REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE: 28 February 1995

3. REPORT TYPE AND DATES COVERED: Final

4. TITLE AND SUBTITLE

Test Operations Procedure (TOP) 2-2-614 Toxic Hazards Tests for Vehicles and Other Equipment

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Commander
U.S. Army Combat Systems Test Activity
ATTN: STECS-AC-I
Aberdeen Proving Ground, MD 21005-5059

8. PERFORMING ORGANIZATION REPORT NUMBER

TOP 2-2-614

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Commander
U.S. Army Test and Evaluation Command
ATTN: AMSTE-CT-T
Aberdeen Proving Ground, MD 21005-5055

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

Same as Item 8

11. SUPPLEMENTARY NOTES

Defense Technical Information Ceneter (DTIC), AD No: A
(This TOP supersedes TOP 2-2-614, 14 December 1984)

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release,
Distribution unlimited

12b. DISTRIBUTION CODE

19950216 072

13. ABSTRACT (Maximum 200 words)

Details are specified as to requirements and conduct of tests governing the measurement and analyses (as pertains to human exposure) of concentrations of common toxic gas/metal compounds produced during equipment/systems operations including: weapons firing from combat vehicles; automotive operations; operation of fueled fired heaters; firing of rockets/missiles using either solid or liquid propellants; operation of fuel burning systems; and activation of fire extinguishing systems. Included are the associated air standards for air quality and exposure as well as requirements and general specifications/criteria governing the measuring instrumentation. Particular attention is devoted to exposure to carbon monoxide (CO) and the details as to the analysis of CO exposure since it is the leading indicator of airborne toxicity.

14. SUBJECT TERMS

Carbon Monoxide	Sulfur Dioxide	Halon
Carbon Dioxide	Oxides of Nitrogen	Lead Fumes/Particulates
Ammonia	Hydrogen Chloride	

15. NUMBER OF PAGES: 52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED			SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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

*Test Operations Procedure (TOP) 2-2-614 — 28 February 1995

TOXIC HAZARDS TESTS FOR VEHICLES AND OTHER EQUIPMENT

1. SCOPE. This TOP details specific tests designed to both measure and analyze the concentrations of toxic gas/metal compounds produced during equipment/systems operations such as would occur during:

a. Firing of weapons from combat vehicle systems.

b. Operation of engines during automotive operations.

*This TOP supersedes TOP 2-2-614 dated 14 December 1984.

Approved for public release; distribution unlimited.

c. Operation of fuel fired personnel heaters.

d. Firing rockets/missiles, which burn either solid or liquid propellants, from air and ground weapons systems such as the Multiple Launch Rocket System (MLRS), HELLFIRE (HMMS (Air or Ground launched)), STINGER, TOW, etc.

e. Operation of any fuel burning systems, e.g., generators and compressors.

f. Activation (intentional, unintentional) of fire extinguishers and/or automated extinguishant systems.

The emphasis of these tests is to verify compliance with Army occupational safety and health standards in accordance with AR 40-5[1]**. Beyond the scope of this document are toxic fumes tests associated with the "Live Fire Program" as part of Vulnerability/Lethality/Survivability Studies. The evaluations and hazards of toxic fumes resulting from Live Fire Testing will be addressed separately.

1.1 Toxic Contaminants Covered. The toxic contaminants addressed in this document include:

a. Carbon Monoxide (CO).

b. Carbon Dioxide (CO_2).

c. Ammonia (NH_3).

d. Sulfur Dioxide (SO_2).

e. Oxides of Nitrogen (NO_x).

f. Hydrogen Chloride (HCl).

g. Fire Suppressants (FE 1301 (Bromotrifluoromethane) - ($CBrF_3$)).

h. Lead (Pb -(fumes/particulates)).

These toxicants are the leading contaminants to which soldiers and other personnel, working with the Army, may be subjected. Appendix A summarizes/ discusses, individually, the physiological issues and hazards to health associated with each of the listed compounds. Appendix C (and Paragraph 4.0) lists the applicable standards for exposure to these toxic compounds.

**Superscript numbers correspond to references in Appendix G.

Note: The policies and procedures specified in AR 70-25[2] 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 TECOM tests will not be used as the subjects of experimentation. Additionally, because the equipment, systems, and operational environment subject to tests, as provided by this document, are military unique, they are exempt from OSHA standards dealing with toxic contaminants except those mandated by the Surgeon General in Executive Order 12196.[3]

2. FACILITIES AND INSTRUMENTATION. Because the test facilities and instrumentation may be unique to specific test types, and basically, toxic fumes testing is best guided by the format in which detailed test plans (DTP) are prepared,[4] the "Facilities and Instrumentation" details are presented in paragraph 4. (Test Procedures) below.

3. REQUIRED TEST CONDITIONS. These details also are presented in paragraph 4 for the reasons given in the preceding paragraph.

4. TEST PROCEDURES. This paragraph addresses five (5) specific test types including: Automotive, Weapons Systems (Ground), Chamber, Fire Extinguishing Systems, and Miscellaneous. As much as is applicable for each test type, this paragraph will include subparagraphs which are detailed under specific heading titles including: Objectives, Facilities and Instrumentation, Required Test Conditions, Criteria (standards), Required Data, Test Methods, and Data Reduction/Presentation.

4.1 Automotive Tests.

a. These tests usually form a part of overall testing governing "Automotive Safety and Health Hazard Evaluation"[5]. Paragraph 4.7 of Reference 4 covers "Toxic Gas Measurement" and specifies that details will be presented in TOP 2-2-614.

b. Automotive tests include conventional wheeled vehicles such as autos, trucks, multipurpose/utility vehicles (High Mobility Multipurpose Wheeled Vehicle (HMMWV)), fork lifts, earth movers, tankers, cranes, etc., which usually traverse primary and secondary roads as well as cross country terrain. Excluded from the Automotive category are tests involving weapons fire. Weapons fire tests will be detailed in paragraph 4.2.

4.1.1 Objective. Measure concentrations of toxic gasses resulting from realistic operations of automotive type vehicles (under development or in the inventory) to determine the degree of hazard to operating and maintaining crews and vehicle occupants.

4.1.2 Facilities and Instrumentation.

a. Facilities.

(1) Automotive test courses as specified in the detailed test plan (DTP) or as required.

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

b. Instrumentation. Automotive tests require instrumentation to measure concentrations of, basically, five (5) gaseous compounds including: carbon monoxide, carbon dioxide, sulfur dioxide, oxides of nitrogen (NO_2, NO) and hydrocarbons. In addition, instrumentation is needed to obtain ambient atmospheric data consisting of temperature, barometric pressure, and relative humidity (RH). Also, the internal temperature and RH of the vehicle are required. Finally, the speed of the vehicle undergoing testing should be obtained. The following tabulation (table 4.1-1) provides guidance governing the suggested permissible error and minimum detection limit for the instrumentation. It should be noted that these are general guidelines only for usual situations; more stringent requirements may be necessary for special circumstances.

Instruments measuring gas concentrations should have either a dosimeter function or provide an output signal that can be recorded.

TABLE 4.1-1. AUTOMOTIVE TESTING INSTRUMENTATION REQUIREMENTS

Measurement Instrument for	Permissible Measurement Error	Minimum Detection Limit, ppm
Carbon Monoxide (CO)	<5% of Actual Value	5
Carbon Dioxide (CO_2)	<5% of Actual Value	500
Sulfur Dioxide (SO_2)	<5% of Actual Value	0.3
Oxides of Nitrogen (NO_x)	<5% of Actual Value	0.3
Hydrocarbons (HC)	<5% of Actual Value	5
Temperature (int and ext)	1 °C	
Relative Humidity (int and ext)	3%	
Barometric Pressure	1 mm-Hg	
Vehicle Speed*	2-3 km/hr	
Wind Speed and Direction**	0.25 m/sec	

*Vehicle speedometer value acceptable.
**For static automotive tests only.

4.1.3 Required Test Conditions.

a. The test vehicle must be prepared and equipped to the standards required of the operational configuration or as specified in the detailed test plan. The testing should be conducted with any/all auxiliary devices that affect the distribution of engine or heater exhaust, such as applique armor, fording or swimming kits, etc.

b. The engine and its supporting equipment, consisting, e.g., of auxiliary power units and heaters, should be adjusted to approved technical specifications. Referee grade fuel (MIL-F-46162) or MIL-G-46015A should be used during test.

Note: Toxic fumes tests of fuel burning equipment should include tests under less than optimum conditions. A cold engine, one which is "out of proper timing", or otherwise out of adjustment following continued field use, may provide for greater concentrations of toxic contaminants than one adhering rigorously to technical specification.

c. For vehicles where sealing prevents natural ventilation (e.g., with vehicles equipped with NBC protective systems), the build-up of carbon dioxide resulting from crew/occupant(s) respiration should be considered.

d. The test course should be dry (no standing water) and testing should be avoided during inclement weather in that nitrogen dioxide, ammonia, and sulfur dioxide are water soluble.

e. The vehicle operator and/or crew must be certified to operate the vehicle.

f. Test vehicles should be equipped with a functional/proven alarm system or, in its absence, operating crew and occupants must be equipped with respirators to protect personnel from overexposure in the event concentrations of toxic gasses exceed the allowable limits during testing. This requirement will be satisfied if the test instrumentation is equipped with an alarm.

g. Data should not be collected and testing should be avoided if the interior temperature is not within the operating temperature and humidity range of the instrumentation selected, unless the sample can be drawn from the vehicle and conditioned before measurement.

h. For stationary testing only: Testing should be avoided when the ambient RH exceeds 85%, wind speed exceeds 16.1 kph (10 mph) (8.1 kph (5 mph) for open windows) or wind gusts exceed 32.2 kph (20 mph) (16.1 kph (10 mph) for open windows).

4.1.4 Criteria.

a. Personnel shall not be exposed to concentrations of toxic substances in excess of the limits specified in either the Department of Defense (DoD) Occupational Health (OSH) standards or specialized standards applicable to military unique equipment, systems, or operations(1,3,6,7,8,9). In effect, the preceding statement indicates that the published Occupational Health and Safety Administration (OSHA) standards apply to both military and civilian personnel under DoD cognition with the exception of revisions/addenda approved by the Army Surgeon General (TSG) or "specialized standards applicable to military unique equipment, systems, or operations" such as the standards for exposure to carbon monoxide(1,8,9). Table 4.1-2 presents the exposure criteria for those toxic substances normally found during automotive operations.

