | Yes | Define the potential exposure.   | Operators, in this case, are the same as the supported population. Operators are the individuals who wear the IPTU. |
| <b>Potential Exposure Characterization</b>                                  |     | <ul style="list-style-type: none"> <li>• <b>Skin injury.</b> Chronic exposure to microbes, soil, plant toxins, and parasites embedded in/on improperly laundered IPTU fabric can cause dermal irritations (e.g., skin rash, itching, blisters) that can lead to varying degrees of skin infection.</li> <li>• <b>Health effects.</b> Although uncommon, continued wear and soiling of the IPTU without proper laundering, coupled with poor sanitation and hygiene, can result in a parasitic infestation (body lice), which can transmit disease (louse-borne typhus). Fleas and ticks attached to clothing can also transmit disease. Severe health reactions that may occur (e.g., anaphylaxis) from continued exposure to toxic plant residues on the fabric could lead to death.</li> </ul> |   |

Legend:

IPTU = Improved Physical Training Uniform

**Step 5.** Determine the **initial** risk level (RAC: HS, HP) to the operators for the deficiencies identified. If multiple deficiencies are identified, a RAC is assigned for each, and the most conservative RAC is assigned for the hazard. Table 2–12 displays the identified deficiency and the assigned RAC for the IPTU.

**Table 2–12. Example 2: Deficiencies and Initial Risk**

| Key Assessment Questions   | If        | Then   | Deficiencies  | HS | HP | Risk Level (RAC)   |
|--|-----------|--|---|----|----|--------------------|
| Is the system designed and/or constructed to prevent operators/supported populations from being exposed? | <b>No</b> | Describe the deficiencies.<br><br>Assign <b>initial</b> HS based on potential exposure.<br><br>Assign <b>initial</b> HP based on controls. | Manufacturer’s required laundering process of cold/cool wash and low-heat dry will not adequately destroy harmful microbes, plant residues, or parasites in the fabric. | 2  | B  | <b>High (2, B)</b> |

Legend:

HP = hazard probability

HS = hazard severity

RAC = risk assessment code

**Step 6.** Provide recommended control(s) for deficiencies; and determine the **residual risk level (RAC: HS, HP)** to the operator and/or supported population. Table 2–13 provides the recommendations and residual risk for the IPTU.

**Table 2–13. Example 2: Recommendations and Residual Risk**

| Key Assessment Questions   | If         | Then  | Recommendations  | HS | HP | Risk Level (RAC)  |
|--|------------|---|--|----|----|-------------------|
| Would engineering controls be feasible to prevent or reduce operator exposure?   | <b>Yes</b> | Provide recommended engineering controls.<br><br>Assign <b>residual</b> HS and/or HP <b>based on the recommendations.</b> | Modify the IPTU fabric components for compatibility with hot-temperature (140 degrees Fahrenheit) washing and drying laundering processes. | 4  | E  | <b>Low (4, E)</b> |
| Are there administrative controls and/or personal protective equipment available to prevent or reduce operator exposure? | <b>No</b>  | No change in the HP   | Not applicable   | -  | -  | -                 |

Legend:

HP = hazard probability

HS = hazard severity

IPTU = Improved Physical Training Uniform

RAC = risk assessment code

## **2–8. Limitations and Potential Future Work**

(1) Typically, the assessment of potential hazards associated with biological substances and materiel is limited to qualitative methods, such as design reviews and site surveys. With few exceptions (e.g., biological warfare agents), testing is not performed to measure the levels or concentration of pathogens and toxins present beyond those required for system performance (e.g., water treatment). A collaborative effort of SMEs is essential to the assessment.

(2) Clothing items are often designed for performance parameters that do not consider the temperatures required to clean the material properly, or the durability required to launder the material using field laundry systems. Design and health protection criteria need to be developed to ensure clothing items meet sanitation and public health standards. The assessment of clothing items containing chemical treatment (e.g., anti-microbial and permethrin) requires coordination with the APHC Toxicology Directorate (refer to TG 351D, Chapter 3, Chemical Substances).

## APPENDIX 2A

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**APPENDIX 2B**  
**CHAPTER 2 GLOSSARY**

**APHC**

U.S. Army Public Health Center

**ATP**

Army Techniques Publication

**CFR**

Code of Federal Regulations

**DA**

Department of the Army

**DOD**

Department of Defense

**HHA**

health hazard assessment

**HP**

hazard probability

**HRA**

health risk assessment

**HRP**

Human Remains Pouch

**HRTC**

Human Remains Transport Case

**HS**

hazard severity

**IPTU**

Improved Physical Training Uniform

**MATDEV**

materiel developer

**PPE**

personal protective equipment

**RAC**

risk assessment code

**SME**

subject matter expert

**TB MED**

Technical Bulletin, Medical

**TG**

Technical Guide



## CHAPTER 3. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO CHEMICAL SUBSTANCES



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The use of trademarked names does not imply endorsement by the U.S. Army but is intended only to assist in the identification of a specific product.

### 3–1. Purpose

This chapter of Technical Guide (TG) 351D provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to chemical substances that occurs during the normal use and maintenance of materiel systems.

### 3–2. Definitions of Key Terms

**Caliber:** Approximate internal diameter of the barrel or the diameter of the projectile it fires. When the barrel diameter is given in inches, the abbreviation "cal" is used in place of "inches." For example, a small-bore rifle with a diameter of 0.22" is a .22 cal; however, the decimal point is generally dropped when spoken, as in "twenty-two caliber" or a "two-two caliber." Calibers of guns can also be referred to in millimeters (mm), as in a "caliber of eighty-eight millimeters" (88 mm).

**Ceiling (C):** The concentration that should not be exceeded during any part of the exposure.

**Chemical substances:** Any element, compound, or mixture of elements and/or compounds used in or produced by a chemical process. A chemical substance may be considered hazardous due to a physical hazard (e.g., flammability, corrosivity) or health hazard (e.g., irritation, specific target organ system damage, carcinogenicity). This TG chapter focuses on health hazards associated with chemical substances.

**Combustion product:** Chemicals generated by the burning of fuels and munitions, including any unburnt or partially combusted vapors. In an HHA, health hazards may be categorized as fuel combustion products or weapon combustion products depending on the source of combustion.

**“Dirty dozen”:** Generally used term for common weapon and fuel combustion products. These common chemicals are the drivers for test plans and analyses. Refer to Table 3–1 for the common combustion products by platform.

**Hazard index (HI):** Specific method for calculating the combined effects of additive exposures. Additive exposure limits are needed for simultaneous exposures to two or more chemicals that have toxic effects on the same target organs of the body. The HI is equal to:

$$HI = \frac{\text{concentration}_1}{OEL_1} + \frac{\text{concentration}_2}{OEL_2} + \dots + \frac{\text{concentration}_n}{OEL_n} \quad (\text{Equation 3-1})$$

Where:

*HI* = hazard index

*OEL* = occupational exposure limit

An HI of greater than 1.0 indicates an overexposure to the combination of additive compounds. Short-term and peak concentrations for certain chemicals may need to be evaluated separately from the HI.

**Inhalable particles:** Particles considered hazardous when deposited anywhere in the respiratory tract. The ability of a particle to deposit in the respiratory tract depends on its size (i.e., aerodynamic diameter). The particle size having a 50% inhalable fraction is commonly considered to be about 100 microns ( $\mu\text{m}$ ) in diameter. A portion of these particles, depending upon size, can be ingested through mucociliary clearance.

**Military exposure guideline (MEG):** Established by the U.S. Army Public Health Center (APHC) in TG 230, concentrations of chemicals in air, water, and soil that are designed as decision aids for health risk assessors to evaluate the significance of field exposures to chemical hazards during deployments. A MEG is a chemical concentration which represents a safe-sided estimate of the level above which certain types of health effects may begin to occur in individuals after an exposure of the specified duration. The MEGs may be used in an HHA to assess risk when OELs are exceeded (refer to section 3-6A).

**Nanomaterials:** Materials that have been purposefully manufactured, synthesized, or manipulated to have a size with at least one dimension in the range of approximately 1 to 100 nanometers (nm) and that may exhibit unique properties determined by their size, shape, and surface chemistry. A nanometer is one billionth of a meter, which is near-atomic scale.

**Nanoparticles:** Typically described as having at least one dimension in the size range of approximately 1 to 100 nm.

**Nanotechnology:** A term referring to a wide range of technologies that measure, manipulate, or incorporate materials and/or features with at least one dimension between approximately 1 and 100 nm. Such applications exploit the properties, distinct from bulk/macroscopic systems, of nanoscale components.

**Occupational exposure limit (OEL):** The general term referring to the exposure limit applicable to the U.S. Army. The OEL may be an Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) (i.e., federal regulation), an American Conference of Governmental Industrial Hygienists (ACGIH<sup>®</sup>) Threshold Limit Value (TLV<sup>®</sup>), a military-unique standard, or another appropriate standard based on Department of the Army Pamphlet (DA Pam) 40-503 guidance. Some OELs are authoritative, i.e., based on federal regulations and Army policy (e.g., PELs, TLVs), and some are used only as guidelines. The authoritative OELs take precedence in Army HHAs.

**Ototoxic substance:** Chemicals that cause hearing loss independently through inhalation, ingestion, or dermal exposure routes or work synergistically with hazardous

noise to damage the inner ear (e.g., cochlea or auditory nerve) and, at times, the vestibular or peripheral nervous systems.

**Permissible exposure limit (PEL):** An OEL promulgated by OSHA and enforceable by law (29 Code of Federal Regulations (CFR) Part 1910.1000). Most PELs are defined as an 8-hour time-weighted average (TWA). The TWA PEL is the level of exposure established as the highest level of exposure to which an employee may be exposed in an 8-hour work shift of a 40-hour work week without incurring the risk of adverse health effects. Some chemical substances may have a 15-minute short-term exposure limit (STEL), ceiling limit, and/or action level.

**Recommended Exposure Limit (REL):** An OEL promulgated by the National Institute for Occupational Health and Safety (NIOSH). The RELs are often more conservative than the PELs and are not legally enforceable limits. Historically, the full-shift RELs were 10-hour TWAs, but some are now 8-hour TWAs.

**Respirable particles:** Particles considered hazardous when deposited in the gas-exchange region. The ability of a particle to deposit in the respiratory tract depends on its size. Fifty percent of the particles with an aerodynamic diameter of 4  $\mu\text{m}$  are in the respirable fraction.

**Threshold Limit Value<sup>®</sup> (TLV<sup>®</sup>):** An OEL promulgated by the ACGIH. If a TLV is exceeded, a potential health hazard from that substance is presumed to exist. The ACGIH uses three categories of TLVs, specified as 8-hour time-weighted average (TLV-TWA), short-term exposure limit (TLV-STEL), or ceiling (TLV-C) value. For the full definition, refer to the ACGIH *Threshold Limit Values (TLVs<sup>®</sup>) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs<sup>®</sup>)*, hereafter referred to as the “ACGIH TLV Book” (see Appendix 3A).

**Threshold Limit Value Short-term Exposure Limit (TLV-STEL):** Established by the ACGIH, a 15-minute TWA exposure limit to which nearly all workers may be exposed without experiencing adverse health effects. The TLV-STEL supplements the TLV-TWA when a substance has acute effects in addition to chronic effects. The ACGIH includes conditions to which the TLV-STEL should be applied (e.g., number of exposures per 8-hour workday, time between successive exposures). Refer to the ACGIH TLV Book for the full definition.

**Threshold Limit Value Short-term Exposure Limit (TLV-STEL) Default Value:** The ACGIH recommends default short-term exposure limits for substances with a TLV-TWA but no TLV-STEL in order to control short-term peak exposures. These values provide conditions for the TLV-TWA by limiting the extent to which the TLV-TWA may be exceeded in a 15-minute period and how often it may be exceeded. It is good practice to apply these conditions to excursions above other 8-hour OELs where there are no STELs. Refer to the ACGIH TLV Book for the full definition.

**Threshold Limit Value Time-weighted Average (TLV-TWA):** Established by the ACGIH, an 8-hour TWA exposure limit to which nearly all workers may be exposed repeatedly, day after day, that should not be exceeded over an 8-hour workday and 40-hour workweek. Most workers may be repeatedly exposed at this TWA concentration over a 40-hour workweek and their working lifetime without experiencing adverse health effects. Refer to the ACGIH TLV Book for the full definition.

**Time-weighted average (TWA):** Concentration averaged over a specified time period (typically an 8-hour workday and a 40-hour work week for the exposure limits in this chapter). The equation used to calculate the TWA is:

$$TWA = \frac{t_1C_1+t_2C_2+\dots+t_nC_n}{t_1+t_2+\dots+t_n} \quad (\text{Equation 3-2})$$

Where:

TWA = time-weighted average

t = duration of exposure

C = concentration for n number of exposures

**Workplace Environmental Exposure Level® (WEEL®):** An OEL promulgated initially by the American Industrial Hygiene Association (AIHA), and more recently by the Occupational Alliance for Risk Science (OARS). Nearly all of these OELs are for chemicals for which no TLVs exist.

### 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. Occupational Exposure Limits.** As practicable, the Army will apply the standards set by OSHA, ACGIH, and other non-DOD regulatory health standards to military-unique equipment, systems, and operations. Department of Defense Instruction (DODI) 6055.01 directs the use of the OSHA PELs for compliance with federal regulations. DA Pam 40–503 further directs the Army to use the ACGIH TVLs when they are more stringent than the PELs. The RELs or WEELs may be used when there is neither a TLV nor a PEL, or when mandated. (Note: The chemical substances assessed in HHAs nearly always have PELs and TLVs.) When existing OELs are infeasible or inappropriate, the Army will use the health risk management process to develop military-unique occupational health standards. These military-unique OELs and standards may be applied to military-unique exposures. In the absence of OELs, limits established by others may be used with appropriate judgment.

(1) **Occupational Safety and Health Administration and American Conference of Governmental Industrial Hygienists.** Table 3–1 provides the OSHA PELs and ACGIH TLVs for common combustion products by platform. The Army OEL is the more stringent of the ACGIH and OSHA OELs. For example, the Army OEL 8-hour

TWA for ammonia (NH<sub>3</sub>) is 25 parts per million (ppm) (ACGIH TLV), not 50 ppm (OSHA PEL). Refer to the Z-Tables of 29 CFR 1910.1000 and the ACGIH TLV Book to obtain OELs for other chemical substances. In the event that there is no PEL or TLV, refer to the OARS website for WEELs (<https://www.tera.org/OARS/>) and the *NIOSH Pocket Guide to Chemical Hazards* for RELs (<https://www.cdc.gov/niosh/npg/search.html>). Otherwise, refer to DA Pam 40–503 for examples of alternative exposure limits.

**Table 3–1. Occupational Exposure Limits for Common Combustion Products by Platform<sup>a</sup>**

| Platform  | Compound   | OSHA PEL <sup>b</sup>                                   | ACGIH TLV-TWA   | ACGIH TLV-STEL              |                 |
|---|--|---|---|-----------------------------|-----------------|
| <b>Product Compounds Common to Combustion Processes</b> | Carbon Dioxide (CO <sub>2</sub> )                    | 5,000 ppm   | 5,000 ppm   | 30,000 ppm                  |                 |
|   | Carbon Monoxide (CO) <sup>c</sup>                    | 50 ppm  | 25 ppm  | 75 to 125 ppm <sup>d</sup>  |                 |
|   | Nitric Oxide (NO)                                    | 25 ppm  | 25 ppm  | 75 to 125 ppm <sup>d</sup>  |                 |
|   | Nitrogen Dioxide (NO <sub>2</sub> )                  | 5 ppm (C)   | 0.2 ppm   | 0.6 to 1.0 ppm <sup>d</sup> |                 |
|   | Sulfur Dioxide (SO <sub>2</sub> )                    | 5 ppm   | –   | 0.25 ppm                    |                 |
| <b>Additional Platform-Specific Product Compounds</b>   | <b>Small Arms &amp; Large Caliber Weapons Firing</b> | Ammonia (NH <sub>3</sub> )                              | 50 ppm  | 25 ppm                      | 35 ppm          |
|   |  | Hydrogen Cyanide (HCN)                                  | 10 ppm  | –                           | 4.7 ppm (C)     |
|   |  | Lead (Pb) <sup>e</sup>                                  | AL = 0.03 mg/m <sup>3</sup><br>TWA = 0.05 mg/m <sup>3</sup> | 0.05 mg/m <sup>3</sup>      | –               |
|   | <b>Automotive and Generator Engine Operation</b>     | Acrolein (C <sub>3</sub> H <sub>4</sub> O) <sup>f</sup> | 0.1 ppm   | –                           | 0.1 ppm (C)     |
|   |  | Benzene (C <sub>6</sub> H <sub>6</sub> ) <sup>f</sup>   | AL = 0.5 ppm<br>TWA = 1 ppm<br>STEL = 5 ppm                 | 0.5 ppm                     | 2.5 ppm         |
|   |  | Formaldehyde (CH <sub>2</sub> O) <sup>f</sup>           | AL = 0.5 ppm<br>TWA = 0.75 ppm<br>STEL = 2 ppm              | 0.1 ppm                     | 0.3 ppm         |
|   |  | Particulate (as total organic carbon)                   | 160 µg/m <sup>3</sup> (MSHA PEL)                            | –                           | –               |
|   | <b>Rocket/Missile Firing/Launching</b>               | Hydrogen Chloride (HCl)                                 | 5 ppm (C)   | –                           | 2 ppm (C)       |
|   |  | Lead (Pb) <sup>e</sup>                                  | AL = 0.03 mg/m <sup>3</sup><br>TWA = 0.05 mg/m <sup>3</sup> | 0.05 mg/m <sup>3</sup>      | –               |
|   |  | Tungsten (W)  | -   | See footnote g.             | See footnote g. |

## Legend:

– = no applicable limit established  
ACGIH = American Conference for Governmental Industrial Hygienists  
AL = action level as an 8-hour time-weighted average  
C = ceiling limit  
 $\mu\text{g}/\text{m}^3$  = micrograms per cubic meter  
 $\text{mg}/\text{m}^3$  = milligrams per cubic meter  
MSHA = Mine Safety and Health Administration  
OSHA = Occupational Safety and Health Administration  
PEL = permissible exposure limit  
ppm = parts per million  
R = respirable particulate matter  
STEL = 15-minute short-term exposure limit  
TLV = Threshold Limit Value  
TWA = 8-hour time-weighted average

## Notes:

- <sup>a</sup> Information contained in this table appears in the OSHA Annotated Table Z-1 (<https://www.osha.gov/annotated-pels/table-z-1>).
- <sup>b</sup> Criteria reported are an 8-hour time-weighted average unless otherwise specified.
- <sup>c</sup> For military-unique exposure, use the Military Standard 1472H carboxyhemoglobin limits instead of OSHA and ACGIH limits (refer to section 3-3B(2)).
- <sup>d</sup> No STEL or ceiling limit is published for the TLV-TWA. Refer to the definition for "Threshold Limit Value Short-term Exposure Limit (TLV-STEL) Default Value" in section 3-2.
- <sup>e</sup> Due to research findings demonstrating adverse health effects of lead in adults at blood-lead levels previously considered acceptable in the workplace, the Department of Defense is updating its lead exposure guidance. The new OEL, when promulgated, is expected to be lower. The U.S. Army Public Health Center has established an interim criterion of  $10 \mu\text{g}/\text{m}^3$  (refer to Appendix 3B).
- <sup>f</sup> Sampling for this chemical may not be required. Coordinate test plans with the APHC.
- <sup>g</sup> Refer to the ACGIH TLV Book for this value.

Biologically inert, insoluble, or poorly soluble particles, for which little data exist, may have adverse effects. The ACGIH recommends that airborne concentrations be kept below 3 milligrams per cubic meter ( $\text{mg}/\text{m}^3$ ) for respirable particles, and  $10 \text{ mg}/\text{m}^3$  for inhalable particles, until a TLV is set for a particular substance.

(2) ***Military-unique OELs and Guidelines.*** Military-unique OELs and guidelines may be applicable for certain chemicals of concern depending on the use scenario. Established in Military Standard (MIL-STD) 1472H, the carboxyhemoglobin (COHb) limit for carbon monoxide (CO) exposure during weapons firing is the only authoritative military-unique OEL. An update to DODI 6055.01 is expected to include appendices with additional military-unique OELs for select contaminants (e.g., lead, hexavalent chromium).

