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This TOP supersedes TOP 02-2-614 Toxic Hazards Tests for Vehicles and Other Equipment, dated 31 October 2003.

Marginal notations are not used in this revision to identify changes, with respect to the previous issue, due to the extent of the changes.

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 vehicles.

15. SUBJECT TERMS
toxic hazards, military vehicle, exposure, concentration, toxic gas, toxic aerosol, weapons firing, live fire vulnerability, toxicologists, gas monitor, emission monitor, sampling system, FTIR

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

*Test Operations Procedure 02-2-614A 14 May 2020
DTIC AD No.

TOXIC HAZARDS TESTING FOR MILITARY VEHICLES

*This TOP supersedes TOP 02-2-614 Toxic Hazards Tests for Vehicles and Other Equipment, dated 31 October 2003.

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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 vehicles.

b. The agency / personnel performing these tests should be experienced 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. 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 vehicles. 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, Preventive Medicine.

(2) Title 3, Executive Order 12196, 26 February 1980, Subject: Occupational Safety and Health Programs for Federal Employees[2].

(3) Code of Federal Regulations, Title 29, Subpart Z, Air Contaminants, Final Rule; Occupational Safety and Health Administration (OSHA), Part 1910.1000[3].

(4) Department of Defense Instruction (DODI) 6055.1, Department of Defense Occupational Safety and Health Program[4].

(5) DOD Design Criteria Standard, Military Standard (MIL-STD) 1472G CN1 Human Engineering[5].

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

(7) DA PAM 40-503, The Army Industrial Hygiene Program[7].

e. In effect, the preceding statement indicates that the published OSHA standards apply to both DOD military and civilian personnel 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[1,6].

** Superscript numbers correspond to Appendix F, References.

f. This document also addresses the conduct of toxic fumes sampling as part of vehicle Live Fire vulnerability testing. It must be emphasized that Live Fire testing is very different from typical toxic hazards tests. Live Fire vulnerability testing is performed on combat vehicles against conventional weapons threats. Instead of testing for occupational exposure hazards, these tests are used to determine the degree of vehicle and crew survivability to realistic battlefield combat threats. The results of these tests typically are not evaluated against the published civilian exposure standards, rather they are compared with available U.S. Army casualty criteria. Guidance on these standards may be found in the following:

(1) DA PAM 73-1, Test and Evaluation in Support of Systems Acquisition[8].

(2) DoDI 5000.02, Operation of Defense Acquisition Systms[9].

NOTE: The policies and procedures specified in AR 70-25[10] 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.

g. This revision of the TOP now only addresses the testing of military vehicles. A separate TOP (TOP 02-2-622[11]) has been developed for the testing of other military equipment and/or materiel.

h. The criteria listed in this document are based upon 2019 published resources referenced in Appendix A. Current threshold limit values should be confirmed from 2020 onwards.

1.1 Purpose.

a. The main purposes of this TOP are:

(1) To reinforce the need for early inclusion and participation of test personnel in the planning phase of a test program.

(2) To ensure all stakeholders understand the objectives of these procedures.

(3) To ensure all required data are collected.

b. This TOP details some of the specific tests designed to both measure and analyze the concentrations of toxic gases and aerosols produced during vehicle systems operations. The subtests listed below have been organized to follow the recommended logical progression in which these tests would be conducted.

1.2 Subtests.

The test types covered by this document include:

a. Air Exchange Ventilation Tests (paragraph 4.1).

b. Overpressure Tests [optional] (paragraph 4.2).

c. Automotive Toxic Gas Tests (paragraph 4.3).

d. Weapon Firing Combustion Products Tests (paragraph 4.4).

e. Automatic Fire Extinguishing Systems (AFES) Safety / Mapping Tests (paragraph 4.5).

f. AFES Performance and Live Fire Vulnerability Toxic Fumes Tests (paragraph 4.6).

1.3 Analytes Covered.

The list of analytes addressed in this document are listed in Tables 1 through 3. These compounds are some of the more common contaminants to which Soldiers and other personnel working with military vehicles 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 MILITARY VEHICLE SYSTEMS

COMPOUND NAME	CHEMICAL FORMULA	CHEMICAL ABSTRACTS SERVICE (CAS) NUMBER
Acrolein	CH_2CHCHO	107-02-8
Ammonia	NH_3	7664-41-7
Bromotrifluoromethane (Halon 1301)	$CBrF_3$	75-63-8
Carbon Dioxide	CO_2	124-38-9
Carbon Monoxide	CO	630-08-0
Carbonyl Fluoride	COF_2 or FCOF	353-50-4
Formaldehyde	CH_2O or HCHO	50-00-0
Heptafluoropropane (FM200)	CF_3CHFCF_3	431-89-0
Hydrocarbons (Aliphatic C1-C4)	CH_4, C_2H_6, C_3H_8, C_4H_{10}, etc…	Various
Hydrogen	H_2	1333-74-0
Hydrogen Bromide	HBr	10035-10-6
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

TABLE 1. CONTINUED

COMPOUND NAME	CHEMICAL FORMULA	CHEMICAL ABSTRACTS SERVICE (CAS) NUMBER
Oxygen	O_2	7782-44-7
Pentafluoroethane (FE-25)	CHF_2CF_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_2FCF_3	811-97-2

TABLE 2. TYPES OF AIRBORNE PARTICULATE SAMPLING ENCOUNTERED DURING TESTING OF MILITARY VEHICLE SYSTEMS

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 µm
Thoracic Fraction	50% cut-point for particles at an aerodynamic diameter of 10 µm
Respirable Fraction	50% cut-point for particles at an aerodynamic diameter of 4 µm

TABLE 3. LEAD AND OTHER SELECTED ELEMENTAL ANALYTES FOUND IN AIRBORNE PARTICULATE SAMPLES COLLECTED DURING TESTING OF MILITARY VEHICLE SYSTEMS

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

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 consultation with an appropriate Subject Matter Expert (SME) (i.e., chemists, industrial hygienists, toxicologists, etc.) and documented in the DTP. Additional details pertaining to the specific subtests being performed are provided in Section 4.

2.1 Facilities.

The specific facilities requirements for each subtest type will be addressed in Section 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 the data to be recorded for analysis purposes. Parameters such as gas concentrations, temperature, relative humidity, and wind speed should ideally be measured in this manner.

b. An SME, knowledgeable in equipment principles of operation, is responsible for the selection of test 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.

c. Some of the considerations involved in selection of test instrumentation include: 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.

d. 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 vehicles.

2.2.1 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.

2.2.2 Hand-held Gas Monitors.

a. This type of instrumentation is suitable for basic automotive 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 automotive toxic gas tests where the primary concern is for accumulation of exhaust gases inside of a vehicle. 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 using electrochemical toxic gas sensors are not recommended as a first choice for tests involving weapons-firing activities for multiple reasons:

(1) They are susceptible to interferences when multiple analytes are present simultaneously.

(2) They typically are not designed for detection of transient high concentration events. The response time lag of electrochemical sensors prevents them from fully quantifying spikes in concentrations.

(3) The chemicals in the detectors become depleted with exposure to the analyte.

b. Additional information regarding hand-held gas analyzers, and their use and limitations, is provided in Appendix B.

2.2.3 Continuous Emission Monitor (CEM).

a. For the purpose of this TOP, this is a general term describing a type of gas analyzer typically 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.

b. If continuous measurement analyzers are not available to measure a toxic gas or aerosol hazard at the expected concentration or necessary detection limit, then other sampling methods and analytical techniques may be employed. These methods should be determined acceptable and appropriate by qualified personnel.

3. REQUIRED TEST CONDITIONS.

a. It is incumbent upon the Test Manager / Test Officer to seek out and consult with the appropriate SME (i.e., chemists, industrial hygienists, toxicologists, the Army Public Health Center (APHC) Health Hazard Assessment (HHA) Division, etc.) to provide adequate input while developing their DTP to ensure all potential toxic hazards are considered. For specific issues / hazards encountered with Live Fire Vulnerability and Fire Suppression testing, consultation with the APHC Toxicity Evaluation Division (TED) is recommended for the evaluation criteria used in conjunction with combat casualty assessments.

b. Testing should be conducted in compliance with all applicable organizational safety, environmental, and security regulations. Occupational health and safety of test personnel should 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.

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

d. 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.

e. Daily instrument calibration and sampling system checks (as applicable), using certified gas standards, must be performed prior to testing. All certified gas standards used should have an associated certificate of analysis traceable to a National Institute of Standards and Technology (NIST) or comparable standard. A copy of each certificate should be retained as part of the test record.

f. When additional sampling media are 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 relative humidity, and temperature) must be considered during testing as it may affect test validity. Applicable recommendations and/or restrictions for each of the specific subtests will be addressed individually in Section 4.

4. TEST PROCEDURES.

The information provided for each of these subtests is meant to serve as basic guidelines for the development of adequate procedures for testing military vehicles. 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 Air Exchange Ventilation Tests.

The air exchange rate will be determined to provide a measurement of the amount of fresh air introduced into the test vehicle. A tracer gas compound will be introduced and uniformly dispersed into the vehicle. The concentration of the tracer gas is monitored as the vehicle 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) International Method E741[12], Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution.

4.1.1 Objectives.

a. To determine the rate at which fresh air enters a closed test vehicle via mechanical or natural ventilation.

b. Compute the vehicle 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.

4.1.2 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 (or sub-) part per million (ppm) range. The minimum data collection rate of at least one sample every 10 seconds is recommended.

4.1.3 Required Test Conditions.

The vehicle configuration 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. Example conditions may include testing with vehicle configuration setting at maximum ventilation (all ventilation fans on and set to highest setting) and again at minimum ventilation (all fans on but set to lowest setting). A list of the typical required conditions that may be required for testing are provided in Section 3.

4.1.4 Criteria.

The specific vehicle ventilation requirements should be identified in the DTP or vehicle system specification. In the absence of a system-specific requirement, utilize MIL-STD-1472G CN1. This document specifies that enclosure volumes (i.e., vehicle interior crew spaces) of 150 ft^3 (4.25 m^3) or less per person are required to have a minimum of 30 ft^3/min (0.85 m^3/min) of ventilation air per person and 20 ft^3/min (0.57 m^3/min) of outdoor air per person. For a vehicle with interior volumes greater than 150 ft^3 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 vehicle and cannot be used to evaluate the total ventilation or air velocity requirements.

4.1.5 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 Section 5.

4.1.6 Test Procedures (Method).

a. Chose an appropriate tracer gas material. The recommended compound is sulfur hexafluoride (SF_6), as it is easily measured with the FTIR at very low concentrations.

b. Obtain from the manufacturer and/or perform a rough estimate of the vehicle volume will be made in order to calculate the approximate amount of tracer gas needed for testing.

c. The nominal amount used for each test should result in a dispersed tracer gas concentration within the dynamic measurement range and 100-200 times the minimum reporting limit of the instrumentation.

d. Place supplemental fans inside the vehicle to improve mixing and aid in quickly dispersing the tracer gas.

e. If extractive sampling (i.e., drawing air out of the vehicle with a sample line) is used to deliver to the gas analyzer, ensure that the sample stream will be exhausted back into the vehicle to eliminate any interior air loss due to the sampling system.

f. A known amount of tracer gas will be introduced into the test vehicle from a cylinder containing a known gas concentration (such as a certified standard or neat material). This information and the concentration of the steady-state dispersed tracer gas will be used for vehicle 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:
C_1 = the concentration of the tracer gas introduced to the vehicle.
V_1 = the volume of the tracer gas introduced to the vehicle.
C_2 = the steady state concentration of the tracer gas dispersed inside the test vehicle.
V_2 = the volume of the interior of the test vehicle.

g. Prior to the start of each test trial, the ventilation systems in the vehicle will be configured and the vehicle will be sealed. For volume determination trials, the vehicle ventilation system should be off and mixing accomplished with the supplemental fans.

h. 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 vehicle. The data collected will be monitored at the computer by the analyst.

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

j. At the conclusion of each of the trials, the vehicle 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.

4.1.7 Data Reduction/Presentation.

a. 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. The following steps listed below, to determine the air exchange rate, are extracted from ASTM International E741.

(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 vehicle volume (V_2 obtained from Equation 1 paragraph 4.1.6.f).

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

4.2 Overpressure Tests.

The measurement of the pressure difference between the vehicle interior and the exterior atmosphere is measured using a digital differential pressure manometer. Vehicle Nuclear, Biological, and Chemical (NBC) systems operate by filtering the incoming air and maintaining higher internal air pressure than the external pressure (overpressure). Contaminated external air is prevented from infiltrating the vehicle resulting in a contaminant-free environment for work and relief from continuous wearing of protective masks and other equipment (i.e., collective protection). Additionally, overpressure measurements may be made in conjunction with air exchange data in assessing and/or troubleshooting ventilation system deficiencies.

4.2.1 Objectives.

a. For NBC system assessments. Operate the NBC system and ensure that the air flow capacity and vehicle seals are adequate to maintain crew compartment overpressure preventing the entry of exterior contaminants.

b. For ventilation system assessments (optional). Operate the ventilation system in vehicles that fail to meet Air Exchange requirements to determine whether the system has inadequate air flow capacity or if additional ventilation exhaust is required. Air exchange and overpressure data can be useful in optimizing the performance of vehicle Heating, Ventilation, and Air Conditioning (HVAC) systems.

4.2.2 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 sensor inputs. Differential pressure is calculated and displayed in inches of water gauge (inches H_2O (iwg)). The manometer should meet the following minimum measurement specifications:

(1) Range: 0 to 55.4 inches of water.

(2) Resolution: 0.01 inches of water.

(3) Accuracy: 1% of full scale.

(4) Ability to record or transmit measurement data at a recommended rate of 1 Hertz (Hz).

