

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188	
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for information on Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.						
1. REPORT DATE (DD-MM-YYYY) 14-05-2020		2. REPORT TYPE Final		3. DATES COVERED (From - To)		
4. TITLE AND SUBTITLE Test Operations Procedure (TOP) 02-2-622 Toxic Hazards Testing for Military Equipment and Materiel				5a. CONTRACT NUMBER		
				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER		
6. AUTHORS				5d. PROJECT NUMBER		
				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Warfighter Directorate (TEAT-WFA) U.S. Army Aberdeen Test Center 6943 Collieran Road Aberdeen Proving Ground, MD 21005-5059				8. PERFORMING ORGANIZATION REPORT NUMBER TOP 02-2-622		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Policy and Standardization Division (CSTE-CI-P) U.S. Army Test and Evaluation Command 6617 Aberdeen Boulevard Aberdeen Proving Ground, MD 21005-5001				10. SPONSOR/MONITOR'S ACRONYM(S)		
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) Same as item 8		
12. DISTRIBUTION/AVAILABILITY STATEMENT Distribution Statement A. Approved for public release; distribution is unlimited.						
13. SUPPLEMENTARY NOTES Defense Technical Information Center (DTIC), AD No.:						
14. ABSTRACT This TOP is designed to act as a guidance document to aid in the development and conduct of tests used to determine the toxic gas/aerosol exposure hazards associated with realistic operations of military equipment. It is incumbent upon the test manager/test officer to seek out and consult with the appropriate Subject Matter Experts (i.e., chemists, toxicologists, physical scientists) to provide adequate input while developing their Detailed Test Plan to ensure all potential toxic hazards are considered.						
15. SUBJECT TERMS toxic hazards, military equipment, exposure, concentration, toxic gas, toxic aerosol, toxicologists, gas monitor, emission monitor, sampling system, FTIR						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 89	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code)	

(This page is intentionally blank.)

U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-622
DTIC AD No.

14 May 2020

TOXIC HAZARDS TESTING FOR MILITARY EQUIPMENT AND MATERIEL

		<u>Page</u>
Paragraph	1. SCOPE.....	2
	1.1 Purpose	3
	1.2 Subtests.....	3
	1.3 Toxic Analytes Covered	4
	2. FACILITIES AND INSTRUMENTATION.....	5
	2.1 Facilities	6
	2.2 Instrumentation.....	6
	3. REQUIRED TEST CONDITIONS.....	7
	4. TEST PROCEDURES	8
	4.1 Chamber Test - Ammunition and Weapons Comparison Test	8
	4.2 Chamber Test -Weapons Firing Health Hazard Assessment	13
	4.3 Chamber Test - Emission Characterization Test Programs...	18
	4.4 Tents and Shelters - Air Exchange Ventilation Tests.....	24
	4.5 Tents and Shelters - Overpressure Tests	26
	4.6 Tents and Shelters - Toxic Gas Tests	28
	4.7 Miscellaneous Test - Battery Abuse Testing.....	32
	4.8 Miscellaneous Test - Medical Air / Oxygen Generator Systems.....	33
	5. DATA REQUIRED.....	35
	6. PRESENTATION OF DATA	36
	6.1 Data Reduction	36
	6.2 Data Analysis	37
	6.3 Report	37
APPENDIX	A. COMMON CONTAINMENT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS	A-1
	B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION	B-1
	C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES	C-1
	D. EXAMPLE DATA TABLES	D-1
	E. ABBREVIATIONS.....	E-1
	F. REFERENCES	F-1
	G. APPROVAL AUTHORITY.....	G-1

1. SCOPE.

a. This Test Operations Procedure (TOP) is designed to act as a guidance document to aid in the development and conduct of tests used to determine the toxic gas/aerosol exposure hazards associated with realistic operations of military equipment. It is incumbent upon the Test Manager / Test Officer to seek out and consult with the appropriate Subject Matter Expert (SME) (i.e., chemists, physical scientist, industrial hygienists, toxicologists, the U.S. Army Public Health Center (APHC) Health Hazard Assessment (HHA) Division, etc.) to provide adequate input while developing their Detailed Test Plan (DTP) to ensure all potential toxic hazards are considered.

b. The agency/personnel performing these tests should have experience in their conduct and have developed and documented their own detailed testing procedures.

c. The emphasis of these tests are to verify compliance with Army occupational safety and health in accordance with Army Regulation (AR) 40-5^{1**} as defined in the system specific Test and/or Evaluation Plan.

d. Occupational health and safety of test personnel shall be covered by a specific job hazard analysis under the purview of the test officer and the testing agency's industrial hygiene and/or safety professionals.

e. These tests are used to collect the data used to assess the risk to military personnel exposed to concentrations of toxic substances while operating military equipment and materiel. Occupational exposure limits are specified in either the Department of Defense (DOD) Occupational Safety and Health (OSH) standards or specialized standards applicable to military unique equipment, systems, or operations. These standards include:

(1) AR 40-5, Medical Services - Preventive Medicine¹.

(2) Title 3, Executive Order 12196, Subject: Occupational Safety and Health Programs for Federal Employees².

(3) Code of Federal Regulations, Title 29, Subpart Z, Air Contaminants, Final Rule; Occupational Safety and Health Administration (OSHA), Part 1910.1000³.

(4) Department of Defense Instruction (DODI) 6055.1, Department of Defense Occupational Safety and Health Program⁴.

(5) DOD Design Criteria Standard, Military Standard (MIL-STD)-1472G Human Engineering⁵.

(6) AR 40-10, Health Hazard Assessment Program in Support of the Army Acquisition Process⁶.

** Superscript numbers correspond to Appendix F, References.

(7) Department of the Army Pamphlet (DA PAM) 40-503, The Army Industrial Hygiene Program⁷.

f. In effect, the preceding statement indicates that the published OSHA standards apply to both military and civilian personnel under DOD cognition with the exception of revisions/addenda approved by The Surgeon General of the U.S. Army (TSG) or specialized standards applicable to military unique equipment, systems, or operations such as the standards for exposure to carbon monoxide^{1,5,6}.

g. The policies and procedures specified in AR 70-25⁸ governing the use of volunteers in Department of the Army research, wherein human subjects are deliberately exposed to unusual or potentially hazardous conditions, will apply to tests involving exposure of personnel to toxic contaminants. With rare exception requiring special approval, civilian or Soldier participants in U.S. Army Test and Evaluation Command (ATEC) tests will not be used as the subjects of experimentation.

h. The criteria listed in this document are based upon 2019 published resources referenced in Appendix A. Exposure criteria should be confirmed with current standards at the time of testing.

1.1 Purpose.

a. This TOP details specific tests designed to both measure and analyze the concentrations of toxic gases and aerosols produced during operations of military equipment and materiel. The subtests listed below describe tests and procedures equipment may undergo in order to generate a Safety Confirmation prior to use by Soldiers.

b. To reinforce the need for early inclusion and participation of test personnel in the planning phase of a test program to ensure all stakeholders understand the objectives of these procedures and ensure all required data are collected.

1.2 Subtests.

a. Chamber Test - Ammunition and Weapons Comparison (paragraph 4.1).

b. Chamber Test - Weapons Firing Health Hazard Assessment (paragraph 4.2).

c. Chamber Test - Emission Characterization Test Programs (paragraph 4.3).

d. Tent and Shelter Test - Air Exchange Ventilation Tests (paragraph 4.4).

e. Tent and Shelter Test - Overpressure Tests (paragraph 4.5).

f. Tent and Shelter Test - Toxic Gas Tests (paragraph 4.6).

g. Miscellaneous Test - Battery Abuse Testing (paragraph 4.7).

h. Miscellaneous Test - Medical Air / Oxygen Generator Systems (paragraph 4.8).

1.3 Toxic Analytes Covered.

The list of toxic contaminants addressed in this document are listed in Tables 1 through 4. These compounds are some of the more common contaminants to which Soldiers and other personnel working with Army materiel may be exposed. The analytes are in no way meant to represent the only potential exposure hazards possible. Early consultation with the appropriate test personnel while preparing the DTP is critical to ensure adequate testing is performed. Appendix A summarizes the associated physiological issues, health hazards, and applicable exposure standards for each of the analytes.

TABLE 1. COMMON GASEOUS ANALYTES ENCOUNTERED DURING TESTING OF EQUIPMENT AND MATERIEL

COMPOUND NAME	CHEMICAL FORMULA	CHEMICAL ABSTRACTS SERVICE (CAS) NUMBER
Acrolein	CH ₂ CHCHO	107-02-8
Ammonia	NH ₃	7664-41-7
Carbon Dioxide	CO ₂	124-38-9
Carbon Monoxide	CO	630-08-0
Carbonyl Fluoride	COF ₂ or FCOF	353-50-4
Formaldehyde	CH ₂ O or HCHO	50-00-0
Heptafluoropropane (FM200)	CF ₃ CHF ₂ CF ₃	431-89-0
Hydrocarbons (Aliphatic C1-C4)	CH ₄ , C ₂ H ₆ , C ₃ H ₈ , C ₄ H ₁₀ , etc...	various
Hydrogen Chloride	HCl	7647-01-0
Hydrogen Cyanide	HCN	74-90-8
Hydrogen Fluoride	HF	7664-39-3
Nitric Oxide	NO	10102-43-9
Nitrogen Dioxide	NO ₂	10102-44-0
Oxygen ^a	O ₂	7782-44-7
Pentafluoroethane (FE-25)	CHF ₂ CF ₃	354-33-6
Sulfur Dioxide	SO ₂	7446-09-5
Sulfur Hexafluoride	SF ₆	2551-62-4
1,1,1,2-Tetrafluoroethane (R-134a)	CH ₂ FCF ₃	811-97-2

Note:

^a Not a toxic gas, but this analyte is measured during testing.

TABLE 2. SELECTED ELEMENTAL ANALYTES FOUND IN AIRBORNE PARTICULATE SAMPLES COLLECTED DURING TESTING OF MILITARY EQUIPMENT SYSTEMS

ELEMENT (SYMBOL)	CAS NUMBER	ELEMENT (SYMBOL)	CAS NUMBER
Aluminum (Al)	7429-90-5	Lead (Pb)	7439-92-1
Antimony (Sb)	7440-36-0	Lithium (Li)	7439-93-2
Arsenic (Ar)	7440-38-2	Manganese (Mn)	7439-96-5
Barium (Ba)	7440-39-3	Molybdenum (Mo)	7439-98-7
Cadmium (Cd)	7440-43-9	Nickel (Ni)	7440-02-0
Cobalt (Co)	7440-48-4	Strontium (Sr)	7440-24-6
Chromium (Cr)	7440-47-3	Tin (Sn)	7440-31-5
Copper (Cu)	7440-50-8	Tungsten (W)	7440-33-7
Iron (Fe)	7439-89-6	Zinc (Zn)	7440-66-6

TABLE 3. TYPES OF AIRBORNE PARTICULATE ENCOUNTERED DURING TESTING OF MILITARY MATERIEL FOR ENVIRONMENTAL REPORTING

PARTICULATE TYPES	SIZE CLASSIFICATION
Total Suspended Particulate (TSP)	$\leq \approx 50$ Microns
Inhalable (PM ₁₀ or Coarse)	2.5 – 10 Microns
Respirable (PM _{2.5} or Fine)	< 2.5 Microns

TABLE 4. TYPES OF AIRBORNE PARTICULATE SAMPLING ENCOUNTERED DURING TESTING OF MILITARY EQUIPMENT AND MATERIEL FOR PERSONNEL INHALATION REPORTING

PARTICULATE CLASSIFICATION TYPES	SIZE SELECTIVE PARTICULATE AIR SAMPLER COLLECTION EFFICIENCY SPECIFICATIONS
Total Particulates	Not Specified
Inhalable Fraction	50% cut-point for particles at an aerodynamic diameter of 100 μ m
Thoracic Fraction	50% cut-point for particles at an aerodynamic diameter of 10 μ m
Respirable Fraction	50% cut-point for particles at an aerodynamic diameter of 4 μ m

2. FACILITIES AND INSTRUMENTATION.

Some test facilities and instrumentation may be unique to specific test types and toxic gas and aerosol testing. Suitability of the specific facility and instrumentation is best guided by the consultation with SMEs (i.e., chemists and/or toxicologists, and APHC HHA Division) and documented in the DTP. Additional details pertaining to the specific subtests being performed are provided in paragraph 4.

2.1 Facilities.

The specific facilities requirements for each subtest types will be addressed in paragraph 4.

2.2 Instrumentation.

a. To the greatest extent possible, continuous direct reading instrumentation is preferred when conducting these types of tests. This instrumentation should also be capable of storing or transmitting data to be recorded for analysis purposes. Parameters such as gas concentrations, temperature, Relative Humidity (RH), and wind speed should be measured in this manner.

b. The principal considerations involved in selection of test instrumentation are: principle of operation, accuracy, measurement range, sensitivity, response time, reliability, portability, specificity, repeatability, ruggedness, size, ease of calibration, complexity of human interface, recording capability, sensitivity to shock and vibration, and cost. Many of these considerations are intertwined with one another in that if the accuracy, sensitivity, response time and reliability are acceptable, the probability is high that, with the exception of cost and insensitivity to shock and vibration, the other considerations will also be acceptable.

c. The statement above is designed to allow for some flexibility in the selection of instrumentation suitable for a specific test. However, the responsibility for selection of test instrumentation must be with an experienced SME. The SME must be knowledgeable in both the principles of operation and proper use of the equipment. Selection of the proper instrumentation is critical to ensure that the test data collected meets the program objectives and requirements. Additional general information outlining the different types of gas analyzers and sampling equipment is provided in Appendix B for reference purposes.

d. While no single instrument is ideal for all types of sampling, it is important to leverage past experience and the lessons learned to aid in selecting appropriate analytical equipment. The following subparagraphs briefly describe the three primary types of preferred/proven field instrumentation used for real time toxic gas analysis during the operation of military equipment.

(1) Fourier Transform Infrared (FTIR) Spectrometers. The ruggedized version of this type of gas analyzer has proven to be ideal for the majority of the types of tests outlined in this TOP. Using the principles of infrared spectroscopy, these instruments measure the interaction of infrared energy with the analytes in a gas sample. The primary strengths of the FTIR analyzer are its flexibility, sensitivity, and the ability to quantify multiple analytes simultaneously. The spectral data collected during testing also provides the analyst with the capability of post-test qualitative analysis to potentially identify additional unknown analytes. A more detailed description of the FTIR is provided in Appendix B.

(2) Hand-held Gas Monitors. This type of instrumentation is suitable for basic toxic gas testing where it may not be practical to use other larger analyzers (such as the FTIR). Hand-held analyzers are equipped with individual sensors, each designed to detect a specific gas. These devices are also often used in industrial hygiene situations such as confined space monitoring, personnel monitoring, and other applications where space is limited. It is

recommended that these analyzers be used in test scenarios where the potential analytes are well characterized, such as toxic gas tests where the primary concern is for accumulation of exhaust gases inside occupied structures from engines or generators. Hand-held analyzers are ideal for verifying a space is free of contamination. However, when potential hazards are detected it may be necessary to conduct additional analyses with more sophisticated equipment to fully characterize the hazards. Hand-held gas monitors are not recommended as a first choice for tests involving weapons-firing activities. The response time lag of electrochemical sensor prevents them from fully quantifying spikes in concentrations. Additional information regarding hand-held gas analyzers, and their use and limitations, is provided in Appendix B.

(3) Continuous Emission Monitors (CEMs). For the purpose of this TOP, this is a general term describing a type of gas analyzer used for the continuous measurement of a single analyte. There are numerous types of CEMs, each of which uses a specific technology that is designed to exploit unique physical and/or chemical characteristic of the analyte being measured. Each instrument type may have advantages or disadvantages based on the specific test conditions or application. Instruments should be selected on a case by case basis by considering known or potential interferences, available sampling volume, expected analyte concentration, as well as other factors that may not be listed. Additional information regarding the different types of CEM analyzers is provided in Appendix B.

e. If continuous reading analyzers are not available to measure a toxic gas or aerosol hazard at the expected concentration or necessary detection limit, then other analytical techniques that are determined acceptable and appropriate by qualified personnel must be employed.

3. REQUIRED TEST CONDITIONS.

a. Testing should be conducted in compliance with all applicable organizational safety, environmental, and security regulations.

b. Test personnel should be properly instructed/trained on the operation of the equipment and, in particular, the specific ventilation sub-systems that are the focus of these toxic hazard tests. Whenever possible, having a manufacturer's field service representative present during early stages of testing would be beneficial.

c. Gas analysis instrumentation should be either capable of recording test data (i.e., using an associated computer or internal memory) or provide an output signal proportional to the measured concentration.

d. Daily instrument calibration and sampling system checks (as applicable), using certified gas standards, must be performed prior to testing.

e. All certified gas standards used should have an associated certificate of analysis traceable to a National Institute of Standards and Technology (NIST) standard. A copy of each certificate should be retained as part of the test record.

f. When additional sampling media is required, record all pertinent information to complete any associated forms, chain-of-custody, and/or sample submission documentation required for laboratory analysis.

g. All other test equipment, as applicable, should be calibrated. All calibration records should be retained as part of the test record.

h. Environmental and/or meteorological conditions (i.e., wind speed, percent RH, and temperature) must be considered during testing as it may affect test validity. Applicable recommendations and/or restrictions for each of the specific subtests are addressed individually in paragraph 4.

4. TEST PROCEDURES.

a. As previously mentioned, it is crucial that the Test Manager / Officer seek out and consult with the appropriate subject matter experts to provide adequate input before and during the development of the DTP. This will help to ensure that the potential toxic hazards have been identified and the appropriate data are collected.

b. The procedures for each of these subtests are meant to serve as an outline for the development adequate procedures for testing military equipment and materiel. This document does assume that the test personnel performing these tests have experience in their conduct and have developed / documented their own detailed testing procedures.

4.1 Chamber Test - Ammunition and Weapons Comparison Test.

a. Weapon combustion products and aerosol chamber tests are comparison-type tests to determine differences in the emissions of small arms (up to 30 millimeter (mm)) ammunition lots.

b. The data obtained from these tests can be used to assess the effects of weapons or ammunition modifications, and/or firing rates, on the levels of combustion products and aerosol produced.

c. These tests are conducted in chambers, rather than in Armored Combat Vehicles (ACV) to provide assurance that the subtle differences in vehicle ventilation system performance, or in the test conditions themselves, do not impact the results of combustion product concentrations emitted by the small arms ammunition.

d. Several chambers may be utilized to correctly match the caliber of weapon with an appropriately sized chamber volume to produce weapon combustion products in a measureable concentration range.

4.1.1 Objective.

- a. To determine whether the test ammunition or a specific test condition provides increases in combustion emissions when compared with results obtained with the reference ammunition or test condition.
- b. Due to the small size and enclosed nature of these chambers, the concentrations of weapon combustion products are artificially inflated to increase the detection and reporting limit of measured analytes.

4.1.2 Facilities and Instrumentation.

a. Small Arms Characterization Chamber (SACC).

- (1) The SACC is an approximately 40 cubic feet (ft³) chamber that is used to test handguns, shotguns, and rifles up to .30 caliber.
- (2) For rifles and shotguns, the muzzle extends outside the chamber, therefore only breech gases are captured and measured during testing.
- (3) The chamber is modified similar to a glove box that allows magazines to be changed during testing, or manually operated weapons to be cycled between shots.
- (4) The SACC is shown in Figure 1.



Figure 1. SACC.

b. Medium Caliber Characterization Chamber (MCCC).

(1) The MCCC is an approximately 300 ft³ chamber that is used to test rifles larger than .30 caliber and mounted weapons used on military vehicles (i.e., 25 or 30 mm cannons).

