



**M1A1 ABRAMS MAIN BATTLE TANK CREW MEMBER OCCUPATIONAL
HEALTH HAZARD ANALYSIS DURING LIVE-FIRE OPERATIONS**

THESIS

Christopher A. Swift, Captain, USMC

AFIT-ENV-MS-17-M-228

**DEPARTMENT OF THE AIR FORCE
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THESIS

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In Partial Fulfillment of the Requirements for the
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Christopher A. Swift

Captain, USMC

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Abstract

Currently, the U.S. Army Public Health Center possesses limited data on M1A1 Abrams Main Battle Tank crew member occupational exposures. While not directly related to M1A1 Main Battle Tank crew member occupational exposures, current research has established a relationship between chronic exposure to pollutants below exposure guidelines and adverse health effects, which exposure to in a confined space may exacerbate. Additionally, inhalation of particulate matter has continually been referenced as a probable cause in delayed manifestation of adverse health effects related to military service. As such, advances in sampling and analytical technology may illuminate exposures previously considered not significant as significant. This research project aims to address two primary questions: what current occupational health hazard risks are M1A1 Main Battle Tank crew members subjected to during live-fire operations, and do any of these exposures present more than a negligible health hazard risk? Using current sampling equipment positioned in five separate locations within the tank, the author evaluates multiple inhalation exposures. Based on the total data collected, particulate matter, hydrogen cyanide, and lead present the greatest potential health risks. Recommendations from these results include continued monitoring to establish health risk potentials over time, future biological monitoring of crew members, and evaluation of personal filtration devices.

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M1A1 ABRAMS MAIN BATTLE TANK CREW MEMBER OCCUPATIONAL HEALTH HAZARD ANALYSIS DURING LIVE-FIRE OPERATIONS

I. Introduction

General Issue

“When you need a tank, you need a tank!”

*-LTC Greg Reilly, Commander, First Squadron, Third Armored Cavalry Regiment in
Iraq*

Maintaining fire superiority on the battlefield requires tempo, lethality, and the ability to destroy an enemy’s will to fight. No weapon system is as capable of accomplishing this simply by its presence on the battlefield as a tank. The M1A1 Abrams Main Battle Tank (MBT) provides the Marine Air-Ground Task Force (MAGTF) with armor-protected firepower, shock effect, and cross-country mobility. An inherently offensive weapon, the M1A1 MBT performs a diverse set of missions across the range of military operations and provides precision lethal effects — all while operating within restrictive rules of engagement (DoN, 2014).

To defeat today’s enemies, while avoiding fratricide and minimizing collateral damage, it is imperative that M1A1 MBT crew members possess in-depth knowledge of the M1A1 MBT, and a thorough understanding of their weapon systems’ capabilities and limitations. This knowledge includes both developing and sustaining applicable techniques, tactics, and procedures (TTPs) to effectively maneuver and survive on the battlefield (DoA, 2009). A critical component to this success is frequent live-fire training evolutions, which include semi-annual gunnery evaluations, and participation in Marine Corps Integrated Training Exercises. Throughout a fiscal year, a single crew will fire a

minimum of 74, 120 mm cartridges; 750, .50 caliber cartridges; and 2,800, 7.62 mm cartridges during their required two semi-annual gunnery crew evaluations alone (DoA, 2009).

During these live-fire training evolutions, M1A1 MBT crews routinely engage targets with training rounds designed to replicate the ballistic performance of their service round counterpart. Each of these 120 mm cartridges contains more than 7.0 kg of propellant and produces a multitude of hazardous chemicals when fired. These chemicals include, but are not limited to, ammonia (NH₃); carbon dioxide (CO₂); carbon monoxide (CO); chlorine (Cl₂); nitric oxide (NO); nitrogen dioxide (NO₂); hydrogen chloride (HCl); hydrogen cyanide (HCN); sulfur dioxide (SO₂); lead (Pb); metals; and metal oxides (DoA, 2014a; DoA, 2004).

To minimize chemical exposures within the M1A1 MBT's turret while firing, the M256 120mm smoothbore cannon is equipped with an eccentric bore evacuator, Figure 1. The bore evacuator scavenges exhaust gases and forcibly releases them through the muzzle end, as the projectile exits the cannon. The bore evacuator is not 100% efficient and, therefore, allows some of the propellant exhaust gases to leak back into the turret while the breech is in the open position. This accumulation of propellant exhaust gases in the turret is especially true when firing large quantities of ammunition. Each successive round fired deposits particulate matter in the bore evacuator holes — decreasing its efficiency. While easily correctable with post-operation maintenance, conducting this maintenance is not always feasible nor possible during extended operations.

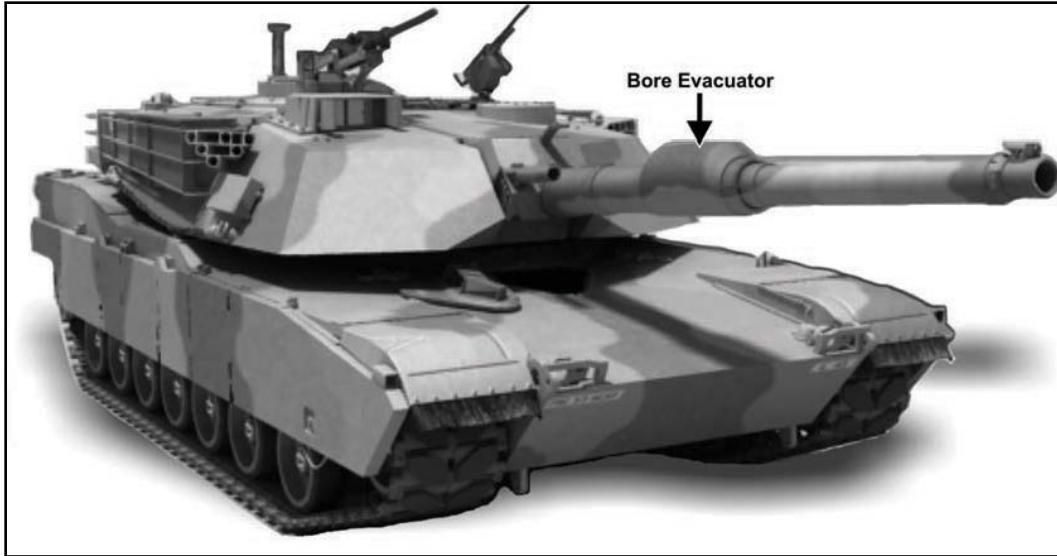


**Figure 1: M256 120mm Smoothbore Cannon Eccentric Bore Evacuator
(DoA, 2009)**

Problem Statement

Department of Defense (DoD) Instruction (DoDI) 6055.01 (2014) states, “DoD components must apply [Occupational Safety and Health Administration] OSHA and other regulatory safety and health standards to uniquely military equipment, systems, operations, or workplaces, in whole or in part, as practicable.” Department of Defense Instruction 6055.01 also allows for flexibility when application of these standards is neither feasible nor appropriate, through the application of risk-management procedures. The results of risk-management procedures must be promulgated to all affected personnel (DoD, 2014).

The nature of war brings with it a rapid cycle of offensive and defensive capability improvement. As one side brings cutting-edge technology to bear on the battlefield, the opposing side quickly reacts to develop technology capable of defeating it. This cycle continues indefinitely — limited only by material availability and human ingenuity.

This cyclic arms race results in changes to weaponry, standard operating procedures (SOPs), and TTPs. Weaponry advancements result in variation of the chemical exposures to those responsible for the weapons employment. Likewise, SOP and TTP modifications correlate to fluctuations in exposure magnitude. These changes require constant data to track the long-term exposures of service members, as required by National Science and Technology Council Presidential Review Directive 5 (1998).

Currently, the U.S. Army Public Health Center (USAPHC) possesses limited data on M1A1 MBT occupational exposures. The age of the limited data used for the health hazard assessment reports (HHARs) for current 120 mm training ammunition ranges from 4 to 27 years old, with the bulk being 12 years old (DoA, 2014a; DoA, 2006; DoA, 2004). As such, USAPHC currently recommends continued monitoring of all cartridges to acquire sufficient data capable of producing statistically valid conclusions to M1A1 MBT crew member exposure potential over time (J. Cambre, personal communication, November 20, 2015).

In addition to the limited amount and age of the collected data, a majority of the data are for either a different tank cartridge or a different caliber round, using the same propellant as the assessed round. Additionally, the testing procedures reflect SOPs and TTPs from their respective periods and do not always accurately reflect current training standards. Specifically, the test's parameters did not account for tank platoon collective gunnery training or combined arms breaching training. Both of these scenarios possess longer exposure durations and higher exposure concentration potentials. These discrepancies further reinforce the need for additional data collection from cartridges currently in use today.

Research Objectives/Questions/Hypotheses

This research project aims to quantify chemical concentrations within the M1A1 MBT in order to answer the following questions:

- 1) What current occupational health hazard risks are M1A1 MBT crew members subjected to during live-fire operations?
- 2) Do any of these exposures present more than a negligible health hazard risk to M1A1 MBT crew members?

To accomplish these objectives, all data collection will occur within the turret during live-fire training. Each collection event will not require modifications to present training SOPs. Therefore, each collection event will accurately represent current conditions in which M1A1 MBT crew members train. These conditions will consist of standardized gunnery evaluation scenarios designed to replicate different combat operations the M1A1 MBT is responsible for conducting.

Final determination of the potential health hazard risks will be through laboratory and descriptive analyses of the collected samples/data. These analyses will include:

- 1) Quantification of concentrations present,
- 2) Comparison of current American Conference of Governmental Industrial Hygienists (ACGIH[®]) threshold limit values (TLVs), National Institute for Occupational Safety and Health (NIOSH) recommended exposure limits (RELs), and OSHA permissible exposure limits (PELs),
- 3) Comparison of concentrations present to their most stringent respective current exposure limit (EL) regulation or standard, and

- 4) Assignment of risk-assessment codes (RACs) in accordance with DoDI 6055.01 (Appendix A).

It is the author's hypotheses that concentration levels will be below current exposure standards and limits, and present an overall negligible health hazard risk to crew members. However, based on recent literature evidence, exposure to unique properties of ammunition generated particulate matter (PM), such as small size and heterogeneous composition, may present an adverse long-term health hazard risk to crew members.

Research Focus

This research will focus on the specific occupational exposure risk to M1A1 MBT crew members of combustion by-products and toxic fumes generated by the following 120 mm tank cartridges, and small arms cartridges used during live-fire training, Figure 2 and 3:

- 1) C785: M865, Tank Cartridge, 120 mm, Target Practice, Cone Stabilized Discarding Sabot with Tracer (TPCSDS-T)
- 2) CA31: M1002, Tank Cartridge, 120 mm, Target Practice Multi-Purpose with Tracer (TPMP-T)
- 3) CA38: M1028, Tank Cartridge, 120 mm, Canister
- 4) A131: Cartridge, 7.62 mm, 4 Ball M80 / 1 Tracer M62, Linked
- 5) A576: Cartridge, .50 Caliber, 4 Armor Piercing Incendiary M8 / 1 Armor Piercing Incendiary with Tracer M20, Linked



Figure 2: 120mm Tank Cartridges

(Images © General Dynamics Ordnance and Tactical Systems: <http://www.gd-ots.com/>)



Figure 3: Small Arms Cartridges

These five cartridge types comprise the primary ammunition M1A1 MBT crews fire during live-fire gunnery training.

Of specific interest are the eight primary combustion products and toxic fumes of greatest concern identified by USAPHC, Table 1 (DoA, 2014a; DoA, 2006; DoA, 2004). This research will also evaluate potential health hazard risks resulting from incomplete propellant combustion, projectile compositions, and the amount of force generated during the firing of each round. These additional health hazards are listed in Table 2.

Table 1: Primary Chemicals of Concern and Respective Exposure Limits

Substance	ACGIH [®]	NIOSH	OSHA
CO	25 ppm TLV-TWA [®]	35 ppm TWA 200 ppm C	50 ppm TWA
CO ₂	5,000 ppm TLV-TWA [®] 30,000 ppm TLV-STEL [®]	5,000 ppm TWA 30,000 ppm ST	5,000 ppm TWA
HCN	4.7 ppm TWA-C [®]	4.7 ppm ST	10 ppm TWA
NH ₃	25 ppm TLV-TWA [®] 35 ppm TLV-STEL [®]	25 ppm TWA 35 ppm ST	50 ppm TWA
NO	25 ppm TLV-TWA [®]	25 ppm TWA	25 ppm TWA
NO ₂	0.2 ppm TLV-TWA [®]	1 ppm ST	5 ppm C
Pb	0.05 mg/m ³ TLV-TWA [®]	0.05 mg/m ³ 10-hr TWA 0.06 mg Pb/100 g Whole Blood	0.05 mg/m ³ TWA
SO ₂	0.25 ppm TLV-STEL [®]	2 ppm TWA 5 ppm ST	5 ppm TWA
ACGIH [®] : TLV-TWA [®] = 8-hour time weighted average (TWA), TLV-STEL [®] = 15-minute TWA Short Term Exposure Limit (STEL), TLV-C [®] = Ceiling (value that should not be exceeded at any point) NIOSH: TWA = 8-hour TWA (unless otherwise specified), ST = 15-minute TWA STEL, C = Ceiling OSHA: TWA = 8-hour TWA, C = Ceiling			

Table 2: Additional Health Hazards and Respective Exposure Limits

Substance	ACGIH®	NIOSH	OSHA
Cl ₂	0.5 ppm TLV-TWA® 1 ppm TLV-STEL®	0.5 ppm C [15-min]	1 ppm C
HCl	2 ppm TLV-C®	5 ppm C	5 ppm C
Copper (Cu) (as fume) (as dust / mist)	0.2 mg/m ³ TLV-TWA® 1 mg/m ³ TLV-TWA®	0.1 mg/m ³ TWA 1 mg/m ³ TWA	0.2 mg/m ³ TWA 1 mg/m ³ TWA
Aluminum (Al)	1 mg/m ^{3(R)} TLV-TWA®	10 mg/m ^{3(total)} TWA 5 mg/m ^{3(R)} TWA	15 mg/m ^{3(total)} TWA 5 mg/m ^{3(R)} TWA
Particulate Matter	3 mg/m ^{3(R)} TLV 10 mg/m ^{3(I)} TLV	None	15 mg/m ^{3(total)} TWA 5 mg/m ^{3(R)} TWA
R – Respirable particles, particle size ≤ 4 µm I – Inhalable particles, particle size ≤ 100 µm Total – Total particles			

Methodology

Due to the expense and limited frequency of M1A1 MBT live-fire evolutions, data collection will follow current methods published by OSHA (OSHA, 1993) and NIOSH (NIOSH, 2016), and incorporate direct reading instruments (DRIs), when possible, to obtain a more complete exposure profile. Table 3 lists the specific analytical method(s) to analyte match-up.

Table 3: Analytical Methods

Analyte	Analytical Method
Cl ₂	NIOSH 6011
CO	OSHA ID 209
CO ₂	DRI
HCl	NIOSH 7907
HCN	NIOSH 6010
Total Metals / Metalloids (Particles)	NIOSH 7300
Pb (Particles)	NIOSH 7300
NH ₃	NIOSH 6016
NO	NIOSH 6014
NO ₂	NIOSH 6014
SO ₂	NIOSH 6004
PM	DRI, Microscopy, and Spectroscopy

The use of these validated methods will also ensure the data collected are scientifically defensible for use by USAPHC in developing M1A1 MBT crew member occupational exposure profiles over time. These methods will also provide an approved scientific basis for the resulting conclusions and recommendations made by the author.

Assumptions

Due to time constraints, limited number of available sampling opportunities, and insufficient space within the M1A1 MBT's turret to allow for a complete aerosol particle characterization, the following condition is assumed to be true in order to allow for analytical conclusions to be drawn:

- 1) The size distribution of ammunition generated PM is log-normally distributed.

The log-normal distribution assumption is based on multiple studies showing log-normal distributions accurately describe the natural particle size distribution of combustion generated aerosols (Aleixandre, Riera, Gallego-Juárez, Delgado-Tardáguila, & Herranz, 2016; Ramachandran, 2011).

Additionally, given the tank commander's (TC) .50 caliber machine gun is externally mounted on the top of the turret, Figure 4, and fired by the TC from within the turret, the combustion by-products of the .50 caliber cartridges are quickly dispersed. Therefore, for purposes of this research project the author assumes chemical concentrations generated by the .50 caliber cartridges entering the turret are negligible and can be ignored as a significant source of exposure.



Figure 4: Stabilized Commander's Weapon Station

(Image obtained from:
http://www.armorama.com/modules.php?op=modload&name=SquawkBox&file=index&req=viewtopic&topic_id=180001&page=37)

Limitations

The primary limitation of this research project is the cost of ammunition. Table 4 presents the fiscal year 2017 cost per round. This cost basis and the number of cartridges allocated for each engagement scenario (DoA, 2009) results in a total cost per scenario ranging from \$325.50 (small arms only) to \$36,164.51 (individual crew qualification). Cost prohibits the author from supplying additional rounds to the supporting unit for testing purposes. Accordingly, the number of rounds available for sampling is based on the supporting unit's current ammunition allocations as assigned by Headquarters USMC. As such, the combination of cost and time factors limits the number of sampling events per scenario to one or two.

Table 4: FY17 Ammunition Cost per Round

DODIC:	Nomenclature:	Cost per Round ¹ :
A131	7.62 mm (M80 and M62)	\$0.55
A576	.50 caliber (M8 and M20)	\$2.11
CA31	TPMP-T (M1002)	\$2,945.17
CA38	Canister (M1028)	\$1,899.64
C785	TPCSDS-T (M865)	\$1,166.56
1 – Cost data obtained from the U.S. Army’s Total Ammunition Management Information System (https://tamis.army.mil/default.aspx).		

Implications

Given the anticipated small sample collection size, further additional sampling is necessary to obtain data sufficient to make statistically valid long-term occupational exposure conclusions for the entire M1A1 MBT community. This implication does not invalidate the study but further reinforces USAPHC’s requirement for continued monitoring.

Additionally, any scenario exceeding established exposure limits, or presents an elevated health hazard risk, will require research beyond the scope of this research project into feasible risk-mitigation options for the M1A1 MBT community. Possible risk-mitigation options include personal filtration compatible with current crew member personal protective equipment (PPE), or the incorporation of integral air filtration systems. Both of these options will require evaluation of hazard removal efficiency and a detailed cost analysis.