4.2.3 Required Test Conditions.

Configure test vehicle as specified in the DTP.

4.2.4 Criteria.

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

4.2.5 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 Section 5.

4.2.6 Test Procedures (Method).

a. Place the manometer inside the vehicle. 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 vehicle is normally sealed, duct tape or putty should be used around the tube to maintain the seal.

c. Perform with test personnel inside the vehicle 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 vehicle hatches are open and start the data acquisition software.

e. Close the vehicle doors/hatches and operate the NBC system according to the DTP. Each configuration should be tested for a duration of approximately 15 to 30 minutes.

4.2.7 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 Section 6.

4.3 Automotive Toxic Gas Tests.

a. These tests are usually performed in the early stages of testing, to ensure the vehicle complies with all applicable regulations governing automotive safety and health hazard evaluations. A safety assessment of the vehicle will be conducted to determine: the extent of any existing toxic gas hazard, what gases may be prevalent in the vehicle, 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. If special equipment could affect exposure (i.e., fording, swimming kits, curtains, etc.), tests should be conducted with this equipment installed.

b. 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 (CO_2), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Nitric Oxide (NO), and Sulfur Dioxide (SO_2). If the initial test results reveal potential issues, additional testing beyond the basic steps outlined in this subtest may be required.

c. Please note that this type of test only characterizes the potential hazards from the vehicle fuel fired combustion exhaust sources, to include: the main engine, Auxiliary Power Units (APUs), heaters, etc. This subtest does not include weapons firing activities/scenarios.

4.3.1 Objectives.

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

4.3.2 Facilities and Instrumentation.

a. Facilities.

(1) An approved area for stationary testing (pad, range) 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 vehicle. 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 vehicle.

(2) Automotive test courses as specified in the DTP or as required (for mobile automotive trials).

(3) Swimming and fording facilities as specified in the DTP or as required.

b. Instrumentation.

(1) The instrumentation and/or sampling media should be chosen to address the particular toxic gas hazards identified during the examination of the vehicle. The preferred type of instrumentation for initial basic automotive toxic gas testing are the hand-held analyzers as described in Section 2. Table 4 contains the recommended configuration and sensor specifications. Additional information regarding toxic gas instrumentation types and sampling can be found in Appendix B. The recommended data collection rate of 1 Hz when using hand-held gas analyzers.

TABLE 4. RECOMMENDED HAND-HELD GAS ANALYZER CONFIGURATION

ANALYTE	SENSOR TYPE	MEASUREMENT RANGE	RESOLUTION	REPORTING LIMIT
		Concentration units expressed in parts per million (ppm)		
CO	Electrochemical	0 – 500	± 1	3
CO_2	Non-Dispersive Infrared (NDIR)	0 – 50000	± 100	500
NO	Electrochemical	0 – 250	± 1	3
NO_2	Electrochemical	0 – 20	± 0.1	0.3
SO_2	Electrochemical	0 – 20	± 0.1	0.3

(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 Relative Humidity (RH).

4.3.3 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 Section 5.

4.3.4 Criteria.

a. Personnel should not be exposed to concentrations of hazardous substances in excess of the values established as the Department of the Army (DA) Occupational Exposure Limits (OELs)[7] as defined in Appendix A. Three exposure types are used to categorize the relative hazard levels, these include: Time-Weighted Average (TWA), Short-Term Exposure Limit (STEL), ceiling values. A detailed explanation of each category is also provided in appendix A. The Army OELs for the five standard toxic gas analytes are listed in Table 5 and should be used as the assessment criteria for these types of tests. Review of these exposure standards should be conducted annually. Consult with APHC's HHA Division for most up to date or specific additional medical criteria.

TABLE 5. RECOMMENDED MINIMUM ANALYTES AND ARMY OCCUPATIONAL EXPOSURE LIMITS (OEL) FOR STANDARD AUTOMOTIVE TESTS

COMPOUND	EXPOSURE TYPE	ARMY OEL (ppm)
Carbon Monoxide (CO)	TWA STEL Ceiling	25 NA 200
Carbon Dioxide (CO_2)	TWA STEL Ceiling	5000 30000 NA
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

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 with their associated exposure standards.

4.3.5 Data Required.

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

b. Vehicle speed (miles per hour (mph) or kilometers per hour (kph)) for trials where mobile testing has been specified in the DTP or as requested.

4.3.6 Test Procedures (Method).

a. A safety assessment of the vehicle will be conducted to determine: the extent of any existing toxic gas hazard, what gases may be prevalent in the vehicle, 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. If special equipment could affect exposure (i.e., fording, swimming kits, curtains, etc.), tests should be conducted with this equipment installed.

b. The vehicle configuration during toxic gas and aerosol 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 4.3.5 will be collected for time periods of not less than 30 minutes under the conditions determined during the safety assessment as follows:

(1) Stationary vehicle testing with the engine at the specified tachometer (i.e., normal, tactical, etc.) idle speed(s). Orient the vehicle with the prevailing wind to simulate the worst case scenario combination(s) of wind direction, windows/hatches, ventilation intakes, and exhaust.

(2) Multiple trials should be performed with different ventilation system settings and vehicle configurations as appropriate.

(3) If necessary, additional data on long-term exposures (4 to 8 hours) should be obtained during endurance testing to supplement the data obtained during the 30 minute trials.

(4) Mobile vehicle at 0.25 and 0.5 percent of the vehicle’s maximum speed or other speeds considered appropriate.

(5) During fording with engine idling and at vehicle speeds compatible with the fording operation.

c. If detectable levels of any of the gases measured with the hand-held analyzers are observed during testing, particularly CO, NO_2, and SO_2, the test officer must be notified immediately. The vehicle must be thoroughly examined to determine the condition(s) which allowed these noxious gases to enter the vehicle. Measures should be taken to either correct the problem (if possible) and/or provide the appropriate precautions to avoid the vehicle operational condition(s) which would potentially result in exposure.

4.3.7 Data Reduction / Presentation.

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

4.4 Weapon Firing Combustion Products Tests.

a. Weapons systems tests include combat vehicle systems such as tanks, personnel carriers, mobile armored systems carrying an operating crew, self-propelled howitzers, infantry fighting vehicles, etc. These systems usually involve an enclosed crew, where internal ventilation, although designed rigorously to appropriate specifications, is marginally functional particularly when rapid weapons fire results in a quick build-up of weapons combustion products.

b. Ground mounted weapons and ammunition, which can also be mounted/used in vehicles (towed artillery, mortars, individual weapons, rifles, pistols, etc.), are normally tested in the vehicles from which they are fired. Weapons combustion products and aerosol testing in open air or externally mounted weapons are not normally conducted due to the rapid dissipation of the gases and the significant effects that even very light winds would have on the gas concentrations.

c. To the greatest extent possible, weapon-firing combustion products testing should be conducted in the early stages of a test program to identify the potential hazards and/or conditions associated with the vehicle and weapons system. If the vehicle/weapons platform is a developmental test item, weapons combustion products testing must be conducted prior to any other test types involving the weapons-firing activities.

d. Test Personnel Safety Limitation. While this section deals with the testing and assessment of a vehicle weapons platform, the military unique criteria provided below pertains to the exposure of military personnel operating the system once fielded. The civilian exposure limits for carbon monoxide identified in Appendix A must be observed for testing personnel. Typically, initial testing is performed with the occupants using respirators with supplied air. The test report should identify the scenarios or vehicle configurations that are likely to produce CO levels above the 25 ppm 8-hour TWA or 200 ppm Ceiling limits. It should be clearly communicated to the Test Officer that if the vehicle is to be operated in these conditions, the test personnel must continue to use respirators with supplied breathing air.

4.4.1 Objective.

During weapon system testing, the objective is to measure concentrations of weapon combustion products resulting from simulations of realistic operations of weapons systems to determine the degree of combustion products and aerosol hazard to operating crew, maintaining crews, and vehicle occupants.

4.4.2 Facilities and Instrumentation.

a. Facilities.

(1) Specialized outdoor firing ranges as specified in the DTP or as required for weapons combustion products testing.

(2) Vehicle or weapons platform as required or as specified in the DTP.

(3) Instrumentation structure/trailer/location suitable for all required equipment and personnel necessary for weapons combustion products analysis and sampling.

(4) Instrumentation shielding (as needed) to protect equipment from blast, fire, fragments, and other hazards.

b. Instrumentation.

(1) The instrumentation and/or sampling media should be chosen to address the particular weapons combustion products hazards identified during the examination of the vehicle/weapons system. Weapon systems tests require instrumentation to continuously measure concentrations of the standard suite of analytes listed below in Table 6. Some weapons systems, such as the Multiple Launch Rocket System, require the measurement of Hydrogen Chloride (HCl) in addition to the gases already mentioned. Weapon systems that use new or exotic propulsion systems (e.g., liquid propellants) may require analyses of other gases in addition to those listed below. These individual systems should be evaluated to determine potential toxic gas and aerosol threats based on the chemical constituents in the system. The preferred instrumentation is the FTIR spectrometer as described in Section 2. The minimum data collection rate of at least one sample every 10 seconds is recommended.

TABLE 6. RECOMMENDED MINIMUM ANALYTE MEASUREMENT SUITE

ANALYTE	MEASUREMENT RANGE (ppm)	REPORTING LIMIT (ppm)
CO	0 - 5000	1
CO_2	0 - 10000	100
HCN	0 - 50	1
NH_3	0 - 300	1
NO	0 - 500	5

TABLE 6. CONTINUED

ANALYTE	MEASUREMENT RANGE (ppm)	REPORTING LIMIT (ppm)
NO_2	0 - 50	1
SO_2	0 - 50	1

(2) Air particulate sampling equipment/media for Lead (Pb) and/or other elements as specified in the DTP or required.

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

4.4.3 Required Test Conditions.

a. Testing shall be conducted in accordance with an approved firing scenario provided by the user or developer. The scenario shall be representative of those conditions likely to be encountered in either training or combat and should specify the vehicle configuration (position of hatches, ventilator, engine status, firing rate, and number of rounds to be fired). Representative test scenarios that may be used for large (105 - 120 millimeter (mm)) and medium (20 - 40 mm) caliber direct fire weapons systems are presented at the end of Appendix C. It is incumbent upon the Test Manager / Test Officer to seek out and consult with the appropriate SME (i.e., chemists, industrial hygienists, toxicologists, the APHC HHA Division, etc.) to provide adequate input while developing their DTP to ensure all potential toxic hazards are considered.

b. The test request 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 weapons combustion products exposure criteria.

c. The system to be tested must be examined carefully in terms of the locations of ventilation air intakes, hatches, etc. relative to the weapon(s) exhaust and the operational modes of the ventilation system(s). A set of system configurations should be developed based on its characteristics and intended tactical use. Guidance should be solicited from the user or developer as necessary. The test design should encompass trials for configurations most likely to produce the greatest weapons combustion product and aerosol hazard that is consistent with tactical or training use.

d. If lead aerosol concentration measurements are planned, the area surrounding the firing position should be surveyed for lead contamination prior to the test start. If such contamination is found, the soil should be moistened with water during the test to prevent re-suspension of lead-laden dust, which can interfere with lead concentration measurements.

e. Tests should include simulations of realistic degraded mode operations such as conditions resulting from failures or combat damage of critical system components including ventilation equipment, exhaust fans, filter systems or duct openings that are designed to provide a safe environment for the crews and/or occupants.

f. Safety and industrial hygiene personnel should ensure the protection of test personnel (i.e., combat vehicle technicians (gunners)) from overexposure in the event concentrations of toxic gases exceed the allowable limits during testing. This is normally accomplished by supplying respirators and compressed breathing air to all personnel inside the test vehicle while firing operations are conducted.

g. Testing should be avoided when the ambient RH exceeds 85 percent or wind speed exceeds 10 mph (5 mph for hatches open) or wind gusts exceed 20 mph (10 mph for open hatches).

4.4.4 Criteria.

a. Carbon Monoxide. 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 percent. COHb levels are estimated by solving the empirical equation known as the Coburn-Forster-Kane Equation (CFKE) [5]. Details on the evaluation of CO exposures during weapon-firing activities are provided in Appendix C.

b. Personnel should not be exposed to concentrations of hazardous substances in excess of the values established as the Department of the Army (DA) Occupational Exposure Limits (OELs) [7] as defined in Appendix A. Three exposure types are used to categorize the relative hazard levels, these include: time-weighted average (TWA), short-term exposure limit (STEL), ceiling values. A detailed explanation of each category is also provided in Appendix A. The Army OELs for the five standard toxic gas analytes are listed in Table 7 and should be used as the assessment criteria for these types of tests. Review of these exposure standards should be conducted annually.

TABLE 7. RECOMMENDED MINIMUM ANALYTES AND EXPOSURE LIMITS FOR STANDARD WEAPONS FIRING TESTS

COMPOUND ANALYTE(S)	EXPOSURE TYPE [a]	ARMY 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

TABLE 7. CONTINUED

COMPOUND ANALYTE(S)	EXPOSURE TYPE [a]	ARMY OEL (ppm)
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.

4.4.5 Data Required.

The specific data required for individual tests will be explicitly defined in the DTP. A list of some additional data that typically may be required for testing are provided in Section 5. Additional required data that are unique to this subtest, include:

a. Weapon elevation and direction.

b. Number of rounds fired, firing rate and/or interval.