Military-unique guidelines include the MEGs established by the APHC in TG 230, and the permissible exposure guidance levels (PEGLs) and emergency exposure guidance levels (EEGLs) established by the National Research Council (NRC) for military use. While these guidelines do not take precedence over Army OELs, they may provide benchmarks for assessing risk.



(a) Carboxyhemoglobin. When CO exposures due to weapon combustion products are military-unique and not consistent with civilian occupational exposures, the COHb limits are the most appropriate criteria to apply. MIL-STD-1472H states that “Personnel shall not be exposed to concentrations of CO that will result in carboxyhemoglobin (COHb) levels in their blood greater than 5 percent for aviation system performance limits” and “greater than 10 percent (threshold) and 5 percent (objective) for all other system performance limits.” For exposures to weapon combustion products in settings such as indoor firing ranges, and for exposures to fuel combustion products, the TLVs and PELs apply because these exposures are similar to those encountered in civilian occupations; however, there may be rare instances where the COHb limit is used.

Abundant literature is available regarding human exposure to CO. The Coburn-Forster-Kane (CFK) equation represents CO exposure as a COHb percentage to evaluate military-unique exposure scenarios. The equation and constants are specified in MIL-STD-1472H. (Note: The original constants were provided in Military Handbook 759 and were replaced and revised in MIL-STD-1472). Smith, Steinberg, and Gaydos (1996) thoroughly review and describe the derivation of the CFK equation and the revision of the constants. Given the necessary input, the CFK equation provides the flexibility of solving for the CO air concentration, partial pressure of inhaled CO, or COHb percentage. It can be used to estimate the instantaneous percent COHb from a series of CO measurement intervals or to estimate a single COHb value using the average CO concentration and exposure time. The CFK equation is:

$$\%COHb_t = \%COHb_i(e^{-t/A}) + M(1 - e^{-t/A})\left(\frac{1}{B} + \frac{CO}{PI_{CO}}\right) \quad (\text{Equation 3-3})$$

Where:

$\%COHb_t$  = predicted percent COHb in blood at time  $t$

$\%COHb_i$  = initial percent COHb (1% as specified in MIL-STD-1472H for non-smoking adults) or the  $\%COHb_t$  calculated from the previous interval

$t$  = exposure time in minutes

$A$  = work level A (refer to Table 3-2)

$B$  = work level B (refer to Table 3-2)

$M$  = Haldane coefficient (constant value = 218)

$CO$  = air concentration of CO (ppm)

$PI_{CO}$  = partial pressure of inhaled CO (constant value = 1403)

In the CFK equation,  $A$  and  $B$  are constants obtained from Table 3-2; they depend on the estimated physical activity level of the individual during the exposure.

MIL-STD-1472H assigns a work effort of 4 for weapons firing and a work effort of 3 for all other mission activities. The CFK equation accounts for the minute respiratory volume of contaminated atmosphere actually inhaled by an exposed individual whose level of physical activity is either estimated or specified. The CFK equation also accounts for the elimination of CO by the body, which is much slower than the

hemoglobin binding ability of CO. The CFK equation is applicable to short-duration high-level exposures as well as low-level exposures of long duration. The CO exposure magnitude, frequency, and duration are unlimited provided the adopted medical criterion specified by MIL-STD-1472H is met.

**Table 3–2. Work Effort Constants for Predicting Carboxyhemoglobin Blood Content**

| Work Effort Scale | Work Effort Description                           | Alveolar Ventilation Rate (liters per minute) | A Value | B Value |
|-------------------|---|---|---------|---------|
| 1                 | Sedentary   | 6   | 425     | 806     |
| 2                 | Light Work<br>(e.g., cooking, truck driving)      | 12  | 241     | 1421    |
| 3                 | Moderate Work<br>(e.g., light walking, cycling)   | 18  | 175     | 1958    |
| 4                 | Heavy Work<br>(e.g., loading, shoveling)          | 24  | 134     | 2553    |
| 5                 | Very Heavy Work<br>(e.g., jogging, hill climbing) | 30  | 109     | 3144    |

(b) *Military Exposure Guidelines (MEGs)*. APHC TG 230 provides MEGs for various exposure durations and severities, and discusses the application of these guidelines. The MEG chosen should be representative of the exposure duration, route of exposure, and use scenario. The air MEGs are most commonly applied in an HHA to assess exposures to chemicals via the inhalation or ocular routes of exposure. TG 230 also includes the basis for which the MEG was determined (e.g., health protection criteria, health effects). APHC TG 230 and the current MEGs are available at: (<https://phc.amedd.army.mil/topics/envirohealth/hrasm/Pages/TG230.aspx>). As of the date of this publication, the MEGs are undergoing revision. Check the website for the most current values and guidance. Note: The MEGs are also listed in the APHC Riskit® Substance Index (RDEX) (<https://ephc.amedd.army.mil/RDEX>).

(c) *Permissible Exposure Guidance Levels (PEGLs)*. The PEGLs are established by the NRC for **military** populations. A PEGL is the concentration of a substance in air to which personnel can be exposed repeatedly, up to a specified total exposure, on a weekly basis (usually 8 hours per day, 5 days per week), for several years without experiencing adverse health effects or degradation in performance. The PEGLs are similar to guidelines for occupational exposures although the duration of exposure specified can be more or less than 40 hours per week, depending on military training regimens. PEGLs specific to Soldier training exposures to smokes and obscurants are commonly used in HHAs. The PEGLs are listed in the RDEX.

(d) *Emergency Exposure Guidance Levels (EEGLs)*. The EEGLs are established by the NRC for **military** populations. An EEGL is defined as a concentration of a

substance in air (as a gas, vapor, or aerosol) that will permit continued performance of specific tasks during emergency exposures ranging from 1 to 24 hours—an occurrence expected to be infrequent in the lifetime of a person, and a rare and unexpected situation with potential for significant loss of life, property, or mission accomplishment if not controlled. An EEGL is acceptable only during an emergency, when some discomfort or risk must be taken to avoid greater risks, such as fire, explosion, or massive releases of toxic material. Because an HHA addresses normal use and does not include emergencies or rare occurrences in its scope, the EEGLs are not normally applied for their intended purpose. Exposures above the EEGL may, however, cause transient adverse effects, such as increased respiratory rate, headache (but not debilitating headache), mild central-nervous-system effects, or irritation to the eyes or upper respiratory tract. These values are listed in the RDEX.

(3) **Other Guidelines.** Other organizations such as the U.S. Environmental Protection Agency (EPA), AIHA, and NIOSH, provide additional exposure guidelines. While these guidelines do not take precedence over Army OELs, they may provide benchmarks for assessing risk. Most of these values are listed in the RDEX.

(a) Acute Exposure Guideline Levels (AEGLs). The AEGLs are established by the EPA for the **general** population for exposure durations ranging from 10 minutes to 8 hours.

- AEGL-1: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

- AEGL-2: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

- AEGL-3: The airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

(b) Emergency Response Planning Guidelines (EPRGs™). The EPRGs are established by the AIHA for the **general** population. They are air concentration guidelines for single exposures to agents and are intended for use as tools to assess the adequacy of accident prevention and emergency response plans.

- ERPG-1: Maximum concentration in air below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

- ERPG-2: Maximum concentration in air below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

- ERPG-3: Maximum concentration in air below which nearly all individuals could be exposed up to 1 hour without experiencing or developing life-threatening health effects.

(c) Immediately Dangerous to Life and Health values (IDLHs). The IDLH values are established by NIOSH for a **worker** population; they are maximum airborne concentration levels above which only a highly reliable breathing apparatus providing maximum worker protection is permitted. The IDLH values are based on a 30-minute escape window after a respirator fails. The IDLH values may be found at: <https://www.cdc.gov/niosh/idlh/intridl4.html>.

(d) National Aerospace Standard (NAS) 411-1. The Hazardous Material Target List (HMTL) is a list of chemical substances subject to restrictions and/or reporting requirements related to military systems developed under defense acquisition and related service contracts. The HMTL is intended to be used within a risk management framework such as described in NAS 411 and MIL-STD-882E. The HHA Program is not responsible for verifying that systems meet these requirements.

**C. Toxic Materials.** The APHC Toxicology Directorate performs Toxicity Clearances (TCs) and Toxicity Assessments (TAs) on toxic materials for specific systems and applications based on available research and health protection criteria (refer to section 3-5F for more information).

**D. Ototoxicants.** Ototoxicants are chemicals that cause damage to the inner ear (cochlea), vestibular system, or peripheral nervous system (8<sup>th</sup> cranial nerve). Thus, ototoxic chemicals are classified as neurotoxicants, cochleotoxicants, or vestibulotoxicants based on the part of the ear they damage. The resultant damage may lead to temporary or permanent hearing loss and/or loss of balance. Ototoxicants may cause health hazards independently, or synergistically with hazardous noise. The potential for ototoxicity has not been determined for many chemicals. Examples of ototoxicants in the workplace include organic solvents, metals, and asphyxiants. Of the common combustion products listed in Table 3-1, likely ototoxicants include CO, hydrogen cyanide (HCN), lead, and benzene. Organic solvents used in jet fuels and to clean weapons may have ototoxic effects. Based on common exposure levels, CO and lead are likely the main ototoxicants of concern during weapons firing. Exposure factors (e.g., duration, medication use) may affect the risk of injury.

Health protection criteria for ototoxicants are still under development. The ACGIH designates certain chemicals as ototoxic in order to focus attention on the need to control exposures; however, ototoxicity is not used as a basis for the TLVs. As a general guideline, effects on hearing loss may need to be considered when exposures

to ototoxicants are above 50% of the OEL, even if there is no concurrent hazardous noise exposure. In accordance with DA Pam 40–501, the Army Hearing Program requires hearing conservation and medical surveillance programs for all Soldiers. These monitoring programs may help prevent hearing loss as a result of exposure to ototoxicants. APHC Fact Sheet 51-002-0713 and the NIOSH provide more information about ototoxicants and hearing loss.

Refer to TG 351A, *Health Hazard Assessor's Guide: Acoustic Energy*, for more information on HHAs related to acoustic energy.

**E. Nanomaterials.** Nanomaterials have many commercial applications (e.g., paint, fabrics, decontamination agents, biocides, paper, additives, food). Currently, health protection criteria and medical models for nanomaterial exposures are very limited. Carbon nanotubes (CNT) and titanium oxide (TiO<sub>2</sub>) are the only two nanomaterials with nationally recognized exposure limits.

The NIOSH has adopted a REL of 1 microgram per cubic meter (µg/m<sup>3</sup>) of respirable elemental carbon as an 8-hour TWA. For comparison, the PELs for carbon black and graphite are 3500 µg/m<sup>3</sup> and 5000 µg/m<sup>3</sup>, respectively. Analysis is performed by the NIOSH 5040 method.

The NIOSH recommends exposure limits of 2.4 mg/m<sup>3</sup> for fine TiO<sub>2</sub> and 0.3 mg/m<sup>3</sup> for ultrafine (including engineered nanoscale) TiO<sub>2</sub>, as TWA concentrations for up to 10 hours per day during a 40-hour work week. Ultrafine is defined as the fraction of respirable particles with a primary diameter of less than 100 nm (i.e., nanoparticles). The NIOSH has determined that ultrafine TiO<sub>2</sub> is a potential occupational carcinogen; however, there are insufficient data at this time to classify fine TiO<sub>2</sub> as a potential occupational carcinogen. For comparison, the PEL for bulk TiO<sub>2</sub> is 15 mg/m<sup>3</sup>. Analysis is performed by the NIOSH 0600 analytical method using a standard 10-millimeter nylon cyclone or equivalent particle sizes elective sampler. The military application of TiO<sub>2</sub> as smoke and obscurants is of particular interest for its potential inhalation hazard to Soldiers. The NRC recommends a 15-minute EEGL for TiO<sub>2</sub> smoke of 1800 mg/m<sup>3</sup>. Toxicity of many nanoparticles is based upon shape, size, and surface chemistry. Characterizing nanoparticles is often complex and resource intensive.

**F. Fire-Extinguishing Agents and Refrigerants.** Evaluation of automatic fire-extinguishing systems (AFES) and handheld fire extinguishers is not within the scope of the HHA Program. Fire suppression systems are used in the event of a fire, mishap, or failure and not during normal use scenarios. Accidental release of refrigerants is not within the scope of the HHA Program; however, refrigerants may be assessed in specific systems where exposure to the hazardous substances is routine and/or prolonged (e.g., maintenance kits). The APHC Toxicity Evaluation Division (TEV) performs TCs on these agents for specific systems and applications (refer to section 3–5F for more information). The TEV, U.S. Army Ground Vehicle Systems Center (GVSC), and the U.S. Army Research Laboratory Survivability and Lethality Directorate (SLAD) are the main proponents involved in live-fire test and evaluation (LFTE), toxicity

evaluations, pyrolysis by-product assessments, and development of health-based criteria for LFTE. Survivability criteria are specified in Military Handbook 684 and the Walter Reed Army Institute of Research report, *Medical Evaluation of Nonfragment Injury Effects in Armored Vehicle Live Fire Tests*. The EPA (<https://www.epa.gov/snap>) and National Fire Protection Association (<https://www.nfpa.org/Codes-and-Standards/All-Codes-and-Standards/List-of-Codes-and-Standards>) provide additional guidelines.

**G. Batteries.** Most Army systems use batteries; however, these batteries do not present a significant health risk to users under normal operating conditions and are not assessed in an HHA. The U.S. Army Communications-Electronics Command provides guidance on safety and health, use, storage, and disposal requirements for batteries in Technical Bulletin 43-0134.

### 3-4. Health Effects of Chemical Substance Exposures

**A. General Health Effects.** Potential health effects associated with chemical substances vary based on multiple factors, such as the following:

- Chemical properties/characteristics
- Chemical concentration
- Toxicity/dose-response
- Use scenario
- Route of exposure
- Exposure duration and frequency
- Interactions with other chemicals and hazards present
- Individual susceptibility

Exposure to chemical substances may elicit an immediate or acute response to a high-intensity exposure or may result in a delayed response to a low-level chronic exposure.

A number of variables such as age, sex, ethnicity, smoker or non-smoker status, level of fitness, diet, underlying chronic diseases or injuries, and medication use may affect tolerance or susceptibility to chemical substances exposure, which may impact the probability of an adverse health outcome. While evaluating individuals to ascertain their status regarding these variables may be optimal, it is impractical to consider all of these risk factors for each Soldier in an HHA. Evaluation methods to estimate probability of injury and to account for variability differ based on the chemical substance, as described in section 3-6. For example, Soldier respiratory rate may be factored into the assessment. Soldiers are subject to increased rates of respiratory effort due to the high levels of stress combined with the urgent and excitable nature of combat. This stress, in addition to level of work effort, can increase respiratory rate and subsequently increase the rate of chemical uptake by inhalation. Increased stress and work effort can also result in other reactions in the body that may affect the health effects of exposures (e.g., increase in heart rate and circulation). Health effects that are dependent on exposure

concentration only (e.g., certain portal of entry effects for irritants) may not be dependent on respiratory rate, chemical uptake, or dose.

Simultaneous exposures to multiple chemical substances may lead to additive, potentiating, or synergistic effects, particularly when different chemicals produce toxic effects in the same target organs of the body. Additive effects are combined health effects of simultaneous exposures equal to the sum of the individual effects (i.e.,  $1+1=2$ ). For example, simultaneous exposure to CO, HCN, and nitric oxide (NO) may be considered additive because each may affect the body's oxygen supply. Potentiating effects are combined health effects of simultaneous exposures where the effects of one chemical are enhanced when another chemical is present. Synergistic effects are combined health effects of simultaneous exposures greater than the sum of the individual effects (i.e.,  $1+1>2$ ). Refer to section 3–5F for more information about assessing additive, potentiating, and synergistic effects.

The following two resources provide health effects of many chemical substances:

<https://www.cdc.gov/niosh/npg/default.html>

<https://www.atsdr.cdc.gov/substances/index.asp>

**B. Health Effects of Common Combustion Products.** Table 3–3 provides a summary of health effects of common weapon and fuel combustion products. Appendix 3B provides further descriptions for these commonly assessed chemical substances.

**Table 3–3. Health Effects of Common Combustion Products**

| Chemical                          | Health Effects  |
|-----------------------------------|---|
| Acrolein                          | Irritation of the eyes and respiratory tract.   |
| Ammonia (NH <sub>3</sub> )        | Irritation of eyes, nose, throat, and lower respiratory tract.  |
| Benzene                           | Known human carcinogen that causes leukemia.  |
| Carbon Dioxide (CO <sub>2</sub> ) | Although a simple asphyxiant, it is also a potent stimulus to respiration and affects the central nervous system. Weakly narcotic at high concentrations.   |
| Carbon Monoxide (CO)              | Impairs the body's uptake of oxygen by preferentially combining with the hemoglobin that normally takes up inhaled oxygen to form a compound called carboxyhemoglobin (COHb). COHb is slow to break down and release the hemoglobin molecule. High exposures may lead to unconsciousness and death. Lower exposures can reduce task and work performance. |
| Formaldehyde                      | Irritation of the eyes and upper respiratory tract. Sensitizer and known human carcinogen.  |
| Hydrogen Chloride (HCl)           | Irritation of mucous membranes. Corrosive to the skin. Severe effects from exposure to the eyes.  |
| Hydrogen Cyanide (HCN)            | Dizziness, nausea, weakness. Impairs the body's uptake of oxygen (can be considered additive when a combined CO exposure exists).   |
| Lead (Pb)                         | Acute: lung and eye irritation, acute encephalopathy, renal failure, severe gastrointestinal distress.<br>Chronic: numbness in extremities, anemia, reproductive changes, brain damage, nervous system damage, kidney damage, behavioral changes, learning and memory disturbances.   |

| Chemical  | Health Effects   |
|---|--|
| Nitric Oxide (NO) and Nitrogen Dioxide (NO <sub>2</sub> ) | Irritation of eyes, skin, nose, and throat. NO may produce nervous system impairment and fetal damage. NO forms a hemoglobin compound (methemoglobin) that reduces the supply of oxygen to body tissues. This effect is similar and additive to that of CO. NO <sub>2</sub> is more toxic than NO. High NO <sub>2</sub> exposures may cause lung damage. |
| Particulate   | Lung inflammation and impairment. Particles may also adsorb carcinogenic compounds.  |
| Sulfur Dioxide (SO <sub>2</sub> )                         | Irritation of eyes, nose, throat, and lower respiratory tract; pulmonary impairment.   |
| Tungsten (W)  | Acute: irritation of the eyes, skin, and respiratory system.<br>Chronic: pulmonary fibrosis, dermatitis, memory impairment.  |

### 3–5. Pre-assessment Procedures

**A. Hazard Identification.** Identify all sources of potentially hazardous chemical substance exposure in the system. This may include, but is not limited to, any system that produces combustion products (e.g., weapon systems, vehicle engines, generators, cooking burners) or requires routine, prolonged exposure to toxic materials. Early HHA involvement in the development of systems with these identified chemical hazards may eliminate or control health hazards by allowing implementation of more effective mitigation strategies.

(1) **Fuels and non-fuel petroleum, oil, lubricants, and coolants.** Nearly all Army systems, from cooking burners to helicopters, use fuels such as jet propellant 8 (JP-8), diesel fuel #2 (DF-2), and kerosene. Gasoline and other similar fuels that may be used in some systems (e.g., unmanned aerial vehicles) are likely to produce more CO than diesel or gas turbine engines. The Department of Defense has adopted a single-fuel concept that requires U.S. forces to use only one fuel (JP-8) while deployed. The chemical compositions of JP-8 can vary widely, depending on the crude oil from which it was refined, and may contain a wide variety of additives (e.g., antioxidants, static inhibitors, corrosion inhibitors, fuel system icing inhibitors, lubrication improvers, biocides, and thermal stability improvers). Army Regulation (AR) 70–12 provides specifications for fuels and their additives, petroleum, oil, lubricants, coolants, and more.

HHAs should include risk assessments associated with fuel combustion products. Refer to the applicable rows in Table 3–1 (i.e., product compounds common to combustion processes; automotive and generator engine operation) for combustion products associated with these fuels.

Routine exposures to fuels and non-fuel petroleum products, oil, lubricants, and coolants are typically not assessed in an HHA because they are widely used in nearly every Army system. Operational exposures are expected to be limited to dermal or inhalation exposures during refueling and occasional maintenance. Personnel serving in a specific military occupational specialty (MOS) (e.g., 92F) are trained in handling these compounds. Recommended controls include wearing appropriate personal protective



equipment (PPE), washing exposed skin, and changing into clean clothes promptly after exposure.