(2) The weapons are attached to a mount and the entire weapon and barrel are contained inside the chamber. This chamber requires a crane to move into position after the weapon mount is positioned.

(3) The MCCC is shown in Figure 2.



Figure 2. MCCC.

c. Military Operations in Urban Terrain (MOUT) Chamber.

(1) The MOUT Chamber is approximately 640 ft³, and is used to test handguns, shotguns, and rifles up to .50 caliber.

(2) The weapons are attached to a mount and the entire weapon (including barrel) is contained inside the chamber.

(3) The MOUT Chamber is shown in Figures 3 and 4.



Figure 3. MOUT Chamber front view.



Figure 4. MOUT Chamber rear view.

d. Instrumentation.

(1) The preferred type of gas analyzer is the FTIR spectrometer, as described in paragraph 2. The FTIR used should be capable of measuring gas concentrations in the low parts per million (ppm) range.

(2) The use of a pump or dry gas meter may be necessary to collect air samples on media for analysis. The equipment should have a mechanism to adjust the flow rate and be capable of calculating the total volume sampled. The sample media will be extracted and an appropriate analytical technology will be used to assess the media content.

4.1.3 Test Conditions.

a. These tests require an enclosed chamber that captures and mixes the weapon combustion products. Because the chamber volume is constant, the relative amount of each effluent gas produced during each trial can be determined by comparing the gas concentrations following thorough mixing of the ammunition effluents. Circulating fans should be utilized to thoroughly mix the ambient air and effluent gases in a homogeneous atmosphere.

b. Since these chambers are enclosed, it has been determined that firing rates (single shots versus bursts) do not change the average concentration, but has an effect on the peak concentration. Only average concentrations are important for ammunition comparison studies.

c. The chamber should be cleaned of residual particulates prior to testing and should be dry. Weapons that were recently cleaned or lubricated should be fired prior to testing to remove any solvent or lubricant byproducts that may affect the results being compared.

d. Testing should be avoided when the ambient RH exceeds 85 percent, so that it does not artificially bias the results for analytes that are water soluble.

4.1.4 Criteria.

a. Data collected during this type of testing are for comparing between trials and informational purposes only.

b. Data will not be assessed to any health hazard criteria due to the small confined chambers utilized, which do not correspond to any realistic occupied space.

4.1.5 Data Required.

The specific data required for individual tests should be defined in the DTP. A list of some additional typical data that may be required for testing are provided in paragraph 5.

4.1.6 Test Procedures (Method).

a. The muzzle of the weapon may be located internal or external of the chamber depending on the desired results. Internal muzzle configurations result in total combustion emissions production being captured, while external muzzle configurations only capture breach gas exposure.

b. An adequate number of rounds should be fired during each trial to generate a sufficient concentration of weapon combustion products and particulates to be assessed. The desired

number of replications for each lot or condition is five. Cost or weapon availability may preclude conducting five replications. The number of replications should not be less than three.

c. After firing all rounds for a test scenario, the concentrations of weapon combustion products will be measured for a minimum of 15 minutes to permit an adequate volume to be sampled for test media and measurement of particulate concentrations at detectable levels.

d. The chamber should be adequately ventilated after each trial.

4.1.7 Data Reduction/Presentation.

a. Report all necessary data as required in the DTP. If not specified, this may include analyte peak and steady-state concentration average for each trial.

b. Tables, graphs, and the associated final report should be formatted as described in paragraph 6.

4.2. Chamber Test - Weapons Firing Health Hazard Assessment.

4.2.1 Objective.

a. To measure concentrations of weapon combustion products resulting from simulations of realistic operations of weapons systems, and to determine the degree of weapons combustion product hazard to operators and bystanders.

b. To generate data that can be assessed to specific criteria and used to generate a Safety Confirmation and a Health Hazard Assessment Report.

4.2.2 Facilities and Instrumentation.

a. The MOUT Chamber is used to generate data for all Health Hazard Assessment Reports (HHAR) with hand-held weapons and ammunition by collecting real-time concentration data for toxic combustion products and assessing to health hazard criteria.

b. The chamber simulates a realistic firing position in an urban environment and is designed to allow for wind movement and the realistic dispersal of combustion products generated from a weapon being fired indoors or in an enclosed room.

c. The chamber has a removable 2 feet (ft) x 4 ft window (1152 cubic inches) and four individually controlled room exhaust fans that can generate an inward air flow that mimics wind blowing into the structure. This inward wind condition creates a worst-case weapon combustion product situation. During this testing the fans are adjusted to create a 1 - 3 mile per hour (mph) inward wind flow through the window.

d. Instrumentation.

(1) The preferred type of gas analyzer is the FTIR spectrometer as described in paragraph 2. The FTIR used should be capable of measuring gas concentrations that can accurately measure concentrations at or below the criteria for each analyte.

(2) The use of a pump or dry gas meter may be necessary to collect air samples on media for analysis. The equipment should have a mechanism to adjust the flow rate and be capable of calculating the total volume sampled. The sample media will be extracted and an appropriate analytical technology will be used to assess the media content.

(3) Figure 5 shows the interior of the MOUT Chamber.



Figure 5. MOUT Chamber interior view.

4.2.3 Test Conditions.

a. Testing should be avoided when the ambient RH exceeds 85 percent so that it does not artificially bias the results for analytes that are water soluble.

b. The target inward wind speed measured at the window opening should be between 1-3 mph. Variable speed exhaust fans will be utilized to maintain this condition. Testing should be avoided when the wind speed or direction inhibits the recommended sustained wind conditions.

c. The chamber should be cleaned of residual particulates prior to testing and should be dry. Weapons that were recently cleaned or lubricated should be fired prior to testing to remove any solvent or lubricant byproducts that may affect the results.

d. The DTP must include minimum acceptable firing rates and the minimum number of rounds to be fired under each specific set of conditions. Firing rates provided should be realistic and reflect weapon temperature restrictions, the number of rounds carried by the system, and the tactical doctrine or training scenario. In the absence of providing a tactical (battle) or training scenario, a system specific test firing capability must be designated which is expected to meet the weapon combustion product exposure criteria.

4.2.4 Criteria.

a. The U.S. Army is concerned with the effects of combustion products exposure on personnel when firing weapons, especially from enclosed locations. The MOUT chamber was designed to simulate these situations and estimate the concentrations of combustion products that are generated from firing hand-held weapons. Data will be assessed to criteria listed below unless other specific criteria are identified in the DTP.

b. Carbon Monoxide (CO). When firing weapons in enclosed locations, CO is usually transient and at elevated concentrations. In contrast, the civilian exposure standards generally assume relatively low levels and essentially steady (i.e., small variation about the mean concentration) for long durations. To account for this difference, a military unique CO exposure standard⁹ was adopted that states: "Personnel shall not be exposed to concentrations of carbon monoxide in excess of the value which will result in Carboxyhemoglobin (COHb) levels in their blood greater than 10%". COHb levels are estimated by solving the empirical equation known as the Coburn-Forster-Kane (CFK) Equation^{10,11}. Details on the evaluation of CO exposures during weapon-firing activities are provided in Appendix C.

c. Personnel should not be exposed to concentrations of weapon combustion products in excess of the values by the American Conference of Governmental Industrial Hygienists (ACGIH)¹² and OSHA¹³. The recommended limits for the additional seven standard analytes are listed in Table 5. These represent a composite of the most stringent civilian regulations, identified as Army Occupational Exposure Limits (OEL), as defined in DA PAM 40-503⁷ and AR40-10⁶, and should be used as the assessment criteria for these types of tests. Exposure to Lead is a high concern to the military due to its presence and residue from firing ammunition. The criteria for Lead comes from the references above and specific research from OSHA (29 Code of Federal Regulations (CFR) 1910.1025¹⁴). Consult with APHC's HHA Division for the most up to date or specific additional medical criteria.

d. Terms and acronyms listed in Table 5, and throughout this document, are defined from the sources of ACGIH¹² and OSHA¹³. A Time Weighted Average (TWA) is a calculation that refers to an 8-hour average for a typical work day. A Short Term Exposure Limit (STEL) is calculated as a 15-minute average concentration. A Ceiling concentration is an upper limit made by an instantaneous monitor that should not be exceeded during any part of a workday.

TABLE 5. ARMY EXPOSURE LIMITS FOR
STANDARD WEAPONS FIRING TESTS

COMPOUND ANALYTE(S)	EXPOSURE TYPE	ARMY OCCUPATIONAL EXPOSURE LIMIT (OEL) (ppm)
Ammonia (NH ₃)	TWA STEL Ceiling	25 35 NA
Carbon Dioxide (CO ₂)	TWA STEL Ceiling	5000 30000 NA
Hydrogen Cyanide (HCN)	TWA STEL Ceiling	NA NA 4.7
Nitric Oxide (NO)	TWA STEL Ceiling	25 NA NA
Nitrogen Dioxide (NO ₂)	TWA STEL Ceiling	0.2 ^a 1 5
Sulfur Dioxide (SO ₂)	TWA STEL Ceiling	NA 0.25 ^a NA
ELEMENT ANALYTE(S)	EXPOSURE TYPE	ARMY OEL (mg/m ³)
Lead (Pb)	TWA	0.05

Note:

^a The exposure limit value cannot be reliably assessed because it is below the detectable levels obtained by the current gas analyzer technologies. The exposure limit is based solely on health factors and not technical feasibility (see Appendix A). Until suitable instrumentation can be fielded to meet these standards, consult Army Health Hazard Assessment personnel for risk assessments.

e. The civilian personnel testing these weapons and ammunition are not covered by the unique U.S. Army CO criteria. Civilian and contractor exposure while testing these systems will be regulated by workplace standards established by OSHA and listed in Table 6.

TABLE 6. CIVILIAN AND CONTRACTOR TEST PERSONNEL CO
EXPOSURE LIMITS

COMPOUND	EXPOSURE TYPE	RECOMMENDED LIMITS (ppm)
Carbon Monoxide (CO)	TWA STEL Ceiling	25 NA 200

4.2.5 Data Required.

The specific data required for individual tests should be defined in the DTP. A list of some typical data that may be required for testing are provided in below. Additional details on these items are explained in paragraph 5.

- a. Tables, graphs, and the associated final report should be formatted as described in paragraph 6.
- b. COHb calculations using the CFK Equation¹⁰ and assessments as required/specified in the DTP. Details of the weapons firing CO hazard evaluation processes are outlined in Appendix C.

4.2.6 Test Procedures (Method).

- a. The chamber should be cleaned of all particulate residue prior to testing.
- b. The muzzle of the weapon may be located inside the box or outside, depending on the desired result. Muzzles inside the chamber will assess all weapon combustion products generated by the shooter. In some specific circumstances, the objective of the test may be to assess only breech gases emitted from the weapon. In this situation, the barrel will be located outside of the box.
- c. An adequate number of rounds should be fired during each trial to generate a sufficient concentration of weapon combustion products to be evaluated. The desired number of replications for each lot or condition is five. Cost or weapon availability may preclude conducting five replications. The number of replications should not be less than three.
- d. After firing all rounds for a test scenario, the concentrations of weapon combustion products will be measured for a minimum of 15 minutes to permit an adequate volume to be sampled for test media and measurement of particulate concentrations at detectable levels. This also allows the data to be compared to STEL criteria and to be extrapolated to TWA criteria.
- e. The chamber should be adequately ventilated after each trial.

4.2.7 Data Reduction/Presentation.

- a. Report all necessary data as required in the DTP. If not specified, this may include analyte peak and steady-state concentration average for each trial.
- b. Tables, graphs, and the associated final report should be formatted as described in paragraph 6.

4.3 Chamber Test – Emission Characterization Test Programs.

a. This testing program was designed to fully assess the emission compounds produced under normal operation of the weapon or munition.

b. Extensive testing of two programs were conducted for items in the military inventory between 1998 and 2008. Limited follow-on testing has occurred since this time.

(1) The Firing Point Emission Characterization Study¹⁴ assessed toxic compounds produced from the firing of a weapon at the source. Phase I of this study investigated existing data, predictive emission and air dispersion models, and test methodologies. Phase II of this study involved the firing of test munitions to generate the required emission data.

(2) The Exploding Ordnance Emission Study¹⁵ assessed toxic compounds that are produced from the down range functioning of munitions containing explosives or other energetic fills.

4.3.1 Objectives.

a. The purpose of these projects was to identify and quantify the emissions resulting from range operations that involve weapons firing, smoke and pyrotechnic devices, and exploding ordnance.

b. To assess the environmental and health hazard impacts resulting from their use. The data gathered from this program provided information for the concentration, transport, dispersion, and fate of the emission products.

c. These programs were developed to generate emissions data that supported U.S. Army responses to regulatory (as well as) public concerns and questions directed at many training and testing issues.

d. Uses for the data included Health Hazard Assessments, Environmental Impact Statements, Environmental Assessments, Resource Conservation and Recovery Act (RCRA) Subpart X Permits, Emergency Planning and Community Right-To-Know Act (EPCRA) input, and Health Risk Assessments for surrounding communities.

4.3.2 Facilities and Instrumentation.

a. The Emission Characterization Chamber (ECC)¹⁵.

(1) A 3/8-inch thick steel cylinder with parabolic caps welded to each end. The chamber is approximately 7 feet in diameter and 15 feet long with a high-solids epoxy coating on all interior and exterior surfaces.

(2) A removable interior partition allows the test volume of the ECC to be adjusted to approximately 219, 240, or 520 ft³ depending on the physical size of the weapon to be tested and the expected quantity of emissions to be generated.

(3) This partition also permits the emissions generated from the breech of the weapon to be segregated from the emissions generated at the muzzle of the weapon.

(4) A personnel access door and remotely operated firing port door are integrated into the rear and front parabolic caps, respectively. The firing port door allows the projectile to exit the chamber and then closes maintaining the seal required for sampling and emissions characterization.

(5) A separate instrumentation and test control building is part of the facility enabling the remote control of the test instrumentation and firing of the weapon. The ECC is shown in Figure 6.



Figure 6. The ECC.

b. The Large Octagon Test Chamber (LOTC)¹⁶.

(1) An eight-sided structure with flat ends made from 1-inch thick steel plates and is designed to withstand the pressures and stress generated by detonation of ordnance mounted internally.

(2) The eight sides, hence octagon, are increased to 16 sides internally with the addition of plates welded over each seam. These plates serve to strengthen the LOTC and remove sharp interior corners that would inhibit gaseous mixing during testing.

(3) The interior wall-to-wall dimension of the LOTC is 14.5 feet. The interior floor-to-ceiling dimension is 14 feet.

(4) This structure provides an interior volume of approximately 2400 ft³ arranged to maximize gaseous mixing of ordnance emissions for accurate measurement.

(5) A measurement assembly and an instrumentation enclosure mounted on top of the chamber are not included in the floor-to-ceiling dimension. The measurement assembly is situated in the center of the chamber ceiling and is lowered into the chamber through the center of the ceiling. The LOTC is shown in Figure 7.



Figure 7. The LOTC.

c. The Blast Sphere¹⁵.

(1) The Blast Sphere was the largest facility structure used during the Exploding Ordnance Emission Study. It is a spherical structure with walls made from 2 and 3/4-inch thick steel sections welded together and was designed to withstand the pressures and stress generated by detonation of ordnance mounted internally.

(2) This structure has an interior volume of approximately 14,100 ft³ arranged to maximize gaseous mixing of ordnance emissions for accurate measurement. The interior wall diameter of the Blast Sphere is 30 feet.

(3) The Blast Sphere was engineered to withstand a 75-pound Trinitrotoluene (TNT) charge, however the ordnance charge weight was limited to 40 pounds for emissions testing.

(4) There is a 5-foot-wide equatorial walkway located along the interior wall. The Blast Sphere has two flanged viewing ports for video recording of testing, and five ports with hinged internal doors through which mixing fans and a sampling rack are inserted into the chamber.

(5) An access port connecting the Flight Tunnel to the Blast Sphere allows for the sampling rack to be deployed into the chamber. Photographic and video recordation is provided through Lexan port covers. The Blast Sphere is shown in Figure 8.



Figure 8. The Blast Sphere and flight tunnel attachment.

d. Instrumentation. A total of 265 specific analytes can be measured and reported during the Emission Characterization Program. Table 7 identifies the classes of chemical compounds to be analyzed during this testing. The instrumentation used to collect the samples are identified in the table. Specific methodologies will be utilized by the analytical laboratories to analyze the samples collected. The test instrumentation and equipment provide thermal, projectile velocity, emission products, and photographic data collection.

TABLE 7. ANALYTES AND INSTRUMENTATION

CLASS OF CHEMICAL COMPOUND	SAMPLING/ANALYTICAL INSTRUMENTATION
Permanent Gases (CO, CO ₂ , NO _x , SO ₂)	CEM
Tracer Gas, unknown gas identification	FTIR
C ₁ -C ₄ Hydrocarbons	Bag sampler / GC
Hydrogen Cyanide	Filter & Impinger / IC
Volatile Organic Compounds (VOCs)	Canister / GCMS
Toxic Metals	Filter/ ICP
Polyaromatic Hydrocarbon (PAH)	Filter & XAD cartridge / GCMS
Semi-Volatile Organic Compounds (SVOCs)	
Carbonyls/Aldehydes	DNPH Sorbent Tube / HPLC
Acid gases (HF, HCl, HNO ₃ , H ₂ SO ₄)	Sorbent Tube, IC
Dioxins/Durans	PUF Cartridge / High Resolution GCMS
Hexavalent Chromium	PVC Filter / IC
Total Suspended Particulates (TSP, PM10, PM2.5)	Filter, Gravimetric analysis
Residual Energetic Materials	Filter & XAD Cartridge, GC

GC – Gas Chromatography

IC – Ion Chromatography

GCMS – Gas Chromatography Mass Spectroscopy

ICP – Inductively Coupled Plasma

XAD – Amberlite ® XAD-2 polymeric adsorbent crosslinked polystyrene copolymer resin

DNPH – 2,4-dinitrophenylhydrazine

HPLC – High Pressure Liquid Chromatography

PUF – Polyurethane Foam

PVC – Polyvinyl Chloride

4.3.3 Test Conditions.

a. These tests are conducted in a closed chamber. A tracer gas will be utilized to assess the percentage of analytes that escapes the chambers during firing/detonation through pressure vents. Circulating fans will be used to homogeneously mix the remaining gases so that the sampling media extracts a representative sample of the atmosphere created during the test.

b. The chamber should be cleaned of residual particulates prior to testing and should be dry. Weapons that were recently cleaned or lubricated should be fired prior to testing to remove any solvent or lubricant byproducts that may affect the results being compared.

c. Testing should be avoided when the ambient RH exceeded 85 percent so that it does not artificially bias the results for analytes that are water soluble.

4.3.4 Criteria.

- a. Data collected during this type of testing is for informational purposes only.
- b. Data will not be assessed to any health hazard criteria due to the confined chambers utilized which do not correspond to any realistic occupied space.
- c. The data collected are used to calculate emission factors for each weapon and can be used to determine the amount of specific analytes deposited on U.S. Army test ranges.

4.3.5 Data Required.

The specific data required for individual tests should be defined in the DTP. A list of some additional typical data that may be required for testing are provided in paragraph 5. Additional specific analytes can be measured if modeling and simulation suggests the other compounds may be formed during testing. The composition of the munition or propellant must be known prior to testing.