TABLE 4.1-2. APPLICABLE EXPOSURE CRITERIA[6,10]

Gaseous Compound	PEL-TWA ppm	PEL-TWA mg/m^3	STEL ppm	STEL mg/m^3	Ref No.
Ammonia (NH_3)	25	17	35	24	6, 10*
Carbon Dioxide (CO_2)	5,000	9,000	30,000	54,000	6, 10
Carbon Monoxide (CO)	35/25	40/29	200/	229/	6, 10**
Nitrogen Dioxide (NO_2)	5(C)/3	9(C)/5.6	1.0/5.0	1.8/9.4	6, 10
Sulfur Dioxide (SO_2)	2.0	5.2	5.0	13.0	6, 10

*/**Note explanation of codes on page 2, Appendix C.

b. Criteria governing other gasses not presented in this paragraph will be as stated in the DTP.

4.1.5 Required Data. The specific required data/information to be obtained during tests is specified in the DTP. The data usually required to be gathered/measured during testing are as follows:

a. Time-weighted average (TWA) concentrations of the toxic gasses measured at the breathing zones of the crew members/occupants (ppm).

b. Vehicle interior temperature (°C).

c. Vehicle interior relative humidity (%RH).

d. Ambient barometric pressure (mm Hg).

e. Ambient temperature (°C).

f. Ambient relative humidity (%RH).

g. Vehicle configuration, i.e., hatch(es) position(s) (open/closed), heater(s) (on/off), A/C (on/off), ventilation fan (on/off), APUs (running/off), etc.

h. Time of test (minutes).

i. Vehicle speed (kph) (as applicable).

j. Vehicle ID number.

k. Total hours on engine, total time on vehicle, and any additional pertinent information.

l. Subjective questionnaire responses by crew (see app E).

m. Wind speed (kph) (stationary vehicle tests only).

n. Engine idle speed (rpm) (stationary vehicle tests only).

o. Sampling probe(s) (analyzer(s) type, model, serial numbers, and manufacturer).

4.1.6 Method. The following test procedures and methods are common to "Automotive Tests" only. For tests involving weapons fire, see the applicable paragraphs (4.2, 4.3) which follow.

a. A safety assessment of the vehicle will be conducted to determine: the extent of any existing toxic gas hazard, what gasses are prevalent in the vehicle, and the critical operational mode(s) that are most likely to produce significant concentrations of these gasses in occupied areas. Findings sought during the safety assessment will determine the test instrumentation required and the operational conditions that are involved. If special equipment (fording/swimming kits/curtains) that might affect exposure is used with the vehicle, tests will be conducted with these configurations installed.

b. The vehicle configuration during toxic fumes testing will depend on both the design and expected use. An appropriate scenario should be developed, but in the absence of a specific scenario, the following procedure is recommended:

(1) Measurement data, as specified in paragraph 4.1.5 will be collected for time periods of not less than 30 minutes under the condition(s) determined during the safety assessment as follows:

(a) 10, 30 and 50 kph or other speeds considered appropriate.

(b) Stationary vehicle with the engine at TAC idle and the prevailing wind against each side of the vehicle (4 conditions).

(c) For sealed vehicles, collect CO2 data for 30 to 60 minutes or in accordance with the operational requirement.

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

(e) If appropriate, 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.

(2) Obtain subjective questionnaire data from crew personnel to determine the presence of irritating and/or obnoxious odors, or physical distress. Appendix E presents a sample subjective questionnaire to be administered to the subjects. If positive responses are obtained, collect air samples and conduct laboratory analyses to identify the compounds and the sources.

4.1.7 Data Reduction and Presentation. The data obtained during the automotive tests will be reduced and presented as is specified in the following subparagraphs:

a. Determine the time-weighted average concentration for each gas, and the specific location of the measurement in the vehicle, in accordance with the following formula:

$$TWAc = [c1t1 + c2t2 + c3t3 + \ldots\ldots\ldots cntn]/T$$

where:

TWAc is the total equivalent exposure for a single test episode of "T" (min), where "t" is an individual exposure period (min) and "c" is the measured gas concentration (ppm) for the specific exposure time period. The subscripts represent the individual time segments (1 thru n) for each test episode.

b. For the exposure episodes during which carbon monoxide (CO) was measured (ppm), calculate the carboxyhemoglobin (COHb) blood levels using the predictive algorithm presented in both Appendix B and Reference 8 using the TWA episodic data.

c. A summary of the comments obtained from each subject who responded to the questionnaire that was administered to them.

d. A summary table of test conditions, vehicle configuration and test results, by individual trial numbers, will be included.

4.2 <u>Weapons Systems Tests</u>.

a. Ground mounted weapons (towed artillery, mortars, individual weapons (machineguns), etc.) and ammunition are normally tested in the vehicles from which they are fired. Open air toxic fumes testing of weapons or tests of externally mounted weapons are not normally conducted due to the rapid dissipation of the gasses and the significant effects that even very light winds would have on the gas concentrations one is likely to measure near the breathing zones of personnel interacting with the weapons.

b. 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 marginal particularly when rapid weapons fire results in an equally rapid build-up of toxic gasses.

4.2.1 Objective. Measure concentrations of toxic gasses resulting from simulations of realistic operations of weapons systems (under development or in the inventory) to determine the degree of hazard to operating and maintaining crews and vehicle occupants.

4.2.2 Facilities and Instrumentation.

a. Facilities.

(1) Firing ranges as required or as specified in the DTP.

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

b. Instrumentation.

(1) Weapon systems tests require instrumentation to measure concentrations of, basically, five (5) gaseous compounds including: ammonia, carbon monoxide, carbon dioxide, sulfur dioxide, and oxides of nitrogen. Some weapons systems, such as the Multiple Launch Rocket System, require the measurement of hydrogen chloride (HCl) in addition to the gasses already mentioned. This will be discussed in the instrumentation section of paragraph 4.5.2b rather than in this paragraph. Weapon systems which use new or exotic propulsion systems (e.g., liquid propellants) may require analyses of other gasses in addition to those listed above.

(2) In addition to concentrations of the five gasses noted in the prior paragraph, instrumentation is needed to obtain ambient atmospheric data consisting of temperature, barometric pressure, wind speed, and relative humidity (RH) as well as the internal temperature and RH. The following tabulation (table 4.2-1) provides guidance governing the suggested "response time", "maximum permissible measurement error", and "frequency of measurement". It should be noted that these are general guidelines only for usual situations; more stringent requirements may be necessary for special circumstances.

TABLE 4.2-1. WEAPONS SYSTEMS TESTING INSTRUMENTATION REQUIREMENTS

Measurement Instrument for	Response Time	Permissible Measurement Error (%)	Minimum Measurement Frequency
Ammonia (NH_3)	<10 sec to 90%FS*	≤2% @ FS	1 Hz
Carbon Monoxide (CO)	<10 sec to 90%FS*	≤2% @ FS	1 Hz
Carbon Dioxide (CO_2)	<10 sec to 90%FS*	≤2% @ FS	1 Hz
Sulfur Dioxide (SO_2)	<10 sec to 90%FS*	≤2% @ FS	1 Hz
Nitrogen Oxides (NO_x)	<10 sec to 90%FS*	≤2% @ FS	1 Hz
Temperature (int & ext)	< 30 sec	1 °C	.01 Hz
Relative Humidity (int & ext)	< 30 sec	3%	.01 Hz
Barometric Pressure	< 30 sec	1 mm-Hg	.01 Hz
Wind Speed and Direction	< 30 sec	0.25 m/sec	.01 Hz

*Response Time to 90% of Full Scale (FS) reading = 1.8 to 10 sec dependent on measured value.

Notes: Additional Specifications for Instruments:
Zero Drift per day <1% @ FS.
Sensitivity Drift per day <0.3% @ FS.
Typical Temp effect per °K ≤0.1% @ FS.
Influence of gas on ambient pressure = 0.1% of measured value per mbar pressure difference.

4.2.3 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 (open versus closed), ventilator (on versus off), engine/rpm, etc), firing rate, and number of rounds to be fired. Typical test scenarios are presented in Appendix F.

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 specified which is expected to meet the toxic fumes exposure criteria.

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

d. If lead fume 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 wetted 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. Test vehicles should be equipped with a functional/proven alarm system or, in its absence, operating crew and occupants must be equipped with respirators to protect personnel from overexposure in the event concentrations of toxic gasses exceed the allowable limits during testing.

g. Testing should be avoided when the ambient RH exceeds 85% or wind speed exceeds 16.1 kph (10 mph) (8.1 kph (5 mph) for hatches open) or wind gusts exceed 32.2 kph (20 mph) (16.1 kph (10 mph) for open hatches).

4.2.4 Criteria. Carbon monoxide is considered the leading indicator gas which results from weapons fire in that it exceeds all the remaining gasses combined in both exposure volume and threat. The exposures to CO generally consist of short term high level transient type exposures rather than the steady state type exposures encountered during automotive operations. The following paragraph summarizes the material presented in detail in Appendix B. The criteria for the other gasses are as presented in Table 4.1-2 of the Automotive Tests.

a. Personnel shall not be exposed to concentrations of CO in excess of values which will result in carboxyhemoglobin (COHb) levels in their blood greater than the following percentages: 5% COHb (all system design objectives and aviation system performance limits); 10% COHb (all other system performance limits). It is acceptable to estimate COHb blood levels in personnel by solving the empirical equation presented in Appendix B (see reference 8 if greater detail is needed).

b. No military unique short-term exposure criteria for lead fumes currently exist. Concentrations in excess of the OSHA Permissible Exposure Limit (PEL) should be referred to the US Army Environmental Hygiene Agency, ATTN: Health Hazards Assessment Office for evaluation.

