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NATO LETTER OF PROMULGATION

30 August 2021

1. The enclosed Allied ENGINEERING Publication AEP-4785, Volume III, Edition A, Version 1, TEST PROCEDURES FOR THE MEASUREMENT OF GAS BLOWBACK, which has been approved by the nations in the NATO ARMY ARMAMENTS GROUP (NAAG), is promulgated herewith. The recommendation of nations to use this publication is recorded in STANREC 4785.

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Major General, GRC (A)
Director, NATO Standardization Office

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CHAPTER	RECORD OF RESERVATION BY NATIONS
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CHAPTER - 1 INTRODUCTION

1.1. INTRODUCTION

1. "Blowback" is the term used to describe the combustion products that emanate from a small arms system's operating group and chamber area due to backpressure within the system, typically as a result of the addition of a suppressor or other muzzle device (such as a blank firing adaptor) to the weapon system. These products are "blown back" toward the Operator, thus the term "blowback." Specifically, the procedures in this Volume are intended to measure the increase in blown back gases as a result of the addition of a suppressor or other muzzle device to the small arms system. Annex A provides a more detailed explanation of blowback in suppressed small arms systems.

1.2. SCOPE

1. The procedures in this Volume describe the facilities, equipment, and methods used to measure and quantify the phenomenon of "blowback" in a small arms system, particularly when a signature suppressor is added to the system.

2. The following procedures are a balance between practicalities ('ease of use') and an acceptable level of error ('completeness').

3. The test procedures described within this Volume were developed through a series of experimentation and testing that focused on the measurement of concentrations of the three primary toxic gases (CO, HCN, NH_3) that occur commonly in small arms blowback. With some general knowledge of the measurement methods and equipment, the same methodology can be used to quantify a variety of blowback constituents. The User of the method is responsible for determining which blowback constituents they are interested in, and for tailoring the method as necessary for those constituents.

4. Two methods are described in this Volume. The User is responsible for determining which of these methods, or both, meet their specific data requirements.

   a. The "Chamber Test Method" describes a method for measuring the total quantity of gases of interest that are blown back out of the weapon's chamber and operating group area. This is method is based largely on NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8.1. "Potentially Hazardous Effects," with some modifications and additions to take into account the nuances of gas blowback. U.S. Army Test Operations Procedures (TOP) 2-2-614[2], paragraph 4.3, and TOP 3-2-045[3] offer some guidelines for measurement of gas blowback, and were also used as a basis for the Chamber Test Method. Thus, this Volume does not replace, but complements the NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8.1. "Potentially Hazardous Effects," as well as TOP 2-2-614[2] and 3-2-045[3], with a focus on the blowback gases.

b. The “Breathing Zone Method” describes methods to assess blowback from the system level, taking into account the directionality of the event and other system attributes or features that may affect the amount of gases that are blown back from the chamber and operating group and that reach the Operator’s breathing zone.

5. All of the tests described in this Volume are intended to be comparative tests. In other words, the blowback measurements should always be compared back to a baseline system tested at the same time as the modified system. If the test is being done to assess the increase in blowback resultant from the addition of a suppressor or muzzle device, the baseline system should always be the same weapon system with the standard muzzle device, such as a “bird cage” style flash hider. If the test is being done to assess blowback in a weapon system with an integral suppressor, the baseline system should be a comparable standard issue system, and/or a comparable standard issue system with similarly performing muzzle device. For instance, if an M4A1 system with an integrally suppressed upper receiver were to be tested, the baseline system would be a standard M4A1 with a birdcage flash hider, and/or an M4A1 outfitted with a suppressor that achieves a similar level of signature reduction. For purposes of this Volume, these are all referred to as the “baseline” systems.

6. The intent of this Volume is to describe the methodology to measure the blown back gases in a small arms system that may bring about immediate operational effects on the weapon operator, such as burning eyes, difficulty breathing, or other immediate operational effects that could take the Operator out of the fight, and therefore put him or her in danger. This Volume does not define how to use the measurements to determine operational effects, and instead builds a foundation that results in consistent and repeatable measurements that can be used to compare systems. Additionally, this Volume is intended to focus on blowback specifically, and the nuances associated with measuring it, versus total weapon toxicity.

7. This Volume is intended to be primarily used for measuring gas blowback, as opposed to the metallic aerosols that are also part of the combustion products and that are also sometimes blown back toward the user. While measurement of blown back metallic aerosols is not a primary measurement in this method, it is addressed in Annex B.

CHAPTER - 2 TESTING PROTOCOL

2.1. FACILITIES AND INSTRUMENTATION

1. Facilities and instrumentation described in this section are common to all methods under this Volume. Any additional requirements that are specific to either test method will be detailed in Section 2.3, Test Procedures.

a. Facilities

(1) The test facilities are largely unique to the test method being performed (Chamber Test Method or Breathing Zone Test Method). While some of the same basic facilities could be used for both methods, each method's specific requirements are outlined in Section 2.4.3 and 2.5.3.

b. Instrumentation

(1) There are two measurement techniques that are recommended for use to measure gas concentrations within either the Chamber Test Method or the Breathing Zone Test Method of the Small Arms Blowback Measurement Test. The two measurement techniques are:

i. Fourier Transform Infrared (FTIR) Spectroscopy; and

ii. Electrochemical Detectors

(2) Each of these measurement techniques have different instrumentation requirements, and these requirements, as well as a detailed description of each method, and guidance governing the suggested permissible error and the minimum detection limits for the instrumentation are provided in Annex C. Manufacturer's guidance shall be followed for calibration and/or bump testing.

2.2. REQUIRED TEST CONDITIONS

1. One of the key components of a successful Small Arms System Blowback Measurement Test is reducing error and uncertainty in the test. This is largely achieved by maintaining a highly controlled and repeatable environment. Many of the required test conditions are unique to the test method being performed (Chamber Test Method or Breathing Zone Test Method), and are outlined in Section 2.4. and 2.5.

2. The following required test conditions shall be met, regardless of the test method being employed. Any requirements specific to a certain test method are outlined in Section 2.4. and 2.5.

a. Weapon

(1) The same weapon receiver (upper and lower) shall be used for all testing, including both the baseline and modified configurations, in order to eliminate any error caused by using different weapon receivers and/or gas systems.

(2) The weapon shall be cleaned and lubricated, IAW the weapon's approved operator or technical manual, prior to the test.

(3) The weapon shall be configured in such a way that it most closely replicates the weapon's configuration in a combat or training situation. This is critical, since even a slight difference in the weapon's configuration could potentially affect the blowback.

i. If the weapon is magazine fed, a magazine shall be in place. If the weapon is belt fed, the feed cover shall be closed.

ii. If the weapon typically fires from the closed bolt, the weapon shall be configured such that the bolt closes after the firing of the single round or the burst being measured. This could be done through the use of a dummy round at the bottom of the magazine. If the weapon fires from the open bolt, provisions shall be made to ensure that it returns to the open bolt after firing the single round or burst being measured.

(4) All muzzle devices shall be installed per the manufacturer's instructions.

(5) If a weapon is damaged during the test requiring replacement of any weapon components, this should be documented. If any major component is replaced that might affect the results, re-starting the test sequence should be considered and employed as appropriate.

b. Ammunition

(1) To minimize variability in results, the ammunition used throughout testing shall be of the same type and from the same lot, based on the expected employment of the subject system.

(2) If multiple ammunition types are required, they shall each be tested in their entirety. Ammunition types shall not be mixed, unless a specific mix is considered such as 4:1 ball/tracer configuration. The type of ammunition used in the test is subject to the detailed test plan (DTP), which shall be developed based on the unique requirements of the end user of the data.

c. Range and Environmental Conditions

(1) Relative Humidity shall be 50% +/- 25%.

(2) Temperature shall be 21°C +/- 6°C.

2.3. TEST PROCEDURES

1. The measurement of CO, HCN, and NH_3 are the focus of this Volume. While current small arms propellants have the primary toxic gas combustion products of CO, HCN, and NH_3, future propellants or developmental propellants may produce different combustion products. Thus, it is important for the User of the test method to tailor the measurements to the gases that are of interest for the particular system being assessed.

2. If the full system toxicity (weapon and ammunition) has been measured through the processes outlined in NATO D/14 (AC/225(DSS)D(2018)0006)[1], then the ratio of each gaseous constituent of the combustion product is already known. While the addition of a suppressor to the system could have some effect on the combustion as compared to the unsuppressed system due to secondary combustion within the suppressor, this effect is often assumed to be negligible to the total combustion products. Further, even if the mixture of combustion products from unsuppressed to suppressed is different, the methods in this AEP still accurately reflect the concentrations and masses of gases that are blown back toward the User as a result of each configuration, regardless of the reason (secondary combustion or increased system pressure). As such, much can be gained simply from measuring the concentration of only a single gas, called an “indicator gas,” and then estimating the concentrations of other gases based on the known ratios to that indicator gas. Additionally, if only the increase in blowback as compared to a baseline system is of interest, than a carefully chosen indicator gas can provide the required comparative measurement. In the case of current propellants, CO is the most prevalent toxic gas, and therefore provides the highest fidelity measurements. In addition, it is also the easiest and most accurate to measure using electrochemical detectors. For these reasons, CO was chosen as an indicator gas for the development of this Volume. Thus, while the methods refer to measurement of all three gases (CO, HCN, and NH_3), CO is the focus and represents the sample data presented.

3. Testing shall be conducted with single shots, and with burst lengths that are representative of how the weapon would be fired in a combat or training situation. The User of the method is responsible for determining appropriate burst lengths during development of the DTP.

4. The tests described in this volume are comparative tests, and as such must be performed in both the modified and unmodified weapon configurations. The final comparison in blowback will be the percent increase in blowback of the modified as compared to the baseline configuration as measured by concentrations and mass of gases of interest. For each test method (Chamber Test Method or Breathing Zone Test

Method) the baseline and modified configurations shall be tested using identical methods, techniques and procedures. It is critical that the tests are performed identically in order for the data to be compared on a one for one basis. This includes all test setup, test procedures, and instrumentation type and settings.