4.4.6 Test Procedures (Method).

a. Position the test vehicle on the firing range and mount air sampling tubes (also, sample collectors, as required) at the breathing zones of the crew members or occupants.

b. Close hatches and configure ventilation components or other auxiliary equipment in accordance with the DTP.

c. Start sampling pumps.

d. Begin firing scenario in accordance with the DTP.

e. Record gas concentrations for the duration specified in the DTP. Generally, concentrations are recorded until the values reach a steady state condition (no ventilation of vehicle) or decay to pre-fire levels (active ventilation).

f. Vehicle should be opened and purged with fresh air as required between trials.

g. Recover any sampling media (filters, sorbent tubes, etc.) used during the trial. Cap the media, ensure proper labelling, and secure until submitted for laboratory analysis.

h. Repeat the preceding test method for other scenarios, as required.

4.4.7 Data Reduction/Presentation.

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

b. COHb calculations using the CFKE and evaluations as required/specified in the DTP. Details of the weapons firing CO hazard evaluation processes are outlined in Appendix C.

4.5 Automatic Fire Extinguishing Systems (AFES) Safety/Mapping Tests.

4.5.1 Objectives.

Conduct tests, where the AFES is manually discharged, to determine the concentration of halocarbon extinguishing agents. The three chemicals of this type commonly used in military vehicles include: Heptafluoropropane (FE-227ea/FM200), Bromotrifluoromethane (Halon 1301), and Pentafluoroethane (FE-25). The primary reasons for this type of testing are:

a. Ensure test personnel operating vehicles equipped with an AFES will not be exposed to harmful levels of the extinguishing agent in the case of an accidental discharge.

b. Ensure that the AFES will produce the desired design concentration of extinguishing agent. Sampling positions throughout the vehicle are used to verify adequate dispersion of the agent. Testing of this vehicle subsystem should always be conducted prior to any AFES performance and/or Live Fire testing.

c. Ensure that oxygen concentrations in the vehicle remain above established criteria once AFES has been discharged.

4.5.2 Facilities and Instrumentation.

a. Facilities.

(1) An approved area for stationary testing (pad, range) 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 vehicle. Testing should not occur in confined or congested areas.

NOTE: If the vehicle is equipped with an AFES that uses either an explosive squib or pyrotechnic (such as a gas generator), then handling and discharge of the system must be the responsibility of a qualified explosives technician. Consequently, a specialized outdoor firing range may be required.

(2) Instrumentation structure suitable for all required equipment/personnel necessary for toxic gas/fume analysis and sampling.

(3) Instrumentation shielding (as needed) to protect equipment from blast, fire, fragments, and other hazards.

b. Instrumentation. AFES Safety and mapping tests require gas analyzers capable of continuously measuring the concentration of the specific extinguishing agent discharged and oxygen.

(1) Extinguishing agent concentration. The two most common techniques are fast response nondispersive infrared analyzers or FTIR. While the specific extinguishing agent may vary depending on the system being tested, the nominal instrument/measurement specifications are:

(a) Full-scale measurement range of 0 - 20 percent by volume.

(b) Accuracy of ± 2 percent of the full-scale measurement; not to exceed an absolute accuracy of ± 0.5 percent by volume.

(c) Measurement response time of < 5 seconds; includes instrument and sampling system.

(2) Oxygen concentrations should be measured by rapid response CEM analyzers. The preferred measurement technologies are either paramagnetic detection or diode laser absorption technology. The nominal instrument specifications are the same as the agent concentration measurement, except that the full-scale measurement range for the oxygen analyzers is either 0 - 25 percent or 0 - 100 percent by volume.

(3) The data collection rate is ultimately determined by the type of instrumentation chosen. The recommended rates are: (1) at least 1 Hz for CEM analyzers, and (2) at least one sample every 5 seconds if FTIRs are used.

4.5.3 Required Test Conditions.

a. A trained vehicle technician or a manufacturer’s field service representative must be present to instruct test personnel on the proper functioning of the AFES. This individual must also be responsible for the installation of a device or some other means of manually discharging the AFES for the purposes of these tests. If a trained vehicle technician or a manufacturer's FSR is not present for the test, a manual discharging method of the AFES system should be evaluated and approved by the AFES manufacturer, vehicle manufacturer, and test officer prior to execution.

b. Installation of the AFES bottles must be performed by qualified personnel equipped with all necessary Personal Protective Equipment (PPE).

c. Once the AFES has been activated, all personnel entering the vehicle must wear appropriate PPE for eye and hearing protection.

d. If the vehicle engine must be running during these tests, test personnel should avoid the area immediately around and downwind of the vehicle exhaust following the discharge of the AFES. It is possible for some of the extinguishing agent to be ingested into engine air intake and be combusted. If this occurs, the exhaust gases may be highly irritating as they will contain some of the common agent decomposition by-products (HF, COF_2, etc.) similar to what may be observed in AFES performance and Live Fire tests.

4.5.4 Criteria.

a. The safe exposure guidance varies for the different extinguishing agents commonly used in military vehicles. Appendix A contains information regarding the hazards and exposure criteria for FM200, Halon 1301, and FE-25.

b. Oxygen concentrations in the vehicle during and after the AFES discharge must remain above 16 percent[13].

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 Section 5.

4.5.6 Test Procedures (Method).

a. Position sample lines at the locations specified in the DTP. If not specified, sample from the breathing zone of each crew member/occupant. Any remaining available sample lines should positioned either at floor level, in the vicinity of any critical locations (i.e., near fuel or hydraulic lines), or at obstructed areas not in the direct path of the AFES discharge nozzle(s).

b. When extractive sampling is used, ensure that the length and the flow rate of all sample lines is uniform. This is critical in ensuring that the response of the analyzers will be comparable and that the data will be valid when comparing the agent concentration at different locations in the vehicle.

c. Configure the vehicle ventilation system as specified in the DTP. In the absence of any specific ventilation system requirement, at a minimum conduct the following scenarios:

(1) An AFES discharge with the vehicle sealed (i.e., close all windows, hatches, ramps, etc.) and the ventilation system off. This configuration represents the potential "worst case" personnel exposure hazard as no fresh air is being introduced into the vehicle. The data from this trial will be useful in determining if the amount of agent in the system is sufficient to achieve the design concentration.

(2) An AFES discharge with the vehicle hatches open and ventilation system operational. This scenario provides the most rigorous condition that challenges the performance aspects of the AFES.

d. Start the sample pumps. Data collection should commence approximately 30 seconds prior to the manual discharge of the AFES and continue for a minimum of 6 additional minutes. Longer sampling times may be required depending on the specific extinguishing agent being used.

e. Following each test trial, open the vehicle to vent the remaining extinguishing agent before reentering. An external forced air ventilation system may be required to adequately ventilate the vehicle's crew compartment after the test trial if access doors are limited in size and appropriate configuration to allow adequate ventilation.

f. Repeat the preceding test method for other configurations, as required.

4.5.7 Data Reduction/Presentation.

Tables, graphs, and the associated final report should be formatted as described in Section 6 and/or as required by the DTP.

4.6 AFES Performance and Live Fire Vulnerability Toxic Fumes Tests.

a. AFES performance testing is performed on combat and tactical vehicles to assess the effectiveness of the fire extinguishing system when challenged with realistic fire threats. These tests are typically performed before Live Fire vulnerability tests in order to ensure the installed systems in the vehicle are suitable. For practical purposes, toxic gas measurements for these tests are performed in the same manner as the live fire testing described below.

b. Live fire vulnerability testing is performed on combat vehicles against conventional weapon threats. These tests assess the vulnerability of systems that are designed to provide protection to crew members against weapons that do not pose a nuclear, chemical, or biological threat. These threats could include, but are not limited to, gun-fired ammunition, missiles, rockets, mines, and artillery projectiles that may be statically detonated or dynamically fired. These tests may include several different scenarios or subtests that are designed to comprehensively evaluate vehicle performance. Each test, scenario, or subtest should be evaluated to ensure that all objectives related to toxic gas and aerosol measurement will be adequately addressed.

c. Many live fire vulnerability tests result in armor penetration events that can create several toxic gas and aerosol hazards. Combat vehicles are equipped with fire extinguishing systems that contain fire suppression agents. When a fire is detected, onboard systems automatically discharge the fire suppression agent. The toxic byproducts of pyrolyzed fire extinguishing agent are dependent upon the chemical composition, but can include CO, CO_2, COF_2, HBr, and HF. Burning propellant will release CO, CO_2, NO, and NO_2. Burning plastics might also produce HCl, acrolein, formaldehyde, and HCN. Comprehensive testing may also include oxygen depletion, particulate characterization and quantification, and metals analysis. Testing programs will analyze test data for the presence and concentration levels of gases specified in the DTP, which can vary dependent on the test objective.

4.6.1 Objective.

Measure the concentration of toxic gas and aerosol hazards during AFES performance and Live Fire vulnerability testing. These hazards are discussed in paragraph 4.6.c and may include: the fire extinguishing agent, toxic byproducts of pyrolyzed fire extinguishing agent, as well as, combustion products of propellant and plastics. Testing may also include the measurement of oxygen depletion, particulates, and metal aerosols. Each test, scenario, or subtest should be evaluated to determine if any additional toxic gas and aerosol hazards should be measured.

4.6.2 Facilities and Instrumentation.

a. Facilities.

(1) Specialized outdoor firing ranges as specified in the DTP or as required for AFES performance and Live Fire vulnerability toxic fumes tests.

(2) Instrumentation structure suitable for all required equipment/personnel necessary for toxic gas/fume analysis and sampling.

(3) Instrumentation shielding (as needed) to protect equipment from blast, fire, fragments, and other hazards.

b. Instrumentation. Whenever possible, continuous reading gas analyzers will be used and positioned as outlined in the DTP. 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. The sampling and measurement requirements for this type of test are complex and necessitate the use of multiple types of gas analyzers and media sampling equipment. Table 8 provides an outline of the required analyte suite and the current/preferred measurement methodologies. The data collection rates are ultimately determined by the type of instrumentation chosen. The recommended rates are: (1) at least 1 Hz for CEM analyzers, and (2) at least one sample every 5 seconds for FTIRs.

TABLE 8. RECOMMENDED MINIMUM ANALYTE MEASUREMENT SUITE

ANALYTE	MEASUREMENT RANGE	PREFERRED MEASUREMENT TECHNIQUES
Acrolein	NA	Discrete Sorbent Tubes with lab analysis
CO	0 - 10,000 ppm 0 - 10%	FTIR CEM
CO_2	0 - 16%	CEM
COF_2	0 - 2000 ppm	FTIR
Fire Extinguishants (FM-200, Halon 1301)	0 - 20%	FTIR
Formaldehyde [a]	NA 0 – 200 ppm < ~ 25 ppm	Discrete Sorbent Tubes with lab analysis CEM [a] FTIR
HBr	0 - 2000 ppm	FTIR
HCl	0 - 2000 ppm	FTIR
HCN [a]	0 - 100 ppm 0 – 200 ppm < 100 - 2000 ppm	Continuous ion selective electrode (ISE) CEM [a] FTIR
HF	0 - 2000 ppm	FTIR
NO	0 - 10,000 ppm	CEM
NO_2	0 - 500 ppm	CEM
O_2	0 - 25%	CEM
Oil Mist	NA	Discrete Air Filter Cassette with lab analysis
Particulates (Size-Selective)	NA	Discrete Air Sampling using a Cascade Impactor or Cyclone Sampler

Note:

[a] Measurement of formaldehyde and HCN are shifting to a newly acquired laser-based CEM analyzer.

4.6.3 Required Test Conditions.

The required test conditions are governed by the DTP.

4.6.4 Criteria.

The Walter Reed Army Institute of Research (WRAIR) has established military specific standards that are used to evaluate Live Fire Test toxic fumes data[14]. These standards are based upon hazard estimates developed from published toxicity data and from animal experiments sponsored by the U.S. Army. These criteria take into account that, when evaluating combat survivability, avoiding crew/soldier incapacitation is of primary concern. The criteria presented in Table 9 are military unique incapacitation standards and do not equate to civilian exposure limits which are necessarily conservative because of their regulatory nature. The recommended exposure limits for these analytes present in Appendix A do not apply to Live Fire Vulnerability Testing. Additionally, the exposure criteria provided in paragraph 4.5.4 regarding fire extinguishing agents and oxygen apply for these test.

TABLE 9. ARMY LIVE FIRE INCAPACITATION CRITERIA FOR TOXIC GASES

ANALYTE	DOSE [a] (ppm-min)	
	0% INCAPACITATION	100% INCAPACITATION
CO + NO	37,250	62,750
CO_2 [b]	-	-
NO_2	125 (delayed)	375 (delayed)
	250 (immediate)	750 (immediate)
HCN [c]	75	225
Acid halides (HX)[d]	746 (delayed)	2,237 (delayed)
	1,491 (immediate)	4,473 (immediate)
Acrolein	26	None available
Formaldehyde	150	None available

[a] All Time Weighted Averages (TWAs) and dosages are calculated from the time of threat initiation except HCN and CO_2 which are calculated as “worst-case”

[b] CO_2 concentrations equal to or greater than 3 percent for 1 minute or longer in duration increases breathing rates which doubles the toxicity of other gases (CO, NO, NO_2, HF, HCl, HCN). CO_2 is calculated as the rise above ambient.

[c] Doses indicated apply to a 5-minute exposure period; however, any 1-minute exposure average in excess of 90 ppm is considered immediately incapacitating

[d] Combined HF + HBr + HCl + 2(COF_2) dose (Reference 15)

Notes: Incapacitation represents the fractional degradation in performance of physically and mentally demanding military tasks. Figures representing delayed incapacitation assume significant post-exposure exertion. Intermediate degrees of incapacitation are linearly interpolated.

4.6.5 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 Section 5.