4.3.6 Test Procedures (Method).

- a. The test item will be secured inside the test chamber and readied for firing/detonation.
- b. A tracer gas (Sulfur Hexafluoride (SF_6)) is released inside the chamber and the concentration monitored by FTIR. When the gas concentration reaches a steady state, the test item will be fired/detonated.
- c. After the item functions and the blast wave generated dissipates to pretest pressures, mixing fans will be deployed to create a homogeneous atmosphere.
- d. The sampling equipment will be inserted into the chamber and sampling conducted for a specific time period so that an adequate sample is collected.
- e. The chamber will remain sealed until the end of the predetermined sampling time, and then opened and vented. Media will be recovered when the chamber is cleared by safety personnel.
- f. The chamber will be cleaned prior to the next item being tested to prevent cross contamination between test items.

4.3.7 Data Reduction/Presentation.

- a. Report all necessary data as required in the DTP. If not specified, this may include analyte peak and steady-state concentration average for each trial.

b. Tables, graphs, and the associated final report should be formatted as described in paragraph 6.

4.4 Tents and Shelters - Air Exchange Ventilation Tests.

a. The U.S. Army utilizes shelters and tents to accommodate personnel and equipment and protect them from environmental elements. These structures require certain ventilation requirements and need to be evaluated prior to occupancy. A subtest that is routinely conducted to ensure the safety of personnel occupying these structures is an air exchange ventilation test.

b. The air exchange rate will be determined to provide a measurement of the amount of fresh air introduced into the test equipment. A tracer gas compound will be introduced and uniformly dispersed into the shelter. The concentration of the tracer gas is monitored as the ventilation system is then operated. This test method is based upon the "Procedure for the Concentration Decay Test Method" contained within American Society for Testing and Materials (ASTM) Method E741¹⁶, Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution.

4.4.1 Objectives.

a. To determine the rate at which fresh air enters a closed tent or occupied shelter via mechanical or natural ventilation.

b. Compute the estimated structure interior volume based upon the measured dilution of the tracer gas.

c. Use both the exchange rate and measured volume estimates to determine the fresh air flow rate for comparison to the criteria.

4.4.2 Facilities and Instrumentation.

a. Facilities. An approved area for stationary testing (pad, range) as specified in the DTP or as required.

b. Instrumentation. The preferred type of gas analyzer is the FTIR spectrometer as described in paragraph 2. The FTIR used should be capable of measuring the tracer gas concentrations in the low ppm range or lower.

4.4.3 Required Test Conditions.

The structure during the air exchange test will depend upon the design and expected operation. Specific required conditions for individual tests will be explicitly defined in the DTP. A list of the typical required conditions that may be required for testing are provided in paragraph 3.

4.4.4 Criteria.

The specific ventilation requirements should be identified in the DTP or system specification. In the absence of a system specific requirement, utilize MIL-STD-1472G⁵. This document specifies that enclosure volumes (i.e., vehicle interior crew spaces) of 150 ft³ (4.25 m³) or less per person are required to have a minimum of 30 ft³/min (0.85 m³/min) of ventilation air per person and 20 ft³/min (0.57 m³/min) of outdoor air per person. For vehicle with interior volumes greater than 150 ft³ per person, the ventilation system must achieve a minimum of six complete air changes per hour. Please note that this type of air exchange test only measures the amount of outdoor (fresh) air entering the structure and cannot be used to assess the total ventilation or air velocity requirements.

4.4.5 Data Required.

The specific data required for individual tests should be defined in the DTP. A list of some additional typical data that may be required for testing are provided in paragraph 5.

4.4.6 Test Procedures (Method).

- a. An estimate of the test item volume will be made in order to calculate the amount of tracer gas needed for testing. The nominal amount used for each test should result in a dispersed tracer gas concentration of 100-200 times the minimum reporting of the measurement instrumentation.
- b. Place mixing fans inside the test item to improve mixing and aid in quickly dispersing the tracer gas.
- c. If extractive sampling (i.e., drawing air out of the test item with a sample line) is used to deliver to the gas analyzer, ensure that the sample stream will be exhausted back into the structure to eliminate any interior air loss due to the sampling system.
- d. A known amount of tracer gas will be introduced into the test item from a certified gas standard. This information and the concentration of the steady state dispersed tracer gas will be used in interior volume estimates based upon dilution calculations, using Equation 1.

Dilution Equation: $C_1V_1 = C_2V_2$, solve for $V_2 = (C_1V_1)/C_2$ (Equation 1)

where:

- C₁** = the concentration of the tracer gas introduced to the test item.
- V₁** = the volume of the tracer gas introduced to the test item.
- C₂** = the steady state concentration of the tracer gas dispersed inside the test item.
- V₂** = the volume of the interior of the test item.

- e. Prior to the start of each test trial, the ventilation systems in the test item will be configured and the structure will be sealed.

f. The test trials will begin with the initiation of data collection by the gas analyzer. Approximately 30 seconds later the tracer gas will be released into the test item. The data collected will be monitored at the computer by the analyst.

g. The tracer gas will be monitored for enough time to collect sufficient data to calculate the resultant exponential decay equation.

h. At the conclusion of each of the trials, the test item will be opened to allow venting of any remaining tracer gas. The gas analyzer will be used to verify that all of the tracer gas is vented prior to the start of the next trial.

4.4.7 Data Reduction/Presentation.

a. The following steps to determine the air exchange rate are extracted from ASTM E741¹⁶.

b. Test data will be analyzed and plotted using a spreadsheet program, such as Microsoft Excel. The portion of the data showing a smooth decay of the tracer gas concentration will be used in the air exchange calculations.

(1) The first mathematical step will be to take the natural logarithm of the concentration values obtained from each test.

(2) Second, a linear regression analysis will be performed on the logarithmic values; the slope of the regression line equals the air exchange rate.

(3) The air exchange flow rate is calculated by multiplying the air exchange rate by the test item volume (V_2 obtained from Equation 1 in paragraph 4.4.6.d).

c. Tables, graphs, and the associated final report should be formatted as described in paragraph 6. In addition to concentration versus time, air exchange graphs should also include the regression line depicting the analysis region used to determine the air exchange rate (slope).

4.5 Tents and Shelters - Overpressure Tests.

a. The U.S. Army utilizes shelters and tents to accommodate personnel and equipment and protect them from environmental elements. These structures require certain ventilation requirements and need to be evaluated prior to occupancy. A subtest that may be required to ensure the safety of personnel occupying these structures is an overpressure test.

b. The measurement of the pressure difference between the interior and the exterior atmosphere of a test item is measured using a digital differential pressure manometer.

4.5.1 Objectives.

a. To operate a test item Nuclear, Biological, and Chemical (NBC) system and ensure that the test item maintains an overpressure and prevents the entry of exterior contaminants. The NBC system operates by filtering the incoming air to the test item and maintaining higher internal air pressure than the external pressure (positive pressure or overpressure). Contaminated external air is prevented from infiltrating the structure resulting in a contaminant-free environment for work and relief from continuous wearing of protective masks and other equipment.

b. This type of test can also be used in conjunction with an Air Exchange Test to aid in the assessment of ventilation exhaust(s) in order to achieve adequate fresh air requirements for the personnel. Utilizing air exchange and overpressure data, NBC and Heating, Ventilation and Air Conditioning (HVAC) systems can be optimized for performance.

4.5.2 Facilities and Instrumentation.

a. Facilities. An approved area for stationary testing (pad, range) as specified in the DTP or as required.

b. Instrumentation. A digital differential pressure manometer equipped with two electronic pressure sensors inputs. Differential pressure is calculated and displayed in inches of water gauge (in. H₂O, (iwg)). The manometer should meet the following minimum measurement specifications.

- (1) Range: 0 to 55.4 iwg.
- (2) Resolution: 0.01 iwg.
- (3) Accuracy: 1 percent full scale.
- (4) Ability to record or transmit measurement data.

4.5.3 Required Test Conditions.

Configure the test item as specified in the DTP.

4.5.4 Criteria.

There is currently no MIL-STD which specifies a general overpressure requirement for military structures equipped with a NBC collective protection. Refer to either the test item system specification or the DTP for guidance.

4.5.5 Data Required.

The specific data required for individual tests will be explicitly defined in the DTP. A list of the typical data that may be required for testing are provided in paragraph 5.

4.5.6 Test Procedures (Method).

- a. Place the manometer inside the test item. One of the inputs measures the interior pressure, the second is connected to tubing vented to the outside to measure the exterior atmospheric pressure.
- b. If the area where the vent tube exits the structure is normally sealed, duct tape or putty should be used around the tube to maintain the seal.
- c. Perform with test personnel inside the structure at one of the crew positions to activate the NBC system controls and operate the manometer and data acquisition system.
- d. Zero the manometer while the test item doors are open and start the data acquisition software.
- e. Close the doors/openings and operate the NBC system according to the DTP. Each configuration should be tested for a duration of approximately 15 to 30 minutes.

4.5.7 Data Reduction/Presentation.

- a. Report all necessary data as required in the DTP. If not specified, this may include the peak and steady-state pressures and the various conditions tested.
- b. Tables, graphs, and the associated final report should be formatted as described in paragraph 6.

4.6 Tents and Shelters - Toxic Gas Tests.

- a. The U.S. Army utilizes shelters and tents to accommodate personnel and equipment and protect them from environmental elements. These structures require certain ventilation requirements and need to be assessed prior to occupancy. A subtest that is routinely used to ensure the safety of personnel occupying these structures is a toxic gas investigation.
- b. These tests are usually performed in the early stages of testing, to comply with all applicable regulations governing safety and health hazard evaluations. A safety assessment of the test item will be conducted to determine: the extent of any existing toxic gas hazard, what gases may be prevalent in the structure, and the critical operational mode(s) that are most likely to produce significant concentrations of these gases. The findings of the safety assessment will determine the test instrumentation required and the operational conditions that are involved.

c. These tests are performed with hand-held gas monitors and serve as an initial screening for any potential toxic gas hazards. The five gases measured during these assessments are: Carbon Dioxide (CO₂), Carbon Monoxide (CO), Nitrogen Dioxide (NO₂), Nitric Oxide (NO), and Sulfur Dioxide (SO₂). If the inspection and/or the initial test results reveal potential issues, additional testing beyond the basic steps outlined in this subtest may be required.

d. This type of test characterizes the potential hazards from the fuel fired combustion exhaust sources, primarily from heaters or generators.

e. Other sources of toxic gases in these test items include new plastic or composite materials that may under-go an off-gassing period after construction. These materials may emit toxic gases or irritants. The types of gases will vary based on the material used and construction methods. It may be necessary to identify the odor, source of the gas, and the toxicity of the analyte.

4.6.1 Objective.

To measure concentrations of toxic gases resulting from realistic operations of military equipment to determine the toxic gas exposure hazard to personnel or occupants of the test item. Testing is conducted to assess the degree of entrainment of exhaust (or other combustion sources, i.e., fuel fired heaters) into the test item's ventilation system and/or the occupied interior compartment(s).

4.6.2 Facilities and Instrumentation.

a. Facilities. An approved area for stationary testing as specified in the DTP or as required. The area should be free of obstructions that would interfere with the natural air flow around the test item. Testing should not occur in confined or congested areas (unless requested or specified as an operational condition) that would bias the results by artificially retaining exhaust gases in the immediate vicinity of the test item.

b. Instrumentation.

(1) The preferred type of instrumentation for initial basic toxic gas testing are the hand-held analyzers as described in paragraph 2. Table 8 contains the recommended configuration and sensor specifications.

TABLE 8. RECOMMENDED HAND-HELD GAS ANALYZER CONFIGURATION

ANALYTE	SENSOR TYPE	MEASUREMENT RANGE	RESOLUTION	REPORTING LIMIT
CO	Electrochemical	0 – 500 ppm	± 1 ppm	3 ppm
CO ₂	Non-Dispersive Infrared (NDIR)	0 – 50000 ppm	± 100 ppm	500 ppm
NO	Electrochemical	0 – 250 ppm	± 1 ppm	3 ppm
NO ₂	Electrochemical	0 – 20 ppm	± 0.1 ppm	0.3 ppm
SO ₂	Electrochemical	0 – 20 ppm	± 0.1 ppm	0.3 ppm

(2) In addition to concentrations of the gases noted in the prior paragraph, instrumentation is needed to obtain ambient atmospheric data consisting of temperature, wind speed and direction, and RH.

4.6.3 Required Test Conditions.

The specific data required for individual tests will be explicitly defined in the DTP. A list of the typical data that may be required for testing are provided in paragraph 5.

4.6.4 Criteria.

a. Personnel should not be exposed to concentrations of toxic gases in excess of the values identified as the Army OEL. The OEL for the five standard analytes are listed in Table 9. These represent a composite of the most stringent civilian regulations and should be used as the assessment criteria for these types of tests.

TABLE 9. RECOMMENDED ANALYTES AND EXPOSURE LIMITS FOR
STANDARD TOXIC GAS TESTS

COMPOUND	EXPOSURE TYPE	ARMY OEL (ppm)
Carbon Monoxide (CO)	TWA	25
	STEL	NA
	Ceiling	200
Carbon Dioxide (CO ₂)	TWA	5000
	STEL	30000
	Ceiling	NA
Nitric Oxide (NO)	TWA	25
	STEL	NA
	Ceiling	NA
Nitrogen Dioxide (NO ₂)	TWA	0.2 ^a
	STEL	1
	Ceiling	5
Sulfur Dioxide (SO ₂)	TWA	NA
	STEL	0.25 ^a
	Ceiling	NA

Note:

^a The exposure limit value cannot be reliably assessed because it is below the detectable levels obtained by the current gas analyzer technologies. The exposure limit is based solely on health factors and not technical feasibility (see Appendix A). Until suitable instrumentation can be fielded to meet these standards, consult Army Health Hazard Assessment personnel for risk assessments.

b. Any additional analytes identified during the initial safety assessment and inspection will be reported and compared and their associated exposure standards.

4.6.5 Data Required.

The specific data required for individual tests should be defined in the DTP. A list of some typical data that may be required for testing are provided in below. Additional details on these items are explained in paragraph 5.

- a. Determination of the peak concentration of each toxic analyte.
- b. Determine the time-weighted average concentrations for each toxic analyte.
 - (1) Calculation of a STEL.
 - (2) Calculation of an 8-hour TWA exposure.

4.6.6 Test Procedures (Method).

a. A safety assessment of the test item will be conducted to determine: the extent of any existing toxic gas hazard, what gases may be prevalent in the structure, and the critical operational mode(s) that are most likely to produce significant concentrations of these gases. The findings of the safety assessment will determine the test instrumentation required and the operational conditions that are involved.

b. The test item configuration during toxic gas testing will depend on both the design and expected use. Appropriate scenarios should be developed and included in the DTP. In the absence of any specific scenario, measurement data as specified in paragraph 4.6.5 will be collected for time periods of not less than 30 minutes under the conditions determined during the safety assessment as follows:

- (1) Orient the test item with the prevailing wind to simulate the worst case scenario combination(s) of wind direction, test item openings, ventilation intakes, and exhaust.
- (2) Multiple trials should be performed with different ventilation system setting as appropriate.
- (3) If necessary, additional data on long-term exposures (4 to 8 hours) should be obtained if the test item will be occupied for long periods of time and toxic gas concentration show increasing trends during the initial 30-minute trials. This testing will supplement the data obtained during the 30-minute trials.

4.6.7 Data Reduction/Presentation.

Tables, graphs, and the associated final report should be formatted as described in paragraph 6.

4.7 Miscellaneous Tests - Battery Abuse Testing.

4.7.1 Objectives.

a. To determine the toxic hazards associated with various battery chemistries that may be used in conjunction with military equipment.

b. To determine the toxic hazards associated with batteries when damaged or subjected to heat that will compromise the stability of the electrical system and result in a thermal decomposition of the battery components.

4.7.2 Facilities and Instrumentation.

a. Facilities. An approved area for testing (pad, range) as specified in the DTP or as required.

b. Instrumentation.

(1) The preferred type of gas analyzer is the FTIR spectrometer as described in paragraph 2. It is suggested to use both a short and long analytical path configurations of the FTIR in order to accurately measure the concentrations of the decomposition products which may range from low ppm to percent level concentrations. Utilizing two configurations provides the best data for these tests.

(2) The use of a pump or dry gas meter may be necessary to collect air samples on media for analysis. The equipment should have a mechanism to adjust the flow rate and capable of calculating the total volume sampled. The sample media will be extracted and an appropriate analytical technology will be used to analyze the media content.

(3) Other instrumentation may be specified in the DTP based on the chemical composition of the batteries and components to measure oxygen, metals, or other potential toxic products based on previous data or model and simulation results.

4.7.3 Required Test Conditions.

The structure utilized for this type of test will depend upon the design and expected operation. Specific required conditions for individual tests will be explicitly defined in the DTP. A list of the typical required conditions that may be required for testing are provided in paragraph 3.

4.7.4 Criteria.

The criteria should be specified in the DTP. In the absence of specific criteria in the DTP, one or more of the following criteria types may be applicable. The criteria will be determined based on the appropriate scenario being tested and should be identified by the appropriate evaluation agency prior to testing.

a. Standard Army OEL criteria will be utilized. The recommended limits for the five standard analytes are listed in Table 8.

b. Any additional analytes will be identified during the analysis phase based on results obtained by the analytical instrumentation. The compounds identified should be assessed to appropriate criteria identified in Report 6357 (Field Test to Verify the Coburn-Forster-Kane Equation)¹¹ and International Standard Book Number (ISBN) 978-1-607261-05-6 (Threshold Limit Values for Chemical Substances and Physical Agents, Biological Exposure Indices)¹².

4.7.5 Data Required.

The specific data required for individual tests should be defined in the DTP. A list of some additional typical data that may be required for testing are provided in paragraph 5.

4.7.6 Test Procedures (Method).

a. Testing should be conducted in accordance with the DTP. Depending on the specific purpose of the test the procedure may be different for these types of tests. The batteries should be connected in an operational configuration and the testing should be conducted based on a logical hazard scenario (i.e., overheating or impact by projectile).

b. Battery chemistry vary greatly, and therefore, the predicted toxic gases that would be generated from testing will also vary. It is recommended to conduct a theoretical study based on the battery composition for most likely decomposition products based on stoichiometry of the battery system and chemical reactions.

c. It is recommended to conduct small scale combustion and pyrolysis reactions with available laboratory equipment (i.e., Tube Furnace, Brill Cell attachment for FTIR, and/or pyrolysis probe with GCMS) to determine actual toxic gases produced under these conditions.

d. Once the toxic analytes have been determined, research available sample collection and analysis methods to accurately measure and assess the potential threat when conducting the full scale test.

4.7.7 Data Reduction/Presentation.

a. Report all necessary data as required in the DTP. If not specified, this may include the peak and steady-state concentrations for each trial tested.

b. Tables, graphs, and the associated final report should be formatted as described in paragraph 6.

4.8 Miscellaneous Tests - Medical Air / Oxygen Generator Systems.

4.8.1 Objectives.

- a. To determine the purity of oxygen generated by military systems and determine if it is adequate for use in medical facilities.
- b. To identify impurities in the oxygen stream and determine if they prevent the oxygen from being used in medical facilities.
- c. To determine if the pressure and volume of the system meets the specification.

4.8.2 Facilities and Instrumentation.

a. Facilities. An approved area for testing (pad, range) as specified in the DTP or as required.

b. Instrumentation.

(1) The DTP should identify the required measurements needed for this type of testing. Typically, oxygen purity, concentrations of specific impurities, oxygen flow, pressure, and temperature measurements are made.

(2) The preferred type of gas analyzer is the FTIR spectrometer as described in paragraph 2. A long analytical path configurations of the FTIR is recommended in order to accurately measure the impurities in the sample stream at low ppm concentrations.

(3) A CEM as described in paragraph 2 is used for continuous oxygen measurements at high concentrations.

(4) Pressure transducers, thermocouples, and in-line flow meters are used to collect data to determine if the system is operating correctly and meets the specification requirements.