2.4. CHAMBER TEST METHOD

1. The Chamber Test Method shall be performed in accordance with the methods described in NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8, Potentially Hazardous Effects, with specific considerations to measure blowback as discussed hereafter.

2. Objective

a. The objective of the Chamber Test Method is to measure the direct effect that the addition of a specific suppressor or muzzle device has on the amount of gases blown back toward the operator. The Chamber Test Method is performed by measuring, comparing, and contrasting the total quantity of toxic gases blown back by a weapon system in the modified (suppressed) and baseline (unsuppressed) configurations.

b. In addition to measuring the gases *blown back*, the *total* gases produced can be measured with and without a muzzle device as part of the Chamber Test Method. Measurement of the total gases produced is intended primarily to verify that the suppressor is not significantly changing the overall combustion of the system. If it is already known or assumed that the total combustion is not changed by the suppressor, the total gases do not need to be measured.

3. Facilities and Instrumentation

a. The general facilities and instrumentation used for the Chamber Method should follow the NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8, Potentially Hazardous Effects. In addition to those facilities and considerations, the following items shall be considered.

(1) Facilities

i. Firing Range. The firing range used for this test can be indoor or outdoor. If indoor, the range shall be equipped with an exhaust/ventilation system sufficient to reduce the concentration of measured gases inside the chamber to 0 PPM between shots.

ii. Test Chamber. This test requires that the weapon be placed inside a substantially airtight test chamber during firing. The chamber used in NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8, Potentially Hazardous Effects can be used. Annex D details specific test chamber requirements. Sample test chambers are also detailed in Annex D.

(2) Instrumentation. The instrumentation used for all testing shall meet the requirements set forth in 2.1.1.b., and Annex C of this Volume.

4. <u>Test Procedures</u>

a. PRE-TEST PROCEDURES. In addition to those outlined in Section 2.3. and NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8, Potentially Hazardous Effects, the following test procedures shall be followed:

(1) Weapon and Instrumentation Preparation

i. Prior to taking a shot, all instrumentation and the weapon itself shall be prepared in accordance with Section 2.2.

ii. The weapon system shall be affixed to a stationary mount, inside the test chamber, as required by the specific test being run.

iii. The weapon system shall be hard-mounted so that it does not move under the recoil of firing.

iv. The weapon shall be positioned inside the chamber in order to take the desired measurement (Total Gas or Blowback only). Positioning of the weapon is critical to the test, and shall be recorded and kept consistent for each unique scenario. If a variable volume chamber is being used, the size and volume of the chamber shall be recorded.

1. Total Gas Measurement (indicated as “Inside” in Table E-1). If total gas (blowback and muzzle gas) produced is being measured, the weapon shall be placed fully inside the chamber, in accordance with NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8, Potentially Hazardous Effects.

2. Blowback Measurement (indicated as “Outside” in Table E-1). If blowback gas only is being measured, the weapon shall be positioned so that the entire muzzle device, either the suppressor or flash hider, be outside the chamber, with the rest of the weapon inside the chamber. Specifically on a gas operated weapon system, the gas block or regulator, as well as anything rearward of it, shall be inside the chamber. On a system that does not have a gas block or regulator, the weapon shall be positioned so that the front wall of the chamber is directly behind the muzzle device. For a system without a muzzle device, the weapon shall be placed so that the muzzle itself remains 2.5 to 5 cm (1 to 2”) outside of the chamber throughout the weapon’s operation.

The size of the opening for the muzzle device to pass through shall be minimized to prevent gas from escaping the chamber to the greatest extent possible. For a system that has a recoiling or moving barrel, the opening shall be minimized to the greatest extent possible, while preventing interference between the chamber and the barrel. The weapon shall be positioned either so that the muzzle device remains fully outside the chamber with the chamber's front wall directly behind the muzzle device in the barrel's rear-most position, or on a barrel without a muzzle device, so that the muzzle itself remains outside the chamber with the barrel in its rear-most position.

(2) Instrumentation Setup.

i. If FTIR or sampled/pumped electrochemical detectors are used, 6 mm (0.25") diameter tubing (or similar) shall be used to sample the gas in the chamber. The inlet to the tubing shall be inserted into the chamber, and located above the weapon and centered in the top of the chamber. The length of the tubing between the inlet and the analysis instrumentation shall be minimized to the extent possible.

ii. Alternately, if an immersible electrochemical sensor unit is being used, the unit itself can be placed inside the chamber during firing. In this case, a circulation fan is recommended to ensure that the gases are properly mixed throughout the chamber.

(3) Baseline Data Collection. Baseline data shall be collected for the range air. In most cases, the range air should show 0 PPM of all gases being analyzed. The baseline sample should be collected in the same manner as a test sample, using the same flow rate and timing used for testing. The baseline samples should be collected when the range and chamber are deemed cleared of any combustion gases, preferably at the beginning of the day, prior to any firing, at the end of the day after firing is complete, and periodically as necessary.

(4) With the weapon mounted and prepared as described above, the weapon shall be fired in order to burn off excess lubrication or cleaning products that may be left over. The number of burn-off rounds will be determined by the User and indicated in the DTP. No data should be taken during these shots. If local protocols allow, the burn off shots can be fired with the chamber itself open. If possible, burn off shots shall be taken outside of the chamber to prevent unnecessary surface contamination of the chamber or mount. However, if that is not practical, the chamber should simply be cleaned IAW the procedures outlined

above prior to data collection. Following these burn-off shots, data collection shall begin.

b. LIVE FIRE DATA COLLECTION PROCEDURE. The DTP and local operating procedures shall detail, to the extent necessary, the specific live fire data collection procedures. The following guidelines shall be considered for live fire data collection.

(1) Measurement Considerations. Ensure that combustion gases are cleared from test chamber by verifying that the gas concentration in the test chamber is 0 PPM. This can be done either through the use of an electrochemical sensor, or by observing the FTIR data in real time. If gas concentration is not at 0 PPM, the test chamber should be opened and sufficiently ventilated to clear gases.

(2) Data Collection.

i. Sampling should take place for enough time to allow gases in the chamber to reach a steady state so that a time weighted average can be calculated later. Two (2) minutes is usually sufficient, but more or less time may be appropriate depending on the test.

ii. The chamber shall not be manipulated, and the exhaust/ventilation system and any forced air heating or cooling systems should remain turned off during sampling. All range doors shall remain closed.

5. <u>Data Required</u>

a. Required data to be measured are as follows:

(1) Environmental conditions:

i. Relative humidity;

ii. Temperature; and

iii. Atmospheric Pressure.

(2) Dimensions of the firing chamber, including length, width, height (or diameter if cylindrical). Photos shall be included.

(3) Specific test configuration, including:

i. Weapon type and serial number;

ii. Weapon configuration(s):

1. Muzzle device make, model, serial number, and approximate round count (as applicable);

2. Additional weapon modifications including make, model, serial number of any items installed on the weapon (as applicable); and

3. Additional weapon information such as barrel length, twist rate, etc. if non-standard.

iii. Ammunition type and lot number;

iv. Burst information:

1. Number of rounds fired; and

2. Rate of fire (if possible).

v. Location of gas inlet with respect to weapon, including x, y, z locations from a measureable location; and

vi. Length of tubing from inlet to measurement device.

(4) Gas Concentration Measurement Equipment, including:

i. Gas concentration data measurement method (Electrochemical Detector, FTIR, etc.);

ii. Pump flow rate;

iii. Data sample rate;

iv. Sensor specifications for all sensors:

1. Detection Range (PPM);

2. Resolution (PPM);

3. Detection Limit (PPM);

4. Response Time; and

5. Sensitivity (% measured value).

v. Gas Concentration Measurement Data:

1. Concentration versus time for all gases being analyzed; and

2. Sample time used for average concentrations reported.

6. Processing and Presentation of Data

a. The data obtained during the test will be reduced and presented as follows:

(1) All data necessary to fully define the configuration being tested shall be documented and presented, including all data recorded as outlined above.

(2) Gas Data. Only the blowback gas data needs to be reported. The full weapon gas, if measured and analyzed, can be separately reduced and reported, however it should not be included in the blowback gas data. Data shall be grouped and reduced based on unique test scenarios as defined in Table 2.

i. Gas Concentration Tabular Data and Gas Mass Analysis.

1. Average steady state gas concentration shall be calculated by taking the average concentration measured over a period of time after the concentration reaches steady state within the chamber. The data should be analyzed on a shot by shot basis to determine when steady state is reached and what duration is appropriate for calculating the average. Typically, 60-120 seconds of steady state data is sufficient.

2. Since the chamber volume can vary depending on the weapon, scenario, and configuration being tested, reporting only the gas concentration can be misleading when comparing test results. As such, calculating the mass of gas produced will eliminate the effect of chamber volume on the numbers reported. The mass of gas shall be calculated using Eq. 1.

$$m_{gas} = n \times M_{gas} \qquad \text{Eq. 1}$$

Where:

m_{gas} is the mass of the gas in grams (g),
n is the number of moles (mol),
M_{gas} is the molecular mass of the gas in grams per mole (g/mol).

3. The ideal gas law can be used to calculate the number of moles (n) of each gas using Eq. 2.

$$n = \frac{P \times V_{gas}}{R \times T}$$ Eq. 2

Where:

P is the pressure in Pascals (Pa)
V_{gas} is the volume of gas in cubic meters (m^3),
R is the ideal gas constant in Joules per Mole Kelvin (J/mol*K),
T is the temperature in degrees Kelvin (K).

4. Since the volume of the chamber is variable, and the measured characteristic is concentration of each gas in parts per million (PPM), the total volume of each gas (V_{gas}) can be calculated using Eq. 3.

$$V_{gas} = V_{chamber} \times C_{gas}$$ Eq. 3

Where:

$V_{chamber}$ is the total volume of the chamber (m^3), and
C_{gas} is the concentration of the gas (PPM).