4.6.6 Test Procedures (Method).

a. Position gas sampling lines and other sample media (as necessary) at the locations specified in the DTP. If not specified, sample from the breathing zone of each crew member/occupant.

b. Perform all necessary pre-test sample flow checks for each of the media sampling devices used.

c. Prepare sample pumps and ancillary control equipment, setup remote control data links as necessary.

d. Begin acquiring data with the all continuous reading/real-time analyzers at least 30 seconds prior to test and continue recording for a minimum of 15 minutes after initiation of the fire/threat.

e. At the conclusion of the test, ensure the test vehicle has been made safe (i.e., cleared of any explosives/munitions) and thoroughly ventilated. Perform all post-test flow checks before recovering all sample media.

f. Secure all sample media and transport to the laboratory for analysis.

4.6.7 Data Reduction/Presentation.

Tables, graphs, and the associated final report should be formatted as described in Section 6 and/or as required by the DTP.

a. Tables should include the following data for each analyte: peak concentrations, 30 second, 1-, 5-, 10-, and 15-minute average concentrations.

b. Compute the dosage values for each of the analyte groups listed in Table 9 for comparison to the criteria.

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. The measurements will typically be made at the breathing zone of each crew member or occupant (e.g., ppm versus time). 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) Results of daily quality control checks performed.

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

(5) Meteorological metadata, to include: ambient temperature (degrees Celsius (° C) or degrees Fahrenheit (° F)), ambient relative humidity (percent RH), and wind speed (mph/kph).

(6) Vehicle interior conditions, to include: temperature (°C or ° F) and relative humidity (percent RH).

(7) Vehicle identification number and any additional pertinent information.

(8) Vehicle configuration - i.e., hatch(es) position(s) [open/closed], ventilation fan(s) [on/off], environmental control unit [on/off], auxiliary power unit [on/off], etc.

(9) Engine idle speed (revolutions per minute (rpm)) - if applicable.

(10) Photos of the exterior and interior of the test vehicle. Document all significant details pertinent to the test, such as: locations of the engine/heater exhaust outlet(s), ventilation air intakes, position of sample lines/media, etc...

(11) Test duration (minutes).

(12) 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 Section 4.

6. PRESENTATION OF DATA.

The data obtained during the various toxic gas/fumes subtests will be reduced, analyzed and presented as 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 are saved in a format compatible with spreadsheet software, such as Microsoft Excel. Use of 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, and the specific location of the measurement in the vehicle, in accordance with Equation 2:

$$TWA_c = [c_l t_l + c_2 t_2 + c_3 t_3 \text{ .... } c_n t_n] / T \qquad \textit{(Equation 2)}$$

where:

$\mathbf{TWA_c}$ 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. Please note that if the sum of the individual time segments (1 thru n) is less than T, it is assumed that the analyte concentration is zero for the remaining time.

(1) Example calculation number 1:

If the average concentration of Analyte A was determined to 75 ppm over a single 15-minute episode, then the 8-hour TWA, assuming no additional exposure, for Analyte A would be:

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

(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). Refer to Appendix C for this calculation and an explanation of the evaluative 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 vehicle crew/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 vehicle test. 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 analyzed 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, vehicle conditions, etc. Also include any pictures of the setup.

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

e. Technical Assessment. Provide an initial 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/yellow-caution/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 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 federal standards for occupational exposure[14].

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 armored combat vehicle systems. Armored vehicle crews are particularly vulnerable to the adverse effects of exposure to the toxicants in question[16] because of the closely confined space that typify the design of armored vehicle interiors and the accompanying potential for poor ventilation, particularly when operating in a closed hatch mode.

c. Federal occupational exposure standards for hazardous substances are based on OSHA regulations and published Permissible Exposure Limits (PELs) and Threshold Limit Values (TLVs®) recommended by the American Conference of Government Industrial Hygienists (ACGIH). There are circumstances for which military unique standards are developed and implemented. This is accomplished through the mechanism of the DOD Occupational Safety and Health Program (DODI 6055.14). It is incumbent upon the Test Manager / Test Officer to seek out and consult with the appropriate SME (i.e., chemists, industrial hygienists, toxicologists, the APHC HHA Division, etc.) to provide adequate input while developing their DTP to ensure all potential toxic hazards are considered.

d. The occupational exposure standards that have been formally adopted by the DA are defined in AR 40-5 and PAM 40-503. The DA mandates the use of the ACGIH TLVs® when they are more stringent than the OSHA regulations or when there is no PEL. The National Institute for Occupational Safety and Health (NIOSH) 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 exist[7].

e. The following excerpts taken from “Statement of Position Regarding the TLVs and BEIs” included in the ACGIH annual publication[17] should be considered by user of this TOP with regard to potential exposures and applicable risk assessments.

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

> "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.
>
> "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."

f. 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. An additional metric when assessing a potential exposure hazard is the IDLH concentration value for a substance, as it represents the threshold above which acute toxicity effects may occur.

g. Definitions.

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

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

(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 4 times per day. There should be at least 60 minutes between successive exposures in this range.

(3) Ceiling (C): The concentration that shall 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 include 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.

h. Resources. The information in this document is limited to the common analytes cited, and presents the applicable 2019 exposure guidance[3,17-19]. 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) CDC / NIOSH.

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

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

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(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.

(3) APHC. https://phc.amedd.army.mil/PHC%20Resource%20Library/TG230-DeploymentEHRA-and-MEGs-2013-Revision.pdf. Technical Guide 230: 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, C_3H_4O).

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 vehicle 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 NO_2. Acrolein is also a suspected carcinogen.

b. Standards. Use 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

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A.2.2 Ammonia (NH_3).

Results 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. Armored vehicle crews may be particularly vulnerable to exposure because of the confined crew space inside the vehicles; 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 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 ppm[14].

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

TABLE A-2. COMPOSITE OF CIVILIAN NH_3 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 Bromotrifluoromethane ($CBrF_3$, Halon 1301, FE 1301).

The U.S. Army continues to use Halon 1301 as a fire suppressant in legacy vehicle systems (i.e., Abrams and Bradley) in both occupied and unoccupied crew space. Concentrations of 5-6 percent are considered effective for extinguishing most fires. Halon 1301 has been identified as Ozone Depleting Chemicals (ODCs) and the U. S. government has joined an international treaty to eliminate the production and use of ODCs. The use of Halons as fire extinguishing agents by the U. S. Army will be gradually eliminated.

a. Health Effects. The principal toxic effect of Halon inhalation is upon the Central Nervous System (CNS) and is a cardiac sensitizer. The No Observable Adverse Effect Level (NOAEL) is 5.0 percent by volume, while the Lowest Observed Adverse Effect Level (LOAEL) concentration value is 7.5 percent by volume[20]. Upon discharge into a fire, Halon 1301 thermally decomposes forming by-products such as Hydrogen Bromide (HBr), Hydrogen Fluoride (HF), and Carbonyl Fluoride (COF_2). These compounds are extremely irritating to the respiratory tract, skin, and eyes. At elevated concentrations these compounds are very toxic. The discharge of a Halon extinguisher in a confined area, such as a vehicle interior, will displace oxygen and reduce the amount of oxygen available for respiration (simple asphyxiant).

b. Standards.

(1) The safe exposure times and associated agent concentrations for situations involving fire extinguisher discharges are provided in Table A-3.

TABLE A-3. SAFE HUMAN EXPOSURE TIMES FOR HALON 1301[20]

HALON 1301 CONCENTRATION (percent (v/v))	EXPOSURE TIME (minutes)
7 and below	15.0
7 to 10	1.00
10 to 15	0.50
Above 15	Not Permissible

(2) When considering an occupational hazard to Halon 1301, steady state concentrations of 1000 ppm (0.1 percent by volume) or less for an 8-hour TWA are cited by OSHA, NIOSH, and ACGIH.

A.2.4 Carbon Dioxide (CO_2).

Carbon Dioxide is one of the products of fossil fuel burning in internal combustion engines, including the diesel engine. CO_2 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, CO_2 can lead to unexpected suffocation. Fortunately, the hazard posed by CO_2 emissions (compared to CO) are rather minimal when either firing weapons or operating combat/automotive systems. One must be alert to the potential of CO_2 intoxication for combat vehicle operations in closed hatch mode without adequate ventilation, as might occur during silent watch. The closed hatch mode can cause a build-up of CO_2 in the confines of the vehicle 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-4 when considering an occupational hazard or steady state concentrations.

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TABLE A-4. COMPOSITE OF CIVILIAN CO_2 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.2.5 Carbon Monoxide (CO).

Carbon Monoxide is particularly dangerous in that, aside from its toxicity, it is odorless, colorless, 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 armored vehicles (e.g., tanks and armored personnel carriers). 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-5 describes the progression of possible symptoms and health effects of increasing concentrations of CO in air.

TABLE A-5. 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 % Lower Explosive Limit (LEL), Unconsciousness & Death in 1-3 minutes
128,000 ppm (12.8%)	LEL, Death after 1-3 breaths

b. Standards.

(1) Civilian: Use Table A-6 when considering an occupational hazard or steady state concentrations.

TABLE A-6. 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-1472G CN1[5] 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[21] which is a revised form of the CFKE given in MIL-STD-1472G CN1 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 CO[22]. Some of the common symptoms associated with increasing blood COHb levels are provided in Table A-7 for reference purposes.

TABLE A-7. COHb BLOOD LEVELS AND ASSOCIATED HEALTH EFFECTS

COHb BLOOD LEVEL	EFFECTS / SYMPTOMS
≤ 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
≥ 60%	Death

A.2.6 Carbonyl Fluoride (COF_2).

COF_2 may be produced in the thermal decomposition (burning) of fluorine containing organic (carbon-containing) compounds, including some fire extinguishants (i.e., Halon 1301, FM200, and FE-25), refrigerants (i.e., R-134a, etc...), and plastics (i.e., fluoropolymers).

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

a. Health Effects. The effects of COF_2 inhalation are very similar to that of HF; in that it is a severe irritant to the mucous membranes, causes fluorosis, and cardiac arrhythmia.

b. Standards. Use Table A-8 when considering an occupational hazard or steady state concentrations.

TABLE A-8. COMPOSITE OF CIVILIAN COF_2 EXPOSURE LIMITS

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

A.2.7 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-9 when considering an occupational hazard or steady state concentrations.

TABLE A-9. 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

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

A.2.8 1,1,1,2,3,3,3-Heptafluoropropane (CF_3CHFCF_3, HFC-227ea, FM200).

FM-200 is the fire suppressant agent selected by the U.S. Army as the replacement to FE 1301 in occupied spaces. This agent is mainly used in AFES integral with armored combat vehicle systems. Concentrations of approximately 8 - 9% by volume are considered adequate to extinguish fires of most combustible materials[23]. At higher temperatures this chemical decomposes predominantly into hydrogen fluoride and carbonyl fluoride, amongst other products, which are highly toxic gases to humans.

a. Health Effects. Similar to other halocarbon extinguishing agents, HFC-227 is considered a cardiac sensitizing chemical. The NOAEL concentration value for HFC-227 is 9.0 percent by volume, while the LOAEL concentration value is 10.5 percent by volume[23].

b. Standards.

(1) The safe exposure times and associated agent concentrations for situations involving fire extinguisher discharges are provided in Table A-10.

TABLE A-10. SAFE HUMAN EXPOSURE TIMES FOR HFC-227[23]

FM200 CONCENTRATION (percent (v/v))	EXPOSURE TIME (minutes)
9.0 (NOAEL)	5.00
9.5	5.00
10.0	5.00
10.5 (LOAEL)	5.00
11.0	1.13
11.5	0.60
12.0	0.49

(2) When considering an occupational hazard to HFC-227ea, steady state concentrations of 1000 ppm (0.1 percent by volume) or less for an 8-hour TWA are cited on the Safety Data Sheet (SDS) provided with the product.

A.2.9 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 necessarily represent a toxic gas hazard, but rather represents 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.

A.2.10 Hydrogen (H_2).

Hydrogen is a colorless, odorless gas. The flammable range of hydrogen in air is 4 - 75 percent and burns with little evidence of a flame. If a H_2/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 of the LEL).

A.2.11 Hydrogen Bromide (HBr).

HBr is an acid halide gas, it is colorless and has a sharp irritating odor. The primary sources for HBr are from the burning of some plastics. Brominated compounds have commonly been used as flame or fire retardant additives. Another source of HBr is the thermal decomposition of brominated fire extinguishing agents, such as Halon 1301 (bromotrifluoromethane).

a. Health Effects. Inhalation of HBr can be very irritating to the upper respiratory tract causing coughing, pain, inflammation, and edema.

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 HBr EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	3	--	--	NA
STEL	--	--	--	NA
Ceiling	--	3	2	2
IDLH	--	30	--	NA

A.2.12 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. The Multiple Launched Rocket System (MLRS) is yet another potential source for exposure of military personnel to HCl.

a. Health Effects. Inhalation of HCl at irritating concentrations can result in coughing, pain, inflation, 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 the Table A-12 when considering an occupational hazard or steady state concentrations.

TABLE A-12. 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

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A.2.13 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-13 when considering an occupational hazard or steady state concentrations.

TABLE A-13. 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.2.14 Hydrogen Fluoride (HF).

HF has an immediate effect as a severe irritant and delayed or long-term effects include cardiac arrhythmia, as well as bone deposits. HF is produced in significant quantities during fluorine containing fire suppressant decomposition. Carbonyl fluoride rapidly hydrolyzes to form HF. HF is used in its gaseous form for many industrial processes including glass etching, silicon wafer etching, and CFC production.

a. Health Effects. The irritating effects of HF are felt immediately in the eyes, nose, and throat. These effects are followed by ulcerative tracheobronchitis when exposed to high concentrations. Significant exposures can cause hypocalcemia and hypomagnesemia that may result in cardiac arrest and/or death. Long-term acute effects also include increased bone density caused by fluoride deposits (fluorosis/osteosclerosis).

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b. Standards. Use Table A-14 when considering an occupational hazard or steady state concentrations.

