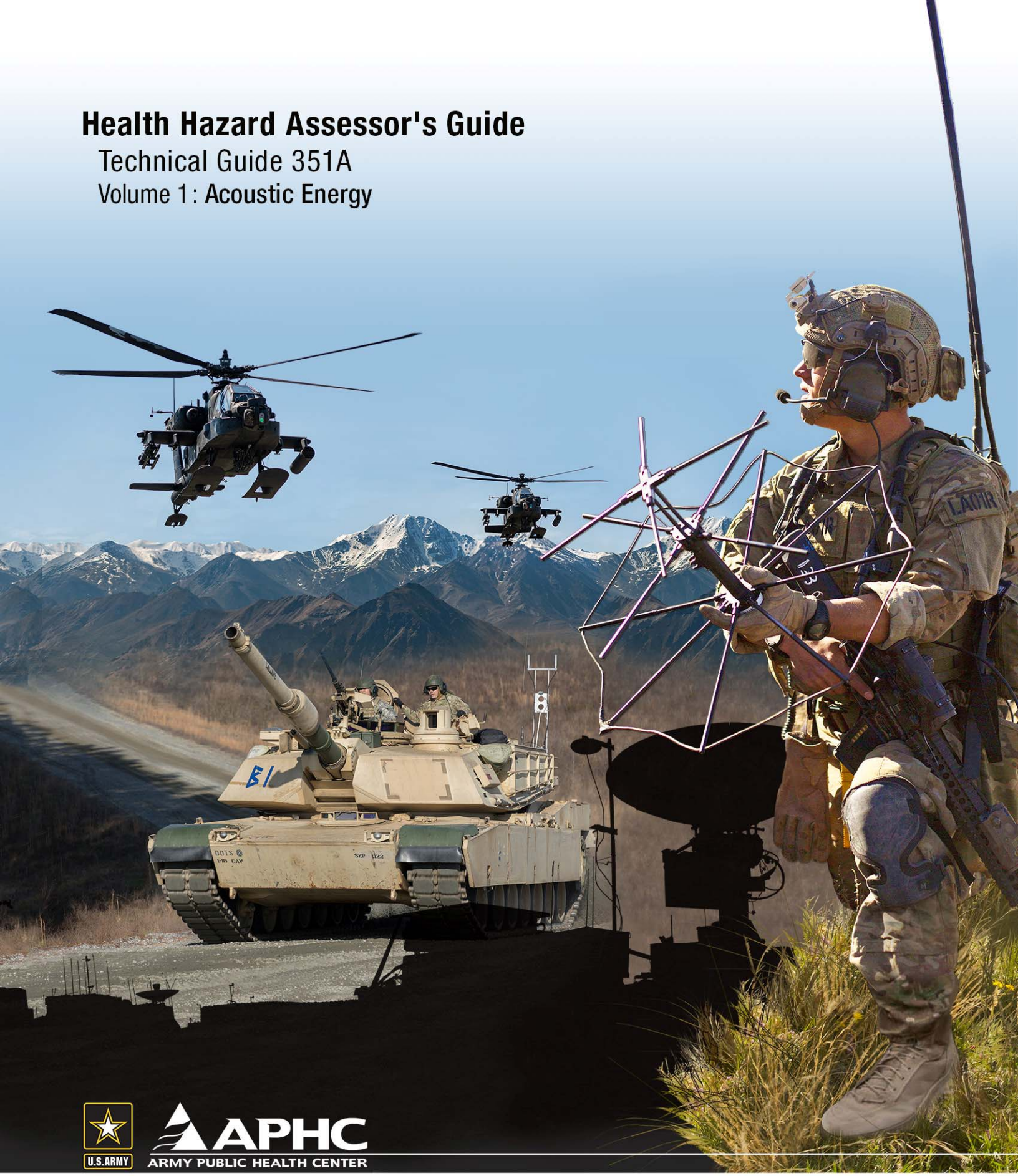
Health Hazard Assessor's Guide

Technical Guide 351A

Volume 1: Acoustic Energy



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PREFACE

TG 351A, Volume 1: Acoustic Energy, consists of guidelines for assessing health hazards related to acoustic energy, including both auditory and non-auditory noise. This volume includes an introductory chapter, followed by three chapters presenting guidelines for conducting health hazard assessments of exposure to steady-state noise, impulse noise, and blast overpressure, respectively.

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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 is preferred over qualitative data. Based on the exposure dose information, the physiological response and potential adverse health effects may be assessed.

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

modeling techniques can yield useful potential exposure data at less cost and in less time than actual testing and sampling. By applying experience and professional knowledge, as logical and appropriate, it is also possible to estimate the significance of the health hazard based on analogy with previous assessments.

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

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

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

Note 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[1]

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

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

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

Table 1–2. Hazard Severity Categories

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

Source: Adapted from MIL–STD–882E

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

Table 1–3. Risk Assessment Matrix

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

Source: MIL–STD–882E

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

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

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

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

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

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

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

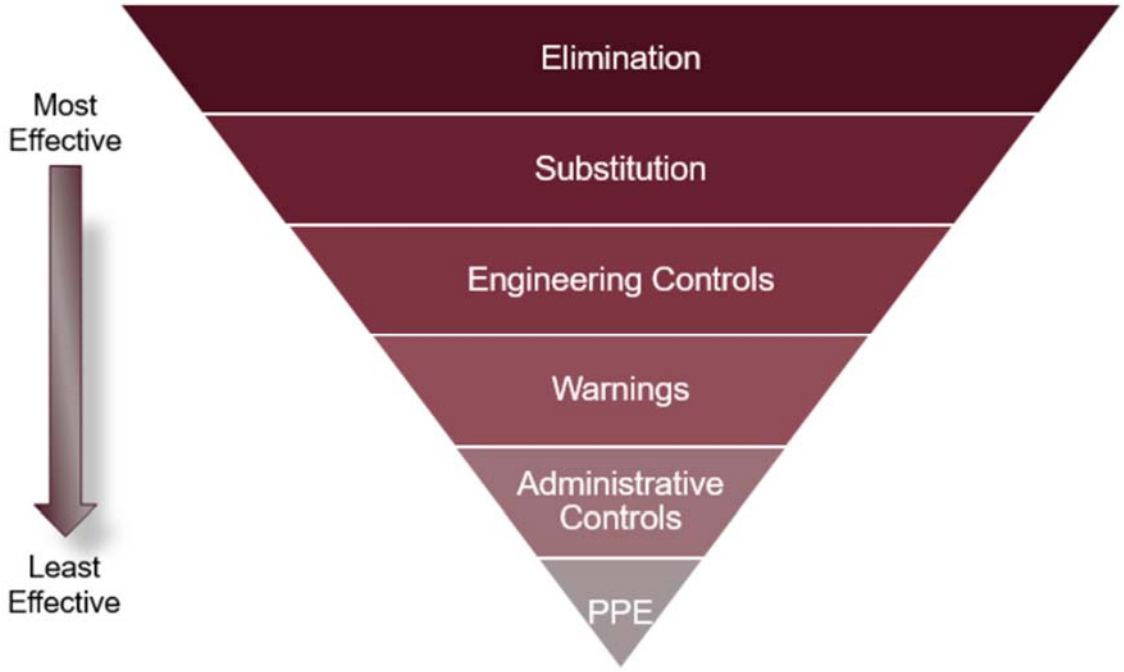

Figure 1–1. Hierarchy of Effectiveness of Controls
(Source: DODI 6055.01)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

APPENDIX 1A

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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 ACOUSTIC ENERGY: STEADY-STATE NOISE

Source: DVIDS

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2–1. Purpose

This chapter provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to steady-state noise that occurs during the normal use and maintenance of materiel systems.

2–2. Definitions of Key Terms

Acoustic energy: Sound created by a vibrating source or an explosion which propagates through an elastic medium such as air.

Contour distance: The area in which sound levels caused by the materiel equal or exceed a specific noise level. The contour distance is calculated using:

$$dB_2 = dB_1 + 20\log\left(\frac{R_1}{R_2}\right) \qquad \text{(Equation 2–1)}$$

Where:
dB_1 = noise level 1 in decibels (dB)
dB_2 = noise level 2 in dB
R_1 = distance from source where noise level dB_1 was measured
R_2 = distance from source where noise level is equal to dB_2

Generally, dB_2 is set to equal 85 decibels A-weighted (dBA) to calculate the 85-dBA contour distance for single hearing protection (SHP). The value dB_2 may also be set to equal 103 dBA to calculate the 103-dBA contour distance for double hearing protection (DHP). However, dB_2 may be set to any value to calculate the distance for any amount of protection. For a single noise source with no obstructions (i.e., free-field), the noise level decreases by 6 dB for every doubling of the distance.

Daily noise dose: The 85 dBA noise limit relative to the cumulative hazardous noise exposure. Workers exposed to 85 dBA for an 8-hour work shift will receive a daily noise dose of 100%. If noise levels are higher than 85 dBA, a 100% dose is received in less exposure time. The formula to calculate the dose is:

$$\%Dose = 100 \times \left(\frac{A_1}{T_1} + \frac{A_2}{T_2} + \cdots + \frac{A_i}{T_i}\right) \qquad \text{(Equation 2–2)}$$

Where:
A = total time of exposure
T = limiting value for that particular noise level

The limiting value (T) in minutes for an 8-hour work day is equal to:

$$T = \frac{480\ minutes}{2\text{^}(L-85\ dBA)/3\ dBA} \quad \text{(Equation 2–3)}$$

Where:
L = noise level in dBA

Note that the numerator may be adjusted to account for exposures lengths in excess of 8 hours. In the military, noise exposure is typically assessed over a 24-hour period, termed the ***daily noise exposure***.

Damage risk criteria (DRC): Define the relationship between the noise exposure and the probability of sustaining hearing loss. For hearing damage to become permanent, many repeated daily noise exposures must occur although temporary effects following a single day of exposure are possible.

Decibel (dB): A unit to express sound pressure level, equal to:

$$dB = 20 \log \frac{P}{P_o} \quad \text{(Equation 2–4)}$$

Where:
P = pressure in microPascals (μPa) at a given distance
P_o = dB reference level (usually 20 μPa, which corresponds to 0 dB)

Decibel A-weighted (dBA): This type of weighting adjusts noise levels by frequency content in a manner similar to how our ears filter what we hear at low levels of sound. Although ears respond differently at various sound levels, the A-weighting adjustment is commonly used to measure steady-state sound at all levels.

Double hearing protection (DHP): In-ear combined with over-ear protection with the objective of limiting at-ear noise to a safe level. The Army requires DHP within the 103-dBA contour distance. The protection afforded by hearing protectors is limited by the properties of the devices, their fit, and other factors. For more information, see section 2–6D.

Frequency: An attribute of a sound describing the rate of pressure variation. A pure tone has a single frequency and is the simplest kind of sound. All other sounds consist of different frequency components and specific decibel levels. The unit for frequency is Hertz (Hz). The audible range includes energies below 20 kilohertz (kHz).

Hearing conservation criteria (HCC): Define the noise exposure levels at which various hearing conservation measures, such as hearing protection or time limits, are implemented. These criteria are often based on DRC and are selected to ensure that members of a limited, predetermined population suffer only a mild hearing loss after

spending their career in a noisy work environment. Administrative considerations, such as the need for criteria that are easy to follow, may influence HCC formulation. The HCC describe the kinds of personal hearing protective devices to use and when and how to use them. Army guidance states that approved hearing protection must be worn whenever noise levels are ≥85 dBA, regardless of the exposure time.

Noise: Usually unwanted or unnecessary sound. However, all sounds contribute to overall noise exposure, so all sound is noise from a hazard perspective.

Noise-related design criteria: Noise-related requirements that are applied during the acquisition process of an item that makes noise. Design criteria evolve from consideration of hearing DRC, speech intelligibility, aural detection, state-of-the-art noise reduction technology, and government legislation. Ideally, the noise-related design criteria are the same as the HCC or DRC. The current Department of Defense (DOD) design criteria for steady-state noise is a level of 85 dBA for all noise sources, regardless of exposure time.

Octave band: A standardized band of sound with lower and upper frequency bounds. It is described in terms of the geometric mean frequency of the range of frequencies involved. Octave bands are often used to characterize the frequency content of a sound. There are 10 octave bands in the audible frequency range.

One-third octave band: One-third octave bands break the octave bands into three contiguous narrower bands and may be used to provide additional detail about the frequency content of a sound. There are 30 one-third octave bands in the audible frequency range.

Ototoxicants: Certain chemicals that may cause hearing loss or balance problems, regardless of noise exposure. Ototoxicants in certain pesticides, solvents, and pharmaceuticals may negatively affect how the ear functions. Simultaneous exposure to these chemicals and elevated noise levels increases the risk of hearing loss.

Single hearing protection (SHP): In-ear or over-ear protection with the objective of limiting at-ear noise to a safe level. The Army requires SHP within the 85-dBA contour distance. The protection afforded by hearing protectors is limited by the properties of the devices, their fit, and other factors. For more information, see section 2–6D.

Steady-state noise: A variation in air pressure, exceeding one second in duration, around the ambient atmospheric pressure; commonly measured in dBA. The frequency range considered in the evaluation of steady-state noise is 20 Hz to 20 kHz. Steady-state noise can be continuous, intermittent, or fluctuating, as defined below:

- ***Continuous*** steady-state noise occurs if its level does not vary over time.
- ***Intermittent*** steady-state noise occurs if its level changes during continuous periods and if some periods of very low levels of noise occur within the duration.

- ***Fluctuating*** steady-state noise occurs when the sound pressure level varies over a wide range.

Time-intensity exchange rate: The relative weighting given to the time and intensity factors when a variable sound is averaged. The exchange rate for the Army is 3 dB per doubling of exposure time. This means that for each increase of 3 dB above 85 dBA, the permissible exposure duration is decreased by half (i.e., 88 dBA is considered two times the 85 dBA dose).

Time-weighted average (TWA): A single-number indicator of daily noise exposure useful in quantifying the daily noise exposure when noise levels vary over the course of a workday and exposure durations differ from the standard 8-hour shift. The TWA is the constant level, having the same severity over 8 hours as the exposure to the actual workday noise, which changes during the course of the day. The workday noise environment may or may not continue for 8 hours, but the TWA is computed as if that same dB level were present for an entire 8-hour shift. The formula used to calculate the TWA (in dBA) is shown below:

$$TWA = 85\ dBA + 10 \log\left(\frac{\%Dose}{100}\right) \qquad \text{(Equation 2–5)}$$

2–3. Applicable References and Health Protection Criteria

A. References. 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.

B. Steady-state Noise Criteria Development. As with impulse noise, there are pertinent DRC, HCC, and design criteria that apply to limiting steady-state noise. The degree of implementation of applicable medical criteria varies based on validity and relevance to Army exposures and materiel systems. Not all methods and references listed below are fully incorporated into the Army Hearing Program's current risk assessment process. The Army Hearing Program's assessment criteria for conducting HHAs are described in section 2–3C. Applicable health protection criteria that led to the development of the current criteria include the following—

(1) In 1965, Working Group 46 of the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) developed one of the most complete sets of HCC, taking into account all of the important variables (e.g., noise level and likelihood of damage to hearing). The CHABA formulated a DRC and established the HCC to ensure a hearing loss no greater than "mild" would result from 10 years of daily exposure in a noisy work environment.

(2) J.H. Botsford (1967) simplified the complex CHABA DRC to a set of curves relating the noise level in dBA, the number of exposures, and the total allowable time in minutes. One simplification was the introduction of a typical industrial noise spectrum so that this DRC applied only to noise typically found in industry.

(3) In 1974, the Occupational Safety and Health Administration (OSHA) adopted a noise exposure DRC using an even simpler formulation. The exposure parameter was the 8-hour TWA with a 5 dB time-intensity exchange rate between noise levels and the length of exposure. The OSHA established HCC that prohibited exposure of employees to an 8-hour TWA greater than 90 dBA.

(4) By various estimates as summarized in National Institute for Occupational Safety and Health Publication No. 98-126, daily exposure to 90 dBA causes a hearing loss of more than a 25 dB in the 500 to 2,000 Hz frequency range for 21 to 29 percent of the exposed population after a lifetime of exposure. Based on those estimates, the Army considered that level of risk excessive and established a DRC using the more conservative TWA of 85 dBA. Due to the dynamic nature of military-unique training scenarios and combat, the use of time-weighting was eliminated in the Army's HCC.

(5) In 1993, the American Conference of Governmental Industrial Hygienists (ACGIH) and the Army reviewed the OSHA DRC and determined that a 3 dB time-intensity exchange rate was more applicable to the noise exposure patterns encountered by Soldiers. The Army also adopted a time-weighting factor for inclusion in the Army Hearing Division. Department of the Army Pamphlet (DA Pam) 40–501 required that hearing protection be worn at 85 dBA regardless of the noise exposure's duration. This requirement remains in effect.

C. Current Health Hazard Assessment Steady-state Noise Criteria. The Army Hearing Program and HHA criteria are continually assessed and updated as necessary. Based on the developments described above, the current steady-state noise HCC, below, apply to the Army's Hearing Conservation Program (HCP) and form the basis for recommended steady-state noise risk mitigation strategies in the HHA process:

- Noise levels ≥85 dBA for any duration and <103 dBA TWA require SHP.
- Noise levels ≥103 dBA TWA and ≤108 dBA TWA require DHP.
- Exposure to steady-state noise levels >108 dBA TWA are not permitted unless at-ear levels are proven to be <85 dBA TWA in accordance with DA Pam 40–501.
- The time-intensity exchange rate used to calculate the TWA is 3 dB per halving (or doubling) of the exposure time.

All military personnel are enrolled in the Army HCP because they are noise-exposed at least once a year during weapon qualification. Therefore, it is not necessary to recommend enrollment in the Army HCP in an HHA. Although they are not assessed in an HHA, civilians who are exposed to a TWA of ≥85 dBA must also be enrolled in the Army HCP. The requirement to wear hearing protection may be waived under certain conditions, such as if the TWA of the noise is clearly <85 dBA, even though there are brief excursions at levels ≥85 dBA (e.g., nuisance noise).

D. Ultrasonic Noise Criteria. Frequencies above 20 kHz are considered ultrasonic. The criteria for high or ultrasonic frequencies are defined in one-third octave bands, and

time-weighting is not used. The hazards from high or ultrasonic noise are rare because noise control is usually feasible, and hearing protectors are effective. The maximum permissible ultrasound exposure levels (Table 2–1) are described in DOD Instruction (DODI) 6055.12, following recommendations of the ACGIH Threshold Limit Values (TLVs). In Table 2–1, the levels below 20 kHz have been established to prevent possible hearing loss from the subharmonics of those frequencies.

Table 2–1. Maximum Permissible Ultrasound Exposure Levels

One-Third Octave Band Center Frequency (kilohertz)	One-Third Octave Band Sound Pressure Level (dB relative to 20 μPa)
10	80
12.5	80
16	80
20	105
25	110
31.5	115
40	115
50	115

Legend:
dB = decibels
μPa=microPascals

Note: The 85 dBA criterion applies only to energies below 16 kHz. However, the 85 dBA criterion includes ultrasonic noise limits that extend below the ultrasonic range (and below 16 kHz); these limits depend upon the level in the particular one-third octave band (see Table 2–1). The remainder of this chapter applies to audible noise (energy below 20 kHz), rather than ultrasonic noise.

E. Other Steady-state Noise Criteria.

(1) Federal Law. Title 29, *Code of Federal Regulations* (CFR), Part 1910.95 (29 CFR 1910.95), Occupational noise exposure, applies to DOD civilian employees; Soldiers are exempt. This regulation establishes the joint OSHA and Department of Labor Occupational Noise Exposure Standard, which defines noise as a hearing health risk and provides direction on actions to be taken if noise is detected (i.e., this standard is an HCC). These noise standards include a 90 dBA 8-hour TWA exposure limit and a 5 dB time-intensity exchange rate. The Hearing Conservation Amendment was added to the CFR in 1983 to define the essential elements of an effective HCP. The Army HCP meets or exceeds all Federal requirements.

(2) Department of Defense Instructions. DODI 6055.12, *Department of Defense Hearing Conservation Program,* sets forth the minimum requirements for DOD HCPs. The Instruction is an HCC applicable to Army military and civilian personnel and is

stricter than 29 CFR 1910.95. Each DOD component is required to establish and maintain its own HCP.

(3) Military Standard (MIL–STD) 1474E, *Noise Limits for Military Materiel.* This MIL–STD establishes noise-related design criteria for various types of materiel. It provides information on noise-measurement procedures, including specific details applicable to the measurement of impulse and steady-state noise.

(4) Army Standards.

(a) Army Regulation (AR) 40–5, *Army Public Health Program*, established an Army HCP.

(b) DA Pam 40–501, *Army Hearing Program,* superseded Technical Bulletin, Medical 501 and provides the guidance and HCC for all facilities controlled by the DA.

(5) International standards. The International Organization for Standardization (ISO) 1999, *Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing,* contains recommended DRC and HCC. This standard is used in other countries, many of which have adopted their own regulations, each with its own unique requirements. Some international standards are as stringent as the Army standards, whereas some are less stringent.

(6) ACGIH TLVs. The ACGIH publishes TLVs for various hazards, including noise. Similar to the Army's HCC, the TLV for noise comprises an 85-dBA, 8-hour TWA exposure limit and a 3-dB time-intensity exchange rate. The Army noise standards are more conservative than the TLV since the former consider any noise exposure over 85 dBA a hazard (rather than the 8-hour TWA) due to unique military operations.

F. Historical Noise Criteria. Steady-state noise criteria may derive from previous superseded or outdated criteria. In order to preserve the historical information and growth of HHA methodology, this Guide includes these historical references. Pertinent historical noise criteria include, but are not limited to, the following:

(1) MIL–STD–1294A, *Acoustical Noise Limits in Helicopters* discussed specific noise limits and measurements, and was superseded by MIL–STD–1474E.

(2) Special Text 4–02.501, *Army Hearing Program*, supplemented an earlier version of DA Pam 40–501 and provided information and guidance to prevent noise-induced hearing loss.