5. Eq. 3 can be substituted into Eq. 2 to get Eq. 4.

$$n = \frac{P \times V_{chamber} \times C_{gas}}{R \times T}$$ Eq. 4

6. Assuming that the gas pressure is approximately atmospheric and the temperature is room temperature, and using the molecular mass of each gas, conversion factors (k_{gas}) can be calculated for each gas in order to calculate the mass of each gas in milligrams (mg) (see Table 2). Eq. 1 can then be simplified to Eq. 5 to calculate the mass of gas in mg.

$$m_{gas} = k_{gas} \times C_{gas} \times V_{chamber}$$ Eq. 5

Table 1 Conversion Factors for Mass Calculations of CO, HCN, NH_3

Gas	**Conversion Factor (k_{gas})**
CO	1.16
HCN	1.12
NH_3	0.71

7. The following data should be tabulated for each gas being analyzed, and for each unique configuration of weapon, ammunition, muzzle device, burst length, and muzzle location:

a. Median gas mass (mg gas as calculated from the gas concentration measured over some steady state time period) of all shots or bursts for each configuration;

b. Percent difference between the baseline (unsuppressed) median gas mass and the modified (suppressed) median gas mass;

c. Mean gas mass (mg gas as calculated from the gas concentration measured over some steady state time period) of all shots or bursts for each configuration;

d. Percent difference between the baseline (unsuppressed) mean gas mass and the modified (suppressed) mean gas mass;

e. Minimum mass of gas (mg gas as calculated from the gas concentration measured over some steady state time period) for each configuration on a per shot/burst basis; and

f. Maximum mass of gas (mg gas as calculated from the gas concentration measured over some steady state time period) for each configuration on a per shot/burst basis.

Table 2 Sample Table of Gas Data - Chamber Method

		Outside					
		Single			Burst		
		Baseline	Modified	% Change	Baseline	Modified	% Change
Mass CO (mg)	Median	86.016	267.315	210.77%	197.285	737.312	273.73%
	Mean	91.422	251.017	174.57%	204.364	729.002	256.72%
	Min	71.696	191.302		194.233	652.678	
	Max	121.960	278.135		228.655	788.706	

ii. Gas Mass Graphical Data. The following data should be shown graphically for each gas analyzed. A sample is shown in Figure 1.

1. Average gas mass (mg) for each shot or burst sorted by each unique test scenario – shown as individual data points; and

2. Mean of all of the average gas mass (mg) for each unique test scenario – shown as bar plot.

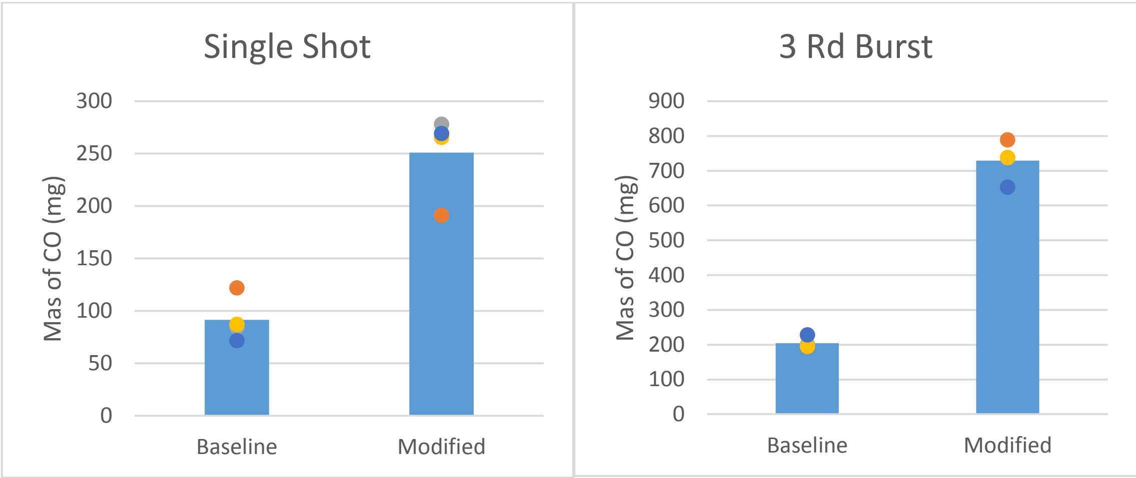

Figure 1. Sample Data Presentation for Gas Mass Using Chamber Test Method

2.5. BREATHING ZONE TEST METHOD

1. The Breathing Zone Test Method shall be performed in accordance with the methods described below, as well as the overarching guidance provided in Sections 1.1 to 2.3 of this document.

2. Objective

a. The objective of the Breathing Zone Test Method is to assess blowback from a system and operational level by measuring concentrations of toxic gases (CO, HCN, NH_3) in the location of the weapon system Operator's breathing zone during firing with a suppressor, muzzle device, or other accessory of interest. The intent of the test is to take into account where the blowback gases go after they leave the weapon. This test takes into account variables like weapon layout (traditional versus bullpup) and other blowback re-direction devices or weapon design factors that may have an effect on the amount of blowback gas that reaches the Operator and causes an Operational impact.

b. The Breathing Zone Test Method requires a highly controlled environment in order to generate repeatable results. The primary consideration for the environment is that air movement is eliminated during firing, or in the case that the test is intended to replicate a specific firing position or vehicle, the test environment mimics the operational environment sufficiently.

3. Facilities and Instrumentation

a. In addition to the facilities and instrumentation described in Section 2.1., the following facilities and instrumentation shall be used:

(1) Facilities.

i. Firing Range

1. An enclosed firing position shall be used for the Breathing Zone Method. The term “enclosed firing position” means that the area where the weapon is mounted shall be fully enclosed from the outside environment. It is permissible to use firing position where the projectile impact area is outdoors, as long as the firing position itself is indoors and enclosed.

2. If the test is intended to simulate an open air environment, the indoor range must have an enclosed firing position that is large enough so that gas flow, including blowback gases and muzzle gases, is not affected by the structure or ancillary items in the range. This means that all walls to the sides, forward, and behind the weapon, as well as the range floor and ceiling, shall be sufficiently far away as to not affect any of the gas that emanates from the weapon system. All ancillary items inside the range shall also be placed in such a way as to not affect gas flow. Video (high speed or regular) of the blowback event, as well as subject matter expertise can be used to determine if a particular range is of sufficient size to approximate an open air environment.

3. If the test is intended to assess the blowback effects in a particular scenario or enclosed area (i.e. in a specific vehicle, room, etc.) then the enclosed firing position shall be set up to sufficiently replicate that scenario.

4. The indoor firing range /enclosed firing position shall be climate controlled (Temperature, Relative Humidity, Elimination of wind/airflow).

ii. Range Exhaust/Ventilation System

1. The range exhaust/ventilation system shall be sufficient to replace the air within the enclosed firing position with fresh, clean air from the outside or from somewhere else within the building. The system must be

capable of exchanging the air within the firing position in a few minutes.

2. Exhaust/ventilation system equipment must be capable of being manually turned on and off within a few minutes. With exhaust system turned off, there shall be no airflow within the enclosure. Local Standing Operating Procedures must allow for the exhaust/ventilation system to be cycled on and off throughout the test.

(2) Instrumentation. The instrumentation used for all testing shall meet the requirements set forth in 2.1.1.b., and Annex C of this Volume.

4. Required Test Conditions

a. The required test conditions for the Breathing Zone Test Method are intended primarily to ensure that the environment is free of airflow, wind, and obstructions during data collection, as well as to ensure that all other test conditions are controlled to the maximum extent possible. It is critical that the conditions are closely controlled, since the Breathing Zone Test Method requires that the blowback gases leave the weapon and begin to mix with the environment before they are measured. In addition to those outlined in Section 2.2., the following are the required test conditions for the Breathing Zone Test Method:

(1) With the exhaust/ventilation system turned off, there shall be no airflow within the enclosed firing position. This may require additional air conditioning or heating units to be turned off, depending on the set-up of the heating, ventilation, and air conditioning (HVAC) systems at a specific test site.

(2) When range ventilation is turned on, flow rate shall be sufficient to renew the air in the enclosure, indicated by CO sensor measurement return to 0PPM, within several minutes. The air in the enclosed firing position shall be sufficiently cleared between tests, to ensure that the concentration of CO has reached 0PPM at the start of each data collection (shot/burst).

b. In addition to the considerations above, close attention should be paid to the specific test setup for each test, including the location of air inlets, blast shield size and location, and instrumentation setup. These details shall be documented and kept consistent.

5. Test Procedures

a. PRE-TEST PROCEDURES. In addition to those outlined in Section 2.3., the following test procedures shall be followed:

(1) Weapon and Instrumentation Preparation

i. Prior to taking a shot, all instrumentation and the weapon itself shall be prepared in accordance with Section 2.2.

ii. The weapon system shall be affixed to a stationary mount, and shall be placed as close to the range center from the left and right walls as possible. As indicated previously, the location of the weapon within the enclosed firing position shall be measured and documented.

iii. The weapon system shall be hard mounted so that it does not move under the recoil of firing.

iv. All testing shall take place in a firing range in accordance with one of the following:

1. Indoor firing range with firing position that is physically isolated from the impact area, such as one where the firing position is in standalone room. The firing position shall either be large enough to sufficiently replicate an open air environment, or shall be sized and configured to replicate a specific vehicle, room, building, or other scenario. The weapon shall be positioned so that the muzzle is located fully outside of the enclosed firing area (on the “downrange” side), while the rest of the weapon is inside the enclosed firing position (on the “up-range” side). The perforation for the muzzle shall be minimized in order to shield the firing position from muzzle gases. This can be done using a thick rubber gasket with an opening minimized for the muzzle.