(2) **Weapon combustion products.** Nearly all weapon systems produce combustion products that may be considered potential health hazards. The compositions of the primer, propellant, projectile, and fuze may affect the types of products generated. Weapons exclusively used outdoors may not be subject to weapon combustion product testing. Refer to the applicable rows in Table 3–1 (i.e., product compounds common to combustion processes; small arms and large caliber weapons firing; rocket/missile firing/launching) for combustion products associated with weapons.

(3) **Toxic materials.** Toxic materials used within a system or associated with the normal use and maintenance of a materiel system may be assessed in an HHA when exposure to the hazardous substances is routine and/or prolonged. Examples of systems that may expose Soldiers to toxic materials include test kits with reagents, chemically-treated clothing, and chemical, biological, radiological, and nuclear (CBRN) defense systems. A TC may be required if the material is new, its use has changed, or the amount has changed (refer to section 3–5F).

Evaluation of fire-extinguishing agents and batteries are not within the scope of the HHA Program. Refer to sections 3–3F and 3–3G for more information about these materials.

**B. Internal Points of Contact.** The APHC Industrial Hygiene Field Services Division provides subject matter expert (SME) consultation and recommends risk assessment codes (RACs) for chemical substances in HHAs. SMEs in other APHC divisions and programs should be contacted for specific systems and types of chemical substances hazards (Table 3–4).

**Table 3–4. Points of Contact for Chemical Substances Health Hazard Assessments**

| Division/Program                              | Subject Matter Expertise  |
|---|---|
| Industrial Hygiene Field Services Division    | <ul style="list-style-type: none"> <li>• Industrial hygiene</li> <li>• Occupational exposure limits</li> <li>• Assignment of risk assessment codes</li> </ul>   |
| Toxicity Evaluation Division                  | <ul style="list-style-type: none"> <li>• Toxic materials</li> <li>• Toxicity Clearances</li> <li>• Fire-extinguishing agents and refrigerants</li> <li>• Explosives, pyrotechnics, and propellants</li> </ul> |
| Health Effects Research Division              | <ul style="list-style-type: none"> <li>• Toxicity Assessments</li> <li>• New and alternative materials</li> </ul>   |
| Environmental Health Risk Assessment Division | <ul style="list-style-type: none"> <li>• Military exposure guidelines (Technical Guide 230)</li> <li>• Chemical, Biological, Radiological, and Nuclear equipment</li> </ul>                                   |
| Occupational Medicine Branch                  | <ul style="list-style-type: none"> <li>• Clinical toxicology</li> </ul>   |
| Army Hearing Program                          | <ul style="list-style-type: none"> <li>• Ototoxicants</li> </ul>  |

**C. Information Required for a Health Hazard Assessment.** Obtain the system's detailed use scenario, including the operational mode summary/mission profile (OMS/MP) if available, from the materiel developer (MATDEV). Required information varies by hazard source. The MATDEV should provide adequate information to determine the risk of adverse health effects, such as:

- Test data providing chemical concentrations (i.e., exposure levels) with supporting test plan and test report.
- Duration and frequency of exposure (e.g., number of rounds expected to be fired, firing rate, hours spent inside a vehicle or shelter, missions per day, training days per month or year).
- Required tasks of the system operators.
- Operational environment (e.g., vehicle platform, use of suppressors, urban operations, subterranean operations, altitude).
- Expected concentrations of chemicals (e.g., munition composition, amount of toxic materials).

**D. Data Requirements for Combustion Products.**

(1) **Test Standards.** The U.S. Army Test and Evaluation Command (ATEC) Test Operations Procedures (TOP) 02-2-614A and TOP 02-2-622 provide test standards for toxic hazard testing for military vehicles and for military equipment and materiel, respectively.

(2) **Test Plan and Conditions.** Developing an adequate test plan and analyzing the test results require coordination among the user, MATDEV, test agency, and Independent Medical Assessor (IMA). This coordination must begin early enough to permit medical input to the test plans. The coordination should include an opportunity for IMAs to observe the test and provide information necessary to produce a relevant operational analysis of the test data. Testing costs can be reduced by ensuring early IMA involvement and review of test plans. For example, early involvement may help determine which conditions should be tested and which chemicals should be measured.

Chemicals measured should include most of the common combustion products specified in Table 3-1, as applicable to the platform. The TOPs include additional contaminants commonly associated with Army materiel. Test plans should be developed based on the expected contaminants and knowledge of exposure levels associated with similar systems or munition compositions. Some chemicals may be used as indicators of other chemicals likely to be present.

Testing should be representative of the system's normal use and operational conditions. The test conditions should represent conditions of the use scenario and may include, but are not limited to, firing rates; number of rounds expected to be fired; ventilation settings; personnel breathing zones; hatch positions; quadrant elevation; azimuth; and engine speed. Testing should include worst-case conditions for factors affecting air movement, such as ventilation levels and wind conditions (direction and speed).

Data should be collected in durations sufficient for determining a TWA (usually 15 minutes at a minimum) and the effects of varying test conditions. Gases released during firing may become trapped inside the vehicle or persist in and around the vehicle for some time depending on ventilation levels and wind conditions. Generally, concentrations are measured until the values reach steady-state (no ventilation) or decay to pre-fire levels (active ventilation). For a reasonable statistical conclusion to be made, multiple samples at each test condition are necessary (usually 3 to 6 samples at a minimum).

Specific considerations for different types of combustion sources include the following:

- Weapons and munitions should be tested from the vehicles or weapon platforms from which they are fired. Weapon testing is not normally conducted in open air or for externally mounted weapons due to wind and the rapid dissipation of the gases.
- Fuel combustion products from vehicles are typically tested inside the vehicle while stationary with the engine at normal tachometer idle speed. It is recommended that the vehicle be tested each with the front, back, left, and right sides facing the prevailing wind to determine if engine exhaust from the engine and exhaust pipe is entering through open doors, hatches, or the fresh air intake port.
- Non-vehicular fuel burning systems are tested in accordance with normal expected operating arrangements (e.g., inside tents or other enclosures where cooking and space heating equipment are used; normal distances between personnel and generators).

(3) **Test Methods.** Historically, test methods for weapons testing included using specially designed test chambers that enclose the weapon with the muzzle protruding outside the chamber. This method does not provide a practical means for assessing true Soldier exposures when firing the weapon under normal use. Personal air sampling on Soldiers has also been used historically; however, it only allows for TWA measurements, not instantaneous or peak measurements.

Current tests should be conducted using Fourier-transform infrared (FTIR) spectrometers where feasible. This measurement method allows for real-time, continuous data collection of multiple chemicals simultaneously. FTIR is especially beneficial when evaluating transient exposures with peaks in concentration over short durations (e.g., CO exposures during weapons firings). Weapons firing typically produces transient exposures. Some chemicals (e.g., diatomic molecules, chemicals that absorb infrared (IR) radiation similar to water vapor, poor absorbers of IR radiation) are not well detected by FTIR and require a different measurement method. Other air sampling measurement methods may involve the use of handheld direct reading gas monitors or sorbent tubes. More information is provided in Appendix B of TOP 02-2-614A and TOP 02-2-622.

TOP 02-2-622 provides information about the Military Operations in Urban Terrain (MOUT) chambers used to test handheld weapons and ammunition used in urban environments. The MOUT chamber collects real-time concentration data and simulates a realistic firing position for urban environments. The design allows for wind movement and realistic dispersal of combustion products. Small arms weapons used exclusively outdoors may not require testing for combustion products.

**E. Combustion Products Data Analysis.** Calculate the TWA and peak level for each measured compound using the available data. For comparison to the OELs, TWAs may need to be estimated for 8-hour exposures based on the provided use scenario and the data collected over 15-minute periods. Risk levels are based on the maximum likely exposure level. The assessor must consider exposure duration and frequency (e.g., number of missions per day).

(1) **Adjustment for Unusual Work Schedules.** OELs for full shifts are intended for 8-hour per day exposures for 40 hours per week. There are a variety of methods for applying an adjustment factor (AF) for longer daily or weekly exposures, two of which are outlined below. AFs should **not** be used to calculate increases in the 8-hour OEL for shorter exposure durations.

The Brief and Scala method is recommended by the ACGIH as a simple model, and discussed in the Canadian Centre for Occupational Health and Safety Fact Sheet. It takes into account the hours worked daily and the periods of rest between them. This results in an AF which reduces the TLV by a factor for different work schedules. The Brief and Scala AF is calculated on either a daily or weekly basis (Equations 3-4 and 3-5). The weekly basis is used only for a 7-day shift.

$$AF = \frac{8}{\text{daily hours}} \times \frac{(24 - \text{daily hours})}{16} \quad (\text{Equation 3-4})$$

Where:

*AF* = adjustment factor

*daily hours* = number of hours worked per 24-hour period

$$AF = \frac{40}{\text{weekly hours}} \times \frac{(168 - \text{weekly hours})}{128} \quad (\text{Equation 3-5})$$

Where:

*AF* = adjustment factor

*weekly hours* = number of hours worked per 7-day workweek

While a simpler model to use, these formulas may lead to an overestimate of the AF because they do not account for differing half-lives of chemicals in the body. The formulas are not applicable to exposures for fewer than 8 hours per day or exposures

for fewer than 40 hours per week, or to certain chemicals with OELs based on irritation only.

The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) Technical Guide T-22 uses a method that is reported by the ACGIH to produce results similar to those obtained from detailed pharmacokinetic models. Chemicals are assigned a classification of I through IV depending on their toxicological properties, with varying AFs. Technical Guide T-22 lists the adjustment classifications for 705 substances. Table 3-5 provides the IRSST adjustment categories.

**Table 3-5. Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) Adjustment Classifications**

| Adjustment Category and Classification |  | Type of Adjustment  |
|--|--|---|
| I-a                                    | Substances regulated by a ceiling value  | No adjustment   |
| I-b                                    | Irritating or malodorous substances  |   |
| I-c                                    | Simple asphyxiants, substances presenting a safety risk or a very low health risk, whose half-life is less than 4 hours. Technological limitations |   |
| II                                     | Substances that produce effects following <i>short-term</i> exposure   | Daily adjustment  |
| III                                    | Substances that produce effects following <i>long-term</i> exposure  | Weekly adjustment   |
| IV                                     | Substances that produce effects following a <i>short- or long-term</i> exposure  | Daily or weekly adjustment (most conservative of the two) |

Source: IRSST Technical Guide T-22.

Note: The daily adjustment factor (AF) is 8 hours divided by the number of hours worked per daily shift. The weekly AF is 40 hours divided by the average number of hours worked per week.

(2) **Adjustment for Firing Rate.** Occasionally, the assessor is presented with data collected during weapon tests conducted for reasons other than simulating likely actual exposures. With detailed data in spreadsheet form, it is possible to calculate a total exposure expressed as units multiplied by minutes (such as ppm-minutes). Divide that number by the number of rounds, and apply the result to a more realistic firing scenario to estimate the likely average exposure levels.

For example, 25 rounds were fired from a weapon over a test period of 55 minutes. The maximum rate of fire as specified in the weapon's use scenario is 10 rounds per minute. The total exposure is calculated by multiplying the mean of the individual readings by the duration of the exposure. The total exposure of HCN calculated was 24.2 ppm (multiplied by) minutes (ppm-min) over the 25 test rounds, resulting in a maximum exposure per round of 0.97 ppm-min. Firing 10 rounds over a period of 1 minute would produce an estimated mean concentration of 9.7 ppm.

(3) **Common assumptions.** Concentrations of different combustion products in a system may be related. CO is a common indicator of other combustion products. For

example, overexposures to other compounds may be unlikely if overexposures to CO and HCN did not occur. In some cases where all compounds are not able to be measured in real-time, conclusions about peak levels may be inferred by comparison with available CO data. Average concentrations that are a substantial fraction of the ceiling limit may indicate momentary peaks that exceed the ceiling limit.

(4) **Inadequate data.** Limited sample quantity or test conditions often results in an inaccurate determination of risk. If a representative maximum likely exposure level is not able to be determined based on available data, assign a conservative RAC until adequate data are provided. If data are not available for a system, analogy to a similar weapon and/or ammunition of similar chemical composition may be used. Variation in chemical compositions of ammunition of similar calibers is often minor; therefore, combustion products are likely to be similar.

**F. Additive, Potentiating, and Synergistic Effects.** Consider the potential for additive health effects based on the combined effects of two or more chemical exposures that target the same organ(s). Additive effects are normally evaluated by calculating the HI (Equation 3-1). A unique application is the combined effect of CO (as COHb) and HCN on the cell uptake of oxygen developed by the NRC in 2008. (Note: The NRC uses the term hazard quotient (HQ) in this paper, rather than HI, with the same meaning.) The HI for CO and HCN exposure is equal to:

$$HI = \frac{\%COHb, \text{instantaneous}}{10.0\%} + \frac{\text{concentration of HCN, 15 minute running average (ppm)}}{4.7 \text{ ppm}} \quad (\text{Equation 3-6})$$

An HI of greater than 1.0 indicates an overexposure to the combination of CO and HCN, assuming additivity. It is possible to be overexposed to HCN as a result of short-term peak concentrations without exceeding an HI of 1.0.

Effects are synergistic when the presence of one chemical multiplies the toxicity of another chemical. Effects are potentiating when one chemical enhances the health effects of another chemical. These effects have not been identified for the common chemicals that are assessed, and they are rarely encountered otherwise. If they have been identified, the assessment must take these effects into account.

APHC TG 373 Supplement C provides more guidance related to target organs for these types of calculations.

**G. Toxicity Assessments and Clearances.** In accordance with AR 40-5 and AR 70-1, the APHC TEV performs TCs of materials prior to their introduction into the Army supply system to ensure the safety of Army personnel. The MATDEV is responsible for identifying new materials within their program and requesting a TC. The HHA Division may assist in identifying new materials. Requests for a TC or TA may be requested by email (usarmy.apg.medcom-phc.mbx.tox-info@mail.mil) using the formal, signed memorandum template and information here:

<https://phc.amedd.army.mil/topics/labsciences/tox/Pages/Toxicity-Clearances.aspx>

The toxicity evaluation is based on the specific product application or use condition. New uses or a change in product formulations require a new TC. Examples of materials that require a TC are fire-extinguishing agents, fabric treatments, chlorofluorocarbon replacements, solvents, cleaners, corrosion inhibitors, and new chemicals. In addition to a toxicity evaluation, the TC may provide hazard information related to maintenance, PPE, disposal, and the environment. The TEV requires the following information to assist in the completion of a TC:

- Final chemical formulations (handled as proprietary information if required).
- Identity and application of new materials.
- Identity of materials being replaced, if applicable.
- Safety data sheets (SDSs).
- Reports from manufacturers pertaining to commercial use of the products in the marketplace.
- Available human and animal toxicity studies and epidemiology information.

The completion of the TC may not necessarily preclude completion of the HHA because the TEV has a broader scope; that is, it may include environmental, occupational, and other life cycle concerns. However, TEV input is needed for certain HHAs, depending on the system's normal use. For example, a system that involves the routine, prolonged use of a toxic material will be assessed in both a TC (if it is a new material or application) and an HHA. Conversely, a ground vehicle or shelter with an AFES requires a TC but not an HHA because AFES are not considered normal use. The TEV and the HHA Division should collaborate to ensure both required documents are completed for Army materiel undergoing the acquisition process, as applicable.

TAs are reviews of the toxicity of specific chemicals considered for use prior to acquisition. They are technical reviews of all chemicals used or considered for use in systems, to include formulations, and provide recommendations for moving forward. TAs provide the MATDEV with the technical foundation for making sound decisions regarding alternatives and processes and may also inform other documents required for risk-based decision making.

### **3–6. Risk Assessment Process**

The process described in sections A and B is general and may be applied to multiple types of chemical substances exposure. Section C applies to the risk assessment process for CO only. Subsequent sections apply to all HHAs.

**A. Determining Hazard Severity.** Table 3–6 provides a system for assigning hazard severity (HS) based on a comparison of the likely exposure level of a single chemical to the OEL and the anticipated health effects of the exposure level. The table is intended as a general outline for chemical substances with varying health effects, and its use

requires SME judgement and careful consideration of potential exceptions (e.g., OELs are greatly exceeded, data are not representative of the use scenario).

The HS is based on the health effects associated with the maximum likely exposure level, which are not necessarily the same as the health effects upon which the OEL is based. Assessments of exposures above the OEL are based on the dose-response relationships, which are not linear for most chemicals. Some chemicals have multiple routes of exposure (e.g., inhalation and dermal) that may increase the health risk.

If the sample results are below the OEL, significant exposure may be unlikely, and no significant health concerns are expected to be present. For lead (Pb) exposures only, sample results below the Army OEL but above the interim criterion established in Appendix 3B ( $10 \mu\text{g}/\text{m}^3$ ) are assigned an HS 3.

When available, representative quantitative data that define frequency or rate of occurrence for the hazard are preferable to qualitative analysis. If the quantity and/or quality of available data is inadequate (even if sample results are below the OEL), assign a conservative RAC and/or request additional data.

**Table 3–6. Hazard Severity Categories and Health Effects Matrix for Chemical Substances**

| Hazard Severity  |              | Maximum Likely Exposure Level <sup>1</sup> | Health Effects Associated with Maximum Likely Exposure Level <sup>5</sup>  |
|------------------|--------------|--|--|
| Varies           |              | >> OEL <sup>2</sup>                        | Vary   |
| 1                | Catastrophic | > OEL <sup>3</sup>                         | Permanent, severe, disabling, irreversible illness; death  |
| 2                | Critical     |  | Permanent, chronic illness of limited severity (e.g., asthma); loss of capacity; temporary reversible illness with limited disability period |
| 3                | Marginal     |  | Temporary, reversible illness that may result in lost work day(s); performance effects (e.g., dizziness, loss of concentration)              |
| 4                | Negligible   | > OEL <sup>3</sup>                         | Temporary, reversible illness not resulting in a lost work day (e.g., irritation, odor)  |
| No risk assigned |              | < OEL <sup>4</sup>                         | No health effects expected   |

Legend:

OEL = Army occupational exposure limit (Threshold Limit Value or permissible exposure limit)

Notes:

<sup>1</sup> Exposure level of a single chemical only. Mixtures must be assessed in more detail (see section 3–6A(6)).

<sup>2</sup> Exposures that greatly exceed the OEL require further assessment and consideration of the basis of OELs, toxicological data, and other guidelines. Refer to sections 3–6A(2) through (5).



- <sup>3</sup> Includes exposures above the American Conference of Governmental Industrial Hygienists Default Short-term Exposure Limit (refer to section 3-2 for definition).
- <sup>4</sup> Lead (Pb) exposures below the Army OEL but above the interim criterion established in Appendix 3B (10 micrograms per cubic meter) are assigned an HS 3.
- <sup>5</sup> Health effects are determined by the basis of OELs and general toxicological data. Refer to sections 3-6A(2) and (3).

Sub-sections 1 through 6 provide further information about how to use Table 3-6:

(1) **Definitions.** The HS categories for chemical exposures align with Chapter 1 of this Guide, which is based on AR 40-10. Table 3-7 provides the HS category definitions.

**Table 3-7. Hazard Severity Categories**

| Description and 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                                    |

Note: The MEGs are also divided into HS categories. By definition, these HS categories are similar to those in Table 3-7 but with some differences. Table 3-4 of TG 230 provides the health effects descriptions for the HS categories applicable to the MEGs.

(2) **Documentation and Basis of Occupational Exposure Limits.** Each TLV is supported by ACGIH documentation that reviews the known human and animal health effects of various exposure levels, identifies routes of exposure and target organs for toxicity, and explains the health effects that were used to determine the TLV. The health effects are summarized in the ACGIH TLV Book.

Preambles to the final rules of new PELs implemented since 1970 include some documentation of the PELs. PELs implemented prior to 1970 were derived from the existing TLVs.

Appendix E of TG 230 provides the health effects basis of the MEGs.

The NIOSH Pocket Guide lists the target organs, routes of exposure, and symptoms of overexposure associated with each REL. Documentation for WEELs is not posted.

(3) **General Toxicological Data.** In addition to OEL documentation and basis, it may be necessary to review general toxicological data to determine the dose-response relationship and health effects associated with the overexposure. The Agency for Toxic Substances and Disease Registry (ATSDR) provides detailed Toxicological Profiles for many chemicals of interest (<https://www.atsdr.cdc.gov/substances/index.asp>).