2–4. Health and Performance Effects of Steady-state Noise

A. Exposure Factors. Steady-state noise can cause noise-induced hearing loss, one of the most prevalent occupational illnesses among Soldiers. The relationship between exposure to steady-state noise and the onset and growth of temporary or permanent

hearing loss is complex. Some of the variables that may affect this relationship include—

- Magnitude (dB) of the noise level.
- Frequency level (Hz/kHz) of the noise
- Character (pure tone or complex wave).
- Intermittency of the noise.
- Number of quiet rest periods.
- Noise level of quiet rest periods.
- Duration of noisy and quiet rest periods.
- Number of years of exposure.
- Previous injuries.
- Individual traits or characteristics.
- Presence of ototoxicants.

B. Health Effects. High-intensity noise initially causes a loss of hearing sensitivity (a temporary hearing loss) which recovers in most cases. After repeated long-term exposure to steady-state noise, the hearing loss may become permanent. Additionally, noise exposure is cumulative; that is, steady-state noise, impulse noise, environmental noise, and off-duty exposures all contribute to noise-induced hearing loss. Other health effects from steady-state noise exposure (e.g., tissue heating) are physically possible but are not encountered at the noise levels generated by current and anticipated Army materiel systems.

Noise-induced hearing loss is progressive, and the incremental changes are generally imperceptible. Following exposure to hazardous noise, individuals may initially be unaware of a hearing loss and may have no difficulty hearing in quiet listening situations. However, they may find it difficult to hear in noisy environments. Noise-induced hearing loss is initially characterized by reduced hearing sensitivity at frequencies above 2000 Hz. Other symptoms may include ringing in the ears (tinnitus), temporary muffling of sound after noise exposure, and a sensation of fullness in the ears. Continued unprotected exposure to hazardous noise results in the progression of hearing loss into the lower frequencies and may include a loss of communication ability. Individuals with a high-frequency, noise-induced hearing loss may report that they can hear people talking but cannot understand the words being spoken.

The main difference between steady-state noise and impulse noise is that with the former, the mechanism causing the damage is believed to involve mostly metabolic processes rather than mechanical processes. In other words, impulse noise may cause acute physical damage whereas steady-state noise may cause chronic-type injuries. Blast overpressure (BOP) exposure generally occurs coincidentally with impulse noise exposure. Steady-state noise has not been reported to result in BOP exposure. Refer to Chapters 3 and 4 for more information about impulse noise and BOP, respectively.

C. Performance Effects. Temporary or permanent hearing loss adversely affects combat readiness and effectiveness. For example, adequate hearing is necessary for

offensive operations such as localizing snipers, locating patrols, and determining the position, number, and type of friendly and enemy vehicles. In defensive positions, Soldiers must be able to hear the activation of perimeter alarms as well as enemy movement through leaves, grass, and twigs. Soldiers require adequate hearing to determine the enemy's location by means of recognizing sounds such as those made by wildlife, cartridges being loaded, safety locks being activated, and barbed wire being clipped.

Soldiers with hearing loss may confuse similar-sounding words. Radio transmissions are especially difficult for Soldiers with hearing deficits to understand. Poor hearing can lead to misinterpretation of verbal commands, possibly causing errors, accidents, or mission failure. A significant hearing loss may result in Soldier ineffectiveness.

2–5. Pre-assessment Procedures

A. Early Involvement. Many sources such as wheeled and tracked vehicles, generators, aircraft, power tools, and other equipment produce steady-state noise. Early HHA involvement in the development of these noise-producing materiel, such as the approaches described below, may help eliminate or reduce health hazards.

(1) Provide materiel developers with noise-related design criteria containing specific noise limits and other requirements for the materiel. If the materiel is deemed acceptable by the procuring activity, the materiel's stated maximum noise limit must not be exceeded after fielding.

(2) The inclusion of the noise-related criteria in equipment specifications and capability documents may increase the probability of the development or procurement of quieter equipment, but the required noise limits may not be technically feasible due to current engineering best practices. A professionally qualified acoustic consultant or laboratory must conduct and report testing and analysis; the laboratory must submit documentation to the procuring activity to justify increasing the required limit(s).

B. Test Standards. Data must be collected in accordance with MIL–STD–1474E and the U.S. Army Test and Evaluation Command Test Operations Procedure (TOP) 01-2-608A. In addition to design criteria, MIL–STD–1474E contains detailed measurement requirements for military materiel that emit excessive steady-state noise. The standard states that the noise levels for each operator or crew position, as well as other positions where persons may be exposed (e.g., passengers, maintenance personnel), must be obtained for tested systems in their normal operating mode with all auxiliary equipment functioning. The noise data measured should include A-weighted and octave-band sound pressure levels (if above 85 dBA). The instrumentation used must conform to applicable American National Standards Institute and Society of Automotive Engineers specifications. Should TOP 01-2-608A and MIL–STD–1474E conflict, MIL–STD–1474E takes precedence.

C. Test Data Requirements for Steady-state Noise Assessments.

(1) Steady-state noise data, including noise levels at all Soldier-occupied or potentially Soldier-occupied positions (including potential bystander locations, and at-ear positions of operator-, crew-, and unit-level mechanics), should be collected for all equipment that may produce hazardous noise. When in doubt, verify levels produced, and proceed accordingly. This means that sufficient noise measurements need to be obtained in all normal-use environments to determine the overall TWA exposures. Source and contour distance measurements should also be taken when possible. Noise dosimetry may be conducted where representative duty cycles can be determined. In the absence of adequate data, assumptions may be made based on assessments of similar materiel. These should be caveated to support the validity of the assumptions. Quantitative data typically result in a more comprehensive assessment. In addition, assumption-based risk determinations must be made conservatively to account for the worst-case scenario.

(2) Assessing the probability of steady-state noise exposure requires information such as how a system is to be used during normal use and where a Soldier will be located relative to the noise source. If data are collected for a short amount of time, additional usage information is necessary for estimating a TWA. For these reasons, an understanding of the use scenario or mission profile is necessary to perform an HHA.

2–6. Risk Assessment Process

A. Time-weighted Average Calculation or Estimation. If noise levels of the source are known for all operational conditions during the workday, calculate the TWA of the data using Equation 2–5. The TWA may also be determined via noise dosimetry as long as the measurement period includes representative activity of the materiel. If there is insufficient information available to construct a TWA exposure (e.g., data provide only a maximum and/or average), conservative assumptions based solely on the measured sound levels are applied to yield an assumed exposure. Applying professional judgement based on experience and the system’s use scenario may be necessary to estimate a TWA. Conservative assumptions may also be made based on analogy to assessments of similar materiel. The confidence in the assessment increases with the amount of specific quantitative data. Table 2–2 shows the hazard severity (HS), hazard probability (HP), and risk level assignments based on the TWA exposure level.

Table 2–2. Time-weighted Average Risk Levels

8-hour Exposure Level (dBA, TWA)	Hazard Severity (HS)		Hazard Probability (HP)		Risk Level
>115	1	Catastrophic	A	Frequent	High
>110 and ≤115	2	Critical	A	Frequent	High
>100 to ≤110	2	Critical	B	Probable	High
85 to ≤100	2	Critical	C	Occasional	Serious
<85 TWA with some exposure to levels >85	2	Critical	D	Remote	Medium
Instantaneous levels always <85*	2	Critical	E	Improbable	Medium

Legend:
dBA = decibels A-weighted
TWA = time-weighted average
Note: The risk assessment codes for systems with insufficient data and assumed exposures may vary conservatively from Table 2-2.
* This row only applies to situations mitigated with hearing protection. Use of personal protective equipment does not change the severity of the underlying hazard.

B. Hazard Severity and Hazard Probability Determination. The risk levels are based on MIL–STD–882E and are further discussed in Chapter 1. Since a TWA is dependent on both the measured noise level and exposure time, HS and HP may both be assigned based on the single value. The initial risk is based on unprotected exposure to the noise level (i.e., no hearing protection).

The conservative 115-dBA threshold level was chosen because the result criteria of catastrophic hearing loss have not been studied extensively. Steady-state sound levels in excess of 115 dBA and reaching 130 dBA or more may exist (e.g., near jet aircraft, on the flight decks of aircraft carriers, or during industrial sandblasting operations). The OSHA does not allow noise exposures at levels higher than 115 dBA, regardless of their duration. The Army's allowable exposure time for a level of noise higher than 115 dBA is fewer than 30 seconds per day.

The HCC of 85 dBA, regardless of duration of exposure, is also conservative and may overstate the probability of harm because the effects of brief periods of exposure may be transient or non-existent. The transition from temporary to permanent effects usually requires repeated daily exposures over a period of many years.

C. Residual Risk Determination.

(1) The effectiveness and feasibility of controls determine residual risk for steady-state noise. According to DODI 6055.01, a preferred hierarchy of effectiveness of controls should be considered: 1) elimination, 2) substitution, 3) engineering controls, 4) warnings, 5) administrative controls, and 6) personal protective equipment (PPE).

Warnings, administrative controls, and PPE are the most commonly used mitigation techniques for lowering noise exposure levels although they are less effective according to the hierarchy of effectiveness of controls. Examples of steady-state noise controls in priority order appear below.

(a) Reducing noise levels at the source through ***elimination*** is the most desirable noise control option because it eliminates harmful health effects. However, elimination may not be feasible since some types of materiel are inherently noisy (e.g., burst firing of a weapon).

(b) ***Substituting*** noisy materiel components with less noisy ones may reduce the materiel's overall noise exposure level. For example, selecting commercial-off-the-shelf components that meet Army standards rather than the less stringent OSHA standards will result in less noise exposure.

(c) ***Engineering controls*** may include redesigning the materiel or soundproofing equipment (e.g., barriers between the noise source and personnel).

(d) ***Warnings*** may include clearly designated hazardous noise areas posted with appropriate signage. Calculate the contour distance using Equation 2–1 to determine the hazardous noise area and control the number of personnel exposed.

(e) ***Administrative controls*** include reducing the time spent in a hazardous noise area to lower the overall exposure level and, consequently, lower the potential for adverse health effects. If practical, modify the typical use scenario for a particular materiel system to reduce personnel exposure.

(f) Use ***PPE***, i.e., SHP or DHP, to reduce the risk of health effects. Typically, SHP is required within the 85-dBA contour distance, and DHP is required within the 103-dBA contour distance. Due to known issues with PPE (e.g., improper fit, inconsistent usage) and because using PPE does not eliminate the actual hazard, the benefits of this mitigation are quantified conservatively and are never assumed to eliminate the hazard. Reductions in noise levels depend on the spectrum of the offending sound and the specific attenuation characteristics of the hearing protection. For very high levels, require double protectors and/or limit the time of exposure so as not to exceed an at-ear TWA of 85 dBA after implementing controls. Double protection is required for ranges from 103 to 108 dBA TWA. Exposure to steady-state noise levels greater than 108 dBA TWA is not permitted unless at-ear levels are proven to be 85 dBA or less. If such is not the case, exposures will need to be reduced administratively (i.e., exposure time must be reduced).

(2) Based on the available data, applied controls, and the use scenario, assess the adjusted TWA and re-compare to Table 2–2 to assign the residual risk. For PPE usage, apply the following methods in the listed hierarchical order to assign the residual risk. Use of PPE does not change the severity of the underlying hazard since the noise environment is unchanged.

(a) If data collected using specialized auditory manikins clearly demonstrate mitigated at-ear noise levels <85 dBA, or otherwise demonstrate no hearing loss, the TWA can be re-compared to Table 2–2 to reduce the risk level. Since collecting this type of data requires specialized equipment and a known type of hearing protection, these tests may be expensive and are not performed often. Most commonly, these tests are performed for communication headsets.

(b) Calculate at-ear noise levels using octave band analysis if the data collected provide the octave bands of the noise exposure. Each octave band represents a frequency range, and noise level measurements are associated with each band. Octave band analysis also requires standard octave band specifications, including noise-attenuation characteristics, for the particular hearing protector. The mean attenuation and standard deviation are measured for each octave band by the most current applicable national standard, which varies by the type of hearing protection. To calculate hearing protector effectiveness, subtract one standard deviation from the mean attenuation determined for experimenter-assisted fit (or equivalent). Subtracting the standard deviation or reducing the expected attenuation accounts for variability due to sizing, fitting, and insertion. Subtract these expected attenuations from the measured noise levels within the same octave band. Then, calculate an overall TWA in dBA and compare the TWA to the exposure levels in Table 2–2 to assign a residual risk level.

(c) If less detailed noise data are provided, some assumptions about the protection afforded need to be made. Ideally, hearing protectors (earplugs or noise muffs) should provide at least 29 dB of protection, regardless of model or type, and an additional 5 dB if worn as double protection (e.g., earplugs with noise muffs). However, this assumption assumes perfect sizing and fitting, which are not often attained. Fit checks are extremely useful in proving that 29 dB of attenuation has been reached. If fit checks are not performed, it is reasonable to assume that SHP provides 15 dB of attenuation and DHP provides 18 dB of attenuation. To assign a residual risk level, subtract the assumed reduction from the TWA, and compare the reduced exposure to the risk designations in Table 2–2.

(d) If there is insufficient information to use the above methods, or if each Soldier does not undergo a fit check, the residual risk level may be assigned by lowering the exposure level in Table 2–2 by one row for SHP use and two rows for DHP use.

D. Personal Protective Equipment for Noise Exposure.

(1) Many brands of hearing protection must be sized and fitted correctly; all must be worn properly to be effective. Hearing protection is more complex than simply placing earplugs in one’s ears. Multiple factors can impact the effectiveness of hearing protection, including ear shape and size, properties and age of the device(s), and improper use, such as breaking the protector’s cushion seal (e.g., using earmuff-type protectors while wearing eyeglasses).

(2) The types of hearing protection include the following:

(a) ***Preformed earplugs (triple- and quadruple-flange).*** Preformed earplugs are available in three sizes. Medically trained personnel must initially fit these earplugs and perform an annual inspection of their proper fit and condition. Triple-flange earplugs are usually the first type that trained personnel attempt to fit. They may be inappropriate for difficult-to-fit cases such as crooked ear canals or extreme sizes. If preformed earplugs do not fit properly, they will be ineffective. Single-flange earplugs may still be available at some installations, but they are no longer commercially made.

(b) ***Hand-formed earplugs (silicone and foam).*** Hand-formed earplugs also require medical fitting and are disposable after a few uses. They should not be used when hazardous materials may be transferred from the hand to the earplug.

(c) ***Noise muffs.*** Certain noise muffs provide attenuation and are designed with a suspension system worn over and in back of the head or under the chin. Noise muffs are impractical in some situations. They are incompatible with eyeglasses and certain required headgear, and may not be suitable in excessively warm conditions or in areas with limited head space. When noise muffs are used, ensure the headband is adjusted properly to guarantee a snug fit against the head and around each ear. If the headband is worn in back of the head or under the chin, ensure the crown strap is also adjusted properly.

(d) ***Ear canal caps.*** This form of hearing protection is recommended only for short-term exposures to noise levels of 95 dBA or less. They do not attenuate noise as effectively as earplugs or noise muffs. The ear canal caps' design includes a headband worn over and in back of the head or under the chin. Ear canal caps are useful for intermittent exposures in which noise muffs would be too warm or bulky.

(e) ***Helmets*** (e.g., SPH-4 Aviator, HGU-56 Aviator, and DH-132 Combat Vehicle Crewman). Helmets provide hearing protection only if the Soldier wears the correct size helmet and wears it properly. The helmet is individually fitted and adjusted to obtain proper hearing, impact, and ballistic protection. The environments in which these devices are used include aircraft and tactical vehicles.

(f) ***Noise-attenuating headsets, communications aural protection system (CAPS), and artillery CAPS (ACAPS).*** Headsets, which act as noise muffs if both ears are covered, are used in environments similar to those described for helmet use. Tactical CAPS devices have recently been developed for use in dismounted operations. However, noise transmitted into the ears through built-in headset speakers may represent its own hazard depending on the use scenarios and the headset's features.

(g) ***DHP.*** In situations where any one type of hearing protector does not provide adequate noise attenuation, DHP is recommended. This involves wearing a combination of two types of hearing protection (e.g., earplugs and noise muffs, CAPS and ACAPS noise muffs with the Personal Armor System for Ground Troops Helmet). When DHP is necessary but impractical, time limits for daily noise exposure must be

imposed. When DHP is worn, it is not uncommon to impose time limits to keep the daily noise dose below 100%.

(3) The following hearing protection products are commonly used in the Army and are considered acceptable:

- Sound Guard® regular size and 3M® Amigo (small size) and Grande (large size) foam plugs.
- Tasco® Triple-flange preformed plugs.
- Elvex® Quattro™ Quad-flange preformed plugs.
- Three versions of 3M Combat Arms Earplugs.
- SureFire® EP3 and EP4 plugs.
- Moldex® Combat Earplugs.
- Television Equipment Associates, Inc. Tactical Communication and Protective System communication headset (earmuff that has communication capabilities and also provides hearing protection).

2–7. Risk Assessment Example

Step 1. A sound level meter was used to map an 85-dBA noise contour around the Mobile Tower System (MOTS) generator platform. One of the two generators on the platform was operating during this measurement, as would be the case during a normal MOTS mission. Additional noise measurements were collected at the operator control station inside the MOTS shelter.

Step 2. The sound levels measured were no higher than 80 dBA inside the MOTS shelter and were considerably lower for most operating scenarios.

Step 3. The sound levels measured at the generators were found to be 81 dBA at the control station and 87 dBA within a confined area approximately 12 inches from one side of the operating generator.

Step 4. Because MOTS personnel would spend only brief periods of time (if any) within the 85-dBA generator noise contour, it is expected that no TWA noise exposure caused by generator noise would reach 85 dBA. The MOTS personnel are exposed to noise at levels slightly higher than 85 dBA for short durations only.

Step 5. Using Table 2–2, this scenario is assigned a risk level of Medium (risk assessment code (RAC): HS 2 (Critical), and HP D (Remote)).

Step 6. Since personnel may be exposed to noise levels above 85 dBA, hearing protection is required for MOTS operators. SHP provides adequate noise attenuation because the noise level only slightly exceeds 85 dBA.

Step 7. A residual risk level is assigned based on the recommendation to wear hearing protection. Since data measurements were limited, use the least preferred method from

section 2–6C. Lower the exposure by one row in Table 2–2 for the use of SHP, which results in a risk level of Low (RAC: HS 2 (Critical), and HP E (Improbable)).

2–8. Limitations and Potential Future Work

(1) An updated hearing protector approval process has been partially developed by the Hearing Conservation Working Group, The Hearing Center of Excellence, and the Army Hearing Program to take into account new hearing protector technology and new information about Soldier needs for hearing protection. Further development is required before the approval process can be implemented.

(2) Hearing protection products with a lower impact on situational awareness are a current focus of both product development and scientific research. The use of personal hearing protection without adequate training will degrade situational awareness.

(3) There is no standard method of evaluating the noise exposure from the deliberate transmission of voice and signal traffic through communication headsets. Use of hearing protection to intervene in such transmissions would be self-defeating. Although standardized measurement and evaluation methods are lacking, developers have the means to limit at-ear levels, and the exposure can be measured with manikins. To address this issue, the Army is developing applicable new procedures, and the DOD is considering the formation of an Army-wide interagency task group.

(4) Ensuring the correct use, size, and fit of personal hearing protection for Soldiers is challenging, especially during in-theatre operations. The incorporation of fit checks is being studied to validate hearing protection attenuation not only when hearing protection is issued but also prior to noise exposure in training scenarios. Future work includes ensuring these fit checks are implemented for each Soldier in the most efficient and effective manner.

APPENDIX 2A

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APPENDIX 2B

CHAPTER 2 GLOSSARY

ACAPS
Artillery Communications Aural Protection System

ACGIH
American Conference of Governmental Industrial Hygienists

BOP
blast overpressure

MIL–STD
Military Standard

CFR
Code of Federal Regulations

CHABA
Committee on Hearing, Bioacoustics, and Biomechanics

DA Pam
Department of the Army Pamphlet

dB
decibels

dBA
decibels, A-weighted

DHP
double hearing protection

DOD
Department of Defense

DODI
Department of Defense Instruction

DRC
damage risk criteria

HCC
hearing conservation criteria

HCP
Hearing Conservation Program

HP
hazard probability

HS
hazard severity

Hz
hertz

ISO
International Organization for Standardization

kHz
kilohertz

MOTS
Mobile Tower System

OSHA
Occupational Safety and Health Association

PPE
personal protective equipment

RAC
risk assessment code

SHP
single hearing protection

TLV
Threshold Limit Value

TOP
Test Operations Procedure

TWA
time-weighted average

µPa
microPascal

CHAPTER 3. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO ACOUSTIC ENERGY: IMPULSE NOISE

Source: DVIDS

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3–1. Purpose

This chapter provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to impulse noise that occurs during the normal use and maintenance of materiel systems. The HHAs are conducted in support of the Army HHA process.

Additionally, this chapter augments the discussion in Chapter 2 on steady steady-state noise and focuses on the auditory effects of impulse noise. Impulse noise is considered separately from non-auditory blast overpressure (BOP) because of differences in the part of the body affected (rather than any difference in the underlying physical phenomenon); Chapter 4 addresses the non-auditory effects of impulse noise. The term “impulsive noise” refers to auditory effects; “blast overpressure” refers to non-auditory effects. The term “impulse” refers to a specific event or waveform; whereas “impulsive” describes the type of noise. The two are often used interchangeably.

3–2. Definitions of Key Terms

Allowable number of rounds (ANOR): A value calculated from peak pressure level and B-duration in accordance with the various impulse noise criteria formulas (refer to the *Interim Impulse Noise Damage Risk Criterion* in Appendix 3C). The ANOR estimates the number of rounds that may be fired within a 24-hour period that will produce less than 5% incidence of permanent hearing loss. The lower the ANOR, the more hazardous the noise level. Refer to Chapter 4 of this Guide for the ANOR definition applicable to BOP. Typically, the ANOR assigned due to impulse noise is more restrictive than the ANOR assigned due to BOP.

Blast pressure wave (also referred to as pressure time-history or waveform): Characterized as variations in ambient pressure over time (Figure 3–1). This increase in ambient pressure is called overpressure. The level of overpressure at a specific location depends on the energy of the source of the blast, the distance from its point of origin, the elapsed time since onset, and the measurement technique. Fuel air mixtures produce large overpressures with long durations, whereas weapons produce lower peaks with shorter durations. Explosions often produce waveforms that contain significant pressure changes that precede the main spike (not shown in Figure 3–1).

Clipping: Occurs when the measurement instrumentation has reached the maximum value of what is being measured such that the impulse time-history contains a plateau between the ascending and descending pressure values of the impulse. The peak is essentially “clipped” prior to its actual maximum value.