2. Open indoor range with firing position and impact area not physically isolated from each other. In this case, a standard sheet of plywood (125cm x 250 cm, or four foot by eight foot), or larger barrier shall be constructed and used as a blast wall between the muzzle and the rest of the weapon, including the gas block. The blast wall shall have a hole cut in the center, and the hole shall be sized to allow the muzzle to pass through, with any gaps around the barrel minimized or closed with a thick rubber gasket, or other means. For firing, the weapon’s muzzle shall be placed through the center of the blast wall. The intent here is to prevent muzzle gases from mixing with blowback gases during measurement. For a pistol or other recoil operated weapon where the barrel moves during operation, the blast shield shall be configured in such a way that it

does not interfere with the weapon's operation. Range size, weapon location, blast wall location, and all other range details shall always be documented and reported.

v. The projectile impact and the muzzle can be located outdoors if required by the range setup, as long as the rest of the weapon is located inside the enclosed firing position.

vi. If a bullet trap is being used, the bullet trap shall be positioned in such a way that the weapon's muzzle is sufficiently far from both the front wall of the range and the bullet trap itself, so that neither will affect the muzzle blast.

(2) Instrumentation Setup.

i. A 10 to 12.7 cm (4 to 5”) air inlet funnel shall be affixed at the location of the Operator's breathing zone, as measured from an approximate 50% operator shouldering the subject weapon system. The breathing zone location shall be considered for both left handed and right handed Operators. This location shall be carefully documented. While the specific location itself is not critical, the consistency of placement is. Since the air inlet is moved from left to right throughout the test, it is a good idea to mark the weapon in some way to ensure that the funnel is placed at the same location each time. The funnel's opening shall face forward, with the axis of the opening parallel to the axis of the barrel.

ii. 6 mm (0.25”) diameter tubing or similar shall be inserted in the throat of the air inlet funnel, with the tubing's opening located at the point where the funnel's neck meets the funnel body. The length of tubing shall be minimized to the greatest extent possible to prevent mixing of gas within the tube, prior to reaching the electrochemical sensor(s). A length of around two meters or less has shown to be sufficient. Tubing shall be routed from the throat of the funnel rearward and downward of the mounted weapon system, so that all data collection equipment can be placed in such a way as to not disturb or alter the blowback gas flow. The tubing shall be secured in the funnel and any clearance between the exterior of the tubing and the interior of the funnel's neck shall be sealed. Duct tape works well both to secure the tubing as well as to seal the clearance. The opposite end of the tubing shall be attached to the air inlet on the sampling pump, or to the air inlet on the electrochemical detector unit on systems where the pump is integral to the unit. If multiple measurement methods are being used simultaneously, all tubes shall be configured and attached in this way.

iii. High speed video, while not required, is a good tool to subjectively observe the blowback gas flow and to tie qualitative data to the measurements recorded using the objective method(s). The high speed video camera(s), if used, shall be set up in such a way to capture the blowback gases in the area of interest. While this could vary depending on the test configuration, typically a side view and/or a top view of the weapon system, from the ejection port rearward, captures the event. High speed video shall be done with a contrasting background so that the gas flow can be adequately captured. A flat black background works well, along with sufficient lighting. The ideal setup will vary from location to location, so it is important to individually develop the best high speed video parameters for the specific test site. If high temperature lights are being used, the lights shall be turned off between shots in order to prevent the weapon and the room from overheating, which could affect the results.

(3) Baseline Data Collection. Baseline data shall be collected for the range air. In most cases, the range air should show 0 PPM of all gases being analyzed.

(4) With the weapon mounted and prepared as described above, the weapon shall be fired in order to burn off excess lubrication or cleaning products that may be left over. The number of burn-off rounds will be determined by the User and indicated in the DTP. No data shall be taken during these shots. Following these burn-off rounds, data collection shall begin.

b. Live Fire Data Collection Procedure. Since each range has specific operating procedures and safety considerations, there is no standard, step by step procedure for live fire data collection. The DTP and local operating procedures shall detail, to the extent necessary, the specific live fire data collection procedures. The following guidelines shall be considered for live fire data collection.

(1) Measurement Considerations. Ensure that combustion gases are all cleared from firing position by verifying that the gas concentration in the enclosed firing position is 0 PPM. This can be done either through the use of an electrochemical detector, or by observing the FTIR data in real time. If gas concentration is not at 0 PPM, range exhaust/ventilation should be turned on. When the gas concentration is steady at 0 PPM, the range exhaust/ventilation should be turned off.

(2) Data Collection.

i. It is important to ensure that no personnel are near the weapon system during firing. If at all possible, firing should be performed remotely to ensure that personnel do not affect the airflow within the firing position. At a minimum, personnel should be far enough away from the firing position to not interfere with airflow, and should limit movement near the firing position during data collection.

ii. Sampling shall take place for at least two (2) minutes after a shot or burst. During this time, no personnel shall be permitted in the vicinity of the weapon system, the exhaust/ventilation system and any forced air heating or cooling systems shall remain turned off. All range doors shall remain closed. There shall be no movement of personnel or equipment in the vicinity of the weapon system during this time, in an effort to allow the gases to dissipate naturally and without any external interference.

6. <u>Data Required</u>

a. Required data to be measured are as follows:

(1) Environmental conditions:

i. Relative humidity (% RH);

ii. Temperature; and

iii. Atmospheric Pressure.

(2) Description and overall dimensions of the enclosed firing position, and position of the weapon within the enclosure.

(3) Size of enclosed firing position, including height, width, and length of the enclosed area. For an indoor range in which the firing position is not physically isolated from the impact area with a wall, the overall length of the range shall be reported, as well as the distance from the rear wall of the range to the blast shield. For a range where the enclosed firing position is isolated from the impact are with a wall, or for a range where a bullet trap is used some short distance from the firing position, the length of the room (front to back) shall be reported, as well as the width from side to side. Photos shall be included.

(4) Position of weapon, including position from side to side, position from front to rear, and location of the blast shield, both within the range and with respect to the weapon system. If the blast shield acts in conjunction with the isolation wall between the firing position and the impact area, this shall be indicated. Additionally, the size of the blast shield shall be recorded.

(5) Specific test configuration, including:

i. Weapon type and serial number;

ii. Weapon configuration:

1. Muzzle device make, model, serial number, and approximate round count (as applicable);

2. Additional weapon modifications including make, model, serial number of any items installed on the weapon (as applicable); and

3. Additional weapon information such as barrel length, twist rate, etc. if non-standard.

iii. Ammunition type and lot number;

iv. Burst information:

1. Number of rounds fired; and

2. Rate of fire (if possible).

v. Location of gas inlet with respect to weapon, including x, y, z locations from a measureable location on the weapon system, as well as indication of left or right hand mounting.

vi. Length of tubing from inlet to measurement device.

(6) Gas Concentration Measurement Equipment, including:

i. Gas concentration data measurement method (Electrochemical Detector, FTIR, etc.);

ii. Pump flow rate;

iii. Data sample rate;

iv. Sensor specifications for all sensors:

1. Detection Range (PPM);

2. Resolution (PPM);

3. Detection Limit (PPM);

4. Response Time; and

5. Sensitivity (% measured value).

v. Gas Concentration Measurement Data:

1. Concentration versus time for all gases being analyzed.

7. Presentation of Data

a. The data obtained during the test will be reduced and presented as follows:

(1) All data necessary to fully define the configuration being tested shall be documented and presented, including all data recorded as outlined above.

(2) Gas Data. Data shall be grouped and reduced based on unique test scenarios. Table 3 shows an example of how the data should be grouped per test scenario.

i. Gas Concentration Tabular Data.

1. The gas concentration data should be tabulated for each gas being analyzed, and for each unique configuration of weapon, ammunition, muzzle device, burst length, and inlet location. The gas concentration data points indicated below should be tabulated for peak concentration, 15 second time weighted average (TWA) concentration, 30 second TWA concentration, and 45 second TWA concentration, starting at the first non-zero data point of the shot or burst. Since this is an open air method and there is no steady state or known volume, mass of gas cannot be computed. Thus, concentrations should be used for all comparisons.

a. Median gas concentration (peak PPM, 15 second TWA PPM, 30 second TWA PPM, 45 second TWA PPM) of all shots or bursts for each configuration.

b. Percent difference between the baseline (unsuppressed) median gas concentration and the modified (suppressed) median gas concentration (peak PPM, 15 second TWA PPM, 30 second TWA PPM, 45 second TWA PPM).

c. Mean gas concentration (peak PPM, 15 second TWA PPM, 30 second TWA PPM, 45 second TWA PPM) of all shots or bursts for each configuration.

d. Percent difference between the baseline (unsuppressed) mean gas concentration and the modified (suppressed) mean gas concentration (peak PPM, 15 second TWA PPM, 30 second TWA PPM, 45 second TWA PPM).

e. Minimum gas concentration (peak PPM, 15 second TWA PPM, 30 second TWA PPM, 45 second TWA PPM) for each configuration on a per shot/burst basis.

f. Maximum gas concentration (peak PPM, 15 second TWA PPM, 30 second TWA PPM, 45 second TWA PPM) for each configuration on a per shot/burst basis.