(4) **Other Guidelines.** Other guidelines are available for deployment or emergency use. While these guidelines do not take precedence over Army OELs, they may provide benchmarks for assessing HS if needed. Examples of these guidelines include MEGs, PEGs, EEGs, AEGs, EPRGs, and IDLHs (refer to section 3–3B). The basis of the guidelines differs in regard to population, health effects, exposure durations, and routes of exposure. When using these guidelines to assign HS, these differences must be considered. For example, exposures exceeding the maximum concentrations and durations specified by the ERPG-3 or IDLH may be assigned an HS 1 because the EPRG-3 and IDLH are designed to prevent death.

(5) **Overexposures and MEGs.** When exposure levels exceed the Army OEL, the MEGs may be used to assess the health hazard. The MEG chosen should be representative of the exposure duration, route of exposure, and use scenario. Refer to section 2.3 of TG 230 for information about selecting the proper MEG. If the MEGs are used, the APHC Environmental Health Risk Assessment Division (EHRAD) should be contacted for assistance. The EHRAD may assist in determining the basis of the MEGs and selecting the proper MEG for use in a specific HHA.

MEGs must be used cautiously in HHAs due to differences in purpose and scope. While the military population assumptions are similar, the risk matrix and definitions of HS and hazard probability (HP) in TG 230 differ from those used in an HHA as defined by AR 40–10. The MEGs are designed to assess overall risks for populations completing missions or at deployment sites where other conventional sources of health risk (e.g., direct combat, environmental stressors) are also present, whereas an HHA assesses risks associated with operators of materiel still in development. Exposures to health hazards assessed using OELs in an HHA may be controllable via risk mitigation strategies (e.g., engineering or administrative controls, PPE), whereas MEGs are typically used to assess environmental or external exposure, where the hazard source may not be controlled. Because HHAs are conducted prior to the release of materiel to the Soldiers for normal use (i.e., materiel release), hazards are evaluated independently from the environment.

An important difference is the definition of “Critical” HS. According to TG 230, a “Critical” HS may include a limited number of fatalities, while an HHA would consider this outcome “Catastrophic.” In most cases, linking the Critical MEG to an HS 2 for HHA use is reasonable. Of the common chemicals of concern in Table 3–1, exposures to HCN and NH<sub>3</sub> above the Critical MEG should be assigned an HS 1. Additionally, some MEGs are designed for nonrepetitive, once-in-a-lifetime, or rare exposures. Such MEGs may not be appropriate for continuous, repetitive, or regularly intermittent exposures typical of systems assessed in an HHA (e.g., weapon systems).

Appendix G of TG 230 provides a ranking system and decision logic for determining HS and HP. (Note: Definitions for HP and HS in TG 230 differ from the HHA definitions.) The TG 230 criteria for selecting an HP level are broadly similar to the HHA HP selection criteria.

Refer to TG 230 for a more in-depth discussion on how to apply MEGs to assess exposures to chemical substances. For assistance in using TG 230 MEGs, contact the APHC EHRAD.

(6) **Special Considerations.** Further investigation by an SME is required when the general guidelines in Table 3–6 are insufficient. If the HHA deviates from Table 3–6, the reasoning must be explained in the report. Circumstances in which an SME may need to deviate from the general guidelines may include, but are not limited to, the following:

- Data are not representative of the use scenario.
- Multiple missions per day require estimation of higher exposure levels (e.g., chemicals that are slow to be eliminated from the body).
- The exposure includes mixtures that may elevate risk due to additive or more than additive effects.
- Assessment of specific chemicals with additional military-unique guidelines (e.g., smokes and obscurants).
- Assessment of specific chemicals with inadequate or emerging toxicological data.

**B. Determining Hazard Probability.** Selection of the appropriate HP level is based on factors such as the following:

- Duration and frequency of exposures.
- Use scenario.
- Representativeness of the test data (e.g., quantity, quality, test conditions).
- Type and adequacy of controls (e.g., engineering controls, administrative controls, PPE).

The probability of a chronic health effect is heavily dependent on exposure duration and frequency. Table 3–8 provides HP levels for chemical substances associated with both acute and chronic health effects. The likelihood of occurrence at the maximum likely exposure level is based on the HP levels defined in AR 40–10. They have been adapted slightly to apply to acute and chronic chemical exposures.

**Table 3–8. Hazard Probability Levels for Chemical Substances**

| Description and Level |   | Likelihood of Occurrence at Maximum Likely Exposure Level        |  |
|-----------------------|---|--|--|
|                       |   | Insignificant or Acute Health Effects                            | Chronic Health Effects*                                      |
| Frequent              | A | Very likely (exposure is frequent and regular)                   | Very likely (exposure is almost continuous)                  |
| Probable              | B | Likely (exposure is intermittent)                                | Likely (several significant exposure durations)              |
| Occasional            | C | Likely to occur sometime   | Somewhat likely (at least one significant exposure duration) |
| Remote                | D | Unlikely, but possible to occur                                  | Unlikely but possible significant exposure duration          |
| Improbable            | E | So unlikely, it can be assumed occurrence may not be experienced | Very unlikely but possible significant exposure duration.    |
| Eliminated            | F | Incapable of occurrence because the hazards are eliminated       | Incapable of occurrence because the hazards are eliminated   |

Note:

\*An exposure duration is considered significant when the exposure level is expected to exceed the applicable OEL.

Special considerations and HP adjustments may be required for some exposures. Systems that require heavy work effort may increase an individual's respiratory rate and consequently increase the HP. The HP may be further increased if overexposures occur with little warning (e.g., odorless, colorless, no acute effects). Alternatively, acute health effects such as mild irritation may cause Soldiers to notice potential overexposures and remove themselves from the hazardous area to limit additional exposure.

**C. Risk Assessment Process for Carbon Monoxide.** Systems that produce either weapon or fuel combustion products require a CO assessment. Assign HS based on Table 3–9. Assign HP based on the general risk assessment process described in section 3–6A.

Table 3–9 provides HS categories based on the progression of signs and symptoms of CO poisoning and increasing levels of COHb. The table was developed based upon available research and was modified slightly for a healthy Soldier population. The critical target organs of CO exposure are metabolically active and require continuous supplies of oxygen-rich blood. The heart and the central nervous system (CNS) are considered the most critical organ systems.

The COHb levels from a single mission or dataset may need to be evaluated over time if there are multiple missions per day or exposure duration is expected to be longer than the test duration. This adjustment is needed because COHb levels in the body decline

slowly over time. Thus, each mission will start with a higher COHb than the previous mission or assumed baseline.

**Table 3–9. Acute Health Effects and Hazard Severity Categories of Carbon Monoxide Exposure as Carboxyhemoglobin (COHb)**<sup>1–6</sup>

| Range of Blood Saturation COHb (%)                    | Range Typical of:                     | Response and Symptoms of Healthy Adults*   | Hazard Severity (HS) Category   |
|---|---------------------------------------|--|---|
| 0.4 to 0.7<br>(increasing up to 2.6 during pregnancy) | Normal                                | No known detrimental effect  | N/A   |
| 1 to 2  | Background levels in urban population |  | N/A   |
| 2 to 5  | Commuters on urban highways           | Possible slight decrements in psychomotor function (e.g., reduced video game performance)  | N/A   |
| >5 to 10  | N/A                                   | Compensatory increase in central nervous system and coronary blood flow<br><i>Exercise performance capacity:</i> slight decrease in capacity for strenuous exercise<br><i>Neurobehavioral effects:</i> Prolonged levels may affect the performance of tasks requiring a high degree of vigilance, such as flying an aircraft or attending a control panel. | N/A for the majority of the Soldier population and operations.<br>(HS 4 for aviation system performance levels) |
| >10 to 20   | N/A                                   | Slight headache, fatigue, lightheadedness.<br>Note: Tri-Service laboratory diagnosis for CO poisoning: >10% in non-smokers, >15% smokers   | HS 4<br>(HS 3 for aviation system performance levels)   |
| >20 to 30   | N/A                                   | Moderate headache, nausea, fine manual dexterity impaired, visual evoked response abnormal, flushing and tachycardia   | HS 3<br>(HS 2 for aviation system performance levels)   |
| >30 to 40   | N/A                                   | Severe headache, nausea and vomiting, blood pressure changes (hypotension), ataxia (gross incoordination)  | HS 2<br>(HS 1 is for aviation system performance at COHb levels in excess of 35%)                               |
| >40 to 50   | N/A                                   | Syncope  | HS 1  |
| >50 to 65   | N/A                                   | Coma and convulsions   | HS 1  |
| >65   | N/A                                   | Lethal if not treated  | HS 1  |

Note:

\*Exposure to CO at high, brief concentrations greater than 50,000 ppm can result in a fatal cardiac arrhythmia and death before the COHb is significantly elevated.

References:

<sup>1</sup> Likeauf GD and DR Prows. 2021. Inorganic Compounds of Carbon, Nitrogen, and Oxygen. In: *Patty's Toxicology, Seventh Edition, Volume 3: Physical and Biological Agents*. Hoboken, New Jersey: John Wiley & Sons, Inc.

- <sup>2</sup> National Research Council (NRC) Committee on Toxicology. 1985. *Emergency and Continuous Exposure Guidance Levels for Selected Airborne Contaminants*. Vol. 4. Washington, D.C.: National Academies Press.
- <sup>3</sup> NRC Committee on Toxicology. 2010. *Acute Exposure Guideline Levels for Selected Airborne Chemicals*. Vol. 8. Washington, D.C. National Academies Press.
- <sup>4</sup> American Conference of Governmental Industrial Hygienists. 2020. *Documentation of the Threshold Limit Values and Biological Exposure Indices*. Atlanta, Georgia.
- <sup>5</sup> American Industrial Hygiene Association. 1999. *Carbon Monoxide Documentation for Emergency Response Planning Guidelines*. Fairfax, Virginia.
- <sup>6</sup> U.S. Army Center for Health Promotion and Preventive Medicine. 1998. U.S. Army Medical Surveillance Activity. *Tri-Service Reportable Events, Guidelines, and Case Definitions, Version 1.0*. Aberdeen Proving Ground, Maryland.

**D. Risk Assessment Process for Chemicals Related to Oxygen Level.** Chemicals related to the reduced oxygen levels of an enclosure (e.g., carbon dioxide, asphyxiants) should be assessed as a chemical exposure using the methodology described in this chapter. The oxygen deficiency assessor and chemical substances assessor must communicate and collaborate closely to estimate the risk of chemical overexposures based on both ventilation rates and results of combustion products testing, if applicable. Estimated concentrations of chemicals of concern may be derived from test data or calculations. Refer to TG 351D, Chapter 4, Oxygen Deficiency, for more information about assessing oxygen-deficient environments.

**E. Risk Mitigation and Recommendations.** 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) PPE. Consider the feasibility and the effectiveness of controls on other types of health hazards. For example, firing a tank with the hatch open may reduce chemical substance exposure but may increase the impulse noise exposure. Examples of chemical substance controls in priority order include—

- (1) **Elimination.** Completely eliminating the human exposure and/or the use of hazardous materials, tasks, or operations.
- (2) **Substitution.** Replacing a hazardous material, task, or operation for one that is less hazardous. For example, replacing legacy, toxic munitions with modern, green munitions.
- (3) **Engineering Controls.** Adding adequate ventilation or isolating an operation by means of barriers or enclosures (e.g., placing the breech of the gun exterior to the crew compartment).
- (4) **Warnings.** Equipping wall-mounted chemical concentration monitors with audible and/or visual warnings that sound/appear when OELs are exceeded. For example, an engine repair shop may be equipped with alarmed CO monitors.

(5) **Administrative Controls.** Administrative controls may restrict specific operational conditions (e.g., limiting the number of rounds fired over a specific period of time, firing with an open hatch where feasible, requiring the maximum ventilation setting). Other types of controls may include implementing training, implementing safety and cleaning procedures, and/or rotating Soldiers in and out of exposure areas.

(6) **PPE.** PPE is a last resort when other types of controls are ineffective or not feasible. PPE for chemical substances hazards is specific to the type and route of exposure and includes respiratory protection, eye protection, gloves, chemical protective clothing, safety boots, etc. Respiratory protection has been used as an internal protective device incorporated in certain mobile artillery systems, such as the Paladin, Stryker, and Bradley Fighting Vehicle. These respiratory protective systems provide nuclear, biological, and chemical (NBC) protection but are also used to reduce Soldier exposures to combustion gases when the breech of the gun is located in occupied spaces. The military protective mask (e.g., M-40, M-17) is officially approved for use against military NBC warfare agents only, it is not intended to be used for protection against industrial chemicals.

**F. Residual Risk.** Residual risk may remain after the implementation of all recommendations and risk mitigation strategies. For elimination, substitution, and engineering controls, the assigned HS is changed. For warnings, administrative controls, and PPE, which depend on consistent compliance and are therefore subject to human error, the assigned HS is not changed.

Risk mitigation is a holistic, complex, and dynamic process, taking into account that recommendations to reduce risk from one hazard might increase risk from another hazard. Tradeoffs must be considered when providing recommendations to reduce chemical substance exposures. For example, methods to reduce weapon blowback may increase the aural signature, and full-body PPE required to protect against chemical substances may increase the risk of heat stress.

### 3–7. Example Assessment Scenarios

**A. Example 1 – Weapon Combustion Products.** An HHA was requested for an armored combat vehicle with a mounted 25mm main gun and 7.62mm coaxial machine gun. Exposure to weapon combustion products was identified as a potential health hazard.

**Step 1.** If possible, coordinate development of the system's test plan with ATEC. Previous combustion product testing of similar variants showed the worst-case measurements while all hatches were closed and the vehicle was stationary. Common weapon combustion products of concern for this weapon system include CO, CO<sub>2</sub>, nitric oxide (NO), nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), HCN, NH<sub>3</sub>, and lead (refer to Table 3–1).

**Step 2.** After testing is completed, obtain the test data and test report from ATEC. Table 3–10 and the following provide a summary of the test event:

- **Measurement methods:** CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, SO<sub>2</sub>, HCN, and NH<sub>3</sub> were monitored using FTIR spectroscopy at all crewmember positions. Lead was monitored using a filter and air pump during one trial at each test condition.
- **Test conditions:** The previously identified worst-case test conditions were used (all hatches closed and vehicle stationary). Tests were conducted at two ventilation settings (High and Low) and three crew member positions (commander, driver, and gunner).
- **Repetition:** Three trials of testing were conducted for each scenario.
- **Number of rounds/duration:** During each trial, 150 rounds were fired from the main gun, and 500 rounds were fired from the coaxial machine gun over a period of about 15 minutes. Combustion products were monitored during firing and for 15 minutes after firing ended. Frequency of rounds fired (e.g., number of rounds per burst, burst duration, length of pause between bursts) was conducted according to the use scenario.

**Table 3–10. Example 1: Test Conditions**

| Trial # | Position  | Ventilation Setting | # of Rounds Fired per Trial   | Other Test Conditions                        |
|---------|-----------|---------------------|---|--|
| 1a      | Commander | High                | 150 rounds from<br>25mm main gun<br><br>+<br><br>500 rounds from<br>7.62mm coaxial<br>machine gun | All hatches closed<br><br>Vehicle stationary |
| 1b      |           |                     |   |  |
| 1c      |           |                     |   |  |
| 2a      | Driver    | High                |   |  |
| 2b      |           |                     |   |  |
| 2c      |           |                     |   |  |
| 3a      | Gunner    | High                |   |  |
| 3b      |           |                     |   |  |
| 3c      |           |                     |   |  |
| 4a      | Commander | Low                 |   |  |
| 4b      |           |                     |   |  |
| 4c      |           |                     |   |  |
| 5a      | Driver    | Low                 |   |  |
| 5b      |           |                     |   |  |
| 5c      |           |                     |   |  |
| 6a      | Gunner    | Low                 |   |  |
| 6b      |           |                     |   |  |
| 6c      |           |                     |   |  |

**Step 3.** Ensure the data were collected according to TOP 02–2–614A and are representative of the use scenario. This test event is consistent with the use scenario (e.g., similar number of rounds and firing rate), which minimizes the amount of assumptions required. Repetition of trials is considered adequate.



**Step 4.** Analyze the test data. The peak, 8-hour TWA and 15-minute TWA values were provided in the test report along with the COHb percentage (%) calculations. Graphs of concentration over time may be requested for specific trials if needed for further assessment.

**Step 5.** Determine the worst-case measurement for each combustion product from the test data, and find the applicable OEL from Table 3–1. (Consult the ACGIH TLV Book and/or the OSHA Z-Tables for any OELs not provided in Table 3–1.)

The exposure levels were highest when the ventilation was on the Low setting, and there were no overexposures while it was on the High setting. Table 3–11 summarizes the applicable worst-case measurement at each position across the three trials with the ventilation set to Low. The OELs are provided for comparison where applicable. Red text indicates exposures above the OEL.

**Table 3–11. Example 1: Test Data and Occupational Exposure Limits**

| Combustion Product                   | Measurement/<br>Exposure<br>Duration | Concentration by Position |                     |                     | Army OEL  |
|--------------------------------------|--------------------------------------|---------------------------|---------------------|---------------------|---|
|                                      |                                      | Commander                 | Gunner              | Driver              |   |
| Ammonia<br>(NH <sub>3</sub> )        | Peak/Ceiling                         | 11 ppm                    | 12.1 ppm            | 10.5 ppm            | NA  |
|                                      | 15-minute                            | 9.5 ppm                   | 11.3 ppm            | 9.2 ppm             | 35 ppm  |
|                                      | 8-hour <sup>a</sup>                  | 0.3 ppm                   | 0.4 ppm             | 0.3 ppm             | 25 ppm  |
| Carbon<br>Dioxide (CO <sub>2</sub> ) | Peak/Ceiling                         | 1,020 ppm                 | 1,350 ppm           | 1,280 ppm           | NA  |
| Carbon<br>Dioxide (CO <sub>2</sub> ) | 15-minute                            | 970 ppm                   | 1,260 ppm           | 1,115 ppm           | 30,000 ppm  |
|                                      | 8-hour <sup>a</sup>                  | 428 ppm                   | 437 ppm             | 432 ppm             | 5,000 ppm   |
| Carbon<br>Monoxide<br>(CO)           | Maximum<br>COHb                      | 8.3% COHb                 | 11.7% COHb          | 4.1% COHb           | 10% COHb  |
| Hydrogen<br>Cyanide<br>(HCN)         | Peak/Ceiling                         | 5.3 ppm                   | 5.5 ppm             | 4.9 ppm             | 4.7 ppm   |
|                                      | 15-minute                            | 1.02 ppm                  | 1.92 ppm            | 0.96 ppm            | NA  |
|                                      | 8-hour <sup>a</sup>                  | 0.03 ppm                  | 0.06 ppm            | 0.03 ppm            | 10 ppm  |
| Lead (Pb)                            | 8-hour <sup>a</sup>                  | 5 µg/m <sup>3</sup>       | 6 µg/m <sup>3</sup> | 5 µg/m <sup>3</sup> | 50 µg/m <sup>3</sup><br>(AL =<br>30 µg/m <sup>3</sup> ) |

| Combustion Product                  | Measurement/<br>Exposure Duration | Concentration by Position |                      |                      | Army OEL |
|-------------------------------------|-----------------------------------|---------------------------|----------------------|----------------------|----------|
|                                     |                                   | Commander                 | Gunner               | Driver               |          |
| Nitric Oxide (NO)                   | Peak/Ceiling                      | 1.40 ppm                  | 2.14 ppm             | < 1 ppm <sup>b</sup> | NA       |
|                                     | 15-minute                         | < 1 ppm <sup>b</sup>      | < 1 ppm <sup>b</sup> | < 1 ppm <sup>b</sup> | NA       |
|                                     | 8-hour <sup>a</sup>               | < 1 ppm <sup>b</sup>      | < 1 ppm <sup>b</sup> | < 1 ppm <sup>b</sup> | 25 ppm   |
| Nitrogen Dioxide (NO <sub>2</sub> ) | Peak/Ceiling                      | 3.51 ppm                  | 4.05 ppm             | 3.97 ppm             | 5 ppm    |
|                                     | 15-minute                         | 3.20 ppm                  | 3.84 ppm             | 3.52 ppm             | NA       |
|                                     | 8-hour <sup>a</sup>               | 0.10 ppm                  | 0.12 ppm             | 0.11 ppm             | 0.2 ppm  |
| Sulfur Dioxide (SO <sub>2</sub> )   | 15-minute                         | < 1 ppm <sup>b</sup>      | < 1 ppm <sup>b</sup> | < 1 ppm <sup>b</sup> | 0.25 ppm |

Legend:

AL = action level

COHb = carboxyhemoglobin

µg/m<sup>3</sup> = micrograms per cubic meter

NA = no applicable OEL exists for the exposure duration

OEL = occupational exposure limit

ppm = parts per million

Red text = exposures above the OEL

Notes:

<sup>a</sup> Exposure outside of the 30-minute test event is assumed to be 0 ppm (or 410 ppm for CO<sub>2</sub>).