4.2.5 Required Data. The specific required data/information to be obtained during tests is specified in the DTP. The data usually required to be gathered/measured during testing are as follows:

a. Concentration versus time data for each gas. The measurements will be made at the breathing zone of each crew member/occupant (ppm versus time).

b. The predicted percent COHb level for each crew member/occupant as determined by the algorithm specified in Appendix B.

c. Vehicle interior temperature (°C).

d. Vehicle interior relative humidity (%RH).

e. Ambient barometric pressure (mm Hg).

f. Ambient temperature (°C).

g. Ambient relative humidity (%RH).

h. Wind speed (kph) and direction.

i. Vehicle configuration, i.e., hatch(es) position(s) (open/closed), heater(s) (on/off), A/C (on/off), ventilation fan (on/off), APUs (running/off), etc..

j. engine idle speed (rpm).

k. Time duration of test (minutes).

l. Vehicle ID number.

m. Total hours on engine, total time on vehicle, and any additional pertinent information.

n. Precipitation? (y, n).

o. Weapon(s) type(s) and serial number(s).

p. Weapon elevation and azimuth (relative to both the vehicle axis and the wind direction).

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

r. Ammunition type(s) and lot number(s).

s. Subjective questionnaire responses by crew (see app E).

t. Lead fume concentration measured at the breathing zones of the crew members/occupants (if ammunition contains lead) (micrograms/m^3).

u. Sampling probe(s) (analyzer(s) type, model, serial numbers, and manufacturer).

4.2.6 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/occupants.

b. Close hatches, turn on blowers 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 until the values reach a steady state condition (no ventilation of vehicle) or decay to pre-fire levels (active ventilation).

f. Vehicle should be purged as required between trials.

g. Repeat preceding test methods for other configurations, as required.

4.2.7 Data Reduction and Presentation. The data obtained during the weapons firing tests will be reduced and presented as is specified in the following subparagraphs:

a. Evaluation of CO Toxic Hazard: The evaluative procedure is specified and detailed in Appendix B. A hazard classification for CO exposure, (method extracted from MIL-STD-882, Appendix D) is also included in Appendix B.

b. Analysis of Lead Fumes: Lead fume samples are analyzed in accordance with the NIOSH method 7082.

c. Analysis of any other gasses for which tests are performed will be based on the use of the appropriate applicable exposure criteria using Table 4.1-2 (ref 6 or 10, whichever is more stringent).

4.3 Chamber Tests. Toxic fumes chamber tests are comparison-type tests to determine differences in the emissions of small arms (up to 30 mm) ammunition lots. The data obtained from these tests can be used to evaluate the effects of weapons or ammunition modifications, and/or firing rates on the levels of toxic fumes produced. Such tests conducted in chambers, rather than in armored combat vehicles (ACV), provide the assurance that the subtle differences generally present in vehicle ventilation system performance or in the test conditions themselves do not impact upon the results of toxic gas concentrations emitted by the small arms ammunition. Details of such tests follow.

4.3.1 Objective. To determine whether the test ammunition (or test condition) provides increases in toxic gas emissions when compared with results obtained with the reference ammunition (or test condition).

4.3.2 Facilities and Instrumentation.

a. Facilities. An enclosed chamber that captures and mixes the weapon exhaust products. Because the chamber volume is constant, the relative amount of each effluent gas produced during each trial can be determined by comparing the gas concentrations following thorough mixing of the ammunition effluents.

b. Instrumentation. Gas analyzers as used for the weapons firing tests for the applicable gasses.

4.3.3 Required Test Conditions. Firing rates, including number of burst fires, number of rounds to be fired, etc, for each type and lot of ammunition in accordance with the detailed test plan. Testing should be avoided when the ambient RH exceeds 85% or wind speed exceeds 16.1 kph (10 mph).

4.3.4 Criteria.

a. The test ammunition (condition) shall not develop concentrations of toxic gas that are in excess of that produced by the reference ammunition (condition).

b. Other/additional criteria applicable specifically to a particular test as specified in the DTP or test request.

4.3.5 Required Data.

a. Zero time, peak, and stabilized concentrations, and times for each effluent gas measured/specified in the DTP or test request.

b. Chamber dimensional specifications, sampling probe positions in the chamber, and details of weapon mounting.

c. Chamber temperature(°C)/pressure(mm Hg)/RH (%).

d. Ambient temperature/pressure/RH (units as in c. above)/and wind speed and direction.

e. Identifications: Weapon model, serial number, ammunition type, caliber, lot numbers, manufacturer.

f. Time duration of test.

g. Details of test conditions.

h. Sampling probe(s) (analyzer(s) type, model, serial numbers, and manufacturer).

i. Type of calibration gas used, manufacturer, lot number, and concentration.

4.3.6 Method.

a. Select a toxic fumes test chamber with size dependent upon the weapon to be tested. The weapon will be mounted such that the muzzle is external to the chamber. All openings in the chamber are sealed and a circulating fan will be used to ensure that the air/gas in the chamber is homogeneous.

b. The gas analyzers (e.g., CO, NH_3, SO_2, etc.) used in the trials will be zeroed within the chamber (prior to firing), and will be spanned using a calibration gas of known concentration.

c. Gas sampling will be taken continuously from at least two positions within the chamber and will be analyzed for whatever gasses are relevant to the test.

d. The desired number of replications for each lot (or condition) is ten (10); cost or weapon availability may preclude conducting 10 replications, but, in any event, the number of replications must not be less than three (3).

e. Each replication will be fired in random order to preclude unintended test bias. Procedure as follows:

(1) Select 1st lot (or condition) by random number generator.

(2) Select 2nd lot (or condition) (randomly) from remaining lots (or conditions).

(3) Proceed as in (2) until all lots (or conditions) have been fired once.

(4) Repeat (1) thru (3) for all subsequent replications.

f. After completing a trial, the concentrations of all toxic gasses will be recorded for a minimum of 5 minutes to permit complete mixing of the chamber gasses prior to stopping the test and venting the chamber.

g. If the difference in the steady-state concentration values of any two analyzers for any gas exceeds 25 ppm or 2% of the full scale range of the analyzer, whichever is smaller, the analyzer calibrations should be checked. If the calibration is correct, the variation cause should be sought and corrected prior to continuing the test. If the calibration is incorrect, those involved will be recalibrated and all data obtained previously with those analyzers will be eliminated from computations of the mean steady-state gas concentration for that trial.

4.3.7 Data Reduction and Presentation.

a. Determine the mean steady-state concentration for each toxic gas and trial by averaging the readings for all analyzers used.

b. Calculate the sample means and standard deviations for each gas and ammunition lot (or condition).

c. Lot to lot (or condition to condition) differences in mean steady-state gas concentrations will be compared at the 5% significance level using a one way analysis of variance model. The variable to be analyzed is the mean steady-state concentration as calculated in paragraph 4.3.7a above.

d. If applicable, differences in mean steady-state gas concentrations will be compared at the 5% significance level using a two-way (lot to lot, condition to condition) analysis of variance model. Again, the variable to be analyzed is the mean steady-state concentration.

e. Conclusions in the test report will state whether the mean concentrations of each gas produced by the test lot (or condition) exceeds significantly the mean concentrations produced by the reference lot (or condition). If there are more than 2 levels of lot and/or condition, linear contrasts will be used to address the report criteria.

f. Typical concentration versus time data graphs will be included in the test report for at least one trial (or condition), for each lot.

4.4 Fire Extinguishing Systems Tests.

a. The majority of tests that are conducted on fire extinguishing systems are with Automatic Fire Extinguishing Systems (AFES). Such tests are conducted principally as part of the "Live Fire Program" and include efficacy testing of AFES as well as testing for the effects on personnel of the pyrolized extinguishant. In the past, these tests, which included both types of fire extinguishing systems tests (efficacy, toxicity) have been supported, in part, by an activity of TSG, namely the Walter Reed Army Institute of Research (WRAIR), Respiratory Research Division. It has been proposed that an exclusive TOP is needed for the "Live Fire Program". Accordingly, complete details related to the toxic effects resulting from exposure to the effluent of AFES tests, e.g., Halon FE 1301, are beyond the scope of this document and will be dealt with briefly considering halon only in the stable state (not pyrolized/decomposed). Generally, the tests will cover what is specified in the DTP.

4.4.1 Objective. Measure the concentration levels of undecomposed halons (FE 1301, 1211, 2402) and oxygen following activation of the fire extinguishing system to determine the degree of hazard to both the operating crew and occupants on issues of health and safety.

4.4.2 Facilities and Instrumentation.

a. Facilities.

(1) Firing ranges as required or as specified in the DTP.

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

b. Instrumentation. Whenever possible, continuous reading spectrometric gas analyzers will be used and positioned as outlined in the DTP.

(1) Halon 1301 concentrations should be measured continuously at each position by rapid response nondispersive infrared analyzers. The instrument specifications are as follows:

Full-scale range = 0 to 35% concentration
Accuracy = +/- 0.7%
Response Time = <3 sec

Analog concentration data should be digitized and recorded at 4 Hz for a period of 15 minutes.

Note: Instrumentation requirements for Halons 1211 and 2402 are identical to that for 1301.

4.4.3 Required Test Conditions. The required test conditions are governed by what is detailed in the DTP. The sole generalization that can be made is that testing for exposure to halon would be required when the fire extinguishing system is activated either, as a result of detection of a fire in the vehicle, or inadvertently. There is no relationship between testing for efficacy of the automatic fire extinguishing system and tests to determine the toxic hazard of halon or the effluents resulting from its use.

4.4.4 Criteria. The criteria for exposure to halon is specified in Appendix C, paragraph 2.03.

4.4.5 Data Required. The measurements required have been discussed in paragraph 4.4.2b (Instrumentation). Briefly, the measurements to be made are summarized as follows:

a. Using appropriate gas analyzers, measure and record the concentrations of the halon under test in accordance with the locations specified in the DTP.

b. In support of those measurements, meteorological data as specified in paragraph 4.2.5 of this document and in the DTP should also be obtained.

c. Gas samples in accordance with paragraph 4.4.2b.

d. Sampling probe(s) (analyzer(s) type, model, serial numbers, and manufacturer).

4.4.6 Method. As indicated in paragraph 4.4a above, the method of testing should conform to the DTP. Generally, the test methods will approximate those specified in the paragraph governing (4.2.6) Weapons Systems Tests.

4.4.7 Data Reduction and Presentation.

a. Data should be reduced in the same manner as specified in the Weapons Systems Tests (paragraph 4.2.7) and the DTP.

b. Data should be presented in plot form as a full 15 minute concentration-time history for each toxic gas measured.

c. Peak concentration, 30 sec, 1-, 5-, 10-, and 15-minute time weighted average concentrations, and half-life should be provided in tabular form for each measured gas.

d. The data should be analyzed in terms of the safety and health hazards to crew/occupants in keeping with the standards and criteria as specified by TSG and as stated in the DTP.