Definition of Terms

Aerosol: The term aerosol is used to define any dispersed system of liquid or solid particles which are suspended in a gas (Vincent, 1995). With respect to this research project, the suspension gas is ambient air.

Dust: An aerosol comprised of solid particles formed and dispersed through the mechanical disintegration of a larger solid material (i.e. cutting, crushing, grinding, etc.). Dust particles vary in size from sub-micron to greater than 100 μm (Vincent, 1995).

Eccentric Bore Evacuator: A component of the M256 120 mm smoothbore cannon which aids in the removal of spent propellant gases from the gun tube via an eccentric pressure scavenging system. It is comprised of a fiberglass bore evacuator housing with evenly-spaced holes drilled, at an angle towards the muzzle, into the gun tube. As the projectile passes the bore evacuator holes, propellant gases fill the bore evacuator to a maximum of 150 psi. Once the projectile exits the muzzle, it creates a vacuum, and the built-up pressure forces the propellant gases out the muzzle and away from the turret's interior (DoA, 2009).

Fume: An aerosol comprised of fine solid particles formed through condensation of vaporous or gaseous combustion by-products. These particles are primarily aggregates of individual nanometer sized particles and have a usual total size of less than or equal to 1.0 μm (Vincent, 1995).

MAGTF: Marine Air-Ground Task Force: Principal organizational structure used by the United States Marine Corps (USMC) to conduct missions across the range of military operations. While always comprised of a command element, ground combat element, aviation combat element, and logistics combat element, the number and type of Marines

and equipment are always mission specific. This flexible design allows for the timely commitment of a credible force while maintaining economy of force (26th MEU, 2016).

Mist: An aerosol comprised of fine liquid droplets with sizes ranging up to a couple micrometers. A mist is produce through either condensation or atomization (Vincent, 1995).

PM_x: Particulate matter “x” μm or smaller in diameter, Figure 5. Given both a respiratory tract particle size deposition model, Figure 6, and natural human biological functions, respirable particles (PM₄) are capable of depositing deep inside the lungs and potentially entering the bloodstream (Ramachandran, 2011). Exposure to particles of this size and smaller are linked to numerous cardiovascular health issues which include, but are not limited to, decreased lung function, airway irritation, difficulty breathing, irregular heartbeat, and premature death (USEPA, 2016). PM_{2.5} is listed by the United States Environmental Protection Agency (USEPA) as a criteria pollutant (USEPA, 2016).

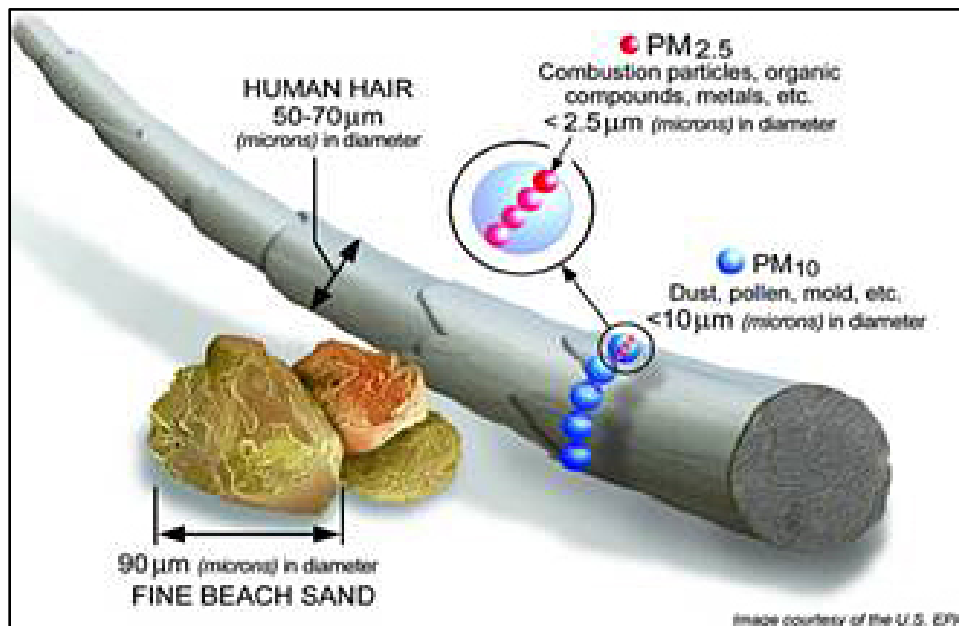


Figure 5: PM Size Comparison (USEPA, 2016)

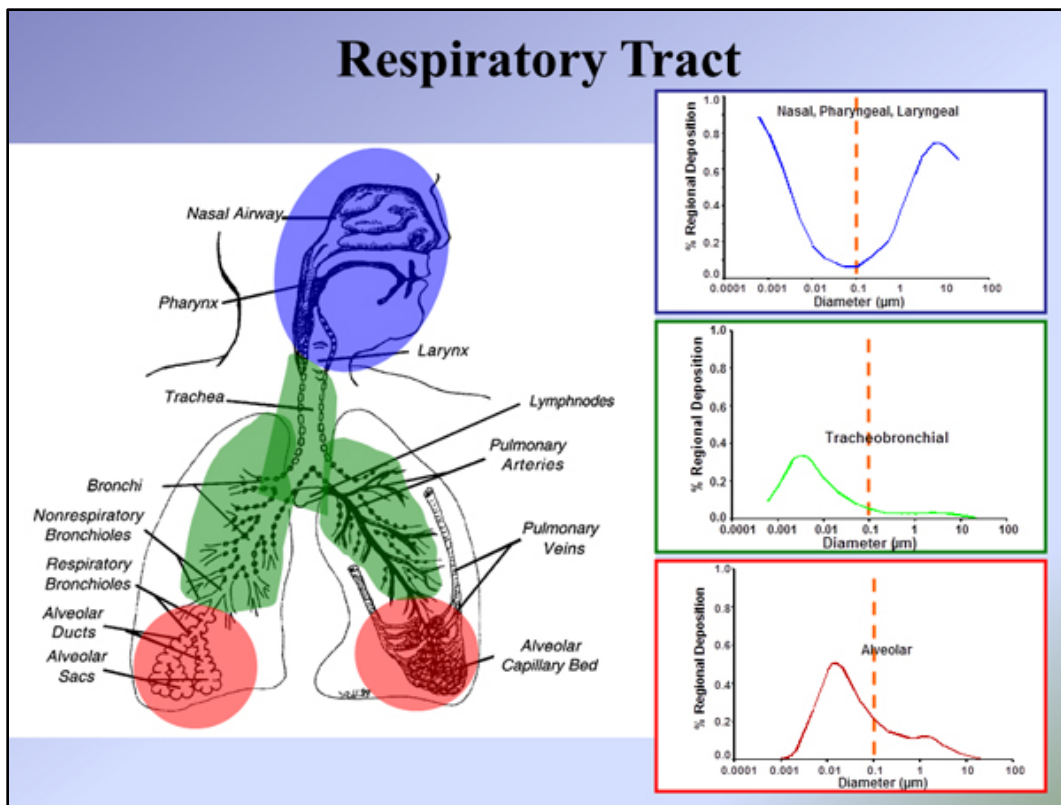


Figure 6: Respiratory Tract Particle Size Deposition Fractions (URMC, n.d.)

Preview

The important role tanks play in modern warfare is just as vital now, as it has been since the introduction of the tank onto the battlefield. The shock effect and armor-protected firepower tanks bring to the battlefield are capable of altering the battle's outcome. As such, the importance of maintaining healthy, well-trained crews is of utmost importance. The proceeding chapters discuss the history of combustion-related aerosol exposure; outline the sample collection and analytical methodologies; and present and discuss the results, implications, and recommendations of the data.

In Chapter 2, the author will present a review of literature focusing on the following topics:

- 1) Occupational and Environmental Health Background,
- 2) Previous M1A1 MBT crew member exposure research,
- 3) Current sampling equipment and techniques,
- 4) Current exposure limits and standards, and
- 5) Human health effects of the primary chemicals of concern.

II. Literature Review

Occupational and Environmental Health Background

Resulting from illnesses following the 1991 Gulf War, greater emphasis was placed on preventive medicine and environmental health measures, during both pre-deployment and deployment phases of the deployment cycle. Starting in 1991, the six geographic combatant commands began conducting deployment occupational and environmental health (OEH) surveillance activities for major conflicts. The main objective of these OEH activities was to identify, characterize, and assess environmental exposures. The ultimate goal of these activities was the identification and evaluation of risks, the assessment of potential adverse effects, and the development and implementation of control strategies (Martin, Richards, & Kirkpatrick, 2011). However, some of these OEH risks are not unique to deployment-related activities and require surveillance in garrison as well.

One such risk is exposure to lead containing combustion-related aerosols from military weapons. A May 2010, Symposium and Workshop at the Uniformed Services University of the Health Sciences in Bethesda, MD addressed operational environment exposures, but did not adequately address other potentially harmful exposures (Gaydos, 2011). These other potentially harmful exposures — including weapons-related lead exposures — frequently result in adverse health effects long after the exposure has ceased (ATSDR, 2016). Both the DoD and Department of Veteran's Affairs (VA) have dealt with these delayed situations, such as exposure to Agent Orange and Gulf War Syndrome, since the 1970s (VA, 2017; Gaydos, 2011).

Current Measured Data

Historical health hazard assessment testing consisted of firing 11 rounds over a period of 14 – 16 minutes. During the testing period, swipe samples were taken for Pb particle analysis, and air samples were collected from the crew members' approximate breathing zones using either fourier transform infrared spectroscopy instruments; or nondispersive infrared or ultraviolet analyzers and chemiluminescent analyzers — instrumentation varied by HHAR (DoA, 2014a; DoA, 2014b; DoA, 2006; DoA, 2004). In regard to semi-annual gunnery evaluations, the number of rounds fired during the tests were representative of the total number of rounds fired per training gun table (GT); however, the duration of exposure was greatly under-represented.

In an enclosed environment, such as the M1A1 MBT's turret, the health risk of an airborne chemical exposure depends heavily on ventilation conditions (DoA, 2014b). It has been shown contamination concentrations increased, when the contaminant source was located in an airflow stagnation area (Chang, 2007). A recent study of indoor firing ranges showed poor ventilation greatly increases the associated health risks of ammunition by-product exposure (Park, Lee, Lee, Yoon, & Moon, 2016). With air exchange rates varying between 1.09 and 6.59 volumes per hour, the interior of the M1A1 MBT possesses the potential to create an environment nearing stagnation, Table 5 (Holmes, 2009).

Table 5: M1A1 Air Exchange Rates (Holmes, 2009)

Exchange Rate (Volumes per hour)			
M1A1 Test Number	Fan Off Hatches Closed	Fan On Hatches Closed	Fan Off Hatches Open
1	1.17	6.59	2.96
2	1.09	6.58	2.86

Regardless of poor ventilation conditions, current HHARs did not indicate concentrations exceeding current prescribed exposure limits for M865, M1002, and M1028 cartridges, Tables 6, 7, and 8, respectively (DoA, 2014a; DoA, 2004). The recommended exposure limits used for comparison included the ACGIH's[®] Threshold Limit Values (TLV[®]) for 8-hour Time Weighted Averages (TLV-TWA[®]), 15-minute Short-Term Exposure Limits (TLV-STEL[®]), or ceiling limits (TLV-C[®]).

Table 6: Historical Chemical Emission Data for M865 Cartridge

Propellant	Chemical	Year Assessed	ACGIH® Exposure Type	Measured Value	Recommended Limit
RPD-596	NH ₃	2013	TLV-TWA®	1.6 ppm	25 ppm
	CO ₂		TLV-STEL®	<100 ppm	30,000 ppm
	CO		TLV-TWA®	<10 ppm	25 ppm
	HCN		TLV-C®	<1 ppm	4.7 ppm
	NO		TLV-TWA®	<5 ppm	25 ppm
	NO ₂		TLV-TWA®	<1* ppm	0.2 ppm
	SO ₂		TLV-STEL®	<1* ppm	0.25 ppm
M14	NH ₃	1990	TLV-TWA®	1.9 ppm	25 ppm
	CO ₂		TLV-STEL®	825 ppm	30,000 ppm
	CO		TLV-TWA®	23 ppm	25 ppm
	HCN		TLV-C®	<1 ppm	4.7 ppm
	NO		TLV-TWA®	6 ppm	25 ppm
	NO ₂		TLV-TWA®	<1* ppm	0.2 ppm
	SO ₂		TLV-STEL®	<1* ppm	0.25 ppm
Remarks:					
* - Below Limit of Detection for Respective Analyzer (DoA, 2014a).					

Table 7: Historical Chemical Emission Data for M1002 Cartridge

Propellant	Chemical	Year Assessed	ACGIH [®] Exposure Type	Measured Value	Recommended Limit
RPD-596	NH ₃	2013	TLV-TWA [®]	1.4 ppm	25 ppm
	CO ₂		TLV-STEL [®]	<100 ppm	30,000 ppm
	CO		TLV-TWA [®]	12 ppm	25 ppm
	HCN		TLV-C [®]	<1 ppm	4.7 ppm
	NO		TLV-TWA [®]	<5 ppm	25 ppm
	NO ₂		TLV-TWA [®]	<1* ppm	0.2 ppm
	SO ₂		TLV-STEL [®]	<1* ppm	0.25 ppm
M14	NH ₃	Unknown^	TLV-TWA [®]	<1 ppm	25 ppm
	CO ₂		TLV-STEL [®]	538 ppm	30,000 ppm
	CO		TLV-TWA [®]	12 ppm	25 ppm
	HCN		TLV-C [®]	<1 ppm	4.7 ppm
	NO		TLV-TWA [®]	<5 ppm	25 ppm
	NO ₂		TLV-TWA [®]	<1* ppm	0.2 ppm
	SO ₂		TLV-STEL [®]	<1* ppm	0.25 ppm
Remarks: * - Below Limit of Detection for Respective Analyzer (DoA, 2014a). ^ - Data obtained referenced previous HHARs (DoA, 2014a). Author was unable to determine actual date of tests referenced.					

Table 8: Historical Chemical Emission Data for M1028 Cartridge

Propellant	Chemical	Year Assessed	ACGIH [®] Exposure Type	Measured Value ⁺	Recommended Limit
JA-2	NH ₃	1992	TLV-TWA [®]	<1* ppm	25 ppm
	CO ₂	N/A	TLV-STEL [®]	Not Evaluated	30,000 ppm
	CO	1992	TLV-TWA [®]	33 [#] ppm	25 ppm
	HCN	N/A	TLV-C [®]	Not Evaluated	4.7 ppm
	NO	1992	TLV-TWA [®]	<1* ppm	25 ppm
	NO ₂	1992	TLV-TWA [®]	<1* ppm	0.2 ppm
	SO ₂	1992	TLV-STEL [®]	<1* ppm	0.25 ppm
Remarks: + - Results are from a previous HHAR for the 120 mm High Explosive Anti-Tank-Multi-Purpose – Tracer M830 cartridge which uses the JA-2 propellant. M1028 rounds were not specifically evaluated (DoA, 2004). * - Below Limit of Detection for Respective Analyzer (DoA, 2004). # - 15-minute TWA, highest measured value observed during testing (DoA, 2004).					

The results of previous air sample testing — used in granting health clearances for the M865, M1002, and M1028 rounds provided suitable foundations for the approved use of

these cartridges. However, these results may not have accurately reflected normal operating exposure conditions, may have underestimated total exposure concentrations, failed to address effects of chemical mixtures, and, in the case of the M1028 round, they did not directly reflect the specific ammunition used, as the M830 cartridge is a service cartridge and the M1028 is a training cartridge. These limitations introduced multiple sources of uncertainty for quantifying the general nature of occupational exposure.

The cartridges used in the 7.62 mm A131 configuration, M80 and M62, were established in 1962. Due to their age, associated fielding records and stand-alone HHARs were not available for comparison purposes (E. Vainchenker, personal communication, January 24, 2017).

A HHAR for the .50 caliber A576 configuration, M8 and M20, was conducted in July 2006, by the U.S. Army Center for Health Promotion and Preventive Medicine. The chemical substances assessment was based on a previous study of both the M1022 and MK211 .50 caliber cartridges which possess a similar chemical composition as both the M8 and M20. The M1022 and MK211 HHAR (DoA, 2006) included a detailed air sample assessment for those chemicals listed in Table 1, and did not indicate a significant health concern when fired in a well ventilated outside environment. A caution noted a potential over exposure if a high number of rounds, fired for an extended duration, were fired in a poorly ventilated or confined space. Combustion product concentrations for the M8 and M20 cartridges were calculated using the National Aeronautics and Space Administration-Lewis Thermo-chemical Code, but did not indicate any significant exposures (DoA, 2006).

Uncertainty

The entire crew evaluation cycle consists of 12 separate GTs, with each scenario containing 9 – 11 individual engagements or required tasks, broken up into a day- and a night-run. Gun tables I – VI comprise the individual crew evaluation, GTs VII – IX are section gunnery evaluations, and GTs X – XII are platoon gunnery evaluations (DoA, 2009). The author’s experience with semi-annual gunnery qualification is that for GTs I – VI, each engagement averages five to seven minutes from start to finish — for a total exposure time of approximately 60 minutes. The duration of GTs VII – XII vary by commander and are driven by the section’s or platoon’s performance, but in the author’s personal experience, usually last four to eight hours. This extended exposure duration was one source of uncertainty introduced into the representative nature of the referenced testings’ design.

A second source of uncertainty rested within the sampling equipment itself. “Total” particle sampling methods, such as those used in previous tests, tended to underestimate total inhalable aerosols by 50%, as compared to Institute of Occupational Medicine (IOM) personal inhalable aerosol samplers (Vincent, 2007). These IOM filter cassettes, and other more recent sampling methods, have been proven to withstand extreme sampling environments (Holmes, 2009; Parkhurst, 2003). Additionally, real-time monitoring equipment using electrochemical sensors have exhibited uncertainty in reliability, while operating in complex high aerosol-concentration environments due to the cross-sensitivity of the electrochemical sensors (Holmes, 2009).

Additionally, historical testing of Pb, which was not included in all HHARs, focused solely on Pb particle matter; whereas recent research indicates at high temperatures,

780 The majority of Pb is present as a fume, resulting from vaporization during combustion (Strand, Bohgard, Swietlicki, Gharibi, & Sanati, 2004). This suggests condensation Pb particles in the accumulation mode may not be collected by traditional filter media. The importance and implications of this are addressed later in this chapter during the discussion of mass concentration vs. surface area respiratory response.