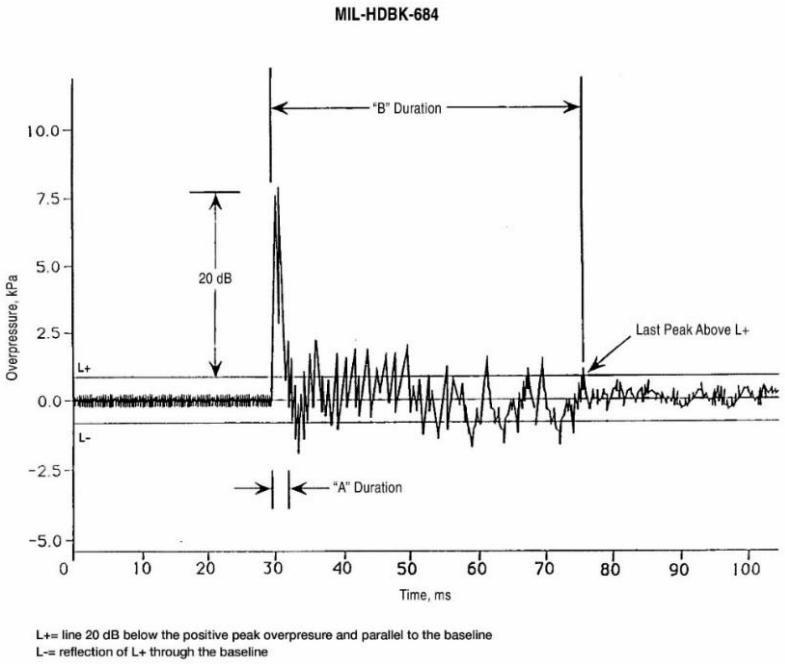

Figure 3–1. Example of Pressure-Time History

Contour distance: The distance at which generated peak sound levels no longer exceed a specific noise level. The doubling rule (Equation 3–1) is the basis for determining the impulse noise contour distance within which single hearing protection (SHP) is required, calculated as:

$$D_2 = D_1 \left(10^{\frac{(L_1 - 140)}{20}}\right) \qquad \text{(Equation 3–1)}$$

Where:
D_2 = 140 decibel (dB) contour distance
D_1 = distance of measurement from source of noise
L_1 = decibel, peak (dBP) measurement

For noise levels above 165 dBP, the contour distance within which double hearing protection (DHP) is required may also be calculated by substituting 165 dBP for 140 dBP in Equation 3–1.

Drift: Refers to changes in the baseline pressure time-history of a measurement. Drift affects pressure values positively or negatively and can be caused by a variety of factors such as wind or exposing the transducer to flashes of light or heat. Drift can often be zeroed out or edited out of a waveform for data processing purposes.

Free-field: A classification established by the *Interim Impulse Noise Damage Risk Criterion* that may be given to individual test rounds for a weapon system. A round that qualifies will have a higher ANOR than it would have if it were not free-field. (For more information, see U.S. Army Public Health Command (USAPHC) Technical Guide (TG) 338.) To qualify as free-field, a given round for a weapon system must meet all five conditions: (1) it is used outdoors, (2) its noise level does not exceed 190 dBP, (3) its B-duration is not above 60 milliseconds (ms), (4) no more than two significant peaks occur in its waveform, and (5) its A-duration is not below 2 ms or above 6 ms. A peak is significant when it equals or exceeds 50% of the amplitude of the highest peak, with each peak occurring in separate portions of the waveform determined from first to last crossing of the baseline.

Impulse noise: A variation in air pressure above the average atmospheric pressure lasting <1 second (most often for only a few ms). The most common sources for impulse noise are the firing of weapons, detonation of explosives, rapid release of high-pressure gases, and impact of solid objects (e.g., pile-driving operations, jackhammer operations, and other impact tool operations). The distinction between impulse noise and impact noise is made because of characteristic shapes of the two waveforms, but this distinction is not useful in assessing the potential health hazard from acoustic energy. BOP is a special case of impulse noise, generally produced by the rapid burning of material (such as weapons propellants) or the detonation of explosives. The quantitative description of impulse noise is based on the following parameters:

- ***Peak pressure level*** is the highest instantaneous positive pressure above the mean ambient pressure; it is usually represented in units of dBP.

- ***A-duration*** (sometimes called the positive-phase duration) is the length of time in which the pressure rises from the ambient to the peak and then returns to the ambient (see Figure 3–1).

- ***B-duration*** is generally the length of time in which the instantaneous pressure decreases by 1/10 from the peak pressure (i.e., the 20-dB down point from peak pressure). Military Standard (MIL–STD) 1474D provides examples of B-duration determination for waveforms of varying complexity. Figure 3–1 represents the vast majority of waveforms.

- ***A-impulse*** is the integral of peak pressure and A-duration, or the peak pressure over the time of the A-duration. Although not currently used in any Army criteria, this attribute is included in one of the impulse noise risk criteria metrics in MIL–STD–1471E. A-impulse had previously been included in materials related to free-field criteria.

Proportional dose methodology: An alternative method used to calculate the ANOR to remove a layer of conservatism inherent in using the worst-case round. This method uses the formulas from MIL–STD–1474D and the free-field exception, but instead of

using the worst-case round, it uses all test rounds to calculate an ANOR by accumulating the hazard associated with each test round. The methods employed in conducting a proportional dose assessment require a minimum of 20 waveforms for each test condition. For more information, see TG 338.

Trading points: A numeric value, based upon the ANOR calculated using the *Interim Impulse Noise Damage Risk Criterion*, assigned when a weapon is fired or an explosive device is detonated. It is the inverse of the ANOR multiplied by 1,000. These points are accumulated for exposures to impulse noise during a 24-hour period to determine a total number of points. Trading points determine whether or not Soldiers have exceeded the maximum 1,000-point allowance when operating multiple weapon systems that have dissimilar ANORs (refer to Appendix 3E).

3–3. Applicable References/Medical 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. Medical Criteria. As with steady-state noise, there are pertinent damage risk criteria (DRC) and hearing conservation criteria (HCC) that apply medical considerations to limiting impulse noise. The degree of implementation of applicable medical criteria varies based on validity and relevance to Army exposures and materiel systems. Not all methods and references listed below are fully incorporated into the Army Hearing Program's risk assessment process. The Army Hearing Program's *Interim Impulse Noise Damage Risk Criterion* (Appendix 3C) is the assessment method currently accepted as the standard for conducting HHAs. Other medical criteria and non- or partially-medically based design criteria that differ from the Army DRC include the following:

(1) Federal Law. As an HCC, Title 29, *Code of Federal Regulations,* Part 1910, Occupational Safety and Health Standards; Section 95, Occupational noise exposure*,* includes limited information about impulse noise. However, this Occupational Safety and Health Administration (OSHA) regulation states that impulse noise should not exceed 140 dBP. This level corresponds to the W-curve stated in MIL–STD–1474E (described below), and dBP is the standard unit of measure for Army applications. Almost all weapon firing noise exceeds 140 dBP.

(2) Department of Defense/Department of the Army (DOD/DA) Standards.

(a) MIL–STD–1474D*, Department of Defense Design Criteria Standard: Noise Limits,* February 12, 1997. Although version D of this military standard has been superseded by version E, the former's content remains relevant to this chapter. This DOD standard practice contains exposure limits derived from the 1968 Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) limit (see Appendix 3B). These limits are expressed as the ANOR per 24-hour day for a specific combination of peak pressure level levels and B-durations. Figure 3–2 illustrates the limit curves provided in

MIL–STD–1474D for selected values of ANOR presented in Table 3–1. Table 3–1 lists the ANOR for each of these curves according to MIL–STD–1474D when either no, single, or double hearing protection is used.

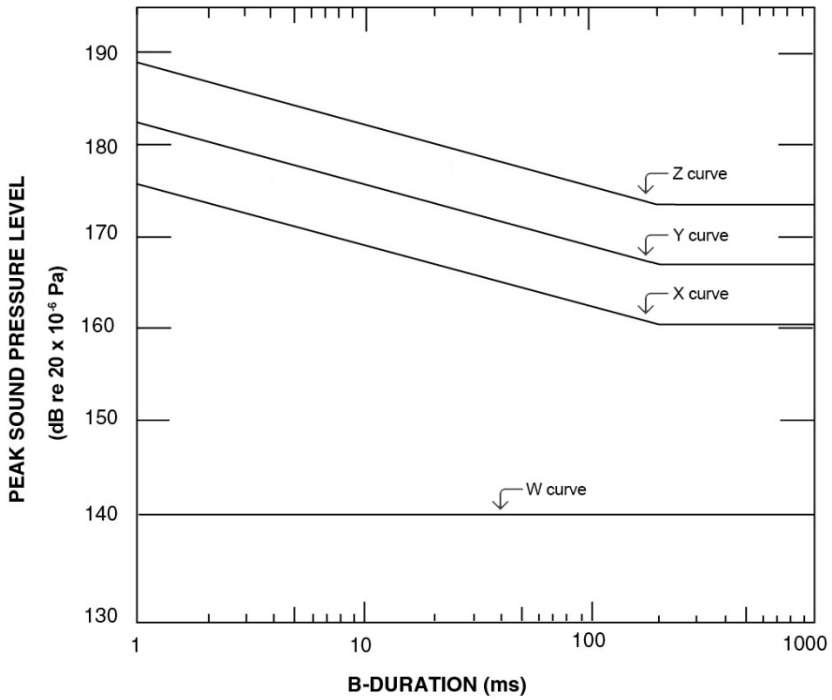

Figure 3–2. Limit Curves

The W-curve simplifies the CHABA limit and is intended for unprotected exposures. It ignores B-duration and permits any number of impulses for levels below 140 dBP. The X-, Y-, and Z-curves set limits for exposures when SHP (of any kind) is used; the curves correspond to different amounts of allowed impulses. If DHP is worn, multiply the ANOR for SHP by 20.

Table 3–1. Allowable Number of Rounds for Each Limit Curve in Military Standard 1474D

Limit Curve	Without Hearing Protection	With Single Hearing Protection	With Double Hearing Protection
W	Unlimited	Unlimited	Unlimited
X	0	2000	40000
Y	0	100	2000
Z	0	5	100

Use Equation 3–2 (from MIL–STD–1474D) to determine the ANOR that lies between the curves:

$$N_1 = 10\text{^}\left[\left(177 - L + 6.64\log_{10}\left(\frac{200}{T}\right)\right)/5\right] \qquad \text{(Equation 3–2)}$$

Where:
N_1 = ANOR for SHP
N_2 = ANOR for DHP and is 20 times N_1
L = measured peak pressure level in dB
T = measured B-duration in ms

(b) MIL–STD–1474E*, Department of Defense Design Criteria Standard: Noise Limits*. This version of MIL–STD–1474 establishes criteria for impulse noise that differ from those found in MIL–STD–1474D. In version E, the Z-curve was eliminated as an indicator for a system to be evaluated separately for BOP. Two new impulse noise criteria are discussed in Version E: $L_{IAeq100msec}$ and the Auditory Hazard Algorithm Assessment for Humans (AHAAH). Note that these are design criteria, not medical criteria. The $L_{IAeq100msec}$ metric employs the "equal energy" model characterizing the equivalent total energy of the impulse calculated for 100 ms to compute a noise dose. The AHAAH criterion identified in Version E is an electro-acoustic model of the ear's response to impulse noise. Per provisions in the standard, only the AHAAH model, not $L_{IAeq100msec}$, is applicable to the Army. The model processes an impulse waveform and outputs a new metric, the Auditory Risk Unit (ARU), which relates to the risk of damage. As defined in the standard, the risk criterion is 200 ARU per day for repetitive exposures and 500 ARU per day for occasional exposures. The Army medical community has taken a reserved approach to this new standard and is sponsoring research to examine various aspects of the model details in lieu of immediately accepting the design standard as a medical standard. A new interim medical standard has been adopted, as described in section 3–3B(4). Separate design and medical standards will remain applicable until ongoing research has been concluded and the results have been accepted by the U.S. Army Public Health Center's (APHC) HHA Division and Army Hearing Program.

(c) DA Pamphlet (Pam) 40–501, *Army Hearing Program*. The design limits in MIL–STD–1474D were intended for weapon system developers; however, the DOD had also adopted them as HCC, as referenced in DA Pam 40–501. The next revision of DA Pam 40–501 will reflect the supersession of MIL–STD–1474D.

(3) USAPHC TG 338, *Criteria and Procedures for Auditory Health Hazard Assessment of Impulse Noise (Blast Overpressure)*. This document augmented MIL–STD–1474D by providing two methods that may relax firing restrictions to more feasible levels while still protecting health. These methods apply when impulses meet the free-field criteria, or when a proportional dose methodology assessment is performed. All TG 338 references to MIL–STD–1474D are now out-of-date. The firing restrictions as determined from the *Interim Impulse Noise Damage Risk Criterion*, discussed in section 3–3B(4), will now be used in lieu of the TG 338 firing restrictions that would have been

determined using the free-field criteria. The proportional dose methodology discussed in TG 338 now incorporates natural variability in noise levels associated with weapons firing, instead of the traditional worst-case noise assessment. As a result, all of the weapons firing data is now considered and weighted according to its individual hazard.

(4) *Interim Impulse Noise Damage Risk Criterion.* The HHA Division has accepted a new interim criterion to be used in HHA efforts until the medical community integrates the ongoing research validating AHAAH and its underlying assumptions (Appendix 3C). The interim criterion updates MIL–STD–1474D with the latest scientific data on health effects of impulse noise exposure and uses the equations that were included in MIL–STD–1474D. The interim criterion relaxes MIL–STD–1474D equations by 10 dB for impulses that satisfy the criteria stipulated in the memorandum in Appendix 3C. A 10-dB relaxation has the net effect of permitting 100 times more rounds to be fired than without the relaxation. The original MIL–STD–1474D equation applies to waveforms that do not meet the criterion.

(5) *American Conference of Governmental Industrial Hygienists* (*ACGIH)*® *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.* For impulse noise, the ACGIH criteria recommend no exposures above the 140-dBP sound pressure level. However, the ACGIH believes that impulse noise levels below 140 dBP may also be hazardous. The ACGIH recommends 100 impulses per day at 140 dBP and a 3-dB reduction in peak level for each doubling of the number above 100 impulses.

3–4. Health Effects of Impulse Noise Exposure

Impulse noise can produce injury to many organ systems in the body. The consequences of these injuries can range from transitory dysfunction to death. From the auditory perspective, hearing loss is considered the main effect. The health effects of steady-state noise discussed in Chapter 2 also apply to impulse noise. The main difference between steady-state and impulse noise is that with impulse noise, the mechanism causing the damage is believed to be mostly mechanical processes rather than metabolic processes. In other words, impulse noise may cause acute physical damage whereas steady-state noise may cause chronic-type injuries.

Impulse noise is believed to be nonhazardous at low levels. As the noise level increases, it produces a loss in hearing sensitivity which may or may not recover after the exposure. This type of hearing loss is called a temporary threshold shift (TTS). If the TTS is small and recovers rapidly, long-term consequences are minimal. However, the short-term consequences could have adverse effects on mission accomplishment when the detection of faint sounds and/or the use of communications equipment and signal monitoring equipment is important. Recovery from a large TTS may require more than 24 hours. An injury of this type could be cumulative and could lead to permanent hearing loss in addition to an adverse effect on mission accomplishment.

Higher levels of impulse noise will result in larger losses of hearing sensitivity which will never completely recover. A 25-dB TTS is often described as the critical point where the transition between temporary and permanent injury occurs, but the exact number of decibels depends on frequency. A non-recoverable hearing loss is called a permanent threshold shift (PTS) and indicates a permanent organ injury.

At very high levels, impulse noise can result in tympanic membrane (eardrum) rupture and damage to the ossicular chain (the tiny bones in the middle ear). The noise levels producing these effects may also cause significant damage in the inner ear. The short-term consequences of eardrum rupture or middle ear damage can include loss of hearing sensitivity, tinnitus, and varying degrees of pain. The long-term consequences range from negligible effects on hearing sensitivity to conductive hearing loss. Conductive hearing loss may require surgical intervention. An eardrum rupture increases the risk of infection and, if untreated, may result in serious health impacts. For more information on the likelihood of eardrum rupture, refer to APHC Technical Information Paper (TIP) 51-070-0217.

3–5. Pre-assessment Procedures

A. Test Standards. Specific requirements for data acquisition, recording systems, selection of gauges, and orientation of noise sources and sensors are described in the U.S. Army Test and Evaluation Command (ATEC) Test Operations Procedure (TOP) 01–2–608 and TOP 04–2–822. MIL–STD–1474E describes data collection processes and procedures to be used by the test centers, as well as the test conditions that need to be evaluated. The authoritative standard for reconciling any differences among measurement requirements is MIL–STD–1474E.

Impulse noise data may be collected with equipment that outputs FiLTer (.flt) files. These files are directly readable by the AHAAH software program used by the Army Hearing Program. Instructions for importing and converting the data into an assessment-ready format within AHAAH are provided in U.S. Army Research Laboratory (ARL) Technical Report 6748, *Using the Auditory Hazard Assessment Algorithm for Humans (AHAAH) With Hearing Protection Software, Release MIL–STD–1474E*. Issues may arise when impulse noise data are provided in other formats (e.g., .jif files) that are not importable into AHAAH. Proprietary software (e.g., the Analog Data Employment package used by Yuma Proving Ground to analyze digital files) may have the capability of converting non-.flt files; however, data processing limitations may require external subject-matter expert (SME) support for complicated cases.

B. Test Plan Coordination. In practice, developing an adequate test plan and analyzing the test results will require coordination among the user, the capability developers, the test agency, and the Independent Medical Assessor (IMA). This coordination must begin early enough to permit medical input to the capability documents and 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 may be minimized by ensuring early IMA

involvement and review of test plans. For example, if temperature conditioning is an important acoustical test variable, then early determination of the worst-case temperature condition can drive further testing to be performed at that worst-case temperature only, versus all other temperature choices.

After a complete test plan has been developed, it is necessary to determine which test variables are operationally controllable. The results of controllable test variables are compared in order for separate analyses of each condition to take place and for relevant, enforceable recommendations to be made in the HHA. For example, the temperature of an artillery-propelling charge is not likely to be controlled in the operational environment, but the choice of a propelling charge is controllable.

C. Test Conditions. It is essential that all conditions affecting data used in the impulse noise assessment be considered when the test plan is designed. Many military systems that produce impulse noise have multiple modes of operation, locations where personnel are exposed, or propelling charges. Different azimuths and quadrant elevations are used in firing artillery systems. Additionally, some propellant materials are temperature sensitive, resulting in a temperature-dependent variation in the impulse noise levels. Crew-served weapons involve exposure of a number of personnel to the same impulse noise source. Typically, the noise levels are different at various locations around the system. It is frequently impossible to test all conditions; however, data should be collected for all anticipated worst-case conditions to the fullest extent possible.

To establish materiel-associated noise exposures, measurements need to be taken at positions and conditions that represent occupied positions during both normal operations and maintenance operations. To determine possible exposure of other personnel who might be in the vicinity, collect additional data for at least two positions straddling the 140-dB contour distance at radial directions that could possibly be occupied during normal operations.

The minimum number of repetitions required to adequately address shot-to-shot noise variability is five repetitions at each test condition. More than five rounds may be appropriate for weapons whose variability exceeds 5 dB from shot to shot. As the number of repetitions increases, the confidence in the assessment also increases. The methods employed in conducting a proportional dose assessment require a minimum of 20 waveforms for each test condition, rather than the usual 5 repetitions (each waveform must be manually examined to determine whether it qualifies as being free-field). Although test costs may increase when the proportional dose methodology is used, the additional data are beneficial in the sense that worst-case results become less influential on determining the firing restrictions, thus increasing the ANOR.

3–6. Risk Assessment Process

A. Assessment Preparation. Based on the mission profile and user information, identify the normal use of the weapon/system in the operational and training environments. Review the test report and data submission from the weapon tester. Information about how the test was conducted (e.g., system name, test date, name of test center, description of the test's purpose, sensor information, and test environment) should accompany the test data to help the assessor better understand the data.

The test collectors may specify certain rounds in the dataset as erroneous data. These rounds may be ignored in the assessment. The IMA should determine the ANORs, free-field criteria, and all other calculations independently, even if the calculations are provided by the test collectors.

Data are sorted into categories related to the use of the system. Examples of category types include propelling charge, personnel locations, weapon orientation, or temperature. These categories are system-specific and are developed from Army doctrine and other information about the system's intended use both in training and in combat. Categorization permits recommendations for as many feasible configurations of use as possible to provide flexibility, particularly in the training environment.

Data collected by ATEC and provided directly to the IMA are initially screened for artifacts and inconsistencies. Some of the data may require trimming by the IMA to eliminate drift and/or other irrelevant parts of the waveform (e.g., reflections). This process results in a subset of data that is considered valid.

Artifacts can occur easily during impulse noise measurement, even when the test is conducted according to all procedural requirements. Appendix 3F includes a description of common artifacts and recommends how to proceed with the assessment when the artifacts are present. However, other artifacts may exist and may be difficult to detect. Therefore, detecting artifacts usually requires personnel who are experienced in measuring and interpreting impulse noise measurements. Note that a variation of 3 to 5 dB between rounds is normal, and mortars tend to be more variable than other weapons. Additionally, the IMA needs to consider whether the event is outside the scope of normal use. Uncommon events (e.g., maximal noise) may be considered outliers and do not need to be assessed as part of the system's normal use scenario. An event that occurs in <5% of the test results could be excluded from the assessment, based on the concept that the analysis seeks to identify when hearing loss occurs in <5% of the instances of exposure.

Organizations may not always agree to retesting if artifacts are present in existing data and, in some instances, may not agree to test the item or provide the data. (This situation often occurs in the testing of commercially available items, such as power tools.) In such cases, the IMA will have to exercise judgment on how to complete the assessment. One course of action may be to utilize prior test data of acoustically similar items (e.g., from vendor websites or published studies). The IMA should use a medically

conservative approach when utilizing prior test data. If this approach results in an assessment that is unacceptable to the customer, the IMA should require the materiel developer to provide additional data.