4.5 Miscellaneous Tests. This section is applicable to tests of miscellaneous engine-driven, fuel-burning or other equipment having the potential of creating a toxic hazard to operating, maintaining and other personnel following the completion of a safety assessment of the materiel under study. Included in this category of equipment are work shelters in which solvents or chemicals may be used, where operations are likely to produce toxic gasses, mists, or dusts, or where out-gassing of chemicals or solvents used in construction may occur as a result of the items being exposed to high temperature or solar loads.

4.5.1 Objective. To identify and measure concentrations of toxic/hazardous gasses that may result from the operation of miscellaneous materiel including engines, generators, air conditioners, shelters, repair enclosures, fuel fired burners and heaters, etc., and determine the degree of hazard to interfacing personnel.

4.5.2 Facilities and Instrumentation.

a. Facilities:

(1) Test article(s) and ancillary systems as identified in the DTP

or Test Request.

(2) Test range or emplacement where testing is to be performed as well as supporting personnel and equipment, as required to operate the range/emplacement.

b. Instrumentation:

(1) Calibrated, continuously operating gas analyzers and supporting subsystems (amplifiers, recorders, CRTs, calibration gas, etc) for measuring concentrations of all toxic gasses expected.

(2) Calibrated gas sampling devices where only steady state concentrations are expected.

(3) Temperature and pressure measuring transducers and supporting equipment.

(4) Collector devices for sampling atmosphere carried particles, e.g., lead, dust, carbon laden particulates, etc.

(5) Equipment for collecting and recording meteorological measurements.

4.5.3 Required Test Conditions. The test conditions should duplicate realistic operational scenarios which are expected to provide for the production of toxic gasses and particulate matter in or near the workplace/ station of interacting personnel. Usually the DTP (or Test Request) will include specification of the test conditions.

4.5.4 Criteria. The criteria for exposure to gasses is as stated previously in this document (see para 4.1.4, 4.2.4, table 4.1-2, app B and C, and ref 3, and 6 through 13). Generally, the exposure criteria will depend upon the substances which are used or produced. Unless military unique criteria and/or medical bulletins issued by TSG are applicable, the criteria recommended by OSHA[6] or ACGIH[10] (whichever is more stringent) should be presumed to apply.

4.5.5 Required Data. The data required are as specified in the DTP. Generally, the data requirements as specified in paragraphs 4.1.5 and 4.2.5 are appropriate for these tests also. However, in addition, samples of particulates, as applicable, would be required. Finally, the test conditions, and duration of sampling periods would be tabulated.

4.5.6 Method.

a. Prior to the conduction of actual tests, a safety assessment of the equipment will be conducted to determine: the extent of any existing toxic gas hazard (or particulate matter), what gasses (particulates) are prevalent in the enclosure/emplacement of the equipment, and the critical operational mode(s) that are most likely to produce significant concentrations of these toxic compounds in occupied areas. Findings sought during the safety assessment will determine the test instrumentation required and the operational conditions that are involved.

b. Test methods used will basically follow the methods specified in paragraphs 4.1.6, 4.2.6, 4.3.6, and 4.4.6, as applicable for the specific test item involved.

4.5.7 Data Reduction and Presentation. Reduction and presentation of the data is dependent on the type of toxic contaminant for which tests were conducted (gas versus particulates) and will generally follow the guidelines presented in the preceding paragraphs for Automotive, Weapons, Chamber, and Automatic Fire Extinguishing Systems tests.

5. DATA REQUIRED. Data requirements have been specified for each type test, individually in the preceding paragraph 4.0. Where necessary, additional specific data requirements are presented in the various Appendixes which follow the main body of this document. Also included in an Appendix (C) are the air quality standards to which the data obtained are compared for evaluation purposes.

6. DATA PRESENTATION. Paragraph 4, above presents the requirements for presentation of data for each of the type tests that are performed and covered by this document. In addition, details for how data are presented and the evaluative procedure for exposure to CO are given in Appendix B.

APPENDIX A. CONTAMINANTS SUMMARY

CONTAMINANTS (TOXIC HAZARDS) SUMMARY

A1.0 Background

1.01 The ingestion 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 about 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: carbon monoxide (CO), carbon dioxide (CO_2), ammonia (NH_3), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), lead (Pb) fumes, hydrogen chloride (HCl), the halons (1301 ($CBrF_3$), 1211, 2402) and any other noxious compound/substance identified as either being hazardous to health/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] Appendix D, of this document, presents the standards for all of the toxic compounds addressed in this document.

1.02 While exposure to emissions from ammunition propellants may be encountered by soldiers in a variety of operational settings, the US 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[14] 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. Brief discussions of each of the aforementioned compounds follow in a later paragraph.

1.03 Federal occupational exposure standards[6] for toxic compounds are based mainly on threshold limit values (TLV) recommended in 1968 by the American Conference of Government Industrial Hygienists (ACGIH). The Federal occupational exposure standards (OSHA and ACGIH) are formally adopted by the US Army in AR 40-5[1]. There are circumstances for which military unique standards are developed and implemented. This is accomplished through the mechanism of the "Department of Defense (DoD) Occupational Safety and Health Program" (DoDI 6055.1)7[7]. TLVs are usually specified in terms of 8-hour time weighted averages (TWA), occasionally as ceiling values (C), and are <u>general guideline</u> specifications. The National Institute of Occupational Safety and Health (NIOSH) recommends occupational standards for selected agents, specifically for the Occupational Safety and Health Administration (OSHA). In addition, the ACGIH also recommends "short term exposure limits" (STEL) which are absolute ceilings, generally, for 15-minute exposures. The American Industrial Hygiene Association (AIHA) recommended "emergency exposure limits" (EEL) for NO_2 in 1964 and the National Research Council of the National Academy of Science (NRC-NAS) recommended EELs for SO_2 in 1966[14].

2.0 <u>Carbon Monoxide (CO):</u> Carbon Monoxide is particularly dangerous in that, aside from its toxicity, it is odorless, colorless and tasteless and is not ordinarily detectable by the human senses. This gaseous compound is undoubtedly one of the most dangerous and common industrial exposure hazards. The US 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, armored personnel carriers). Additionally, even if particular CO exposures are not categorized as safety or health hazards, such exposures can degrade human performance with resulting degradation of system effectiveness.

2.01 The predominate effect of CO exposure results from 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 may ways, to absorption. The rate at which CO is eliminated from the blood is an exponential and relatively slow decay, and is a function of many physiological variables. The half life of CO in the blood can be as much as 4 hours for healthy people at rest in an environment free of contaminants (See para 5.4.7.5 of MIL-HDBK-759B[8] and Appendix C for algorithm). Also, see Reference 10 which contains data relating to the efficacy of the algorithm used for evaluating CO exposure.

2.02 Paragraph 5.13.7.4.2. of MIL-STD-1472D[9] specifies the exposure standards for CO in terms of the permissible carboxyhemoglobin (COHb) blood levels for personnel in aviation systems and all other systems separately. The prediction of COHb blood level for individual exposures is made by a mathematical model which is a revised form of the Coburn-Forster-Kane (CFK) equation[11] given in the handbook[8] and reprinted 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, it's 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.[12]

3.0 <u>Carbon Dioxide (CO_2):</u> Carbon Dioxide is one of the exhaust products of fossil fuel burning internal combustion engines, including the Diesel engine. CO_2 is considered to be a noxious gas in that, like CO, it is colorless and odorless and, where an unusually large exposure is involved, can lead to unexpected suffocation. Fortunately, 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 a closed hatch mode without adequate ventilation as might occur during silent watch. It is then that a build-up of CO_2 in the confines of the vehicle is possible and when levels exceed 5-7.5 percent concentrations, it is expected that soldier performance might degrade below acceptable limits.

4.0 **Ammonia (NH_3):** Ammonia results from the combustion of ammunition propellants. Exposure of soldiers to combustion emissions may occur during either training or battle with the various fielded weapons systems. Armored vehicle crew persons may be particularly vulnerable to exposure because of: **a**. the confined crew space inside the vehicles; and, **b**. the proximity of personnel to the emission source.

4.01 Exposure to ammonia gas primarily affects ones eyes and the respiratory tract. The irritant effects are: **a**. immediate at exposure onset, **b**. primarily concentration dependent, and **c**. 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].

4.02 The criteria for exposure to ammonia has become more stringent and more encompassing as a function of time. The ACGIH, in 1979, revised its standard to 25 ppm expressed as a TWA with a short term exposure limit (STEL) of 35 ppm for 15 minutes. This standard is still current.[10] In 1974, NIOSH specified 50 ppm as an occupational standard, expressed as a ceiling not to be exceeded during an 8-hour workday[14]. OSHA, in reference 4, specifies a "Transitional Limit" TWA (PEL) of 50 ppm TWA for 8 hours and does not specify a ceiling value. It does specify, however, that exposures of 500 ppm could be immediately dangerous to life (IDLH)[6]. Appendix D presents the most recent information available relative to exposure to ammonia. Should any of this information be unclear, the Office of the Surgeon General (TSG) should be contacted for any needed clarification.

5.0 **Sulfur Dioxide (SO_2):** Sulfur Dioxide is a pungent, irritating gas that is produced voluminously by the combustion of sulfur or those compounds containing sulfur. Human exposure to concentrations of 1-50 ppm for 5-15 minutes may cause irritation of the eyes, nose, and throat, nasal discharge, choking, coughing, and reflex constriction of the airways. Approximately 10-20 percent of the healthy young adult population are estimated to be hypersusceptible to the effects of SO_2. The ACGIH 8-hour TLV-TWA is 2 ppm while they also recommend a STEL of 5 ppm. The OSHA 8-hour PEL is 5 ppm.

6.0 Oxides of Nitrogen (NO_x): Nitrogen oxides are a product of the combustion of propellants associated with weapons firing. The primary concern is with the production of both nitric oxide (NO) and nitrogen dioxide (NO_2). Nitric oxide has been reported to cause narcosis in laboratory animals exposed to concentrations greater than 2500 ppm. By itself, it has no irritant properties, but is frequently oxidized in air to form NO_2. At concentrations below 50 ppm, the conversion of NO to NO_2 is slow. 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. The ACGIH TLV-TWA for NO_2 is 3 ppm with a recommended STEL of 5 ppm. OSHA specifies that exposures not exceed a 1 ppm STEL.