A final source of uncertainty regarding exposure health effects was the lack of addressing both chronic metal toxicity and the cumulative effects of exposure to several chemicals simultaneously. While unbeknownst at the time, recent research into chronic exposure to particle air pollution indicates observable negative health effects are present in many U.S. cities, with pollution levels below established National Ambient Air Quality Standards for particle air pollution. In these cases, there are no currently established safe threshold levels, and adverse health effects often increase with pollution levels in a near-linear dose-response relationship (Pope, Bates, & Raizenne, 1995).

Additional research has also demonstrated the addition of non-chemical stressors — such as fatigue, smoking, and poor physical health — to air pollution exposure may increase the associated health risks as well (Malecki, Schultz, Bergmans, LeCaire, & Palta, 2015). While not directly related to M1A1 MBT crew member occupational exposures, these results established a relationship between chronic exposure to pollutants below exposure guidelines and adverse health effects, which exposure to in a confined space may exacerbate.

Research regarding the health effects of metal exposures at levels considered safe indicated physiological alterations occur at these levels (Lewis & Kosnett, 2014). With increasing evidence of biological system toxicity and carcinogenicity at low-exposure

levels, it is imperative those responsible for risk-management decisions consider these factors. This is especially true of metals which serve no human biological process and are nearly impossible to remove from the body once ingested, such as Pb (Flora, Gupta, & Tiwari, 2012). Advances in sampling and analysis technology may illuminate exposures previously considered not significant as significant.

In terms of exposures to chemical mixtures — “Any set of multiple chemical substances that may or may not be identifiable, regardless of their sources, that may jointly contribute to toxicity in the target population” (USEPA, 2000) — much uncertainty exists. Evidence suggests interactions between chemicals may result in effects ranging from decreased toxicity (inhibition) to cumulative toxicity (additivity) to increased toxicity (potentiation) of one or more chemicals (Godleski & Koutrakis, 2015; Hertzber & MacDonell, 2002). This source of uncertainty requires further analysis beyond the scope of this project.

Exposure Pathways

For adverse health effects to occur, there must exist a complete exposure pathway. Once aerosolized within the M1A1 MBT’s turret, chemicals may enter the crew member’s body via any of the following three pathways: absorption, ingestion, or inhalation. Properly worn PPE covers greater than 95% of the crewmember’s body, which greatly mitigates exposure through adsorption. This leaves exposure through ingestion and inhalation as the primary exposure pathways of greatest risk.

Particle deposition within the respiratory tract is dependent on diffusional, gravitational, and inertial forces acting on the inhaled particles. The International

Commission on Radiological Protection (ICRP) developed a model, which has been experimentally validated to predict particle deposition as a function of the particles aerodynamic diameter. These results are shown in Figure 7.

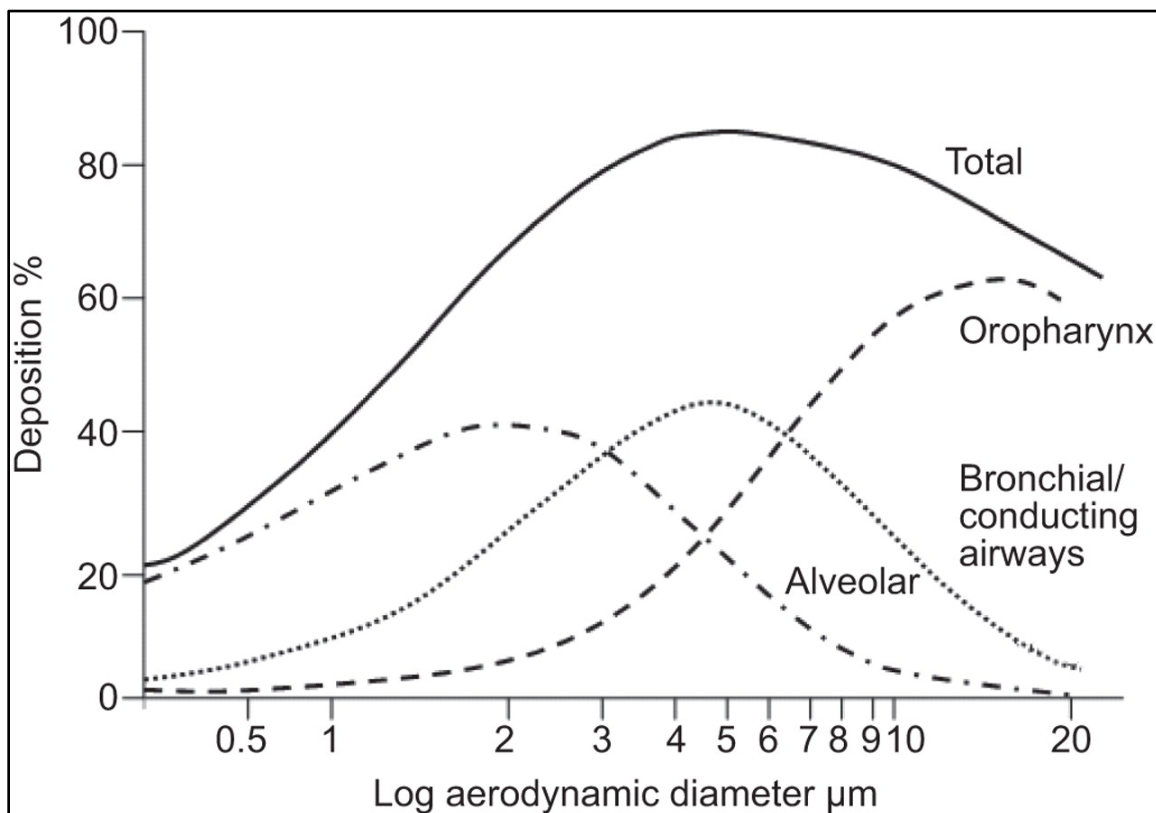


Figure 7: ICRP Model Respiratory Tract Particle Deposition (Laube, et al, 2011)

Ambient air is laden with a multitude of debris and pathogens and, as such, requires filtration prior to reaching the lungs. Since proper PPE does not include personal air filtration devices, M1A1 MBT crew members rely on the body's natural filtration defenses. These include hairs and mucus lining both the nasal and tracheobronchial regions — both of which capture particles and pathogens with an aerodynamic diameter

(d_{ae}) value greater than or equal to 5 μm (Laube, Janssens, de Jongh, Devadason, Dhand, Diot, Everard, Horvath, Navalesi, Vosharr, & Chrystyn, 2011). Air inhaled through the mouth is only minimally filtered through mucus lining these regions. However, if a particle or pathogen is small enough, d_{ae} value of 3 μm and below (Laube, et al, 2011), it will bypass these natural filtration mechanisms and may deposit in various regions of the body including both the brain (Cacciottolo, Wang, Driscoll, Woodward, Saffari, Reyes, Serre, Vizuite, Sioutas, Morgan, Gatz, Chui, Shumaker, Resnick, Espeland, Finch, & Chen, 2017; Elder, Gelein, Silva, Feikert, Opanashuk, Carter, Potter, Maynard, Ito, Finkelstein, & Oberdörster, 2006), and the alveoli deep within the lungs. Particles reaching the alveoli are likely to be ingested by macrophages, where they are transported from the respiratory system to the circulatory system (Johnson & Nolan, 2016).

Particles trapped in mucus are elevated by mucociliary epithelia towards either the glottis or oropharynx, depending on the region where they are trapped, where they are ingested. Once ingested, any sub-micron particles present are efficiently absorbed by the gastrointestinal system, where they can easily pass through tissue and enter the lymphatic and circulatory systems (Ramachandran, 2011).

Mass Concentration vs. Surface Area Respiratory Response

For aerosolized particles, specifically those d_{ae} value 10 μm and below, a majority of both the mass and numbers are contained in particles d_{ae} value 1.0 μm and below, as seen in Figure 8. This disparity results from larger d_{ae} value particles settling out faster due to gravitational forces. The smaller d_{ae} value particles not only stay suspended longer, but may also not be captured by collection elements used in traditional air sampling methods

(Vincent, 1995), this allows for the possibility that mass based exposure assessments may underestimate the true exposure risk.

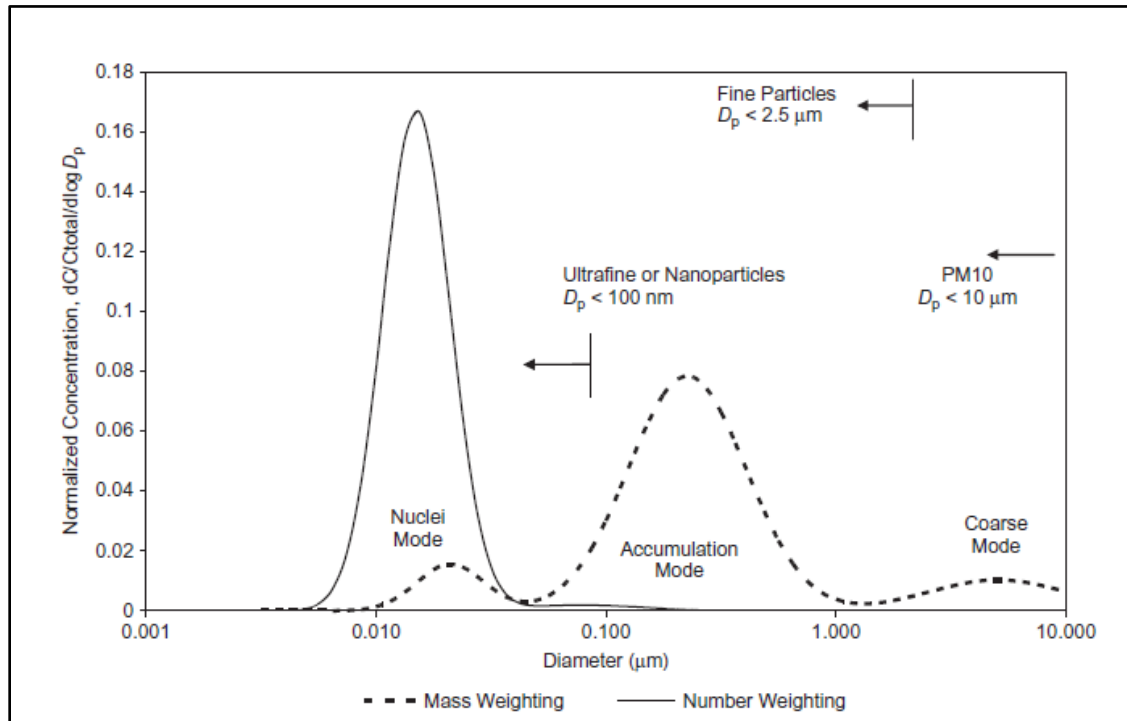


Figure 8: Idealized Size Distribution Showing Particle Numbers, Mass, and Different Modes (Ramachandran, 2011).

Additionally, PM, specifically respirable particles (PM₄), presents a unique exposure hazard. PM₄ is not only more likely to bypass the body's natural filtration mechanisms, but also contains a much larger surface area per mass compared to an equivalent mass of bulk material due to its high number count. This substantial increase in surface area may increase the chemicals' reactivity and biological activity, within the exposed crew member's body, that may result in increased toxicity. Numerous studies conducted between 1990 and 2005, showed samples of particles (i.e. aluminum oxide and titanium

dioxide) of varying diameter triggered varying degrees of inflammatory response in the lungs of rats.

Notably, a study by Maynard and Kuempel in 2005 (Ramachandran, 2011), showed a range of less chemically active dusts followed a similar pulmonary inflammation dose-response curve in rats; whereas more chemically active dusts elicited substantially different dose-response curves. Although the exact relationship between dose-response and particle surface area remains uncertain, there is good evidence to suggest chemical toxicity within the respiratory system is better represented by surface area and chemistry — rather than mass concentration exposure alone (Ramachandran, 2011).

Metal-Containing Aerosols

In addition to the previously-discussed issues of mass vs. surface area, metal-containing aerosols present a unique issue. Current exposure evaluation is primarily based on the concentration of present airborne metals and their molecular form. This is relevant as certain forms elicit a more harmful response than others, i.e. epidemiological studies suggest that despite being water soluble, sulphidic and oxidic forms of nickel may be associated with lung and nasal cancer; whereas there is currently no supporting evidence suggesting nickel's metallic form possess this association.

Another aspect of this issue is that certain non-water-soluble metals may be soluble in the lung environment, i.e. Pb and cadmium. Possible lung solubility is defined as once deposited within the lungs, the material may be transferred through the lung tissue into the blood stream, where it will be transported to various other parts of the body far removed from the lung (Vincent, 1995). This issue suggests simple workplace

monitoring may not be sufficient to fully characterize the exposure risk. Although the author does not address additional monitoring needed to fully characterize the exposure risk, as it falls outside the scope of this research project, such additional monitoring could include medical surveillance such as periodic blood testing for metals.

Conclusion

Workplace aerosol measurements are performed to assess aerosol concentrations present in any given working environment, i.e. office, factory, M1A1 MBT. Comparing these measured concentration levels against established health-related exposure limits provides a decision basis to risk managers for control actions (Vincent, 1995). However, in order to make correct risk-management decisions, consideration of the following points are necessary:

- 1) Exposure to combustion by-products in confined spaces with inadequate ventilation may result in increased risk resulting from exposure concentrations of chemicals, such as HCN and NH₃, higher than those encountered in well-ventilated environments (Rotariu, et al., 2015).
- 2) Epidemiological studies have established a well-defined link between exposure to fine particles and adverse health effects at all levels (Kennedy, 2007).
- 3) Several studies have demonstrated better correlation between dose-response and number count/surface area than between dose-response and mass concentration (Ramachandran, 2011).

As such, and combined with a current lack of data required for statistical determination of exposure risk (J. Cambre, personal communication, 2015), further

monitoring of M1A1 MBT crew member occupational exposures is well warranted and required. Especially when considering the wide range of potential exposure environments M1A1 MBT crew members may be exposed to in the execution of the M1A1 Abrams MBT's diverse set of tactical tasks across the range of military operations (DoN, 2014).

III. Methodology

This chapter outlines the methodology used to postulate answers to the research objective and questions proposed in Chapter I.

- 1) What current occupational health hazard exposures are M1A1 MBT crew members subjected to during live-fire operations?
- 2) Do any of these exposures present more than a negligible health hazard to M1A1 MBT crew members?

This chapter also describes the collection of historical data used in granting the current health hazard clearances for the M865, M1002, and M1028 120mm main gun ammunition; as well as the M80 and M62 7.62 mm; and M8 and M20 .50 caliber cartridges, used during live-fire training operations. Additionally, the sampling equipment used during data collection, and all collection points inside the turret, will be discussed. Furthermore, this chapter will detail the live-fire events associated with each sampling event. The final point of discussion in this chapter is the specific procedures followed to collect and analyze all analytes of interest during M1A1 MBT live-fire operations.

Historical Data Request

As the United States Army is the program manager for M1 series tanks, an e-mail requesting any information regarding the M865, M1002, and M1028 120mm main gun ammunition was sent to USAPHC. In response to the request, current HHARs for each respective round were delivered as well as propellant chemical compositions, a guidance

document outlining the chemicals considered most prevalent, and current exposure standards. Mr. J. Cambre was the point of contact who provided these documents.

A separate e-mail was sent to Picatinny Arsenal requesting any information regarding the M80 and M62 7.62 mm; and M8 and M20 .50 caliber cartridges used in the A131 and A576 configurations respectively. This e-mail was received by the Picatinny Arsenal Public Affairs Office and forwarded to the Program Manager for Maneuver Ammunition Systems' 7.62 mm Project Officer, Mr. E. Vainchenker. In response to the request, the limited historical data available for both the M80 and M62 legacy cartridges, as well as the current HHAR for the M8 and M20 cartridges were delivered. The limited M80 and M62 data consisted of each cartridges design drawings which provided basic cartridge design specifications.

Analytes of Concern

As the chemical compositions of all three 120mm main gun ammunition types are similar, Table 9; they present identical analytes of concern. These primary analytes of concern are:

- 1) Ammonia (NH₃)
- 2) Carbon Monoxide (CO)
- 3) Hydrogen Cyanide (HCN)
- 4) Lead (Pb)
- 5) Nitric Oxide (NO)
- 6) Nitrogen Dioxide (NO₂)
- 7) Sulfur Dioxide (SO₂)

Additional analytes of interest, mentioned in HHARs, include carbon dioxide (CO₂) (above atmospheric concentrations); chlorine (Cl); hydrogen chloride (HCl); and oxides of barium (Ba), magnesium (Mg), sodium (Na), and strontium (Sr). These additional analytes were included in the overall sampling plan to determine average concentrations for purposes of identifying if further sampling is necessary.

Table 9: 120 mm Main Gun Ammunition Propellant Compositions

Propellant / Primer	Composition	Round
M14 (12956320-1)	Nitrocellulose (MIL-DTL-244) Dinitrotoluene (12982933) Dibutylphthalate (ASTM-D608) Diphenylamine (12982932) Graphite (12982931)	M865 M1002
RPD-596	Nitrocellulose (MIL-DTL-244) Nitroglycerine (MIL-N-246) Acetyl Triethyl Citrate (MIL-A-47059) Methyldiphenyl Urea (DoD-M-64040A) Carbon Black (MIL-C-82665)	M865 M1002
Benite Strands (MIL-B-45451)	Potassium Nitrate (MIL-P-156) Nitrocellulose (MIL-N-244) Charcoal (JAN-C-178) Sulfur (MIL-S-487) Ethyl Centralite (JAN-E-255)	M865 M1002 M1028
JA2 (DOD-P-64035)	Nitrocellulose (MIL-N-244) Diglycol Nitrate (DOD-D-64015) Nitroglycerin (MIL-N-246) Methyldiphenyl Urea (DoD-M-64040A) Graphite (MIL-G-155) Magnesium Oxide (MIL-M-14779)	M1028

As both the M865 and M1002 cartridges have two potential propellants, M14 and RPD-596, the lot numbers of each round were collected prior to commencement of live-fire operations. Basic ammunition data are included in Appendix B.

The compositions of both the M80 and M62 7.62 mm cartridges, Table 10, present similar analytes of concern as those of the 120 mm cartridges listed above. The

additional analytes of concern associated with the 7.62 mm cartridges are Sb and Cu.

The specific composition of the M62's trace compound does not introduce any analytes of concern which have not already been previously listed.