4.8.3 Required Test Conditions.

The structures utilized for this type of test will depend upon the design and expected operation. Specific required conditions for individual tests will be explicitly defined in the DTP.

4.8.4 Criteria.

The criteria should be specified in the DTP. The criteria will be determined based on the appropriate scenario being tested and should be identified by the appropriate evaluation agency prior to testing.

4.8.5 Data Required.

The specific data required for individual tests should be defined in the DTP. A list of some additional typical data that may be required for testing are provided in paragraph 5.

4.8.6 Test Procedures (Method).

The equipment should be assembled and operated as specified in the product manuals. If various environmental conditions are being assessed (i.e., extreme hot/cold operations, sand/dust, rain, etc.) the equipment should undergo a specified soak period for those conditions as determined in the DTP prior to assessment. Parameters may be checked on a continuous basis or during specific intervals as determined by the DTP.

5. DATA REQUIRED.

a. The specific data required for individual subtests should be explicitly defined in the DTP. Typical data that may be required for testing are as follows.

(1) Concentration versus time data for each gas of interest. Ensure that the recorded data includes the date and timestamp for each interval.

(2) Analyzer type(s), to include: model, serial number, calibration date, and manufacturer.

(3) Other type(s) of sampling media used, include: lot number and expiration date.

(4) Meteorological metadata, to include: ambient temperature (degrees Celsius (° C) or degrees Fahrenheit (° F)), ambient Relative Humidity (%RH), and wind speed (mph/kph).

(5) Test item identification number and any additional pertinent information.

(6) Test item configuration (i.e., window and door position(s) [open/closed], HVAC settings [on/off], etc.).

(7) Photos of test item and sampling equipment used including exterior and interior views. Document all significant details pertinent to the test, such as: locations of the generator exhaust outlet(s), ventilation air intakes, position of sample lines/media, etc.

(8) Test duration (minutes).

(9) A summary of any other significant test information and/or conditions.

b. Any additional data requirements unique for a specific subtest have been included in the appropriate sub-sections in paragraph 4.

6. PRESENTATION OF DATA.

The data obtained during the various toxic gas/fumes subtests will be reduced, analyzed and presented as is specified in the following subparagraphs or as specified in the DTP.

6.1 Data Reduction.

In most cases, the data collected from real time gas analyzers is saved in a format compatible with spreadsheet software, such as Microsoft Excel. Such software should be used, as applicable, for the analysis, summary and visualization of test data.

6.1.1 Tables.

When summarizing the test findings, tables should be used to summarize test data from each trial and may include values such as: the maximum and average measured gas concentration for each instrument/sampling position, sampling duration, applicable meteorological data, and other pertinent metadata as necessary (i.e., number of rounds fired, etc.). Representative examples of data tables for each type of subtest are provided in Appendix D.

6.1.2 Graphs.

Test data should be plotted in line graphs presenting the full concentration verse time history of each analyte measured during the test. When applicable, data from each of the sampling locations should be included on the same graph for comparison and analysis purposes.

6.1.3 Calculations.

a. Time Weighted Average. Determine the time-weighted average concentration for each gas in accordance with Equation 2.

$$TWA_c = [c_1t_1 + c_2t_2 + c_3t_3 \dots\dots\dots c_nt_n] / T \quad (Equation 2)$$

where:

TWA_c is the total equivalent analyte exposure for a single test episode of "T" (min).

"c" is the measured gas concentration (e.g., ppm) for the specific exposure time period.

"t" is an individual exposure period (min).

The subscripts represent the individual time segments (1 thru n) for each test episode.

(1) Example calculation number 1:

If the average concentration of Analyte A was determined as 75 ppm over a single 15 minute episode, then the 8-hour TWA for Analyte A would be:

$$8\text{-Hour TWA} = [75\text{ppm} * 0.25\text{hrs}] / 8\text{hrs} = 2.3\text{ppm}$$

(2) Example calculation number 2:

For multiple exposure episodes to Analyte A in a single 8-hour day. If the first episode average of 75 ppm over 15 minutes followed by second episode average of 85 ppm for 45 minutes, then the 8-hour TWA for Analyte A would be:

$$\text{8-Hour TWA} = [(75\text{ppm} * 0.25\text{hrs}) + (85\text{ppm} * 0.75\text{hrs})] / 8\text{hrs} = 10.3\text{ppm}$$

b. Predicting percent Carboxyhemoglobin (% COHb)^{9,10}. Refer to Appendix C for this calculation and an explanation of the assessment process of characterizing the CO exposure hazard during weapons firing activities.

6.2 Data Analysis.

The test data should be analyzed in terms of the safety and health hazards to the occupants in accordance with the applicable criteria/standards and as specified in the DTP.

6.3 Report.

The reduced data and analysis results should be presented in a scientific report format with the following elements or as required/specified by the DTP.

a. Introduction. A brief paragraph describing the type, purpose, testing date(s), and location of the test item. If applicable or requested, this section may be also be written in the form of an abstract or executive summary.

b. Criteria. This section should clearly state the pass/fail criteria that the test data will be assessed against, and its associated performance specification. Generally this information is taken directly from the DTP. The source of any criteria should be clearly identified/referenced.

c. Test Procedure and Item Description. This section should include details pertaining to the conduct of the test. Document the test setup and the sequence of any important pertinent steps/events performed. Reference any task specific Internal Operating Procedures (IOP) used. List all relevant data, such as instrumentation used, meteorological conditions, equipment conditions, etc. Also include any pictures of the setup.

d. Test Findings. This sections should be a logical presentation of the reduced data in the form of data tables and graphs.

e. Technical Assessment. Provide an assessment of the data and calculations presented in the test findings section against the criteria. Where appropriate, use tables to organize the data using color coding (green-pass/red-fail) to visualize compliance with the criteria. If necessary, include explanations of any deficiencies encountered during testing or highlight inconclusive data that would potentially require additional or follow-on testing.

f. References. List all cited references used in the report.

g. Appendices. These should include all quality control information, such as calibration details and certificates of analysis for gas standards. Copies of any supplemental laboratory reports should as be included here for reference.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

A.1. BACKGROUND.

a. The exposure of toxic contaminants by operators and maintainers of U.S. Army materiel systems, in addition to having the potential of affecting their health and safety, can have degrading effects upon human performance, even when health and safety issues are not involved. The surreptitious nature of the buildup of exposure levels in and around the systems underscores the need, to the fullest extent possible, for detecting, measuring, and eliminating these hazards. The critical issue that is addressed in this TOP is the potential of overexposure of Soldiers to noxious compounds/substances identified as either being hazardous to health and safety or contributing to degraded human performance. Exposures for some of these compounds are likely to be intense and above the present Army standards for occupational exposure¹⁷.

b. While exposure to emissions from ammunition propellants may be encountered by Soldiers in a variety of operational settings, the U.S. Army's concern about the potential for the deleterious effect(s) of various air pollutants has focused on those exposures found in enclosed or confined spaces. Firing weapons indoors creates a potentially toxic atmosphere and produces an environment that makes Soldiers particularly vulnerable to the adverse effects of exposure to the toxicants in question¹⁷ because of the closely confined space and the accompanying potential for poor ventilation.

c. The occupational exposure standards that have been formally adopted by the Department of the Army (DA) are documented in AR 40-5¹. The DA mandates the use of the ACGIH Threshold Limit Values (TLVs[®]) when they are more stringent than the OSHA regulations or when there is no Permissible Exposure Limits (PEL). The National Institute for Occupational Safety and Health (NIOSH)¹⁷ Recommended Exposure Limits (RELs[™]) and American Industrial Hygiene Association (AIHA[®]) Workplace Environmental Exposure Levels (WEELs[™]) are to be used when no other OEL exists or is mandated by other Army regulation or guidance. Additionally, DA endorses appropriate professional use of alternate standards when none of these OELs exist⁷.

d. The following excerpts taken from “Statement of Position Regarding the TLVs and Biological Exposure Indices (BEIs)” included in the ACGIH annual publication¹² should be considered by user of this TOP with regard to potential exposures and applicable risk assessments.

“Each year, ACGIH[®] publishes its TLVs[®] and BEIs[®] in a book. In the introduction to the book, ACGIH[®] states that the TLVs[®] and BEIs[®] are guidelines to be used by professionals trained in the practice of industrial hygiene. The TLVs[®] and BEIs[®] are not designed to be used as standards. Nevertheless, ACGIH[®] is aware that in certain instances the TLVs[®] and the BEIs[®] are used as standards by national, state, or local governments.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

“Governmental bodies establish public health standards based on statutory and legal frameworks that include definitions and criteria concerning the approach to be used in assessing and managing risk. In most instances, governmental bodies that set workplace health and safety standards are required to evaluate health effects, economic and technical feasibility, and the availability of acceptable methods to determine compliance...

“Since ACGIH® TLVs® and BEIs® are based solely on health factors, there is no consideration given to economic or technical feasibility. Regulatory agencies should not assume that it is economically or technically feasible for an industry or employer to meet TLVs® or BEIs®. Similarly, although there are usually valid methods to measure workplace exposures at the TLVs® and BEIs®, there can be instances where such reliable test methods have not yet been validated. Obviously, such a situation can create major enforcement difficulties if a TLV® or BEI® was adopted as a standard.

“ACGIH® does not believe that TLVs® and BEIs® should be adopted as standards without full compliance with applicable regulatory procedures, including an analysis of other factors necessary to make appropriate risk management decisions. However, ACGIH® does believe that regulatory bodies should consider TLVs® or BEIs® as valuable input into the risk characterization process (hazard identification, dose-response relationships, and exposure assessment). Regulatory bodies should view TLVs® and BEIs® as an expression of scientific opinion.”

e. Exposure limit values are generally categorized into three types: TWA; STEL; and ceiling (C). For most substances, the TWA alone or with a STEL is relevant. For some substances (e.g., irritant gases), only the ceiling (C) value is applicable. If any of the exposure limit types are exceeded, a potential hazard from that substance is presumed to exist.

f. Definitions.

(1) Time-Weighted Average (TWA): The exposure concentration for a conventional 8-hour workday and a 40-hour workweek.

(2) Short-Term Exposure Limit (STEL): Usually a 15-minute time-weighted average exposure that should not be exceeded at any time during a workday, even if the 8-hour TWA is within the recommended/permissible limits. Exposures up to the STEL should not be longer than 15 minutes and should not occur more than four times per day. There should be at least 60 minutes between successive exposures in this range.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

(3) Ceiling (C): The concentration that should not be exceeded during any part of the working exposure. If instantaneous measurements are not available, sampling should be conducted for the minimum period of time sufficient to detect exposures at or above the ceiling value.

(4) Immediately Dangerous to Life and Health (IDLH): This value is considered the concentration at which a worker should immediately vacate the exposure area, because serious and potentially irreversible health effects could result. Additional considerations included transient effects such as severe eye or respiratory irritation, disorientation, and incoordination that could prevent egress/escape. As a safety margin, IDLH values are based on effects that might occur as a consequence of a 30-minute exposure. However, the 30-minute period was not meant to imply that workers should stay in the work environment any longer than necessary; in fact, every effort should be made to exit immediately. Only highly reliable respiratory protection equipment tailored to address each specific toxic gas should be used in environments with these concentrations. These values are provided in the tables for reference only and will not be used to assess hazards.

f. Internet Resources. The information in this document is limited to the common analytes cited and presents the applicable 2019 exposure guidance. Links to various OSHA, NIOSH, and APHC websites are provided below.

(1) OSHA - <https://www.osha.gov/>. OSHA's annotated PELs tables include a side-by-side comparison of OSHA PELs, Cal/OSHA PELs, NIOSH RELs and ACGIH® TLVs®. The TLVs® in the annotated tables are reprinted with permission from ACGIH®.

(a) <https://www.osha.gov/dsg/annotated-pels/tablez-1.html>

(b) <https://www.osha.gov/dsg/annotated-pels/tablez-2.html>

(c) <https://www.osha.gov/dsg/annotated-pels/tablez-3.html>

(2) Centers for Disease Control (CDC) / NIOSH.

(a) <https://www.cdc.gov/niosh/index.htm> (NIOSH Website).

(b) <https://www.cdc.gov/niosh/npg/> (NIOSH Pocket Guide to Chemical Hazards¹²).

(c) <https://www.atsdr.cdc.gov/> Agency for Toxic Substances and Disease Registry (ATSDR).

(d) <https://www.atsdr.cdc.gov/substances/index.asp> (ATSDR Toxic Substance Portal).

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

(3) APHC. <https://phc.amedd.army.mil/PHC%20Resource%20Library/TG230-DeploymentEHRA-and-MEGs-2013-Revision.pdf> (Technical Guide 230¹⁸: Environmental Health Risk Assessment and Chemical Exposure Guidelines for Deployed Military Personnel).

A.2. ANALYTE HEALTH EFFECTS AND EXPOSURE SUMMARY.

A.2.1 Acrolein (2-propenal, C₃H₄O).

Acrolein is an aldehyde compound that can be produced in the combustion of hydrocarbon fuels and some plastics. This compound should be considered as a potential analyte when assessing situations where engine exhaust accumulates and/or the possibility of fire or extreme heat in the vicinity of plastics.

- a. Health Effects. Acrolein is very irritating to the mucus membrane surfaces and it causes delayed pulmonary toxicity similar to NO₂. Acrolein is also a suspected carcinogen.
- b. Standards. Use the Table A-1 when considering an occupational hazard or steady state concentrations.

TABLE A-1. COMPOSITE OF CIVILIAN ACROLEIN EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	0.1	0.1	--	NA
STEL	--	0.3	--	NA
Ceiling	--	--	0.1	0.1
IDLH	--	--	--	NA

A.2.2 Ammonia (NH₃).

Produced from the combustion of propellants and other nitrogen containing substances. Exposure of Soldiers to combustion emissions may occur during either training or battle with the various fielded weapons systems. Soldiers firing from confined spaces in training or in battle may be particularly vulnerable to exposure because of the confined space and lack of air movement inside the room; and the proximity of personnel to the emission source.

- a. Health Effects. Exposure to ammonia gas primarily affects the eyes and the respiratory tract. The irritant effects are immediate at exposure onset, primarily concentration dependent, and probably completely reversible at concentrations of 500 ppm and below, except possibly under conditions of prolonged exposure. Between concentrations of 50-100 ppm, most

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

personnel will experience moderate eye, nose and throat irritation. The degree of discomfort should normally not degrade task performance unless eye discrimination is critical. Mostly, the irritant effect from the military viewpoint is the lacrimation (tearing) that will occur in approximately 50 percent of the personnel exposed to concentrations of about 130 ppm¹⁸.

b. Standards. Use Table A-2 when considering an occupational hazard or steady state concentrations.

TABLE A-2. COMPOSITE OF CIVILIAN NH₃ EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	50	25	25	25
STEL	--	35	35	35
Ceiling	--	--	--	NA
IDLH	--	300	--	NA

A.2.3 Carbon Dioxide (CO₂).

Carbon Dioxide is one of the products of fossil fuel burning in internal combustion engines, including the diesel engine. CO₂ is considered to be a gas in that, like CO, it is colorless and odorless.

a. Health Effects. Where an unusually large exposure is involved, CO₂ can lead to unexpected suffocation. Fortunately, the hazard posed by CO₂ emissions (compared to CO) are rather minimal when either firing weapons. One must be alert to the potential of CO₂ intoxication for tents and structures that utilize a generator to produce electricity or operate an HVAC system when the structure is completely sealed and without adequate ventilation. The configuration can cause a build-up of CO₂ in the confines of the structure and levels can exceed 5-7.5 percent concentrations. It is expected that Soldier performance might degrade below acceptable limits when these high concentrations are reached.

b. Standards. Use Table A-3 when considering an occupational hazard or steady state concentrations.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

TABLE A-3. COMPOSITE OF CIVILIAN CO₂ EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	5000	5000	5000	5000
STEL	--	30000	30000	30000
Ceiling	--	--	--	NA
IDLH	--	40000	--	NA

A.2.4 Carbon Monoxide (CO).

Carbon Monoxide is particularly dangerous in that, aside from its toxicity, it is odorless, colorless, and tasteless and is not ordinarily detectable by the human senses. This gaseous compound is undoubtedly one of the most dangerous and common industrial exposure hazards. The U.S. Army is concerned with the effects of CO exposure on personnel in the field when operating items of equipment or firing weapons from enclosed spaces. Additionally, even if particular CO exposures are not categorized as safety or health hazards, such exposures can degrade human performance and adversely impact system effectiveness.

a. Health Effects. CO exposure results in impaired oxygen transport by the blood, thus resulting in hypoxia. Normally, oxygen from the lungs is carried through the body by the blood's Hemoglobin (Hb). CO has an affinity for blood Hb, which can reduce the oxygen carrying capacity of the blood to the degree that the exposed human suffocates. The affinity of CO for Hb can be as much as 300 times greater than that of oxygen. The elimination of CO is solely through the lungs and is similar, in many ways, to absorption. The rate at which CO is eliminated from the blood is an exponential and relatively slow delay, and is a function of many physiological variables. Table A-4 describes the progression of possible symptoms and health effects of increasing concentrations of CO in air.

TABLE A-4. HEALTH EFFECTS OF CO EXPOSURE

CO CONCENTRATION	EFFECTS / SYMPTOMS
< 1 ppm	Concentration in ambient (fresh) air
25 ppm	ACGIH TLV-TWA , max. concentration for a 8-hour workday
200 ppm	ACGIH TLV-Ceiling , slight headache, dizziness and nausea in 2-3 hours
1200 ppm	NIOSH - IDLH , Headache Dizziness, nausea in 20 minutes
3200 ppm	Dizziness & Headache in 5 - 10 minutes Death within an hour
6400 ppm	Irreversible Damage or Death in 10 -15 minutes
12,800 ppm	10 % LEL, Un-consciousness & Death in 1-3 minutes
128,000 ppm (12.8%)	Lower Explosive Limit (LEL), Death after 1-3 breaths

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

b. Standards.

(1) Civilian. When considering an occupational hazard or steady state concentrations, see Appendix A for details on applicable standards. See Table A-5 for reference purposes.

TABLE A-5. COMPOSITE OF CIVILIAN CO EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	50	35	25	25
STEL	--	--	--	NA
Ceiling	--	200	--	200
IDLH	--	1200	--	NA

(2) Military unique as pertaining to weapons-firing activities. MIL-STD-1472G⁶ specifies the exposure standards for CO in terms of the permissible Carboxyhemoglobin (COHb) blood levels of 5 percent COHb for personnel in aviation systems and 10 percent COHb for all other systems. The prediction of COHb blood level for individual exposures is made by a mathematical model which is a revised form of the CFK equation⁹ given in MIL-HDBK-759C⁵ and provided in Appendix C for convenience. This empirically derived equation predicts the percent COHb blood level of personnel exposed to CO through knowledge of the CO exposure level, its duration, and the work-stress level (ventilation rate) of exposed individuals. Accordingly, the equation is a useful tool for evaluating the toxic hazard associated with exposure to CO¹⁰. Some of the common symptoms associated with increasing blood COHb levels are provided in Table A-6 for reference purposes¹⁸.

TABLE A-6. COHB BLOOD LEVELS AND ASSOCIATED HEALTH EFFECTS

COHB BLOOD LEVEL	EFFECTS / SYMPTOMS
$\leq 5\%$	Mild headache
6 – 10%	Mild headache, shortness of breathing with exertion
11 – 20%	Moderate headache, shortness of breathing
21 – 30%	Worsening headache, nausea, dizziness, fatigue
31 – 40%	Severe headache, vomiting, vertigo, altered judgement
41 – 50%	Confusion, syncope (fainting/loss of consciousness), tachycardia
51 – 60%	Seizures, shock, apnea, coma
$\geq 60\%$	Death

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

A.2.5 Formaldehyde (HCHO).