Table 3 Sample Table of Gas Data - Breathing Zone Method

Concentration CO (PPM)		Left Inlet						Right Inlet					
		Single			Burst			Single			Burst		
		Baseline	Modified	% Change	Baseline	Modified	% Change	Baseline	Modified	% Change	Baseline	Modified	% Change
Peak	Median	75.000	1535.000	1946.67%	280.000	3490.000	1146.43%	102.500	707.500	590.24%	335.000	1715.000	411.94%
	Mean	70.000	1505.000	2050.00%	290.000	3792.500	1207.76%	168.750	678.750	302.22%	411.250	1670.000	306.08%
	Min	30.000	1100.000		85.000	3040.000		20.000	335.000		205.000	1110.000	
	Max	100.000	1850.000		515.000	5150.000		450.000	965.000		770.000	2140.000	
15 Second Avg	Median	45.313	1135.000	2404.83%	165.000	2316.406	1303.88%	68.594	444.302	547.73%	201.406	1240.469	515.90%
	Mean	41.719	1159.922	2680.34%	163.359	2493.984	1426.69%	106.016	439.026	314.11%	245.391	1172.813	377.94%
	Min	20.938	899.063		37.813	2160.938		17.188	185.313		97.813	649.375	
	Max	55.313	1470.625		285.625	3182.188		269.688	682.188		480.938	1560.938	
30 Second Avg	Median	48.306	1140.806	2261.60%	178.387	1884.516	956.42%	56.452	401.801	611.76%	207.500	999.677	381.77%
	Mean	45.524	1062.258	2233.39%	180.726	1902.742	952.83%	78.790	394.328	400.48%	260.484	980.766	276.52%
	Min	12.097	757.419		59.677	1408.710		13.226	208.387		140.968	634.677	
	Max	73.387	1210.000		306.452	2433.226		189.032	565.323		485.968	1289.032	
45 Second Avg	Median	39.348	897.772	2181.63%	151.685	1467.935	867.75%	43.913	300.524	584.36%	176.957	717.772	305.62%
	Mean	40.163	807.255	1909.95%	149.402	1434.973	860.48%	59.293	300.670	407.09%	213.098	729.918	242.53%
	Min	8.152	530.870		66.087	1045.543		13.370	164.457		118.152	514.565	
	Max	73.804	902.609		228.152	1758.478		135.978	437.174		380.326	969.565	

ii. Gas Concentration Graphical Data. The data shown below should be shown graphically for each gas analyzed. Individual plots should be created for peak concentration, 15 second TWA concentration, 30 second TWA concentration, and 45 second TWA concentration. A sample is shown in Figure 2.

1. Gas concentration (PPM) for each shot or burst, sorted by each unique test scenario – shown as individual data points.

2. Mean gas concentration (PPM) for each unique test scenario – shown as bar plot.

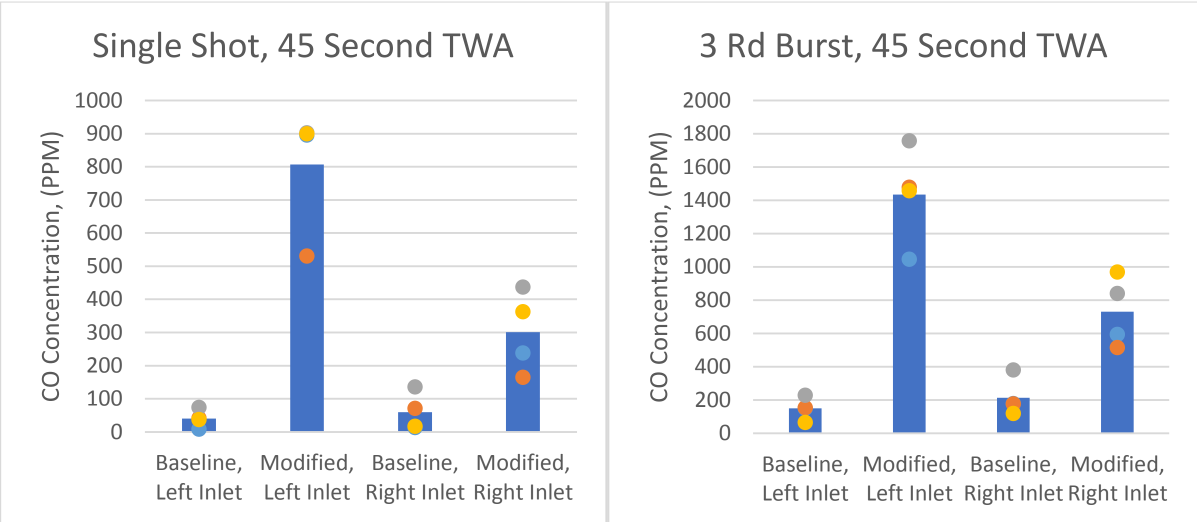

Figure 2. Sample Data Presentation for Breathing Zone Test Method (45 second average shown)

Annex - A BLOWBACK BACKGROUND

1. When a muzzle device, specifically a suppressor, is added to a small arms system, it typically has a tendency to increase the system's backpressure, therefore increasing the blowback. Different muzzle device designs result in different increases in backpressure, different gas dynamics, and therefore different levels of blowback. Generally speaking, a suppressor tends to trap high-pressure propellant gas inside it, and block the flow of gas from the barrel's muzzle. Fundamentally, backpressure is caused by this reduction in flow rate at the muzzle of the barrel, due to the increase in pressure at the muzzle caused by the suppressor.

2. The suppressor, when added to the weapon barrel, operates in two phases relative to the type of gas flow. The first phase is a very dynamic, time varying, shock dependent flow as the blast wave strength is decreased coming from the weapon, and the sound levels are reduced. This typically occurs within the first couple of milliseconds. After the flow starts to settle down in the suppressor, a more constant flow field is established, and much of the dynamic change slows down. At this point, the suppressor acts more like a plenum attached to the muzzle, allowing the gas pressure to decrease much more slowly as it "blows down," or the gas is slowly released from the suppressor. This second phase can last from 10 to 100 milliseconds depending on the type of suppressor and level of restriction. During this second phase, organ piping, or time varying pressure can cause pressure waves to move up and down the barrel. This can cause increases in the pressure at the chamber as organ piping occurs in the barrel/suppressor system. This causes a cyclic effect in the pressure at the chamber that is dictated by the speed of sound in the gas and the overall length of the suppressor and barrel.

3. It is during this second phase that the bolt starts to open (typically around 5 to 10 milliseconds) and significant pressure can still be present in the chamber (0.34 MPa to 1.38 MPa (50 to 2000 psi) or higher). At this point, propellant gases escape from the chamber at the same time they are exiting from the muzzle. The pressure at the chamber at the time the bolt opens typically determines the amount of propellant gases that escape back into the operating group. In a gas operated system, in addition to gas escaping from the chamber area, the pressure at the gas block tends to sustain a higher pressure for a longer period of time, thereby increasing the overall powering of the weapon system. This in turn increases the bolt velocity and subsequently the firing rate, unless the system is designed to accommodate the higher pressure (such as a gas adjustment feature).

4. Blowback gases consist of combustion byproducts that result from the burning primer and propellant from the ammunition cartridge within the small arms system. These combustion byproducts consist of various toxic gases, and a human can experience a variety of physiological effects as a result of exposure or inhalation. While the combustion byproducts consist of a variety of gases,[1,2,3,4] the following gases are three of the primary toxic constituents in small arms combustion gases:[1,2,3,4]

a. Carbon Monoxide (CO);

b. Hydrogen Cyanide (HCN); and

c. Ammonia (NH_3).

5. The effects of these toxins can vary. Carbon monoxide typically impairs the blood’s ability to transport oxygen; typically a long term exposure issue, but also important for short term exposure at high concentrations[5]. The effects of ammonia are typically immediate at the onset of exposure, and consist of eye, nose, and throat irritation. It is typically believed that the ammonia constituent causes the most significant operational issues in blowback gases, due to these physiological effects[5]. Short duration exposure to hydrogen cyanide can cause eye irritation, breathing difficulty, headache, nausea, and vomiting[5].

Annex - B Metallic Aerosol Measurement

B-1. INTRODUCTION

1. In addition to the toxic gases present in the combustion products, metallic aerosols are also present and can also cause short term onset of health issues, most commonly called "metal fume fever". Metal fume fever typically results in flu-like symptoms.[6] Metals are aerosolized from the primer and propellant, as well as the projectile as it travels down the barrel and the outer layer of the projectile ablates. While there are a wide variety of metallic aerosols produced during the firing event, this Annex focuses on the measurement of:

a. Lead (Pb);

b. Copper (Cu);

c. Zinc (Zn); and

d. Bismuth (Bi).

2. Measurement of metallic aerosols in suppressed small arms system have shown interesting results. While one may expect that the amount of metallic aerosols in the gas suspension fired from a suppressed weapon would be proportional to the amount of metallic aerosol in the gas suspension fired from an unsuppressed weapon, research has shown that the total amount of some of the metallic aerosols actually decrease with the use of a suppressor. The reason for this is that the aerosolized metals can actually deposit in the suppressor during firing, depending on suppressor design and the source of the aerosol within the ammunition or weapon system. This is also evidenced by the fact that suppressors tend to get heavier as more rounds are fired through them. Thus, if aerosolized metals are of concern to the User, it is important to measure the aerosolized metals as part of the test.

B-2. FACILITIES AND INSTRUMENTATION

1. The facilities and instrumentation for the measurement of metallic aerosols shall meet the following requirements:

a. Facilities. Measurement of metallic aerosols should be performed as part of the Chamber Test Method, and all facilities required to perform the measurements are identical to those required for the Chamber Test as outlined in Section 2.4.

b. Instrumentation. The following instrumentation is required for the measurement of metallic aerosols as part of the Chamber Test Method:

(1) <u>Sampling Pump.</u> The pump is the unit that controls the flow of gas through the sample filter. These units are precisely controlled to ensure consistent sampling. Flow rate adjustable between 3 and 5 l/min.

(2) Sampling Filters. The sample filters are used to collect the metallic aerosols for future analysis. The sample filters shall meet the following specifications.

i. Pore size shall be appropriate to collect the aerosols of interest. For collection of Pb, Cu, Zn, and Bi, pore size of .2 µm is sufficient.

ii. Cassette size/filter size shall be 37 mm (1.46”) or similar in order to be sufficient to collect the amount of metallic aerosol expected in this type of test.

iii. Cassette type shall allow the face of the filter to be fully exposed to the inside of the chamber, and the filter cassette shall be installed with the open face inside the chamber.