TABLE A-14. COMPOSITE OF CIVILIAN HF EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	3	3	0.5	0.5
STEL	--	--	--	NA
Ceiling	--	6	2	3
IDLH	--	30	--	NA

A.2.15 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 NO_2 and discussed as collectively as oxides of Nitrogen (NO_x). However unlike NO_2, 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 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 NO_2. At concentrations below 25 ppm, the conversion of NO to NO_2 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-15 when considering an occupational hazard or steady state concentrations.

TABLE A-15. 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.2.16 Nitrogen Dioxide (NO_2).

NO_2 may be produced during the combustion of nitrogen containing compounds, such as smokeless propellants, explosives, and certain plastics (i.e., nylon). As with nitric oxide, NO_2 may also be present in the exhaust of internal combustion engines. NO_2 is also formed through the oxidation of NO in air, though the rate of this conversion is concentration dependent. NO_2 has a strong acrid odor and can be very irritating.

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 cause severe pulmonary edema, chronic airway damage, and death.

b. Standards. Use Table A-16 when considering an occupational hazard or steady state concentrations.

TABLE A-16. COMPOSITE OF CIVILIAN NO_2 EXPOSURE LIMITS

EXPOSURE TYPE	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
	Concentration in parts per million (ppm)			
TWA	--	--	0.2	0.2
STEL	--	1	--	1
Ceiling	5	--	--	5
IDLH	--	13	--	NA

A.2.17 Oxygen (O_2).

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-17.

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TABLE A-17. 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.

A.2.18 Pentafluoroethane (CHF_2CF_3 , HFC-125, FE-25).

Pentafluoroethane is a Hydrofluorocarbon (HFC) compound commonly used as a fire extinguishing agent in unoccupied areas.

a. Health Effects. Similar to other halocarbon extinguishing agents, HFC-125 is considered a cardiac sensitizing chemical. The NOAEL concentration value for HFC-125 is 7.5 percent by volume, while the LOAEL concentration value is 10 percent by volume.

b. Standards. The safe exposure times and associated agent concentrations for situations involving fire extinguisher discharges are provided in Table A-18.

TABLE A-18. SAFE HUMAN EXPOSURE TIMES FOR HFC-125[21]

HFC-125 CONCENTRATION (percent (v/v))	EXPOSURE TIME (minutes)
11.5 and Below	5.00
12.0	1.67
12.5	0.59
13.0	0.54
13.5	0.49

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A.2.19 Sulfur Dioxide (SO_2).

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 airways. Approximately 10-20 percent of the healthy young adult population is estimated to be hypersensitive to the effects of SO_2.

b. Standards. Use Table A-19 when considering an occupational hazard or steady state concentrations.

TABLE A-19. COMPOSITE OF CIVILIAN SO_2 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
Ceiling	--	--	--	NA
IDLH	--	100	--	NA

A.2.20 Sulfur Hexafluoride (SF_6).

Sulfur hexafluoride is colorless, odorless, non-toxic, and generally considered an inert gas. SF_6 is commonly used as a dielectric gas in high voltage electrical components and switches. SF_6 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 SF_6.

a. Health Effects. SF_6 is non-toxic and is generally classified as a simple asphyxiant.

b. Standards. When considering an occupational hazard to SF_6, the Army OEL is 1000 ppm or less for an 8-hour TWA.

A.2.21 1,1,1,2-Tetrafluoroethane (CF_3CH_2F, R-134a).

R-134a is a Hydrofluorocarbon (HFC) compound commonly used as a refrigerant in vehicle air conditioning systems.

a. Health Effects. Similar to other halocarbon extinguishing agents, R-134a is considered a cardiac sensitizing chemical. The NOAEL concentration value for R-134a is 5.0 percent by volume, while the LOAEL concentration value is 7.5 percent by volume.

b. Standards. When considering an occupational hazard to R-134a, the Army OEL is 1000 ppm or less for an 8-hour TWA.

A.2.22 Particulate Matter (PM) / Aerosols.

For the purposes of this document, PM and aerosols 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[15].

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.

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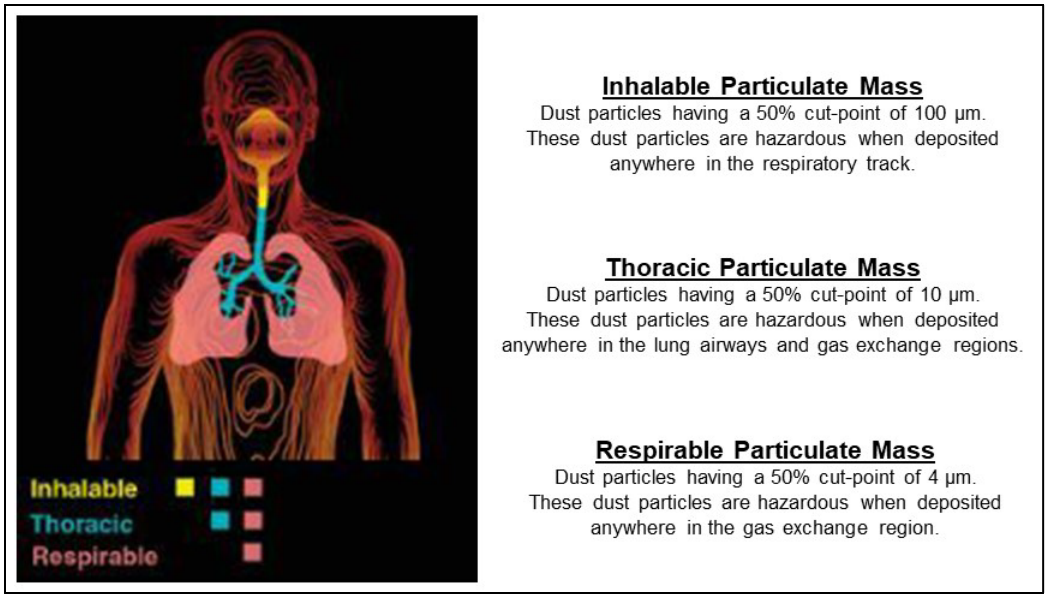

Inhalable Particulate Mass
Dust particles having a 50% cut-point of 100 µm. These dust particles are hazardous when deposited anywhere in the respiratory track.

Thoracic Particulate Mass
Dust particles having a 50% cut-point of 10 µm. These dust particles are hazardous when deposited anywhere in the lung airways and gas exchange regions.

Respirable Particulate Mass
Dust particles having a 50% cut-point of 4 µm. These dust particles are hazardous when deposited anywhere in the gas exchange region.

Figure A-1. Particle Size Classifications (ACGIH).

(1) The term “total” represents the collection of all airborne particulate with no size differentiation.

(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 is 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.

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c. Standards. The recommended airborne concentrations for nuisance dust (PNOR / PNOS) is provided in Table A-20.

TABLE A-20. RECOMMENDED NUISANCE DUST / PNOR / PNOS TWA 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.2.23 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 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 severe central nervous system development inhibition in children or pregnant Soldiers. 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 colic. Lead is also considered a carcinogen.

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b. Standards.

The current civilian criteria for assessing exposure to lead (metal and inorganic compounds) are provide in Table A-21. 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, shall be reduced according to Equation A-1.

TABLE A-21. 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	--	--	--	NA
Ceiling	--	--	--	NA
IDLH	--	100	--	NA

Note:

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

Maximum permissible limit (in micrograms/m^3) = 400 divided by hours worked in the day *(Equation A-1)*

A.2.24 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 (aka “green” 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 a total particulates using a standard filter cassette. Current exposure guidance for a number 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 particle size deposition site within the respiratory tract, 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.

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c. The following sections provide exposure information regarding selected elements commonly encountered during military vehicle test activities. The values cited represent 8-hour TWA limits unless otherwise stated.

(1) Aluminum (Al).

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).

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

(3) Arsenic (Ar) (potential carcinogen).

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 (Ceiling Value)	0.01	0.002 (Ceiling Value)

Notes:

[a] for inorganic compounds.
[b] for organic compounds.

(4) Barium (Ba).

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

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(5) Cadmium (Cd) (potential carcinogen).

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

(6) Chromium (Cr).

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).

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).

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

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(9) Iron (Fe).

IRON	PARTICLE SIZE FRACTION	OSHA PEL	NIOSH REL	ACGIH TLV	ARMY OEL
		Concentration in milligram per cubic meter (mg/m^3)			
Iron Oxide (Fe_2O_3)	Total	10[a]	5[a]	--	5
	Respirable	--	--	5	5

Note:

[a] for metal dust and fume

(10) Manganese (Mn).

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).

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

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

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	
Ni, insoluble compounds	Total	1	0.015	--	0.015
	Inhalable	--	--	0.2	
Ni, soluble compounds	Total	1	0.015	--	0.015
	Inhalable	--	--	0.1	

(13) Tin (Sn).

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).

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	--	--	--	3
	Respirable	--	--	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

Note:

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

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(15) Zinc (Zn).

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 vehicle 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. Fourier Transform Infrared (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 N_2, O_2, and Cl_2 do not have a dipole moment and cannot be detected by FTIR. FTIR operates on the principal of Beer's Law (Equation B-2), which shows a logarithmic relationship between absorbed light and gas concentration.

$$\text{Beer's Law Equation: Absorbance} = \log (I_o/I) = \varepsilon bc \qquad \textit{(Equation B-1)}$$

(2) Where I_o 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 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. NO_2 provides a good example, because its prime absorption overlaps with water vapor. Other gases, such as H_2S, are very poor absorbers of infrared radiation, and therefore cannot be adequately analyzed via this technique. Each particular scenario should be evaluated by a trained analyst to determine if FTIR is a viable technique. FTIR has been successfully used to measure numerous compounds and is useful in the identification of unknown or unanticipated materials in the sample stream. Table B-1 shows basic FTIR gas analyzer configurations.

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 MCT (77° 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:

MCT = Mercury Cadmium Telluride.

[a] 15 cm gas cells are used for systems where an AFES system is employed to avoid signal saturation.

[b] 10 m multi-pass or “White” cell are used for weapons firing or other test requiring low detection limits.

[c] The pressure in the gas cell will vary depending upon sampling configuration and flow rate.

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

(a) NIOSH Method 3800[24], Organic and Inorganic Gases by Extractive FTIR Spectrometry.

(b) Environmental Protection Agency (EPA) Test Method 320[25], Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR) Spectroscopy.

(c) ASTM International Method D6348[26], Standard Test Method for the Determination of Gaseous Compounds by Extractive Direct Interface Fourier Transform Infrared (FTIR) Spectroscopy.

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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 monitor a wide variety of toxic gases, O_2, and combustible gases. 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. 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, CO_2, NO, NO_2, NH_3, SO_2, CH_4, 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 $NO + O_3 \rightarrow NO_2 + O_2 + h\nu$ (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 NO_2 and NH_3 to NO. Bypassing the converter gives NO concentration, while a molybdenum converter gives combined NO and NO_2 (NO_x) concentration, and a

stainless steel converter is used to get NO, NO_2, and NH_3. Using a combination of these converters and bypasses can accurately produce simultaneous NO, NO_2, NO_x, and NH_3 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, $SO_2 + h\nu_1 \rightarrow SO_2^* \rightarrow SO_2 + h\nu_2$, 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 SO_2 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 & Media.

a. The following sites contain links to Occupational Health Analytical Resources:

(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 aide 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 are shown in Figure B-1.

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

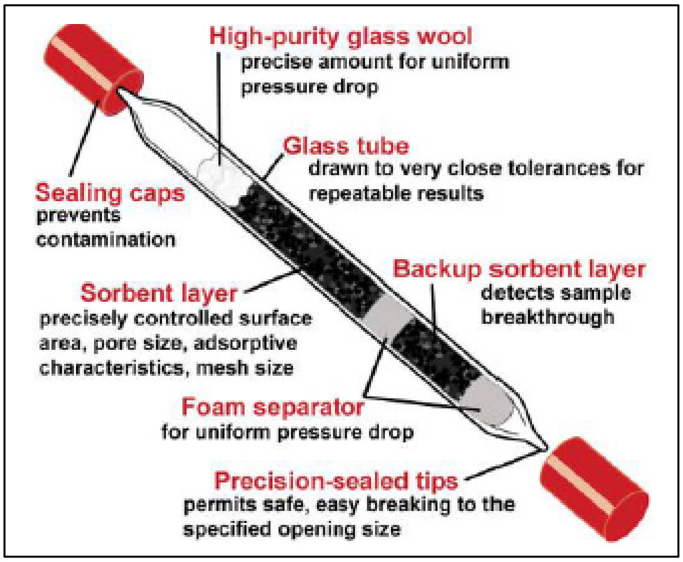


Figure B-1. Elements of a Typical Sorbent Tube.

c. Colorimetric Detector Tubes. Similar to a traditional sorbent tube, detector tubes are designed to be read in the field immediately after sampling. Figure B-2 shows a typical colorimetric detector tube.

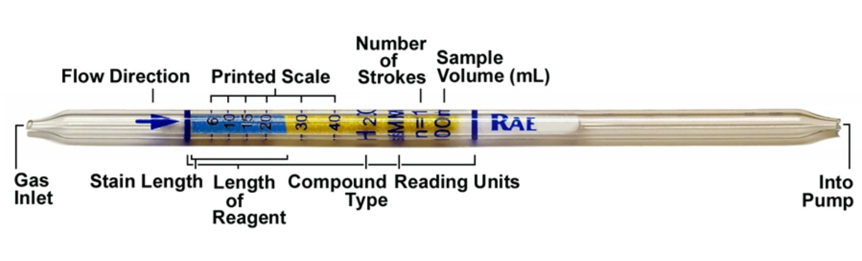


Figure B-2. Colorimetric Detector Tube.

d. Impingers with laboratory analysis. Trapping solutions can be used to extract gas vapors from air and keep the compound in solution for later laboratory analysis. Generally, a filter will be placed at the front of an impinger sampling train, so that any analyte that may be adsorbed on particulate matter can be captured on this media. The particulate and vapor phase concentrations can then be combined for a total dose calculation. Acid gases such as HF and HCl, as well as HCN can be accurately analyzed by this technique. A typical impinge sampler with pump is shown in Figure B-3.