6.01 The OSHA and ACGIH standards for occupational exposure to NO_x is 5 ppm (ceiling) and 3 ppm for an 8-hour TWA, respectively.[6/10] The AEHA recommended limits for NOx are based on tolerance of a single exposure without encountering adverse health effects but not necessarily without acute discomfort. Appendix D lists recommended limits for NO_x as well as for other toxic compounds covered by this TOP.

7.0 Hydrogen Chloride (HCl): 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 major area affected on humans is with the surface components of the upper respiratory tract where it is retained or deposited unless the exposure is so concentrated as to overwhelm the scrubbing capacity of the tract. At high concentrations, penetration to the bronchioles and alveoli might result.

7.01 The major source of HCl emissions for 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 one of the products of combustion of firing explosives containing chlorine. The firing of the hand-held Stinger missile releases large amounts of HCl. The Multiple Launched Rocket System (MLRS) is yet another source for exposure of personnel to HCl.

7.02 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.

7.03 Detection by humans of HCl occurs at 1-5 ppm; at 5-10 ppm, it is disagreeable. Some humans have stated that up to 35 ppm, HCl cannot be detected by either odor or taste. Researchers have noted that the tolerance to HCl is time dependent in that 1 hr exposures at 50-100 ppm are tolerable whereas 10-50 ppm is the maximum tolerable for a few hours, and 10 ppm concentrations for prolonged periods have no effects. Although, no firm standard exists for Army personnel, the recommendations of the National Research Council Committee on Toxicology is found in Table A7-1.

TABLE A7-1. RECOMMENDED EXPOSURE LIMITS FOR HYDROGEN CHLORIDE (HCl)

Exposure Time	1977	1986
10 min	100 (EEL)	100 (EEGL)
30 min	50 (EEL)	-
1 hr	20 (EEGL)	20 (EEGL) 1 (SPEGL)
24 hrs		20 (EEGL) 1 (SPEGL)
90 days		0.5 (CEGL)

Codes: EEGL - Emergency Exposure Guidance Level.
SPEGL - Short-term Public Emergency Guidance Level.
CEGL - Continuous Exposure Guidance Level.

"EEGLs, SPEGLs, and CEGLs are not standards or judgments of acceptable risk and must not be so construed; they are the Committee's best judgment, based on available evidence, of exposures at which people can continue to function in an emergency situation (EEGL, SPEGL) or an environment like that of a submarine (CEGL) and be unlikely to suffer irreversible effects."[15 Preface]

Note: Almost all of the material presented in paragraph 7 has been extracted from reference 15 including some direct quotations.

8.0 **Halon - FE 1301 ($CBrF_3$):** With the exception of carbon dioxide (CO2) fire extinguishers, which are ineffective as automatic extinguishers in combat vehicles, FE 1301 (bromotrifluoromethane) is the fire suppressant agent selected by the Army as least toxic (most safe) (most effective in automated fire suppressant systems) to humans. Agent concentrations of 5 - 6% by volume are considered adequate to extinguish fires of most combustible materials and this agent is the most stable thermally of the halogenated extinguishing agents. However, at temperatures above 810 deg K (Kelvin) (1,000 deg F), the agent decomposes into irritating and potentially toxic by-products, which can cause respiratory tract, skin, and eyes irritations at elevated concentrations.

8.01 FE 1301 can enter the body in three different ways to provide the potential of a toxic threat by: ingestion, inhalation, or absorption through the skin. For Army civilians and soldiers alike, the primary route of entry, for a gaseous compound such as halon, is inhalation. The principal toxic effect of halon is upon the central nervous system (CNS) and its profound irritating influence following its decomposition at temperatures greater than approximately 810 deg K (Kelvin) (1,000 deg F) on the respiratory tract, skin and eyes. However, this document deals only with halon (FE 1301, 1211, 2402) in the stable state. It should be noted, however, that decomposed products of halon such as hydrofluoric acid (HF) and hydrobromic acid (HBr) can result from fires associated with thermo-electric heaters.

9.0 <u>Lead Fumes/Particulates (Pb):</u> 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 a metal or in a compound form. Lead can be absorbed by inhalation or ingestion. Absorption of excessive amounts of lead cause diseases of the kidneys and of the peripheral and central nervous systems[16]. 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.

9.01 <u>Standards:</u> The standards for exposure to lead are presented in Paragraph 2.04 of Appendix C. In addition to the OSHA and ACGIH criteria, permissible limits for intermittent exposures as relates to firing ranges are presented in that Appendix.

9.02 <u>Health Effects:</u> The adverse effects associated with exposure to lead range from acute to relatively mild. Reversible stages include inhibition of enzyme activity, reduction in motor-nerve conduction velocity, behavioral changes, and mild central-nervous-system symptoms. Irreversible damage causes chronic disease and death. The symptoms of severe lead intoxication include loss of appetite, metallic taste, constipation, nausea, pallor, excessive tiredness, weakness, insomnia, headache, nervous irritability, muscle and joint pains, fine tremors, numbness, dizziness, hyperactivity, and colic.[16]

APPENDIX B. EVALUATION OF THE CARBON MONOXIDE (CO) TOXIC HAZARD

EVALUATION OF THE CO HAZARD

B1.0 Background

1.01 Just as might occur in the industrial environment, the Army is particularly concerned with personnel exposure to carbon monoxide in that such exposure, in addition to potentially affecting health and safety, can result in performance degradation for the concerned population. The principal difference between exposure to CO in the industrial community with the military is that the military exposure is usually a transient, high level exposure, typical of weapons firing scenarios, while the exposure that is associated with the civilian community is generally one that is relatively low level and essentially steady state (small variation about the mean).

1.02 Prior to 1980, the Army essentially evaluated soldier exposure to CO using the civilian (OSHA) standards[6] and MIL-STD-800[17] (now obsolete) for dealing with steady state and transient type exposures respectively. As is discussed in Steinberg and Nielsen[18], the civilian standards were considered too stringent for Army personnel which, fundamentally, represents a population of young, healthy soldiers in contrast to the general civilian population which consists of infants developing physiologically as well as adults that may have ischemic heart disease (IHD) or pulmonary function abnormalities. Accordingly, the Army was in need of both adopting appropriate standards and an evaluative procedure that was acceptable to the Army Surgeon General and could be applied simply and effectively. In essence, the standard would be categorized as military unique[7]. Such a standard was adopted in May 1981 and published in MIL-STD-1472[9] (see Para 5.13.7.4.2 Carbon Monoxide). The evaluative procedure is specified in MIL-HDBK-759[8] (see Para 5.4.7.5 Evaluation of Carbon Monoxide Toxic Hazard) and was published initially in June 1981.

1.03 The standard is specified in terms of permissible percentage carboxyhemoglobin (COHb) levels in the blood. A 5% COHb level is stated as "all system design objectives and aviation system performance limits". A 10% 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 (given later) developed by researchers Coburn, Forster, and Kane[11] which calculates the percentage COHb levels in ones 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.

1.031 The prior "time weighted average (TWA)" method of determining compliance with the then existing standards was unrealistic for the military environment because it neglected to account for the actual CO uptake by the exposed person who may have been at an elevated work effort scale at the time of the exposure. Additionally, repetitive transient exposures are possible which are not accounted for properly using the TWA method of evaluation such as would be the case when, e.g., firing or loading the main weapon of a tank, or trying to fly "nap-of-the-earth" missions with a helicopter after being exposed to CO. In these examples, performance of the individual is a critical issue which 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% COHb level standard was selected for the aviation community as opposed to the 10% 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% vs 10%).

1.04 **Empirical Equation.** The following is extracted from MIL-HDBK-759B for convenience to the user:

$$\% \, COHb_t = \% \, COHb_o \, [e^{(-t/A)}] + 218 \, [1-e^{(-t/A)}][1/B + ppmCO/1403]$$

% $COHb_t$ is the predicted carboxyhemoglobin in the exposed subject;
% $COHb_o$ is the amount of COHb found in non-smoking adults;
t is the exposure duration of exposure in minutes;
ppmCO is the carbon monoxide exposure in parts per million of contaminated atmosphere;
e is the mathematical constant **2.7182818** (base of LN (natural log));
A and B are constants which are obtained from **Table B-I.** Both constants are dependent on the estimated activity level of the individual during the actual exposure. For combat vehicle crewpersons, the work effort level to be substituted in the equation is specified. These required levels are "4" and "3" for weapons fire and intermediate mission episodes respectively. These constants account for the minute respiratory volume of contaminated atmosphere actually respired by an exposed individual.

TABLE B-1. CONSTANTS FOR SUBSTITUTION IN EMPIRICAL EQUATION 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

1.041a. The equation is popularly known as the Coburn-Forster-Kane Equation (CFKE). In its present modified form, extracted from the publication "Occupational Exposure to Carbon Monoxide"[13], the CFKE is adaptable easily to main-frame or desk top computation and, because of its simplistic form, can also be programmed for use with a hand calculator. 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[12] 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.

B2.0 Evaluative Programs:

2.01 <u>Standard Use of CFKE:</u> The CFKE is best adaptable to exposure data gathered on the basis of conducting realistic operational scenarios for the particular weapon system (combat vehicle) being evaluated. Such operations might include a projected 24hr, 48hr, or other battle or training scenario. If the Training and Doctrine Command (TRADOC) provides the materiel developer with such a scenario, the data gathered during the scenario can be used directly with the computer model described by Steinberg[19] 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 chronologically and the output would be as given on page 12 of Reference 19 (21 chronologic segments). 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 (COHbt 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.

2.02 RATES Computer Program: This program is used by the US Army Combat Systems Test Activity (USACSTA) to compute (predict) COHb blood concentrations from CO exposure data gathered during testing for toxic fumes. Because approved toxic fumes 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, the RATES program examines the boundary conditions for safe operation which are (for this analysis) defined as follows:

a. 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 proviso that background CO levels are not unusually high (<35 ppm).

b. 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% COHb blood level in accordance with Reference 9, paragraph 5.13.7.4.2.

c. 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% 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% 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.