(3) Metallic Aerosol Instrumentation Setup. Metallic aerosols shall be sampled using a sampling pump connected to an open faced filter cassette as described in Annex B. The sampling pump should be set to sample between 3 to 5 l/min. A flow rate verification system should be used to measure the flow rate approximately once every second. One quarter inch diameter tubing (or similar) shall be used to connect the sampling pump to the filter. The inlet to the filter shall be located above the weapon and centered in the top of the chamber. The filter cassette shall have the bottom cap removed with the filter exposed at the end of the sample tubing inside the chamber. The length of tubing between the filter and the sampling pump shall be minimized to the greatest extent possible.

B-3. MEASUREMENT PROCEDURES

1. Collection and measurement of metallic aerosols shall be performed through controlled filtering and acid digestion. Acid digestion and analysis of filters should be performed by individuals or labs familiar with these processes.

a. Metallic Aerosol Measurement Methods.

(1) Baseline data for aerosols should be performed prior to any data collection. This can be done by sampling the air within the chamber through a filter without taking a shot for the same sampling time being used for a shot. The mass concentration of each metal without a shot is then the baseline level in the air, and should be subtracted from measured levels during firing.

(2) Metallic aerosols shall be sampled and collected through the use of controlled flow filtering. This method uses filter cassettes and a precisely controlled sampling pump to pull samples through the filter. The

filters are then collected and acid digested to analyze the type and quantity of metallic aerosols collected.

(3) When possible, it is prudent to perform collection of metallic aerosols simultaneously with blowback gas sampling in the Chamber Test Method. Similarly sized and placed tubing, including inlet location into the chamber, length and type of tubing, etc. shall be used to attach to sampling pump and filters. The filter cassette itself shall be placed within the chamber near the blowback gas sampling inlet tube.

(4) Sampling should take place for enough time to collect aerial dust in the filter, and to allow the combustion gases in the chamber to reach a steady state so that a time weighted average can be calculated later. Five (5) minutes has been found to be typically sufficient, but more or less time may be appropriate depending on the ammunition and weapon system being tested.

(5) Ensure that the front cap of the filter cassette is removed so that the filter face is exposed. Aerosol filter pump should be turned on the pre-shot flow rate should be measured. Filter exposure time should be minimized outside the sampling time, and as such, these steps should be done as close to firing as possible.

(6) The front cap of the aerosol filter shall be immediately installed back on the filter cassette when the chamber is opened. The time from when the shot was taken until the cap was replaced shall be recorded. This is critical to the mass concentrations to be calculated later. After the chamber is clear of gas, the cap shall be removed and the post shot flow rate can be measured and recorded.

B-4. DATA REQUIRED

1. The following data is required for measurement of metallic aerosols, in addition to the data provided for the Chamber Test Method, Section 2.4.

a. Filter specifications:

(1) Filter type and material;

(2) Pore size; and

(3) Filter cassette diameter.

b. Pre-shot flow rate;

c. Post-shot flow rate;

d. Sampling time; and

e. Mass concentrations of metals being analyzed.

B-5. PROCESSING AND PRESENTATION OF DATA

1. The following guidelines should be followed for processing and presentation of metallic aerosol data:

a. Data Processing. Filters shall be acid digested and analyzed by a competent laboratory. The digestion process should be sufficient to generate a mass/volumetric concentration of each metallic aerosol of interest. In the event that the quantity of metallic aerosol is less than the detection limit of the instrumentation being used, it should be indicated on the table as "< Limit."

b. Tabular Data. The following metallic aerosol data should be tabulated for each metal being analyzed, and for each unique configuration of weapon, ammunition, muzzle device, burst length, and muzzle location. A data sample is shown in Table B-1.

(1) Median mass concentration of metallic aerosol for all shots or bursts in each configuration (mg/m^3).

(2) Percent difference of the baseline (unsuppressed) median mass concentration and the modified (suppressed) median mass concentration.

(3) Mean mass concentration of metallic aerosol for all shots or bursts in each configuration (mg/m^3).

(4) Percent difference of the baseline (unsuppressed) mean mass concentration and the modified (suppressed) mean mass concentration.

(5) Minimum mass concentration of metallic aerosol for each configuration (mg/m^3).

(6) Maximum mass concentration of metallic aerosol for each configuration (mg/m^3).

Table B-1. Sample Table of Metallic Aerosol Data.

		Single			Burst		
		Baseline	**Modified**	**% Change**	**Baseline**	**Modified**	**% Change**
Bi	**Median**	< Limit	< Limit	N/A	< Limit	0.167	N/A
(mg/m^3)	**Mean**	< Limit	< Limit	N/A	< Limit	0.165	N/A
	Min	0.000	0.000		0.000	0.162	
	Max	0.000	0.000		0.000	0.167	
Cu	**Median**	0.098	0.132	34.87%	0.324	0.411	27.05%
(mg/m^3)	**Mean**	0.138	0.121	-12.48%	0.381	0.414	8.52%
	Min	0.056	0.072		0.285	0.379	
	Max	0.302	0.149		0.593	0.454	
Pb	**Median**	0.088	0.120	36.57%	0.290	0.392	35.41%
(mg/m^3)	**Mean**	0.123	0.114	-7.30%	0.339	0.398	17.17%
	Min	0.056	0.075		0.265	0.375	
	Max	0.262	0.143		0.513	0.431	
Zn	**Median**	0.038	0.055	44.74%	0.063	0.141	125.60%
(mg/m^3)	**Mean**	0.038	0.050	31.58%	0.068	0.141	107.75%
	Min	0.038	0.038		0.060	0.135	
	Max	0.038	0.057		0.086	0.146	

c. Metallic Aerosol Graphical Data. The following data should be shown graphically for each metal analyzed. A sample is shown in Figure B-1.

(1) Mass concentration (mg/m^3) for each shot or burst, sorted by each unique test scenario – shown as individual data points.

(2) Mean mass concentration (mg/m^3) of all shots or bursts for each unique test scenario – shown as bar plot.

Figure B-1. Sample Graphical Data Presentation for Metallic Aerosols – Lead (Pb).

Annex - C TEST INSTRUMENTATION DETAILS

C-1. INTRODUCTION

1. This Annex is intended to provide the details and descriptions of the acceptable test instrumentation for the measurement of blowback through the Breathing Zone Test Method and the Chamber Test Method. While there are a variety of other instrumentation that may prove to be valid for measurements of blowback, the instrumentation described below are those which have been tested and proven to produce sufficient results for the purpose of small arms toxic gas measurement.

C-2. MEASUREMENT METHODS

1. There are two methods which have been tested and proven to be acceptable for the use of small arms toxic gas measurement. These gas concentration measurement methods are:

a. FTIR Spectroscopy. This technique operates on the principle of Beer's Law, using a logarithmic relationship between absorbed light and gas concentration. FTIR has been successfully used to measure all three gases that are measured in the suppressor blowback tests (CO, HCN, and NH_3). While FTIR is an accurate and reliable method of measurement, it is also relatively expensive and requires specially trained personnel to operate it. Thus, unless a system is already in place at the facility performing the test, it is often not a feasible or cost effective method to measure blowback gas concentrations.

b. Electrochemical Detectors. This technique uses commercially available, electrochemical detectors to sample and measure blowback gas concentrations in real time. The data is logged to the unit's internal memory and then uploaded to a PC for analysis. Since electrochemical sensors operate on chemical reactions with the gases of interest, one of the drawbacks of this method is that there is a delay between exposure and response, based on the time of reaction for the specific gas being measured. Thus, if electrochemical detectors are being used, they should always be "bump tested" at the beginning of each day. Bump testing is the process of exposing the electrochemical sensors to their respective gases, thereby reducing the response time for future exposure. Bump testing can usually be accomplished through the calibration process, where the sensors are exposed to their respective gases.

2. Both FTIR and electrochemical detectors are capable of producing acceptable results. However, it is not prudent to compare absolute values of gas concentrations obtained using different methods to each other, due to the unique way in which each of these methods measure gas concentrations. Thus, the measurement method used for a particular data set shall always be reported with any test results, and shall always be considered when comparing results.

3. While FTIR is typically a more accurate method of measurement, it is also more expensive and requires specially trained personnel to operate it. Electrochemical detectors, on the other hand, are less expensive and do not require specialized training, however they are not as accurate as an FTIR system. While FTIR has been successfully used to measure CO, HCN, and NH_3, among a host of other gases, it is often not a feasible or cost effective method to measure blowback gas concentrations. Thus, measurement through the use of electrochemical detectors is the most common and accessible method for the measurement of blowback gases, and is considered the preferred method in the absence of an FTIR system.

C-3. INSTRUMENTATION AND EQUIPMENT REQUIREMENTS

1. Each measurement method requires specific instrumentation and equipment in order to accurately and effectively measure suppressor blowback gas concentrations. The required instrumentation, equipment, and specifications are described below.

a. Gas Concentration Measurement Instrumentation.

(1) FTIR Spectroscopy. This method requires specialized laboratory equipment, including an FTIR spectrometer and all associated calibration equipment. Detailed information about the specific laboratory instrumentation and equipment required are not included in this Annex. If FTIR is being used, the personnel operating the FTIR spectrometer shall be sufficiently trained, and will be able to advise on the specific instrumentation and equipment required to measure concentrations using this method.

(2) Electrochemical Detectors. This method requires the following instrumentation, equipment, and associated minimum specifications.

i. Handheld Gas Sampling Unit. This is the unit that houses the electrochemical sensors and provides output of PPM.

1. Recommended manufacturer and part number: Draeger Model XAM 5000 (PN 4543748)[8]

2. Must be capable of housing and simultaneously reading a minimum of three electrochemical sensors, including carbon monoxide (CO), hydrogen cyanide (HCN), and ammonia (NH_3).