Table 10: 7.62 mm Cartridge Compositions

Component	Composition	Cartridge
Igniter	Polyurethane Strontium Peroxide Magnesium Powder	M62
Projectile Core	Lead-Antimony (MIL-L-13283)	M80
Projectile Jacket	Copper Alloy Clad Steel (MIL-S-13468)	M80
Projectile Filler Point	Lead-Antimony (MIL-L-13283)	M62
Projectile Closure Cup	Copper Alloy	M62
Projectile Jacket	Copper Alloy	M62
Propellant	Nitrogen in Nitrocellulose Graphite Sodium Sulfate Nitroglycerin Diphenylamine Dibutyl Phthalate Calcium Carbonate Nitrocellulose Dinitrotoluene Potassium Salt Tin Dioxide	M80 M62
Primer	Lead Styphnate (MIL-L-757) Tetracene (MIL-T-46938) Barium Nitrate (MIL-B-162) Antimony Sulfide (MIL-A-159) Aluminum Powder (MIL-DTL-512) Pentaerythritol Tetranitrate (MIL-P-387) Gum Arabic	M80 M62
Tracer	Polyvinyl Chloride Strontium Nitrate Magnesium Powder	M62

The compositions of both the M8 and M20 .50 caliber cartridges, Table 11, present similar analytes of concern as both the 120 mm and 7.62 mm cartridges listed above, and do not introduce any new analytes of concern.

Table 11: .50 Caliber Cartridge Compositions

Component	Composition	Cartridge
Projectile	Lead-Antimony Manganese-Molybdenum Steel Copper Alloy	M8 M20
Incendiary Composition	Magnesium-Aluminum Alloy Powder Potassium Perchlorate Barium Nitrate	M8 M20
Tracer	Strontium Nitrate Anhydrous Magnesium Powder Polyvinyl Chloride	M20
Igniter	Polyurethane Strontium Peroxide Magnesium Powder	M20
Propellant	Nitrogen in Nitrocellulose Graphite Nitroglycerin Diphenylamine Dibutyl Phthalate Calcium Carbonate Nitrocellulose Potassium Salt	M8 M20
Primer	Lead Styphnate Tetracene Barium Nitrate Antimony Sulfide Aluminum Powder Pentaerythritol Tetranitrate	M8 M20

Data Collection

Data collection was accomplished during a five-day air sampling event conducted aboard Fort Knox, Kentucky at the Yano Multi-Purpose Range Complex (MPRC).

Sampling Equipment

Table 12 lists the primary sampling equipment used during this project. A complete list of equipment and information, to include serial numbers and calibration dates, is found in Appendix C.

Table 12: Sampling Equipment List

Item	Vendor	Catalog Number	Analyte
MultiRAE Pro (MRAE) (x 2)	RAE Systems	N/A	CO CO ₂ H ₂ S HCN NH ₃ NO NO ₂ SO ₂
Dräger Pac® 7000	Dräger	N/A	CO
HAZ-DUST IV	SKC	N/A	Inhalable Particle Mass
DustTrak DRX	TSI	N/A	Particle Mass (Total, PM ₁₀ , Respirable, PM _{2.5} , and PM ₁)
Personal Ultrafine Particle Counter (PUFP C100)	Enmont	N/A	Particle Concentration (d ₅₀ = 4 nm)
Gilian GilAir Plus Personal Sampling Pump (x 6)	Sensidyne	N/A	N/A
Defender 510 DryCal® Calibrator (1 – High Flow, 1 – Low Flow)	Mesa Labs	N/A	N/A
Sorbent Tubes, Silica Gel, Sulfuric Acid	SKC	226-10-06	NH ₃
Sorbent Tubes, Soda Lime	SKC	226-28	HCN
Sorbent Tubes, 2 Molecular Sieve (Triethanolamine) Tubes and 1 Oxidizer Tube	SKC	226-40	NO NO ₂
MCE Filters Preloaded in Cassettes, 0.8 µm, 37 mm	SKC	225-3-01	Total Metals / Metalloids Pb
Polycarbonate Filters Preloaded in Black Conductive Cassette, 0.8 µm, 25 mm	SKC	225-1604	Particles
Coated PTFE Filters Preloaded in Cassettes, Silver Membrane	SKC	225-9006	Cl ₂
Coated MCE Filters Preloaded in Cassettes, Sodium Carbonate	SKC	225-9005	SO ₂
Coated Quartz Filters Preloaded in Cassettes, Sodium Carbonate	SKC	225-9032	HCl
Tygon® Tubing (1/4 inch ID x 3/8 inch OD)	SKC	225-1345	N/A
Quad Adjustable Low Flow Tube Holder (x 2)	SKC	224-26-04	N/A

Sampling Equipment Locations

Sampling equipment was positioned in five separate locations within the tank, Figure 9. Figure 10, shows the proximity of each station to the weapon systems located inside the turret. The TC's .50 caliber machine gun is externally mounted directly above the

TC's station, and the driver's station is forward of the 120 mm main gun, directly beneath the gun tube. Specific data collected at each location is shown in Table 13.

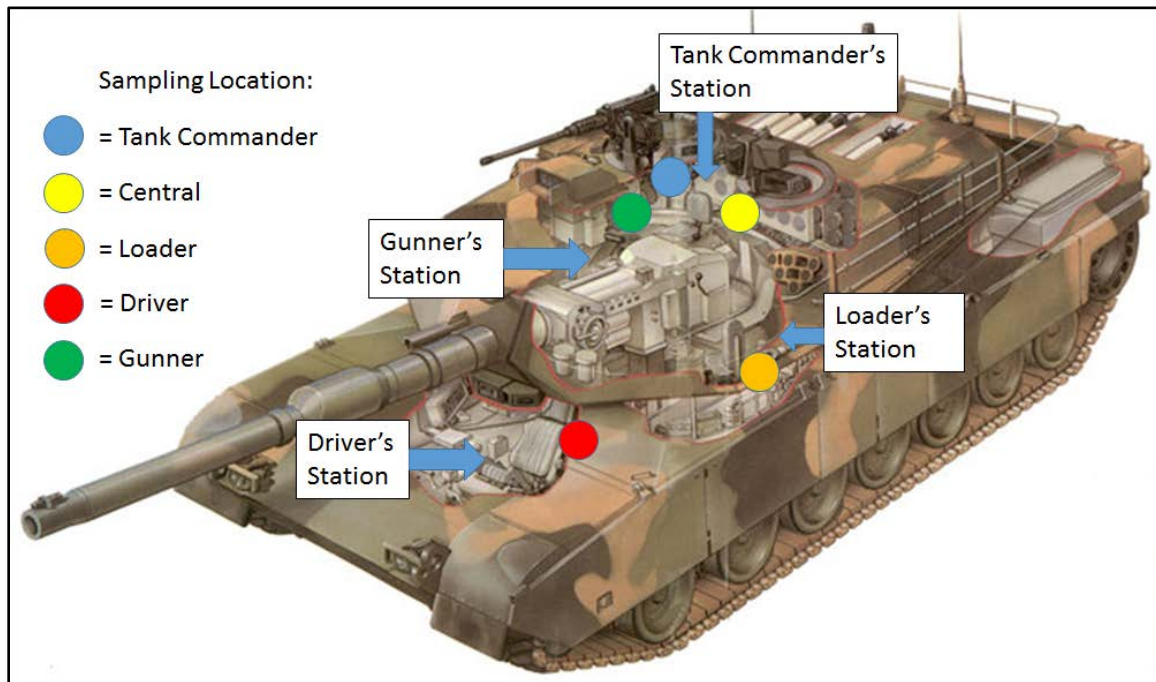


Figure 9: Sampling Locations

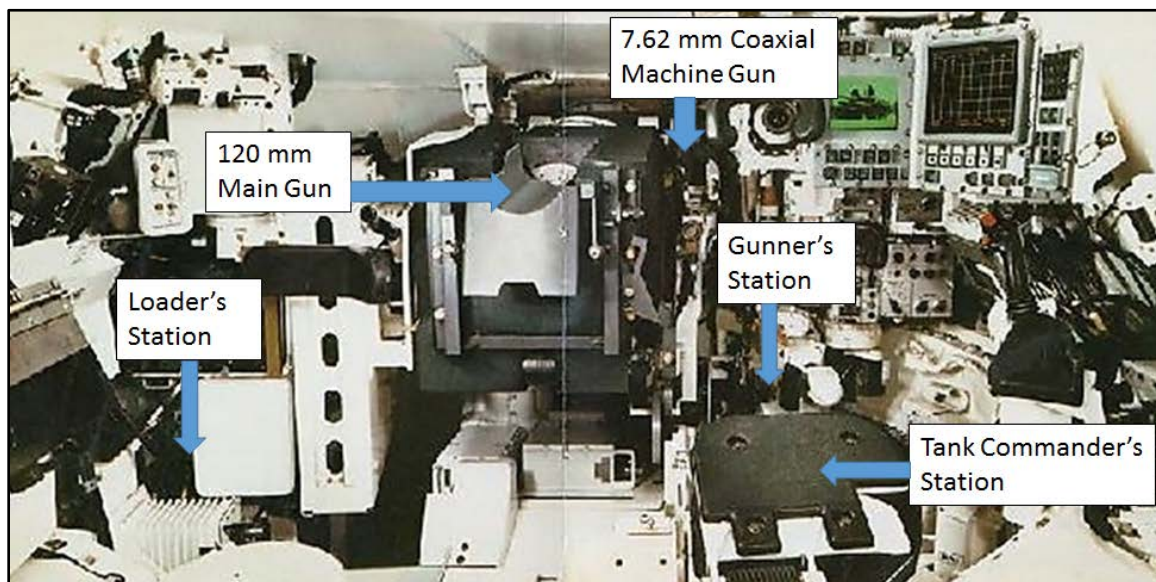


Figure 10: Station Proximity to Weapons

Table 13: Sampling Equipment Set-Up

Location	Equipment	Analyte	Sampling Frequency
Central	PUFP C100	Ultrafine Particles (d_{50} 4 nm)	Total Run - Continuous
	Dräger Pac [®] 7000	CO	
	MRAE	CO / H ₂ S / HCN / NO / NO ₂ / SO ₂	
	DustTrak	Total Particles	
	HAZ-DUST IV	Inhalable Particles	
Tank Commander	GilAir Plus w/ Quad Low-Flow Tube Holder	Cl ₂ / HCN / NH ₃ / NO / NO ₂	Total Run - Continuous
Loader	GilAir Plus	Total Particles	Total Run - Continuous
	GilAir Plus	HCl	
	MRAE	CO ₂ / HCN / NH ₃ / NO ₂ / SO ₂	
Driver	GilAir Plus w/ Quad Low-Flow Tube Holder	Cl ₂ / HCN / NH ₃ / NO / NO ₂	Total Run - Continuous
	GilAir Plus	SO ₂	
Gunner	GilAir Plus	SO ₂	Total Run - Continuous

Positioning the PUFP C100, Dräger Pac[®] 7000, HAZ-DUST IV, DustTrak DRX, and one of the MRAE units in a central location of the turret allowed collection of samples representative of the average environmental concentrations within the M1A1 MBT turret. Figure 11, depicts the arrangement of centrally-located sampling equipment as installed during all sampling events.

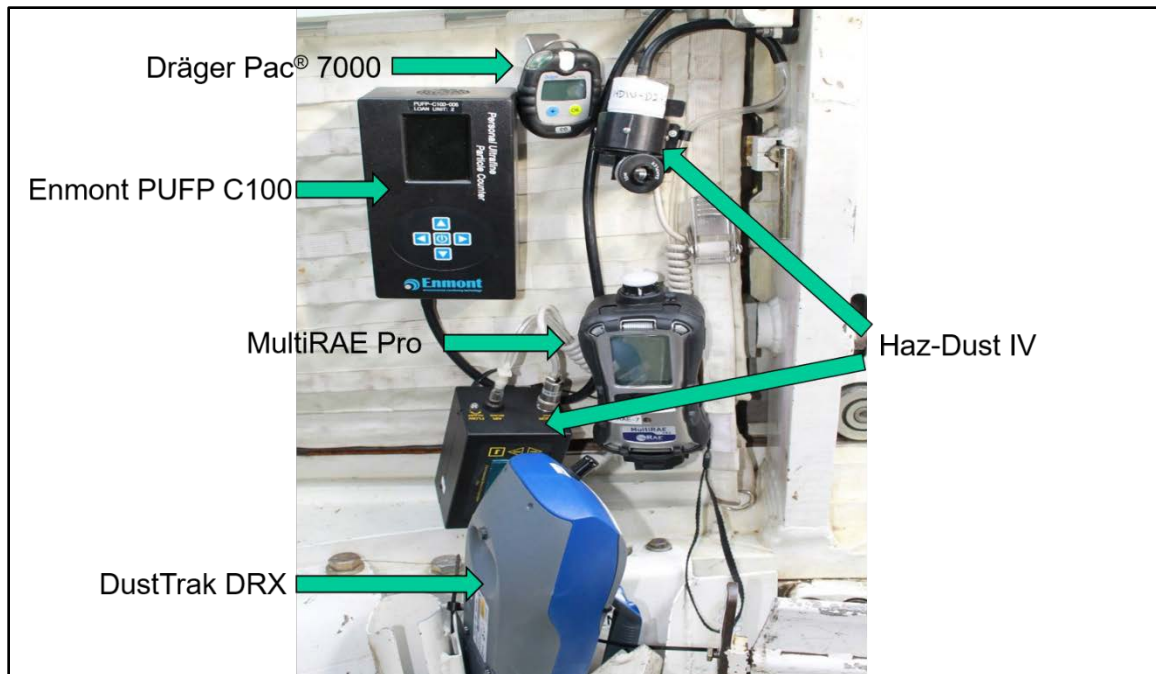


Figure 11: Centrally Located Sampling Equipment (Photo by author)

Identical equipment configurations installed in the general breathing zones of both the TC and driver, Figure 12, included a silica gel sorbent tube, with a 0.8 μm , 37 mm, mixed cellulose ester (MCE) pre-filter, a soda lime sorbent tube, a molecular sieve and oxidizer sorbent tube, and a sodium carbonate coated MCE filter connected to a GilAir Plus personal sampling pump via a quad low flow adjustable tube holder using Tygon[®] tubing. A silver membrane coated polytetrafluoroethylene (PTFE) filter was connected to a second GilAir Plus personal sampling pump by Tygon[®] tubing.

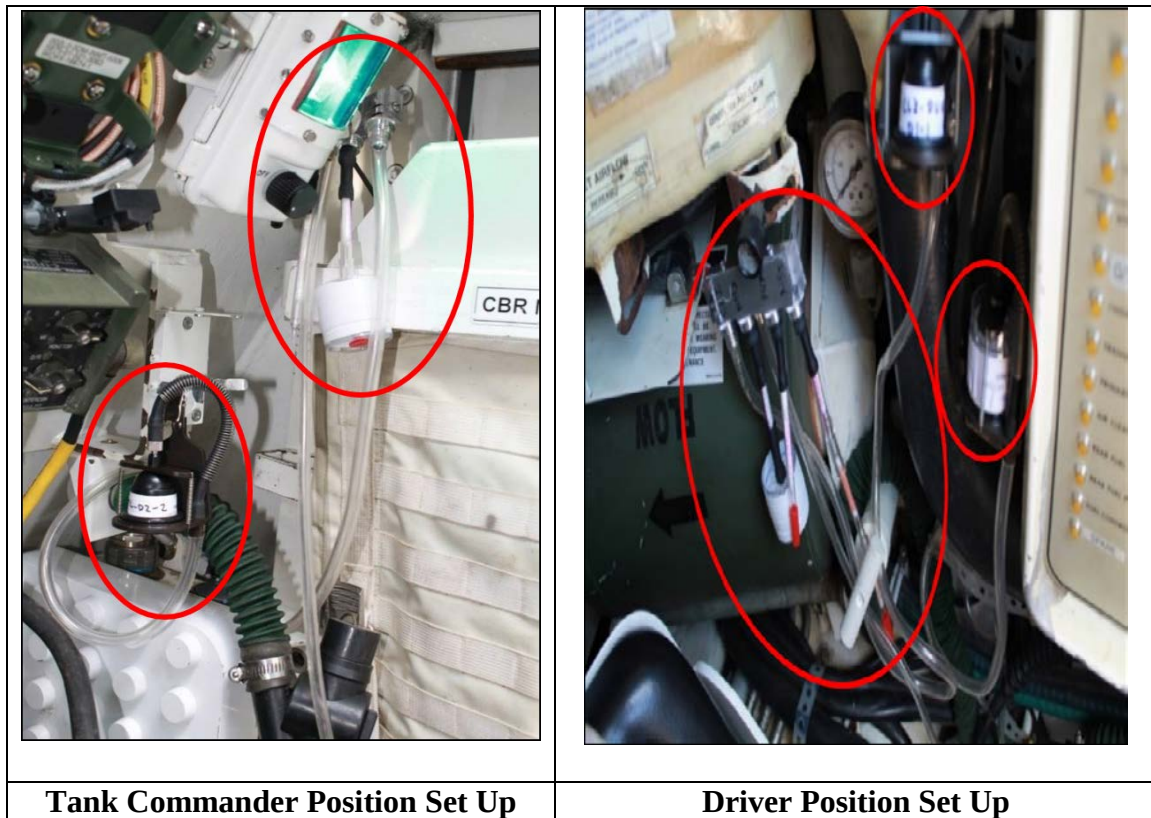


Figure 12: TC and Driver Installation Configurations (Photos by author)

A sodium carbonate coated quartz filter connected to a GilAir Plus personal sampling pump with Tygon® tubing was installed in a location within the general breathing zones of both the TC and gunner, Figure 13. This location was chosen due to limited useable space availability in the gunner's position.



Figure 13: TC / Gunner Position Installation (Photo by author)

In the loader's general breathing zone two GilAir Plus personal sampling pumps were installed, Figure 14. The first pump was connected to a second sodium carbonate coated quartz filter, and the second pump was connected to a 0.8 μm , 25 mm polycarbonate filter. Both filters were connected using Tygon[®] tubing.