2.021 Obviously, 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% 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 weapon firing. In this scenario the boundary conditions are MACE and SFR. A MACE which is equivalent to several times the system's combat load is of no practical use since the available ammunition will have been expended before reaching MACE. However, MACE does provide for a basis of comparing CO exposures among test scenarios which involve different conditions, ammunition types, numbers of rounds fired, etc. which provides the systems analyst with the means for improving combat effectiveness just as was discussed above in paragraph b(1) for the standard use of the CFKE.

2.022 The firing rates discussed above do not consider temperature related firing restrictions, which may impose greater constraints upon firing than those imposed by toxic fumes. 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, account should be made of such items as temperature, blast overpressure, and other system specific constraints so that firing rate restrictions stated in system safety releases are coherent and coordinated.

B3.0 Summary: The preceding paragraphs presented a discussion of:

a. The background and bases of the current CO standard for operators/ maintainers/occupants of aircraft and ground combat vehicles.

b. Details of the algorithm used to predict the COHb blood levels in exposed soldiers and the basis for using it.

c. The computer models used to evaluate the data collected.

APPENDIX C. STANDARDS FOR AIR QUALITY AND EXPOSURE

AIR QUALITY STANDARDS/CRITERIA

C1.0 Introduction:

a. This Appendix is intended to provide the Toxic Fumes Tester and/or Evaluator with a complete reference list governing the air quality standards/ criteria used by the U.S. Army for identifying health, safety, and performance hazards/degradations resulting from human exposure to the toxicant concentrations which are measured during conduct of those tests within the scope of this document. Paragraphs 4.1 through 4.5 addresses details governing test procedures for each type of test. Paragraphs 4.(1 thru 5).4 addresses the toxic fumes exposure "criteria" for each type of test covered. Some of the latter information is repeated in this Appendix. Also contained herein is a comprehensive listing of standards/criteria references as are applicable to each of the gasses for which measurements are made.

b. The standards/exposure criteria applicable to toxic fumes testing by the U.S. Army are basically governed by the Federal Code[6] and DoD Instruction[7]. The Army Surgeon General (TSG) likewise can specify alternative standards, where warranted, in place of the Federal Code where special considerations must be applied due, in part, to the character of the military exposure environment which can differ materially from exposures experienced by other populations. For example, the transient nature of some military exposures, when combined with the uncertainties of the synergistic effects of simultaneous exposure to several gases, can provide for an entirely different criteria than specified in the Federal Code.[6] Finally, there is the category of standards/criteria that is not only unique to the military environment, but is also singular to military populations such as the standard for exposure to carbon monoxide.[7,8,App C]. Accordingly, all these criteria will be dealt with in the following paragraphs.

C2.0 Toxic Gas Exposure Criteria: This paragraph addresses the applicable standards/exposure criteria for toxic gasses including carbon monoxide (CO), carbon dioxide (CO_2), ammonia (NH_3), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), hydrogen chloride (HCl), bromotrifluoromethane, (halon) ($CBrF_3$), and lead fumes/particulates.

2.01 The gasses listed in Table C2-1 are common to automotive type vehicles as well as for combat vehicle systems from which weapons may be fired. Whenever possible, the table includes values from more than one reference and this will be evident. Mostly, the standards apply to the industrial workplace where exposures are usually of the steady state type (i.e., reasonably constant) in contrast to transient type exposures which vary as a function of time, especially as would occur when firing weapons from enclosed vehicles. The following are definitions of the column headings which include Permissible Exposure Limit (PEL), Time Weighted Average (TWA), Short Term Exposure Limit (STEL), and Ceiling (C) Value.

a. Column Definitions

(1) Permissible Exposure Limit (PEL): The exposure limit permitted based upon a Time Weighted Average (TWA).

(2) Time Weighted Average (TWA): The time weighted average concentration based upon a normal 8-hour work day and a 40-hour workweek.

$$TWAc = [c1t1 + c2t2 + c3t3 + ...cntn]/8$$

Where TWA_c is the total equivalent exposure for an 8-hour period where "t" is an individual exposure period (hours) and "c" is the measured gas concentration (ppm) for the specific exposure time period. The subscripts represent the individual time segments (1 thru n) for each test segment (hours).

(3) Short Term Exposure Limit (STEL): A 15-minute TWA exposure which should not be exceeded at any time during a workday even if the 8-hour TWA is not exceeded; and,

(4) Ceiling (C): The absolute ceiling value of exposure permitted.

TABLE 4.1-2. APPLICABLE EXPOSURE CRITERIA[6,10]

Gaseous Compound	PEL-TWA ppm	PEL-TWA mg/m^3	STEL ppm	STEL mg/m^3	Ref No.
Ammonia (NH_3)	25	17	35	24	6, 10*
Carbon Dioxide (CO_2)	5,000	9,000	30,000	54,000	6, 10
Carbon Monoxide (CO)	35/25	40/29	200/	229/	6, 10**
Nitrogen Dioxide (NO_2)	5(C)/3	9(C)/5.6	1.0/5.0	1.8/9.4	6, 10
Sulfur Dioxide (SO_2)	2.0	5.2	5.0	13.0	6, 10

Explanation of Codes in Table:
*In terms of time duration of exposure, the following is recommended:[15]
1 hr - 100 ppm (EEGL); 24 hrs - 100 -ppm (EEGL); 90 days - 50 ppm (CEGL)
Note: EEGL = Emergency Exposure Guidance Level
CEGL = Continuous Exposure Guidance Level
**The standard/criteria for exposure to carbon monoxide is specified in Appendix B and References 8 and 9. Those standards are military unique and govern the determination of exposure hazards whether or not the exposure is transient or steady state.

For CO and NO_2, the table specifies 2 sets of values for TWA and STEL. Reference 6 specifies values which differ from those specified in reference 10. The mark "/" separates the values and references. "(C)" denotes that the values are absolute CEILINGS which are also appropriate to the TWA values given for nitrogen dioxide as specified in reference 6.

2.02 Hydrogen Chloride (HCl) Criteria: As discussed in Appendix A, HCl is an irritant that affects the respiratory tract and, for the Army, mainly results when firing rockets (Stinger, MLRS) and rocket engines. The following table contains the exposure recommendations of the National Research Council Committee on Toxicology.[15]

TABLE C2-2. RECOMMENDED EXPOSURE LIMITS (PPM)
FOR HYDROGEN CHLORIDE (HCl)

Exposure Time	1977	1986
10 min	100 (EEL)	100 (EEGL)
30 min	50 (EEL)	-
1 hr	20 (EEGL)	20 (EEGL) 1 (SPEGL)
24 hrs		20 (EEGL) 1 (SPEGL)
90 days		0.5 (CEGL)

Codes: EEGL - Emergency Exposure Guidance Level.
SPEGL - Short-term Public Emergency Guidance Level.
CEGL - Continuous Exposure Guidance Level.

"EEGLs, SPEGLs, and CEGLs are not standards or judgments of acceptable risk and must not be so construed; they are the Committee's best judgment, based on available evidence, of exposures at which people can continue to function in an emergency situation (EEGL, SPEGL) or an environment like that of a submarine (CEGL) and be unlikely to suffer irreversible effects."[15 Preface] It should be noted that the preceding quoted statement does not make clear whether the recommended exposure criteria is:

a) likely to affect soldier performance; and,

b) directly applicable to the entire as well as US soldier populations. These issues are pertinent to the peacetime Army and proper training of personnel. During battle, of course, issues governing survivability override the degradation of performance resulting from exposure to all toxic fumes as well as HCl. Any questions of uncertainty relative to TWAs, TLVs, STELs, etc should be resolved by the Office of the Surgeon General (TSG), such as the U.S. Army Environmental Hygiene Agency (AEHA).

2.03 Halon (FE 1301 - Bromotrifluoromethane CBrF3):

a. FE 1301 is the fire suppressant agent selected by the Army as least toxic of the fire suppressant agents. This agent is mainly used in automatic fire extinguishing systems (AFES) integral with armored combat vehicle systems. Concentrations of 5 - 6% by volume are considered adequate to extinguish fires of most combustible materials. The agent is stable to temperatures below 810 °K (1,000 °F) but at higher temperatures it decomposes predominantly into hydrogen fluoride and hydrogen bromide, among others, which are highly toxic gasses to humans.

b. This document addresses Halons 1301, 1211, and 2402 as a toxic agents only in the undecomposed state. The Live Fire Program (see paragraph 4.4 of the main body of this document) for Halon 1301 requires detailed analyses of the toxic effects resulting from concentrations measured during conduct of that program. The complexities associated with conduct of a Live Fire Program are beyond the scope of this document and should be dealt with on the basis of an exclusive Test Operating Procedure. Accordingly, the following paragraphs cover halons 1301, 1211, and 2402 only in the stable state.

c. Time of exposure is critical in determining the degree of toxicity in the inhalation of gases. Fortunately, it would be unusual for humans to be exposed acutely (involving potentially lethal concentrations) to FE 1301 (and the other extinguishants) because the hazards associated with fires generally override those associated with an extinguishing agent. Although one should avoid unnecessary exposure to FE 1301, all exposures should be limited to the following times for purposes of safety:

7% and below	- 15 minutes
7 - 10%	- 1 minute
10 - 15%	- 30 seconds
Above 15%	- not permissible

Alternatively, TLV represents another guideline for maintaining safe exposure levels in the work place. The TLV for FE 1301 is 1,000 ppm as published by ACGIH[10]. The preceding Table is from Paragraph A-1-6.1 of Reference 20.

d. As indicated in Paragraph 2.03, above, FE 1301 is the least toxic fire suppressant agent of those currently in use. Although not used frequently, halons 1211 and 2402 are also common in some manually operated extinguishers in scenarios other than the battlefield. The following are guidelines governing exposure to those extinguishants.

(1) <u>Halon 1211:</u> Limit exposure to this suppressant to the following times: "up to 4 percent - 5 minutes
4 - 5 percent - 1 minute
Above 5 percent - prevent exposure"[21]

(2) <u>Halon 2402:</u> "Means shall be provided to prevent personnel from being exposed to Halon 2402 vapors in concentrations of greater than 0.05 (500 ppm) percent by volume for 10 minutes or 0.10 (1000 ppm) percent for 1 minute."[22]

2.04 Lead (Inorganic) Fumes:

a. The current criteria for exposure to lead is specified in Reference 16 which are, fundamentally, the civilian occupational standards. Reference 6 refers air contaminants of lead to Reference 16. The specification is quoted as follows: "1910.1025(c)(1) The employer shall assure that no employee is exposed to lead at concentrations greater than fifty micrograms per cubic meter of air averaged over an 8-hour period.