B. Free-field Criteria. Use the *Interim Impulse Noise Damage Risk Criterion* (Appendix 3C) to prepare an HHA. For three classes of weapon systems (shoulder-fired weapons, howitzers, and mortar systems), the free-field exception may apply. The five conditions necessary for a system to meet the free-field criteria, as described in Appendix 3C, are as follows:

1. Used outdoors.
2. Noise level does not exceed 190 dBP.
3. B-duration is not above 60 ms.
4. No more than two significant peaks in the waveform.
5. A-duration is not below 2 ms or above 6 ms.

If the free-field criteria are not met, use Equation 1 in Appendix 3C to calculate the ANOR (restated below as Equation 3–3). This equation is based on MIL–STD–1474D, and is equal to:

$$N_1 = 10\text{^}\left[\left(177-L+6.64\log_{10}\left(\frac{200}{T}\right)\right)/5\right] \quad \text{(Equation 3–3)}$$

Where:
N_1 = ANOR for SHP
N_2 = ANOR for DHP and is 20 times N_1
L = measured peak pressure level in dB
T = measured B-duration in ms

If the round qualifies as free-field, the ANOR will calculate as being 100 times that of a non-free-field round with the same peak level and B-duration. Therefore, if the free-field criteria are met, replace the constant 177 in Equation 3–3 with the constant 187, as shown in Equation 3–4:

$$N_1 = 10\text{^}\left[\left(187-L+6.64\log_{10}\left(\frac{200}{T}\right)\right)/5\right] \quad \text{(Equation 3–4)}$$

Where:
N_1 = ANOR for SHP
N_2 = ANOR for DHP and is 20 times N_1
L = measured peak pressure level in dB
T = measured B-duration in ms

C. Calculations from the AHAAH Software Program. The AHAAH software program provides batch processing capabilities that input a collection of data files and output files that allow the waveform to be visualized for examination. In addition, it outputs a tab-delimited text file that can be converted into an Excel® spreadsheet with

tabulated peak levels and B-durations. Specific test condition information must be manually entered in the spreadsheet along with whether or not the waveform qualifies for being free-field. TG 388 provides guidance on how to set up the spreadsheets. The IMA needs to be very careful in performing this task as multiple manual entries must be made, resulting in many opportunities for Excel data manipulation errors or human typographical errors.

It is not currently possible to customize the ANOR calculation for specific hearing protectors. An assumed 29 dB of protection for SHP is imbedded in Equation 3–3 and Equation 3–4.

D. Hazard Severity Determination. A harmful impulse noise exposure (i.e., ≥140 dBP) almost always results in a permanent partial disability. No hazard severity (HS) or risk level is assigned for unprotected exposure to impulse noise <140 dBP. The HS for auditory health effects of noise generally falls into the Critical hazard category as per the HS definition in the risk assessment process described in MIL–STD–882E. Therefore, a Critical HS category is normally the only HS category assigned for both the initial and residual risk assessment code (RAC). Permanent total disability (essentially, the inability to hear anything) is possible but is not common. Therefore, HS determination generally ignores any categorization of impulse exposure as having a Catastrophic HS.

The risk of unprotected exposure to impulse noise is both difficult to quantify and still being researched. The generally accepted threshold for onset of hazard in the Army is 140 dBP, which is used for the APHC assessment process. A study conducted by the Army Human Engineering Laboratory concluded that a 1% risk of a PTS exists for a single unprotected exposure to 167 dBP, and that risk increases to 4% for a single unprotected exposure to 177 dBP (Appendix 3D). Appendix 3D provides the indicators of risk commensurate with their assigned impulse noise hazard probability (HP) levels.

E. Hazard Probability Determination. When assigning HP for an HHA, an estimated percentage of the population is expected to develop noise-induced hearing loss from high-impulse noise exposures. To determine these percentages, the calendar year 2015 hearing injury incidence rate of 4.5% in Active Duty Soldiers was used to establish the baseline percentage range for the Occasional or C HP level. All other HP percentage thresholds were extrapolated from that baseline (see Appendix 3D). This extrapolation validates that the 5% anticipated risk of exposure associated with 100% ANOR exposures falls in the HP C (Occasional) baseline level. All other HP categories follow from this level if we assume that the Soldier population's susceptibility to impulse noise is normally distributed with a 6-dB standard deviation (an assumption also embodied in the AHAAH model).

Figure 3–3 depicts this assumption. The shaded area under the curve represents the percentage of the population with hearing loss that is determined based on the indicators of risk listed in Table 3D–1 in Appendix 3D. The area is equivalent to the same percentage of risk as displayed in Table 3–2. The ANOR calculation for any noise

level occurs when the shaded area is 5% of the total distribution, or at the HP C (Occasional) level. According to standard statistical equations, the noise level that would yield a 5% shaded area lies about 1.6 standard deviations (or 10 dB) above the mean level.

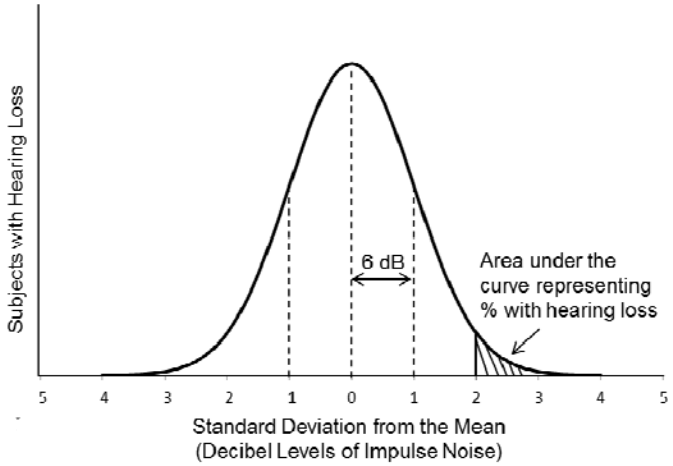

Figure 3–3. Distribution of Hearing Loss

Table 3–2. Hazard Probability Assignments Based on Percentage of Allowable Number of Rounds

Number of Standard Deviations from the Mean	dB from the Mean	Area Under Curve Showing Hearing Loss (Percent of Total Area)	Percent of ANOR	Hazard Probability
1.2	7.4	>10	>300	A
1.6	10	>5 to 10	>100 to ≤300	B
2.3	14	>1 to 5	>15 to ≤100	C
3.0	18.5	>0.1 to 1	2 to ≤15	D
3.7	22.3	>0 to 0.1	<2	E
Not applicable	Not applicable	Not applicable	0	F

Legend:
ANOR = allowable number of rounds
dB = decibel

According to MIL–STD–882E, the HP depends on the probability of the hazard occurring over the lifetime of the materiel being examined, but noise risk criteria calculate the probability of the hazard occurring over a 24-hour period. The probability of the hazard is thus dependent on the number of impulses over a 24-hour period. If the number of impulses fired per 24-hour period is always the same, the HP for auditory effects over the lifetime of a weapon system will be the same as the HP identified for a 24-hour period. If the number of impulses varies each day, the HP for the lifetime will differ from the HP for a 24-hour period. For example, if the calculated ANOR is 100, and

a weapon system is fired 100 times each time it is used, the HP is 5% over the lifetime of the item (5% is the likelihood of damage at the ANOR). However, if a weapon system is fired 100 times only once in 2000 uses, and is fired 15 times in the remaining 1999 uses, the lifetime HP will likely be much less than 5%. Although lifetime HP and the pattern of usage can provide valuable insights (e.g., accounting for regular exposure vs. single exposure), the HHA impulse noise analysis only considers the HP over a 24-hour period. This is reflective of the hazard's being physical damage in the inner ear rather than changes in metabolic processes that manifest as hearing loss after multiple exposures over an extended period of time. In this sense, the HP must be based on short-term exposures.

Use the peak pressure level and Table 3D–1 in Appendix 3D to assign the initial HP. Unprotected exposures (whether single or multiple) to a peak pressure level are assigned to each HP level. Multiple, unprotected exposure risks are conservatively defined due to the lack of studies which better frame the risk. This objective and conservative approach is expected to result in higher HP levels being assigned to unmitigated impulse noise hazards than the previously assigned levels based on the historical approach, which used subjective interpretations of different degrees of probability.

The residual HP depends on the ANOR, the type of hearing protection, and the number of rounds expected to be fired in the training or mission scenario (i.e., the dose). In the Excel spreadsheet tabulated from the AHAAH Software Program (section 3–6C), calculate the ANOR for each round, position, and test condition from the peak pressure levels and B-durations (refer to Equations 3–3 and 3–4). Typically, the worst-case ANOR (the lowest ANOR) for each category is used to assess the hazard unless the resulting recommended firing limitations may become problematic to weapon use. In that case, the proportional dose methodology defined in TG 338 is used. However, this methodology requires considerably more testing.

To calculate the residual HP, compare the calculated ANOR with the dose. To determine the percentage of ANOR fired, divide the dose by the ANOR. Use Table 3–2 to relate this percentage to the HP levels. For example, if the calculated ANOR is 100 rounds, and the dose for the training or mission scenario is 200 rounds, the exposure is 200% of the calculated ANOR, which corresponds with an HP of B (Probable).

F. Risk Mitigation and Recommendations. The implementation of recommendations, such as firing restrictions and using hearing protection, results in the residual RACs. The HS generally remains the same, Critical, except for a rare or special circumstance. According to DOD 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). Following are examples of these impulse noise controls in priority order:

(1) ***Elimination.*** The most desirable hazard control option is to reduce the impulse noise levels at the source through elimination. Quiet weapons design often requires unacceptable performance tradeoffs (e.g., increased weapon weight, decreased payload capacity).

(2) ***Substitution.*** An example of substitution to limit impulse noise exposure is substituting a quieter type of ammunition for a louder type of ammunition. However, this control is not typically feasible since different rounds are designed for different capabilities.

(3) ***Engineering controls.*** A number of engineered changes may reduce noise. Small arms noise may be reduced with suppressors; muzzle brakes can be designed to be quieter (taking into account both the minimization of user noise exposure and the prevention of recoil); and integrated barriers may be employed to block or redirect sound during weapons testing. Furthermore, specific noise-attenuating materials are available for indoor shooting ranges. If engineering controls exist, implementing them may not always be feasible or may result in adding new health hazards (e.g., use of a noise suppressor may increase weapons recoil and combustion product exposure to the operator). When the operational characteristics of the system preclude engineering controls, less preferred methods by which the impulse noise hazard can be controlled may be the only feasible recommendations.

(4) ***Warnings.*** Post warnings in areas within a 140-dB contour distance from a noise hazard. Warnings should be included in user/training manuals to advise anyone within the 140-dB contour of a hazardous system to wear SHP. For noise levels above 165 dBP, the contour distance within which DHP is required may also be calculated. In Equation 3–1, substitute 165 for 140 to calculate the 165-dBP contour distance.

(5) ***Administrative controls.*** The most common administrative control is restricting the amount of rounds fired in a 24-hour period by recommending an ANOR described in section 3–6E. Re-determine the HP based on the level of hearing protection and the percent of the ANOR to be fired based on the training or mission scenario. The trading points may also be assigned using the dose and the ANOR, as described in the Memorandum in Appendix 3D. The impulse noise total should not exceed 1,000 points for all weapons fired within a 24-hour period.

An additional administrative control includes recommendations to remove or swap positions. These types of recommendations are typically only applied to training scenarios. For example, consider an Army tank where the gunner position has an ANOR of 10, and the assistant gunner position has an ANOR of 50 (i.e., the gunner position has a greater impulse noise hazard). When the gunner has fired 8 rounds, the gunner and assistant gunner swap positions. Eight more rounds are fired from their new positions. Calculate the trading points using the formula in Appendix 3E for each Soldier. The total trading points for each Soldier is equal to 960 points (800 points at the gunner position plus 160 points at the assistant gunner position). This total of 960 points

is less than the allowable 1,000 points, yet 6 rounds more than the most restrictive ANOR were able to be fired.

(6) ***Personal protective equipment.*** To ensure safe use, any system producing impulse noise levels exceeding 140 dBP will require its users to wear hearing protection. Refer to Chapter 2 of this Guide, Steady-state Noise, for information on the available types of hearing protection. When sized and fitted properly, all of these named protectors are considered roughly equal in performance. The equation in the *Interim Impulse Noise Damage Risk Criterion* applies an assumed value of attenuation of 29 dB in peak level for SHP and 34 dB for DHP. However, a more detailed analysis may be performed to determine the actual effectiveness of specific hearing protection (e.g., requiring fit checks).

G. Additional Considerations.

(1) The APHC TIP 88–001–0411 requires systems with an impulse noise ANOR for SHP of ≤5 to be tested for BOP. Refer to Chapter 4 for the BOP assessment methodology.

(2) There are weapon-specific factors to consider when conducting assessments. For example, if the rifle can be fired in a burst-mode resulting in noise pressure levels lasting longer than 1 second, then the burst-mode must be assessed according to steady-state criteria (in addition to being assessed based on impulse noise criteria). This means the dBA for such a scenario must be provided or computed (in addition to dBP level) as part of the assessment. A provision in the former MIL–STD–1474D applied to repeated firings with repetitions lasting less than 1 second and was termed “burst-mode firing.” These firings did not qualify as impulse or steady-state noise; therefore, an “effective B-duration” had to be calculated separately for the burst-mode firing situation to replace the measured B-duration. After calculating an effective B-duration, the assessment proceeded as if it were an impulse noise assessment. However, such an assessment scenario is not addressed in Appendix 3C. Therefore, it is recommended that a steady-state noise assessment be performed instead, even though the length of the firing burst is less than 1 second. Refer to Chapter 2 of this Guide for the steady-state noise assessment methodology.

3–7. Example Assessment Scenario

To support a materiel release decision, an HHA is being completed on a new shoulder-fired weapon system with a designated ammunition.

A. Pre-assessment Procedures and Initial Risk Calculation.

Step 1. Obtain the use scenario information from the materiel developer and the test data for all test conditions from ATEC. For this example scenario, there were five test conditions and four shooting postures. Multiple rounds were fired for each test condition

and shooting posture to create repetitive results and minimize errors. The mission profile specifies that the weapon system is designed to be used outdoors.

Step 2. Review the data and information obtained to understand which data were collected, how the data were collected, and which data were relevant to the assessment. This requires familiarity with the requirements and includes parameters such as sample size, measurement location, and measurement equipment used. In this example, data were deemed sufficient to assess exposures to the user and nearby personnel when the system was fired.

Step 3. Ensure the supplied data are in the .flt file format for direct use in the AHAAH software program used by the Army Hearing Program. If the data are not in the .flt file format, use the instructions in ARL Technical Report 6748 to import and convert the data.

Step 4. Communicate with the testers to characterize the dataset and the test conditions. Remove any “bad” data from the dataset; i.e., data that the testers specify as unusable for various reasons. Although the testers may provide ANORs or other calculations, the results should be recalculated from the raw data to ensure an independent assessment and to verify that the appropriate ANOR equation and free-field criteria were used.

Step 5. Use the AHAAH software program to plot waveforms of the noise for each round within each test condition and shooting posture. The AHAAH software program’s batch processing capability inputs a collection of data files and outputs files that allow the waveform to be visualized for examination. Use the output files to determine the peak, B-duration, and potential artifacts; and record the findings.

Step 6. Check the data for artifacts such as those in Appendix 3F, and mitigate as necessary. Note that a variation of 3–5 dB between rounds is normal, and mortars tend to be more variable than other weapons. Uncommon events (<5% of test results) may be considered as non-normal use and need not be assessed. Assume no artifacts exist in this dataset, and continue with the assessment.

Step 7. Assign an HS of 2 (Critical) due to the types of injury that result from impulse noise exposure.

Step 8. Identify the maximum noise level and B-duration from the full dataset. For this example, the maximum noise level was 178.85 dBP, accompanied by a B-duration of 8.5 ms. To assign the HP, compare this maximum peak level to the table in Appendix 3D. Since there are multiple, unprotected exposures to levels greater than 177 dBP, the system is assigned an HP of B (Probable).

Step 9. Assign the initial risk based on the HS and HP determined in Steps 7 and 8. The initial RAC for the system is 2B, which corresponds to a risk level of High according to the risk matrix in MIL–STD–882E.

B. Residual Risk Calculation. If an HHA is coordinated early in the acquisition process, the mitigation strategies may include engineering controls such as a physical barrier between the gunner and the gun muzzle to reduce noise exposure. However, design changes are not an option in this example, so administrative controls and PPE controls are recommended, based on the assessment method below.

Step 10. Determine whether each round meets the free-field definition based on the *Interim Impulse Noise Damage Risk Criterion:*

1. Used outdoors.
2. Noise level does not exceed 190 dBP.
3. B-duration is not above 60 ms.
4. No more than two significant peaks in the waveform.
5. A-duration is not below 2 ms or above 6 ms.

The first criteria is met because the system is designed to be used outdoors. Criteria #2 through #5 should be assessed independently for each round (see Column F in Table 3–3). For this dataset, all waveforms output by the AHAAH software program showed more than two significant peaks. Therefore, the free-field criteria are not met.

Step 11. Because the free-field criteria are not met for this example, use the values output by the AHAAH software program and Equation 3–3 to calculate the ANOR for each round within each test condition and shooting posture. Always calculate the firing restrictions for each round because the firing restrictions depend upon both the pressure level and B-duration. Table 3–3 shows this ANOR calculation in Column G, using the peak pressure level (L) from Column D and B-duration (T) from Column E. For example, the ANOR in the first row (Round 1) is calculated using the following:

$$N_1 = 10\text{^}\left[\left(177-L+6.64\log_{10}\left(\frac{200}{T}\right)\right)/5\right] = 10\text{^}\left[\left(177-176.87+6.64\log_{10}\left(\frac{200}{7.2}\right)\right)/5\right] = 88$$

Where:
N_1 = ANOR for SHP
L = measured peak pressure level in dB
T = measured B-duration in ms

Table 3–3. Allowable Number of Rounds for Kneeling Shooting Posture/Test Condition 1

A	B	C	D	E	F	G
Round	**Shooting Posture**	**Test Condition**	**Peak Pressure Level in Decibels (L)**	**B-duration in Milliseconds (T)**	**Free-field?**	**ANOR Single Hearing Protection (N_1)**
1	Kneeling	1	176.87	7.2	No	88
2	Kneeling	1	176.16	7.3	No	119
3	Kneeling	1	176.75	7.3	No	91

4	Kneeling	1	176.55	7.2	No	102
5	Kneeling	1	176.65	7.3	No	95
6	Kneeling	1	176.06	7.2	No	127
7	Kneeling	1	176.56	7.2	No	101
8	Kneeling	1	176.92	7.2	No	86
9	Kneeling	1	176.66	7.2	No	97
10	Kneeling	1	176.58	7.3	No	98
11	Kneeling	1	176.89	7.2	No	87
12	Kneeling	1	176.89	7.3	No	85

Legend:
ANOR = allowable number of rounds
Red = the most restrictive ANOR for this shooting posture and test condition.

Step 12. Based on the ANORs calculated for each round, find the most restrictive ANOR, or the round with the lowest ANOR from Column G of Table 3–3. The most restrictive ANOR for Kneeling Shooting Posture/Test Condition 1 is shown in red in Table 3–3. Assign this worst-case ANOR (85 rounds) for Kneeling Shooting Posture/Test Condition 1.

Step 13. Repeat Steps 10 through 12 for each test condition and shooting posture to create a matrix of the most restrictive ANORs, as shown in Table 3–4. As indicated by the yellow highlighting, the overall ANOR for the system is 28 rounds since it is the most restrictive ANOR in the matrix.

Table 3–4. Most Restrictive Allowable Number of Rounds for All Conditions and Shooting Postures

Test Condition	Rounds	Most Restrictive ANOR by Shooting Posture When Using Single Hearing Protection			
		Kneeling	Standing	Sitting	Prone
1	1–12	85	141	41	33
2	13–16	88	135	52	32
3	17–21	70	109	37	28
4	22–33	103	122	44	29
5	34–35	151	133	59	40

Legend:
ANOR = Allowable Number of Rounds
Red = the most restrictive ANOR for this shooting posture and test condition identified in Step 12
Yellow = the overall ANOR; most restrictive

Step 14. Assign a residual HS of 2 (Critical) due to the types of injury that result from impulse noise exposure.

Step 15. Assign the residual HP based on the table in Appendix 3D by calculating the percentage of ANOR to be fired during the training scenario or mission profile. If the number of rounds to be fired in a 24-hour period is equal to 100% of the assigned ANOR, the HP is C (Occasional).

Step 16. To calculate the 140-dBP contour distance, use Equation 3–1 with L_1 as the maximum peak level. The test data provided indicated the at-ear noise sensor was placed 0.5 meter from the noise source; thus, the contour distance is as follows:

$$D_2 = D_1\left(10^{\frac{(L_1-140)}{20}}\right) = 0.5\,meter\left(10^{\frac{(178.85\,dBP-140)}{20}}\right) = 44\,meters$$

Where:
D_2 = 140 decibel (dB) contour distance
D_1 = distance of measurement from source of noise
L_1 = decibel, peak (dBP) measurement

Recommend that SHP be worn within 44 meters from the noise source.

Step 17. Another residual risk may be calculated for wearing DHP. Multiply the ANOR for SHP (N_1) by 20 to determine the ANOR for DHP (N_2). Multiplying the assigned SHP ANOR of 28 rounds by 20 results in a DHP ANOR of 560. If the number of rounds specified in the training scenario or mission profile is lower than the DHP ANOR, the HP level will decrease. For example, if the training scenario requires only 84 rounds to be fired per 24-hour period, the HP is D (Remote) because 84 is only 15% of 560.

Step 18. Repeat Step 16 to calculate the contour distance for DHP. Change the 140-dBP contour distance in Equation 3–1 to 165-dBP and calculate as follows:

$$D_2 = D_1\left(10^{\frac{(L_1-165)}{20}}\right) = 0.5\,meter\left(10^{\frac{(178.85\,dBP-165\,)}{20}}\right) = 2.5\,meters$$

Where:
D_2 = 165 decibel (dB) contour distance
D_1 = distance of measurement from source of noise
L_1 = decibel, peak (dBP) measurement

Recommend that DHP be worn within 2.5 meters from the noise source. Note that SHP is still required at distances between 2.5 and 44 meters, according to Step 16.

Step 19. If capability needs allow, the IMA may assign additional residual risk levels recommending the system be fired only under certain test conditions or at certain shooting postures. Typically, these types of recommendations are used only when the DHP ANOR is not suitable for the training scenario or mission profile.