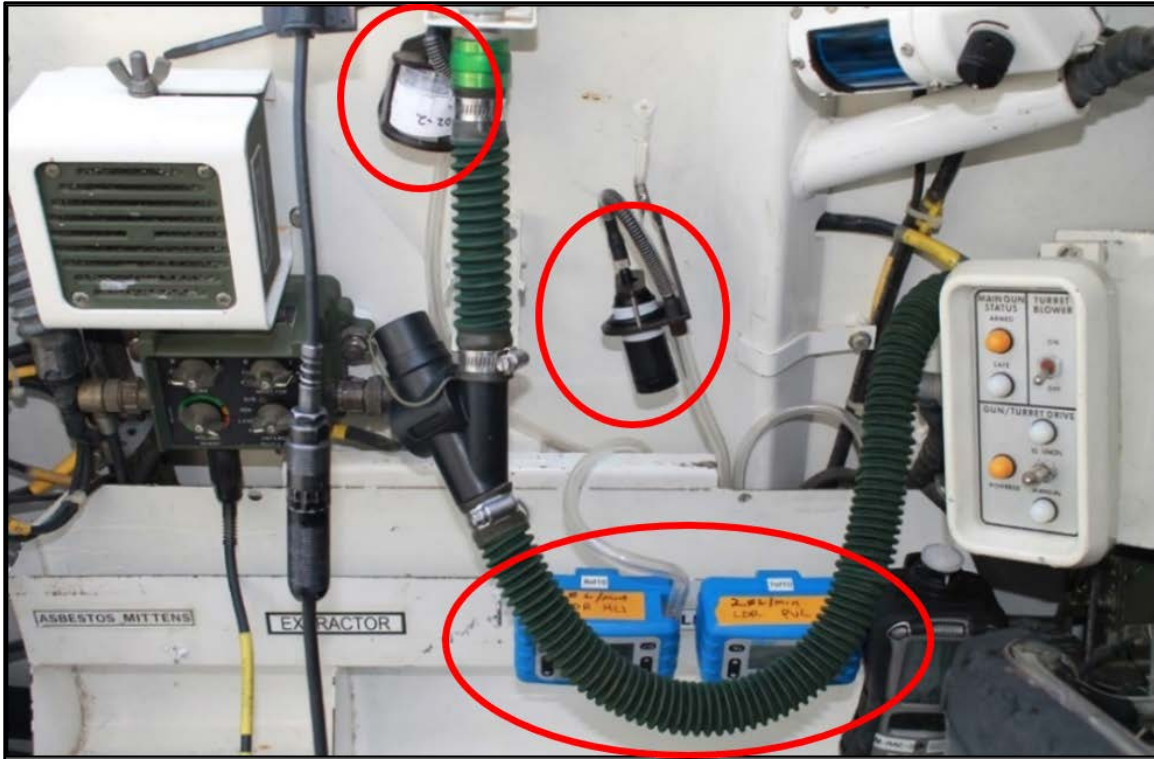


Figure 14: Loader Position Set Up (Photo by author)

Sampling Event (Ft. Knox, KY: 10 – 14 July 2016)

The sampling event was conducted during Company E, 4th Tank Battalion's section and platoon gunnery qualifications at the Ft. Knox, KY, Yano multi-purpose range complex (MPRC). During this event 174 gravimetric samples were collected along with concurrent real time instrument monitoring of select analytes for comparison and analysis. Tank availability precluded the use of a random sampling strategy to obtain samples from a representative sample of the tank population. In total 3 of 14 tanks, and 8 of 14 crews were sampled at least once. The tank / crew match-up is summarized in Table 14.

Table 14: Sample Event Tank / Crew Match-Up

Run	Tank Serial Number	Crew ¹
1-1	632676	A
2-1	572373	B
2-2	632664	C
3-1	632676	D
3-2	632676	D
4-1	632676	E
4-2	572373	F
4-3	632676	E
5-1	632676	G
5-2	632676	H
Environmental Background	N/A	N/A
1 – Letters were assigned to each crew sampled in lieu of recording each individual crewmember’s information. A change in letter indicates a change of at least one crewmember.		
2 – Conducted at the Yano MPRC range tower.		

Day 1 (10 July 2016)

Run 1-1 consisted of sampling equipment initial set-up and refinement, and collecting turret background samples during the 25 km movement from Company E, 4th Tank Battalion’s home training center (HTC) to Yano MPRC. This movement lasted 2 hours and was conducted via the route depicted in Figure 15, on both improved surface and dirt roads. The purpose of this run was to establish a background concentration level baseline within the M1A1 during routine, non-live-fire operations for comparison to those present during live-fire training operations.

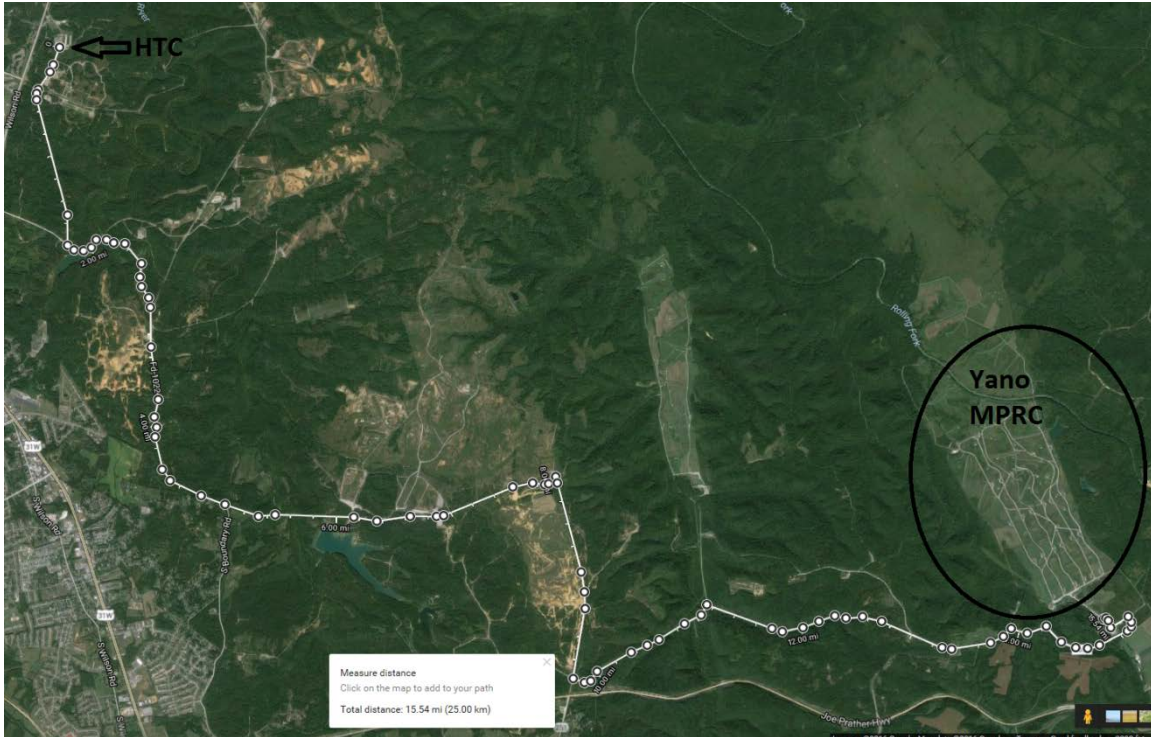


Figure 15: Route from HTC to Yano MPRC
(Imagery ©2017 Google®, Map data ©2017 Google®)

Run 2 (11 July 2016)

Run 2-1 was conducted on Yano MPRC and consisted of collecting samples during initial zeroing of individual tank weapon systems. The purpose of this event was to obtain data in a controlled firing evolution to determine fractional contributions of each weapon system individually. However, this event ultimately resulted in additional non-live fire operation samples being collected as several tanks experienced mechanical malfunctions and the company was unable to proceed with the live fire runs prior to range operator shift change.

Run 2-2 was conducted on Yano MPRC and consisted of collecting samples during a modified GT IX. The purpose of GT IX is to assess a tank section's ability to work

together as a team to quickly and efficiently accomplish their assigned mission. During this event, both tanks experienced main gun malfunctions attributed to excessive residue build-up within the breech. This resulted in the sampled tank to only fire two bursts, of approximately 10 – 15 rounds each, of 7.62 mm from its coaxial machine gun. The excessive residue build-up is attributed to the incomplete combustion of the 120 mm TPCSDS-T combustible cartridge case.

Run 3 (12 July 2016)

Run 3-1 was conducted on Yano MPRC and consisted of collecting samples during a modified GT IX. During this event, the sampled tank experienced no abnormal operating conditions and completed the entirety of the run. This resulted in samples being collected during an initial non-live fire dry run and a live fire run. During the live-fire event approximately (25) .50 caliber rounds, approximately (80) 7.62 mm rounds, and (5) 120 mm TPCSDS-T rounds were fired. The exact amount of .50 caliber and 7.62 mm ammunition fired was not possible to attain as the company's low tank availability required a quick crew change on the sampled tank for the next run. This prevented the author from both conducting an inspection of the tank's turret to ensure all expended brass was collected and to count the number of rounds remaining on the tank. The 120 mm round count is accurate and was validated by both recording the shot times and counting the turned in stub bases. The turned in .50 caliber and 7.62 mm brass was counted and rounded to the nearest 5 to obtain the approximate number of rounds fired.

Run 3-2 was conducted on Yano MPRC and consisted of collecting samples during a modified GT IX. During this event, the sampled tank experienced no abnormal operating conditions and completed the entirety of the run. This resulted in samples being collected

during an initial non-live-fire dry run and a live-fire run. During the live-fire run (100) 7.62 mm rounds, and (6) 120 mm TPCSDS-T rounds were fired. These rounds counts are accurate and was validated by both recording the shot times (120 mm and 7.62 mm burst) and counting the turned in brass and stub bases.

Run 4 (13 July 2016)

Run 4-1 was conducted on Yano MPRC and consisted of collecting samples during a modified GT IX. During this event, the sampled tank experienced mechanical issues with the ammunition compartment door and was not able to complete the live-fire run. This resulted in non-live-fire operation samples being collected. Additionally, the Enmont PUF-P-C100 would not complete start-up and was not used for the remaining events. The configuration of the HazDust IV's inlet was modified due to questionable results being obtained on previous runs, Figure 16.

	
HDIV Initial Set-Up (Photo by author)	HDIV Final Set-Up (Representative Image. © SKC Inc: http://www.skinc.com/catalog/pdf/instructions/1685.pdf)

Figure 16: HDIV Inlet Set-Up Configurations

Run 4-2 was conducted on Yano MPRC and consisted of collecting samples during a modified GT IX for two separate tank crews. During this event, the sampled tank experienced no abnormal operating conditions and completed the entirety of both runs. This resulted in samples being collected during two initial non-live-fire dry runs and two live-fire runs. During the first live-fire run approximately (70) 7.62 mm rounds, and (3) 120 mm TPCSDS-T rounds were fired. During the second live-fire run approximately (50) 7.62 mm rounds, and (4) 120 mm TPCSDS-T rounds were fired. The exact amount of 7.62 mm ammunition fired was not possible to attain as the company's low tank availability required a quick crew change on the sampled tank for the next run. This prevented the author from both conducting an inspection of the tank's turret to ensure all expended brass was collected and to count the number of rounds remaining on the tank. The 120 mm round count is accurate and was validated by both recording the shot times and counting the turned in stub bases. The 7.62 mm brass turned in between runs was counted and rounded to the nearest five to obtain the approximate number of rounds fired by each crew.

Run 4-3 was conducted on Yano MPRC and consisted of collecting samples during a modified GT XII. The purpose of this event was to evaluate the Platoon Commander's ability to tactically employ his platoon, and assess the tank platoon's ability to work together in order to quickly and efficiently complete their assigned mission. During this event, the sampled tank experienced no abnormal operating conditions and completed the entirety of the run. This resulted in samples being collected during an initial non-live-fire dry run and a live-fire run. During the live-fire run (100) 7.62 mm rounds, (9) 120 mm

TPCSDS-T rounds, and (1) 120 mm Canister round were fired. These rounds counts are accurate and was validated by both recording the shot times (120 mm and 7.62 mm burst) and counting the turned in brass and stub bases.

Run 5 (14 July 2016)

Run 5-1 was conducted on Yano MPRC and consisted of collecting samples during a modified GT XII. During this event, the sampled tank experienced no abnormal operating conditions and completed the entirety of the run. This resulted in samples being collected during an initial non-live-fire dry run and a live-fire run. During the live-fire run (100) 7.62 mm rounds, (20) .50 caliber rounds, and (10) 120 mm TPCSDS-T rounds were fired. These rounds counts are accurate and was validated by both recording the shot times (120 mm, and .50 caliber and 7.62 mm burst) and counting the turned in brass and stub bases.

Run 5-2 was conducted on Yano MPRC and consisted of collecting samples during a modified GT XII. During this event, the sampled tank experienced a substantial hydraulic fluid leak within the turret and was not able to complete either the non-live-fire dry run or the live-fire run. This resulted in non-live-fire operation samples being collected.

Run 5-3 was conducted at the range tower, Figure 17, on Yano MPRC and consisted of collecting environmental background samples. The purpose of this event was to collect data on local ambient conditions away from all M1A1 MBT operations. The location selected was located approximately 500 m to the east, and approximately 75 m above of the firing line. The terrain between the sampling location and the firing is a

densely forested, steep hillside. This terrain greatly reduced the likelihood of contaminants migrating from the firing line reaching the sampling location.

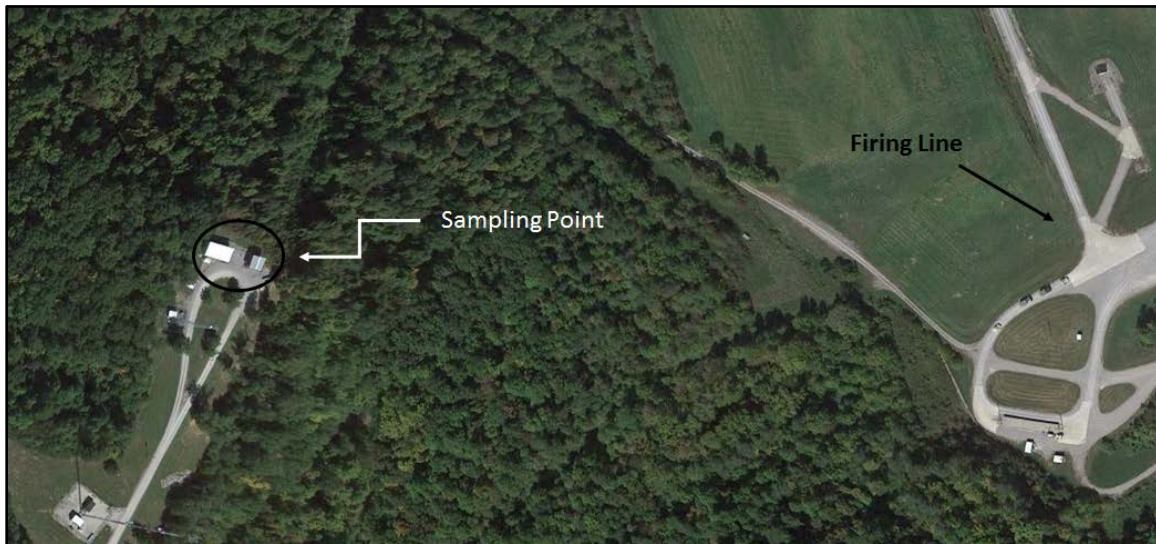


Figure 17: Environmental Background Collection Site
(Imagery ©2017 Google®, Map data ©2017 Google®)

Analyte Collection Methods

Adsorption

Adsorption is the process by which the adsorbate, target analyte, adheres to the outer layer of adsorbent to form a thin monolayer film. This bonding is driven by van der Waals forces and creates a weak bond which is easily overcome during the desorption process through the application of heat (Cooper & Alley, 2011).

Absorption

Absorption refers to the process by which the absorbate, target analyte, is either dissolved by or permeates, and remains within, a liquid or solid absorbent. During absorption, the absorbate diffuses through an interface layer driven by both molecular

and physical forces. The absorbate may either be sampled directly, in the case of a liquid absorbent, or washed from the solid absorbent by means of a secondary absorbent for sampling (Cooper & Alley, 2011).

Direct Reading

Direct reading of chemical concentrations was accomplished through the use of electrochemical sensors. Electrochemical sensors work by the target analyte diffusing through a membrane where it comes in contact with an electrolyte. The addition of the analyte with the electrolyte results in an electrochemical reaction which generates an electrical current. This current is then amplified, filtered, and processed by a calibrated processor unit. While electrochemical sensors are designed for a specific chemical, they have varying degrees of susceptibility to other chemicals. This susceptibility is referred to as cross-sensitivity, and may result in either higher or lower concentration readings. Cross-sensitivity to a single chemical can be corrected for; however exposure to multiple chemicals is nearly impossible to accurately correct for without knowing the target chemicals exact concentration. As electrochemical sensors are reaction based, they are equally susceptible to temperature fluctuations (GDS, 2016; RAE, 2013).

Inertial Impaction

Inertial impaction is the phenomenon whereas a particle's inertial forces are great enough to result in a trajectory which intersects with the collection media's surface. The greater the particle's size or approach velocity are, or the more sharply the airflow's streamline diverges, the greater the particle's tendency to continue on its present path. This tendency increases the likelihood the particle will be unable to pass around the collection media and will impact on its surface (Vincent, 1995).

Interception

Interception is similar to impaction where a particle is collected on the collection media's surface. The primary difference is that interception is more a function of gravity or electrostatic forces than it is of inertia. A particle is said to be collected by interception when its trajectory does not intersect with the collection media's surface, but rather passes close enough to the outside of the collection media to be captured. This phenomenon is typically seen with filter media (Vincent, 1995).

Collection Media Selection Methodology

Sorbent Tubes and Filter Media

The sorbet tubes and filter media were selected based on the requirements of the established NIOSH methods selected for each analyte (NIOSH, 2016). These methods have been evaluated for accuracy and applicability in accordance with established experimental protocols and performance criteria (NIOSH, 2016). This selection criteria is valid given the purpose of the research is to evaluate the occupational exposure, not the evaluation of the collection and analytical methodology.

Direct Reading Instruments

The direct reading instruments selected for use in this research were based on size, operating limitations, collection capability, and availability. Space available within the M1A1 MBT turret is extremely limited and required all sampling equipment to be limited in number and be as small as possible. Additionally, the equipment needed to be capable of both performing in a mobile complex exposure environment; and withstanding

vibration and changes in orientation. All DRIs selected for this research project satisfied all of the above mentioned requirements.

Analytical Methods

All samples collected were analyzed using established NIOSH, and OSHA methods as shown in Table 15.