Formaldehyde is the simplest molecule within the aldehyde family of chemicals. This reactive compound can be formed from any type of combustion process. Formaldehyde is a colorless gas that has a pungent, suffocating odor and its odor can be detected by humans at concentrations less than 1 ppm.

- a. Health Effects. Formaldehyde is a severe irritant to the respiratory system and mucous membranes. Exposure may be followed by cough and bronchial spasms. Exposure studies have resulted in cancer in laboratory animals; therefore, formaldehyde is considered a carcinogen.
- b. Standards. Use Table A-7 when considering an occupational hazard or steady state concentrations.

TABLE A-7. COMPOSITE OF CIVILIAN FORMALDEHYDE EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	0.75	0.016	0.1	0.016
STEL	2	--	--	NA
Ceiling	--	0.1	0.3	0.1
IDLH	--	--	--	NA

A.2.6 Hydrocarbons (C₁-C₄).

This is a general term that is intended to refer to typical light, low molecular weight, hydrocarbons such as methane, ethane, propane, acetylene, etc. These compounds are typically colorless, but may have an odor associated with them. Bottled forms of these gases many times have odor producing additives that assist in human detection.

- a. Health Effects. These gases act as simple asphyxiants without other significant physiological effects. A standard TLV is not recommended since the limiting factor is available oxygen.
- b. Standards. Most hydrocarbons are listed as simple asphyxiates with no specific standard or limitation for health effects. The LEL standard is many times used to assess safety in terms of an explosion hazard. The LEL is the limit of flammability or explosivity of a gas or vapor at ordinary ambient temperatures expressed in percent of the gas vapor in air by volume. The LEL concentration does not necessary represent a toxic gas hazard, but rather represent a concentration that could ignite or explode with an available ignition source. OSHA considers concentrations in excess of 10 percent of the LEL to be a hazardous atmosphere in confined spaces.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

A.2.7 Hydrogen (H₂).

Hydrogen is a colorless, odorless gas. Its explosive range in air is 4 - 75 percent and burns with little evidence of a flame. If a H₂/air mixture is ignited, it will often result in an explosion. Hydrogen can be produced in many metal-acid reactions, as in the case of liquid filled lead-acid batteries. Hydrogen may also be produced as a by-product emitted by other types of batteries, such as lithium ion batteries that have been damaged. Compressed hydrogen gas will heat upon expansion and may spontaneously ignite.

- a. Health Effects. The most hazardous aspect of hydrogen is its extreme flammability. In confined areas, hydrogen may also pose a hazard as a simple asphyxiant as it may displace air.
- b. Standards. Hydrogen levels should be kept below 4000 ppm (< 10 percent LEL).

A.2.8 Hydrogen Chloride (HCl).

The major source of HCl emissions for U.S. Army personnel results from the burning of plastics (particularly polyvinyl chloride). HCl is also released in enormous quantities during the firing of some rocket and missile engines. HCl is a major product when firing explosives containing chlorine. The firing of the hand-held Stinger missiles releases large amounts of HCl.

- a. Health Effects. Inhalation of HCl at irritating concentrations can result in coughing, pain, inflammation, edema, and desquamation (scaling/peeling) in the upper respiratory tract. Acute irritations can bring about larynx and bronchi constriction, and breath holding. HCl is a strong irritant that affects the conjunctiva and the mucous membranes of the respiratory tract. Because of its solubility in water, the major effects of acute exposure of the respiratory system are usually limited to the upper passages and are severe enough to encourage prompt voluntary withdrawal from a contaminated atmosphere. The area most affected on humans is the surface components of the upper respiratory tract where it is retained or deposited unless the exposure is so concentrated that it overwhelms the scrubbing capacity of the tract.
- b. Standards. Use Table A-8 when considering an occupational hazard or steady state concentrations.

TABLE A-8. COMPOSITE OF CIVILIAN HCL EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
Concentration in parts per million (ppm)				
TWA	--	--	--	NA
STEL	--	--	--	NA
Ceiling	5	5	2	2
IDLH	--	50	--	NA

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

A.2.9 Hydrogen Cyanide (HCN).

HCN is classified as an extreme poison and it can be used as a chemical warfare agent. HCN is produced in gaseous form during ammunition propellant combustion and decomposition. The gas, which has a sweet, almond-like odor is inhaled and also absorbed through the skin. Exposure to HCN can occur in ambient air around firing ranges and in armored combat vehicles. This toxic gas is considered very dangerous and can be fatal at relatively low concentrations over long durations.

a. Health Effects. HCN has a high toxicity and in sufficient concentration it rapidly leads to death. HCN is considered among the list of current chemical warfare agents used by “Third World” and “Rogue” nations. The most important toxic effect of hydrogen cyanide is inhibition of metal containing enzymes, particularly cytochrome oxidase. This enzyme is utilized for oxygen transport during cell respiration. The inhibition of this enzyme results in weakness, headache, confusion, nausea, vomiting, and increased respiration rate. The target organs include the central nervous system, cardiovascular system, thyroid, and blood.

b. Standards. Use Table A-9 when considering an occupational hazard or steady state concentrations.

TABLE A-9. COMPOSITE OF CIVILIAN HCN EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	10	--	--	NA
STEL	--	4.7	--	NA
Ceiling	--	--	4.7	4.7
IDLH	--	50	--	NA

A.2.10 Nitric Oxide (NO).

NO is a colorless gas that can be produced from the combustion of smokeless propellants associated with weapons firing activities. NO may also be present at low levels in the exhaust of internal combustion engines. Generally, NO is grouped together with NO₂ and discussed as collectively as Oxides of Nitrogen (NO_x). However unlike NO₂, NO alone does not exhibit pulmonary toxicity.

a. Health Effects. Nitric oxide inhalation causes a chemical reaction in the blood resulting in the formation of Nitrosylhemoglobin (NOHb) which is rapidly metabolized to Methemoglobin (MetHb). The toxicity of from exposure to NO is likely to have a similar

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

mechanism to CO. Carboxyhemoglobin (COHb), NOHb, and MetHb all decrease the ability of the blood to carry oxygen. NO has also been reported to cause narcosis in laboratory animals exposed to concentrations greater than 2500 ppm. By itself, nitric oxide has no irritant properties, but is oxidized in air to form NO₂. At concentrations below 25 ppm, the conversion of NO to NO₂ in ambient air is slow. However this conversion rate is dependent on the oxygen concentration and the square of the nitric oxide concentration.

b. Standards. Use Table A-10 when considering an occupational hazard or steady state concentrations.

TABLE A-10. COMPOSITE OF CIVILIAN NO EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	25	25	25	25
STEL	--	--	--	NA
Ceiling	--	--	--	NA
IDLH	--	100	--	NA

A.2.11 Nitrogen Dioxide (NO₂).

NO₂ is a colorless gas that can be produced from the combustion of smokeless propellants associated with weapons firing activities. NO₂ may also be present at low levels in the exhaust of internal combustion engines. Generally, NO₂ is grouped together with NO and discussed as collectively as Oxides of Nitrogen (NO_x).

a. Health Effects. Nitrogen dioxide is much more toxic than NO, and may cause severe irritation of the eyes, skin and respiratory tract. Short duration exposures to more than 5 ppm may result in coughing and shortness of breath. Exposures of 50-100 ppm can be severe pulmonary edema, chronic airway damage, and death.

b. Standards. Use Table A-11 when considering an occupational hazard or steady state concentrations.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

TABLE A-11. COMPOSITE OF CIVILIAN NO₂ EXPOSURE LIMITS

EXPOSURE TYPE	OSHA	NIOSH	ACGIH	RECOMMENDED EXPOSURE LIMITS
Concentration in parts per million (ppm)				
TWA	--	--	0.2	0.2 ^a
STEL	--	1	--	NA
Ceiling	5	--	--	NA
IDLH	--	13	--	NA

Note:

^a Current instrumentation is not able to measure at this concentration.

A.2.12 Oxygen (O₂).

There are several potential causes for oxygen depletion from a given atmosphere of air. Oxygen is quickly consumed by combustion reactions and oxygen can be displaced from air due to high concentrations of simple asphyxiants like carbon dioxide, methane, or nitrogen. Low oxygen concentrations can cause respiratory issues, while high concentrations of can cause explosive hazards. High oxygen concentrations in air usually require a higher oxygen concentration emission source in the area.

a. Health Effects. Some of the health effects of oxygen depletion are summarized in Table A-12.

TABLE A-12. HEALTH EFFECTS OF OXYGEN DEPLETION

PERCENT O ₂ IN AIR	SYMPTOMS
at 19.5	Respiration volume increases, muscular coordination diminishes, attention and clear-thinking require more effort.
at 19.5 to 12	Shortness of breath, headache, dizziness, quickened pulse, efforts fatigue quickly, muscular coordination for skilled movements lost.
at 12 to 10	Nausea and vomiting, exertion impossible, paralysis of motion
at 10 to 6	Collapse and unconsciousness occurs
at 6 or below	Death in 6 to 8 minutes

b. Standards. Air normally contains 20.9 percent oxygen. The general target concentration for oxygen is between 19.5 and 23.5 percent in air. Concentrations above 23.5 percent can represent an explosion hazard. Concentrations below 19.5 percent can cause detrimental health effects. Oxygen levels lower than 12 percent are considered extremely dangerous and testing should be aborted unless personnel are supplied bottled air.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

A.2.13 Sulfur Dioxide (SO₂).

Sulfur Dioxide is a pungent, irritating gas that is produced by the combustion of elemental sulfur or compounds containing sulfur.

a. **Health Effects.** Human exposure to concentrations of 1-50 ppm for 5-15 minutes may cause irritation of the eyes, nose, and throat. Additional physical effects may include: nasal discharge, choking, coughing, and reflex constriction of the airways¹⁸. Approximately 10-20 percent of the healthy young adult population is estimated to be hypersensitive to the effects of SO₂.

b. **Standards.** Use Table A-13 when considering an occupational hazard or steady state concentrations.

TABLE A-13. COMPOSITE OF CIVILIAN SO₂ EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
Concentration in parts per million (ppm)				
TWA	5	2	--	NA
STEL	--	5	0.25	0.25 ^a
Ceiling	--	--	--	--
IDLH	--	100	--	NA

Note:

^a Current instrumentation is not able to measure at this concentration.

A.2.14 Sulfur Hexafluoride (SF₆).

Sulfur Hexafluoride is a colorless, odorless, non-toxic, and general considered an inert gas. SF₆ is commonly used as a dielectric gas in high voltage electrical components and switches. SF₆ is also widely used as a tracer gas for short-term experiments of ventilation efficiency in buildings and indoor enclosures, and for determining infiltration rates. Two major factors recommend its use: its concentration can be measured with satisfactory accuracy at very low concentrations, and the Earth's atmosphere has a negligible concentration of SF₆.

a. **Health Effects.** SF₆ is non-toxic and is generally classified as a simple asphyxiant.

b. **Standards.** The Army OEL for SF₆ is 1000 ppm.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

A.2.15 Particulate Matter (PM) / Aerosols.

For the purposes of this document this term will refer to the microscopic particles and or droplets suspended in the air. The ACGIH believes that even biologically inert, insoluble, or poorly soluble particles may have adverse effects.

a. Nuisance dusts, Particulates Not Otherwise Regulated / Specified (PNOR / PNOS) are general terms relating to particles meeting the following criteria.

- (1) Do not have an established regulatory limit or applicable TLV.
- (2) Are insoluble or poorly soluble in water.
- (3) Have low toxicity (i.e., are not chemically reactive, and do not emit ionizing radiation, cause immune sensitization, or cause toxic effects other than by inflammation or the mechanism of “lung overload”).

b. Additionally, the particle size is also important in the characterization of these potential effects as it used to determine where deposition in the respiratory track occurs. Generally, the consensus is that relative toxicity increases the deeper into the respiratory track that particles are able to penetrate. Therefore the smaller the particles tend present a greater health hazard. Figure A-1 presents a graphical depiction and brief description of the particle size categories defined by ACGIH. Additional information regarding these definitions is provided below.

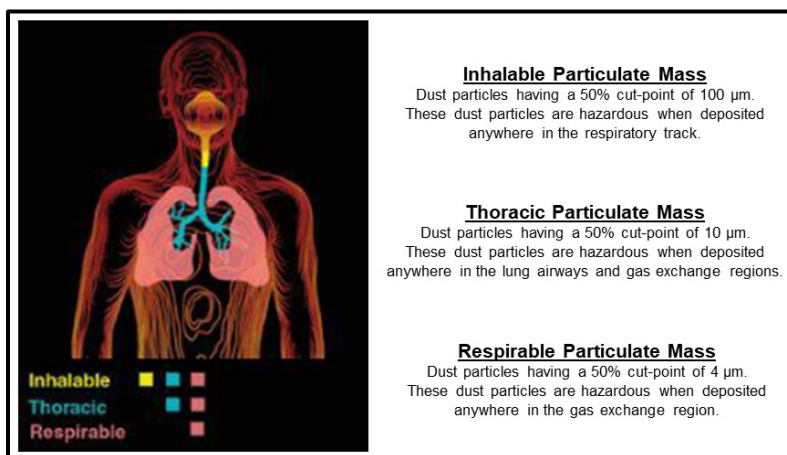


Figure A-1. Particle size classification (ACGIH).

- (1) The term “total” is straight forward, it represents the collection of all airborne particulate with no size differentiation.

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

(2) Inhalable particulates generally refer to those particles small enough to remain aloft to be inhaled through the nose and mouth. Generally speaking the particles are characterized as having a mean aerodynamic diameter of 100 microns (μm) or less. Normally it is expected that most of the particles greater than 10 μm in size should be scrubbed out of the inspired air by the moisture and mucus in ciliated airways of the upper respiratory tract. Under stressful conditions, some of these larger particles will penetrate deeper, especially if the individual is mouth-breathing. It is important to remember that inhalable particulates includes the thoracic and respirable fraction.

(3) The thoracic fraction of inhaled particulate matter are those particles small enough to readily penetrate beyond the larynx. Generally particles in this subset are 10 μm in size and smaller and may be deposited in the lung airway (bronchi) and in the gas-exchange (alveoli) region.

(4) The respirable fraction are those particulates which are small enough to penetrate deep into the lung to the unciliated airway in the gas-exchange (alveoli) region. These are a further subset of fine particles which have a mean aerodynamic diameter of 4 μm or smaller (ACGIH). As a point of clarification, NIOSH defines respirable particulate matter as particles which have a mean aerodynamic diameter of 2.5 μm .

c. Standards. The recommended airborne concentrations for nuisance dust (PNOR / PNOS) is provided in Table A-14.

TABLE A-14. RECOMMENDED NUISANCE DUST / PNOR / PNOS
CONCENTRATION LIMITS

PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
Concentration in milligram per cubic meter (mg/m^3)				
Total	15	--	--	15
Inhalable	--	--	10	10
Thoracic	NA	NA	--	NA
Respirable	5	--	3	3

A.2.16 Lead (Pb): Aerosol/Particulates.

Lead is found naturally in the Earth's crust, and in the atmosphere and hydrosphere. It has been used for thousands of years because of its availability and desirable properties. Ammunition (shells, projectiles, etc.) have been made of alloys of lead ever since ammunition has been in existence. Also, it is used as a decoppering agent to remove rotating band deposits from the bores of weapons. In the earliest days of its use, lead was recognized as a health hazard, both as an elemental metal and bonded in compound form. Lead can enter the body by inhalation or ingestion. Absorption of excessive amounts of lead causes diseases of the kidneys and of the

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

peripheral and central nervous systems. The potential of occupational exposure to lead and its compounds occurs in over 100 industrial occupations in addition to exposures of military personnel during the firing of weapons. The source for most if not all of the airborne lead causing the exposure hazard to Soldiers during weapons-firing activities comes from the chemical lead styphnate (lead 2,4,6-trinitroresorcinate). Lead styphnate is currently used as a primary explosive mainly in the primers for small arms ammunition.

a. **Health Effects.** The adverse effects associated with exposure to lead range from acute to relatively mild. Reversible stages include inhibition of enzyme activity, reduction in motor-nerve conduction velocity, behavioral changes, and mild central nervous system symptoms. Irreversible damage causes chronic disease and death. The symptoms of severe lead intoxication include loss of appetite, metallic taste, constipation, nausea, pallor, excessive tiredness, weakness, insomnia, headache, nervous irritability, muscle and joint pains, fine tremors, numbness, dizziness, hyperactivity, and colic¹³. Lead can cause severe central nervous system development inhibition in children or pregnant Soldiers. Lead is also considered a carcinogen.

b. **Standards.** The current civilian criteria for assessing exposure to lead (metal and inorganic compounds) are provided in Table A-15. These standards are designed to ensure that no employee is exposed to lead at concentrations greater than fifty micrograms per cubic meter of air averaged over an 8-hour period. If an employee is exposed to lead for more than 8 hours in any work day, the permissible exposure limit, as a TWA for that day, should be reduced according to Equation A-1. The Army is in the process of updating this standard.

TABLE A-15. COMPOSITE OF CIVILIAN AIRBORNE LEAD EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL ^a
	Concentration in milligram per cubic meter (mg/m ³)			
TWA	0.05	0.05	0.05	0.05
STEL	--	--	--	--
Ceiling	--	--	--	--
IDLH	--	100	--	NA

Note:

^a DOD is in the process of setting a lower OEL for lead.

Maximum permissible limit (in micrograms/m³) = 400 divided by hours worked in the day (*Equation A-1*)

A.2.17 Selected Additional Elements (Metals Analysis of Particulate Air Samples).

a. Historically, the primary metal element that receives the most focus has been Lead (Pb). However, the U.S. Army recognizes the health hazards of lead and is researching suitable replacements for both the lead in bullet projectiles and in the percussion primers (i.e., “green”

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND APPLICABLE EXPOSURE STANDARDS.

bullets and primers). As these formulations continue to be developed, the primary focus is of course to be less toxic than lead. However, less toxic doesn't imply safe, therefore inclusion of additional information and exposure standards for these elements (metals) is practical.

b. In the past, sampling for many of the metals was performed as total particulate using a standard filter cassette. Current exposure guidance for a number of substances included below now express particle size selective limits. This trend is in recognition that the potential hazard depends on the particle size as well as the mass concentration because of 1) effects of the different deposition site within the respiratory tract for different particle sizes, and 2) the tendency for many occupational diseases to be associated with material deposited in particular regions of the respiratory tract. The Particle Size-Selective TLVs are expressed using one of the following notations next to mass concentration limit for the substance: **I** (the inhalable fraction), **T** (the thoracic fraction), or **R** (the respirable fraction) of the aerosol.

c. Tables A-16 through A-30 provide exposure information regarding selected elements commonly encountered during military test activities. Although these elements are not considered to be part of the normal analyte group, they are routinely requested to be measured. Values in the tables are TWA unless otherwise noted.

(1) Aluminum (Al).

TABLE A-16. COMPOSITE OF CIVILIAN AL EXPOSURE LIMITS

ALUMINUM	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Metal and insoluble compounds	Total	15	10	--	10
	Respirable	5	5	1	1
Pyro powders and welding fumes	Total	--	5	--	5

(2) Antimony (Sb).

TABLE A-17. COMPOSITE OF CIVILIAN SB EXPOSURE LIMITS

ANTIMONY	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Sb and compounds	Total	0.5	0.5	0.5	0.5

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

(3) Arsenic (Ar). Potential carcinogen.

TABLE A-18. COMPOSITE OF CIVILIAN AR EXPOSURE LIMITS

ARSENIC	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Ar and inorganic compounds, except Arsine	Total	0.01 ^a 0.5 ^b	0.002 (C)	0.01	0.02 (C)

Notes:

^a for inorganic compounds.