C. Risk Level and Recommendations Summary. Based on the calculations in Sections A and B, include the following in the HHA Report:

A risk level of High (RAC: HS 2, HP B) is assigned.

A residual risk level of Serious (RAC: HS 2, HP C) is assigned for compliance with all of the following recommendations:

- Require Soldiers within a distance of 44 meters from the system to wear properly sized and fitted SHP.
- Restrict the number of rounds fired per 24-hour period to 28 rounds.

A residual risk level of Medium (RAC: HS 2, HP D) is assigned for compliance with all of the following recommendations:

- Require Soldiers within a distance of 2.5 meters from the system to wear properly sized and fitted DHP.
- Require Soldiers between 2.5 meters and 44 meters from the system to wear properly sized and fitted SHP.
- Restrict the number of rounds fired per 24-hour period to 84 rounds.

3–8. Limitations and Potential Future Work

(1) Additional research and discussion are being conducted to determine a new impulse noise medical criteria to replace the *Interim Impulse Noise Damage Risk Criterion.* Several approaches have been proposed, all of which are under evaluation in the Blast Injury Prevention Standards Process, a DOD-sponsored, structured means of moving forward with identifying and implementing scientifically defensible criteria. The work remains in process; no conclusions are discernible at this time. The primary challenge is that human data relating blast noise to ill effects is scarce and thus insufficient to identify a means of assessing risk.

(2) The protected level determined by the use of the equation in the *Interim Impulse Noise Damage Risk Criterion* applies a value of attenuation presumed representative of typical hearing protection used in the Army. However, this presumption assumes perfect sizing and fitting of hearing protection, which are not often attained. The AHAAH provides an alternative method for determining the at-ear pressure level given a specific model of hearing protection being worn. The at-ear pressure levels must be converted to free-field pressure levels (in accordance with MIL–STD–1474E) to compute the risk of hearing loss; however, the AHAAH is not currently capable of this conversion, resulting in a limited assessment capability.

(3) Additional reflections of weapon noise are generated in urban warfare, depending on exactly where firing takes place. There is currently no standard test available for evaluation of this use. However, it is well known that reflections will affect

B-durations but will not normally affect peak levels. Due to the presence of reflections, none of the waveforms will qualify for the free-field criteria.

(4) Impulse noise data provided in non-.flt formats are not importable into the AHAAH. Proprietary software may be capable of converting non-.flt files; however, data processing limitations may require external SME support for complicated cases. Development of software that converts data to the appropriate format efficiently and correctly would mitigate potential future issues.

APPENDIX 3A

CHAPTER 3 REFERENCES

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APPENDIX 3B

BACKGROUND FOR THE DEVELOPMENT OF IMPULSIVE NOISE STANDARDS

3B–1. *The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) Working Group 57 Criterion*. All impulsive noise exposure limits in the U.S. originate from the criterion proposed by the CHABA Working Group 57 in 1968. The purpose of this criterion was to set safe exposure limits for gunfire without the use of hearing protection.

This criterion was intended to protect 95% of the exposed population from a significant permanent threshold shift (PTS) after a career of occasional exposure. It is based on peak pressure and A-duration or B-duration and provides maximum exposure parameters for 100 impulses in a 24-hour period. For other quantities of impulses, the limit curves are adjusted upward or downward in peak pressure according to the following formula:

$$Adjustment = 5\ log\left(\frac{100}{N}\right) \qquad \text{(Equation 3B–1)}$$

Where:
N = number of impulses

For 10 impulses per day, the limit is raised by 5 dB, and for 1000 impulses per day, the limit is lowered by 5 dB.

In 1992, the CHABA published an update of this criterion based on data which became available after 1968. The 1992 report reaffirmed the 1968 criterion for small arms impulses. It also indicated that the criterion should not be used for other types of impulses or for impulses measured when hearing protection was in use. It deleted the A-duration curve, leaving only peak pressure and B-duration as the primary parameters. At present, the 1992 CHABA exposure limit applies to unprotected exposures to small arms weapon noise.

3B–2. Auditory Hazard Research Issues. The research issues currently under investigation stem from two sources. First, data generated since the 1968 CHABA criterion and Military Standard 1474D were published indicate that these criteria contain fundamental inaccuracies. Second, in the current process of performing hazard assessments, it is necessary to use procedures which cannot be validated with human test subjects. The 1992 CHABA criterion includes an extended discussion of the research issues identified in the working group's review of its 1968 criterion. The group recommended the following areas of research; Army research pertaining to many of these is underway:

- Establish which parameters of an impulse exposure to measure and how to combine them to provide the most simple hazard index.

- Establish the effects of impulse spectrum on hazard.
- Establish the efficiency of various hearing protective devices in reducing hazard.
- Establish the contribution of various protective nonlinearities such as the effect of the middle ear reflex, peak clipping, etc.
- Establish a trading relation between the number of impulse presentations and other hazard metrics.
- Establish procedures for evaluating mixtures of (types and levels of) impulses.
- Establish procedures for assessing the effect of temporal spacing of impulses.

To explore the many parameters of impulsive noise and to resolve the basic issues related to assessing the hazard posed by exposure to impulsive noise, it is necessary to induce temporary and permanent changes in hearing under controlled conditions. Such research necessitates animal experimentation. Quoting from the 1992 CHABA Working Group:

> *"Animal experiments represent the best approach to understanding the complex effects of different peak levels, spectra, durations, temporal variables, etc."*

Since the ultimate goal of developing new exposure criteria is to protect the hearing of the Soldier, animal studies alone cannot provide all the necessary data; human studies are essential. These studies of necessity are temporary threshold shift (TTS) studies. The 1992 CHABA Working Group concluded:

> *"Since it is unlikely that sufficient human PTS data will ever become available, the most practical method to arrive at safe exposure conditions is to obtain TTS data from human experiments...Well-designed human TTS studies are required to produce the data base needed to arrive at more generally applicable impulsive noise exposure criteria and to validate any predictive models."*

The general research strategy is to design human TTS studies that provide data which may have immediate application(s) to the military operational environment and may also be used to scale animal results to humans. A large variety of TTS and PTS animal studies exist and may augment the limited number of human TTS studies.

3B–3. New or Revised Criteria. New or revised criteria may be developed as a result of ongoing research. These criteria may take the form of new limit curves, equations, rules, or computer models. The new or revised criteria must undergo some form of scientific and administrative review (e.g., Verification, Validation, and Accreditation) before it is included in the health hazard assessment process.

APPENDIX 3C

INTERIM IMPULSE NOISE DAMAGE RISK CRITERION

Appendix 3C begins on the next page. The Army Hearing Program established the *Interim Impulse Noise Damage Risk Criterion* to update Military Standard 1474D with the latest scientific data on health effects of impulse noise exposure. The Army Medical Command reviewed and accepted the first version of the *Interim Impulse Noise Damage Risk Criterion* in 2015. The updated version (30 June 2020), shown on the following pages, maintains the same criterion. The Army Health Hazard Assessment (HHA) Program accepted this criterion for use in assessing impulse noise and calculating the allowable number of rounds in support of HHAs.

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MCHB-PH-ACE 30 June 2020

MEMORANDUM THRU

Director, Clinical Public Health and Epidemiology, U.S. Army Public Health Center, 8252 Blackhawk Road, Aberdeen Proving Ground, MD 21010-5403

Director, Occupational Health Sciences, U.S. Army Public Health Center, 8252 Blackhawk Road, Aberdeen Proving Ground, MD 21010-5403

FOR Program Manager, Health Hazard Assessment Office, U.S. Army Public Health Center, 8252 Blackhawk Road, MD 21010-5403

SUBJECT: Interim Impulse Noise Damage Risk Criterion Reaffirmation

1. AUTHORITIES AND REFERENCES.

a. DOD Instruction 6055.12, Hearing Conservation Program, 25 October 2017.

b. MIL STD 1474D, Noise Limits, 12 February 1997.

c. MIL STD 1474E, Design Criteria Noise Limits, 15 April 2015.

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e. Evaluation of Impulse Noise Criteria Using Human Volunteer Data, Philemon Chan et.al., Journal of the Acoustical Society of America, Vol. 110, No. 4, October 2001.

2. The subject medical risk criterion is a modification of the Design Limit published in MIL STD 1474D, which was adopted as a medical risk criterion, and used as such until the D version was replaced by MIL STD 1474E in April 2015. The scientific community developed the medical risk criterion in MIL STD 1474D based on a very limited knowledge of health effects of intense impulse noise exposure, which basically extrapolated the results of rifle noise exposure studies to all other weapon systems in general. Studies since the release of the initial criteria in the early 1970's clearly show that this extrapolation misrepresents the actual effects of noise from large caliber weapons, significantly overestimating them. Since the early 1990's, the scientific community has worked to validate a more acceptable criterion, but is still unable to

MCHB-PH-ACE
SUBJECT: Interim Impulse Noise Damage Risk Criterion Reaffirmation

come to a consensus on the medical risk criterion. They have concluded that for energy-intense weapons systems like shoulder fired weapons (LAW, AT-4, M3 MAAWS), artillery, and mortar systems, the MIL STD 1474D limit overestimates the hazard by at least 10 dB. The MIL STD 1474E criteria are not acceptable as medical criteria.

3. After publication of MIL STD 1474D, a partial supplemental solution evolved that was applicable to certain outdoor waveforms. This has become known as the free-field criterion and it mostly applied to exposures when firing artillery weaponry (e.g., howitzers). This medical risk criterion is based on analysis of the Albuquerque study data conducted at 5-meters. The intention was to do a similar analysis on the 1- and 3-meter Albuquerque study data, but the scientific medical community did not complete this particular analysis.

4. In 2015, despite the lack of scientific consensus, the U.S. Army Human Research and Engineering Directorate rewrote the Army's design standard incorporating a risk assessment tool known as the Auditory Hazard Assessment Algorithm for Humans. The U.S. Air Force and U.S. Navy incorporated a different optional criterion. The U.S. Army medical community does not support either criteria as a replacement medical risk criterion and U.S. Army Medical Command is working through its own research path to develop a better scientifically validated medical risk criterion. In the meantime, the U.S. Army cannot continue to field weaponry using outdated and un-validated design medical risk criterion. Therefore, the U.S. Army needs and supports implementing an interim criterion to extend the free-field criterion, augmenting MIL STD 1474D.

5. The basis for the recommended interim impulse noise criterion is the same equation used in MIL STD 1474D. This equation determines medical risk based on the allowable number of rounds (ANOR) fired within a 24 hour timeframe when wearing properly sized and fitted single hearing protection (earplugs or noise muffs). The equation in MIL STD 1474D is:

$$10^{((177+6.64*\log(200/Tb)-Lp/5))}$$

Tb = B-duration in milliseconds

Lp = Peak sound pressure level, Lp in dBP re: 20MicroPascal
Log = log with base 10

The calculated number is multiplied by 20 if wearing double hearing protection (earplugs AND noise muffs).

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SUBJECT: Interim Impulse Noise Damage Risk Criterion Reaffirmation

6. The interim criterion accepts all the new MIL STD 1474E requirements for making the basic impulse noise measurements and the provisions which apply to steady-state noise, but replaces the standard's determination of allowable number of rounds for impulse noise. It modifies the above equation for 3 classes of weapon systems: shoulder fired weapons, artillery, and mortar systems, relaxing the limits by 10 dB if the noise generated by the weapon system meets the following five requirements:

a. The weapon systems are fired outdoors verses confined or enclosed firing positions.

b. The noise does not exceed 190 dBP.

c. The noise has a B-duration no greater than 60 milliseconds.

d. There are no more than two significant peaks in the waveform (a peak is significant when it equals or exceeds 50% of the amplitude of the highest peak, with the peaks each occurring in separate portions of the waveform determined from first to last crossing of the baseline), and

e. The impulse has an A-duration (duration of the principal peak) of 2 – 6 milliseconds.

7. These requirements ensure the interim criterion does not exceed the investigational bounds of the Albuquerque study (which is the basis of this interim criterion). In the event the weapon noise characteristics do not meet the new firing restrictions, noise control engineers can use the procedures outlined in Technical Guide 338 to weight individual noise sample tests and determine a proportional dose assessment of the ANORS. If a system qualifies for use of the modified equation, it effectively multiplies the allowable number of rounds per day by a factor of 100.

8. The modified equation is:

$$10^{((187+6.64*\log(200/Tb)-Lp/5))}$$

MCHB-PH-ACE
SUBJECT: Interim Impulse Noise Damage Risk Criterion Reaffirmation

9. Point of Contact, on this matter, is Mr. Chuck Jokel, Army Hearing Program, available at (410) 436-3797.

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APPENDIX 3D

IMPULSE NOISE PROBABILITY LEVELS

Table 3D–1. Impulse Noise Probability Levels[a]

Description	Level	Percentage (%)[b]	Indicator of Risk
Frequent	A	> 10	Single, unprotected exposure to levels ≥ 184.9 dBP[c,d,e] **OR** multiple unprotected exposures to levels > 150 dBP[e,f] **OR** exposure to > 300% of the ANOR[g,h,i] calculated for the hearing protection being worn
Probable	B	> 5 to 10	Single, unprotected exposure to a level > 177 dBP and < 184.9 dBP **OR** multiple unprotected exposures > 145 dBP and ≤ 150 dBP **OR** exposure to > 100% and ≤ 300% of the ANOR calculated for the hearing protection being worn
Occasional	C	> 1 to 5	Single, unprotected exposure to a level > 167 dBP and ≤ 177 dBP **OR** multiple unprotected exposures to a level between 140 dBP and 145 dBP **OR** exposure to > 15% and ≤ 100% of the ANOR calculated for the hearing protection being worn
Remote	D	> 0.1 to 1	Single, unprotected exposure to a level of ≥ 140 dBP and ≤ 167 dBP **OR** exposure to between 2% and 15% of the ANOR calculated for the hearing protection being worn
Improbable	E	> 0 to 0.1	Exposure to < 2% of the ANOR calculated for the hearing protection being worn
Eliminated	F	0	Exposure eliminated **OR** mitigated to < 140 dBP by means other than hearing protection

Notes:

[a] The calendar year 2015 hearing injury incidence rate of 4.5% in Active Duty Soldiers[1] was used to establish the baseline percentage range for probability level C; all other probability levels were extrapolated from that baseline.

[b] For unprotected exposures, this is the estimated percentage of the population expected to develop a noise-induced permanent threshold shift (PTS) of any magnitude. For protected exposures, this is the percentage of population expected to develop a noise-induced temporary threshold shift (TTS) of > 25 decibels (dB) for any single audiometric test frequency following a 24-hour exposure period[2]. A criterion of 25 dB TTS was adopted because it is the critical level of hearing loss above which additional TTS will convert to a PTS.

[c] dBP = decibel peak level referenced to 20 microPascals

[d] This sound pressure level (SPL) limit was set according to information from a clinical case study[3] and weapons test data[4].
[e] This indicator of risk was determined by the Army Hearing Program in the absence of established objective criteria.
[f] This SPL limit was set according to information from auditory and acoustical studies[5,6].
[g] The Allowable Number of Rounds (ANOR) per 24-hour period is calculated according to the Army Health Hazard Assessment (HHA) Program's *Interim Impulse Noise Damage Risk Criterion*[7].
[h] An ANOR of ≤5 calculated for single hearing protection requires a Blast Overpressure Assessment by the HHA Program.
[i] The logarithmic nature of the ANOR calculations creates a disproportionate relationship between the Percentage column and the % of the ANOR found in the Indicator of Risk column. Doubling the upper range of the Percentage column (5% to 10%) results in a tripling of the % of the ANOR (100% to 300%).

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4. Memorandum, U.S. Army Missile Command, DRCPM-AMWS-T, subject: *AT4 Pre-DT/OT Report,* 05 June 1984. Redstone Arsenal, Alabama.
5. U.S. Army Human Engineering Laboratories. 1965. *Auditory and Acoustical Evaluation of Several Shoulder Rifles*. Aberdeen Proving Ground, Maryland.
6. Saxena A, Ramseh AV, Mehra PR, Singh DK. 2016. Short-term audiometric profile in army recruits following rifle firing: An Indian perspective. *Indian J Otol*, 22(3):199–202. doi: 10.4103/0971-7749.187984
7. Memorandum, U.S. Army Public Health Center, MCHB-IP-MAH, subject: *Interim Impulse Noise Damage Risk Criterion,* 12 February 2015. Aberdeen Proving Ground, Maryland.

APPENDIX 3E

ASSIGNMENT OF TRADING POINTS FOR WEAPONS FIRE

Appendix 3E begins on the next page. As shown in the following memorandum, the Army Hearing Program established a method of assigning points to quantify the percentage of hazardous impulse noise exposure for firing multiple weapon systems in a 24-hour period. The Army Health Hazard Assessment (HHA) Program accepted this method for use in assessing impulse noise in support of HHAs. Units may also use this method to plan daily training operations that meet the hearing protection requirements.

MCHB-PH-HRG 16 August 2018

MEMORANDUM THRU Director, Occupational Health and Environmental Sciences

FOR Division Chief, Health Hazard Assessment

SUBJECT: Assignment of Points for Weapons Fire

1. The Point System.

a. The point system is used to deal with complex noise exposures made up of weapon noise that varies during the course of the day due to changes in firing condition. An example is the firing of a howitzer at different combinations of elevation and charge strength.

b. Each round for a specific firing condition is assigned points based on the Allowable Number of Rounds for that firing condition. These points are multiplied by the number of rounds fired at that firing condition. All firing conditions are treated this way, with the points summed to get a daily total. The total should not exceed 1000 points to be considered acceptable. The dose per round is calculated by the following equation:

Points = Dose/round = 1000 (1/ANOR)

For example, a shoulder fired weapon is fired twice, using cartridge type 1, and 3 times with cartridge type 2. The ANOR for cartridge 1 is 10 and the ANOR for cartridge 2 is 30.

Points for cartridge 1 = 2 (1000) (1/10) = 200

Points for cartridge 2 = 3 (1000) (1/30) = 100

Total = 200 + 100 = 300, which is acceptable.

2. Point of Contact, on this matter, is Mr. Chuck Jokel, Army Hearing Program, he may be reached at (410) 436-3797.

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APPENDIX 3F

IMPULSE NOISE ARTIFACT EXAMPLES

The waveform examples in Figures 3F–1 through 3F–12 show potential artifacts in impulse noise datasets. In most scenarios, the faulty test round is removed from the dataset and ignored for the assessment. To better understand why an issue occurred, consult with the testers who collected the data. If there is not enough data to perform an assessment after removing the faulty round(s), data may need to be recollected.

The most common causes of artifacts are defective gauge signals (signal drift) or test set-up (e.g., wrong gauge orientation, signal clipping). Such artifacts can include artificial peaks or “ringing” caused by debris striking the sensor or its stand. Other examples include time-history baseline drift due to heating of the sensor, and evidence of reflections that prolong B-durations due to incorrect data collection processes. Peaks caused by improper face-on orientation of the transducer may yield levels that are too high; peaks caused by a secondary detonation (flash) may also generate a potential artifact.

A. Unacceptable Direct Current (DC) Drift. DC drift affects B-duration determinations. Waveform 1 (Figure 3F–1) shows an elevation in the baseline starting at around 20 milliseconds (ms). The return to the original baseline has been artificially induced by a tapering process at the end of the waveform. It is not clear where the drift starts in Waveform 2 (Figure 3F–2). It likely began sometime immediately after the main spike, depressing the subsequent reflections around 320 milliseconds (ms). This drift example includes both a depression of the waveform and a later elevation.

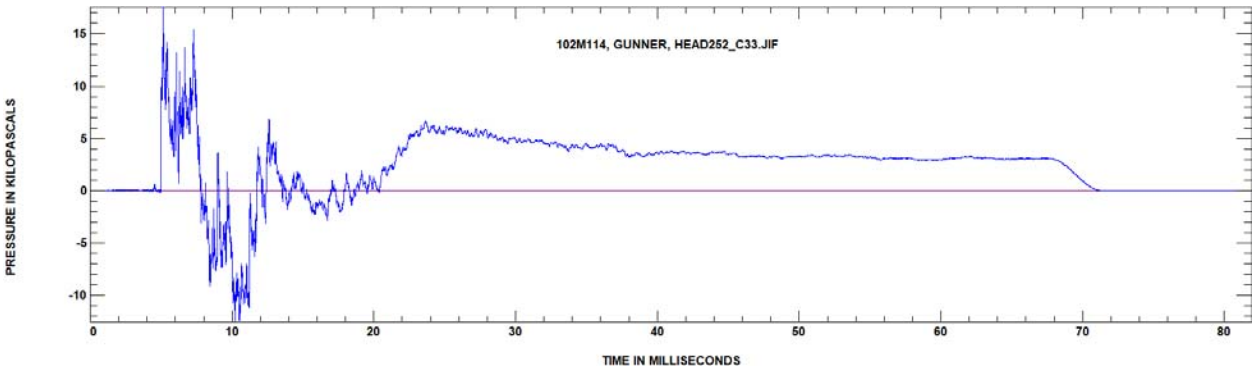

Figure 3F–1. Waveform 1

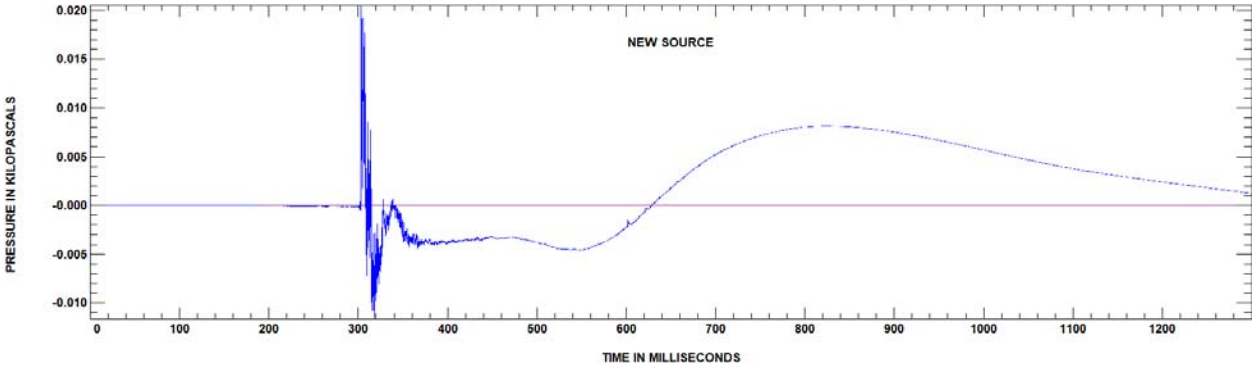

Figure 3F–2. Waveform 2

B. Improper Transducer Placement. As shown in Figure 3F–3, Waveform 3's signal is too close to the noise floor of the transducer. Waveform 4 (Figure 3F–4) has the same noise as Waveform 3 but is measured closer to the source with adequate signal strength.