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

Figure B-3. Impinger Sampler with Pump

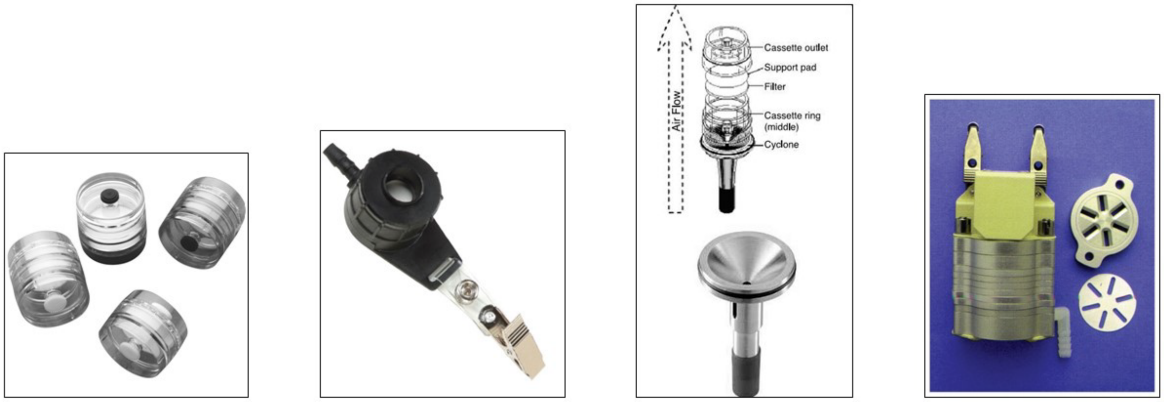
e. Whole air sampling with laboratory analysis. Whole air samples can be drawn from field locations and brought back to the laboratory for later analysis. These samples can be placed in evacuated canisters and/or bags. Canisters must be selected to specifically meet the sampling and analysis requirements 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 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. Figure B-4 shows examples of whole air samplers.

APPENDIX B. INSTRUMENTATION / SAMPLING EQUIPMENT SELECTION.

Various Sizes of
“Inert”* Sample Canisters

Gas Sample Bag

f. 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. Sampler examples are shown in Figure B-5.



37-mm Filter Cartridge (Total Particulates)

IOM Type Filter Cartridge (Inhalable Particulates)

Cyclone Adapter for Filter Cartridge (for Thoracic or Respirable Particulates)

Personal Cascade Impactor (Multiple Stages Collects and Differentiates Inhalable, Thoracic and Respirable Particulates)

Figure B-5. Filter / particle size selective sampler examples.

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APPENDIX C. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.

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 U.S. 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.

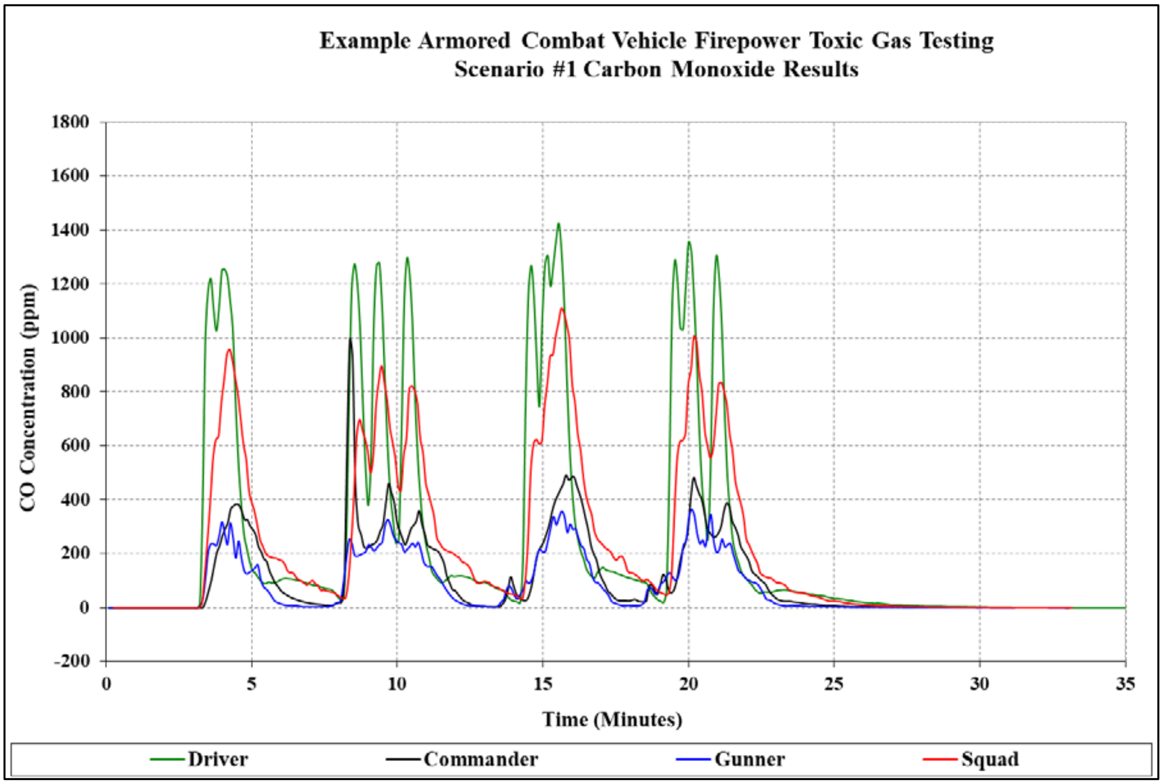


Figure C-1. An example of the plotted CO concentrations in a combat vehicle during a weapons firing test

APPENDIX C. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.

b. Prior to 1980, the U.S. Army essentially evaluated Soldier exposure to CO using the civilian (OSHA) standards[3] and MIL-STD-80017 (now obsolete) for dealing with steady state and transient type exposures respectively. As is discussed in Steinberg and Nielsen[27], 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 U.S. Army Surgeon General and could be applied simply and effectively. In essence, the standard would be categorized as military unique. Such a standard was adopted in May 1981 and is published in MIL-STD-1472G CN1[5] (see paragraph 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 (Equation C-1) 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 evaluation procedure, a brief explanation of the standard should be helpful.

(1) The TWA method of evaluating 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 evaluation. 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 evaluation 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. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.

C.2 PREDICTING PERCENT CARBOXYHEMOGLOBIN (%COHb).

a. The predicted percent COHb level for each crew member or occupant as determined by the CFKE algorithm specified in MIL-STD-1472G CN1[5]. In its present modified form, the CFKE is easily adapted for use with a spreadsheet program for data analysis and visualization (example shown in Figure C-2). The user should note that the modified CFKE, 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 CFKE is fundamentally based upon laboratory experimentation and that verification of the equation should be based on actual field tests. One such test[22] was completed during June/July 1985 and published in 1986. The findings indicated that the CFKE, as currently used, was a reasonable predictor of COHb blood level.

b. Empirical Equation.

$$\%\,COHb_t = \%\,COHb_o\,[\,e^{(-t/A)}\,] + 218\,[\,1 - e^{(-t/A)}]\,[\,1/B + ppm\,CO/1403\,] \qquad \textit{(Equation C-1)}$$

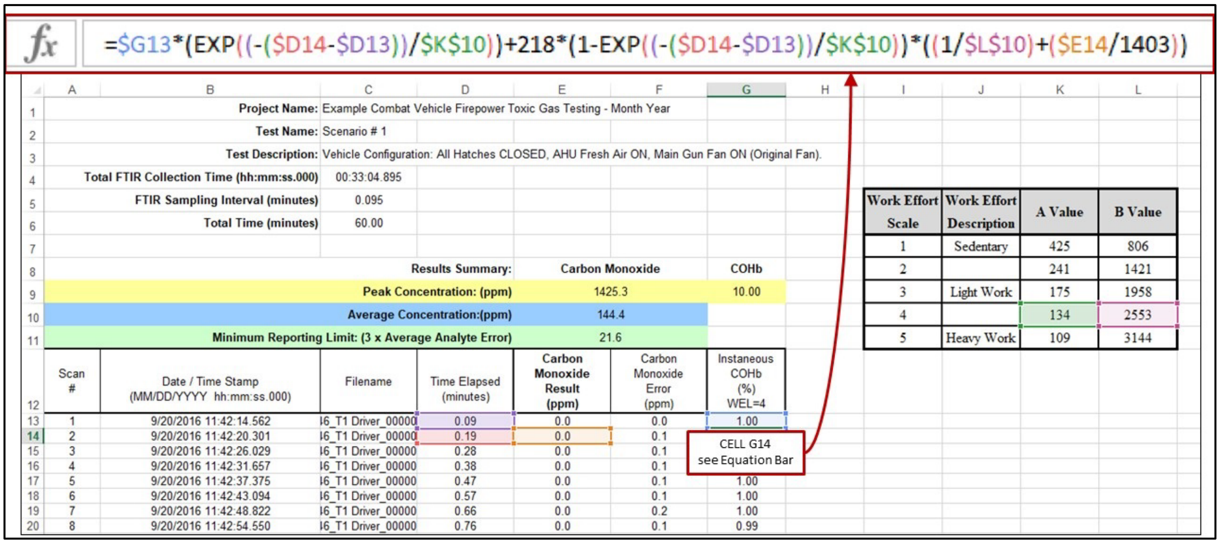
Where:

% $COHb_t$ = the predicted value in an exposed individual.
% $COHb_o$ = the initial amount of COHb usually found in nonsmoking adults.
t = the exposure duration in minutes.
ppm CO = carbon monoxide concentration (in parts per million) in the contaminated air.
e = the mathematical constant, natural exponent, whose value equals 2.71828.
A and B = 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.

TABLE C-1. CONSTANTS FOR CFKE 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 CFKE to estimate the % COHb blood levels for combat vehicle occupants, the following work effort/stress levels shall be applied as appropriate: activities involving weapons fire = Level 4; all other mission activities = Level 3. An initial value of COHb (i.e., % $COHb_o$) equal to 1.0 shall be assumed for all estimates.			

APPENDIX C. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.



```
=$G13*(EXP((-($D14-$D13))/$K$10))+218*(1-EXP((-($D14-$D13))/$K$10))*((1/$L$10)+($E14/1403))
```

Project Name: Example Combat Vehicle Firepower Toxic Gas Testing - Month Year
Test Name: Scenario # 1
Test Description: Vehicle Configuration: All Hatches CLOSED, AHU Fresh Air ON, Main Gun Fan ON (Original Fan).
Total FTIR Collection Time (hh:mm:ss.000) 00:33:04.895
FTIR Sampling Interval (minutes) 0.095
Total Time (minutes) 60.00

Results Summary:	Carbon Monoxide	COHb
Peak Concentration: (ppm)	1425.3	10.00
Average Concentration:(ppm)	144.4	
Minimum Reporting Limit: (3 x Average Analyte Error)	21.6	

Scan #	Date / Time Stamp (MM/DD/YYYY hh:mm:ss.000)	Filename	Time Elapsed (minutes)	Carbon Monoxide Result (ppm)	Carbon Monoxide Error (ppm)	Instaneous COHb (%) WEL=4
1	9/20/2016 11:42:14.562	I6_T1 Driver_00000	0.09	0.0	0.0	1.00
2	9/20/2016 11:42:20.301	I6_T1 Driver_00000	0.19	0.0	0.1	
3	9/20/2016 11:42:26.029	I6_T1 Driver_00000	0.28	0.0	0.1	
4	9/20/2016 11:42:31.657	I6_T1 Driver_00000	0.38	0.0	0.1	
5	9/20/2016 11:42:37.375	I6_T1 Driver_00000	0.47	0.0	0.1	1.00
6	9/20/2016 11:42:43.094	I6_T1 Driver_00000	0.57	0.0	0.1	1.00
7	9/20/2016 11:42:48.822	I6_T1 Driver_00000	0.66	0.0	0.2	1.00
8	9/20/2016 11:42:54.550	I6_T1 Driver_00000	0.76	0.0	0.1	0.99

CELL G14
see Equation Bar

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

Figure C-2. Computing instantaneous percent $COHb_t$ estimates using a spreadsheet program.

C.3 EVALUATIVE PROCESSES.

C.3.1 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 positions (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 evaluation of the overall CO exposure hazard associated with the particular vehicle weapons firing scenario.

APPENDIX C. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.