3. Minimum sampling rate one sample every second (1 Hz).

4. Electrochemical Sensors. These sensors must be compatible with the selected handheld unit. There are a variety of sensors available for different gases. Sensors should be selected so that they sufficiently measure the

gases of interest, including appropriate detection range, resolution, detection limits, response time (particularly important for breathing zone method), and sensitivity. Recommended (but not required) sensor specifications for CO, HCN, and NH_3 are show below.

a. Carbon monoxide (CO):

i. Detection Range – 0-10,000 PPM;

ii. Resolution – 5 PPM;

iii. Detection Limit – 10 PPM;

iv. Response Time – T_{90} – 25 seconds; and

v. Sensitivity - +/-2% of measured value.

b. Hydrogen cyanide (HCN):

i. Detection Range – 0-50 PPM;

ii. Resolution – 0.5 PPM;

iii. Detection Limit – 3 PPM;

iv. Response Time – T_{50} – 10 seconds; and

v. Sensitivity - +/-5% of measured value.

c. Ammonia (NH_3):

i. Detection Range – 0-300 PPM;

ii. Resolution – 1 PPM;

iii. Detection Limit – 4 PPM;

iv. Response Time – T_{50} – 10 seconds; and

v. Sensitivity – +/- 3% of measured value.

5. Sampling Pump. This is the pump unit used to flow gas through the Handheld Gas Sampling Unit. Pump should have a flow rate of 0.5-1.5 l/min. Depending on the manufacturer, a pump may be integral to the unit, or may be separate. Consult the specific manufacturer for further guidance.

6. Calibration Equipment:

a. Calibration gases in known concentrations, per sensor manufacturer's guidelines for each gas being analyzed.

b. Additional calibration-specific equipment, including pressure reduction devices, valves, tubing, and connectors necessary to connect calibration gas cylinders to handheld sampling unit.

b. Ancillary Items:

(1) 10 to 13 cm (4 to 5.5") diameter funnel. This funnel is used as the air intake for the Breathing Zone Test. The 10 to 13 cm (4 to 5.5") diameter opening roughly replicates the size circle that would fit the Operator's mucus membranes including the eyes, nose, and mouth.

(2) Any tubing, particulate filters, connectors, and all other ancillary items to make connections from measurement location to the sampling pump and gas sampling unit.

(3) Any items or special equipment needed to complete connection from gas sampling unit to computer or other data storage and data analysis device.

c. Environmental Monitoring Equipment. In addition to the equipment required to measure gas concentrations, environmental conditions shall also be monitored. This includes equipment to measure temperature, relative humidity, atmospheric pressure, and if possible, wind speed in the range.

d. High Speed Video (HSV) System (optional). The specific settings and specification of the high speed video system are highly dependent on both the test setup, as well as the configuration being tested.

(1) Recommended settings are:

i. Frame Rate – minimum 6,000 frame per second;

ii. Lens –35 mm;

iii. Aperture (F-stop) – 4.00;

iv. Resolution – 640 x 304; and

v. Exposure – 30µs.

(2) Black background. This could be a piece of plywood painted flat back in order to better show the dissipation of gases in high speed video. The background itself shall be placed sufficiently far from the weapon so that gas flow is not affected.

(3) HSV data collection. Data shall be collected from a time just before the round is fired until the time at which the blowback event is no longer evident in the video. This will be highly dependent on the specific weapon configuration being tested.

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Annex - D TEST CHAMBER REQUIREMENTS

D-1. INTRODUCTION

1. This Annex is intended to provide technical and performance requirements for test chambers to be used in the Chamber Test Method. The Annex also provides some examples of test chambers that have been previously used in the Chamber Test Method and have produced sufficient results. These example chamber designs are not intended to be requirements, nor are the details provided in this Annex intended to be a blueprint for a chamber that is guaranteed to produce sufficient results. Rather, the chamber requirements, descriptions, and figures in this Annex are intended to provide appropriate guidance and performance requirements to facilitate the design and fabrication of a chamber that meets the requirements of a given test at a given facility.

D-2. TEST CHAMBER REQUIREMENTS

1. The test chamber used for the Chamber Test Method shall meet the following technical and performance requirements:

a. The chamber shall be of sufficient size to hold the weapon with its muzzle and muzzle device outside of the chamber. If full weapon toxicity is being tested, the chamber shall also be capable of holding the full weapon, including any muzzle devices or suppressors. Preferably, the only change to volume should be when changing between “muzzle inside” and “muzzle outside” chamber configurations.

b. Chamber volume has a direct effect on the concentrations measured, and as such should be carefully considered. Electrochemical sensors have a maximum concentration limit, and if used, it is critical to ensure that the chamber is large enough that sensors will not be saturated during the test. If this is the case, it is prudent to take some “test shots” prior to a full test to ensure that the sensors are not being saturated. In order to do this, several shots shall be taken in the “worst case” scenario, or where the highest gas concentrations are expected to be measured, for each chamber size. The highest concentrations are typically measured during the longest burst length tested, with the muzzle inside the chamber. Chamber volume selection should balance being large enough to prevent sensor saturation with being small enough to produce measurements that have enough fidelity to show differences between configurations.

c. With these considerations, typical chamber volume for a small arms system will generally fall between 0.5 and 1.5 m^3 (17.7 and 53 $ft.^3$), but may vary outside these limits depending on the weapon, muzzle device, ammunition, burst length, and other considerations. The volume shall be carefully measured and documented, and should not be changed within a block of shots (see Table E-1).

d. The chamber shall permit quick ventilation, either through opening or other means, in order to clear out gases between shots. A fan or other forced air method of clearing the chamber is recommended.

e. The chamber shall permit sufficient cleaning of surfaces to prevent metallic dust from previous shots that may have settled inside the chamber from being aerosolized during firing and affecting results of metallic dust filtering. Cleaning can be performed by wiping down the chamber periodically, by changing out chamber lining, or by any other means that substantially eliminates settled dust within the chamber.

f. The chamber shall be substantially sealed when the chamber is closed, with the exception of a small opening for the projectile or muzzle to pass through at the front of the chamber. The area where the muzzle or barrel penetrates the front of the chamber shall be substantially sealed around the barrel to prevent leakage of gases.

g. The chamber shall permit the insertion of two (2) 6 mm (.25”) (or similar) tubes to sample gas through the FTIR or electrochemical detector system as well as to sample and filter the metallic aerosols.

h. While not required, viewing windows are recommended so that the weapon can be observed during operation.

D-3. EXAMPLE TEST CHAMBER DESIGNS

1. Various chamber designs have been tested and shown to produce sufficient results for small arms blowback measurements. Examples of two (2) such chambers are depicted and described below.

a. Variable Volume Test Chamber. The chamber shown in Figure D-1 is a variable volume small arms toxic gas test chamber. This is the same chamber used for toxic gas emission testing in accordance with the NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8. “Potentially Hazardous Effects.” This chamber has been tested and proven sufficient to measure both total toxic gas emission as well as blowback emission from a small arms system. The details of the chamber can be found in the NATO D/14 Handbook (AC/225(DSS)D(2018)0006)[1], Section 2.8. “Potentially Hazardous Effects.”

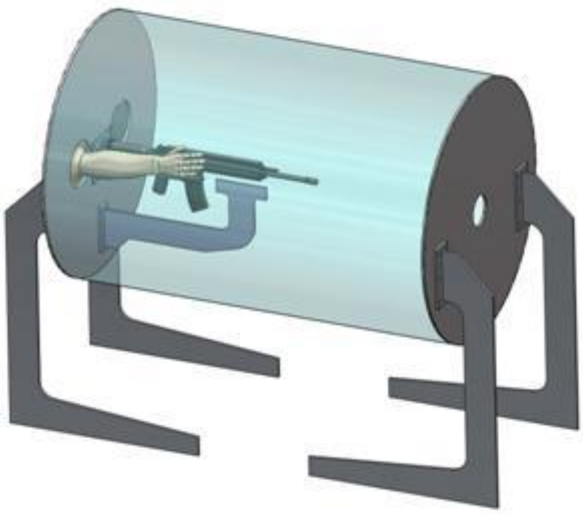


Figure D-1. Example Test Chamber

b. Fixed Volume Test Chamber. The chamber shown in Figure D-2 is a fixed volume small arms toxic gas test chamber. This chamber is sufficient to measure both total toxic gas emission as well as blowback emission from a small arms system. This particular chamber design has been tested and proven to provide sufficient results. While this chamber has proven to be effective, other chamber designs may be used based on the capabilities of the particular test center, assuming they meet all other requirements of the test.

This chamber is constructed primarily of wood, with a volume approximately 1 m^3 (35.3 $ft.^3$). The inside of the chamber is painted with a semi-gloss type paint to allow wiping down between shots. A standard weapon mount is mounted inside, and is moveable to position the weapon for muzzle inside or muzzle outside the chamber. The front face includes a small opening in the center for the projectile or muzzle to pass through. This opening can be covered with a piece of neoprene or similar material which has the ability to almost close itself after a shot. The chamber's top is constructed of Plexiglas, and can be opened to clear the chamber of gas between shots. The chamber includes small fans to aid in clearing between shots. Firing is performed remotely. Small holes are drilled in the top of the Plexiglas, approximately centered in the chamber, and are used to pass gas sampling and aerosol sampling tubes through.