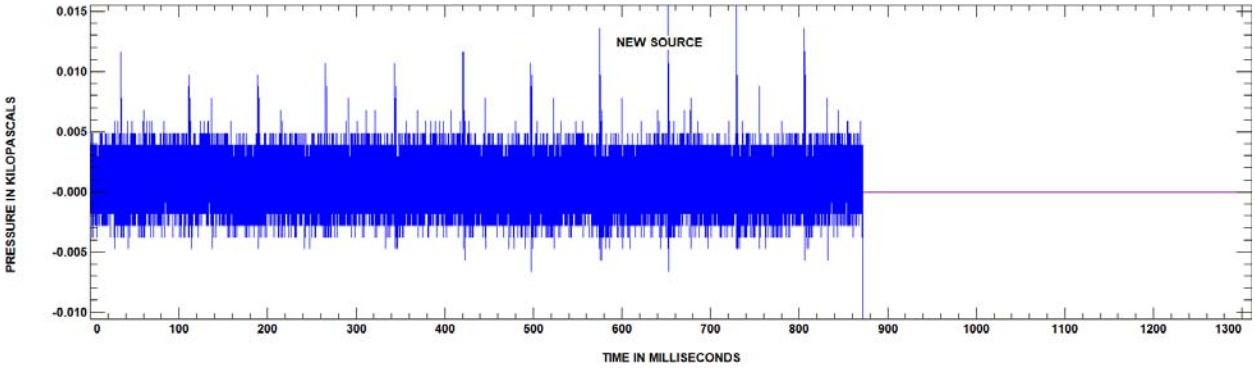

Figure 3F–3. Waveform 3

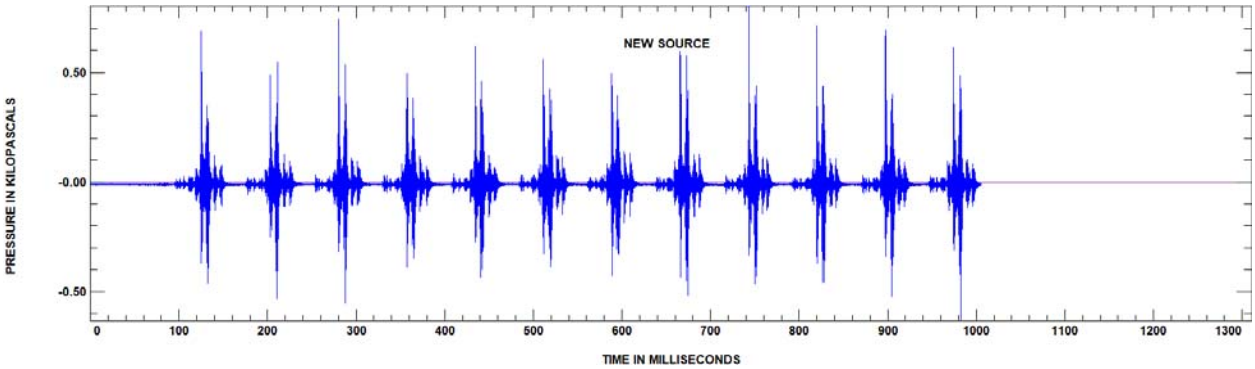

Figure 3F–4. Waveform 4

C. Faulty Cable. Figure 3F–5, Waveform 5 shows spikes due to a faulty cable.

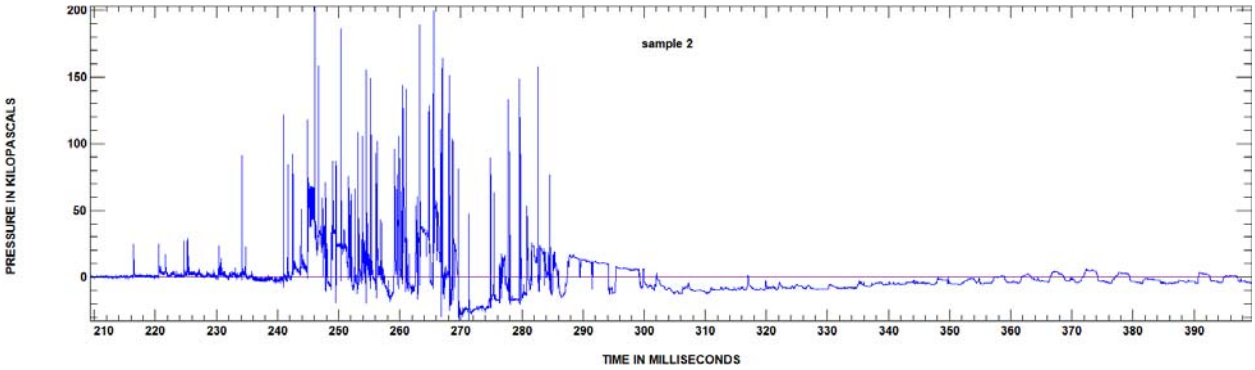

Figure 3F–5. Waveform 5

D. Inconsistencies Between Rounds. Figure 3F–6, Waveform 6 shows two files overlaid from measurements made inches apart. The blue waveform with false peaks was caused by an equipment issue (such as a faulty cable).

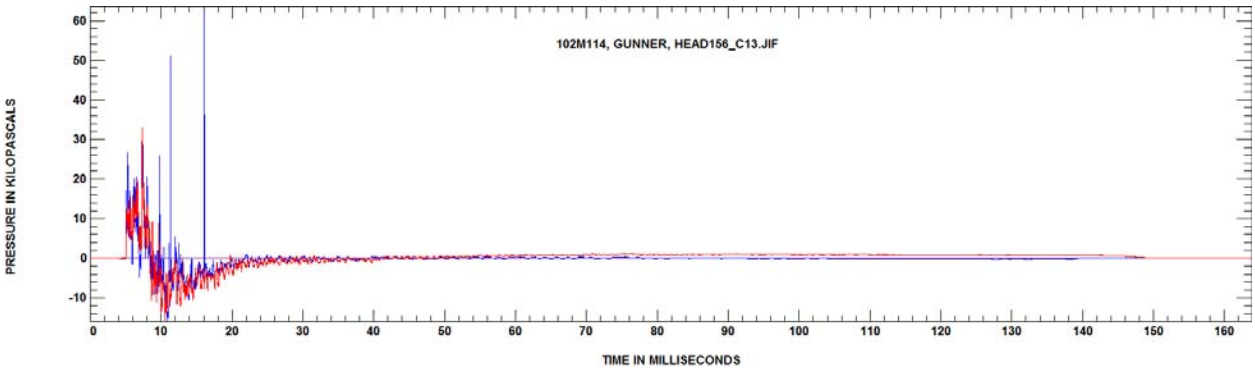

Figure 3F–6. Waveform 6

E. Improper Microphone Orientation. Waveforms 7 through 9 (Figures 3F–7 through 3F–9) were obtained in an indoor firing range for a 9-millimeter (mm) handgun. The handgun was fired in Lane 7, and the data were measured in Lane 5, which was 7 meters distant. The second peak in each waveform is caused by reflection. The measuring transducer orientation relative to the direction of energy flow associated with the muzzle blast is different in each waveform. The correct value of this second peak occurs when the direction is side-on. Any face-on blast reflects off the transducer diaphragm, thus elevating the reading.

In Figure 3F–7, Waveform 7 shows the results obtained with the microphone face pointing up (peak 147.4).

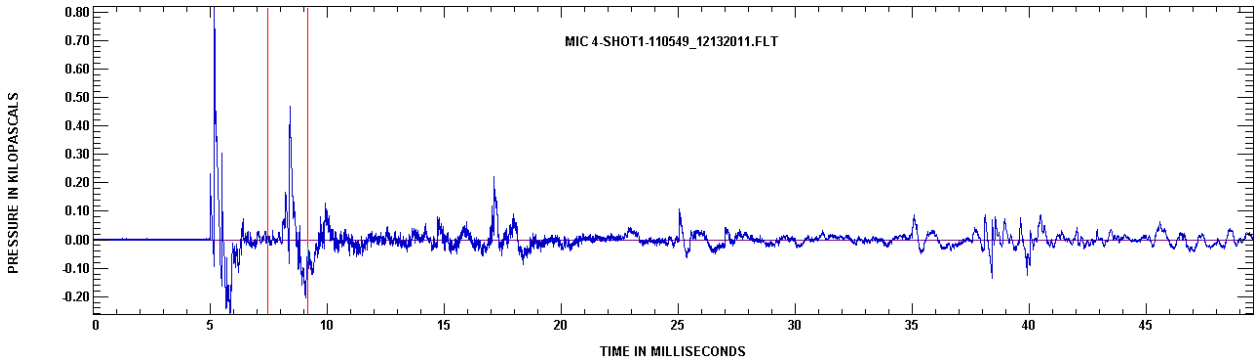

Figure 3F–7. Waveform 7

In Figure 3F–8, Waveform 8 shows the results obtained with the microphone face pointing down (peak 152.6).

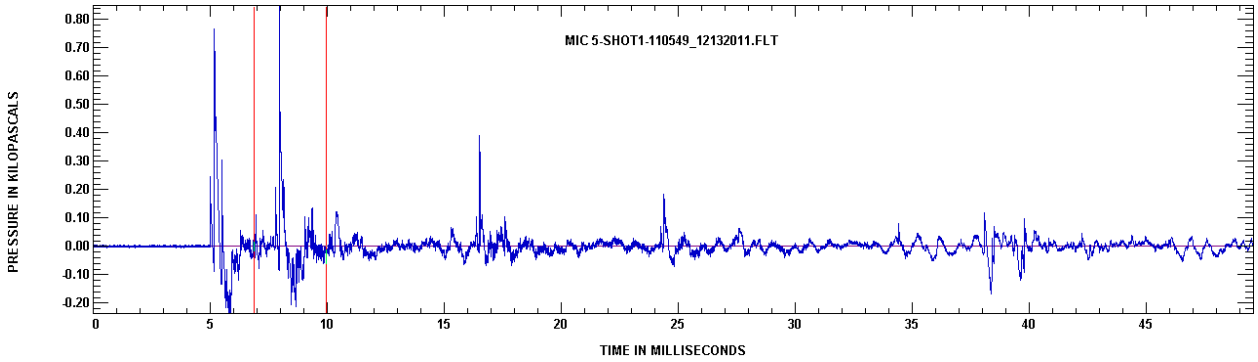

Figure 3F–8. Waveform 8

In Figure 3F–9, Waveform 9 shows the results obtained with the microphone face pointing away from closest reflections (peak 149.6).

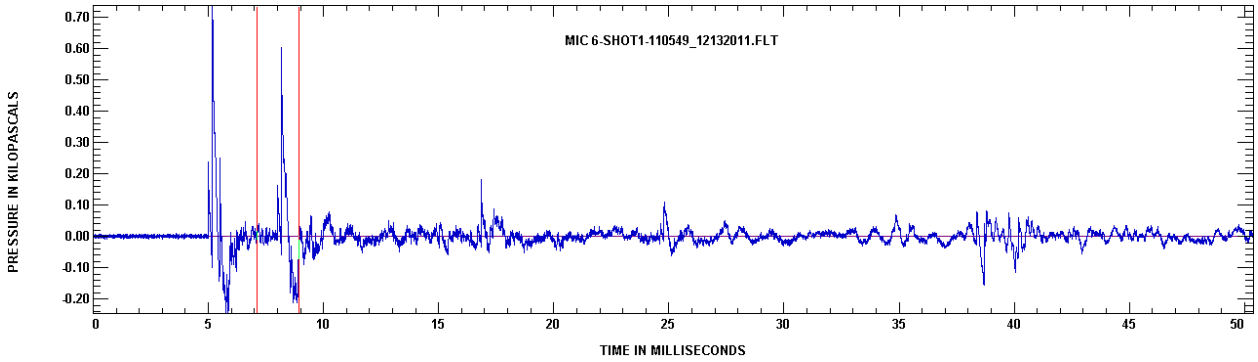

Figure 3F–9. Waveform 9

F. Clipped Waveform. Figure 3F–10 depicts a single shot from an M4 weapon system (Waveform 10). Figures 3F–11 and 3F–12 (Waveforms 11 and 12, respectively) are successive enlargements of Waveform 10. The spike at 5 ms is clipped, meaning the true peak is cut off from the measurement due to the way the measuring equipment was set. This was not obvious from the original waveform and required closer examination to determine what had happened.

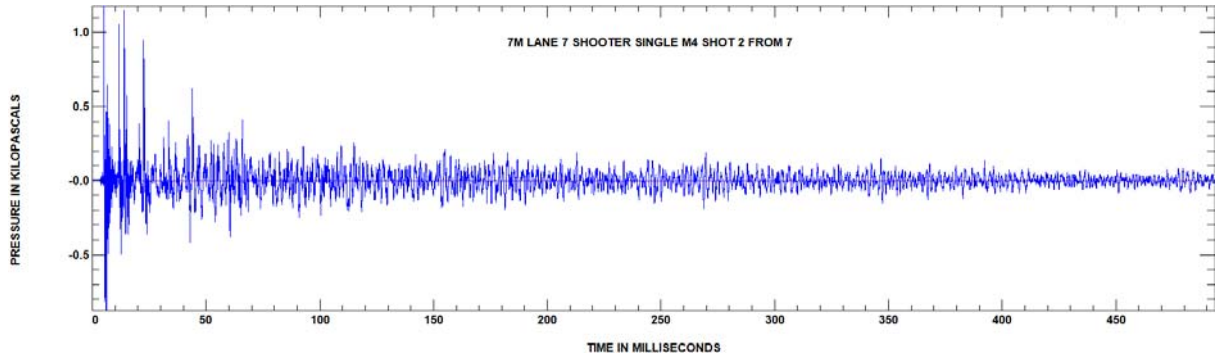

Figure 3F–10. Waveform 10

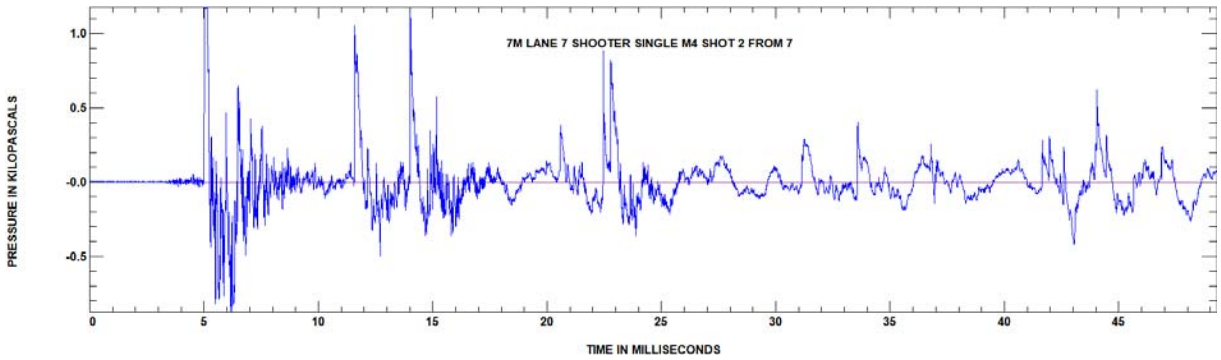

Figure 3F–11. Waveform 11

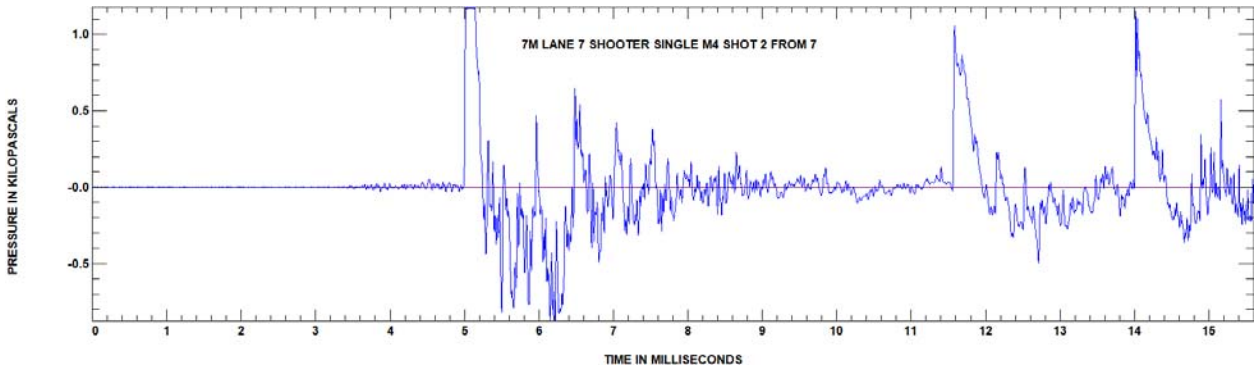

Figure 3F–12. Waveform 12

APPENDIX 3G

CHAPTER 3 GLOSSARY

ACGIH
American Conference of Governmental Industrial Hygienists

AHAAH
Auditory Hazard Algorithm Assessment for Humans

ANOR
allowable number of rounds

APHC
U.S. Army Public Health Center

ARL
U.S. Army Research Laboratory

ARU
Auditory Risk Unit

ATEC
U.S. Army Test and Evaluation Command

BOP
blast overpressure

CHABA
Committee on Hearing, Bioacoustics, and Biomechanics

DA Pam
Department of the Army Pamphlet

dB
decibel

dBP
decibel, peak

DHP
double hearing protection

DOD
Department of Defense

DRC
damage risk criteria

HCC
hearing conservation criteria

HHA
health hazard assessment

HP
hazard probability

HS
hazard severity

IMA
Independent Medical Assessor

MIL–STD
Military Standard

ms
millisecond

OSHA
Occupational Safety and health Administration

PTS
permanent threshold shift

RAC
risk assessment code

SHP
single hearing protection

SME
subject matter expert

TG
Technical Guide

TIP
Technical Information Paper

TOP
Test Operations Procedure

TTS
temporary threshold shift

USAPHC
U.S. Army Public Health Command

CHAPTER 4. GUIDELINES FOR CONDUCTING HEALTH HAZARD ASSESSMENTS OF EXPOSURE TO BLAST OVERPRESSURE

Source: DVIDS

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4–1. Purpose

This chapter provides guidelines for conducting health hazard assessments (HHAs) of Soldier exposure to blast overpressure (BOP) that occurs during the normal use and maintenance of materiel systems. The HHAs are conducted in support of the Army HHA process.

4–2. Definitions of Key Terms

Following are the definitions of key terms used throughout this chapter. Refer to the Glossary for the complete list of terms applicable to the Guide.

Allowable number of rounds (ANOR): A value calculated by the BOP-HHA software which estimates the number of rounds that may be fired within a 24-hour period that will produce a less than 1% incidence of any lung injury. The lower the ANOR, the more hazardous the blast event. Refer to Chapter 3 of this Guide, Impulse Noise, for the ANOR definition applicable to impulse noise. Typically, the ANOR assigned due to impulse noise is more restrictive than the ANOR assigned due to BOP.

Auditory noise: The component of a pressure wave that resonates at frequencies within the range of human hearing.

Blast overpressure (BOP): The sharp, instantaneous rise in ambient atmospheric pressure resulting from an explosive detonation or the firing (i.e., operating) of weapons (Elsayed, 1997). BOP is also known as non-auditory noise.

Blast overpressure-time trace: A line displayed on a graph that depicts the variation in time-pressure measurements due to the change in ambient air pressure associated with blast (Figure 4–1).

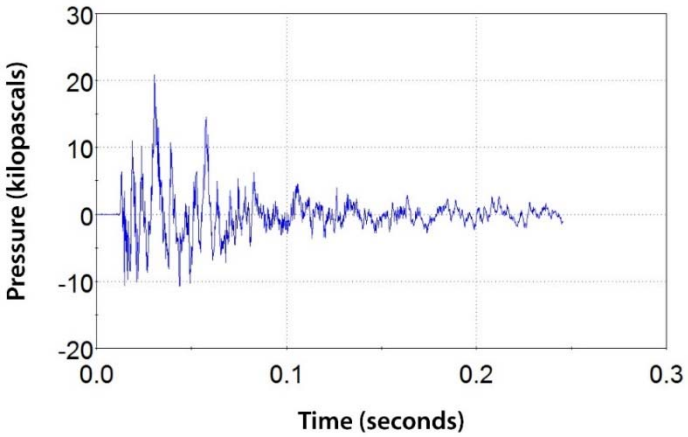

Figure 4–1. Blast Overpressure-Time Trace

Blast test device (BTD): A customized device that consists of an aluminum cylinder containing four transducers that correspond to the relative spatial proximity of a Soldier's chest, back, and left and right sides.

BOP-HHA software: The BOP software used to assess blast exposures in support of the Army HHA process. The BOP-HHA software uses a mathematical algorithm containing the INJURY model to calculate the injury risks associated with occupational blast exposures (Hsu, 2017).

Injury criteria: A physical parameter or a function of several physical parameters which correlates well with the type and severity of injury to the body region under consideration.

INJURY model: A biomechanically-based model that describes how the chest wall responds to impacts from a blast pressure wave. It uses time and pressure data collected from a BTD to estimate the intensity and duration of impact when a blast wave contacts the chest. In addition, the model calculates the amount of work that the blast wave performs on the thoracic wall, and uses information about the material properties of tissues, along with a database of results from over 1,000 experimental animal specimens, to estimate the probabilities of human lung injury for four different HS levels. The mathematical algorithm containing the INJURY model was used in the original INJURY software developed by Jaycor (a Government contractor, now part of L3Harris), for the U.S. Army Medical Research and Development Command (MRDC). The INJURY software was the predecessor of the BOP-HHA software currently used by the U.S. Army Public Health Center (APHC) to calculate the injury risks associated with occupational blast exposures (Stuhmiller, 1996; MacFadden et al., 2011).