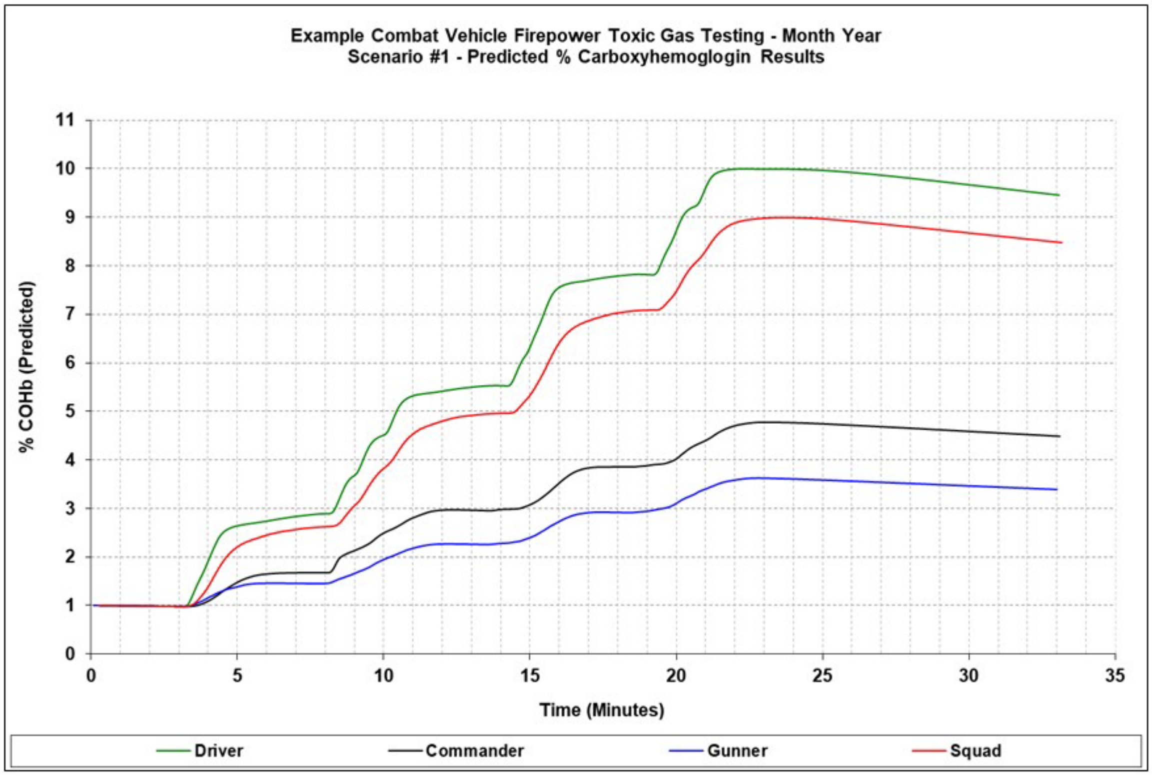


Figure C-3. An example of the plotted instantaneous COHb levels in a combat vehicle during weapons firing activities.

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 CFKE in this manner aids in examining the boundary conditions for safe operation which are (for this analysis) defined as follows:

(1) Maximum Firing Rate. 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.

APPENDIX C. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.

(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 for any crew member or occupant. 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 Sustained Firing Rate coincides with the Maximum Firing Rate.

(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 crew 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.

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

Where:

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

A and B = 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 = the natural logarithm function.

% $\text{COHb}_{\text{target}}$ = the desired COHb value in the individual.

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

b. The maximum firing rate 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 crew 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, number of rounds fired, etc., which provides the systems analyst with the means for improving combat effectiveness.

APPENDIX C. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.

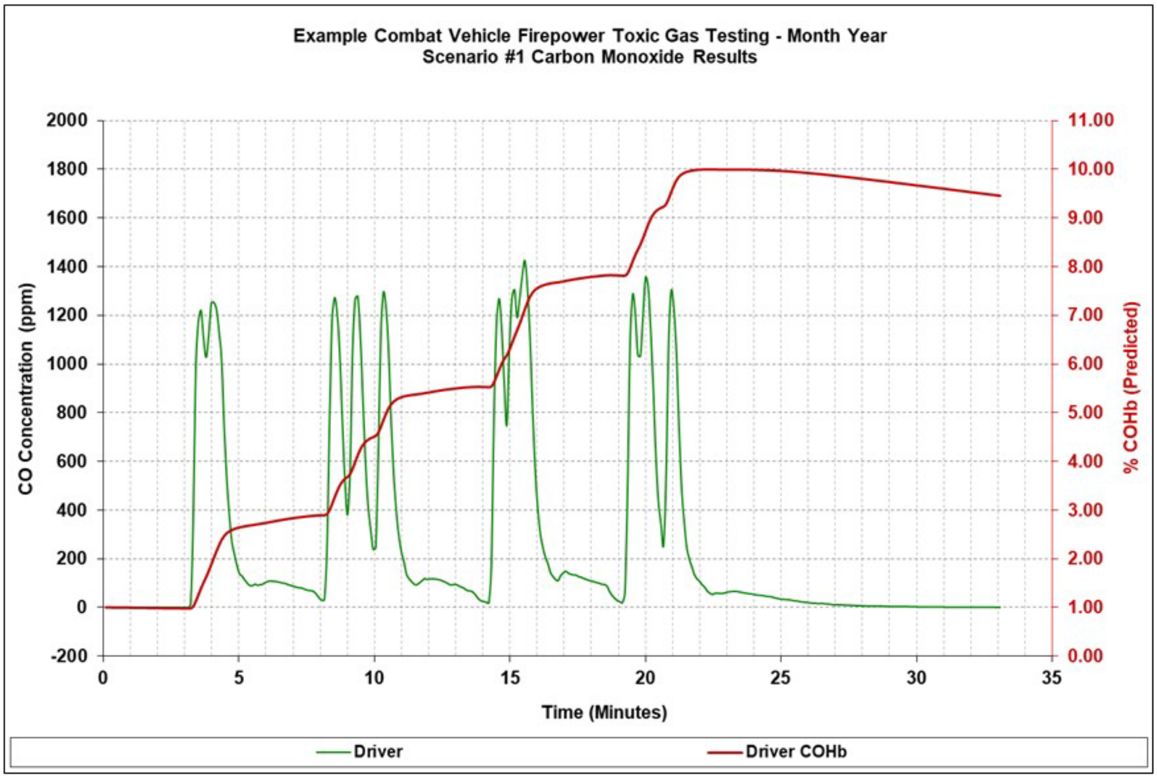


Figure C-4. An example weapons firing scenario where the upper COHb limit is reached at the critical crew position.

C.3.3 Extended Operations.

The CFKE is best adaptable to exposure data gathered on the basis of conducting realistic operational scenarios for the particular weapon system or combat vehicle being evaluated. Such operations might include a projected 24 hour, 48 hour, or other battle or training scenario. If the U.S. Army Training and Doctrine Command (TRADOC) provides the materiel developer with such a scenario, the data gathered during the scenario can be input into a spreadsheet program to determine the degree of compliance with the standard. Basically, the input data to the program consists of CO exposure segments gathered during the scenario simulation. If, for example, a group of segments is comprised of: 3 minute main weapon firing, 2 minute co-axial weapon firing, 4 minute M85 machinegun firing, 15 minute rest period, a replication of the prior firing scenario followed by a 30 minute silent watch, these exposure data are separated into 8 separate segments with 6 of these segments (firing data) being comprised of transient data (work effort level 4) and the 2 intermediate periods comprised of steady state data (work effort level 3). These data would be input to the CFKE spreadsheet chronologically and then sequentially replicated as with the MACE calculation. It should be noted that the data of the intermediate segments could be either estimated or measured depending on the specifications contained in the detailed test plan or what logic would dictate. The results ($COHb_t$ for each segment and crew position) could be plotted as a function of time to determine the extent of compliance with the standard and to indicate the critical crew position for the mission. In the event of non-compliance with the standard, the plotted results could provide the designer and/or combat developer with valuable information as to the potential for design correction or combat doctrine revision. Additionally, the risk of non-compliance with the standard can be addressed easily. In the event compliance with large margins are indicated from the plotted data, doctrine can possibly be altered or battle scenarios revised such that combat effectiveness is improved.

C.3.4 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 combat vehicle and/or weapons platform, 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.

C.4 FIRING SCENARIOS.

a. This section is intended to provide the toxic gas and aerosol tester with sample test firing scenarios in the event the DTP excludes such details. Often, such details are lacking because vehicle tactical operations and analyses are not issues for the developer to resolve and the user (TRADOC) has not finalized plans for the training of crews at the phase of the system development when toxic gas and aerosol testing has been scheduled. Sometimes a standard battle scenario does exist from which the tester is able to develop appropriate test scenarios.

b. In the absence of a realistic test scenario, the tester must provide one that balances system specification constraints with conduction of tests, which are both technically correct and economically sensible. Because the health and safety of interfacing crews are at stake, the tester must be capable of identifying firing rates and crew positions that are critical from a toxic gas and aerosol exposure viewpoint. Ordinarily, experience provides the tester with this knowledge. The test program should not become overly stringent and result in needless testing or testing which departs from a realistic combat or training user scenario as defined in the Operational Mode Summary Mission Profile or as specified by the Materiel Developer; such as exceeding weapons design specifications (unusually rapid firing rates) or firing weapons from vehicles with hatches closed and no active ventilation.

c. The following paragraphs provide guidance as to scenarios used for systems already fielded.

(1) The firing sequence provided in Table C-2 represents a typical training scenario used for a Main Battle Tank (or equivalent vehicle type with a large caliber direct fire gun). This firing sequence was originally provided by the U.S. Army Armor Center at Fort Knox, KY and has been used extensively for the purpose of toxic gas and aerosol testing.

TABLE C-2. EXAMPLE TESTING CADENCE FOR BATTLE TANK

TIME (minutes)	MAIN GUN (105mm or 120mm)	COAX MACHINE GUN (0.50 cal or 7.62mm)	FIRING MODE
0.00	1		SS
0.50	1		SS
1.00	1		SS
4.00	1		SS
4.50	1		SS
5.00		25	B
5.25		25	B
5.50		25	B
5.75		25	B
9.00	1		SS
9.50	1		SS
10.00	1		SS
13.00	1		SS
13.50	1		SS
14.00	1		SS
* 16.00 *	Conclude test once CO levels reach baseline		
Totals: 11 main gun rounds and 100 machine gun rounds			
Note - SS denotes “single shot”; B denotes “burst”			

(2) Bradley Fighting Vehicle (BFV) System Test Scenarios. Table C-3 summarizes the test scenario historically used for developmental test programs for the BFV or other vehicles equipped with a medium caliber (20 - 40 mm cannon) weapons platform. The test scenario is derived from a TRADOC scenario depicting the BFV as part of a mechanized infantry battalion conducting an active 24-hour defense. Events 12 and 15 represent the most intense fighting episodes during the 24-hour period. Events 13 and 14 are non-firing events covering a total of 22 minutes. To assess the worst case toxic gas and aerosol exposure, Events 12 and 15 are typically conducted sequentially, thus omitting the 22 minute pause between the critical firing episodic events.

APPENDIX C. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.

TABLE C-3. BRADLEY TRADOC SCENARIOS 12 AND 15

SCENARIO 12				SCENARIO 15			
TIME (minutes)	MAIN GUN 25 mm	COAX 7.62 mm	FIRING MODE	TIME (minutes)	MAIN GUN 25 mm	COAX 7.62 mm	FIRING MODE
0.0	10		SS	26.0	10		SS
2.0	10		SS	27.0	10		SS
4.0	10		SS	28.0	10		SS
6.0	10		SS	29.0	10		SS
8.0	10		SS	30.0	10		SS
10.0	10		SS	31.0	10		SS
11.0	10		SS	32.0	10		SS
12.0	10		SS	33.0	10		SS
13.0		21	B	34.0	10		SS
14.0		21	B	35.0	10		SS
15.0		21	B	36.0	10		SS
17.0		21	B	36.5	10		SS
19.0		42	B	37.0	10		SS
20.0		21	B	38.0	10		SS
21.0		43	B	39.0	10		SS
21.5	5		SS	40.0	5		SS
22.0	5		B	40.5	5		B
22.5	5		SS	41.0	5		SS
23.0	5		B	41.5	5		B
23.5	5		SS	42.0	5		SS
24.0	5		B	42.5	5		B
25.0	5		B	43.0	5		SS
				43.5	5		B
				44.0	5		SS
				44.5	10		B
				45.0		55	B
				46.0		55	B
Scenario 12 Totals: 115 main gun / 190 coax machine gun				Scenario 15 Totals: 205 main gun / 110 coax machine gun			
Totals when firing sequentially (worst case): 220 main gun / 300 coax machine gun							
Note - SS denotes “single shot”; B denotes “burst”							

(3) A revised firing scenario was proposed by the U.S. Army Infantry Center and adopted by TRADOC that is more representative of a “worst case – most probable” defensive engagement condition. Table C-4 provides a simplified version of this scenario for use in testing in support of BFV safety confirmations. The simplified scenario removes the vehicle movements conducted during training as this reduces the risk of damage to sampling lines during testing. A copy of the TRADOC memorandum can be obtained from the APHC HHA Division.

APPENDIX C. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD DURING WEAPONS FIRING SCENARIOS IN MILITARY VEHICLES.

TABLE C-4. REVISED BFV FIRING SCENARIO - SIMPLIFIED

ELAPSED TIME (min:sec – min:sec)	MAIN GUN 25 mm	COAX 7.62 mm	DESCRIPTION OF FIRING MODES
START – 00:30	25		5x 5 round bursts high rate
00:30 – 01:00	25		5x 5 round bursts high rate
01:00 – 01:30	25		5x 5 round bursts high rate
01:30 – 04:30	-	-	Break
04:30 – 04:45		50	2x 25 round bursts
04:45 – 05:00	-	-	Break
05:00 – 05:15	25		5x 5 round bursts high rate
05:15 – 05:30		50	2x 25 round bursts
05:30 – 05:45	-	-	Break
05:45 – 06:00	25		5x 5 round bursts high rate
06:00 – 06:15	-	-	Break
06:15 – 06:30		50	2x 25 round bursts
06:30 – 06:45		50	2x 25 round bursts
06:45 – 07:00	25		5x 5 round bursts high rate
07:00 – 10:15	-	-	Break
10:15 – 10:30		50	2x 25 round bursts
10:30 – 10:45		50	2x 25 round bursts
10:45 – 11:00	-	-	Break
11:00 – 11:15	25		5x 5 round bursts high rate
11:15 – 11:30	-	-	Break
11:30 – 11:45	25		5x 5 round bursts high rate
11:45 – 12:00	-	-	Break
12:00 – 12:15	25		5x 5 round bursts high rate
12:15 – 15:15	-	-	Break
15:15 – 15:30		50	2x 25 round bursts
15:30 – 15:45	-	-	Break
15:45 – 16:00		50	2x 25 round bursts
16:00 – 16:15	25		5x 5 round bursts high rate
16:15 – 16:30	-	-	Break
16:30 – 16:45	25		5x 5 round bursts high rate
16:45 – 17:00			Break
17:00 – 17:15		50	2x 25 round bursts
17:15 – 17:45	25		5x 5 round bursts high rate
17:45 – END			Monitor gas concentrations and continue sampling until baseline levels are reached
Scenario Totals: 300 main gun rounds / 450 coax machine gun			

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APPENDIX D. EXAMPLE DATA TABLES.