Table 15: Analytical Methods

Analyte	Method
Metal / Metalloid Particles	NIOSH 7303 / 7300 Mod
HCl	NIOSH 7907
Cl ₂	NIOSH 6011
CO	OSHA ID 209
Pb	NIOSH 7303 / 7300 Mod
NH ₃	NIOSH 6016
HCN	NIOSH 6010
NO / NO ₂	NIOSH 6014
SO ₂	NIOSH 6004

NIOSH Method 7303 / 7300 Mod for Total Metal / Metalloid Particles

Detailed instructions for NIOSH Method 7303 are included in Appendix D. During each sampling event, metal / metalloid particles were collected on 0.8 µm, 37 mm, MCE filters preloaded in cassettes connected directly to the Haz-Dust IV. The specific details, to include serial numbers and calibration data, can be found in Appendix C. The Haz-Dust IV was zeroed before each event using a zeroing accessory, details included in Appendix C. Two field blanks, one trip blank, and one environmental background sample were taken to establish non-live-fire environmental background data. All samples were collected, sealed, and cataloged immediately upon the M1A1 MBT's clearance off

the range by the Range Safety Officer (RSO). All samples were stored in a Ziploc[®] bag, in a closed container located inside a range building 600 m behind the firing line.

Each sample was analyzed by Bureau Veritas North America (BVNA) in Novi, Michigan using inductively coupled argon plasma, atomic emission spectroscopy (ICP-AES), in accordance with the established methodology, for quantification. Samples were received by BVNA on July 22, 2016, were analyzed on August 2, 2016, and did not exceed their sample stability period. A chain-of-custody record was maintained throughout the transfer of samples to BVNA. As noted in the final report from BVNA, all samples were received in acceptable condition, all quality control results associated with the sample set were within acceptable limits and/or did not adversely affect the reported results.

NIOSH Method 7907 for Hydrogen Chloride

Detailed instructions for NIOSH Method 7907 are included in Appendix D. During each sampling event, HCN samples were collected on a 37 mm sodium carbonate coated quartz filters preloaded in cassettes connected to GilAir Plus personal sampling pumps by Tygon[®] Tubing (1/4 ID x 3/8 inch OD). The specific pump details, to include serial numbers and calibration data, are found in Appendix C. Pump flow rates were set to 2.0 ± 10% L/min to ensure the carrying capacity of the quartz filters would not be exceeded during the sampling event. Specific details for each sampling event are included in Appendix C. All sampling pumps, with representative media inline, were calibrated pre- and post-sampling with a Mesa Labs Defender 510 calibrator to verify a constant flow rate was maintained during the event's duration. Three field blanks, one trip blank, and

three media blank were taken to establish non-live-fire environmental background data. All samples were collected, sealed, and cataloged immediately upon the M1A1 MBT's clearance off the range by the RSO. All samples were stored in a Ziploc[®] bag, in a closed container located inside a range building 600 m behind the firing line.

Each sample was analyzed by BVNA using ion chromatography (IC) with conductivity detection, in accordance with the established methodology, for quantification. Samples were received by BVNA on July 22, 2016, were analyzed on August 2, 2016, and did not exceed their sample stability period. A chain-of-custody record was maintained throughout the transfer of samples to BVNA. As noted in the final report from BVNA, all samples were received in acceptable condition, all quality control results associated with the sample set were within acceptable limits and/or did not adversely affect the reported results.

NIOSH Method 6011 for Chlorine

Detailed instructions for NIOSH Method 6011 are included in Appendix D. During each sampling event, Cl₂ samples were collected on a 37 mm silver membrane coated PTFE filters preloaded in cassettes connected to GilAir Plus personal sampling pumps by Tygon[®] Tubing (1/4 ID x 3/8 inch OD). The specific pump details, to include serial numbers and calibration data, are found in Appendix C. Pump flow rates were set to 0.5 ± 10% L/min to ensure the carrying capacity of the PTFE filters would not be exceeded during the duration of the sampling event. Specific details for each sampling event are included in Appendix C. All sampling pumps, with representative media inline, were calibrated pre- and post-sampling with a Mesa Labs Defender 510 calibrator to verify a

constant flow rate was maintained during the event's duration. Two field blanks, one trip blank, and one media blank were taken to establish non-live-fire environmental background data. All samples were collected, sealed, and cataloged immediately upon the M1A1's clearance off the range by the RSO. All samples were stored in a Ziploc[®] bag, in a closed container located inside a range building 600 m behind the firing line.

Each sample was analyzed by BVNA using IC with conductivity detection, in accordance with the established methodology, for quantification. Samples were received by BVNA on July 22, 2016, were analyzed on July 28, 2016, and did not exceed their sample stability period. A chain-of-custody record was maintained throughout the transfer of samples to BVNA. As noted in the final report from BVNA, all samples were received in acceptable condition, all quality control results associated with the sample set were within acceptable limits and/or did not adversely affect the reported results.

OSHA ID 209 for Carbon Monoxide

Detailed instructions for OSHA ID 209 are included in Appendix D. During each sampling event, CO samples were collected using the Dräger Pac[®] 7000 single-gas CO detector. The specific detector details, to include serial numbers and calibration data, are found in Appendix C. The Dräger Pac[®] 7000 CO detector was installed in approximately the same location, in the general vicinity of the TC's breathing zone, each run and was started and stopped in sequence with all other pumps and instruments. This was to ensure all sampling durations were as similar as possible. Given the total number of instruments used it was not possible to ensure each sampling duration was exact. In accordance with the established methodology, data from the Dräger Pac[®] 7000 was transferred to the

author's personal HP® Pavilion dv5 laptop computer for quantification and analysis using Dräger's GasVision 7 software via the Dräger Pac® Detector Communication Module 8318587.

NIOSH Method 7303 / 7300 Mod for Lead Particles

Detailed instructions for NIOSH Method 7303 are included as Appendix D. During each sampling event, Pb particles were collected on 0.8 µm, 37 mm, MCE filters preloaded in cassettes connected to GilAir Plus personal sampling pumps by Tygon® Tubing (1/4 inch ID x 3/8 inch OD). The specific pump details, to include serial numbers and calibration data, can be found in Appendix C. Pump flow rates were set to $2.0 \pm 10\%$ L/min to ensure the carrying capacity of the MCE filters would not be exceeded during the duration of the sampling event. Specific details for each sampling event are included in Appendix C. All sampling pumps, with representative media inline, were calibrated pre- and post-sampling with a Mesa Labs Defender 510 calibrator to verify a constant flow rate was maintained during the event's duration. Two field blanks and one media blank were taken to establish non-live-fire environmental background data. A separate trip blank was not required for this analysis as it would have been an unnecessary duplicate of the trip blank submitted for the total metal / metalloid particle analysis. All samples were collected, sealed, and cataloged immediately upon the M1A1 MBT's clearance off the range by the RSO. All samples were stored in a Ziploc® bag, in a closed container located inside a range building 600 m behind the firing line.

Each sample was analyzed by BVNA using inductively coupled argon plasma, atomic emission spectroscopy (ICP-AES), in accordance with the established methodology, for

quantification. Samples were received by BVNA on July 22, 2016, were analyzed on August 2, 2016, and did not exceed their sample stability period. A chain-of-custody record was maintained throughout the transfer of samples to BVNA. As noted in the final report from BVNA, all samples were received in acceptable condition, all quality control results associated with the sample set were within acceptable limits and/or did not adversely affect the reported results.

NIOSH Method 6016 for Ammonia

Detailed instructions for NIOSH Method 6015 are included in Appendix C. During each sampling event, NH₃ samples were collected in silica gel sorbent tubes connected to GilAir Plus personal sampling pumps by Tygon[®] Tubing (1/4 inch ID x 3/8 inch OD) and a quad adjustable low-flow tube holder. The specific pump details, to include serial numbers and calibration data, are found in Appendix C. Pump flow rates were set 0.5 ± 10% L/min to ensure the carrying capacity of the silica gel sorbent tubes would not be exceeded during the duration of the sampling event. Specific details for each sampling event are included in Appendix C. All sampling pumps, with representative media inline, were calibrated pre- and post-sampling with a Mesa Labs Defender 510 calibrator to verify a constant flow rate was maintained during the event's duration. Three field blanks, one trip blank, and one media blank were taken to establish non-live-fire environmental background data. All samples were collected, sealed, and cataloged immediately upon the M1A1 MBT's clearance off the range by the RSO. All samples were stored in a Ziploc[®] bag, in a closed container located inside a range building 600 m behind the firing line.

Each sample was analyzed by BVNA using Visible Absorption Spectrophotometry, in accordance with the established methodology, for quantification. Samples were received by BVNA on July 22, 2016, were analyzed on August 2, 2016, and did not exceed their sample stability period. A chain-of-custody record was maintained throughout the transfer of samples to BVNA. As noted in the final report from BVNA, all samples were received in acceptable condition, all quality control results associated with the sample set were within acceptable limits and/or did not adversely affect the reported results.

NIOSH Method 6010 for Hydrogen Cyanide

Detailed instructions for NIOSH Method 6017 are included in Appendix D. During each sampling event, HCN samples were collected in soda lime sorbent tubes connected to GilAir Plus personal sampling pumps by Tygon® Tubing (1/4 inch ID x 3/8 inch OD) and a quad adjustable low-flow tube holder. The specific pump details, to include serial numbers and calibration data, are found in Appendix C. Pump flow rates were set to $0.2 \pm 10\%$ L/min to ensure the carrying capacity of the soda lime sorbent tubes would not be exceeded during the duration of the sampling event. Specific details for each sampling event are included in Appendix C. All sampling pumps, with representative media inline, were calibrated pre- and post-sampling with a Mesa Labs Defender 510 calibrator to verify a constant flow rate was maintained during the event's duration. Three field blanks, one trip blank, and one media blank were taken to establish non-live fire environmental background data. All samples were collected, sealed, and cataloged immediately upon the M1A1 MBT's clearance off the range by the RSO. All samples

were stored in a Ziploc[®] bag, in a closed container located inside a range building 600 m behind the firing line.

Each sample was analyzed by BVNA using IC with direct current amperometry, in accordance with the established methodology, for quantification. Samples were received by BVNA on July 22, 2016, and were analyzed on August 8, 2016. All HCN samples exceeded their sample stability period of “at least 2 weeks,” as stated in the NIOSH Manual of Analytical Methods, 4th edition. As the samples were not exposed to extreme conditions, the author does not believe this exceedance had a significant impact on their results.

A chain-of-custody record was maintained throughout the transfer of samples to BVNA. As noted in the final report from BVNA, all samples were received in acceptable condition, all quality control results associated with the sample set were within acceptable limits and/or did not adversely affect the reported results.

NIOSH Method 6014 for Nitrous Oxide and Nitrogen Dioxide

Detailed instructions for NIOSH Method 6014 are included in Appendix C. During each sampling event, NO and NO₂ samples were collected in molecular sieve and oxidizer sorbent tubes connected to GilAir Plus personal sampling pumps by Tygon[®] Tubing (1/4 inch ID x 3/8 inch OD) and a quad adjustable low-flow tube holder. The specific equipment and pump details, to include serial numbers and calibration data, are found in Appendix C. Pump flow rates were set at 0.025 L/min to allow for both NO and NO₂ to be determined simultaneously from each sample. Specific details for each sampling event are included in Appendix C. All sampling pumps, with representative

media inline, were calibrated pre- and post-sampling with a Mesa Labs Defender 510 calibrator to verify a constant flow rate was maintained during the event's duration. Three field blanks, 1 trip blank, and 10 media blanks were taken to establish non-live-fire environmental background data. All samples were collected, sealed, and cataloged immediately upon the M1A1 MBT's clearance off the range by the RSO. All samples were stored in a Ziploc® bag, in a closed container located inside a range building 600 m behind the firing line.

Each sample was analyzed by BVNA using visible absorption spectrophotometry, in accordance with the established methodology, for quantification. Samples were received by BVNA on July 22, 2016, and were analyzed on August 9, 2016. All NO and NO₂ samples exceeded their sample stability period of "at least 7 days," as stated in the NIOSH Manual of Analytical Methods, 4th edition. As the samples were stored on dry ice and not exposed to extreme conditions, the author does not believe this exceedance had a significant impact on their results.

A chain-of-custody record was maintained throughout the transfer of samples to BVNA. As noted in the final report from BVNA, all samples were received in acceptable condition, all quality control results associated with the sample set were within acceptable limits and/or did not adversely affect the reported results.

NIOSH Method 6004 for Sulfur Dioxide

Detailed instructions for NIOSH Method 6004 are included in Appendix C. During each sampling event, SO₂ samples were collected on 37 mm sodium carbonate coated MCE filters preloaded in cassettes connected to GilAir Plus personal sampling pumps by

Tygon[®] Tubing (1/4 inch ID x 3/8 inch OD). The specific equipment and pump details, to include serial numbers and calibration data, are found in Appendix C. Pump flow rates were set to 1.5 L/min to ensure the carrying capacity of the sodium carbonate coated MCE filters would not be exceeded during the duration of the sampling event. Specific details for each sampling event are included in Appendix C. All sampling pumps, with representative media inline, were calibrated pre- and post-sampling with a Mesa Labs Defender 510 calibrator to verify a constant flow rate was maintained during the event's duration. Three field blanks, one trip blank, and one media blank were taken to establish non-live fire environmental background data. All samples were collected, sealed, and cataloged immediately upon the M1A1 MBT's clearance off the range by the RSO. All samples were stored in a Ziploc[®] bag, in a closed container located inside a range building 600 m behind the firing line.

Each sample was analyzed by BVNA using IC, in accordance with the established methodology, for quantification. Samples were received by BV on July 22, 2016, were analyzed on July 29, 2016, and did not exceed their sample stability period. A chain-of-custody record was maintained throughout the transfer of samples to BVNA. As noted in the final report from BVNA, all samples were received in acceptable condition, all quality control results associated with the sample set were within acceptable limits and/or did not adversely affect the reported results.

Analytical Techniques

All of the analytical techniques selected for use in this research project were in accordance with the chosen analytical method.

ICP-AES

Inductively coupled argon plasma, atomic emission spectroscopy is used as an analytical technique for detecting trace metals in environmental samples. This technique uses the principle that electrons, when excited, emit a known energy wavelength as they return to their base state. The intensity of the energy emitted is directly proportional to the elements' concentrations present in the sample. Using this proportionality the analyst is capable of quantifying the concentration of the target element.

Electron excitation is achieved through an ionization process. In this technique, an inductively coupled argon plasma torch is used to ionize the sample. The use of the argon plasma torch allows for ionization to occur within a chemically inert environment. This enables a more complete ionization process as it inhibits the formation of oxides. Once the electrons are excited, the light energy emitted is focused through a lens and passes through an entrance slit into the spectrometer. As the light energy enters the spectrometer it is diffracted onto the detector in sequential order of the wavelengths selected by the analyst for analysis (ODP, n.d.).

IC

Ion Chromatography is a type of liquid chromatography which functions on the basis of ion exchange. The sample to be analyzed in liquid form is combined with a carrier fluid, eluent, and is then passed through a pressurized column. The column contains a stationary adsorbent which reacts with the samples ions. The ionic exchange is either a cation or anion exchange. As the eluent passes through the column the various compounds within the sample adhere to the adsorbent with different forces. Those compounds with stronger adhesion forces move through the column more slowly, longer

residence time, than those compounds with weaker adhesion forces. These differences in forces is what separates the compounds from each other. A detector installed at the column's output end analyzes the ions as they emerge and records them, usually as peaks. The detector most frequently used in IC is a conductivity detector, however other detectors such as direct current amperometry can be used. The number of peaks corresponds to the number of elements present, and the height of the peak corresponds with the amount of that element. The residence time for each peak is used to identify the element (Acikara, 2013).

Conductivity Detection represents the simplest form of detector used in IC. The conductivity detector is comprised of two electrodes arranged in a sensor cell. As ions enter the sensor cell, the conductivity between the two electrodes changes and causes an "out of balance" signal to be transmitted to an electronic processor. The processor modifies this signal into an output signal which is linearly proportional to the ion concentration in the sensor cell. The processors output signal is then amplified and transmitted to an output device, usually a computer, for processing, display, and recording (Scott, n.d.).

Direct Current Amperometry is similar to conductivity detection, except that it uses a potentiostat to generate voltage. The potentiostat supplies a constant working potential current between a working electrode and reference electrode. The compounds present react with the working current and allow the current to flow to an auxiliary electrode. The voltage reaching the auxiliary electrode is proportional to the compounds concentration. The auxiliary electrode sends this measurement signal to an electrical

processor, which then sends an output signal to the respective output device for processing, display, and recording (Metrohm, 2012).

Visible Absorption Spectrophotometry

Visible absorption spectrophotometry measures the interaction between visible light and an unknown compound. Light energy is called photons, and each photon has a specific energy that is directly related to its wavelength. The visible light spectrum consists of all wavelengths between 380 nm and 720 nm. This analytical method requires a sample, in liquid form, be placed into a rectangular container with two opposing clear walls called a cuvette. Two cuvettes, one containing a blank and one containing the sample to be analyzed, are placed into a spectrometer. The spectrometer then passes a light through focusing lenses into either a diffraction grating or prism. At this point the light is diffracted into different wavelengths and passed through both cuvettes and onto a photosensitive detector. The photosensitive detector measures the exiting light energy, transforms it into electrical energy and passes it to an amplifier for amplification. Once amplified, the electrical signal is sent to an output device for processing, display, and recording of the absorption spectrum plot. This plot can then be used to identify the unknown compound based on known characteristic absorption spectra (UCI, 2014).

Microscopy

Microscopy is the use of microscopes to magnify an object's image to a point it falls at least within the resolution range of the human eye, approximately greater than or equal to 40 μm (Wong, 2016). The more an object's image is magnified, the greater the amount of detail can be seen. However too much magnification will result in a loss of image resolution. The type of microscope used limits the amount of useful

magnification. A typical compound light microscope is capable of magnification levels of 4X – 400X up to a maximum of approximately 1000X – 2000X (MU, n.d.). In comparison, a scanning electron microscope (SEM) is capable of achieving magnification levels ranging from 20X to approximately 30,000X (Swapp, 2017). Based on the author's need to image particles in the sub-micron range with great detail and resolution, the author chose SEM as the primary microscopy technique.

Scanning Electron Microscopy

A SEM uses a high-energy electron beam to create a range of signals on the object's surface through electron-sample interactions. The electron-sample interaction is characterized by the significant levels of kinetic energy, contained within the electrons of the SEM's electron beam, dissipating upon contact with the sample object. The signals generated by this interaction includes, but not limited to, secondary electrons, which is used for image production, and X-Ray photons. These signals provide useful information regarding a particles characteristics, and if equipped with an energy-dispersive (EDS) X-Ray detector, a particles chemical composition, qualitatively / semi-quantitatively. One of the primary limitations to a SEM is that unless the SEM is capable of operating in a low vacuum mode, an electrically conductive coating must be applied to the sample's surface. This coating can reduce some of the object's surface fine details. Additionally, an EDS generally has poor sensitivity and resolution for compounds with low concentrations (Swapp, 2017).