^b for organic compounds.

(4) Barium (Ba).

TABLE A-19. COMPOSITE OF CIVILIAN BA EXPOSURE LIMITS

BARIUM	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Ba and soluble compounds	Total	0.5	0.5	0.5	0.5

(5) Cadmium (Cd). Potential carcinogen.

TABLE A-20. COMPOSITE OF CIVILIAN CD EXPOSURE LIMITS

CADMIUM	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Cd and compounds	Total	0.005	--	0.01	0.005
	Respirable	--	--	0.002	0.002

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

(6) Chromium (Cr).

TABLE A-21. COMPOSITE OF CIVILIAN CR EXPOSURE LIMITS

CHROMIUM	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Metal	Total	1	0.5	--	0.5
	Inhalable	--	--	0.5	0.5
Cr ^{III} inorganic compounds	Total	0.5	0.5	0.5	0.5
	Inhalable	--	--	0.003	0.003
Cr ^{VI} inorganic compounds, soluble and insoluble	Total	0.005	0.0002	--	0.0002
	Inhalable	--	--	0.0002 ^a 0.0005 ^b	0.0002 ^a 0.0005 ^b

Note:

ACGIH cites both a TWA value (^a) and STEL value (^b).

(7) Cobalt (Co).

TABLE A-22. COMPOSITE OF CIVILIAN CO EXPOSURE LIMITS

COBALT	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Co and inorganic compounds	Total	0.1 ^a	0.05 ^a	--	0.05
	Inhalable	--	--	0.02	0.02
Hard metals containing Co and Tungsten carbide	Thoracic	--	--	0.005	0.005

Note:

^a for metal dust and fume.

(8) Copper (Cu).

TABLE A-23. COMPOSITE OF CIVILIAN CU EXPOSURE LIMITS

COPPER	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Cu Dusts and mist	Total	1	1	1	1
Cu Fume		0.1	0.1	0.2	0.1

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

(9) Iron (Fe).

TABLE A-24. COMPOSITE OF CIVILIAN FE EXPOSURE LIMITS

IRON	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Iron Oxide (Fe ₂ O ₃)	Total	10 ^a	5 ^a	--	5
	Respirable	--	--	5	5

Note:

^a for metal dust and fume

(10) Manganese (Mn).

TABLE A-25. COMPOSITE OF CIVILIAN MN EXPOSURE LIMITS

MANGANESE	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Mn and inorganic compounds including Mn fume	Total	5 (C)	1 ^a 3 ^b	--	1 ^a 3 ^b
	Inhalable	--	--	0.1	0.1
	Respirable	--	--	0.02	0.02

Notes:

^a OSHA cites only a ceiling value.

^b NIOSH cites both a TWA value (^a) and STEL value (^b).

(11) Molybdenum (Mo).

TABLE A-26. COMPOSITE OF CIVILIAN MO EXPOSURE LIMITS

MOLYBDENUM	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Mo and insoluble compounds	Total	15 ^a	--	--	15
	Inhalable	--	--	10	10
	Respirable	--	--	3	3
Mo and soluble compounds	Total	5	--	--	5
	Respirable	--	--	0.5	0.5

Note:

^a Total dust

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

(12) Nickel (Ni) (potential carcinogen).

TABLE A-27. COMPOSITE OF CIVILIAN NI EXPOSURE LIMITS

NICKEL	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Ni, elemental	Total	1	0.015	--	0.015
	Inhalable	--	--	1.5	1.5
Ni, insoluble compounds	Total	1	0.015	--	0.015
	Inhalable	--	--	0.2	0.2
Ni, soluble compounds	Total	1	0.015	--	0.015
	Inhalable	--	--	0.1	0.1

(13) Tin (Sn).

TABLE A-28. COMPOSITE OF CIVILIAN SN EXPOSURE LIMITS

TIN	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Sn as metal, oxides, and inorganic compounds	Total	2	2	2 ^a	2
	Inhalable			2	2

Note:

^a The ACGIH value cited is for Sn metal only.

(14) Tungsten (W).

TABLE A-29. COMPOSITE OF CIVILIAN W EXPOSURE LIMITS

TUNGSTEN	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
W and compounds in the absence of Co	Total	--	--	--	--
	Respirable	--	--	3	3
W and insoluble compounds	Total	--	5 ^a 10 ^b	--	5 ^a 10 ^b
	Respirable	--	--	3	3
W and soluble compounds	Total	--	1 ^a 3 ^b	--	1 ^a 3 ^b
	Respirable	--	--	3	3

APPENDIX A. COMMON CONTAMINANT / ANALYTE SUMMARY AND
APPLICABLE EXPOSURE STANDARDS.

Note:

NIOSH and ACGIH cite both a TWA value (^a) and STEL value (^b).

(15) Zinc (Zn).

TABLE A-30. COMPOSITE OF CIVILIAN ZN EXPOSURE LIMITS

ZINC	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m ³)			
Zinc Chloride, fume	Total	1	1 ^a 2 ^b	1 ^a 2 ^b	1 ^a 2 ^b
Zinc Oxide	Total	15	5 15 ^c		5
	Respirable	5		2 ^a 10 ^b	2 ^a 10 ^b
Zinc Oxide, fume	Total	5	5 ^a 10 ^b		5 ^a 10 ^b

Note:

NIOSH and ACGIH cite both a TWA value (^a) and STEL value (^b).

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

B.1. INTRODUCTION.

This Appendix is prepared to provide the toxic gas and aerosol tester and/or test planner with a central depository for specifying test instrumentation and sampling requirements for making exposure measurements relating to the different types of gaseous compounds discussed in this document. Detailed information regarding laboratory instrumentation that may be required is beyond the scope of this appendix. Although some data governing instrumentation requirements are presented in the main body of this document, additional instrumentation specifications are presented here which may be of use to the planner, tester, and/or evaluator. Please note, this information is provided to convey the general capabilities of the instrumentation/equipment, it is not intended to instruct the user of this document in the proper use of the equipment.

B.2. MEASUREMENT METHODS.

There are several methods used to measure concentrations of gases, vapors, mists, dusts, etc. in the atmosphere. There are two basic categories of equipment used in toxic gas testing, these are: continuous reading (or real-time) instruments, and discrete sampling equipment.

B.2.1 Continuous Reading / Real-Time Instrumentation.

Whenever possible this is the preferred methodology for toxic gas testing as it typically provides the tester with concentration data continuously over the duration of a test event. This is extremely beneficial in characterizing transient hazardous exposures. The three most commonly utilized analyzer types are briefly describe in the following paragraphs.

a. FTIR spectrometer.

(1) FTIR can be used to determine concentrations of several gases simultaneously provided that the molecule of interest has a dipole moment (of inertia). Homonuclear diatomic molecules such as N₂, O₂, and Cl₂ do not have a dipole moment and cannot be detected by FTIR. FTIR operates on the principal of Beer's Law (Equation B-1) which shows a logarithmic relationship between absorbed light and gas concentration.

$$\text{Beer's Law Equation: Absorbance} = \log(I_0/I) = \epsilon bc, \quad (\text{Equation B-1})$$

(2) Where I₀ is the intensity of the incident radiation, I is the intensity after sample absorption, ϵ is the extinction coefficient (fundamental property of each gas), b is the absorption pathlength, and c is concentration. In practice, absorbance is measured at various wavelengths to get a plot of absorbance versus frequency. The pathlength is varied to change instrument sensitivity. These optical pathlengths can produce a detection range that varies from several parts per billion (ppb) to percent levels depending on the chemical properties of particular gas. Measuring absorptions at several gas concentrations forms a calibration curve. Sample

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

spectra are compared to calibration spectra in order to determine gas concentrations. Sometimes gases can be detected by this technique, but spectral interferences elevate detection limits beyond practical use. NO₂ provides a good example, because its prime absorption overlaps with water vapor. Other gases, such as H₂S, are very poor absorbers of infrared radiation, and therefore cannot be adequately analyzed via this technique. Each particular scenario should be reviewed by a trained analyst to determine if FTIR is a viable technique. FTIR has been successfully used to measure CO, CO₂, HCl, HCN, SF₆, NH₃, CH₄, NO, NO₂, H₂O, and SO₂. The recommended FTIR gas analyzer configuration is shown in Table B-1.

TABLE B-1. RECOMMENDED BASIC FTIR GAS ANALYZER CONFIGURATION

CONFIGURATION TYPE	PARAMETER	SETTING
Hardware	Optical Material(s)	Non-hygroscopic (i.e. ZnSe)
	Detector Type	Cooled Mercury-Cadmium-Telluride (MCT) (77° Kelvin (° K) or -196° C)
	Optical Pathlength of Gas Cell	15 centimeters ^a / 10 meters ^b
	Temperature of Gas Cell	121° C
	Pressure of Gas Cell	~ 1 atm ^c
Software	Instrument Optical Resolution	0.5 cm ⁻¹
	Spectral Range	650 – 4500 cm ⁻¹
	Apodization Function	Triangular
	Phase Correction	Mertz
	Zero Filling Factor	1x

Notes:

^a Short path gas cell used for measuring high concentrations (i.e. live fire, fire suppression tests).

^b Long path gas cell used for measuring low concentrations (i.e. tracer gas, unknown irritants).

^c Pressure in the gas cell will vary depending on configuration of sampling system and flow rate.

(3) Excellent reference methods for the use of extractive FTIR sampling include:

(a) NIOSH Method 3800¹⁹, Organic and Inorganic Gases by Extractive FTIR Spectrometry, <https://www.cdc.gov/niosh/docs/2014-151/pdfs/methods/3800.pdf>.

(b) EPA Test Method 320²⁰, Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR) Spectroscopy, https://www.epa.gov/sites/production/files/2017-08/documents/method_320.pdf.

(c) ASTM Method D6348²¹, Standard Test Method for the Determination of Gaseous Compounds by Extractive Direct Interface Fourier Transform Infrared (FTIR) Spectroscopy

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

b. Hand-held toxic gas analyzers. Hand-held gas analyzers are convenient to use for mobile systems where it is not practical to use CEMs. These analyzers are also used for confined space monitoring, personnel monitoring, or other applications where space is limited and extractive sampling is impractical. Hand-held analyzers can be used to quantitatively analyze for CO, CO₂, H₂S, SO₂, H₂, NO₂, HCN, O₂, and combustible gases, as well as other gases that may not be listed. These analyzers typically utilize the following techniques to measure gas concentrations:

(1) Catalytic devices measure the heat produced by chemical reactions on catalytic surfaces or in granular catalytic beds.

(2) Semiconductor sensors utilize an electrical-resistance change of the semiconductor material when the gas of interest is absorbed on its surface.

(3) Electrochemical devices provide for an electrical phenomenon when the gas sample comes in contact with the chemical sensor.

c. Continuous-emissions monitors (CEM) gas analyzers. There are several different types of CEMs that quantitatively react to target gas concentrations by a variety of mechanisms. Some compounds can be detected by more than one type of instrument. Each instrument type may have advantages or disadvantages based on the specific test conditions or application. Instruments should be selected on a case by case basis by considering known or potential interferences in the test, available sampling volume, expected analyte concentration, as well as other factors that may not be listed. Several common types of CEMs are discussed below:

(1) Spectrophotometric devices measure the amount of light energy absorbed in a gas sample. These devices can be divided into two subcategories of non-dispersive spectrometers and gas correlation filters. The following gases can be measured by this technique: CO, CO₂, NO, NO₂, NH₃, SO₂, CH₄, as well as others that may not be listed.

(2) Paramagnetic devices utilize the magnetic properties of molecules to physically deflect a positioning device in a magnetic field. The amount of deflection is proportional to the concentration of the gas of interest. A restoring force is applied to the positioning device to bring it to the null deflection position. The restoring force is usually a current that is applied to a coil that surrounds the positioning device. The restoring force is generally converted to an output voltage. Atmospheric concentrations of oxygen can be measured by this technique.

(3) Chemiluminescence utilizes chemical reactions that result in the production of light. For NO, the reaction involves $\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 + h\nu$ (light). The amount of emitted light is proportional to the NO concentration in the sample stream. The interference problems for this analysis revolve around the conversion of nitrogen species to NO. Various converters can be used to convert NO₂ and NH₃ to NO. Bypassing the converter gives NO concentration, while a molybdenum converter gives combined NO and NO₂ (NO_x) concentration, and a

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

stainless steel converter is used to get NO, NO₂, and NH₃. Using a combination of these converters and bypasses can accurately produce simultaneous NO, NO₂, NO_x, and NH₃ results.

(4) Pulsed fluorescence also utilizes the production of light; however, this process does not involve any chemical reactions. By definition, fluorescence implies that light is emitted after excitation by radiant sources of energy. In this case, $\text{SO}_2 + h\nu_1 \rightarrow \text{SO}_2^* \rightarrow \text{SO}_2 + h\nu_2$, where $h\nu_1$ is pulsed ultraviolet light, SO_2^* is an electronically excited molecule, and $h\nu_2$ is the emitted light. The amount of emitted light is proportional to the SO₂ concentration in the sample stream.

(5) Laser based absorbance analyzers are becoming more common due to their increased sensitivity and specificity. Careful laser wavelength selection allows the analyzer to measure a very narrow spectral absorbance line of the analyte of interest.

B.2.2 Discrete / Grab Sample Collection Equipment and Media.

a. Occupational health analytical resources are provided below.

(1) <https://www.osha.gov/dts/sltc/methods/toc.html> - OSHA Analytical Methods.

(2) <https://www.cdc.gov/niosh/nmam/default.html> - NIOSH Manual of Analytical Methods (NMAM) 5th Edition.

b. Sorbent tubes with laboratory analysis. Air is drawn through a tube that contains media that selectively adsorbs particular analytes. Sorbent tubes generally adsorb gaseous material and they are sometimes used in conjunction with filters, which trap particulate matter. The sorbent media varies depending on the analytes of interest. There are several manufacturers and suppliers of sorbent tubes and the suppliers of these materials generally provide guides to aid in the selection of the correct media. Sorbent tubes are processed in the laboratory to extract or desorb the analyte of interest for quantification. Based on the amount of analyte determined by the laboratory analysis and the volume of air drawn through the sorbent tube, one can calculate the amount of analyte per unit volume of air. One must be careful to follow all instructions for media preparation, holding times, volume limitations, concentration limitations, flow rate limitations that are prescribed by the method being used for collection and analysis. The elements of a typical sorbent tube is shown in Figure B-1.

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

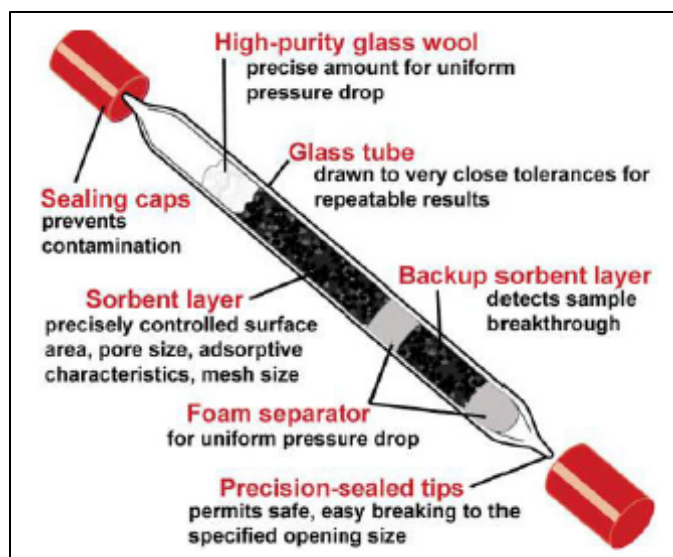


Figure B-1. Elements of a typical sorbent tube.

c. Colorimetric detector tubes. Similar to a traditional sorbent tube, detector tubes are designed to be read in the field immediately after sampling. The elements of a typical colorimetric detector tube is shown in Figure B-2.

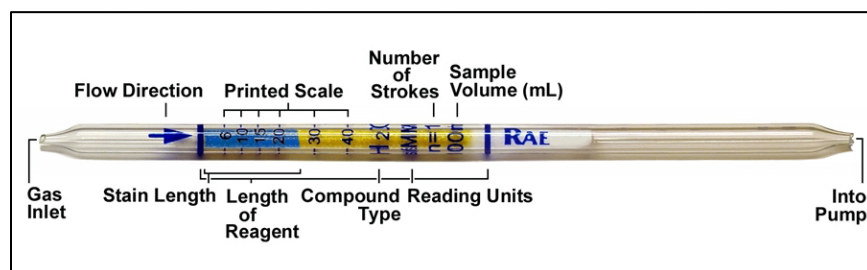


Figure B-2. Colorimetric detector tube.

d. Whole air sampling with laboratory analysis. Whole air samples can be drawn from field locations and brought back to the laboratory for later analysis. These samples can be placed in evacuated canisters and/or bags. Canisters must be selected to specifically meet the sampling and analysis requirements for each particular analyte to be measured. Evacuated canisters can gather air in an active or passive mode. During passive sampling a flow control orifice is opened and air is allowed to enter the canister at a controlled rate. In active sampling, air is directly pumped into the canister. Bag samples are collected in special air tight boxes where an evacuated bag is placed in the box and air is extracted from the box. Tubing is run from a sampling

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

location to a bulkhead fitting (box pass through) and connected to the bag input valve. When a vacuum is created in the box, air flows from the sampling location into the bag. The type of laboratory analysis depends on the analyte of interest. Whole air sampler examples are shown in Figure B-3.



Figure B-3. Whole air sampler examples.

e. Filters and gravimetric-type collectors. These devices collect dust and particulates in a filter medium by drawing the contaminated air with a pump of known flow rate. The collected matter is then weighed which provides one with a known amount of particulate contamination (mg/m^3). Collection devices can be used to segregate the size of particulate matter. An eight stage cascade impactor can be used to speciate the sizes of particulate into eight individual stages which can be measured and analyzed individually. Particulate matter that is 10 microns or less is considered inhalable, while 2.5 microns or less is respirable. The size of the particulate will ultimately affect the body's response to inhalation. Figure B-4 shows filter/particle size selective sampler examples.

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

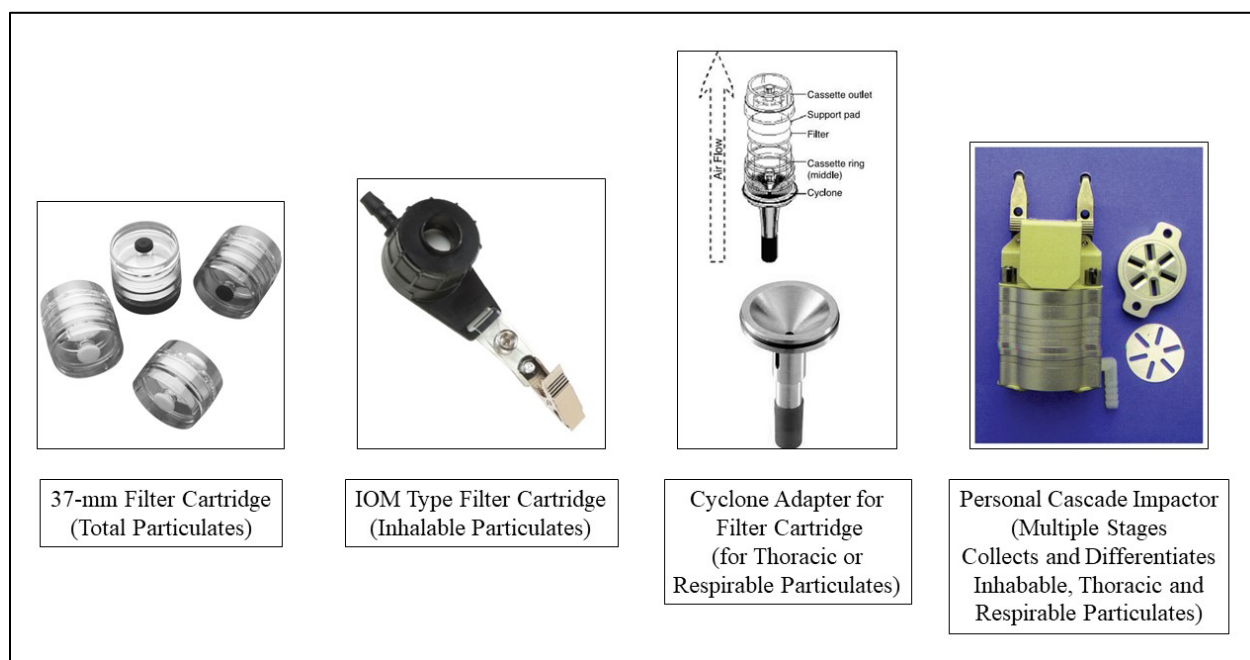


Figure B-4. Filter/particle size selective sampler examples.