Jaycor Information Format (JIF): Format for an American Standard Code for Information Interchange (ASCII) file containing test data (e.g., time and pressure information from a blast) for submission to the BOP-HHA software.

Non-auditory noise: See "blast overpressure."

Trading point: A numeric value, based upon the ANOR calculated by the BOP-HHA software, assigned when a weapon is fired or an explosive device is detonated. It is the inverse of the ANOR multiplied by 1,000. These points are accumulated for all exposures during a 24-hour period in order to determine a total number of points. Trading points determine whether or not Soldiers have exceeded the maximum 1,000-point allowance when operating multiple weapon systems that have dissimilar ANORs (refer to Appendix 3E).

W_{eff}: The effective normalized work done on the lung. W_{eff} is a dimensionless value that the BOP-HHA software calculates using BTD data collected for each crew position and for all exposure conditions tested. This value is resultant of the amount of mechanical work a blast wave imparts to the thorax.

4–3. Applicable References/Health Protection Criteria

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.

4–4. Health Effects of Blast Overpressure Exposure

In general, exposures to BOP occur in military environments from two sources: at the point of firing or detonation proximal to the Soldiers employing the weapon, and downrange at the point of impact or detonation proximal to enemy forces. Some specialized explosive devices, such as stun grenades, may also be detonated near the Soldiers employing them. HHAs are limited to exposure incurred during normal operation of the weapon by the users, and the resultant blasts proximal to the users should be relatively less energetic than downrange detonation. This chapter and the current HHA process focus on the BOP health effect of lung injury; however, there are other possible health effects due to BOP exposure (e.g., brain injury). The mechanism of lung injury for Soldiers operating weapons or detonating explosives can be described as follows: when a weapon or device is fired or detonated, energy is released that produces a pressure wave in the atmosphere that may contact the Soldier's thorax, resulting in a BOP exposure. The thorax deforms, and mechanical energy is transmitted to deeper tissues. The resultant injury includes 1) the immediate mechanical insult (the chest wall abruptly contacting the surface of the lungs); 2) damage from the mechanical stress associated with cavitation as the energy propagates through adjacent tissues; and 3) delayed cell death that occurs secondary to the inflammatory process (Stuhmiller, 2008).

4–5. Pre-assessment Procedures

A. Summary of Requirements for Blast Overpressure Assessment. The following are the components required for conducting a BOP assessment:

(1) A use scenario description, including—

(a) The anticipated health hazard exposures associated with normal use of the system.

(b) A description of special environmental conditions (e.g., high altitude, subterranean), if applicable.

(2) A user population description, including age, sex, military occupational specialty, etc.

(3) Test data, which will be—

(a) Collected using a BTD constructed in accordance with the specifications identified in the APHC Technical Information Paper (TIP) 88-001-0411.

(b) Collected in accordance with the U.S. Army Test and Evaluation Command Test Operations Procedure (TOP) 04-2-831 and International TOP (ITOP) 04-2-822.

(c) Representative of the health hazard. Ensure that the BTDs are placed in locations, orientations, and at heights representative of weapon crew members during live firing. The transducer designated as the chest should be situated in the same location and attitude as the Soldier's chest would be during the blast event. The BTD, which is usually placed on an articulating stand, should be angled and rotated to accurately represent the posture of the Soldier during the specific blast event. The system developer is responsible for determining where BTDs should be placed.

(d) Submitted in the JIF.

B. Scientific Basis of BOP Assessment Methodology. A trained BOP assessor performs a BOP assessment using the BOP-HHA software and subsequently interprets the analysis with subject matter expert (SME) consultation as required. The software provides a quantitative, probabilistic risk assessment based upon over 1,000 data points from animal studies conducted from 1980 through 1998 (Stuhmiller, 2008). Data collected from BTDs placed where crew members would be assigned are processed through a biomechanical model that estimates the amount of work done to the thorax, which is a function of the amount of chest deformation that occurs when a blast wave encounters the thorax. The software uses this estimate to calculate the W_{eff}. The software then estimates the severity of lung injury that would result from the exposure and generates a numeric probability based upon the results of animal research. These results are used to construct the hazard severity (HS) and hazard probability (HP) alphanumeric combination corresponding to a risk assessment code (RAC).

C. Blast Overpressure Assessment Methodology Features. The BOP assessment methodology employed demonstrates the following features that allow it to be designated as a rigorous, evidence-based model:

(1) Injury criteria. Injury criteria are based upon a database that contains the outcomes of over 1,000 blasts recorded from animal studies (refer to the Department of Defense Historical Blast Bioeffects Research Data Archive).

(2) Risk assessment determination.

(a) The HS is based upon direct observation of lung injuries sustained by animals and graded by a quantitative scoring system (Yelveton, 1996).

(b) The HP is based upon injury data from the animal studies.

(3) Assessment fidelity. Specifying the use of specially designed BTD sensors to collect BOP data increases the likelihood that data will match the requirements of the BOP-HHA software application and, therefore, improve the accuracy of the assessment.

(4) Methodological rigor. Assessment accuracy is high when—

(a) BOP data are collected with a properly constructed BTD (refer to APHC TIP 88-001-0411); and

(b) Proper quality assurance considerations are implemented during test instrumentation, data collection, and processing.

(c) The assessment is performed in accordance with this chapter;

D. Assessor Qualifications. The software functions as an expert system that processes data and generates RACs and ANORs. Assessors must be trained in how to set up data files, set up parameters in the graphical user interface, and interpret outputs, including atypical outputs that may be associated with problematic data. The BOP-HHA software generates risk assessment information (e.g., RACs and ANORs) used by the assessor to develop BOP risk levels and hazard mitigation recommendations for the HHA.

E. Test Data Requirements for Blast Overpressure Assessments.

(1) Testing criteria. BOP testing for lung injury risk is required if impulsive noise test results yield an ANOR of 5 or less with single hearing protection; therefore, BOP analysis is not always necessary for all weapon systems. Testing may be deferred for any test condition where previous impulsive noise test results yielded ANORs of greater than 5 with single hearing protection.

(2) Basic concepts/considerations/assumptions.

(a) The INJURY model is calibrated to analyze data collected by a BTD that meets the standard design specifications developed by L3Harris (refer to APHC TIP 88-001-0411).

- In accordance with the design specifications, each BTD contains four transducers that correspond to the relative spatial proximity of a Soldier's chest, back, and left and right sides.

- Data collected by microphones or other transducers that fail to meet BTD design specifications shall not be analyzed using the BOP-HHA software.

(b) BTDs are validated to collect data accurately in specific environments (Masiello, 2003); refer to TIP 88-001-0411.

- Thirty-inch and 24-inch BTDs that meet all other design specifications are validated to collect data in outdoor environments located outside of enclosures.

- Thirty-inch BTDs are validated to collect data inside of enclosures.

- Data collected by BTDs that either deviate from the approved design specifications or have not been validated for the environment in which they collected the data shall not be analyzed using the BOP-HHA software.

(c) Due to variance observed in complex environments (e.g., reflection, refraction, etc.), the BOP assessment methodology assumes that results are only valid for the specific location where the BTD was placed at the time of testing. Data collected by a BTD shall not be interpolated to infer exposures at other locations.

(d) The BOP data shall only be used to determine injury risk for the weapon system from which the data were collected. A rare exception to use data from a similar weapon system may be made only by consensus among the weapon testers, the HHA Program representatives, and the BOP SMEs.

(3) Limitations of the INJURY model.

(a) The INJURY model used for analysis is limited to BOP sustained by the torso. More specifically, the model is calibrated and only applicable to lung injury. The lung was selected as the target organ because of the increased vulnerability of air-containing organs to blast injury and the relative lethality associated with lung injury (Elsayed, 1997).

(b) Because the limitations of the INJURY model do not permit a comprehensive characterization of the injury risk, other susceptible organs such as the tympanic membrane and brain are excluded from consideration at this time. Results should be interpreted with this limitation in mind.

(c) The INJURY model is limited to predicting cumulative lung injury due to one or more blast exposure events occurring within a 24-hour period.

- Physiological responses such as the inflammatory process can increase injury severity over a period of days following the initial injury. However, due to the nature of the animal data used in model development, the INJURY model is only predictive of the injury severity characterized within 24 hours post-injury.

- Also due to the nature of the animal data used in model development, the INJURY model under-predicts the injury severity that occurs from multiple exposures spanning more than 24 hours. The under-prediction occurs because the model does not account for cumulative injuries sustained during a previous exposure that occurred outside the original 24-hour period.

F. Information Required for the Health Hazard Assessment.

(1) Obtain the following information from the materiel developer (MATDEV):

(a) System description. The system description should include the nomenclature needed to identify and classify the system and system components pertinent to the assessment. The information needed to describe a specific system properly may vary but most often includes the name of the weapon, weapon type (such as mortar, grenade, howitzer, or missile), weapon caliber, and type of propellant.

(b) Use scenario description. The use scenario description should include BOP exposure-relevant information about human-system interactions and about the operational environment. Such information should relay important facts about weapon configurations that affect the intensity, duration, and frequency of exposure, including round type, gun elevation, gun azimuth, firing zone, and the quantity of explosive detonated. It is essential to include an estimate of the maximum number of blasts or shots to which the weapon crew members will be exposed during a mission or training scenario. Information about how personnel are positioned with respect to the weapon, such as the crew position or separation distance between the energy source and the Soldier, as well as Soldiers' postures (e.g., standing, sitting, kneeling, or prone), is needed. Information about the environment in which the weapon is employed, such as the type of environment (e.g., an open field or inside an enclosure, such as a vehicle or building) and any environmental conditions (e.g., high altitude, subterranean) that may affect the transmission of blast, should be reported. When appropriate, the name of the vehicle or the dimensions of the enclosure from which a weapon may be fired should be provided.

(c) User population information. User demographic data should be recorded since the biomechanical response of the thoracic wall can be affected by sex and anthropometry. However, the assessment does not use this information at present.

(2) Receive and review the test plan and data submission from the weapon tester, including the following—

(a) Test summary. The following information should accompany the test data to foster a better understanding of how the test was conducted: system name, test date, test center name, a description of the purpose of the test, the weapon tester's name, and the test plan. This information should also be available in the HHA project archive for future reference. Information about the BTDs used to collect data, such as their size and the crew positions they represented, should also be included (a diagram may be helpful). A description of the test environment (e.g., open-field, obstacles present, or within an enclosure) should also be included. Testers need to comply with and affirm that the BTD used in the data collection adheres to the required design specifications provided in APHC TIP 88-001-0411. Any deviations from those specifications must be reported to the HHA Project Manager, along with the submitted data.

(b) Test data. After receiving data, conduct an initial review to determine that the necessary BOP data were collected and compiled by the testers according to the guidelines in section 4–6(A) of this chapter. The data format will be checked to ensure its adherence to the JIF, as described in APHC TIP 88-001-0411. The data will be checked to determine the number of rounds used in each condition. Ideally, each condition should produce a statistically significant number of valid data points (rounds fired, weapons launched, or explosives detonated). For most weapons, each test condition should contain data from a minimum of five firings, launches, or detonations. Rounds should be numbered in a manner that allows them to be readily associated with test conditions. Erroneous rounds that should be excluded from the assessment, as well as other conditions that occurred during testing that may negatively influence the quality of the data collected, should be identified. Any problems that may degrade the quality of the APHC assessment will be documented in the HHA Report. If the data were not submitted in the required format per TIP 88-001-0411 (i.e., not in JIF), or are otherwise incapable of being processed by the BOP-HHA software (e.g., not organized into proper test condition folders), the tester and the MATDEV will be notified of the requirement to correct the problem and provide usable data for the APHC assessment.

(c) Normal use and operation. Based on the use scenario and user information, identify the normal use of the weapon/system in both the operational and training environments.

4–6. Risk Assessment Process.

After the APHC receives the test data in the required format, the risk assessment can proceed. The APHC uses the BOP-HHA software (refer to section 4–2) to assess lung injury risk from BOP. This software contains a complex algorithm that translates the time-pressure data collected by the BTD to estimate the magnitude of the mechanical forces impacting the thorax and transmitted to the lung, yielding an objective probabilistic-based risk assessment. Biomechanical force is expressed as the effective normalized work done on the lung (W_{eff}) which is used to estimate the resulting lung injury at each BTD location for all test conditions.

A. Assessment Preparation.

(1) Create folders. Ensure that two computer pathways for BOP assessment data are present: one for the raw data received and the other for the files that the software will generate during analysis. For example, “<Drive>/INJURY/Input” could be designated for data files, and “<Drive>/INJURY/Output” could be designated for results files. Create two folders to contain the data and results files for the system being assessed, and place them in the pathways named above. For example, a folder containing data for the M829E3 120 millimeter tank cartridge towed howitzer could be named “M829E3.” The data file folder would be established as “<Drive>/INJURY/Input/M829E3,” and the results file folder would be established as “<Drive>/INJURY/Output/M829E3.” Organizing in this manner will ease the association of data files with results.

(2) Copy data files. Copy the BOP files into the appropriate folder. Following the previous example, copy the entire file structure containing *jif data files, desc.txt description files, and their folders and subfolder under “<Drive>/INJURY/Input/M829E3.”

B. Performing the Assessment. Use the BOP-HHA software program to conduct the risk assessment for the HHA.

(1) System Parameters tab. Start the BOP-HHA software program, input the test parameters, and input the values needed to run the assessment. Figure 4–2 shows the input screen with all values entered. A definition of each parameter follows the figure. The parameters outlined in green should be unique to each assessment, whereas the parameter outlined in red should not be changed.

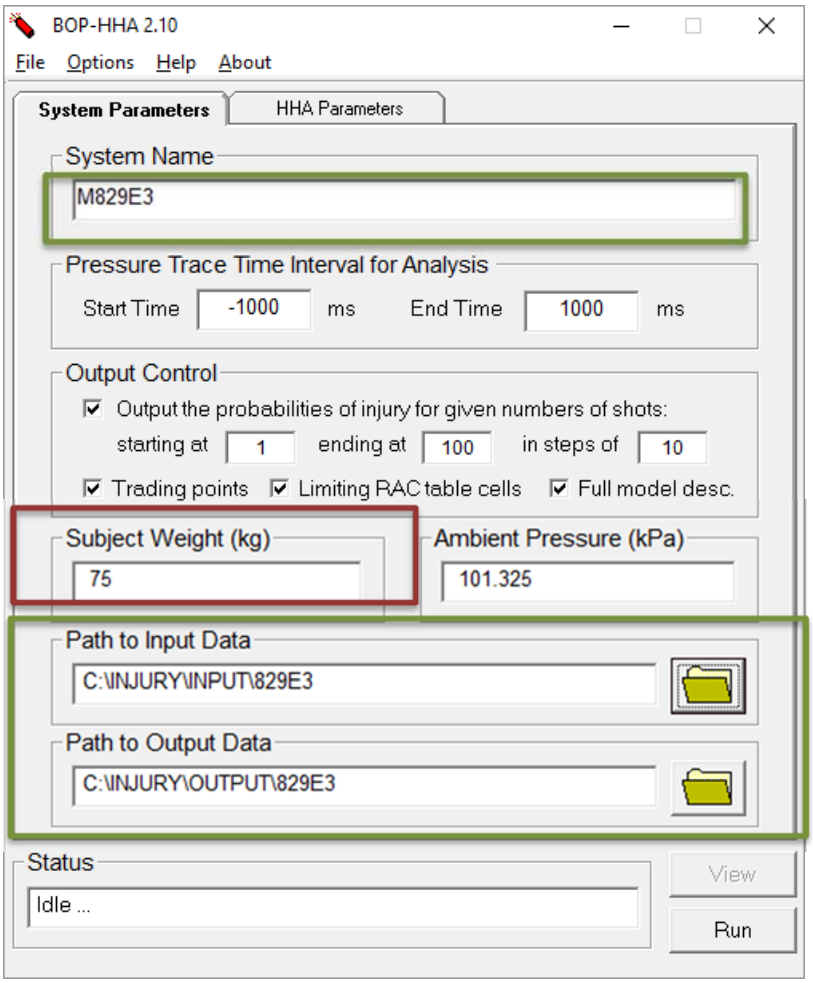

Figure 4–2. Blast Overpressure Assessment Input Screen

(a) System name. Input a name consisting of not more than eight alphanumeric characters. “M829E3” was entered as the system name in Figure 4–2.

(b) Pressure trace time interval for analysis. This range of values describes the time frame in which the BOP-HHA software analyzes the data. The default values (start time −1000 milliseconds (ms) to stop time 1000 ms) apply to most assessments. The need to change these default values can be determined by examining the data if errors are reported. However, unless such changes are necessitated by the data received or directed by the BOP model developers, the start and stop times should remain at −1000 ms to 1000 ms, respectively.

(c) Output control. Output the probabilities of injury severity for given numbers of shots. This checkbox should be checked by default. Based on the use scenario, enter values that are compatible with the number of rounds expected to be fired. The number of steps affects the resolution and run time of the output. For example, the M829E3 MATDEV reported that Soldiers should fire no more than 50 rounds per day. If a starting number of “1” and an ending number of “100” are entered, the software will estimate risk from exposures to twice that dictated by the use scenario. If “1” is entered in the “in steps of” box, the software will report exposure assessment results for all 100 exposures. If “10” is entered, the software will report exposures for every tenth round and generate 10 lines on the report.

- Checkbox option: trading points. Select this checkbox if Soldiers will be exposed to a blast from more than one type of weapon or explosive device within any given 24-hour period. Trading points are a means of tracking exposures to multiple weapons to prevent overexposure. Soldiers are allowed to accumulate 1,000 trading points in a 24-hour period. They will be awarded a specific number of points for each blast, depending upon the value determined by the BOP-HHA software. Be aware of the availability of this function in the event that the MATDEV requests that trading points be reported (refer to the APHC Memorandum in Appendix 3D).

- Checkbox option: limiting RAC table cells. Select this checkbox to include the risk matrix used as the basis for the assessment in the report.

- Checkbox option: full model desc. Select this checkbox to include the full text of all descriptions contained within the desc.txt files. Including the full text is recommended to identify assessment information at a future date. Enter any information to follow the assessment in the future. For example, in the desc.txt file located in the top folder, document unusual circumstances about the test or data, such as when data are collected with a non-standard BTD.

(d) Subject weight (kilograms (kg)). Subject weight should not be changed from the 75.0 kg default value to which the software was calibrated. This value is near the 77.7 kg body mass for 50th-percentile male Soldiers, as per Military Handbook 743A (DOD, 1991). Due to anatomical and physiological differences, this value should not be changed in an attempt to provide a means to account for body type or sex.

(e) Ambient pressure (kilopascals (kPa)). Blast pressure waves propagate differently at different atmospheric pressures. The standard atmospheric pressure on Earth (101.325 kPa) is used by default. If a system will be used in a special environment, enter a more appropriate value in this box.

(f) Path to input data. This path does not need to be entered manually. Click the folder icon to the right of the long text box, and use the popup dialog box to navigate to the copied data files. After clicking “OK,” the text describing the path will populate the long text box.

(g) Path to output data. This path does not need to be entered manually. Click the folder icon to the right of the long text box, and use the popup dialog box to navigate to the location where the results files should be saved. After clicking “OK,” the text describing the path will populate the long text box.

(2) HHA Parameters tab. HP levels used by the BOP-HHA software are stored in the HHA Parameters tab, as illustrated in Figure 4–3. These default probability thresholds correspond to the HP levels and are as follows: frequent ≥ 1.0%; probable ≥ 0.1%; occasional ≥ 0.01%; remote ≥ 0.001%; and improbable > 0.00%.

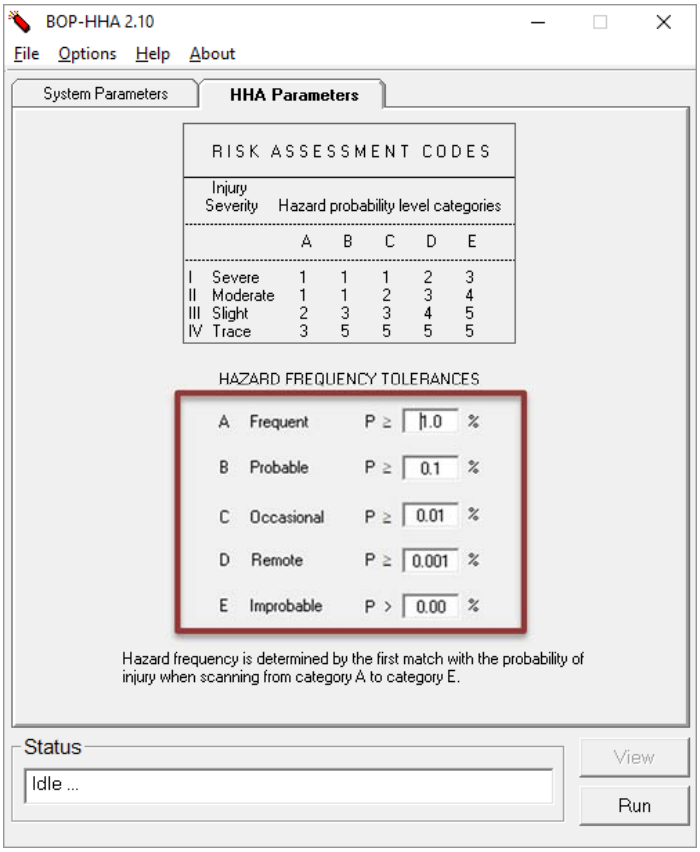

Figure 4–3. Hazard Probability Thresholds as shown in the “HHA Parameters” Tab

C. Running the Blast Overpressure-Health Hazard Assessment Software. After reviewing the values in the BOP-HHA software, click the "Run" button to run the assessment. The status box will update with the name of each file as it is analyzed. After the assessment ends, a dialog box containing links by which the results files can be accessed will appear. If preferred, open the files directly by navigating to the folder described in the output data path.

D. Checking Results. The evaluator should examine the W_{eff} values that the BOP-HHA prints to the <SysName>_THHA.txt file for unusual or unexpected results. In particular, data should be compared with the outputs from BTDs that are at similar distances from the source of the blast energy and are extremely low values. If abnormal results are noted, the evaluator should use Microsoft Excel® to examine the <SysName>_XCEL.csv file, which contains the cumulative computations that the assessment algorithm executes to derive W_{eff}. The file provides a level of resolution that may allow more insight for troubleshooting any unexpected results. Abnormal results should be reported to the tester, who can validate the results and determine whether or not to remove suspect data from the analysis.