<sup>b</sup> The reported value is below the instrument's reporting limit.

**Step 6.** Determine which combustion products exceeded the OELs. The exceedances are highlighted in red in Table 3–11.

CO exceeded the MIL–STD–1472H threshold of 10% COHb at the gunner position. HCN exceeded the ceiling limit of 4.7 ppm at all positions. The SO<sub>2</sub> results were below the instrument's reporting limit of 1 ppm; it possible that the OEL was exceeded. All other chemicals were below the applicable OELs.

**Step 7.** Determine the potential health effects of overexposures. Use Table 3–3 as a starting point. The basis of TLVs may also be used to determine potential health effects.

CO and HCN have a combined effect of impairing the body's uptake of oxygen. High CO exposures may lead to unconsciousness and death, and lower exposures can reduce task and cardiovascular performance. HCN may cause dizziness, nausea, and weakness. No significant health effects beyond minor temporary coughing and possible eye irritation are expected from SO<sub>2</sub> overexposures.

**Step 8.** Use section 3–6C to assess the CO overexposure. Based on Table 3–9, the maximum COHb of 11.7% falls within the range of HS 4. Exposures may result in a slight headache, fatigue, and lightheadedness.

**Step 9.** Use section 3–6A and Table 3–6 to assign the HS to overexposures for other chemicals. In this example, HCN is the only overexposure other than CO. No levels above the SO<sub>2</sub> detection limit were recorded, so it is unlikely that significant overexposures occurred. The peak levels slightly exceeded the ceiling limit. Additionally, the data showed that the 15-minute TWA was well below the peak limit, indicating that exposure to the peak level is transient. The use scenario described in the OMS/MP indicates that only one mission with a 15-minute firing duration per day is expected. The data adequately represent the use scenario.

Health effects associated with intermittent exposures to HCN slightly above the OEL are expected to be temporary and may cause performance effects. Assign an HS of 3 (Marginal) based on Table 3–6.

**Step 10.** Consider any special HS considerations as noted in section 3–6A(6). As noted in Step 7, CO and HCN have a combined effect of impairing the body's uptake of oxygen. In this example, both the COHb and HCN exposure limits were exceeded, so the HI for CO and HCN is well above 1. The combination of gases represents a considerable additive overexposure. An additive exposure may increase the HS in some cases. For this example, the OELs were only slightly exceeded for both CO and HCN. Combined health effects are still expected to result only in temporary symptoms and performance degradation effects, resulting in an HS 3. If exposure levels were higher, or multiple 15-minute firings were expected per day, the HS may have been increased.

**Step 11.** Use the information in section 3–6B and Table 3–8 to assign the HP to the CO and HCN overexposures. Since both CO and HCN may cause acute health effects, the "Insignificant or Acute Health Effects" column in Table 3–8 applies. The use scenario indicates all hatches must remain closed during all weapons firing. Firing while stationary is performed about 25% of the time. The ventilation setting is adjustable, and there is no requirement to fire only with the ventilation set to High. The mission represented by the test data is considered routine according to the OMS/MP.

Based on these considerations, the likelihood of occurrence at the maximum likely exposure level may be considered frequent and regular for the combined effect of CO and HCN, which correlates to an HP A (Frequent), according to Table 3–8.

**Step 12.** Determine the limiting risk level from the chemical overexposures to assign the initial risk level for the overall system. This example results in a risk level of Serious (RAC: HS 3, HP A).

**Step 13.** Provide recommendations to reduce the risk of overexposures. The test data for this system showed that the ventilation setting greatly affected the exposure levels.

With the ventilation set to High, no OELs were exceeded. Recommend the ventilation fan be set only to High during weapons firing.

The risk level is slightly reduced if the recommendation is implemented through administrative controls (i.e., Soldiers are trained to manually adjust the setting to High prior to firing). The HP reduction is limited due to the lower effectiveness of administrative controls. The likelihood of occurrence may be considered unlikely but possible, which correlates to an HP of D (Remote) in Table 3–8. The HS is unaffected because there is still a possibility of the same overexposure. Implementing all of these recommendations results in a residual risk level of Medium (RAC: HS 3, HP D).

If the High ventilation setting is interlocked to turn on during weapons firing, the risk is Eliminated (RAC: HS 3, HP F).

**B. Example 2 – Fuel Combustion Products.** An HHA was requested for a shelter equipped with a generator and heater. Exposure to fuel combustion products was identified as a potential health hazard.

**Step 1.** Coordinate development of the test plan with ATEC. Common fuel combustion products of concern for this weapon system include CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, SO<sub>2</sub>, acrolein, benzene, formaldehyde, and particulate (refer to Table 3–1). Acrolein, benzene, formaldehyde, and particulate were not monitored.

**Step 2.** After testing is completed, obtain the test data and test report from ATEC.

CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, and SO<sub>2</sub> were monitored according to TOP 02–2–614A at three locations in the shelter (back of the room, center of the room, and near the door) using handheld MultiRAE electrochemical analyzers. Five trials of 30 minutes each were conducted. The heater and generator were at their maximum setting during all trials. One trial was repeated as a control. All trials are representative of the potential use scenarios. Table 3–12 shows the test conditions of the 5 trials.

**Table 3–12. Example 2: Test Conditions**

| Trial | Door Position | Exhaust Fan |
|-------|---------------|-------------|
| 1     | Open          | On          |
| 2     | Open          | Off         |
| 3     | Closed        | On          |
| 4a    | Closed        | Off         |
| 4b    | Closed        | Off         |

**Step 3.** Find the applicable OELs from Table 3–1 (consult the TLV Booklet and/or the OSHA Z-Tables for any OELs not provided in Table 3–1). Table 3–13 provides the applicable OELs.

**Table 3–13. Example 2: Occupational Exposure Limits**

| Compound                            | 8-hour TWA Limit | 15-minute STEL | Ceiling Limit |
|-------------------------------------|------------------|----------------|---------------|
| Carbon Dioxide (CO <sub>2</sub> )   | 5,000 ppm        | 30,000 ppm     | -             |
| Carbon Monoxide (CO)                | 25 ppm           | -              | -             |
| Nitric Oxide (NO)                   | 25 ppm           | -              | -             |
| Nitrogen Dioxide (NO <sub>2</sub> ) | 0.2 ppm          | -              | 5 ppm         |
| Sulfur Dioxide (SO <sub>2</sub> )   | -                | 0.25 ppm       | -             |

Legend:

ppm = parts per million

**Step 4.** Table 3–14 provides a summary of the worst-case peak and average measurements at each position across the five trials from the test report. Note that the test report provides separate levels for each trial. Only the highest measurement at each position is reported in the summary table because all trials are representative of the use scenario. Red text represents exposures above the OEL.

**Table 3–14. Example 2: Test Data**

| Combustion Product                  | Measurement Duration | Concentration by Analyzer Position (ppm) |                    |                    |
|-------------------------------------|----------------------|--|--------------------|--------------------|
|                                     |                      | Back                                     | Center             | Door               |
| Carbon Dioxide (CO <sub>2</sub> )   | Peak                 | 800                                      | 1,000              | < 500 <sup>b</sup> |
|                                     | Average <sup>a</sup> | < 500 <sup>b</sup>                       | < 500 <sup>b</sup> | < 500 <sup>b</sup> |
| Carbon Monoxide (CO)                | Peak                 | 40                                       | 45                 | 33                 |
|                                     | Average <sup>a</sup> | 31                                       | 33                 | 24                 |
| Nitric Oxide (NO)                   | Peak                 | 15                                       | 11                 | 8.0                |
|                                     | Average <sup>a</sup> | 5.5                                      | 9.7                | < 3.0 <sup>b</sup> |
| Nitrogen Dioxide (NO <sub>2</sub> ) | Peak                 | 1.6                                      | 1.1                | 0.9                |
|                                     | Average <sup>a</sup> | 0.9                                      | < 0.3 <sup>b</sup> | < 0.3 <sup>b</sup> |
| Sulfur Dioxide (SO <sub>2</sub> )   | Peak                 | < 0.3 <sup>b</sup>                       | < 0.3 <sup>b</sup> | < 0.3 <sup>b</sup> |
|                                     | Average <sup>a</sup> | < 0.3 <sup>b</sup>                       | < 0.3 <sup>b</sup> | < 0.3 <sup>b</sup> |

Legend:

ppm = parts per million

Red text = exposures above the OEL

Notes:

<sup>a</sup> Measurements were averaged over the 30-minute duration of the test event.

<sup>b</sup> The reported value is below the instrument's reporting limit.

**Step 5.** Analyze the test data. The average measurements reported in Table 3–14 are averaged over the 30-minute duration of the test. Exposure levels were stable during the 30-minute test duration, and personnel are expected to spend 8 hours inside the shelter per day. Therefore, assume the 30-minute averages are representative of an 8-hour TWA exposure.

**Step 6.** Determine which combustion products exceeded the OELs by comparing the OELs in Table 3–13 to the exposure levels in Table 3–14 (using assumptions discussed in step 5). Overexposures are indicated by the red text in Table 3–14. CO levels exceeded the 8-hour OEL. NO<sub>2</sub> levels exceeded the 8-hour OEL but did not exceed the peak limit. The SO<sub>2</sub> results were below the instrument's reporting limit of 0.3 ppm; it is possible that the OEL was exceeded. Results for other chemicals were below the applicable OELs.

**Step 7.** Determine the potential health effects of overexposures. Use Table 3–3 as a starting point. The basis of TLVs may also be used to determine potential health effects.

The combined effects of CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, and SO<sub>2</sub> gases may cause temporary respiratory and eye irritation, headache, and nausea, any of which may impair performance. High CO exposures may lead to unconsciousness and death; however, those levels slightly above the OEL are not expected to cause severe effects. The NO<sub>2</sub> levels did not exceed the ceiling limit. These NO<sub>2</sub> exposure levels are unlikely to cause severe, acute effects. Some individuals may be more sensitive and susceptible to the effects of NO<sub>2</sub> exposure.

**Step 8.** Assess the overexposures using section 3–6A and Table 3–6. As discussed in step 7, the health effects expected at these maximum likely exposure levels are limited to temporary, nonsevere effects. These effects are associated with an HS of 3 (Marginal).

**Step 9.** Use the information in section 3–6B and Table 3–8 to assign the HP. Since CO and NO<sub>2</sub> may cause acute health effects for these exposure levels, the “Insignificant or Acute Health Effects” column in Table 3–8 applies.

Exposure durations are 8 hours per day, which is directly comparable to the 8-hour OELs. Test data were collected with the heater and generator set to the maximum setting. The shelter is expected to operate in all weather conditions, so the heater is not expected to always be on the maximum setting. Wind conditions may also affect the amount of combustion products entering the shelter. Likelihood of health effects may be considered slightly less than frequent and regular (i.e., intermittent), resulting in an HP of B (Probable) according to Table 3–8.

**Step 10.** Assign a risk level of Serious (RAC: HS 3, HP B) using the HS and HP determined in steps 8 and 9.

**Step 11.** Provide recommendations to reduce the risk of overexposures. In this example, it is not feasible to adjust the use scenario. Normal use includes all scenarios tested and Soldiers are required to spend 8 hours in the shelter. The ventilation system could be redesigned to prevent intake of combustion products and potential stagnation zones. For example, the intake plenum for the supply air could be moved to the opposite side of the shelter from the generator and heater exhaust.

No residual risk level can be assigned until the system is re-designed and re-tested. New fuel combustion product test data must be collected and submitted to the APHC for reassessment. If exposure levels are shown to be below the OELs, the risk is Eliminated.

**C. Example 3 – Toxic Materials.** An HHA was requested for a portable field maintenance and welding kit. Routine or prolonged exposure to toxic materials was identified as a potential health hazard.

**Step 1.** Identify the toxic materials used in the kit. The kit includes the following:

- Brazing flux pastes containing potassium borate and fluoroborate compounds.
- Soldering paste containing citric acid and nonophenyl.
- Tin-antimony solder, 95/5%.
- Inert shielding gases (CO<sub>2</sub> and argon).
- Brazing filler metals and alloys.
- Degreasing solvents containing petroleum distillates.

These components are primarily commercial off-the-shelf products that are standard repair materials for air conditioning and refrigeration systems. SDSs are available.

**Step 2.** Identify which of these materials have had previous TCs completed by the APHC, if any.

A TC was previously granted for this system which looked at all of these materials. The flux pastes and solder were found to be lead-free. Health effects and recommendations for safe use and disposal were included in the TC.

**Step 3.** Identify the potential routes of exposure to chemical substances for this system. Welding, cutting, brazing, and soldering operations may result in exposure to:

- Fumes from the metals being welded, metals in filler rods, or the metallic coatings (e.g., iron, manganese, hexavalent chromium, nickel, copper, tin, antimony, zinc, vanadium, lead, silver, and cadmium).

- Fumes from flux pastes and flux coatings on filler rods (e.g., borates, fluorides, potassium, lithium, and sodium).
- Gases generated due to heat and light acting on the surround air (e.g., CO, CO<sub>2</sub>, NO<sub>2</sub>, and ozone).
- Gases generated from the breakdown of paints and degreasing solvents (e.g., phosgene, aldehydes, hydrogen chloride).
- Inert shielding gases.

**Step 4.** Evaluate air monitoring data. No data were available for this system.

**Step 5.** Identify potential health effects of exposure to these gases and fumes using the TC and references discussed in section 3–4 (e.g., ASTDR, NIOSH Pocket Guide, IARC).

Short-term overexposure to non-inert gases and fumes may result in irritation of the nose, throat, or eyes; dizziness; nausea; or metal fume fever. Long-term (chronic) overexposure can lead to bronchitis, pneumoconiosis, graying of the skin (argyria), central nervous system effects, or other adverse effects. Overexposure to inert gases in poorly ventilated spaces may cause asphyxiation.

The IARC has classified beryllium, hexavalent chromium, and nickel welding fume compounds as Group 1, carcinogenic to humans. The IARC has classified antimony trioxide, lead compounds, and vanadium pentoxide as Group 2B, possibly carcinogenic to humans.

**Step 6.** Identify controls currently in place by the materiel developer. This kit includes an air-filtering respirator (of unspecified make and model, and unlikely to fit all users), unvented goggles, a face shield, and welding gloves. The operator's manual does not specify further use instructions or details about the respirator (e.g., personal fit testing, type of respirator, type of filter cartridge).

**Step 7.** Assign the HS. Exposures to individual chemicals are expected to be short in duration. Short-term health effects are limited to temporary effects (e.g., dizziness, irritation). Because there are no air-monitoring data, a conservative HS of 3 is assigned.

**Step 8.** Assign the HP. This kit is a supplement to other maintenance tools and duties. Soldiers do not regularly weld, and soldering is more common than welding. Soldering is less likely to produce hazardous exposures than welding. Exposure durations and frequency are limited, but. Exposures are likely to occur sometimes. An HP of C is assigned.

**Step 9.** Recommend additional controls to mitigate the potential exposure to toxic gases and fumes and assign a residual risk for compliance with the recommendations. The following is a potential residual risk for this example. Note that the HS does not change for PPE and warnings.



A residual risk level of Medium (RAC: HS 3, HP D) is assigned for compliance with all of the following recommendations:

- Require personnel to wear coveralls, welders' gloves, and unvented goggles when performing welding, cutting, brazing, or soldering in order to provide protection from dermal and eye exposures.
- Require personnel to be personally fitted with, and use, half-face air purifying respirators with particulate/hydrogen fluoride cartridges.
- Provide spare respirator cartridges with the kit.
- Include the potential chemical hazards, PPE requirements, and use instructions in the operator manual. Include instructions to work in well-ventilated areas and to wash the face and hands before eating, drinking, or smoking. Include instructions to request that exposure levels be assessed if work is required to be performed in poorly ventilated areas.

### **3–8. Limitations and Potential Future Work**

**A. Limitations.** Known limitations with the current risk assessment methodology include the following:

(1) Reporting limits of certain chemical sampling methods are above the OEL. In these cases, concentrations below the OEL are not able to be verified.

(2) All ACGIH TLVs and OSHA PELs do not necessarily apply to military-unique scenarios and populations.

(3) This methodology is based on existing health protection criteria. As research progresses and new health effects of hazardous chemicals emerge (e.g., oxotoxicants, nanomaterials), health protection criteria and risk assessment methodologies should be developed and/or adapted. The HHA Program continually assesses the risk assessment process as applicable standards and research are updated.

**B. Potential Future Work.** Potential future work to support the HHA process includes, but is not limited to, the following:

(1) Develop an assessment methodology and tool that allow assessment of combined health effects of routine engine and weapon combustion product exposures. The assessment methodology should be applicable to exposures at relatively low levels and use existing health protection criteria. The tool should integrate combined health effects among all major combustion products. The Military Operational Medicine Research Program developed the Toxic Gas Assessment Software (TGAS) that predicts physical and functional impairment due to the inhalation of toxic gases in armored vehicles. Additional research is needed to determine whether the TGAS is a

suitable tool for assessing combined exposures to engine and weapon combustion products.

(2) Incorporate the use of physiological-based pharmacokinetic modeling (PBPK) as a risk assessment tool. These models predict the absorption, distribution, metabolism, and excretion of chemicals and can be used to refine exposure assessments and health effects criteria. The exposure criteria for halocarbons (i.e., halons, HFC-227) were derived using a human PBPK model based on animal studies that determined the agent concentration in blood associated with cardiac sensitization. The CFK equation for COHb is another example of a physiological-based model. Such mathematical and physiological models can be useful for assessing brief high concentration and intermittent chemical exposures that are not adequately addressed by OELs. Assessment of hypoxia in low-level oxygen scenarios and HCN exposure from weapons emissions are examples in which PBPK modeling could be used to better inform risks in future HHAs.

(3) Incorporate the TG 230 revision, which is expected soon. Following its publication, assessments of chemical substance overexposures are likely to depend more heavily on the MEGs. The update is expected to include additional MEGs that are more applicable to exposures typical of Army weapon systems (e.g., intermittent exposures in short duration).

(4) Develop risk assessment processes for specific chemical substances of concern. The general risk assessment process does not necessarily represent known dose-response relationships of specific chemicals. In addition, future work may include developing a more quantitative method of assigning HP, such as a ranking system or TWA ranges for adequate data.

(5) Develop risk assessment processes for subterranean environments, which present a unique environment for chemical substance hazards. Additional research and development in the applicability of current standards and health protection criteria are necessary to assess the risk accurately.

(6) Future work may include use of models to predict exposure levels based on chemical composition of propellants and explosives. Modeling results may provide a basis of suspected combustion products.

(7) Although fire suppression system assessments are currently outside the scope of the HHA Program, the Program may help facilitate their future progress and centralization. Certain new applications and agents require the development of health protection criteria. Flammability and toxicity assessments of all materials in a system should be investigated during LFTE. Burn box testing may be used to test the main combustion products associated with a material; however, the cumulative effects of all materials in a system should be considered in pyrolysis assessments.

## APPENDIX 3A

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## APPENDIX 3B

### LEAD EXPOSURE INTERIM CRITERION

**A. Existing Criteria.** The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for lead (Pb) is 50 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) over an 8-hour time-weighted average (TWA). The action level is  $30 \mu\text{g}/\text{m}^3$ .

**B. Department of Defense Criteria.** Due to research findings demonstrating adverse health effects of lead in adults at blood-lead levels previously considered acceptable in the workplace, the Department of Defense (DOD) is updating its lead exposure guidance. The new occupational exposure limit (OEL), when promulgated, is expected to be lower.