IV. Analysis and Results

Assumptions

Gravimetric Sample Blanks

The “--“ in the analytical results columns for all field, trip, and media blanks indicated the respective analyte was either below the analytical LOD or not present.

Gravimetric Results Below Reporting Limits

Many of the analytical results received from BVNA contain concentrations below reporting limits, as indicated by the “<” preceding the respective result. This indicates the analyte was detected, but at or below the analytical method’s reporting limit — minimum detectable concentration after adjusting for volume of air sampled.

Quantitative Analyses

Chlorine

A total of 14 gravimetric samples were collected for Cl₂ analysis, 5 from the TC’s location, 5 from the Driver’s location, 1 media blank, 2 field blanks, and 1 trip blank. All 14 samples came back as either below the analytical method’s reporting limit or not detected, Table 16. Thus, the ACGIH® TLV-TWA® of 0.5 ppm was not exceeded. However, because a Cl₂ DRI was not used, it is not known if NIOSH’s 15-minute ceiling REL of 0.5 ppm was exceeded during these events.

Table 16: Cl₂ Gravimetric Results

M1A1 MBT Samples						Blanks	
Event	D1-1	D2-1	D2-2	D3-1	D3-2	Media	--
TC	< 0.047	< 0.13	< 0.037	< 0.025	< 0.039	Field Blank 1	--
Driver	< 0.047	< 0.14	< 0.041	< 0.025	< 0.040	Field Blank 2	--
All results reported in ppm.						Media Blank	--

These results do not indicate a significant health concern to the M1A1 MBT crew members. Therefore, using the procedures outlined in Appendix A, summarized in Table 17, given inhalation as the most likely sole exposure route, and a maximum run exposure of < 0.14 ppm, M1A1 MBT crew member Cl₂ exposure during semi-annual gunnery is assigned a RAC of 5, negligible.

Table 17: Cl₂ RAC Analysis

Area:	Points:
Exposure Condition	0
Medical Effects Points Assessed	1
Determined HHSC	IV
Exposure Duration	5
Exposure Frequency	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Carbon Monoxide

MRAE / Dräger Pac® 7000 Cross-Sensitivity

As both direct reading instruments use an electrochemical sensors to evaluate CO concentrations, both are susceptible to cross-sensitivity. The respective cross-sensitivity data is shown in Table 18.

Table 18: CO Electrochemical Sensor Cross-Sensitivity Data

Gas	MRAE ¹⁾		Dräger Pac® 7000 ²⁾
	Concentration	Response	Cross-Sensitivity Factor ³⁾
Acetylene	No Data Available		≤ 2
Cl ₂	1 ppm	0 ppm	≤ 0.05
CO ₂	No Data Available		Negligible
Ethane	No Data Available		No Value
Ethanol	No Data Available		Negligible
Ethene	No Data Available		No Value
H ₂	100 ppm	20 ppm	≤ 0.35
H ₂ S	15 ppm	0 – 6 ppm	≤ 0.03
HCl	No Data Available		Negligible
HCN	No Data Available		Negligible
Methane	No Data Available		Negligible
NH ₃	No Data Available		Negligible
NO	35 ppm	0.1 ppm	≤ 0.20
NO ₂	5 ppm	0.1 ppm	≤ 0.05
Propane	No Data Available		Negligible
SO ₂	5 ppm	0 ppm	≤ 0.04
1) – Data obtained from RAE Systems Technical Note TN-114 dated April 2013.			
2) – Data obtained from Dräger Pac® 7000 User's Manual dated January 2016			
3) – Multiply cross sensitivity factor by gas concentration to get reading			

MRAE 7 / Dräger Pac® 7000 Comparison

To determine the effects of cross-sensitivity on both instruments' CO electrical sensors, a comparison curve was generated using the raw recorded data from both instruments. Both instruments were co-located within the vicinity of the TC's breathing zone. Given that the MRAE was programmed to collect one reading every second and the Dräger Pac® 7000 was programmed to collect one reading every minute, the average readings per event were compared. As shown in Figure 18, the complex environment resulted in the MRAE reading approximately 1.4 times higher than the Dräger Pac® 7000, with an R^2 value of 0.998. This suggests that the cross-sensitivity effects remained constant for both devices throughout the sampling evolution.

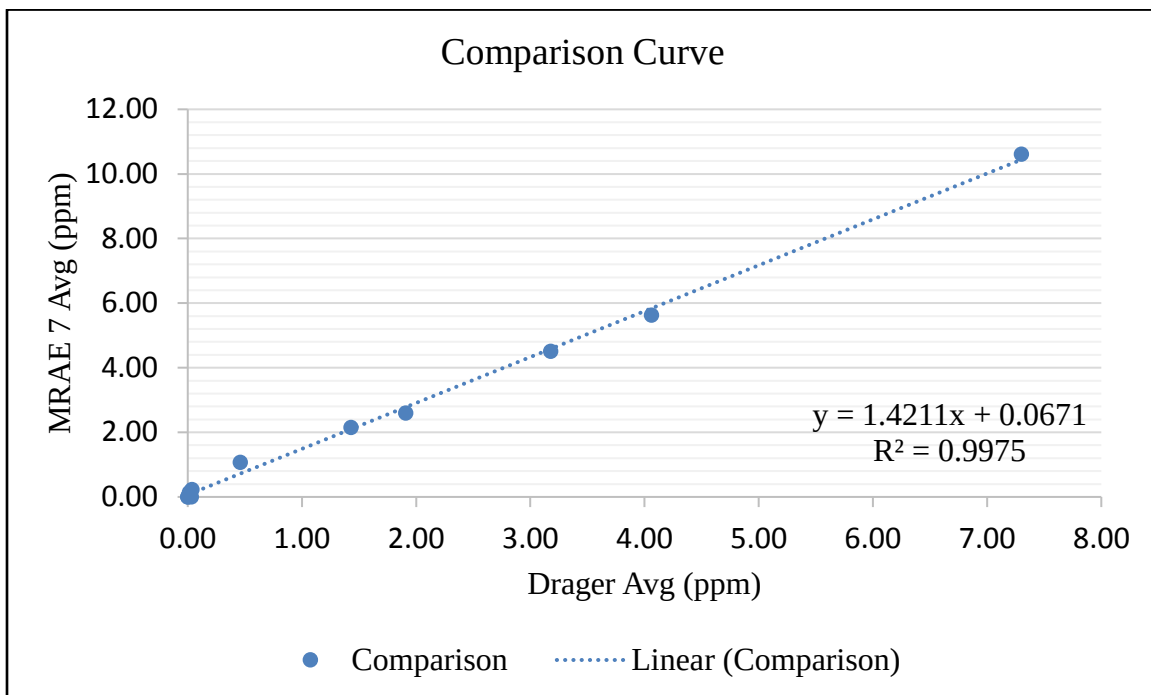


Figure 18: CO Comparison Curve

While the total cross-sensitivity of the Dräger Pac[®] 7000 in a complex exposure environment is uncertain, the manufacturer states, “The measured signals can be affected additively by acetylene, hydrogen, and nitrogen monoxide” (Dräger, 2016). Therefore, the author assumes the other gases listed with a positive cross-sensitivity factor will affect the electrochemical sensor similarly. This results in a total cross-sensitivity response correction of approximately 0.39 ppm, Table 19. This approximated total correction factor is less than the Dräger Pac[®] 7000’s 1 ppm resolution, and is assumed by the author to be negligible and can be ignored for purposes of this analysis.

Table 19: Dräger Pac[®] 7000 CO Cross-Sensitivity Calculation

Gas	Peak Measured Concentration ¹	Cross-Sensitivity Factor ²	Cross-Sensitivity Response Correction
Acetylene	Not Measured	≤ 2	0 ppm
Cl ₂	< 0.14 ppm	≤ 0.05	0.01 ppm
CO ₂	*	Negligible	0 ppm
Ethane	Not Measured	No Value	0 ppm
Ethanol	Not Measured	Negligible	0 ppm
Ethene	Not Measured	No Value	0 ppm
H ₂	Not Measured	≤ 0.35	0 ppm
H ₂ S	0.9 ppm	≤ 0.03	0.03 ppm
HCl	*	Negligible	0 ppm
HCN	*	Negligible	0 ppm
Methane	Not Measured	Negligible	0 ppm
NH ₃	*	Negligible	0 ppm
NO	< 1.4 ppm	≤ 0.20	0.28 ppm
NO ₂	< 1.3 ppm	≤ 0.05	0.07 ppm
Propane	Not Measured	Negligible	0 ppm
SO ₂	< 0.05 ppm	≤ 0.04	0 ppm
Total CO Response Correction			0.39 ppm
1 – For all measurements below reporting limits, the reporting is assumed as peak measured concentration. 2 – All negligible cross-sensitivity factors are assumed to be 0, for all others the respective maximum factor is used. * – Peak measured concentration omitted due to negligible correction factor. Gases not measured are assumed to not be present and assigned a response correction of 0 ppm.			

Given the high correlation between the two sensors, fewer assumptions made for the cross-sensitivity of the Dräger Pac[®] 7000's electrochemical sensor, and a negligible cross-sensitivity factor; only the data from the Dräger Pac[®] 7000 will be used in the following analysis of crewmember CO exposure.

Environmental and Tank Background

Direct reading results from the Dräger Pac[®] 7000 CO detector showed environmental background CO and CO levels inside of the tank during non-live fire operations are both less than 1.0 ppm, as indicated by a reading of 0 and given the Dräger Pac[®] 7000's sensitivity of 1.0 ppm (Dräger, 2014).

Live-Fire Results

During the live-fire evolutions, the peak concentration measured was on 12 July 2016, Run number 2, at 247 ppm, with a peak 15-minute exposure and peak TWA of 54.07 and 2.74 ppm respectively, as measured by the Dräger Pac[®] 7000, Figures 19 and 20. During this event, the NIOSH 200 ppm C REL was exceeded for a total duration of 1 minute; the ACGIH[®] TLV-TWA[®] of 25 ppm was not exceeded.

:

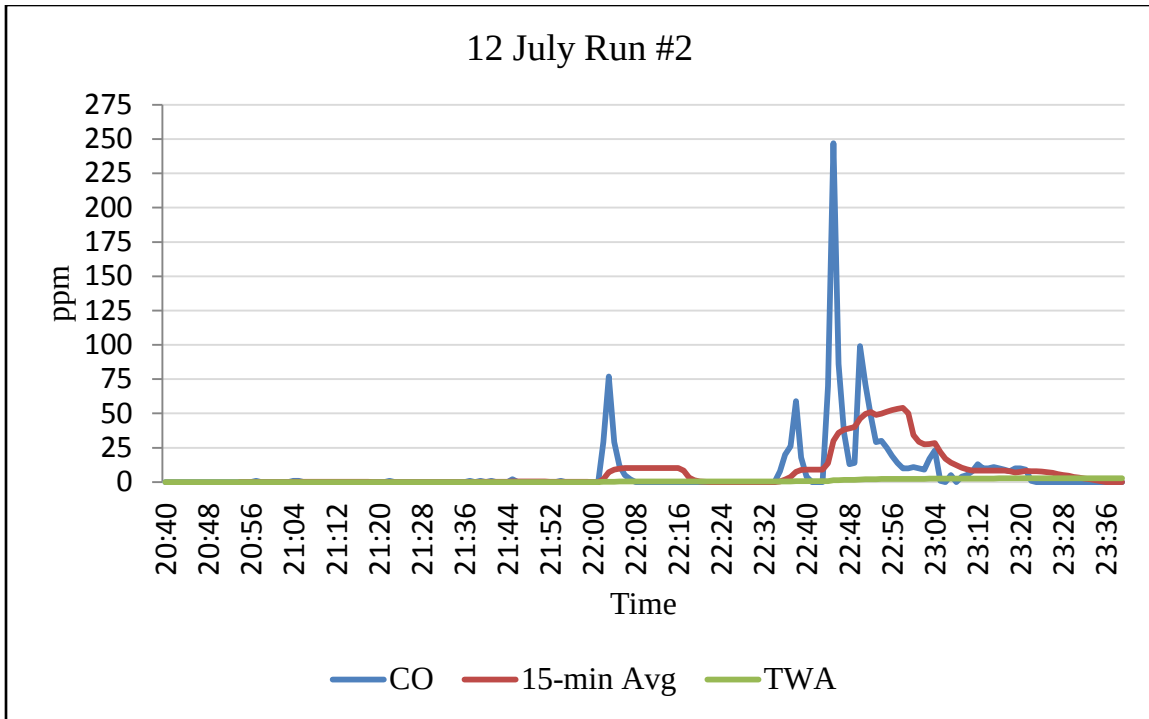


Figure 19: Peak Measured CO Concentration (Total Run)

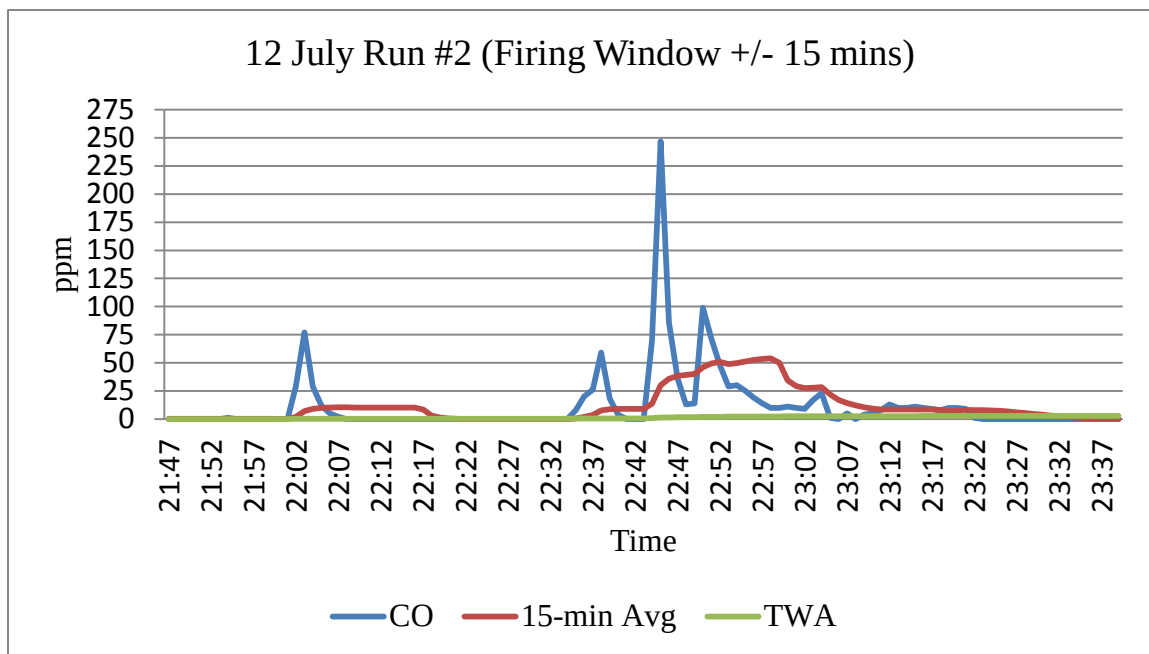


Figure 20: Peak Measured CO Concentration (Firing Window Zoom)

Department of Defense Handbook: Human Engineering Design Guidelines (MIL-HDBK-759C) requires carboxyhemoglobin (COHb) levels in blood for the evaluation of CO toxicity hazard. These COHb levels can be estimated using the following empirical equation, Equation 1.

Equation 1: COHb Blood Content Prediction

$$\%COHb_t = \%COHb_0 \left(e^{\left(\frac{t}{A} \right)} \right) + \left[218 \left(1 - e^{\left(\frac{t}{A} \right)} \right) * \left(\frac{1}{B} + \frac{ppmCO}{1403} \right) \right]$$

Where:

- 1) **%COHb_t** is the predicted COHb present in the exposed individual at time “t”;
- 2) **%COHb₀** is the COHb usually found in non-smoking adults;
- 3) **t** is the exposure duration in minutes;
- 4) **ppmCO** is the CO concentration present in ppm;
- 5) **A** and **B** are constants dependent on the exposed individuals physical activity level during exposure.

From the HHA program toxic gases and particulate assessment guidelines provided by APHC, constants A and B have values of 134 and 2553 respectively for all combat vehicle occupants during weapons firing operations. From a published study on COHb levels and a previous DoA HHAR, **%COHb₀** is equal to 1.0% (DoA, 2014; Light, 2007). A peak 15-minute exposure of 54.07 ppm, results in an estimated maximum COHb level of 1.8%.

$$\begin{aligned}\%COHb_t &= 1 \left(e^{\left(\frac{-15}{134} \right)} \right) + \left[218 \left(1 - e^{\left(\frac{-15}{134} \right)} \right) * \left(\frac{1}{2553} + \frac{54.07}{1403} \right) \right] \\ \%COHb_t &= 1(0.894) + (218(0.106) * (0.039)) \\ \%COHb_t &= 0.894 + 0.901 \\ \%COHb_t &= 1.795\end{aligned}$$

This estimated COHb level is well below the recommended 10% maximum level for personnel operating systems other than aviation systems (DoD, 1995).

Using the procedures outlined in Appendix A, and summarized in Table 20; and given one exposure route, inhalation, a maximum short-term exposure of 54.07 ppm, and a maximum calculated COH_b of 1.8%, crew member CO exposure during semi-annual gunnery is given a RAC of 5, negligible.

Table 20: CO RAC Analysis

Area:	Points:
Exposure Condition	3
Medical Effects Points Assessed	1
Determined HHSC	IV
Exposure Duration	5
Exposure Frequency	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Carbon Dioxide

MRAE 3 Calibration Curve

According to RAE Systems Technical Note TN-114 (RAE TN-114), Sensor Specifications and Cross-Sensitivities, there are no cross-sensitivity corrections required for the non-dispersive infrared CO₂ sensor used. Therefore passing the pre- and post-operation calibration checks deems the obtained data accurate with a resolution of 100 ppm and a maximum drift of less than 5% per month.

Environmental and Tank Background

Direct reading results from the MRAE show environmental background CO₂ concentrations at the Yano MPRC are approximately 300 ppm, Figure 21.