(2) If an employee is exposed to lead for more than 8 hours in any work day, the permissible exposure limit, as a time weighted average (TWA) for that day, shall be reduced according to the following formula:

Maximum permissible limit (in micrograms/m3) = 400 divided by hours worked in the day."

b. The ACGIH[10] specifies a TWA of 0.15 mg/m^3 for lead fumes/dusts and indicates that this value is in excess of the Permissible Exposure Limit (PEL) by OSHA and/or the Recommended Exposure Limit (REL) by NIOSH. The Biological Exposure Index (BEI) for lead is specified in the following table. The BEIs are reference values intended as guidelines for the evaluation of potential health hazards in the practice of industrial hygiene. BEIs represent the levels of the determinant which are most likely to be observed in specimens collected from a healthy worker who has been exposed to the chemical to the same extent as a worker with inhalation exposure to the TLV.

TABLE C2-3. BIOLOGICAL EXPOSURE INDICES FOR LEAD

Sampling Time		BEI
Lead in Blood	Not Critical	50 micrograms/100 ml
Lead in Urine	Not Critical	150 micrograms/g creatinine
Zinc Protoporphyrin in blood	After 1 month expos.	250 micrograms/100 ml erythrocytes or 100 micrograms/100 ml blood

c. The U.S. Army Environmental Hygiene Agency (AEHA), Occupational and Environmental Medicine Division have developed permissible limits for intermittent lead exposures relating to firing ranges. These standards are specified in Table C2-4.

TABLE C2-4. LIMITS OF EXPOSURE FOR LEAD

Airborne Lead Concentrations (mg/m^3)	Firing 30 or More Days/Year Hours/Day	Firing Less Than 30 Days/Year Hours/Day
0 - 0.03	8	8.
0.03 - 0.04	6	8.
0.04 - 0.05	4.5	8.
0.05 - 0.06	4	6.5
0.06 - 0.08	3	5.
0.08 - 0.10	2.25	4.
0.10 - 0.15	1.5	2.5
0.15 - 0.20	1	2.
0.20 - 0.30	0.75	1.25
0.30 - 0.40	0.50	1.
0.40 - 0.50	0.50	0.75
0.50 - 0.75	0.25	0.50
0.75 - 1.00	0.25	0.25
<1.0	0.	0.

APPENDIX D. TEST INSTRUMENTATION TYPES/DETAILS

D1.0 Introduction: This Appendix is prepared to provide the toxic fumes tester and/or test planner with a central depository for specifying test instrumentation requirements for making exposure measurements relating to the different types of gaseous compounds discussed in this document. 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/evaluator.

D2.0 Measurement Methods:

a. There are, at least, three (3) common methods to measure/ determine concentrations of gasses, vapors, mists, dusts, etc in the atmosphere including using:

1. Continuous-Reading Instrumentation.

2. Colorimetric Devices.

3. Gravitational-type Collectors.

Each of these devices/methods will be discussed individually.

2.01 Continuous Reading Instrumentation - Techniques

a. *Photometric Devices* measure the amount of light energy absorbed in a gas sample.

b. *Ionization Devices* generate ions (electrically charged atoms or molecules) by techniques including burning the gas sample in a hydrogen flow, exposing the samples to light of particular frequencies, or exposing the item to radioactive material.

c. *Catalytic Devices* measure the heat produced by chemical reactions on catalytic surfaces or in granular catalytic beds.

d. *Semiconductor Sensors* utilize an electrical-resistance change of the semiconductor material when the gas of interest is absorbed on its surface.

e. *Electrochemical Devices* provide for an electrical phenomenon when the gas sample comes in contact with the chemical sensor.

2.02 Colorimetric Devices: These devices are based on the principle of chemical reaction causing a color change when toxic gas is present. Colorimetric tubes provide for an instantaneous reading when used in conjunction with a hand-aspirated pump. Colorimetric analyses involve different techniques which can be divided broadly into field detectors and laboratory instruments:

a. Field detector devices provide an immediate change in color of a treated substrate. The color change is compared visually with calibrated charts to decode the concentration. Another field detector draws air thru an absorbing medium which results in a color change of that medium. The detection of the color change is measured photometrically with the response recorded on a strip chart.

b. Laboratory instruments are used to determine the change in absorbance of a collecting medium caused by the reaction of the contaminant with specific reagents. This absorbance change can lie within either the visible or ultraviolet electromagnetic spectra. Laboratory instruments are precision devices which generally are not field hardened nor designed for field use.

2.03 **Gravitational-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 the specifics of contamination.

D3.0 Instrumentation Selection: Principal considerations involved in selection of test instrumentation are: Principle of operation, accuracy, measurement range, sensitivity, response time, reliability, portability, repeatability, ruggedness, size, self test capability, standardization of calibration, complexity of human interface, recording capability, sensitivity to shock and vibration, and cost. Many of these considerations are intertwined with one another in that if the accuracy, sensitivity, response time and reliability are acceptable, the probability is high that, with the exception of cost and insensitivity to shock and vibration, the other considerations will also be acceptable. The following paragraphs will deal with the desired characteristics of the instrumentation.

3.01 Although the test type (i.e. Automotive, Weapons Systems, etc.) may be important for selection of instrumentation, the instrumentation generally used for Weapons Systems testing provides the guidance for the Automotive tests as well because the toxic gasses to be measured are similar - only the concentration ranges and needed response times may differ. Generally, the instrumentation should be the continuous reading type whose principle of operation is photometric and whose operation covers the IR (infrared), VIS (visual), and UV (ultra violet) spectral regions. The following table provides the desired specifications for the instrumentation needed for Weapons Systems tests.

TABLE D3-1. TEST INSTRUMENTATION SPECIFICATIONS FOR GAS CONCENTRATIONS MEASUREMENT

Measurement Instrument for	Response Time	Permissible Measurement Error	Minimum Measurement Frequency
Ammonia (NH_3)	<10 sec to 90%FS*	<2% @ FS	1 Hz
Carbon Monoxide (CO)	<10 sec to 90%FS*	<2% @ FS	1 Hz
Carbon Dioxide (CO_2)	<10 sec to 90%FS*	<2% @ FS	1 Hz
Sulfur Dioxide (SO_2)	<10 sec to 90%FS*	<2% @ FS	1 Hz
Nitrogen Oxides (NO_x)	<10 sec to 90%FS*	<2% @ FS	1 Hz

Additional Specifications for Instruments:

Zero Drift per day	<1% @ FS
Sensitivity Drift per day	<0.3% @ FS
Typical Temp effect per oK	≤0.1% @ FS

Influence of gas on ambient pressure = 0.1% of measured value per mbar pressure difference

*Response Time to 90% of Full Scale (FS) reading = 1.8 to 10 sec dependent on measured value.

Additional instrumentation is needed in support of the test. Table D3-2 provides a listing of the instrument specifications for the needed measurements.

TABLE D3-2. ADDITIONAL INSTRUMENTATION SPECIFICATIONS ENVIRONMENTAL/METEOROLOGICAL MEASUREMENTS

Measurement Instrument for	Response Time	Permissible Measurement Error, %	Minimum Measurement Frequency
Temperature (int & ext)	<30 sec	1 °C	0.01 Hz
Relative Humidity (int & ext)	<30 sec	3%	.01 Hz
Barometric Pressure	<30 sec	1 mm-Hg	.01 Hz
Wind Speed and Direction	<30 sec	0.25 m/sec	.01 Hz

a. The preceding tables omitted specifications for shock and vibration sensitivity which will now be addressed:

(1) Vibration and shock sensitivity are parameters that are difficult to evaluate for all circumstances. Accordingly, the following test has been determined to be of value in the military environment.

(a) Vibration sensitivity is evaluated by close looping the analyzer with a concentration of span gas near the center range of the analyzer. The analyzer inside a track-laying vehicle on an unpadded surface with web strapping. The output of the analyzer is recorded on a digital data logger while the vehicle is driven around a test course for 30 minutes. The data in the "logger" are printed and evaluated. Any excursion traceable to vibration effects in excess of 2 percent of the reading shall be cause for rejection of the instrumentation.

(b) Shock sensitivity determination follows closely to that of vibration. The analyzer is closed looped as above and subjected to the blast and shock produced by a large-caliber weapon which could range up to a 8-inch howitzer or larger. Any deviation in readings caused by the shock or blast wave, either direct or reflected, which exceeds 4 percent of full scale shall be cause for rejection.

3.02 Instrumentation for Halon Gas Measurement (undecomposed):

a. Halon (FE 1301, 1211, 2402) concentrations should be measured continuously at each crew position by rapid response nondispersive infrared analyzers. The instrument specifications are as follows:

Full-scale range = 0 to 35% concentrations
Accuracy = +/- 0.7%
Response Time = <3 sec

Analog concentration data should be digitized and recorded at 4 Hz for the time period when sensible readings are discernable and/or constant.

b. The tester should be cautious in the selection of instrumentation for measuring concentrations of halon resulting from fires related to thermoelectric heaters in that the analyzer may not be capable of measuring the pyrolyzed effluent products of combustion due to the high temperatures involved.

APPENDIX E. SAMPLE SUBJECTIVE QUESTIONNAIRE

TOXIC HAZARDS QUESTIONNAIRE FOR TEST PARTICIPANTS

E1.0 Preface: The collection of quantitative data related to the measured concentrations of toxic gasses to which personnel are exposed, mostly constitutes the only data needed to evaluate the hazard. Occasionally, additional data are needed in support of the analysis when findings indicate that a system meets the standards marginally or there is some degree of uncertainty associated with the testing. For these reasons, the results of subjective questionnaires, administered the test participants at the time of test implementation, may provide the evidence needed to bolster the conclusions determined on the basis of the quantitative data. The following is a sample questionnaire which may be useful for some testing and should be obtained for each test performed.

E2.0 Questionnaire:

Instructions to Administers of Questionnaires

The subject should review the questionnaire prior to initiating the test. The importance of completing the questionnaire, completely and accurately must be stressed orally by the administer and any instructions to them must be written in advance and reviewed with them prior to administering the questionnaire. It is preferable that the questionnaire be administered by only one person so as not to bias the results. Instructions to the subjects must be clear and concise. We don't want to tell them how the questions are to be answered.