E. Understanding Results. The RAC is located in the "Allowable Number of Rounds Per Day for Each RAC Value" table output in the <SysName>_THHA.txt file. Below is a general explanation of how the BOP-HHA software determines the HS and HP to assign the RAC in the table output. The example assessment scenarios in section 4–8 provide the sample output tables from the BOP-HHA software.

(1) HS Determination.

(a) The BOP-HHA software uses W_{eff} threshold values to determine HS. Table 4–1 lists the W_{eff} thresholds associated with the HS categories.

Table 4–1. Hazard Severity Categories for Blast Overpressure

Category and Description		Adverse Health Effects That May be Caused by BOP Exposure	INJURY Model W_{eff} Thresholds*
1	Catastrophic	Death or total loss of a bodily system	> 0.00070068
2	Critical	Severe bodily injury, severe occupational illness, or major damage to a bodily system	> 0.00025222
3	Marginal	Minor bodily damage, minor occupational illness, or minor damage to a bodily system	> 0.00013192
4	Negligible	Less than minor bodily injury, less than minor occupational illness, or less than minor damage to a bodily system	> 0.00007414

Note: *The INJURY Model W_{eff} thresholds are ranges of values. Therefore, the HS category is determined by the first match with the W_{eff} thresholds when scanning from Category 1 to 4.

(b) Examine the "Allowable Number of Rounds Per Day for Each RAC Value" table output in the <SysName>_THHA.txt file. Select the crew position with the highest

W_{eff} average as the basis for the risk assessment for each condition. Compare the highest W_{eff} average to the W_{eff} thresholds in Table 4–1 to identify the HS category.

(2) HP Determination.

(a) Before examining how the BOP-HHA software handles HP, it is important to understand that exposures are complex, and live human subjects may respond differently than the model predicts. Reflection of pressure waves may result in individuals receiving different quantities of blast energy. In addition, differences in the physical characteristics of individuals create variations in tolerances to blast energy that affect injury severity and probability. This outcome is consistent with many different kinds of real-world exposures to other hazards. Figure 4–4 was constructed from data collected from blast testing and shows overlapping probabilities for different injury severities. According to this graph, if a population were exposed to a quantity of blast energy that intersected the middle (maximum) of the trace injury curve, the following injury severity probabilities would be estimated: no injury = 0.23; trace injury = 0.54; moderate injury = 0.21; and severe injury = 0.02. Refer to Figure 4–5 to learn how injury severity probabilities relate to the pathological scoring system (source: Walter Reed Army Institute of Research (WRAIR)).

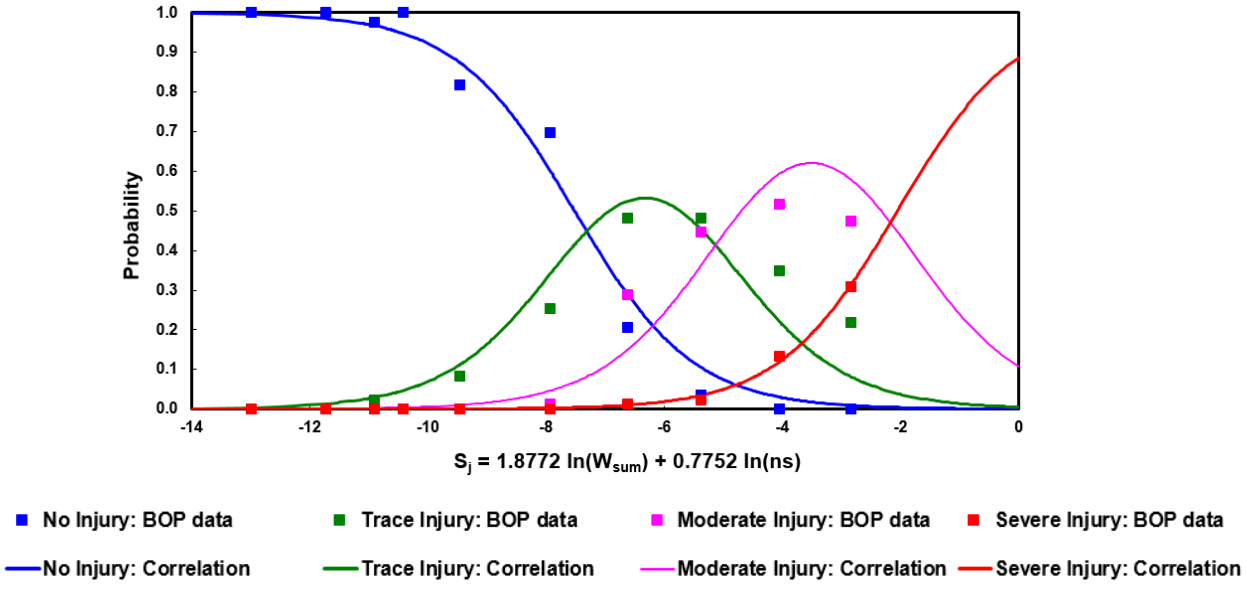

Figure 4–4. Probability of Discrete Lung Injury Levels

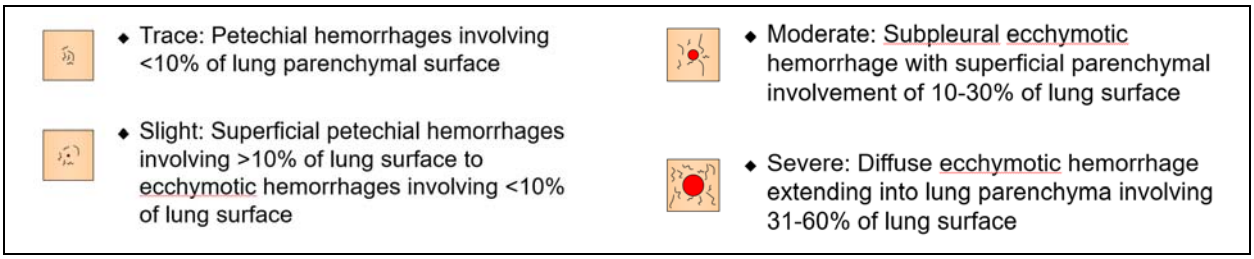

Figure 4–5. Walter Reed Army Institute of Research Pathological Scoring System

(b) To find the probabilities of injury that determine the HP level, use the "Probabilities of Discrete Injury Levels" table output in the <SysName>_THHA.txt file. Locate the rows within the output table that display the probabilities of injury for the maximum number of blast exposures specified in the use scenario. For each condition, calculate probability by averaging all of the non-zero probabilities for the crew member with the highest W_{eff} average (as identified in section 4-7E(1)*(b),* above).

(c) Use Table 4–2 to identify the HP level that corresponds to the average of the non-zeroed probabilities for the crew member with the highest W_{eff} average.

Table 4–2. Hazard Probability Levels for Blast Overpressure

Level	Description	Likelihood of Occurrence	INJURY Model Probability Thresholds*
A	Frequent	Likely to occur often	≥ 1.0%
B	Probable	Will occur several times	≥ 0.1%
C	Occasional	Likely to occur sometime	≥ 0.01%
D	Remote	Unlikely but possible to occur	≥ 0.001%
E	Improbable	So unlikely it can be assumed occurrence may not be experienced	> 0.0%
F	Eliminated	Incapable of occurring. This level is used when potential hazards are identified and later eliminated.	Not applicable

Note: *The probability thresholds are ranges of values. Therefore, the HP level is determined by the first match with the probability thresholds when scanning from Level A to E.

(d) To assign HP F, Military Standard (MIL–STD) 882E paragraph 4.3.4 requires that hazards be eliminated "by selecting a design or material alternative that removes the hazard altogether." Therefore, exposure to any level of BOP should be assumed to carry a potential injury risk and cannot result in an HP F. For the purposes of HHA, there are recognized exposures that are not evaluated because the intensities of other characteristics of the blast wave are deemed to present a very low injury risk. Such is the case when Soldiers are exposed to blast resulting in an ANOR of more than 5 (historically known as sub-Z curve levels), which does not warrant system developer testing. An example of one situation that may be awarded HP F is remote firing, during

which the weapon discharge or detonation is triggered at a remote location, and the operator is completely isolated from the blast.

F. Risk Mitigation and Recommendations.

(1) In BOP assessments, residual risk is the resulting risk after implementation of one or more of the HHA recommendations (e.g., elimination, substitution, engineering control, warnings, administrative control, and personal protective equipment), including, for example, the interventions listed in Table 4–3.

Table 4–3. Risk Mitigation Examples

Intervention	Action	Result
Eliminate a crew position.	Disregard results pertaining to that crew position.	Reassess the risk using only data from the remaining crew positions.
Eliminate a firing condition (e.g. hatch closed).	Disregard results pertaining to that firing condition.	Reassess the risk associated with the weapon system using the remaining firing condition(s).
Modify a firing condition (e.g., change propellant).	Select results pertinent to the modified use scenario, or collect additional data based upon the modified use scenario.	Reassess the risk associated with the weapon system using the data pertinent to the modified firing condition(s).
Add warnings and firing restrictions to operator and technical manuals, training materials, and materiel fielding plans.	None.	No effect on residual risk assessment. Administrative controls do not affect the risk assessment code for blast overpressure exposures.

(a) Depending upon the design of the weapon system and the work demands of the firing crew, it is sometimes possible to eliminate a crew position. Changing the crew member locations for weapons built on vehicular platforms is unlikely to be feasible, but more flexibility may be possible with weapons fired in an open environment. If changes to crew member locations are made, BOP data should be recollected at the proposed new locations.

(b) Residual risk is often based on changes in firing conditions. For example, a MATDEV may desire to ascertain the differences in exposures when a gun uses a blast attenuating device (BAD) compared to when it does not. In this case, the baseline risk assessment and initial RAC will be determined based on all of the conditions. The residual risk would then be determined based on the subset of BAD applicable exposures only if the test results demonstrate less severe blast exposures when the BAD is used.

(c) Commonly, MATDEVs and test centers collect data with the gun barrel positioned at various attitudes to compare firing with the lockout engaged (preventing firing at certain locations) to firing with the lockout disengaged. The baseline assessment would be determined based on all data, and the residual risk would be determined based on a subset of data that excludes firing when the lockout mechanism is disengaged, allowing more operator control of the gun barrel.

(d) Finally, residual risk can be based upon changes in the use scenario. This determination could entail assumptions about the maximum number of rounds a crew will fire during a 24-hour period or the external environment where the weapon will be employed. For example, a use scenario could entail engaging an enemy located inside a cave. The MATDEV may want to compare exposures from firing outside the cave to those from firing inside it. The initial risk would be generated from the entire dataset, and the residual RAC could exclude data associated with firing at locations within the cave where reflections could amplify the blast.

4–7. Example Assessment Scenario

Step 1. Data obtained during a testing event of an armored combat vehicle (ACV) were provided to the APHC.

Step 2. The use scenario obtained from the MATDEV states the crew will be exposed to 8 firings (shots) from the ACV weapon system per 24-hour period.

Step 3. Create two pathways for the BOP-HHA software to receive and generate data that captures all test conditions (i.e., input and output pathways). The software is set to run starting at 1 shot, ending at 20 shots, in steps of 1. This configuration will generate sufficient data for the use scenario of eight firings, as well as additional data which could be used to aid in the determination of residual risk.

Step 4. Run the software analysis.

Step 5. Examine Table 4–4, the ANOR table for condition 1. It contains the W_{eff} average values for all four crew positions.

Table 4–4. ANOR and RAC Output (Condition 1)

Condition	Position	W_{eff} average	RAC = 1	RAC = 2	RAC = 3	RAC = 4	RAC = 5
1	Crew Position 1	0.0002649	1001*	2 (2B)	1 (3B)	0 (3B)	0 (3B)
1	Crew Position 2	0.0006734	1001*	1 (2A)	0 (2A)	0 (2A)	0 (2A)
1	Crew Position 3	0.0002708	1001*	39 (2B)	0 (2B)	0 (2B)	0 (2B)
1	Crew Position 4	0.0002981	1001*	26 (2B)	0 (2B)	0 (2B)	0 (2B)

Legend:
ANOR = allowable number of rounds
Blue = The highest W_{eff} average for Condition 1 among all of the crew positions.
Green = The ANOR and RAC assigned for Condition 1 where the format “1 (2A)” represents an ANOR of 1 and a RAC of 2A.
RAC = Risk assessment code
W_{eff} = Effective normalized work done on the lung
Notes:
The table format and headers displayed are identical to the table output from the BOP-HHA software. The “RAC” label in the table header row is roughly equivalent to the risk levels (i.e., 1 = High, 2 = Serious, 3 = Medium, etc.). Since these do not correspond exactly, the RAC labels in the table header should only be used to locate the applicable ANOR.
*1001 is the default number displayed by the BOP-HHA software to represent its inability to assign a RAC for that ANOR.

Step 6. Since Crew Position 2 has the highest W_{eff} average, and thus the most work done to the lung, use this worst-case crew position to determine the RAC for this condition. As shown in Table 4–4, the software will output the ANOR and RAC for the worst-case position (in this example, a RAC of 2A and an ANOR of 1) and for the other crew positions. Note that the ANOR for this example is less than the 8 rounds expected to be fired. The ANOR and RAC assigned for the overall system are always located within the same row as the crew position with the highest W_{eff} average. Note that the default number of 1001 may be displayed in the same row, representing the software’s inability to assign a RAC for that ANOR. The assigned ANOR is the first ANOR not equal to 1001 in that row when reading from left to right, and the assigned RAC is located in the same cell as the assigned ANOR. The instructions in Steps 7 through 10 below explain the methods for determining the HS and HP to check the RAC from Table 4–4. The RAC matrix appears in Figure 4–6.

RISK ASSESSMENT CODE 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)				

Figure 4–6. Risk Assessment Code Matrix
(Source: MIL–STD–882E)

Step 7. Based upon the HS thresholds in Table 4–1, the highest W_{eff} average of 0.0006734 is greater than 0.00025222 but less than 0.00070068; therefore, the HS is 2 (Critical) (refer to Figure 4–6).

Step 8. Next, examine the list of values for "Probabilities of Discrete Injury Levels" in the <SysName>_THHA.txt file. Table 4–5 provides the probability values attributed to exposures for condition 1.

Table 4–5. Probability of Injury from Exposure (Condition 1)

Condition	Position	P(Trace)	P(Slight)	P(Moderate)	P(Severe)
1	Crew Position 1	0.005262	0.001404	0.000235	0
1	Crew Position 2	0.039997	0.008877	0.002402	0
1	Crew Position 3	0.005441	0.001310	0.000383	0
1	Crew Position 4	0.006736	0.001585	0.000483	0

Legend:
Yellow = The probability values averaged for the HP determination, which are the non-zero probabilities for the crew position with the highest W_{eff} average.

Step 9. Locate the row in Table 4–5 that contains the injury probabilities for Crew Position 2 (chosen above in Table 4–4 for having the highest W_{eff} average). Identify the degrees of injury severity in that row (i.e., trace, slight, moderate, or severe) having probabilities greater than "0", and average them. In this example, the trace, slight, and moderate hazard degrees of injury have the following non-zero probabilities: 0.039997, 0.008877, and 0.002402, respectively. The average of these three values is 0.017092.

Step 10. Since the average probability of 0.017092 is above the probability threshold of 1.0% shown in Table 4–2, the HP is A (Frequent). By combining this HP with the HS from Step 7, the RAC for this condition is 2A, which corresponds to a risk level of High (refer to Figure 4–6).

Step 11. To determine the residual risk for this example exercise, assume that Crew Position 2 is a non-critical crew position that will be eliminated from the team to lower the injury risk. The residual risk assessment will be based on data from the remaining crew positions: 1, 3, and 4 (Table 4–6).

Step 12. Following the previous logic, Crew Position 4 is the remaining crew member with the highest W_{eff}: 0.0002981. Since this value is greater than 0.00025222 but less than 0.00070068 (see Table 4–1), the residual HS is 2 (Critical).

Table 4–6. ANOR and RAC Output for Residual Risk Assessment (Condition 1)

Condition	Position	W_{eff} average	RAC = 1	RAC = 2	RAC = 3	RAC = 4	RAC = 5
1	Crew Position 1	0.0002649	1001*	2 (2B)	1 (3B)	0 (3B)	0 (3B)
~~1~~	~~Crew Position 2~~	~~0.0006734~~	~~1001*~~	~~1 (2A)~~	~~0 (2A)~~	~~0 (2A)~~	~~0 (2A)~~
1	Crew Position 3	0.0002708	1001*	39 (2B)	0 (2B)	0 (2B)	0 (2B)
1	Crew Position 4	0.0002981	1001*	26 (2B)	0 (2B)	0 (2B)	0 (2B)

Legend:
ANOR = allowable number of rounds
~~Strikethrough~~ = Eliminated crew position for the residual risk assessment.
Blue = The highest W_{eff} average for Condition 1 when eliminating Crew Position 2 for the residual risk assessment.
Green = The ANOR (26) and RAC (2B) assigned for Condition 1 when eliminating Crew Position 2 for the residual risk assessment.
RAC = Risk assessment code
W_{eff} = Effective normalized work done on the lung
Notes:
The table format and headers displayed are identical to the table output from the BOP-HHA software. The "RAC" label in the table header row is roughly equivalent to the risk levels (i.e., 1 = High, 2 = Serious, 3 = Medium, etc.). Since these do not correspond exactly, the RAC labels in the table header should only be used to locate the applicable ANOR.
*1001 is the default number displayed by the BOP-HHA Software to represent its inability to assign a RAC for that ANOR.

Step 13. To determine the residual HP, identify the probabilities that are greater than 0 for the various injury levels of the crew position with the highest W_{eff} average (Table 4–7). Averaging the values 0.006736, 0.001585, and 0.000483 yields 0.002935. Based on the table of HP threshold values (Table 4–2), the revised HP is B (Probable). Therefore, the residual RAC is 2B, which still corresponds to a risk level of High (refer to Figure 4–6). However, the ANOR is now 26 rounds which is greater than the 8 rounds expected to be fired.

Table 4–7. Probability of Injury for Residual Risk Assessment (Condition 1)

Condition	Position	P(Trace)	P(Slight)	P(Moderate)	P(Severe)
1	Crew Position 1	0.005262	0.001404	0.000235	0
~~1~~	~~Crew Position 2~~	~~0.039997~~	~~0.008877~~	~~0.002402~~	~~0~~
1	Crew Position 3	0.005441	0.001310	0.000383	0
1	Crew Position 4	0.006736	0.001585	0.000483	0

Legend:
Yellow = The probability values averaged for the HP determination. These are the non-zero probabilities for the crew position with the highest W_{eff} average, when Crew Position 2 is eliminated for the residual risk assessment.
~~Strikethrough~~ = Crew position eliminated for the residual risk assessment

4–8. Limitations and Potential Future Work

(1) Section 734 of the Fiscal Year (FY) 2018 National Defense Authorization Act (NDAA) requires that the Secretary of Defense conduct a longitudinal medical study on BOP exposure of members of the Armed Forces during combat and training. The study will specifically focus on how these BOP exposures affect brain health and cognitive performance. The Assistant Secretary of Defense for Health Affairs established the NDAA Section 734 Work Group (WG) to lead this study effort, which includes five lines of inquiry (LOI) identified by the WG leadership: Surveillance, Weapon Systems, Exposure Environment, Blast Characterization, and Health Effects. The APHC serves as the office of primary responsibility for the Exposure Environment LOI. The study goals include improving how Service members' blast exposures are monitored, recorded, and analyzed; determining how to log Service members' blast exposure histories; and reviewing the current safety precautions for heavy weapons training and updating them with emerging research on blast exposure and its effects on the cognitive performance of Service members.

(2) An optimal BOP-HHA data collection and assessment process requires that the following occur:

(a) Update the TIP 88-001-0411, *Program Guidance for Blast Overpressure Analysis*.

(b) Update the BOP-HHA software model to address known limitations, including those discussed in section 4-5E(3) of this TG.

(c) Validate different types of gauges (including wearable gauges) and sizes of BTDs to standardize testing and data processing procedures for future assessments.

(d) Maintain and sustain validated test devices (e.g., repair part specifications).

(e) Ensure interoperability between the updated BOP-HHA software and validated test devices (e.g., wearable pressure gauges).

(f) Develop specifications and construct a permanent enclosure for enclosed environment BOP testing.

(g) Promote consistency of BOP data collection and data processing procedures (e.g., following test device and enclosure specification requirements, test result reporting, updating and following TOPs) among test centers.

(h) Request that BOP-HHA software developers review this chapter and its future updates.

(3) Examples of Military Operational Medicine Research Program/Joint Program Committee-5 BOP-related projects include—

(a) Determining the relationship between single and repetitive blast exposures and cognitive performance.

(b) Identifying and characterizing acute and chronic physiological responses resulting from repetitive blast exposures in training.

(c) Quantifying the differences in physiological and cognitive performance after blast exposure in order to predict return to duty.

(d) Conducting data surveillance and creating a repository of blast exposure data from training sites to support research investigating the effects of blast exposure on health outcomes.

(e) Developing evidence-based medical standards and guidelines to prevent subclinical neurological changes resulting from repeated low-level blast exposures.

(f) Developing a blast sensor, an algorithm to predict injury threshold, and a field-appropriate neurofunctional impairment screening tool.

APPENDIX 4A

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APPENDIX 4B

CHAPTER 4 GLOSSARY

ACV
armored combat vehicle

ANOR
allowable number of rounds

APHC
U.S. Army Public Health Center

ASCII
American Standard Code for Information Interchange

BAD
blast attenuating device

BOP
blast overpressure

BOP-HHA
Blast Overpressure-Health Hazard Assessment

BTD
blast test device

FY
fiscal year

HHA
health hazard assessment

HP
hazard probability

HS
hazard severity

ITOP
International Test Operations Procedure

JIF
Jaycor Information Format

kPA
kilopascal

LOI
line of Inquiry

MATDEV
materiel developer

MIL–STD
Military Standard

MRDC
U.S. Army Medical Research and Development Command

NDAA
National Defense Authorization Act

RAC
risk assessment code

SME
subject matter expert

TIP
Technical Information Paper

TOP
Test Operations Procedure

W_{eff}
effective normalized work done on the lung

WG
working group

WRAIR
Walter Reed Army Institute of Research