(This page is intentionally blank.)

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

C.1. BACKGROUND.

a. As in the industrial environment, the U.S. Army is particularly concerned with exposure to carbon monoxide and its potential for affecting personnel health and safety. The Army also recognized that Soldiers exposed to CO may experience a degradation in the performance of mission tasks requiring cognitive function, physical exertion and/or visual acuity. In the civilian and industrial communities, exposure to CO is generally at relatively low concentrations and essentially steady state (i.e., small variation about the mean concentration). Whereas military CO exposures during weapons firing scenarios are usually transient and can, in certain cases, be at high concentrations. The graph presented in Figure C-1 illustrates an example of the CO concentration versus time graph of data collected during a weapons firing test event.

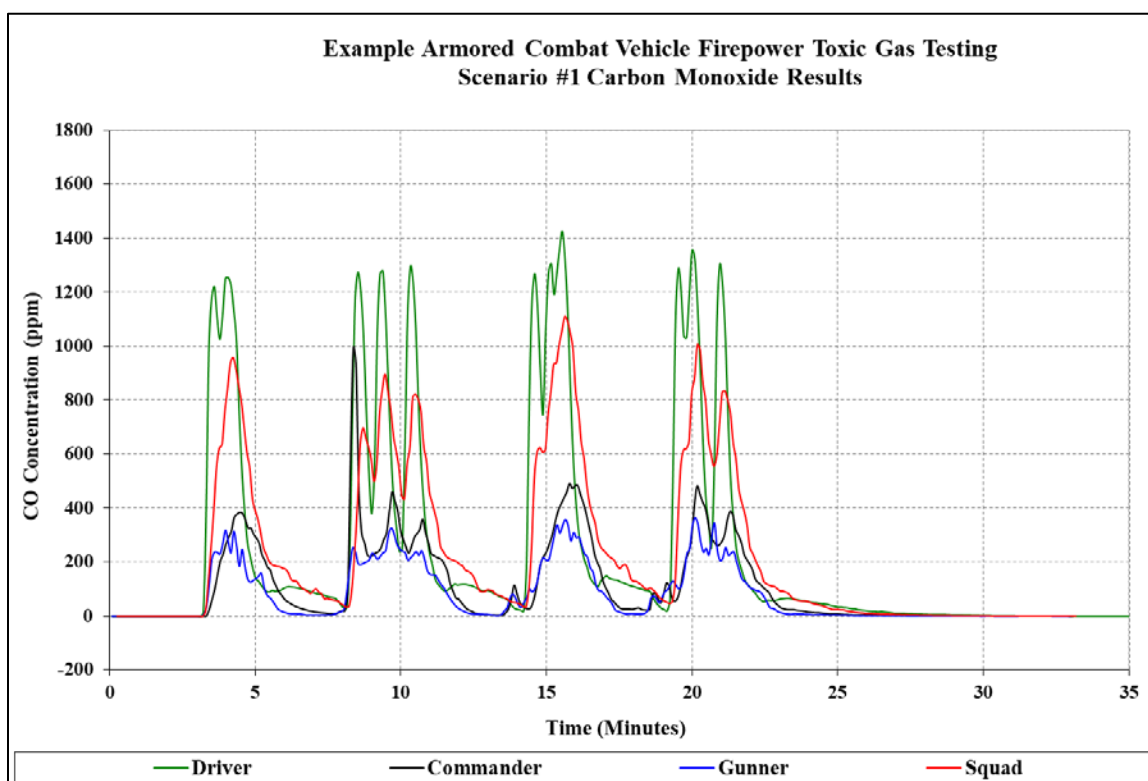


Figure C-1. Example of the plotted CO concentrations in a combat vehicle during a weapons firing test.

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

b. Prior to 1980, the U.S. Army essentially assessed Soldier exposure to CO using the civilian (OSHA) standards³ and MIL-STD-80017 (now obsolete) for dealing with steady state and transient type exposures respectively. As is discussed in Steinberg and Nielsen⁹, the civilian standards were considered too stringent for U.S. Army personnel who, fundamentally, represent a population of young, healthy Soldiers in contrast to the general civilian population which may vary in age and have potential associated health problems. Accordingly, the U.S. Army was in need of both adopting appropriate standards and an evaluative procedure that was acceptable to the Army Surgeon General and could be applied simply and effectively. In essence, the standard would be categorized as military unique⁴. Such a standard was adopted in May 1981 and published in MIL-STD-1472G⁵ (see Para 5.7.9.4.2 Carbon Monoxide).

c. The standard is specified in terms of permissible percentage carboxyhemoglobin (COHb) levels in the blood. A 5 percent COHb level is stated as “all system design objectives and aviation system performance limits”. A 10 percent COHb limit is specified for “all other systems performance limits”. The percentage COHb blood level is predicted by use of a revised form of an empirical equation (provided in paragraph C.2.b) developed by researchers Coburn, Forster, and Kane. This equation estimates the percentage COHb levels in the blood based upon a measured CO exposure level, the time duration of the exposure, and the physical stress level of the exposed individual over the exposure duration. Before presenting the details of the assessment procedure, a brief explanation of the standard should be helpful.

(1) The TWA method of analyzing CO exposure with the previously existing standards was unrealistic for the military environment because it neglected to account for the actual uptake of CO by the exposed person. Specifically, the standard did not factor in the work effort on the affected personnel during the time of the exposure. Additionally, the possibility of repetitive transient exposures is not accounted for properly using the TWA method of assessment. Transient exposures might be encountered in such as cases when firing or loading the main weapon of a tank, or trying to fly "nap-of-the-Earth" missions with a helicopter.

(2) In these examples, individual performance is a critical issue that the TWA method of assessment did not consider. The COHb standard accounts for required performance by the individual which is precisely the reason that a 5 percent COHB level standard was selected for the aviation community as opposed to the 10 percent COHB level standard chosen for all other systems. Visual acuity is considered more critical for the airman than for the combat vehicle crewman, which accounts for the differences in the standard (5 percent vs. 10 percent).

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

C.2. PREDICTING PERCENT CARBOXYHEMOGLOBIN (% COHb).

a. The predicted percent COHb level for each crew member or occupant is determined by the Coburn Forster Kane (CFK) Equation algorithm¹⁰. In its present modified form, the CFK is easily adapted for use with a spreadsheet program for data analysis and visualization. The user should note that the modified CFK, in addition to accounting for the actual minute respiratory volume of contaminated air respired by the subject, also accounts for the elimination of CO by the body. It should be noted that the CFK is fundamentally based upon laboratory experimentation and that verification of the equation should be based on actual field tests. One such test¹¹ was completed during June/July 1985 and published in 1986. The findings indicated that the CFK, as currently used, was a reasonable predictor of COHb blood level.

b. Empirical Equation.

$$\% \text{COHb}_t = \% \text{COHb}_0 [e^{(-t/A)}] + 218 [1 - e^{(-t/A)}] [1/B + \text{ppm CO}/1403] \quad (\text{Equation C-1})$$

Where:

% COHb_t is the predicted value in an exposed individual.

% COHb₀ is the initial amount of COHb usually found in nonsmoking adults.

t is the exposure duration in **minutes**.

ppm CO is the carbon monoxide concentration (in parts per million) in the contaminated air.

e is the mathematical constant, natural exponent, whose value equals 2.71828.

A and **B** are constants obtained from Table C-1. Both constants are dependent on the estimated activity level of the individual during the actual exposure. These constants account for the minute respiratory volume inhaled by the exposed individual for a given exertion (work effort) level. Figure C-2 shows an example spreadsheet calculation of percent COHb_t.

TABLE C-1. CONSTANTS FOR CFK USED TO PREDICT COHb BLOOD CONTENT

WORK EFFORT SCALE	WORK EFFORT DESCRIPTION	A VALUE	B VALUE
1	Sedentary	425	806
2		241	1421
3	Light Work	175	1958
4		134	2553
5	Heavy Work	109	3144
When using the CFK to estimate the % COHb blood levels for combat vehicle occupants, the following work effort/stress levels should be applied as appropriate: activities involving weapons fire = Level 4; all other mission activities = Level 3. An initial value of COHb (i.e., % COHb ₀) equal to 1.0 shall be assumed for all estimates.			

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

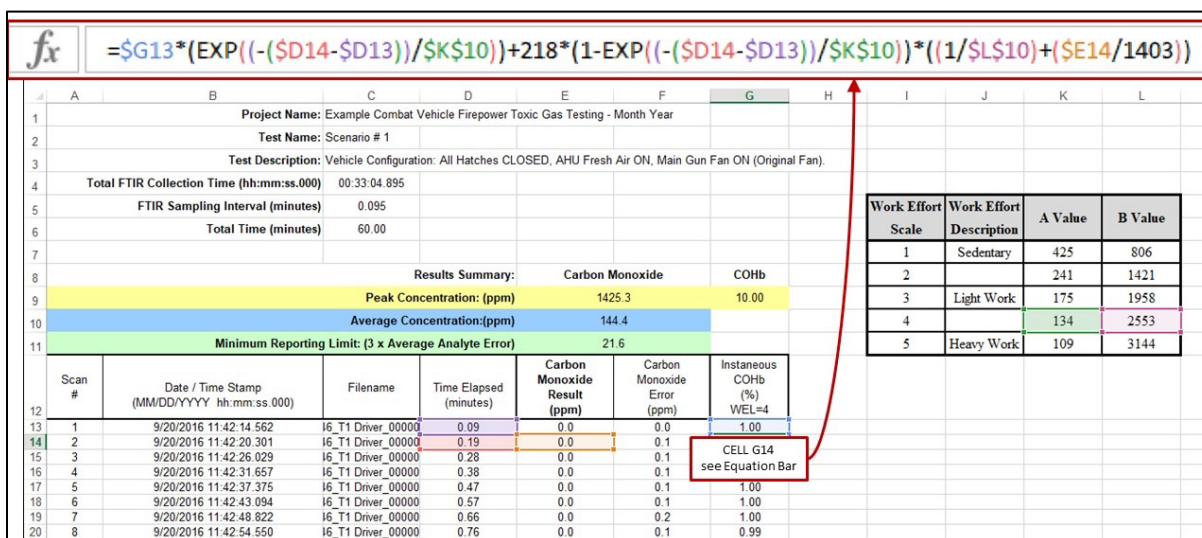


Figure C-2. Computing instantaneous percent COHb_t estimates in a spreadsheet.

C.3. ASSESSMENT PROCESSES.

C3.1 Analysis.

When analyzing the CO concentrations from a weapons firing data set (such as the example depicted in Figure C-1), calculating and plotting the instantaneous COHb_t for each position (Figure C-3) is extremely useful for visualizing compliance with the standard and identifying the critical crew position for the scenario. The critical position represents the vehicle occupant that has the highest COHb_t and is the worst case position that must be used in the assessment of the overall CO exposure hazard associated with the particular vehicle weapons firing scenario.

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

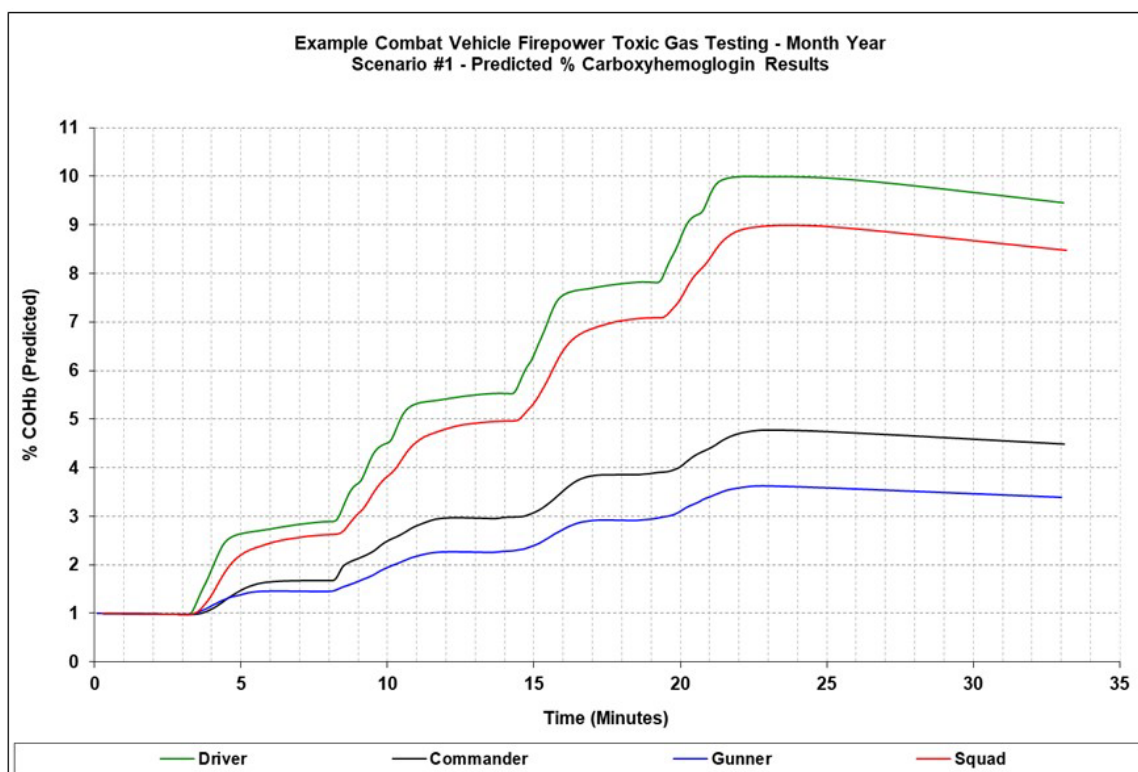


Figure C-3. An example of the plotted instantaneous COHb levels in a combat vehicle during weapons firing activities.

C.3.2 Defining Safe Operational Firing Limits.

a. Because approved toxic gas and aerosol test scenarios are not generally available in terms of many developmental systems, and no system specific criteria (i.e., actual number of rounds required to be fired safely within a specified time period under mission specific operating conditions) exists, use of the CFK in this manner aids in examining the boundary conditions for safe operation which are (for this analysis) defined as follows.

(1) Maximum Firing Rate (MFR). This is a worst case condition in that it assumes additional replications of a given scenario are fired consecutively. The Maximum Allowable Consecutive Episodes (MACE) is defined as the maximum number of consecutive replications of a test scenario that may be fired at the maximum firing rate without exceeding the standard's allowable limit of 10 percent COHb blood level^{6,10,11}.

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

(2) Sustained Firing Rate (SFR). Assuming MACE has been reached; the sustained firing rate is that which is highest for any weapon of the system without exceeding the 10 percent COHb limit. If the CO levels are high (35 to 50 ppm) a non-firing period of sufficient duration must be determined such that COHb levels decay sufficiently to permit additional firings of weapons without exceeding the 10 percent COHb limit. If CO levels are relatively low (<35 ppm), a non-firing period would not be required and the SFR coincides with the MFR.

(3) Wait Time (non firing). This is a degenerative condition in that no firing of weaponry takes place. Accordingly, no exposure to weapon induced CO will occur and this condition can continue indefinitely without hazard to the Soldier with the additional provision that background CO levels are not unusually high (<35 ppm). Equation C-2 is useful in the determination of the amount of time necessary for elevated levels of COHb in an exposed individual to reduce to a specific target level.

$$\text{Wait Time} = -A * \ln \left[(\text{COHb}_{\text{target}} - (218/B)) \div (\text{COHb}_{\text{max}} - (218/B)) \right] \quad (\text{Equation C-2})$$

Where:

Wait Time is the predicted length of time in **minutes** required with no additional CO exposure.

A and **B** are constants obtained from Table C-1. Both constants are dependent on the estimated activity level of the individual during the actual exposure. These constants account for the minute respiratory volume inhaled by the exposed individual for a given exertion (work effort) level.

ln is the natural logarithm function.

% COHb_{target} is the desired COHb value in the individual.

% COHb_{max} is the peak COHb_t value obtained when computing the CO exposure for a given scenario using the CFK.

b. The MFR is the upper boundary in that the system is constrained (by design and performance) to a specific maximum firing rate. Provided the COHb level does not exceed 10 percent when firing at the maximum rate, there would be no firing restrictions. If MACE is reached, periods of non-fire must be observed such that the Soldier COHb levels decay sufficiently prior to permitting additional weapons firing. In this scenario the boundary conditions are MACE and SFR (Figure C-4). A MACE, which is equivalent to several times the system's combat load, is of no practical use since the available ammunition will have been expended before reaching MACE. However, MACE does provide for a basis of comparing CO exposures among test scenarios which involve different conditions, ammunition types, numbers of rounds fired, etc. which provides the systems analyst with the means for improving combat effectiveness.

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

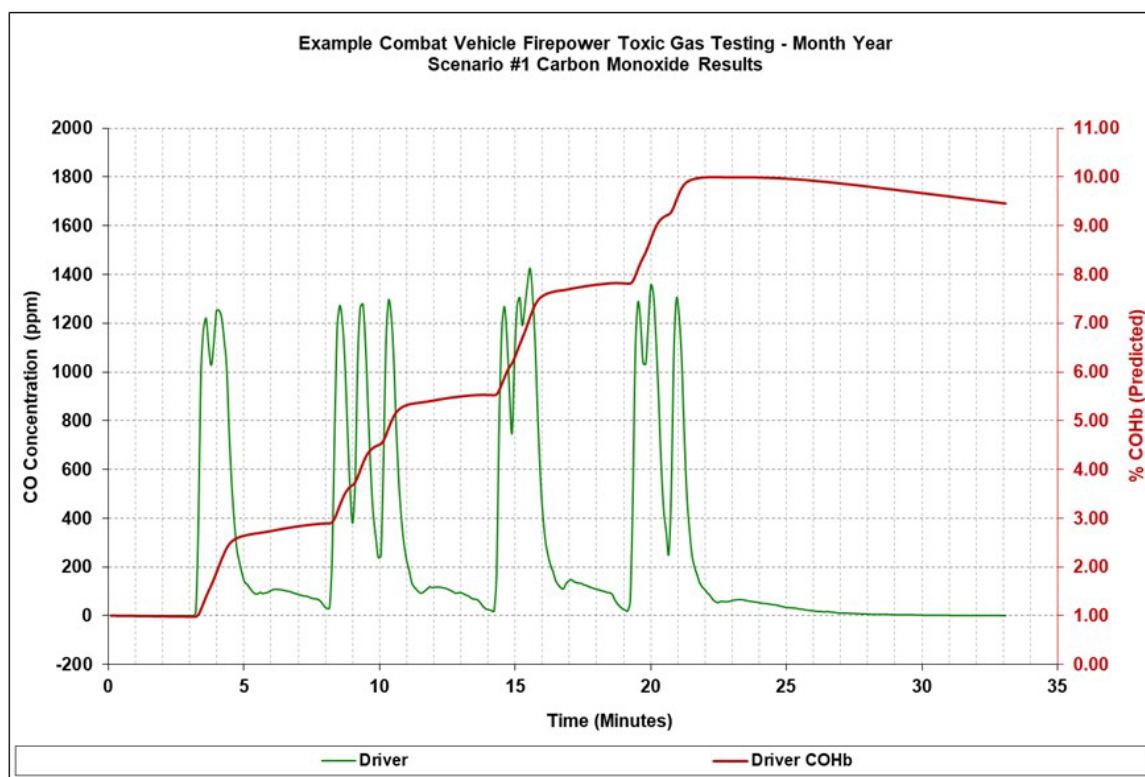


Figure C-4. An example weapons firing scenario where the upper COHb limit is reached at the critical crew position.