The questionnaire should be shown to them in advance of the test so that they are aware of the types of questions it contains. They should execute the questionnaire immediately following the test, and to ensure that they don't respond to the questions during the test, the sheets should be collected prior to test initiation.

Instructions to Test Participants

Your participation in this test is critical to its successful completion and we appreciate your assistance. The accurate completion of this questionnaire is also very important to the test's success because the measurements we make may not be sufficient in forming accurate conclusions and without accuracy, the health and safety of the soldiers who will be using this system may be jeopardized. Accordingly, we ask you to examine this questionnaire in advance of the test so that you will be aware of the types of questions it contains and your responses to those questions will be more accurate because you know what to be looking for during the test conduct. Immediately following the test, these questionnaires will be returned to you so that you can complete the form. Please fill out the demographic information we ask for now so that you won't need to be bothered with that later.

QUESTIONNAIRE FORM

Demographic Information:

Date: Time:

Operator Name: Rank/Organization:

Age: Height/Weight:

Military MOS (If applicable): Years/Months in Specialty:

Years in Service: Position in Vehicle:

Your responses to the questions are very important. Please check the responses which describe how you felt while in the vehicle during the test. If your response to any question is "yes", please rate the duration and severity of the symptom(s) and mark the time of their appearance according to the following scale(s) (numerical codes) as applicable:

SEVERITY

1. Mild 2. Medium 3. Severe

DURATION

1. Very briefly after start
2. Present about 1/4 of the time
3. Present about 1/2 of the time
4. Present about 3/4 of the time
5. Present continuously

TIME OF APPEARANCE

1. Symptoms appeared early in the test
2. Symptoms appeared about 1/4 thru test
3. Symptoms appeared about 1/2 thru test
4. Symptoms appeared about 3/4 thru test
5. Symptoms appeared at conclusion of test

1. Did your eyes water? Yes___ No___

   SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

2. Was your vision affected? Yes___ No___

   SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

3. Did your eyes seem to be irritated? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

4. Did you experience breathing problems? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

5. Did you experience any tingling or numbness in your fingers or around your mouth? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

6. Did you become dizzy or light-headed? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

7. Did you lose your balance? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

8. Did you become nauseous? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

9. Did you experience a headache? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

10. Did you encounter any difficulty to think clearly? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

11. Did you experience any other unusual feelings? Yes___ No___

SEVERITY: 1 2 3 DURATION: 1 2 3 4 5 TIME: 1 2 3 4 5

12. Any additional comments pertaining to the test? Yes___ No___

____

____

____

For Test Engineer Use:
Vehicle:______________________ Registration/Serial No. ______________
Test Course:__________________
Trial No. Start/Stop Times Test Conditions/Remarks

Test Engr Name:________________ Date:__________

APPENDIX F. SAMPLE FIRING SCENARIOS

F1.0 Introduction:

a. This Appendix is intended to provide the Toxic Fumes Tester with sample test firing scenarios in the event the Detailed Test Plan (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 fumes 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 which 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/crew positions that are critical from a toxic fumes exposure viewpoint. Ordinarily, experience provides the tester with this knowledge. However, the tester is also obliged to consider the funds with which he/she is provided so that the issues of concern for the well being of the operating crew does not override sensible testing with the test program becoming overly stringent and resulting in needless testing or testing which departs from realism 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.

1.01 Bradley Fighting Vehicle (BFV) System Test Scenario:

a. TRADOC Scenario Events 12 and 15: The TRADOC Scenario depicts 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 fumes exposure, Events 12 and 15 are conducted sequentially, thus omitting the 22 minute pause between the critical firing episodic events.

EVENT 12

Time (min)	Number of Rounds 25-mm	7.62-mm	Mode
0	10	--	SS
2	10	--	SS
4	10	--	SS
6	10	--	SS
8	10	--	SS
10	10	--	SS
11	10	--	SS
12	10	--	SS
13	--	21	B
14	--	21	B
15	--	21	B
17	--	21	B
19	--	42	B
20	--	21	B
21	--	43	B
21.5	5	--	SS
22	5	--	B
22.5	5	--	SS
23	5	--	B
23.5	5	--	SS
24	5	--	B
25	5	--	B

B = Burst (low rate)
SS = Single Shot

EVENT 15

Time (min)	Number of Rounds 25-mm	7.62-mm	Mode
26	10	--	SS
27	10	--	SS
28	10	--	SS
29	10	--	SS
30	10	--	SS
31	10	--	SS
32	10	--	SS
33	10	--	SS
34	10	--	SS
35	10	--	SS
36	10	--	SS
36.5	10	--	SS
37	10	--	SS
38	10	--	SS
39	10	--	SS
40	5	--	SS
40.5	5	--	B
41	5	--	SS
41.5	5	--	B
42	5	--	SS
42.5	5	--	B
43	5	--	SS
43.5	5	--	B
44	5	--	SS
44.5	10	--	B
45	--	55	B
46	--	55	B

<u>1.02 Tank Main Gun Training Scenario:</u> The following training scenario was provided by the U.S. Army Armor Center at Fort Knox, KY (ATTN: ATSB-WP-GD) during April 1986 for purposes of toxic fumes testing.

1. Fire 3 Main Gun Rounds within 1 minute
2. Pause for 3 minutes
3. Fire 2 Rounds within 1 minute
4. Pause 4 minutes
   Option: Fire 100 rds from the coax machine gun at the start of the 4 minute pause (25 rd bursts @ 15 sec intervals)
5. and 6. Repeat 1 and 2 segments, above
7. Repeat segment 1
8. Pause 2 minutes

Total test time: 16 minutes
Rounds fired: 11 main gun; 100 coax

<u>Note:</u> Training round ammunition usually provides for greater toxic fumes exposure than does conventional battlefield ammunition.

APPENDIX G. REFERENCES

1. AR 40-5, Preventive Medicine, 15 October 1990.

2. AR 70-25, Use of Volunteers as Subjects of Research, 25 January 1990.

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

4. USACSTA Memorandum No. 70-17, "Preparing and Distributing Detailed Test Plans", 9 June 1986.

5. USATECOM Test Operations Procedure (TOP), "Automotive Safety and Health Hazard Evaluation", TOP 2-2-508, 24 November 1982, Aberdeen Proving Ground, Maryland.

6. Code of Federal Regulations, Title 29, Subpart Z, Air Contaminants, Final Rule; Occupational Safety and Health Administration (OSHA), Part 1910.1000, 19 January 1989.

7. Department of Defense Instruction 6055.1, Department of Defense Occupational Safety and Health Program, 26 October 1984.

8. Department of Defense. Human Factors Engineering Design for Army Materiel. MIL-HDBK-759B, Naval Publications Center, Philadelphia, PA, 30 June 1992.

9. Department of Defense. Human Engineering Design Criteria for Military Systems, Equipment, and Facilities. MIL-STD-1472D, Naval Publications Center, Philadelphia, PA, (Notice 2, 30 June 1992).

10. "Threshold Limit Values and Biological Exposure Indices for 1992-1993", ISBN: 0-936712-99-6, American Conference of Government Industrial Hygienists, Cincinnati, Ohio.

11. Coburn, R.F., Forster, R.E., & Kane, P.G.; Considerations for the Physiological Variables That Determine the Blood Carboxyhemoglobin Concentration in Man. Journal of Clinical Investigation, 1965, 44, 1899-1910.

12. Mossa, M., Lucas, T.A., Steinberg, S., et al; Field Test to Verify the Coburn-Forster-Kane Equation. Report No. USACSTA-6357, U.S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD, September 1986.

13. National Institute for Occupational Safety and Health. "Occupational Exposure to Carbon Monoxide", US Department of Health Education, and Welfare, 1972.

14. Legters, L., Morton, J.D., Nightingale, T.E. & Normandy, M.J.; Biological Effects of Short, High Level Exposure to Gases: Ammonia, Carbon Monoxide,

Sulfur Dioxide, and Nitrogen Oxides, June 1980.

15. Emergency and Continuous Exposure Guidance Levels for Selected Airborne Contaminants, Volume 7 (HCl), National Research Council, National Academy Press, Washington, D.C. 1987.

16. OSHA, Occupational Exposure to Lead, 29 CFR 1910.1025, Department of Labor, Occupational Safety and Health Administration, 1989.

17. Department of Defense. Procedure for Carbon Monoxide Detection and Control in Aircraft. MIL-STD-800, Naval Publications Center, Philadelphia, PA (Obsolete - see reference 8 CO standard).

18. Steinberg, S. and Nielsen, G.D.; A Proposal for Evaluating Human Exposure to Carbon Monoxide Contamination in Military Vehicles, Technical Memorandum 11-77, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, March 1977.

19. Steinberg, S.; A Computer Model for Evaluating the Effects on Fighting Vehicle Crewmembers of Exposure to Carbon Monoxide Emissions, Technical Note 1-80, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, January 1980.

20. NFPA Standard 12A, Paragraph A-1-6.1, Halon 1301 Fire Extinguishing Systems, National Fire Protection Association, Quincy MA, 1983.

21. NFPA Standard 12B, Table 18-2F, NFPA Fire Protection Handbook, Halon 1211 Fire Extinguishing Systems, National Fire Protection Association, Quincy MA, 1983.

22. NFPA Standard 12C-T, Paragraph 1-6.1.2, Halon 2402 Fire Extinguishing Systems, National Fire Protection Association, Quincy MA, 1983.

Recommended changes of this publication should be forwarded to Commander, U.S. Army Test and Evaluation Command, ATTN: AMSTE-CT-T, Aberdeen Proving Ground, MD 21005-5055. Phone: (410) 278-1486, DSN 298-1486 and EMAIL: amstectt@apg-9.apg.Army.mil. Technical information may be obtained from the preparing activity: Commander, U.S. Army Combat Systems Test Activity, ATTN: STECS-AC-I, Aberdeen Proving Ground, MD 21005-5059. Phone: (410) 278-4246, DSN: 298-4246, and EMAIL: stecsaci@apg-9.apg.Army.mil. Additional copies are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22304-6145. This document is identified by the accession number (AD No.) printed on the first page.