**C. Interim Criterion.** Because the DOD is expected to lower the OEL based on research findings, the HHA Program is implementing an interim criterion for assessing lead exposures in health hazard assessments (HHAs) of  $10 \mu\text{g}/\text{m}^3$  over an 8-hour TWA. This exposure level is anticipated to maintain blood-lead levels below approximately 20 micrograms per deciliter ( $\mu\text{g}/\text{dl}$ ) in the vast majority of Soldiers exposed to Pb over a full-time working lifetime (Sweeney 2021).

Once the DOD selects a military-unique OEL, the DOD value will be used in place of this interim criterion.

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## APPENDIX 3C

## SUMMARY OF HEALTH EFFECTS FOR COMMON CHEMICAL SUBSTANCES

**A. Acrolein (2-propenal, C<sub>3</sub>H<sub>4</sub>O).** Acrolein is an aldehyde compound that can be produced in the combustion of some plastics and by heating cooking oils. Acrolein is severely irritating to skin, eyes, and the mucous membranes. Inhalation may result in respiratory distress, delayed pulmonary edema, or death. Acrolein is a weak sensitizer. Exposure can produce severe respiratory problems, and individuals with pre-existing breathing difficulties may be more susceptible to its effects.

**B. Aluminum (Al).** Aluminum is a silvery-white, odorless metal. Finely divided aluminum dust is easily ignited. Inhalation of aluminum dust may cause irritation of the eyes, skin, and respiratory system or damage to the nervous system. Aluminized explosives are sometimes used in breaching and room clearing operations, and potential contaminants may affect room entry wait times.

**C. Ammonia (NH<sub>3</sub>).** Ammonia is a colorless gas with a pungent, distinct odor. Ammonia is naturally-occurring or may be produced by decomposition of ammonium nitrate in explosives. Exposure to high levels of ammonia may cause irritation of the eyes, nose, throat, and lower respiratory tract. Ammonia may also cause breathing difficulty, coughing, and burns. Exposure to very high concentrations may cause lung damage and death. Individuals with asthma may be more sensitive.

**D. Benzene (C<sub>6</sub>H<sub>6</sub>).** Benzene is a colorless liquid with a sweet odor. Benzene is highly flammable and quickly evaporates into the air. Exposure to benzene may cause irritation to the eyes, skin, nose, and respiratory system. Additional health effects may include dizziness, headache, nausea, and unconsciousness. Harmful effects on the blood include immunosuppression and a decrease in red blood cells. Benzene is considered a human carcinogen, and long-term airborne exposures can cause leukemia. Benzene is a natural part of gasoline and crude oil, and may be released into the air during operation of engines and generators.

**E. Carbon Dioxide (CO<sub>2</sub>).** CO<sub>2</sub> is a colorless, odorless gas that is 1.5 times heavier than air and accumulates near the ground. CO<sub>2</sub> occurs naturally in the Earth's atmosphere and is a product of combustion and the body's cellular metabolism. This explains why enclosed spaces are vulnerable to CO<sub>2</sub> buildup, displacing oxygen, and possibly causing suffocation. CO<sub>2</sub> can cause asphyxiation by hypoxia and can also act as a toxicant. At low concentrations, it appears to have little toxicity. At higher concentrations, it leads to increased respiratory rate, tachycardia, cardiac arrhythmias, and impaired consciousness. Where high exposures (greater than 10%) are involved, CO<sub>2</sub> can lead to convulsions, coma, and death. Fortunately, the hazard posed by CO<sub>2</sub> emissions (compared to CO) is rather minimal during either weapons firing or operation of combat/automotive systems. One must be alert to the potential of CO<sub>2</sub> poisoning during combat vehicle operations in closed hatch mode without adequate ventilation.

The closed hatch mode can cause a buildup of CO<sub>2</sub> in the confines of the vehicle, and levels can reach about 5 to 7.5%. Soldier performance may be significantly impaired when these high concentrations are reached. The main mode of action of CO<sub>2</sub> is as an asphyxiant, although it also exerts some toxic effects at the cellular level.

**F. Carbon Monoxide (CO).** CO is a colorless, odorless, non-irritating, tasteless gas and is not ordinarily detectable by the human senses. Carbon monoxide is produced by hydrocarbon combustion such as burning gasoline, wood, charcoal, propane, and other fuels. The U.S. Army is concerned with the effects of CO exposure on personnel in the field when operating equipment or firing weapons from enclosed armored vehicles (e.g., tanks and armored personnel carriers). Additionally, even if particular CO exposures are not categorized as health hazards, such exposures can degrade human performance and adversely impact system effectiveness.

The warning signs of CO poisoning can be subtle. Signs and symptoms of CO poisoning may include a dull headache, weakness, dizziness, shortness of breath, confusion, nausea, blurred vision, and loss of consciousness. Carbon monoxide exposures result in impaired oxygen transport by the blood, thus resulting in tissue and cellular hypoxia. Normally, oxygen from the lungs is carried through the body by hemoglobin (Hb). Carbon monoxide has an affinity for blood Hb, which in turn can reduce the oxygen-carrying capacity of the blood. The binding affinity of CO for Hb is 200 to 240 times greater than that of oxygen for Hb. Carboxyhemoglobin (COHb) is a stable complex of CO and Hb that forms in red blood cells upon contact with CO. Formation of COHb decreases the oxygen carrying capacity of blood and impairs release of oxygen from Hb. The CO in a human is mostly eliminated through the lungs and to a lesser extent by oxidation. The half-life of COHb in the blood is 4 to 6 hours for healthy people at rest in an environment free of contaminants.

**G. Formaldehyde (HCOH).** Formaldehyde is a colorless gas that has a pungent, irritating odor that can be detected by most humans at concentrations less than 1 ppm. Formaldehyde can be formed from any type of combustion process. Formaldehyde is an irritant to the respiratory system and mucous membranes. Low concentrations can produce nose and throat irritation, cough, chest pain, shortness of breath, and bronchial wheezing. Higher exposures can cause significant inflammation of the lower respiratory tract, resulting in swelling of the throat, inflammation of the windpipe and bronchi, narrowing of the bronchi, inflammation of the lungs, and accumulation of fluid in the lungs. Formaldehyde is a potent sensitizer and is considered a probable human carcinogen.

**H. Hydrogen Chloride (HCl).** HCl is a corrosive, nonflammable gas that is heavier than air and has a strong, irritating odor. Upon contact with water, it forms hydrochloric acid. The major source of HCl emissions for Army personnel results from the burning of plastics. HCl is also released during the firing of certain rocket and missile engines. HCl is a major product when explosives containing chlorine are fired. HCl exposures can exceed the Army OEL at one or more locations during use of certain military systems.

For example, the firing of the handheld Stinger missile and the Multiple Launched Rocket System may release large amounts of HCl.

HCl is a strong irritant that affects the conjunctiva and the mucous membranes of the respiratory tract. Brief exposures to low levels cause throat irritation. Exposure to higher levels can result in rapid breathing, narrowing of the bronchioles, accumulation of fluid in the lungs, and death. Because of its solubility in water, the major effects of acute exposure of the respiratory system are usually limited to the upper respiratory tract and are generally severe enough to encourage prompt voluntary withdrawal from a contaminated atmosphere.

**I. Hydrogen Cyanide (HCN).** HCN is very volatile, with a flammable and potentially explosive vapor. HCN is colorless (liquid at room temperature may be pale blue) with an almond odor and bitter taste. HCN is among the most rapidly acting of all known poisons. Exposure may cause headache, confusion, nausea, asphyxia, and respiratory collapse. Absorption occurs by all routes. The respiratory, central nervous, and cardiovascular systems are the primary targets. Because HCN impairs the cellular utilization of oxygen, exposure to HCN may be considered additive to a combined CO exposure. Firing of small arms munitions may result in intermittent HCN exposures.

**J. Lead (Pb).** Inorganic lead is a gray solid and a common combustion product of weapons firing due to lead-based munitions. While lead poisoning can affect virtually every organ system, its main targets are the nervous system and blood-forming system. Acute effects of lead exposure include lung and eye irritation, acute encephalopathy, renal failure, and severe gastrointestinal distress. Chronic effects of lead exposure include numbness in extremities, anemia, reproductive changes, brain damage, nervous system damage, kidney damage, behavioral changes, and learning and memory disturbances.

**K. Nanomaterials.** The potential health effects of these engineered nanomaterials are still evolving. Scientific studies indicate that at least some of these materials are biologically active. Nanomaterials may readily penetrate intact human skin and can be ingested and inhaled. Exposure to certain nanomaterials may result in varying health effects such as cancer or lung damage. The ability of a particle to deposit in the respiratory tract depends on its size. Because of their small size, nanoparticles can be inhaled deeply into the lung at the level of the alveoli, where gas exchange occurs. For this reason, pulmonary nanotoxicity is the focus of many toxicology studies and the development of safety guidelines for handling specific nanomaterials. Fortunately, many nanomaterials agglomerate quickly and act similarly to parent materials.

**L. Nitrogen and Nitric Oxides (NO<sub>x</sub>).** The term nitrogen oxide (NO<sub>x</sub>) mainly includes nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>). Oxides of nitrogen are a product of the combustion of propellants associated with weapons firing and may also be produced at low levels in internal combustion engines. NO has been reported to cause narcosis and death in laboratory animals exposed to 2,500 ppm. NO may produce nervous system impairment and fetal damage. NO structurally changes the hemoglobin, forming

methemoglobin (MetHb). Unlike normal Hb, MetHb does not bind oxygen and cannot deliver oxygen to the tissues, resulting in tissue hypoxia and cyanosis (pale or bluish coloration of the skin). This effect is similar and additive to that of CO. Endogenous enzymes reverse MetHb quickly once exposure is reduced.

NO is unstable in air and undergoes spontaneous oxidation to NO<sub>2</sub> (i.e., NO reacts with oxygen in air to form NO<sub>2</sub>), which then reacts with water (moisture in the respiratory tract) to form nitric acid (HNO<sub>3</sub>). NO<sub>2</sub> is more toxic than NO and may cause severe irritation of the eyes, skin, and respiratory tract. Effects of exposure to NO<sub>2</sub> may be delayed in onset. Prolonged exposures to NO<sub>2</sub> at levels up to 2 ppm do not produce detectable symptoms in non-asthmatic individuals. Occasional, very brief exposures to NO<sub>2</sub> in the 10-ppm range are not expected to produce adverse health effects in nonasthmatic individuals. Exposures of greater than or equal to 50 ppm can result in bronchospasm, severe pulmonary edema, chronic airway damage, hypoxemia, hypotension, loss of consciousness, and death. Certain groups, such as persons with pre-existing cardiopulmonary disease, might be more sensitive to the effects of NO<sub>2</sub> exposure than others. Lower concentrations of NO<sub>2</sub> might affect susceptible individuals to a greater extent than healthy adults, or the severity of an effect at a given concentration might be greater among susceptible individuals.

**M. Particulate.** Airborne particles vary in chemical composition, solubility, chemical reactivity, mass, size, number, shape and surface area. Particulate is a heterogeneous complex mixture. In general terms, it is a component of diesel exhaust and is primarily comprised of carbon, ash, metallic abrasion particles, sulfates, and silicates. Particles may adsorb carcinogenic compounds. Exposure to particulate may cause lung inflammation and impairment. Chronic exposures to particulate may increase the risk of cardiovascular disease, respiratory disease, and lung cancer.

**N. Sulfur Dioxide (SO<sub>2</sub>).** SO<sub>2</sub> is a colorless, pungent, irritating gas that is produced by the combustion of compounds containing sulfur (e.g., fossil fuels). SO<sub>2</sub> is an irritant because it rapidly forms sulfurous acid (H<sub>2</sub>SO<sub>3</sub>) on contact with moist mucous membranes. Most effects occur in the upper respiratory tract because 90% of inhaled sulfur dioxide is rapidly deposited there. With large exposures, sufficient gas reaches the lower airways to cause chemical pneumonitis and pulmonary edema. Exposures to SO<sub>2</sub> at levels above 1 part per million (ppm) and up to 5 ppm may cause temporary coughing. Exposure to concentrations of 5 to 20 ppm may cause irritation of the eyes, nose, and throat, nasal discharge, choking, coughing, reflex constriction of the airways, and shortness of breath. Some people are hypersensitive to SO<sub>2</sub>, and people with asthma may have bronchoconstriction with exposures as low as 0.1 to 0.5 ppm.

**O. Tungsten (W).** Tungsten is a white to steel-gray metal and commonly mixes with other metals to form alloys. Finely divided tungsten powder is combustible. Tungsten and its compounds are not considered very toxic for humans. Acute tungsten intoxication is rare. Most of its toxicology is from chronic occupational exposure (pulmonary fibrosis, dermatitis, memory impairment). Acutely, in sufficiently high concentrations, tungsten compounds may cause irritation of the eyes, skin, and

respiratory system (cough). When ingested (typically accidental), they may cause seizures, clouded consciousness, coma, encephalopathy, and renal failure. With long-term exposure, pulmonary fibrosis and neuropsychological impairment may occur. Tungsten compounds have multiple military-applicable uses, such as a catalyst to accelerate chemical reactions, and a component of welding electrodes, ammunition, and fire-retardant fabric coatings.

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**APPENDIX 3D**  
**CHAPTER 3 GLOSSARY**

**ACGIH**

American Conference of Governmental Industrial Hygienists

**AEGL**

acute exposure guideline level (EPA)

**AF**

adjustment factor

**AFES**

automatic fire-extinguishing system(s)

**AIA**

Aerospace Industries Association

**AIHA**

American Industrial Hygiene Association

**APHC**

U.S. Army Public Health Center

**AR**

Army Regulation

**ATEC**

U.S. Army Test and Evaluation Center

**C**

ceiling

**cal**

caliber

**CBRN**

chemical, biological, radiological, and nuclear

**CFK**

Coburn-Forster-Kane

**CFR**

Code of Federal Regulations

**CNS**

central nervous system

**CO**

carbon monoxide

**CO<sub>2</sub>**

carbon dioxide

**COHb**

carboxyhemoglobin

**DA Pam**

Department of the Army Pamphlet

**DF-2**

diesel fuel #2

**DODI**

Department of Defense Instruction

**EEGL**

emergency exposure guidance level (NRC)

**EHRAD**

Environmental Health Risk Assessment Division

**EPA**

U.S. Environmental Protection Agency

**EPRG**

Emergency Response Planning Guideline (AIHA)

**FTIR**

Fourier-transform infrared

**HCN**

hydrogen cyanide

**HHA**

health hazard assessment

**HI**

hazard index

**HP**

hazard probability

**HQ**

hazard quotient

**HS**

hazard severity

**IDLH**

immediately dangerous to life and health

**IMA**

independent medical assessor

**IR**

infrared

**IRSST**

Institut de recherche Robert-Sauvé en santé et en sécurité du travail

**JP-8**

jet propellant 8

**LFTE**

live-fire test and evaluation

**MATDEV**

materiel developer

**MEG**

military exposure guideline

 **$\mu\text{g}/\text{m}^3$** 

micrograms per cubic meter

 **$\mu\text{m}$** 

micrometers

 **$\text{mg}/\text{m}^3$** 

milligrams per cubic meter

**MIL-STD**

Military Standard



**mm**  
millimeter

**MOS**  
military occupational specialty

**MOUT**  
Military Operations in Urban Terrain

**NAS**  
National Aerospace Standard

**NBC**  
nuclear, biological, and chemical

**NH<sub>3</sub>**  
ammonia

**NIOSH**  
National Institute for Occupational Safety and Health

**nm**  
nanometer

**NO**  
nitric oxide

**NO<sub>2</sub>**  
nitrogen dioxide

**NRC**  
National Research Council

**OARS**  
Occupational Alliance for Risk Science

**OEL**  
occupational exposure limit

**OMS/MP**  
operational mode summary/mission profile

**OSHA**  
Occupational Safety and Health Administration

**PBPK**

physiological-based pharmacokinetic modeling

**PEGL**

permissible exposure guidance level (NRC)

**PEL**

permissible exposure limit (OSHA)

**PPE**

personal protective equipment

**ppm**

parts per million

**ppm-min**

parts per million times minutes

**RAC**

risk assessment code

**RDEX**

RisKit Substance Index

**REL**

recommended exposure limit (NIOSH)

**SDS**

safety data sheet

**SME**

subject matter expert

**SO<sub>2</sub>**

sulfur dioxide

**STEL**

short-term exposure limit

**TA**

Toxicity Assessment

**TC**

Toxicity Clearance

**TEV**

Toxicity Evaluation Division

**TG**

Technical Guide

**TiO<sub>2</sub>**

titanium oxide

**TLV**

Threshold Limit Value (ACGIH)

**TLV-C**

Threshold Limit Value Ceiling (ACGIH)

**TLV-STEL**

Threshold Limit Value Short-term Exposure Limit (ACGIH)

**TLV-TWA**

Threshold Limit Value Time-weighted Exposure (ACGIH)

**TOP**

Test Operations Procedure

**TWA**

time-weighted average

**WEEL**

Workplace Environmental Exposure Level (AIHA/OARS)

## CHAPTER 4. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO OXYGEN DEFICIENCY



Source: DVIDS

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The use of trademarked names does not imply endorsement by the U.S. Army but is intended only to assist in the identification of a specific product.

## 4–1. Purpose

This chapter of Technical Guide (TG) 351D provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to oxygen (O<sub>2</sub>) deficiency that occurs during the normal use and maintenance of materiel systems.

## 4–2. Definitions of Key Terms

**Air changes per hour (ACH):** Number of times one volume of air is replaced in the space per hour. The number of ACH is equal to:

$$ACH = \frac{Q_o(\text{cfm})}{\text{Enclosure Volume (cubic feet)}} \times \frac{60 \text{ minutes}}{1 \text{ hour}} \quad (\text{Equation 4-1})$$

Where:

$Q_o$  = outdoor airflow rate in cubic feet per minute (cfm)

$ACH$  = air changes per hour

**Asphyxiants:** Gases or substances that deprive the tissues of O<sub>2</sub> and may be classified as “simple” or “chemical.” Simple asphyxiants (e.g., nitrogen, propane) displace O<sub>2</sub>, thereby reducing the fraction of O<sub>2</sub> inspired in air, resulting in hypoxemia. Chemical asphyxiants (e.g., carbon monoxide, hydrogen cyanide) may interfere with O<sub>2</sub> transport in blood or cellular respiration through various mechanisms, resulting in hypoxia. Other common asphyxiants include hydrocarbons, halocarbons, carbon dioxide, hydrogen sulfide, and helium.

**Balometer:** An airflow measurement device that can be fitted with hoods in a range of sizes to take accurate measurements at vents on flat surfaces.

**Confined space:** A space that meets all of the following characteristics:

- Large enough that an employee can enter and perform work.
- Limited or restricted means for entry or exit.
- Not designed for continuous occupancy.

**Dilution ventilation:** General ventilation that is intended to reduce toxic or nuisance emissions within the enclosure to levels below applicable occupational exposure limits (OELs).

**Duct traverses:** Measurement of airflow rates in a duct using point measurements at specified locations across the cross-section of the duct.

**General ventilation:** Ventilation of an entire enclosure to provide *dilution ventilation* or comfort.

**Hot wire anemometer:** Instrument that takes point measurements of air velocity based on the change in electrical resistance in a heated wire that is proportional to air velocity.

**Local exhaust ventilation (LEV):** Exhaust ventilation specifically designed to protect personnel from toxic or nuisance emissions by capturing them as close to the source as possible. The design and performance standards for LEV systems are listed in the American Conference of Governmental Industrial Hygienists® (ACGIH®) Industrial Ventilation manual.

**Manned space:** For the purposes of Military Standard (MIL-STD) 1472G, a space occupied continuously for more than 20 minutes, but not a **confined space**.

**Oxygen-deficient environment:** An environment containing less than 19.5% O<sub>2</sub> by volume (29 Code of Federal Regulations (CFR) Part 1910.146).

**Permit-required confined space:** A space that meets the characteristics for a confined space and also meets one or more of the following characteristics:

- Contains or has the potential to contain a hazardous atmosphere.
- Contains a material that could engulf an entrant.
- Has an internal configuration such that an entrant could be trapped or asphyxiated by converging walls or tapered floors.
- Contains any other recognized serious safety or health hazard.

**Steady-state:** An unvarying condition in a physical process. For example, after initial start-up of a ventilation system, an enclosure may reach an unchanging O<sub>2</sub> concentration over time. May also be referred to as equilibrium for this use.