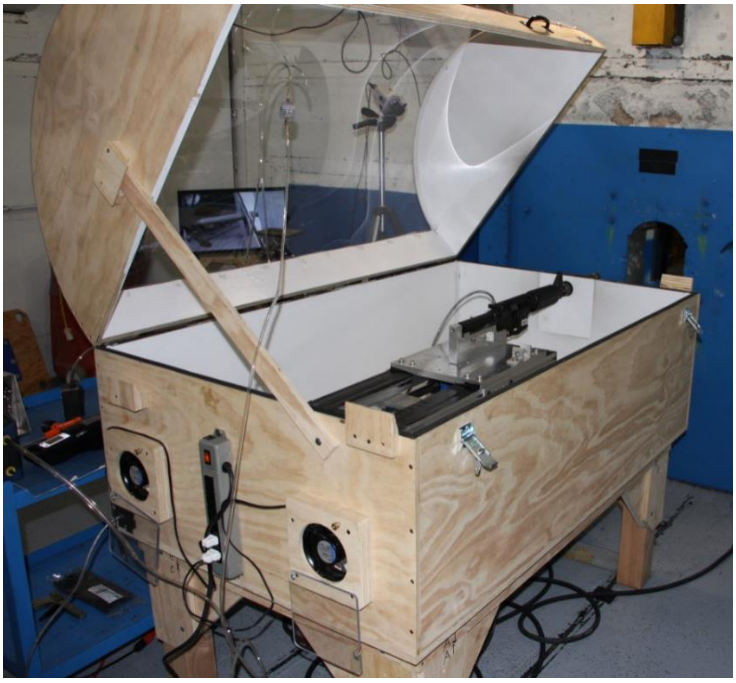


Figure D-2. Example Test Chamber

Annex - E STATISTICAL METHODS

E-1. INTRODUCTION

1. Statistical methods can be used during testing, data collection, and reporting in order to optimize statistical confidence while minimizing the number of data points that need to be taken. This Annex describes a Design of Experiments (DOE) Method that can be used to accomplish this.

E-2. DESIGN OF EXPERIMENTS

1. Data can be collected following DOE procedures, using the concept of a designed experiment. A designed experiment is a test in which purposeful, systematic changes are made to the input variables of a process or system so that one may observe and identify the reasons for changes in the output response variable. This is often done to quantify the impact of inputs on the response, quantify how input variables interact to affect the response, and to utilize this information to provide insight in how to improve the product or process.

2. Randomization, Replication, and Blocking are fundamental to DOE. Randomization is used to minimize the risk of nuisance variables, such as temporally correlated error sources, corrupting the test results. Some modifications can be made to statistically ''ideal'', full randomization for practical, test execution reasons (as was done with these test matrices), though at some risk. However, it is imperative that the test be run in the order specified in the test matrices, rather than re-ordering to simplify test execution, as this will result in significant reduction to test statistical power.

a. Data Collection. To simplify setup and test preparation, and to enable consistent data across test centers, test matrices in Tables E-1 and E-2 show the order in which testing should be performed for the Chamber Method and the Breathing Zone Method, respectively. These test matrices were designed using DOE best-practices, leveraging analysis from past test data to inform the Prospective Power & Sample Size analysis, assuming 95% statistical confidence, 80% min threshold for statistical power, standard deviation (Root Mean Squared Error, or RMSE) determined from within-group variations in previous analysis (Peak CO = 124 ppm), factors and factor-levels of interest (Firing Mode, Inlet Side, and Configuration). The 32-run matrices provide approximately 80% power to detect effects equal to or greater than the within-group standard deviation (RMSE) for all main effects and two-factor interactions, 98.3% power to detect effects equal to or greater than 1.5 x RMSE, and 99.97% power to detect effects equal to or greater than 2 x RMSE for all main effects and two-factor interactions, at 95% statistical confidence. The test data must be collected in the order specified in Tables E-1 and E-2 for the results to be statistically valid.

Table E-1. Chamber Test Method Matrix

Run	Block	Firing Mode	Muzzle Position	Configuration
1	L1	Burst	Outside	Standard
2	L1	Single	Outside	Standard
3	L1	Burst	Outside	Modified
4	L1	Single	Outside	Modified
5	L1	Single	Outside	Standard
6	L1	Burst	Outside	Standard
7	L1	Single	Outside	Modified
8	L1	Burst	Outside	Modified
9	L2	Burst	Inside	Standard
10	L2	Single	Inside	Standard
11	L2	Burst	Inside	Modified
12	L2	Single	Inside	Modified
13	L2	Single	Inside	Standard
14	L2	Burst	Inside	Standard
15	L2	Single	Inside	Modified
16	L2	Burst	Inside	Modified
17	L3	Burst	Outside	Standard
18	L3	Single	Outside	Standard
19	L3	Burst	Outside	Modified
20	L3	Single	Outside	Modified
21	L3	Single	Outside	Standard
22	L3	Burst	Outside	Standard
23	L3	Single	Outside	Modified
24	L3	Burst	Outside	Modified
25	L4	Burst	Inside	Standard
26	L4	Single	Inside	Standard
27	L4	Burst	Inside	Modified
28	L4	Single	Inside	Modified
29	L4	Single	Inside	Standard
30	L4	Burst	Inside	Standard
31	L4	Single	Inside	Modified
32	L4	Burst	Inside	Modified

Table E-2. Breathing Zone Test Method Matrix

Run	Block	Firing Mode	Inlet Side	Configuration
1	L1	Burst	Left	Standard
2	L1	Single	Left	Standard
3	L1	Burst	Right	Standard
4	L1	Single	Right	Standard
5	L1	Burst	Left	Modified
6	L1	Single	Left	Modified
7	L1	Burst	Right	Modified
8	L1	Single	Right	Modified
9	L2	Single	Left	Standard
10	L2	Burst	Left	Standard
11	L2	Single	Right	Standard
12	L2	Burst	Right	Standard
13	L2	Single	Left	Modified
14	L2	Burst	Left	Modified
15	L2	Single	Right	Modified
16	L2	Burst	Right	Modified
17	L3	Burst	Left	Standard
18	L3	Single	Left	Standard
19	L3	Burst	Right	Standard
20	L3	Single	Right	Standard
21	L3	Burst	Left	Modified
22	L3	Single	Left	Modified
23	L3	Burst	Right	Modified
24	L3	Single	Right	Modified
25	L4	Single	Left	Standard
26	L4	Burst	Left	Standard
27	L4	Single	Right	Standard
28	L4	Burst	Right	Standard
29	L4	Single	Left	Modified
30	L4	Burst	Left	Modified
31	L4	Single	Right	Modified
32	L4	Burst	Right	Modified

b. The test matrices in Tables E-1 and E-2 are broken into four separate blocks of eight shots or bursts. Each block contains every unique test combination of firing mode, muzzle position (Chamber Method), inlet side (Breathing Zone Method), and weapon configuration within the test, assuming that a single modified configuration is being compared to the standard system. For the Chamber Method, if full weapon toxicity is not being assessed during this test, blocks L2 and L4 can be eliminated from the Matrix in Table E-1, reducing it to only sixteen shots. If additional modified weapon configurations are to be tested alongside the baseline configuration, those can be added at the end of each block, creating blocks that are twelve, sixteen, twenty, etc. shots long, rather than eight. The within-block order of “Firing Mode” and “Configuration” shall be maintained when adding an additional modified configuration to the block.

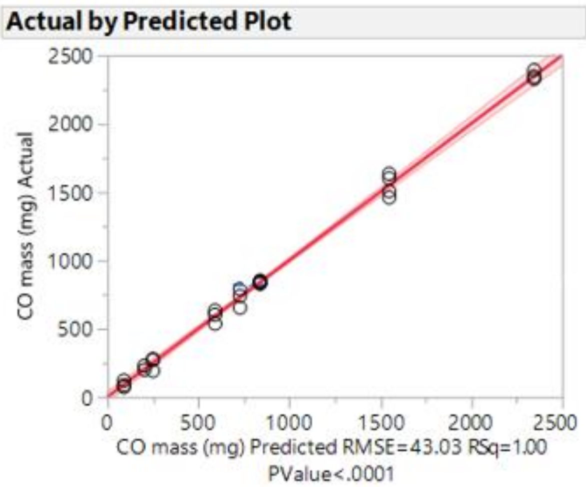
E-3. PRESENTATION OF DATA

1. In addition to the data presentation presented in the main body of the AEP, the following statistical data can be presented. This statistical data can be presented for any data category being analyzed. Thus, for the Chamber Method, the statistical data shall be presented for mass of each gas and each metallic aerosol being analyzed. For the Breathing Zone Method, the statistical data shall be presented for peak gas concentration and any time weighted average gas concentrations that were analyzed. Figure E-1 shows a sample of the statistical data that should be presented.

a. Analysis of Variance (ANOVA). ANOVA shall accompany the graphical data presentation. The test factors, and their second-order interactions shall be entered into model fit, this can be readily accomplished using commercially available software. Key elements of the output from the ANOVA shall include as shown in the sample (Figure E-1):

(1) Summary Statistics: Root Mean Squared Error (RMSE, or response standard deviation), P-value for F-statistic.

(2) Diagnostics: Actual-by-Predicted Plot, R-squared/adjusted R-squared, Durbin-Watson autocorrelation statistic.



Response CO mass (mg)

Whole Model

Summary of Fit

RSquare	0.997334
RSquare Adj	0.996556
Root Mean Square Error	43.03027
Mean of Response	825.3861
Observations (or Sum Wgts)	32

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	16623707	2374815	1282.572
Error	24	44438	1852	Prob > F
C. Total	31	16668146		<.0001*

Durbin-Watson

Durbin-Watson	Number of Obs.	AutoCorrelation
1.6819345	32	0.1355

Figure E-1. ANOVA Summary and Diagnostics

Annex - F ABBREVIATIONS

ANOVA	Analysis of Variance
ATEC	Army Test and Evaluation Command
Bi	Bismuth
CO	Carbon Monoxide
Cu	Copper
DOE	Design of Experiments
DTP	Detailed Test Plan
FTIR	Fourier Transform Infrared Spectroscopy
HCN	Hydrogen Cyanide
HRPP	Human Release Protection Plan
HSV	High Speed Video
Hz	Hertz
IAW	In Accordance With
mm	Millimeters
MOS	Military Occupational Specialty
NH_3	Ammonia
Pb	Lead
PN	Part Number
PPM	Parts Per Million
PSI	Pounds per Square Inch
RH	Relative Humidity
RMSE	Root Mean Squared Error
SOMTE	Soldier-Operator/-Maintainer Test and Evaluation
SR	Safety Release
TOP	Test Operations Procedure
TSARC	Test Schedule and Review Committee
TWA	Time Weighted Average
Zn	Zinc
μs	Microseconds

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Annex - G REFERENCES

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