TABLE D-1. EXAMPLE AIR EXCHANGE TEST REPORT DATA TABLE

SCENARIO	TRIAL	AIR EXCHANGE RATE		OUTDOOR (FRESH) AIR ENTERING	
		Per Minute	Per Hour	(ft^3/min)	(m^3/min)

TABLE D-2. EXAMPLE AUTOMOTIVE TOXIC GAS TEST REPORT DATA TABLE

Vehicle Configuration					
Meteorological Conditions	**Measurement**	**Ambient / Exterior**		**Vehicle Interior**	
	Temperature				
	Rel. Humidity				
	Wind				
Compound	**Calculation**	**Position 1**	**Position 2**	**Position 3**	**Position 4**
		Results (ppm)			
Carbon Monoxide (CO)	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Carbon Dioxide (CO2)	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Nitric Oxide	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Nitrogen Dioxide	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Sulfur Dioxide	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				

APPENDIX D. EXAMPLE DATA TABLES.

TABLE D-3. EXAMPLE WEAPONS FIRING TOXIC FUMES TEST REPORT DATA TABLE

Vehicle Configuration					
Meteorological Conditions	**Measurement**	**Ambient / Exterior**		**Vehicle Interior**	
	Temperature				
	Rel. Humidity				
	Wind				
Compound	**Calculation**	**Position 1**	**Position 2**	**Position 3**	**Position 4**
		Results (% COHb)			
Carbon Monoxide (CO)	**COHb using CFKE**				
Compound	**Measurement**	**Results (ppm)**			
Ammonia	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Carbon Dioxide	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Hydrogen Cyanide	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Nitric Oxide	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Nitrogen Dioxide	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Sulfur Dioxide	**Maximum**				
	15-min AVG				
	Trial AVG				
	8-Hr TWA				
Air Filter Analyte	**Measurement**	**Results (mg/m^3)**			
Lead	**Lab Result**				
	8-Hr TWA				

APPENDIX D. EXAMPLE DATA TABLES.

TABLE D-4. EXAMPLE AFES MAPPING TEST REPORT DATA TABLE (FOR FM200)

Test Item Configuration:					
Analyte	**Measurement Parameter**	Measured Concentration (% volume)			
		Position 1	Position 2	Position 3	Position 4
FM200	**Maximum**				
	0.49 min AVG				
	0.60 min AVG				
	1.13 min AVG				
	5.00 min AVG				
Analyte	**Measurement Parameter**	Measured Concentration (% volume)			
		Position 5	Position 6	Position 7	Position 8
FM200	**Maximum**				
	0.49 min AVG				
	0.60 min AVG				
	1.13 min AVG				
	5.00 min AVG				
Analyte	**Measurement Parameter**	Measured Concentration (% volume)			
		Position 1	Position 2	Position 3	Position 4
Oxygen	**Minimum (5.0 sec AVG)**				

APPENDIX D. EXAMPLE DATA TABLES.

TABLE D-5. EXAMPLE AFES PERFORMANCE / LIVE FIRE TEST REPORT DATA TABLE (FTIR)

Analyte*	**Measurement Parameter**	**Measured Concentrations**			
		Position 1	**Position 2**	**Position 3**	**Position 4**
CO	**Maximum**				
	0.5 min AVG				
	1.0 min AVG				
	5.0 min AVG				
	15.0 min AVG				
COF_2	**Maximum**				
	0.5 min AVG				
	1.0 min AVG				
	5.0 min AVG				
	15.0 min AVG				
FM200 (or other agent)	**Maximum**				
	0.49 min AVG				
	0.60 min AVG				
	1.13 min AVG				
	5.00 min AVG				
HCl	**Maximum**				
	0.5 min AVG				
	1.0 min AVG				
	5.0 min AVG				
	15.0 min AVG				
HF	**Maximum**				
	0.5 min AVG				
	1.0 min AVG				
	5.0 min AVG				
	15.0 min AVG				

* Include additional analytes as necessary.

APPENDIX D. EXAMPLE DATA TABLES.

TABLE D-6. EXAMPLE AFES PERFORMANCE / LIVE FIRE TEST REPORT DATA TABLE (CEM)

Analyte	**Measurement Parameter**	**Measured Concentrations**			
		Position 1	**Position 2**	**Position 3**	**Position 4**
CO_2	**Maximum**				
	0.5 min AVG				
	1.0 min AVG				
	5.0 min AVG				
	15.0 min AVG				
NO	**Maximum**				
	0.5 min AVG				
	1.0 min AVG				
	5.0 min AVG				
	15.0 min AVG				
NO_2	**Maximum**				
	0.5 min AVG				
	1.0 min AVG				
	5.0 min AVG				
	15.0 min AVG				
O_2	**Minimum**				
	0.5 min AVG				
	1.0 min AVG				
	5.0 min AVG				
	15.0 min AVG				
HCN	**Maximum**				
	1.0 min AVG				
	5.0 min AVG				

TABLE D-7. EXAMPLE AFES PERFORMANCE / LIVE FIRE TEST REPORT DATA TABLE (DISCRETE MEDIA)

Analyte	**Measurement Parameter**	**Reported Concentrations**			
		Position 1	**Position 2**	**Position 3**	**Position 4**
Acrolein	**0.5 min**				
	1.0 min				
	5.0 min				
	15.0 min				
Formaldehyde	**0.5 min**				
	1.0 min				
	5.0 min				
	15.0 min				
Oil Mist	**15.0 min**				
Respirable Particulate	**15.0 min**				
Total Particulate	**15.0 min**				

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APPENDIX E. ABBREVIATIONS.

ACGIH	American Conference of Governmental Industrial Hygienists
AFES	Automatic Fire Extinguishing System
Al	Aluminum
APHC	U.S. Army Public Health Center
APU	Auxiliary Power Unit
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
BFV	Bradley Fighting Vehicle
°C	degrees Celsius
C	ceiling
CAS	Chemical Abstracts Service
Cd	Cadmium
CEM	Continuous Emission Monitor
CFKE	Coburn-Forster-Kane Equation
Co	Cobalt
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COF_2	Carbonyl Fluoride
COHb	Carboxyhemoglobin
Cr	Chromium
Cu	Copper
DOD	Department of Defense
DODI	Department of Defense Instruction
DTP	Detailed Test Plan
EPA	Environmental Protection Agency
°F	degrees Fahrenheit
Fe	Iron
FTIR	Fourier-Transform Infrared
Hb	Hemoglobin
HBr	Hydrogen Bromide
HCl	Hydrogen Chloride
HCHO	Formaldehyde
HCN	Hydrogen Cyanide

APPENDIX E. ABBREVIATIONS.

HF	Hydrogen Fluoride
HFC	Hydrofluorocarbon
HVAC	heating, ventilation, and air conditioning
IDLH	Immediately Dangerous to Life and Health
IOP	Internal Operating Procedure
ISE	Ion Selective Electrode
kph	kilometers per hour
LEL	Lower Exposure Limit
LOAEL	Lowest Observed Adverse Effect Level
µm	micron
MACE	Maximum Allowable Consecutive Episodes
MCT	Mercury Cadmium Telluride
MetHb	Methemoglobin
MIL-STD	Military Standard
MLRS	Multiple Launched Rocket System
Mn	Manganese
Mo	Molybdenum
mph	miles per hour
NBC	Nuclear, Biological, and Chemical
NDIR	Non-Dispersive Infrared
NFPA	National Fire Protection Association
NH_3	Ammonia
Ni	Nickel
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NMAM	NIOSH Manual of Analytical Methods
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NO_x	Oxides of Nitrogen
NOAEL	No Observable Adverse Effect Level
NOHb	Nitrosylhemoglobin
O_2	Oxygen
ODC	Ozone Depleting Chemical
OEL	Occupational Exposure Limit
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration

APPENDIX E. ABBREVIATIONS.

Pb	Lead
PNOR/PNOS	Particulates Not Otherwise Regulated / Specified
ppb	parts per billion
ppe	Personal Protective Equipment
ppm	parts per million
RH	Relative Humidity
rpm	revolutions per minute
Sb	Antimony
SDS	Safety Data Sheet
SF_6	Sulfur Hexafluoride
SFR	Sustained Firing Rate
SME	Subject Matter Expert
Sn	Tin
SO_2	Sulfur Dioxide
Sr	Strontium
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
TOP	Test Operations Procedure
TRADOC	U.S. Army Training and Doctrine Command
TSG	The Surgeon General of the U.S. Army
TWA	Time Weighted Average
W	Tungsten
WRAIR	Walter Reed Army Institute of Research
Zn	Zinc

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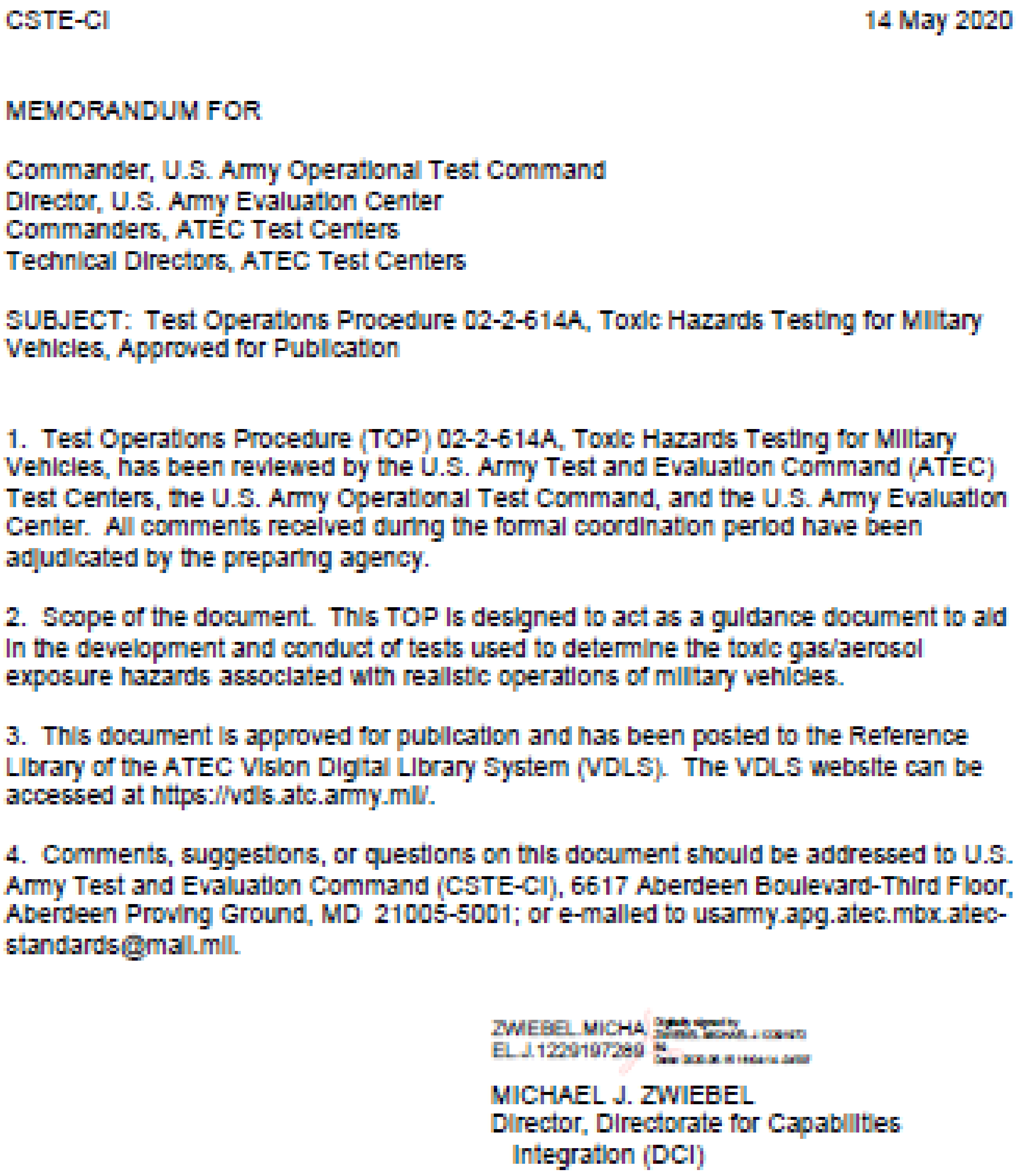
APPENDIX G. APPROVAL AUTHORITY.



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 02-2-614A, Toxic Hazards Testing for Military Vehicles, Approved for Publication

1. Test Operations Procedure (TOP) 02-2-614A, Toxic Hazards Testing for Military Vehicles, 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 vehicles.

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.

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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: Warfighter Directorate (TEAT-WFA), U.S. Army Aberdeen Test Center, 6943 Colleran Road, 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.