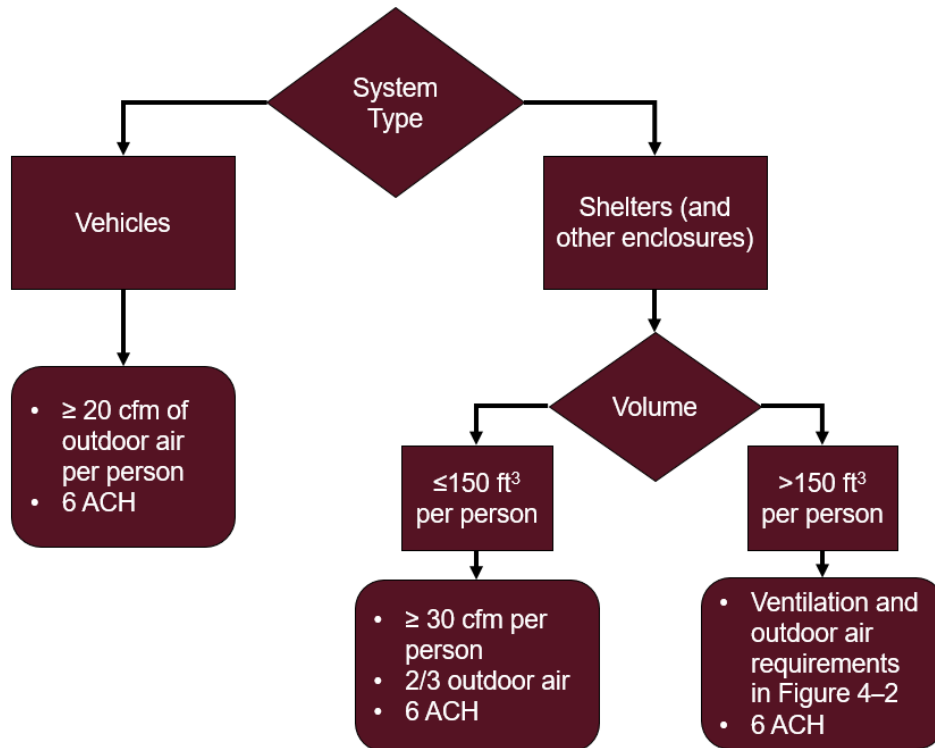
### 4-3. Applicable References/Health Protection Criteria

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

**Important Note:** This TG chapter uses the outdated MIL-STD-1472G although it was superseded by version H in September 2020. The ventilation requirements in MIL-STD-1472H call for very large flows of outdoor air, far beyond the requirements in MIL-STD-1472G and other applicable standards. Meeting the requirements in MIL-STD-1472H would dramatically increase the costs, weights, space requirements, and electrical demands of heating, ventilation, and air-conditioning (HVAC) systems. Version G is being used while the new requirements are under review.

**B. Ventilation.** MIL-STD-1472G includes design requirements for the general ventilation of occupied spaces in military stationary and mobile systems. Ventilation or other protective measures must be adequate to maintain concentrations of harmful substances to within the OELs (i.e., most restrictive of the Occupational Safety and Health Administration (OSHA) permissible exposure limits and the ACGIH Threshold

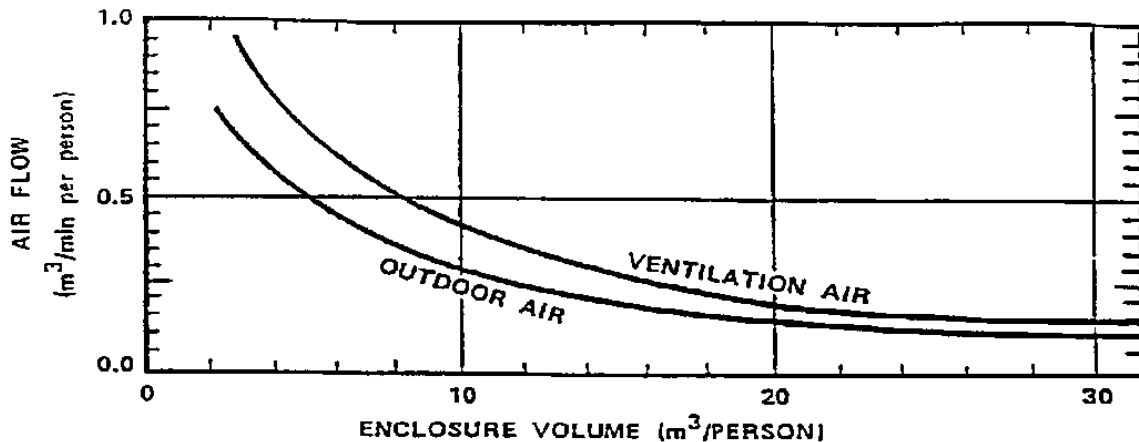
Limit Values® (TLVs®)). Special considerations may be required under chemical, biological, radiological, and nuclear (CBRN) conditions. Refer to TG 351D, Chapter 3, Chemical Substances, for more information about toxic materials, combustion products, and respirable particles. Figure 4–1 provides the MIL–STD–1472G ventilation requirements for manned enclosures based on the system type, volume, and number of occupants. Figure 4–2 provides the minimum ventilation requirements for large enclosures (greater than 150 cubic feet (ft<sup>3</sup>) per person).



**Figure 4–1. Military Standard 1472G Ventilation Requirements**

Legend:  
 ACH = air changes per hour  
 cfm = cubic feet per minute  
 ft<sup>3</sup> = cubic feet





**Figure 4-2. Minimum Ventilation Requirements for Large Enclosures**

(Source: Military Standard 1472G)

In addition to volumetric airflow requirements, MIL-STD-1472G includes air velocity requirements. Air velocity measurements are not normally provided by test centers or assessed in an HHA.

The MIL-STD-1472G states that vehicle ventilation system intakes shall be located in an area where concentration of dust is minimal, including areas in which a vehicle is moving. Filters shall be capable of removing dust particles above five microns in diameter. Dust skirts, which are of great value in reducing the dust raised around a vehicle, shall be provided. Maintenance-type shelters may require both general ventilation and LEV to capture and eliminate airborne health hazards generated during maintenance activities.

As ventilation rates are reduced, carbon dioxide (CO<sub>2</sub>) levels become a concern before O<sub>2</sub> levels do. Calculation methods for steady-state levels for O<sub>2</sub> and CO<sub>2</sub> can be found in Appendix D of American National Standards Institute/American Society of Heating, Refrigerating, and Air-Conditioning Engineers® (ANSI/ASHRAE®) 62.1. Concentrations of O<sub>2</sub> and CO<sub>2</sub> may stabilize quicker in enclosures with smaller volumes; however, the volume of the enclosure does not affect the concentrations at which the levels stabilize.

Refer to TG 351C, Chapter 9, Temperature Extremes, for information about temperature and humidity requirements related to ventilation.

Refer to TG 351D, Chapter 2, Biological Substances, for more information related to ventilation requirements for preventing the spread of communicable diseases.

Refer to TG 351D, Chapter 3, Chemical Substances, for more information about ventilation requirements for toxic materials, combustion products, and nuisance particulates.

**C. Confined Spaces.** Certain systems, such as Army watercraft and tanker vehicles, may have confined spaces. Confined spaces may be rendered O<sub>2</sub>-deficient due to the following:

- O<sub>2</sub> consumption from oxidation, biological reactions, absorption by stored material, thermal decomposition processes, or operation of an internal combustion engine.
- O<sub>2</sub> displacement by inert or toxic gases, such as asphyxiants.

OSHA requirements for permit-controlled confined spaces for general industry are found in 29 CFR 1910.146 and referenced in Department of the Army Pamphlet (DA Pam) 385-10. The general rules for confined space safety developed by the National Institute for Occupational Safety and Health (NIOSH) through experience are discussed in the Confined Spaces chapter of *The Occupational Environment: Its Evaluation, Control, and Management* (Anna 2011).

Department of the Army Technical Manual 4-15.21 provides the requirements for confined space entry programs for Army watercraft. The U.S. Army Combat Readiness Center provides guidance for confined space entry programs. Units are responsible for establishing their own elements of these programs in conjunction with installation safety offices.

Assessors should recognize confined spaces in non-watercraft systems and determine whether technical manuals and other documentation address the potential health hazards.

**D. High Altitude.** Technical Bulletin, Medical (TB MED) 505 includes information related to health effects of high altitude such as hypobaric hypoxia thresholds, physiologic responses and adaptations to altitude, altitude acclimatization tables, physical work performance limitations caused by altitude, and altitude illness probabilities. More information is also available in the Borden Institute Textbook of Military Medicine: *Medical Aspects of Harsh Environments* and at: <https://phc.amedd.army.mil/topics/discond/ai/Pages/default.aspx>.

Materiel expected to be used at high altitudes may be assessed to determine the effect on its users. However, use scenarios and mission needs, not the materiel itself, more commonly influence the risk of altitude sickness. As altitudes rise above 10,000 feet, reduced O<sub>2</sub> partial pressures generally start to reduce the body's maximum rate of O<sub>2</sub> uptake significantly, with adverse psychomotor, cognitive, and visual effects. Without supplementary O<sub>2</sub>, aircraft cockpits and cabins must maintain pressurization equivalent to atmospheric pressures at 10,000 feet or lower. Examples of materiel requiring an assessment for high altitudes include Army fixed-wing aircraft and hypobaric chamber simulation facilities.

**E. Subterranean Environments.** Army Techniques Publication 3-21.51 discusses subterranean operations. Specific health protection criteria related to O<sub>2</sub> deficiency have

not been established for subterranean environments, but equipment expected to be used in subterranean environments may require special considerations. Subterranean spaces may become O<sub>2</sub>-deficient due to thermobaric ordnance, weapon systems, or any of the causes of O<sub>2</sub> deficiency that apply to confined spaces.

**F. Dive Operations.** Dive operations are a special case in terms of O<sub>2</sub> supply, and should be assessed on a case-by-case basis. More information is available in *Medical Aspects of Harsh Environments*.

**G. Asphyxiants.** Exposure to asphyxiants (refer to section 4–2) is assessed on a case-by-case basis and may be considered additive to other exposures to O<sub>2</sub>-deficient environments. Most asphyxiants do not have a standard TLV because the limiting factor is available O<sub>2</sub>. Refer to TG 351D, Chapter 3, Chemical Substances, for more information about TLVs and assessing risk associated with chemical substances.

#### 4–4. Health Effects of Oxygen Deficiency

Under certain conditions, atmospheric O<sub>2</sub> concentrations may be reduced below those commonly found in air (20.9% by volume). O<sub>2</sub>-deficient atmospheres are extremely dangerous. One breath of air at a low enough O<sub>2</sub> level immediately renders a person confused or unconscious, which likely necessitates a rescue. More often than not, rescuers entering the affected space without proper equipment and an understanding of the hazard may become quickly and severely impaired as well. Table 4–1 provides the health effects associated with different O<sub>2</sub> levels. Note that OSHA considers levels below 19.5% to be immediately dangerous to life or health (IDLH), and effects of O<sub>2</sub> deficiency are exacerbated at high altitudes.

**Table 4–1. Health Effects of Oxygen Levels Below 19.5%**

| Oxygen Level (%) | Health Effects   |
|------------------|--|
| < 19.5           | Beginning of hypoxia; minimal effects                                    |
| ≤ 17             | Increase in respiratory volume and heart rate                            |
| ≤ 16             | Impaired judgment and breathing; rapid fatigue                           |
| ≤ 14             | Impaired attention, thinking, and coordination; intermittent respiration |
| ≤ 10             | Nausea, vomiting, and lethargy; possible unconsciousness                 |
| < 6              | Spasmodic breathing; convulsion; death in minutes                        |

General ventilation of occupied spaces provides adequate outdoor (i.e., fresh) and recirculated air for breathing and the elimination of hazardous substances. It contributes not only to the comfort and efficiency of personnel but also to improved worker health because adequate ventilation helps to control odors, extreme temperature and humidity conditions, CO<sub>2</sub> buildup, and the spread of communicable diseases via contamination of airborne dust and droplets.

Regardless of the O<sub>2</sub> level in an indoor atmosphere, inadequate outdoor airflow rates may result in minor health effects such as sick building syndrome. Symptoms of sick building syndrome may include headache, fatigue, and eye and respiratory irritation. These symptoms may lead to a higher incidence rate of respiratory infections or chronic illnesses resulting from long-duration exposures.

## 4–5. Pre-assessment Procedures

**A. Source Identification and Early Involvement.** Identify potential causes for O<sub>2</sub> depletion associated with materiel. O<sub>2</sub> is quickly consumed by combustion reactions and can be displaced from air due to high concentrations of simple asphyxiants such as CO<sub>2</sub>, methane, or nitrogen. Environments that are more likely to be O<sub>2</sub>-deficient include confined spaces, subterranean environments, and high altitudes.

Early HHA involvement in the design process may allow for more efficient risk mitigation and reduced costs. For example, ventilation systems should be designed so that intake positions minimize the possibility of contaminated air entering the enclosure. Intakes should be placed away from exhaust pipes and areas with high potential for dust. Designing with commercial environmental control units (ECUs) and ventilation systems that have been previously assessed may reduce testing requirements and ensure outdoor and recirculated air requirements are met. Preliminary assessments of systems requiring LEV may help in the selection of LEV type and design, based on the use scenario.

**B. General Ventilation Data Requirements.** The information and data required to assess general ventilation in an HHA include the following:

- Total supply airflow rate.
- Outdoor airflow rate or air exchange rate.
- Volume of the enclosure, ideally the net volume with occupants and equipment.
- Number of occupants.
- Use scenario information:
  - Frequency and duration of time spent in the vehicle or shelter.
  - Tasks performed by system operators.
  - Window positions (i.e., open/closed) during operation.
  - Environmental conditions (e.g., high altitude, subterranean).

Air exchange rate data should be collected in accordance with U.S. Army Test and Evaluation Command (ATEC) Test Operations Procedure (TOP) 02–2–614A and TOP 02–2–622. The TOP 02–2–614A describes procedures for measuring the air exchange rate in vehicles, and TOP 02–2–622 describes procedures for measuring the air exchange rate in tents and shelters. Typically, sulfur hexafluoride (SF<sub>6</sub>) is used as a tracer gas to monitor air exchanges and volumetric airflow rate in a shelter or vehicle. A long-path Fourier-transform infrared (FTIR) spectrometer monitors the SF<sub>6</sub>

concentration until the concentration decays to the baseline. After testing, ATEC provides the number of ACH. The outdoor airflow rate ( $Q_o$ ) is calculated using the ACH. Specific required conditions for individual tests are explicitly defined in the detailed test plan. Example conditions may include testing with the vehicle configuration setting at maximum ventilation (all ventilation fans on and set to highest setting) and again at minimum ventilation (all fans on but set to lowest setting). If applicable, the ventilation may need to be tested with the outdoor air option enabled and again with recirculation enabled. Another condition that may need to be tested is the air exchange rate, both with the windows opened and closed, if applicable.

TOP 02–2–614A and TOP 02–2–622 do not include procedures to measure total ventilation supply airflow or air velocities. The best method for determining total supply airflow rate ( $Q_s$ ) is measurement using a balometer. Because this requires a flat surface around the vent(s), it is usually feasible in a shelter but may not be feasible in a vehicle. Air velocity measurements across a vent, typically using a hot wire anemometer, are not expected to be accurate because of high variability over small portions of the vent; however, they may be the only practical method for vehicle vents. Duct traverse results may be reasonably accurate if they can be obtained in a long, straight section of duct, but such a section is usually not found in vehicles or shelters.

An ECU manufacturer's nominal total airflow rate and maximum outdoor airflow rate may be considered, and may be the only data available, but they are only as reliable as the circumstances of the installation. For example, an ECU manufacturer's airflow specifications may only be accurate for a through-wall unit with no added ductwork. Addition of ductwork to a through-wall unit substantially reduces the airflow rate from the rated value due to the increased pressure drop through the system.

If data are not available for a system, analogy to a similar system may be used for an HHA. A conservative initial risk assessment code (RAC) may be assigned based on the available information until adequate data are provided to demonstrate that the system meets requirements.

**C. Dilution Ventilation and Local Exhaust Ventilation System Testing.** If a general ventilation system is designed to provide dilution ventilation, it must be tested under conditions of actual or simulated emissions. A detailed use scenario is required to determine the frequency and duration of exposure and the potential contaminant(s) of concern. LEV systems must be tested to verify that their performance meets the requirements of the ACGIH Industrial Ventilation manual. If their performance is inadequate, assess the chemical hazard from inadequate containment of the contaminant(s) (refer to TG 351D, Chapter 3, Chemical Substances).

## 4–6. Risk Assessment Process

The risk assessment process described in this section applies to general ventilation systems only. Health hazards associated with LEV, confined spaces, high altitudes,

subterranean environments, and dive operations are assessed on a case-by-case basis according to the health protection criteria described in section 4–3.

**A. Estimating Oxygen and Carbon Dioxide Levels.** Estimate the O<sub>2</sub> and CO<sub>2</sub> steady-state levels in the vehicle or shelter using the calculation methods described in Appendix D of ANSI/ASHRAE 62.1. The rates of O<sub>2</sub> consumed and CO<sub>2</sub> generated by occupants are directly proportional to the metabolic rate (MR) (i.e., work effort). For moderate work effort, assume a MR of 3.2 metabolic equivalent of task (mets). An MR of 3.2 mets corresponds to an O<sub>2</sub> consumption rate of about 0.03 cfm/person, and a CO<sub>2</sub> generation rate of about 0.035 cfm/person. Heavier work efforts result in more O<sub>2</sub> consumed and more CO<sub>2</sub> generated. The concentration of O<sub>2</sub> inside the enclosure may be estimated by:

$$C_{O_2,inside} = C_{O_2,outdoors} - \left[ \frac{q_{O_2}/person}{Q_o/person} \right] \quad (\text{Equation 4-2})$$

Where:

$Q_o/person$  = outdoor airflow rate per person

$C_{O_2, inside}$  = concentration of oxygen inside the shelter or vehicle

$C_{O_2, outside}$  = concentration of oxygen outside/entering the shelter or vehicle (typically assumed to be 20.9%)

$q_{O_2}/person$  = O<sub>2</sub> inhalation rate (≈0.03 cfm/person at a moderate work effort)

The concentration of CO<sub>2</sub> inside the enclosure is calculated similarly, except CO<sub>2</sub> is generated instead of consumed. The concentration of CO<sub>2</sub> inside the enclosure may be estimated by:

$$C_{CO_2,inside} = C_{CO_2,outdoors} + \left[ \frac{q_{CO_2}/person}{Q_o/person} \right] \quad (\text{Equation 4-3})$$

Where:

$Q_o/person$  = outdoor airflow rate per person

$C_{CO_2, inside}$  = concentration of carbon dioxide inside the vehicle or shelter

$C_{CO_2, outside}$  = concentration of carbon dioxide outside/entering the vehicle or shelter (typically assumed to be 410 ppm)

$q_{CO_2}/person$  = CO<sub>2</sub> exhalation rate (≈0.035 cfm/person at a moderate work effort)

For example, a person working with a moderate work effort (3.2 mets) in a space with a ventilation rate of 2.5 cfm/person would experience a steady-state O<sub>2</sub> level of about 19.7%. The steady-state level of CO<sub>2</sub> would be about 14,400 parts per million (ppm), well above the Army 8-hour OEL of 5,000 ppm (refer to TG 351D, Chapter 3, Chemical Substances for information about Army OELs). These calculations are shown below using Equations 4–2 and 4–3, and assume outside O<sub>2</sub> and CO<sub>2</sub> concentrations of 20.9% and 410 ppm, respectively.

$$C_{O_2,inside} = 20.9\% O_2 - \left[ \frac{0.03 \text{ cfm}}{2.5 \text{ cfm}} \right] = 19.7\% O_2$$

$$C_{CO_2,inside} = \frac{410 \text{ ppm}}{10^6} + \left[ \frac{0.035 \text{ cfm}}{2.5 \text{ cfm}} \right] = 14,400 \text{ ppm } CO_2$$

Where:

$C_{O_2, inside}$  = concentration of oxygen inside the shelter or vehicle

$C_{CO_2, inside}$  = concentration of carbon dioxide inside the vehicle or shelter

**B. Calculating Minimum Outdoor Airflow Rate.** The Army 8-hour OEL for CO<sub>2</sub> is 5,000 ppm. O<sub>2</sub> is considered deficient below 19.5%. Because outdoor airflow rates cause CO<sub>2</sub> levels to become a concern before O<sub>2</sub> levels do, use the CO<sub>2</sub> OEL as a screening criteria for outdoor airflow rates of concern. By rearranging Equation 4-3 and setting the inside concentration of CO<sub>2</sub> equal to the OEL (5,000 ppm), the outdoor airflow rate where the CO<sub>2</sub> concentration may reach the OEL is equal to:

$$Q_o/person = \frac{q_{CO_2}/person}{C_{CO_2,inside} - C_{CO_2,outdoors}} = \frac{0.035 \text{ cfm}}{5000 \text{ ppm} - 410 \text{ ppm}} \times 10^6 = 7.6 \text{ cfm}$$

(Equation 4-4)

Where:

$Q_o/person$  = outdoor airflow rate per person

$C_{CO_2, inside}$  = concentration of carbon dioxide inside the vehicle or shelter

$C_{CO_2, outside}$  = concentration of carbon dioxide outside/entering the vehicle or shelter  
(assumed 410 ppm)

$q_{CO_2}/person$  = CO<sub>2</sub> exhalation rate (≈0.035 cfm/person at a moderate work effort)

Therefore, a person working with a moderate work effort in a space where the outdoor airflow rate is about 8 cfm/person or less may be overexposed to CO<sub>2</sub>. Below this ventilation rate, O<sub>2</sub> levels may also be deficient, depending on the MR and use scenario. For systems with ventilation rates below 8 cfm/person, estimate the O<sub>2</sub> and CO<sub>2</sub> levels using Equations 4-2 and 4-3, respectively, to determine the risk level.