C.3.3 Limitations.

a. The firing rates discussed above do not consider temperature related firing restrictions, which may impose greater constraints upon firing than those imposed by toxic gases and aerosols. Discussion of a temperature related constraint and others is beyond the scope of this document and is mentioned to apprise the analyst that, when considering additional revisions to the model, adjustments should be made for such items as temperature, blast overpressure, and other system specific constraints. If such considerations are made, firing rate restrictions stated in system safety releases are coherent and coordinated.

b. When assessing firing rates for a Soldier and weapon, it must be remembered that CO is only one of many analytes that must be considered. When discussing firing rate or round count restrictions, other analytes besides CO may end up being the limiting factor.

14 May 2020

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

C.4. APPLICABILITY TO THE MOUT CHAMBER FOR HEALTH HAZARD ASSESSMENT TESTING.

a. When conducting the initial testing in the MOUT chamber it was determined that weapon firing rate and wind could affect the data results. Figures C-5 and C-6 illustrate data collected in the MOUT Chamber. 100 rounds of 7.62mm ammunition was fired from a M240B weapon to collect these data.

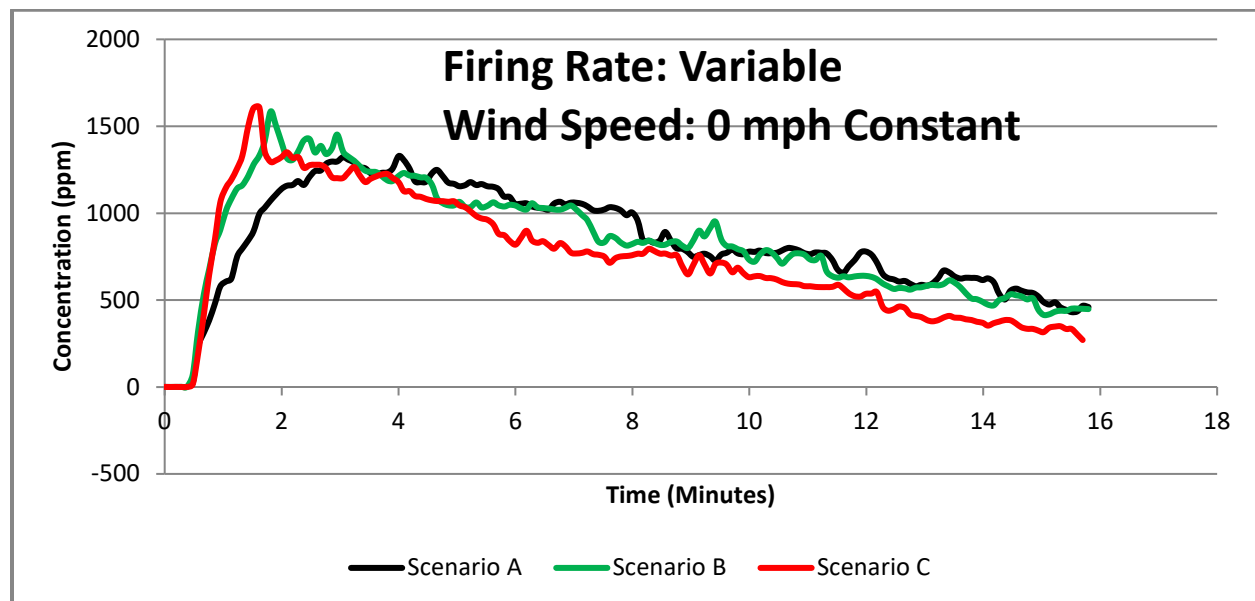


Figure Notes: Rate of Fire Scenarios

Scenario A = 5-7 round bursts every 10 seconds

Scenario B = 5-7 round bursts every 5 seconds

Scenario C = 10-12 round bursts every 5 seconds

Figure C-5. Firing rate effects on CO data collected in the MOUT Chamber.

APPENDIX C. ASSESSMENT OF THE CARBON MONOXIDE TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN ENCLOSED SPACES.

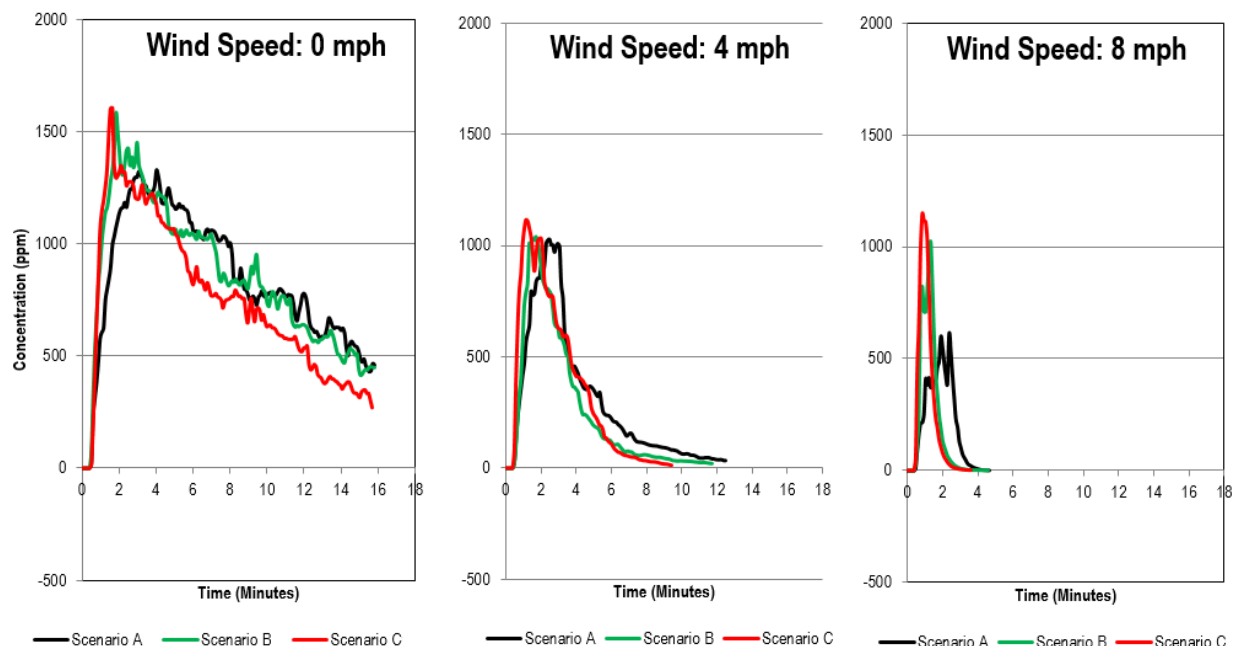


Figure Notes: Rate of Fire Scenarios
 Scenario A = 5-7 round bursts every 10 seconds
 Scenario B = 5-7 round bursts every 5 seconds
 Scenario C = 10-12 round bursts every 5 seconds

Figure C-6. Wind speed effects on CO data collected in the MOUT Chamber.

b. Firing rate for the various weapons tested effected the peak concentration of the analytes (CO, HCN, NH₃, etc.) but it did not affect the average concentration during the sampling period. Wind was determined to have the greatest effect on the average calculation concentrations of toxic gases. When firing from enclosed rooms, air movement is needed to disperse of the toxic gases created from the propellant combustion.

c. The firing rate should be identified in the DTP. When testing in the MOUT chamber, a variety of wind conditions are utilized to simulate various conditions a Soldier may encounter in the field and to provide the best data to assess the toxic gas hazards against criteria. This standardized approach allows for comparison between various weapons and ammunition types.

(This page is intentionally blank.)

APPENDIX D. EXAMPLE DATA TABLES.

TABLE D-1. MOUT CHAMBER WEAPONS FIRING TABLE

<u>Weapon and Firing Cadence</u>					
<u>Meteorological Conditions</u>	<u>Measurement</u>	<u>Trial 1</u>	<u>Trial 2</u>	<u>Trial 3</u>	<u>Trial 4</u>
	Temperature				
	Humidity				
	Wind				
<u>Compound</u>	<u>Calculation</u>	<u>Results (%)</u>			
Carbon Monoxide (CO)	COHb				
<u>Compound</u>	<u>Measurement</u>	<u>Results (ppm)</u>			
Ammonia (NH ₃)	TWA				
	STEL				
	Peak				
Carbon Dioxide (CO ₂)	TWA				
	STEL				
	Peak				
Hydrogen Cyanide (HCN)	TWA				
	STEL				
	Peak				
Nitric Oxide (NO)	TWA				
	Peak				
Nitrogen Dioxide (NO ₂)	TWA				
	STEL				
	Peak				
Sulfur Dioxide (SO ₂)	TWA				
	STEL				
	Peak				
<u>Analyte</u>	<u>Measurement</u>	<u>Results (mg/m³)</u>			
Lead (Pb)	Sample				
	TWA				

APPENDIX D. EXAMPLE DATA TABLES.

TABLE D-2. TOXIC GAS ASSESSMENT FORM

Test Item Configuration:				
Meteorological Conditions	Measurement	Ambient		Equipment Interior
	Temperature	°C		°C
	Humidity	%		%
	Wind			
Analyte		Position 1 (ppm)	Position 2 (ppm)	Position 3 (ppm)
SO ₂	Average			
	Peak			
NO	Average			
	Peak			
NO ₂	Average			
	Peak			
CO	Average			
	Peak			
CO ₂	Average			
	Peak			

TABLE D-3. AIR EXCHANGE TEST RESULTS TABLE

Scenario	Trial	Air Exchange Rate (per minute)	Outdoor Air Entering		Number of Exchanges Per Hour
			(ft ³ /min)	(m ³ /min)	

APPENDIX E. ABBREVIATIONS.

ACGIH	American Conference of Governmental Industrial Hygienists
ACV	Armored Combat Vehicle
AIHA	American Industrial Hygiene Association
Al	Aluminum
APHC	U.S. Army Public Health Center
Ar	Arsenic
AR	Army Regulation
ASTM	American Society for Testing and Materials
ATEC	U.S. Army Test and Evaluation Command
ATSDR	Agency for Toxic Substances and Disease Registry
Ba	Barium
BEI	Biological Exposure Indices
° C	degrees Celsius
C	ceiling
CAS	Chemical Abstracts Service
Cd	Cadmium
CDC	Centers for Disease Control
CEM	Continuous Emission Monitor
CFK	Coburn-Forster-Kane
CFR	Code of Federal Regulations
Co	Cobalt
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
COF ₂	Carbonyl Fluoride
COHb	Carboxyhemoglobin
Cr	Chromium
Cu	Copper
DA	Department of the Army
DA PAM	Department of the Army Pamphlet
DNPH	2,4-dinitrophenylhydrazine
DOD	Department of Defense
DODI	Department of Defense Instruction
DTP	Detailed Test Plan
ECC	Emission Characterization Chamber
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-To-Know Act

APPENDIX E. ABBREVIATIONS.

° F	degrees Fahrenheit
Fe	Iron
ft	feet
FTIR	Fourier-Transform Infrared
GC	Gas Chromatography
GCMS	Gas Chromatography Mass Spectroscopy
H ₂	Hydrogen
Hb	Hemoglobin
HCl	Hydrogen Chloride
HCHO	Formaldehyde
HCN	Hydrogen Cyanide
HF	Hydrogen Fluoride
HHA	Health Hazard Assessment
HHAR	Health Hazard Assessment Report
HPLC	High Pressure Liquid Chromatography
HVAC	Heating, Ventilation, and Air Conditioning
IC	Ion Chromatography
ICP	Inductively Coupled Plasma
IDLH	Immediately Dangerous to Life and Health
IOP	Internal Operating Procedure
ISBN	International Standard Book Number
iwg	inches of water gauge
° K	degrees Kelvin
kph	kilometers per hour
LEL	Lower Exposure Limit
Li	Lithium
LOTC	Large Octagon Test Chamber
µm	micron
MACE	Maximum Allowable Consecutive Episodes
MCCC	Medium Caliber Characterization Chamber
MCT	Mercury Cadmium Telluride
MetHb	Methemoglobin
MFR	Maximum Firing Rate
MIL-STD	Military Standard

APPENDIX E. ABBREVIATIONS.

mm	millimeter
Mn	Manganese
Mo	Molybdenum
MOUT	Military Operations in Urban Terrain
mph	miles per hour
NBC	Nuclear, Biological, and Chemical
NDIR	Non-Dispersive Infrared
NH ₃	Ammonia
Ni	Nickel
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NO	Nitric Oxide
NO ₂	Nitrogen Dioxide
NO _x	Oxides of Nitrogen
NOHb	Nitrosylhemoglobin
O ₂	Oxygen
OEL	Occupational Exposure Limit
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PAH	Polyaromatic Hydrocarbon
Pb	Lead
PEL	Permissible Exposure Limits
PM	Particulate Matter
PNOR/PNOS	Particulates Not Otherwise Regulated / Specified
ppb	parts per billion
ppm	parts per million
PUF	Polyurethane Foam
PVC	Polyvinyl Chloride
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit
RH	Relative Humidity
SACC	Small Arms Characterization Chamber
Sb	Antimony
SF ₆	Sulfur Hexafluoride

APPENDIX E. ABBREVIATIONS.

SFR	Sustained Firing Rate
SME	Subject Matter Expert
Sn	Tin
SO ₂	Sulfur Dioxide
Sr	Strontium
STEL	Short Term Exposure Limit
SVOC	Semi-Volatile Organic Compound
TLV	Threshold Limit Value
TNT	Trinitrotoluene
TOP	Test Operations Procedure
TSG	The Surgeon General of the U.S. Army
TSP	Total Suspended Particulate
TWA	Time Weighted Average
VOC	Volatile Organic Compound
W	Tungsten
WEEL	Workplace Environmental Exposure Level
XAD	Amberlite ® polymeric adsorbent crosslinked polystyrene copolymer resin
Zn	Zinc

APPENDIX F. REFERENCES.

1. AR 40-5, Medical Services, Preventive Medicine, 25 May 2007.
2. Title 3, Executive Order 12196, 26 February 1980, Subject: Occupational Safety and Health Programs for Federal Employees.
3. Code of Federal Regulations, Title 29, Subpart Z, Air Contaminants, Final Rule; Occupational Safety and Health Administration (OSHA), Part 1910.1000, 1 July 1998.
4. Department of Defense Instruction 6055.1, Department of Defense Occupational Safety and Health Program, 19 August 1998.
5. MIL-STD-1472G Change Notice 1, Department of Defense Design Criteria Standard; Human Engineering, 11 January 2012.
6. AR 40-10, Health Hazard Assessment Program in Support of the Army Acquisition Process.
7. DA PAM 40-503, The Army Industrial Hygiene Program, 2 April 2013.
8. AR 70-25, Use of Volunteers as Subjects of Research, 25 January 1990.
9. Steinberg, S. and Nielsen, G.D.; A Proposal for Evaluating Human Exposure to Carbon Monoxide Contamination in Military Vehicles, Technical Memorandum 11-77, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, March 1977.
10. Coburn, R.F., Forster, R.E., & Kane, P.G.; Considerations for the Physiological Variables That Determine the Blood Carboxyhemoglobin Concentration in Man. *Journal of Clinical Investigation*, 1965, 44, 1899-1910.
11. Mesas, M., Lucas, T.A., Steinberg, S., et al; Field Test to Verify the Coburn-Forster-Kane Equation. Report No. USACSTA-6357, U.S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD, September 1986.
12. "Threshold Limit Values for Chemical Substances and Physical Agents, Biological Exposure Indices," ISBN: 978-1-607261-05-6, American Conference of Government Industrial Hygienists, Cincinnati, Ohio, 2019.
13. OSHA, Occupational Exposure to Lead, 29 CFR 1910.1025, Department of Labor, Occupational Safety and Health Administration, 1989.
14. Detailed Test Plan Number 4 for Firing Point Emission Study Phase II, U.S. Army Aberdeen Test Center, 2000.

APPENDIX F. REFERENCES.

15. Detailed Test Plan Number 1 for Exploding Ordnance Emission Characterization Program Phase II, U.S. Army Aberdeen Test Center, 2000.
16. ASTM E741, Standard Test Method For Determining Air Change In A Single Zone By Means Of A Tracer Gas Dilution, 1 September 2011.
17. Pocket Guide to Chemical Hazards, U.S. Department of Health and Human Services, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health, Publication No. 2005-149, Cincinnati, OH, September 2007.
18. Technical Guide 230, APHC, Environmental Health Risk Assessment and Chemical Exposure Guidelines for Deployed Military Personnel
(<https://phc.amedd.army.mil/PHC%20Resource%20Library/TG230-DeploymentEHRA-and-MEGs-2013-Revision.pdf>).
19. NIOSH Method 3800, Organic and Inorganic Gases by Extractive FTIR Spectrometry
(<https://www.cdc.gov/niosh/docs/2014-151/pdfs/methods/3800.pdf>).
20. EPA Test Method 320, Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR) Spectroscopy
(https://www.epa.gov/sites/production/files/2017-08/documents/method_320.pdf).
21. ASTM Method D6348, Standard Test Method For Determination of Gaseous Compounds By Extractive Direct Interface Fourier Transform Infrared (FTIR) Spectroscopy, 1 February 2012.

APPENDIX G. APPROVAL AUTHORITY.

CSTE-CI

14 May 2020

MEMORANDUM FOR

Commander, U.S. Army Operational Test Command
Director, U.S. Army Evaluation Center
Commanders, ATEC Test Centers
Technical Directors, ATEC Test Centers

SUBJECT: Test Operations Procedure 02-2-622, Toxic Hazards Testing for Military Equipment and Materiel, Approved for Publication

1. Test Operations Procedure (TOP) 02-2-622, Toxic Hazards Testing for Military Equipment and Materiel, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency.
2. Scope of the document. This TOP is designed to act as a guidance document to aid in the development and conduct of tests used to determine the toxic gas/aerosol exposure hazards associated with realistic operations of military equipment.
3. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at <https://vdls.atc.army.mil/>.
4. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-CI), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

ZWIEBEL, MICHAEL J.
ELJ.1229197289

Digitally signed by
MICHAEL J. ZWIEBEL
DN: cn=MICHAEL J. ZWIEBEL,
ou=US Army, email=mjzwiebel@us.army.mil, c=US

MICHAEL J. ZWIEBEL
Director, Directorate for Capabilities
Integration (DCI)

(This page is intentionally blank.)

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-CI-P), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Commander, U.S. Army Aberdeen Test Center (TEAT-WFA), Aberdeen Proving Ground, Maryland 21005-5059. Additional copies can be requested through the following website: <https://www.atec.army.mil/publications/documents.html>, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.