Note that Equations 4-2 and 4-3 factor in O<sub>2</sub> consumption and CO<sub>2</sub> generation from breathing rates only and do not consider combustion sources. Enclosures with combustion sources (e.g., weapon systems, kitchen ovens) may require additional consideration. Combustion consumes O<sub>2</sub>; however, weapon propellants typically contain O<sub>2</sub> that is released during firing. As a result, the depletion of O<sub>2</sub> during weapons firing may be considered negligible in most cases. Refer to section 4-6D for more information about estimating CO<sub>2</sub> levels during combustion.

**C. Determining Hazard Severity and Hazard Probability.** The following sections describe the process of determining the hazard severity (HS), hazard probability (HP), and resulting risk levels for general ventilation systems.

(1) **Hazard Severity.** The major parameter for health risk associated with general ventilation is the outdoor airflow rate per person. Depending on the use scenario, very low rates may create an O<sub>2</sub>-deficient atmosphere, as well as potential chemical overexposures. Outdoor airflow rates that maintain adequate O<sub>2</sub> levels but are below the MIL-STD-1472G requirement may create minor temporary health effects (e.g., sick building syndrome) in some personnel but pose a very low health risk. Total supply airflow below the MIL-STD-1472G requirement with adequate outdoor airflow may occasionally cause minor temporary health effects due to poor air movement and distribution.

Using Equation 4-1, calculate the outdoor airflow rate from the ACH provided by ATEC. For systems with outdoor airflow rates below 8 cfm/person, further estimate the O<sub>2</sub> and CO<sub>2</sub> levels using Equations 4-2 and 4-3, respectively.

Assign an HS of 1 (Catastrophic) or 2 (Critical) for an O<sub>2</sub>-deficient atmosphere, depending on the estimated O<sub>2</sub> level. Assign an HS of 4 (Negligible) for a non-O<sub>2</sub>-deficient atmosphere (i.e., outdoor airflow rates above 8 cfm/person, or estimated O<sub>2</sub> levels greater than or equal to 19.5%). Airflow rates are assumed to adequately maintain O<sub>2</sub> levels at 8 cfm/person or greater based on section 4-6B. Assign an HS of 1 for a confined space.

(2) **Hazard Probability.** O<sub>2</sub>-deficient environments may result in very rapid health effects in **all** exposed individuals. Even in a non-O<sub>2</sub>-deficient atmosphere, inadequate airflow rates may result in minor health effects in **some** exposed individuals (e.g., sick building syndrome).

Using Equation 4-1, calculate the outdoor airflow rate from the ACH provided by ATEC. For systems with outdoor airflow rates below 8 cfm/person, further estimate the O<sub>2</sub> and CO<sub>2</sub> levels using Equations 4-2 and 4-3, respectively.

Because all exposed individuals are expected to experience rapid health effects, assign an HP of A (Frequent) for an O<sub>2</sub>-deficient atmosphere (i.e., estimated O<sub>2</sub> levels less than 19.5%). For systems with outdoor airflow rates less than 8 cfm/person and a non-O<sub>2</sub>-deficient atmosphere (i.e., estimated O<sub>2</sub> levels greater than or equal to 19.5%), assign an HP of D (Remote). For systems with outdoor airflow rates greater than 8 cfm/person but less than the MIL-STD-1472G requirement, assign an HP of E (Improbable). Assign an HP of C (Occasional) for a confined space unless technical manuals and training materials are confirmed to provide suitable warnings and instructions for safe entry, such as those found in 29 CFR 1910.146.

(3) **Risk Levels.** Table 4-2 provides the risk levels based on the HS categories and HP levels determined in sections (1) and (2) above.



**Table 4–2. Oxygen Deficiency/General Ventilation Risk Levels**

| Outdoor Airflow Rate ( $Q_o$ ) Per Person (cfm/person) | Estimated Oxygen ( $O_2$ ) Level (%) <sup>a</sup> | Hazard Severity (HS) and Hazard Probability (HP) | Risk Level   |
|--|---|--|--------------|
| $Q_o/\text{person} < 8$                                | $O_2 < 17\%$                                      | HS 1, HP A                                       | High         |
|  | $17\% \leq O_2 < 19.5\%$                          | HS 2, HP A                                       | High         |
|  | $O_2 \geq 19.5\%$                                 | HS 4, HP D                                       | Low          |
| $8 \leq Q_o/\text{person} < \text{MIL-STD-1472G}^b$    | n/a   | HS 4, HP E                                       | Low          |
| $Q_o/\text{person} \geq \text{MIL-STD-1472G}^b$        | n/a   | HP F   | Not assigned |
| Confined spaces (if no proper warnings)                | n/a   | HS 1, HP C                                       | High         |

Legend:

cfm = cubic feet per minute

MIL-STD = Military Standard

n/a = not applicable (see footnote a)

Note:

<sup>a</sup>The estimated oxygen level is calculated using Equation 4–2, which is based on American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ANSI/ASHRAE) 62.1 (2016), Appendix D. Where this column shows “n/a” for the oxygen level, the risk level is not dependent on the estimated oxygen level because the outdoor airflow rate is assumed to maintain adequate oxygen levels.

<sup>b</sup>The MIL-STD-1472G minimum requirement is dependent on the system type, volume, and number of occupants (refer to Figure 4–1). For vehicles, the minimum requirement is  $\geq 20$  cfm/person of outdoor air. For shelters  $\leq 150$  cubic feet ( $\text{ft}^3$ ) in size, the minimum requirement is  $\geq 30$  cfm/person of total supply air with two-thirds being outdoor air. For shelters  $> 150 \text{ ft}^3$  in size, the minimum requirement is ventilation and outdoor airflow rates in accordance with Figure 4–2.

(4) **Additional Considerations.** The risk levels in Table 4–2 assume that steady-state levels are reached during the exposure. The steady-state  $O_2$  and  $CO_2$  concentrations may be estimated using Equations 4–2 and 4–3 above, respectively. Additional considerations may be required for use scenarios where the exposure time is very limited or the mixing rate is assumed to be poor. For example, a shelter occupied during maintenance for only 15 minutes per 8-hour work day may not reach  $O_2$  levels of concern if the time to reach the steady-state level is 2 hours. In this case, the HP may be reduced. Conversely, the HP may be increased if the atmosphere is considered hazardous due to poor mixing. Poor mixing is likely in small spaces and is dependent on

the location of air inlets and outlets, enclosure geometry, and uniformity of distribution in the space. To calculate the CO<sub>2</sub> concentration in a poorly ventilated space at any point in time, use the following equation which has been modified from the original (Pietrucha 2017) to include a mixing factor:

$$C_t = \left(\frac{q}{nV}\right) (1 - e^{-knt}) + (C_i - C_o)e^{-knt} + C_o \quad (\text{Equation 4-5})$$

Where:

- $C_t$  = carbon dioxide concentration in the room ( $\text{m}^3/\text{m}^3 = \text{ppm}/1 \text{ million}$ ) at time  $t$
- $k$  = mixing factor to account for poor ventilation (equal to 1 for ideal mixing, or less than 1 for non-ideal mixing)
- $q$  = carbon dioxide exhalation rate ( $\text{m}^3/\text{h}$ ) ( $\approx 0.035 \text{ cfm/person}$  or  $\approx 0.059 \text{ m}^3/\text{hour/person}$  at a moderate work effort)
- $V$  = volume of the room ( $\text{m}^3$ )
- $n$  = number of outdoor air changes per hour (1/hour)
- $t$  = time (hours)
- $C_o$  = carbon dioxide concentration in the makeup (outdoor) air ( $\text{m}^3/\text{m}^3$ ) (normally  $\sim 410 \text{ ppm}$ )
- $C_i$  = initial carbon dioxide concentration inside the room at start,  $t = 0$  ( $\text{m}^3/\text{m}^3$ )

**D. Assessing Carbon Dioxide Health Hazards.** CO<sub>2</sub> levels are closely related to O<sub>2</sub> levels and are assessed as a chemical exposure (refer to TG 351D, Chapter 3, Chemical Substances). Estimate the CO<sub>2</sub> levels using Equation 4-3. When combustion sources are present (e.g., weapons, gas kitchens), the CO<sub>2</sub> levels should be monitored during testing. The O<sub>2</sub> deficiency assessor and chemical substances assessor must communicate and collaborate closely to estimate the risk of chemical overexposures based on both ventilation rates and the results of combustion products testing, if applicable.

**E. Risk Mitigation and Residual Risk.** Residual risk may remain after the implementation of recommendations and risk mitigation strategies. The risk levels described in Table 4-2 above apply to both initial risk and residual risk. The residual risk may be Eliminated (HP F) when a vehicle or shelter employs a general ventilation system meeting the MIL-STD-1472G requirements. In some cases, additional data may be required to support an HHA. A conservative initial risk may be assigned based on the provided data and analogy to similar systems.

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). Examples of O<sub>2</sub> deficiency controls in priority order include:

- (1) **Elimination.** When the O<sub>2</sub> deficiency is created by the vehicle or shelter, the exposure may be eliminated by increasing the airflow rate of the general ventilation to meet the MIL-STD-1472G requirements. Conversely, when the O<sub>2</sub> deficiency is

created by the outdoor environment, it may not be feasible to alter operational requirements to eliminate the exposure and still complete the mission.

(2) **Substitution.** ECUs known to supply adequate ventilation may be substituted for systems not meeting requirements. However, considerations must be given to the installation, ductwork, enclosure volume, and number of occupants. There is no known feasible substitute for O<sub>2</sub> deficiency caused by the outdoor environment and mission need.

(3) **Engineering Controls.** Supply or exhaust fans and ECUs may provide breathing air, eliminate hazardous substances, control odors, control extreme temperature and humidity conditions, prevent CO<sub>2</sub> buildup, and reduce the spread of communicable diseases via contamination of airborne dust and droplets.

(4) **Warnings.** Systems may be equipped with O<sub>2</sub> meters to alert operators when O<sub>2</sub> levels are deficient, particularly in systems with confined spaces or combustion sources.

(5) **Administrative Controls.** Operator manuals should address the potential health hazards associated with O<sub>2</sub>-deficient environments (including specific information regarding confined spaces), where applicable. Train the operators on the potential health hazards associated with combustion sources, confined spaces, high altitudes, subterranean environments, and dive operations. Recommendations to keep windows open during continuous occupancy may be required when general ventilation systems are not able to meet the outdoor air requirements with the windows closed.

(6) **PPE.** Atmosphere-supplying respirators (e.g., supplied-air respirator, self-contained breathing apparatus (SCBA)) may be recommended in special circumstances such as diving operations or routinely entered confined spaces known to be O<sub>2</sub>-deficient. Compressed breathing air must meet the requirements for Grade D breathing air, at a minimum. Other types of respirators do not supply O<sub>2</sub> and are not safe for use in O<sub>2</sub>-deficient environments.

## 4–7. Example Assessment Scenario

The APHC received a request for an HHA of a new mobile shelter with an interior volume of 500 ft<sup>3</sup>. The shelter is occupied during normal use and provides general ventilation.

**Step 1.** Obtain the use scenario information from the materiel developer. The maximum occupancy of the shelter is four personnel. Personnel may spend up to 8 hours per day in the shelter. Tasks performed in the shelter may include minor maintenance tasks.

**Step 2.** Using the volume of the shelter (500 ft<sup>3</sup>) and number of occupants (four), calculate the volume per person (about 125 ft<sup>3</sup>). Note that equipment and personnel also take up space, so the volume per person is likely slightly less than 125 ft<sup>3</sup>.

**Step 3.** Use Figure 4–1 to determine the MIL–STD–1472G ventilation requirements for the system. The system is a shelter, and the volume is less than 150 ft<sup>3</sup> per person. Therefore, the ventilation must provide six ACH and at least 30 cfm of ventilation air per person with two-thirds being outdoor air. For the four occupants, the ventilation air must be at least 120 cfm total air and 81 cfm outdoor air.

**Step 4.** Obtain the ventilation test data for all test conditions. The testing was performed by ATEC in accordance with TOP 02–2–622 using SF<sub>6</sub> as a tracer gas. An FTIR monitored the SF<sub>6</sub> concentration until the concentration decayed to the baseline. When the ventilation was on the maximum setting, there were 3.6 ACH.

**Step 5.** Use Equation 4–1 to calculate the outdoor airflow rate ( $Q_o$ ) from the provided ACH and shelter volume.

$$Q_o = 3.6 \text{ ACH} \times 500 \text{ ft}^3 \times \frac{1 \text{ hour}}{60 \text{ minutes}} = 30 \text{ cfm}$$

Where:

$Q_o$  = outdoor airflow rate

ACH = air changes per hour

The outdoor airflow rate is 30 cfm total, or about 7.5 cfm/person.

**Step 6.** Obtain the total supply airflow data from the manufacturer. Using a balometer, the manufacturer measured the  $Q_s$  as 240 cfm, or about 60 cfm/person.

**Step 7.** Compare the test data to the MIL–STD–1472G requirements. The supply airflow rate is 60 cfm/person, which meets the 30 cfm/person requirement. However, the ACH were only 3.6, which is below the 6 ACH requirement. The outdoor airflow rate is only 7.5 cfm/person, or 25% of the minimum supply airflow rate (30 cfm/person), which does not meet the two-thirds requirement. The design standard is partially met.

**Step 8.** Because the outdoor airflow rate is less than 8 cfm/person, estimate the O<sub>2</sub> levels in the shelter to determine the health risk. Assume a moderate work effort which corresponds to an MR of 3.2 mets. Based on the MR, estimate the O<sub>2</sub> consumption rate to be about 0.03 cfm/person. Use Equation 4–2 to calculate the steady-state concentration of O<sub>2</sub> inside the vehicle.

$$C_{O_2, \text{inside}} = C_{O_2, \text{outside}} - \left[ \frac{O_2 \text{ consumption rate from breathing}}{Q_o / \text{person}} \right] = 20.9\% - \frac{0.03 \text{ cfm}}{7.5 \text{ cfm}} = 20.5\%$$

Where:

$Q_o / \text{person}$  = outdoor airflow rate per person

$C_{O_2, \text{inside}}$  = concentration of oxygen inside the shelter or vehicle

$C_{O_2, \text{outside}}$  = concentration of oxygen outside/entering the shelter or vehicle (assumed 20.9%)

$O_2$  consumption rate from breathing  $\approx 0.03$  cfm at a moderate work effort

Although the design standard is not met, the  $O_2$  level of the shelter is expected to remain above 19.5% (i.e., not  $O_2$ -deficient). The amount of airflow is not expected to cause significant adverse health effects under normal use of the shelter.

**Step 9.** Because the outdoor airflow rate is less than 8 cfm/person, coordinate with the assessor for the chemical substances health hazard to assess the risk of  $CO_2$  overexposure. Using the same MR as assumed in Step 8 (3.2 mets), estimate the  $CO_2$  generation rate to be about 0.035 cfm. Use Equation 4-3 to calculate the steady-state concentration of  $CO_2$  inside the vehicle.

$$C_{CO_2,inside} = C_{CO_2,outdoors} + \left[ \frac{CO_2 \text{ generation rate from breathing}}{Q_o/person} \right]$$

$$= \frac{410 \text{ ppm}}{10^6} + \frac{0.035 \text{ cfm}}{7.5 \text{ cfm}} = 5,077 \text{ ppm}$$

Where:

$Q_o/person$  = outdoor airflow rate per person

$C_{CO_2, inside}$  = concentration of carbon dioxide inside the vehicle or shelter

$C_{CO_2, outside}$  = concentration of carbon dioxide outside/entering the vehicle or shelter  
(assumed 410 ppm)

$CO_2$  generation rate from breathing  $\approx 0.035$  cfm at a moderate work effort

The  $CO_2$  concentration may exceed the OEL of 5,000 ppm and should be assessed as a chemical hazard. Other combustion sources, such as the heater, may contribute to the  $CO_2$  concentration. Refer to TG 351D, Chapter 3, Chemical Substances, for information about assigning a risk level for the chemical substances exposure.

**Step 10.** Use Table 4-2 to assign the risk level for the  $O_2$  deficiency hazard associated with the shelter. The outdoor airflow rate is below 8 cfm/person, so the risk level is calculated using the top three rows. The estimated  $O_2$  level is 20.8%. Assign a risk level of Low (RAC: HS 4, HP D).

**Step 11.** To eliminate the risk, the ventilation system must provide at least 120 cfm of ventilation air with at least 80 cfm being outdoor air (i.e., two-thirds of the minimum supply airflow). If the ECU is adapted to provide at least 80 cfm of outdoor air and the total supply air remains above 120 cfm, the residual risk may be Eliminated (RAC: HS 4, HP F). New ventilation data must be provided to the APHC to verify.

#### 4-8. Limitations and Potential Future Work

(1) As mentioned in section 4-3, the ventilation requirements in MIL-STD-1472H call for very large flows of outdoor air, far beyond the requirements in MIL-STD-1472G and other standards. The MIL-STD-1472H requirements would

dramatically increase the costs, weights, space requirements, and electrical demands of HVAC systems. The requirements are currently under review.

(2) Obtaining total airflow rates for vehicles and outdoor airflow rates for shelter/building ECUs is often difficult. These calculations generally require data from manufacturers. Developing new TOPs or updating existing TOPs 02-2-614A and 02-2-622 to provide methods for obtaining these parameters (in addition to ACH) would improve data quality and assessments. Refer to section 4-5 for more information.

## APPENDIX 4A

## CHAPTER 4 REFERENCES

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**APPENDIX 4B**  
**CHAPTER 4 GLOSSARY**

**ACGIH**

American Conference of Governmental Industrial Hygienists

**ACH**

air changes per hour

**ANSI**

American National Standards Institute

**ASHRAE**

American Society of Heating, Refrigerating, and Air-Conditioning Engineers

**ATEC**

U.S. Army Test and Evaluation Command

**CBRN**

Chemical, Biological, Radiological, Nuclear

**cfm**

cubic feet per minute

**CFR**

Code of Federal Regulations

**CO<sub>2</sub>**

carbon dioxide

**ECU**

environmental control unit

**ft<sup>3</sup>**

cubic feet

**FTIR**

Fourier-transform infrared

**HHA**

health hazard assessment

**HP**

hazard probability

**HS**

hazard severity

**HVAC**

heating, ventilation, and air-conditioning

**LEV**

local exhaust ventilation

**mets**

metabolic equivalent of task

**MIL-STD**

Military Standard

**MR**

metabolic rate

**O<sub>2</sub>**

oxygen

**OEL**

occupational exposure limit

**OSHA**

Occupational Safety and Health Administration

**PPE**

personal protective equipment

**ppm**

parts per million

**Q<sub>o</sub>**

outdoor airflow rate

**Q<sub>s</sub>**

supply airflow rate

**RAC**

risk assessment code

**SF<sub>6</sub>**

sulfur hexafluoride

**TB MED**

Technical Bulletin, Medical

**TG**

Technical Guide

**TLV**

Threshold Limit Value

**TOP**

Test Operations Procedure