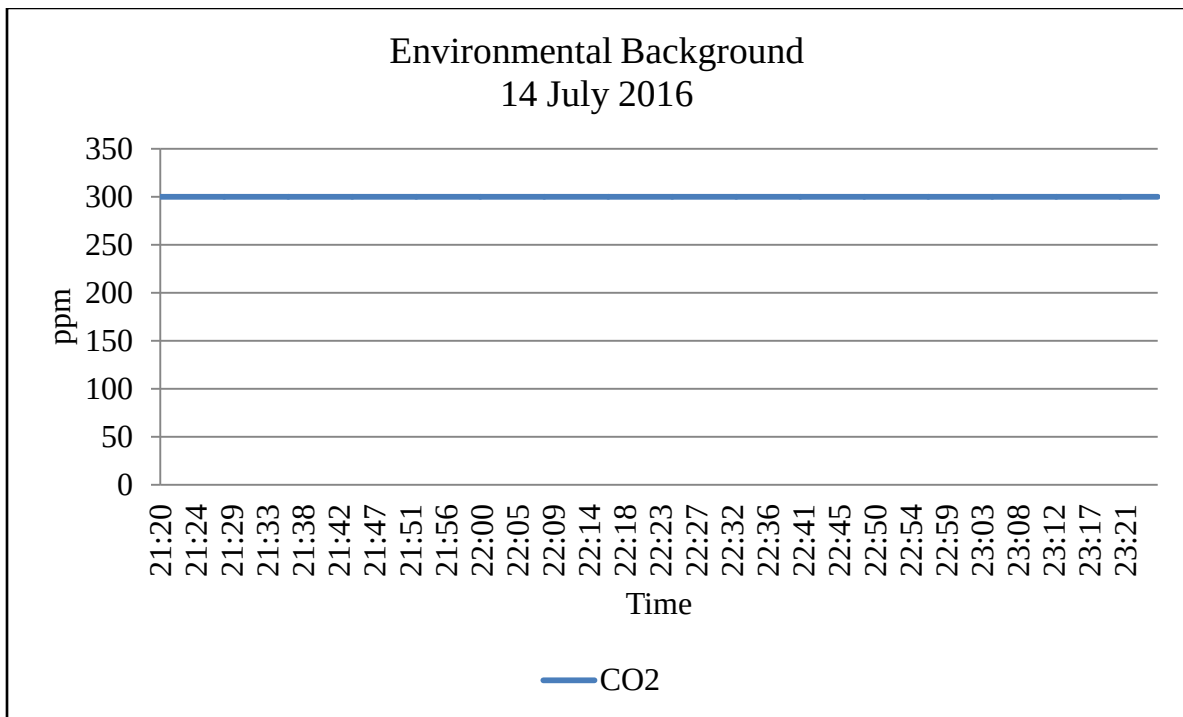


Figure 21: Environmental Background CO₂ Concentration

Direct reading results from the MRAE, Table 21, also showed average CO₂ levels inside of the M1A1 MBT during non-live fire operations varied between 300 ppm (11 July 2016) and 600 ppm (13 July 2016), for a non-live fire average of 400 ppm. The variations in average readings are attributed to the monitored tank's proximity to other vehicles; and duration and speed of movement. Spikes in CO₂ levels were noted during initial tank start-up, periods of no movement in close proximity to other tanks, and during periods of elevated crew member activity inside the turret.

Table 21: Average Measured M1A1 MBT Non-Live Fire CO₂ Concentrations

Date	10 July 2016	11 July 2016	13 July 2016	14 July 2016
Avg CO ₂ (ppm)	400	300	600	400

Both environmental background and average non-live fire CO₂ concentrations are well below OELs and are commensurate with the global average CO₂ levels for July 2016 of 401.80 ppm, as measured by the Earth System Research Laboratory's Global Monitoring Division (NOAA, 2016).

Live-Fire Results

During the live-fire evolutions, the average CO₂ concentrations averaged 400 ppm, which was consistent with the non-live fire run averages, Table 22. This is expected due to the relatively short durations of elevated levels related to firing. Spikes above this are most likely correlated with loader's activity level as the MRAE was located in the general breathing zone of the loader.

Table 22: Average Measured M1A1 MBT Live Fire CO₂ Concentrations

Date	11 July 2016	12 July 2016	12 July 2016	13 July 2016	13 July 2016	14 July 2016
Run Number	2	1	2	2	3	1
Avg CO ₂ (ppm)	400	400	500	400	400	400

ACGIH's® TLV-TWA®, and TLV-STEL® are 5,000 ppm and 30,000 ppm respectively.

These limits were not exceeded at any point during this evolution.

Using the procedures outlined in Appendix A, and given one exposure route, inhalation, and an average run exposure of 400 ppm, crewmember CO₂ exposure during semi-annual gunnery is given a RAC of 5, negligible, summarized in Table 23.

Table 23: CO₂ RAC Analysis

Area:	Points:
Exposure Condition	0
Medical Effects Points Assessed	0
Determined HHSC	IV
Exposure Duration	5
Exposure Frequency	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Hydrogen Chloride

A total of 18 gravimetric samples were collected for HCl analysis, 10 from the loader's station, 3 field blanks, 1 trip blank, 3 media blanks, and 1 environmental background. All 18 samples came back as either below the analytical method's reporting limit or not detected, Table 24. However, because a HCl DRI was not used, it is not known if the ACGIH® TLV-C® of 2 ppm was exceeded during these events.

Table 24: HCl Gravimetric Results

M1A1 MBT Samples		Blanks	
Event	Loader's Station		
D1-1	< 0.0070	Field Blank 1	“__“
D2-1	< 0.018	Field Blank 2	“__“
D2-2	< 0.0058	Field Blank 3	“__“
D3-1	< 0.0037	Trip Blank	“__“
D3-2	< 0.0060	Media Blank 1	“__“
D4-1	< 0.015	Media Blank 2	“__“
D4-2	< 0.0050	Media Blank 3	“__“
D4-3	< 0.0038	Environmental Background	< 0.0082
D5-1	< 0.0037		
D5-2	< 0.016		
All results reported in ppm			

These results do not indicate a significant health concern to the M1A1 MBT crew members. Therefore, using the procedures outlined in Appendix A, given inhalation as the most likely sole exposure route, and a maximum TWA exposure of < 0.018 ppm, M1A1 MBT crew member HCl exposure during semi-annual gunnery is assigned a RAC of 5, negligible, summarized in Table 25.

Table 25: HCl RAC Analysis

Area:	Points:
Exposure Condition	0
Medical Effects Points Assessed	1
Determined HHSC	IV
Exposure Duration (During Gunnery)	5
Exposure Frequency (During Gunnery)	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Hydrogen Cyanide

A total of 27 gravimetric samples were collected for HCN analysis, 10 from the driver's station, 10 from the TC's station, 3 field blanks, 1 trip blank, 1 media blanks, and 2 environmental background. The results of all 27 are shown in Table 26.

Table 26: HCN Gravimetric Results

M1A1 MBT Samples			Blanks	
Event	TC's Station	Driver's Station		
D1-1	< 0.031	< 0.031	Field Blank 1	“--“
D2-1	< 0.084	< 0.094	Field Blank 2	“--“
D2-2	< 0.025	< 0.027	Field Blank 3	“--“
D3-1	0.021	< 0.016	Trip Blank	“--“
D3-2	0.13 ¹⁾	0.075	Media Blank	“--“
D4-1	< 0.063	< 0.066	Environmental Background 1	< 0.037
D4-2	0.030	0.029	Environmental Background 2	< 0.037
D4-3	0.031	0.031		
D5-1	0.059	0.040		
D5-2	< 0.074	< 0.072		
All results reported in ppm				
1) – Breakthrough = 40.6%. Back sorbent tube section contained 1.5 µg of 5.1 total µg of HCN collected.				

MRAE Calibration Curves

Two MRAE direct reading instruments were used to collect data on HCN concentration within the turret. One was set-up in the breathing zone of the TC, and the other was set-up in the breathing zone of the Loader. To account for the MRAE's HCN electrochemical sensor cross-sensitivity, calibration curves were created for each instrument using the gravimetric results above the reporting limits, and the corresponding MRAE readings, Figures 22 and 23. The cross-sensitivity data from RAE TN-114 is shown in Table 27.

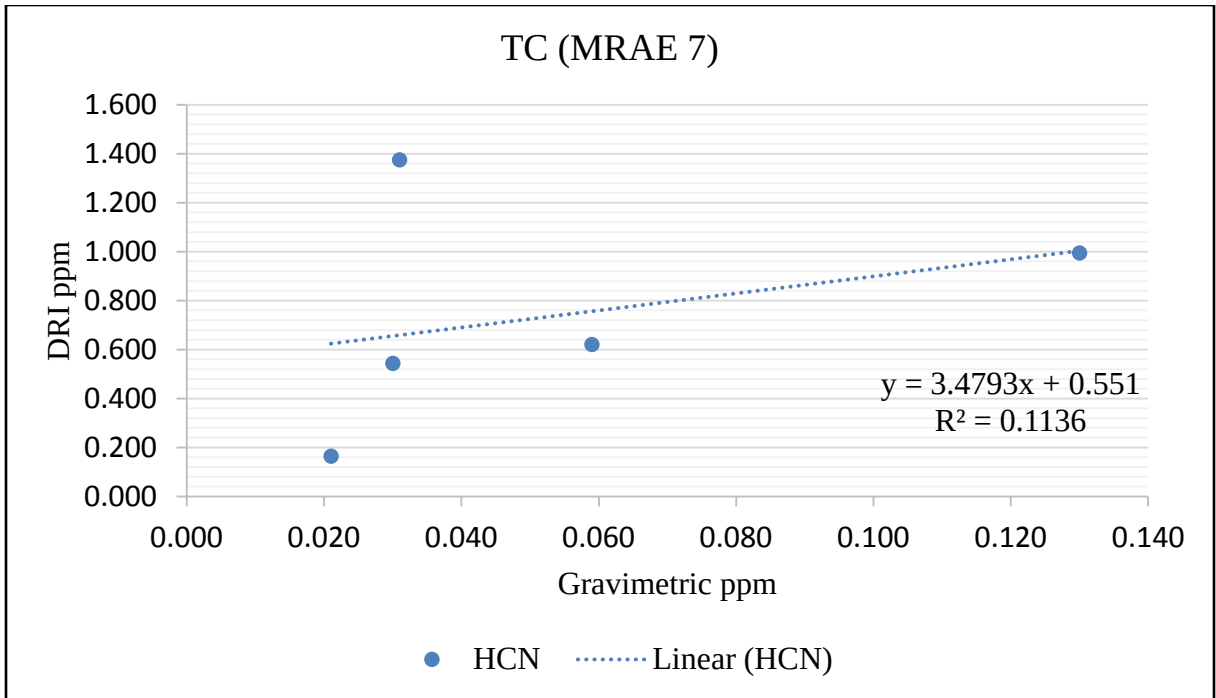


Figure 22: MRAE HCN Calibration Curve – TC

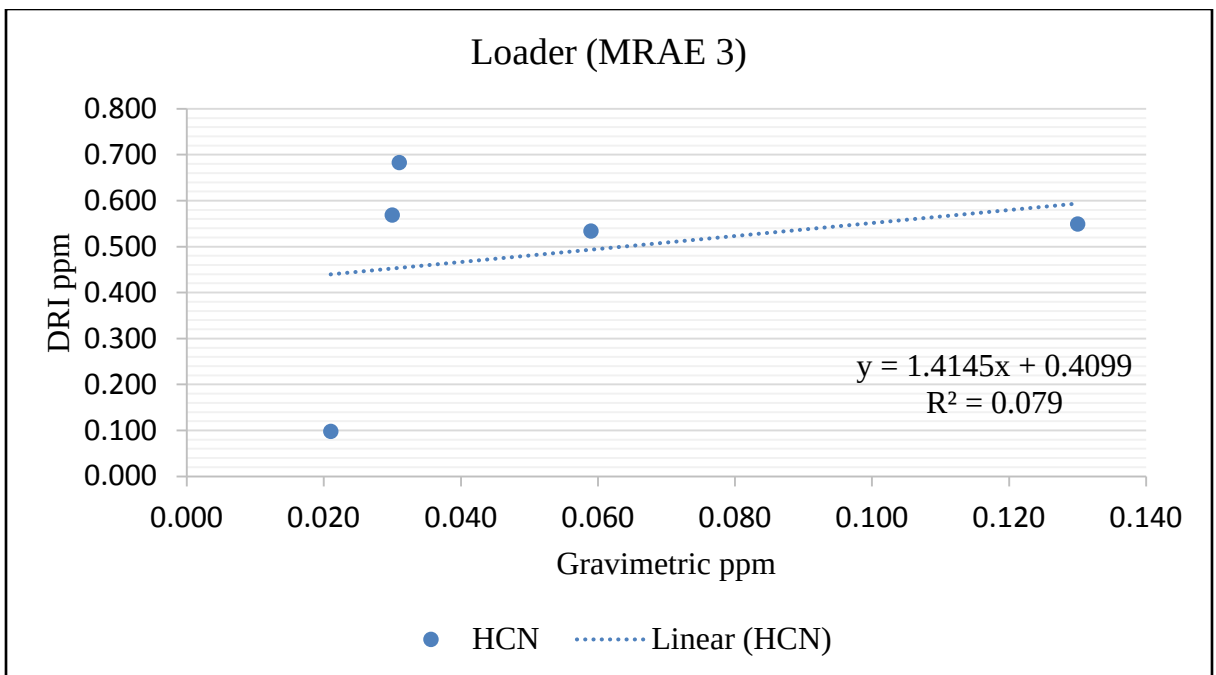


Figure 23: MRAE HCN Calibration Curve - Loader

Table 27: HCN Electrochemical Sensor Cross-Sensitivity

Gas	Concentration	Response
CO	300 ppm	15 ppm
Ethylene	100 ppm	25 ppm
H ₂	200 ppm	0 ppm
H ₂ S	15 ppm	90 ppm ¹
NO	35 ppm	-28 to ~0 ppm ²
NO ₂	5 ppm	-20 to -10 ppm ²
SO ₂	20 ppm	40 ~ 75 ppm
1 – Due to very high cross-sensitivity to H₂S, this sensor is unsuitable for use in atmospheres containing H₂S. 2 – Negative cross-sensitivities may result in readings lower than the true concentration present.		

The readings from the two MRAEs were then compared to establish the relationship between concentrations found at both locations, Figure 24. These comparisons are necessary to determine the feasibility of using direct reading instruments for future occupational exposure analyses, and to determine the concentration distribution within the turret.

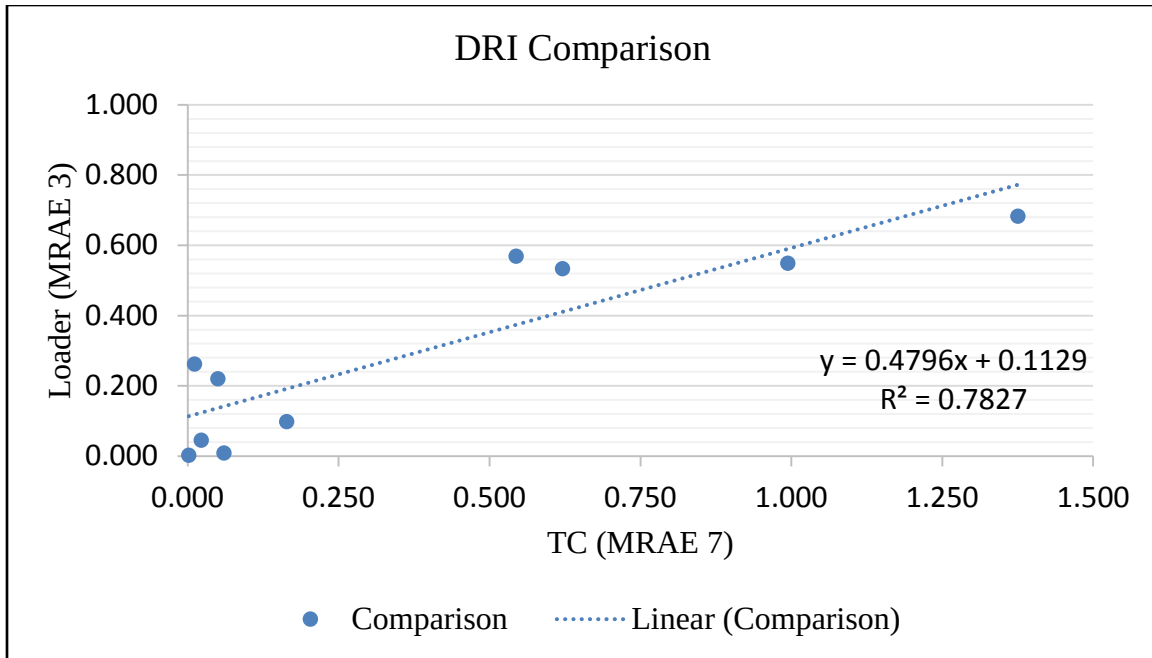


Figure 24: MRAE HCN Concentration Comparison

Given the low R^2 values of the MRAE / Gravimetric calibration curves, approximately 0.11 and 0.08 respectively, there is no apparent direct correlation between the two sampling methods at either location. This suggests a lack of a reliable cross-sensitivity correction factor. Additionally since sampling was conducted on multiple tanks, over multiple days, using multiple crews; tank configuration, crewmember physical size, and gear placement may significantly affect the concentration distribution within the turret. When the two DRIs were compared, the resulting R^2 value of 0.78, suggests concentrations are higher on the TC's side of the turret than they are on the loader's side. This can be accounted for by the TC's closer proximity to all weapon systems' combustion gas discharge locations.

Environmental and Tank Background

Despite no direct correlation between the MRAE's readings and the gravimetric sampling, the lack of detection by both MRAE's, and both the environmental background and M1A1 non-live-fire operation gravimetric results below their respective reporting limits, strongly suggest environmental background HCN concentrations are negligible.

Live-Fire Results

Without a reliable method for correcting the readings acquired by the MRAE's, only the gravimetric results received from BV, were used in determining the overall average exposure during live fire operations. To evaluate the DRI's ability to obtain a more complete exposure profile, a calibration curve was created for the only data set collected on the same day, using both the same M1A1 MBT and crew, 12 July 2016, runs 1 and 2, Figure 25. The resulting R^2 value of 1, strongly suggests it does. This calibration factor was then applied to the higher of the two readings, 12 July 2016, Run 2, and plotted, Figure 26. The DRI reading approximately 7.6 times higher than the gravimetric results is not surprising given the number of other gases present the HCN electrochemical sensor is cross-sensitive to. These elevated readings further reinforce that the use of DRIs as stand-alone instruments for occupational exposure monitoring events is not feasible.

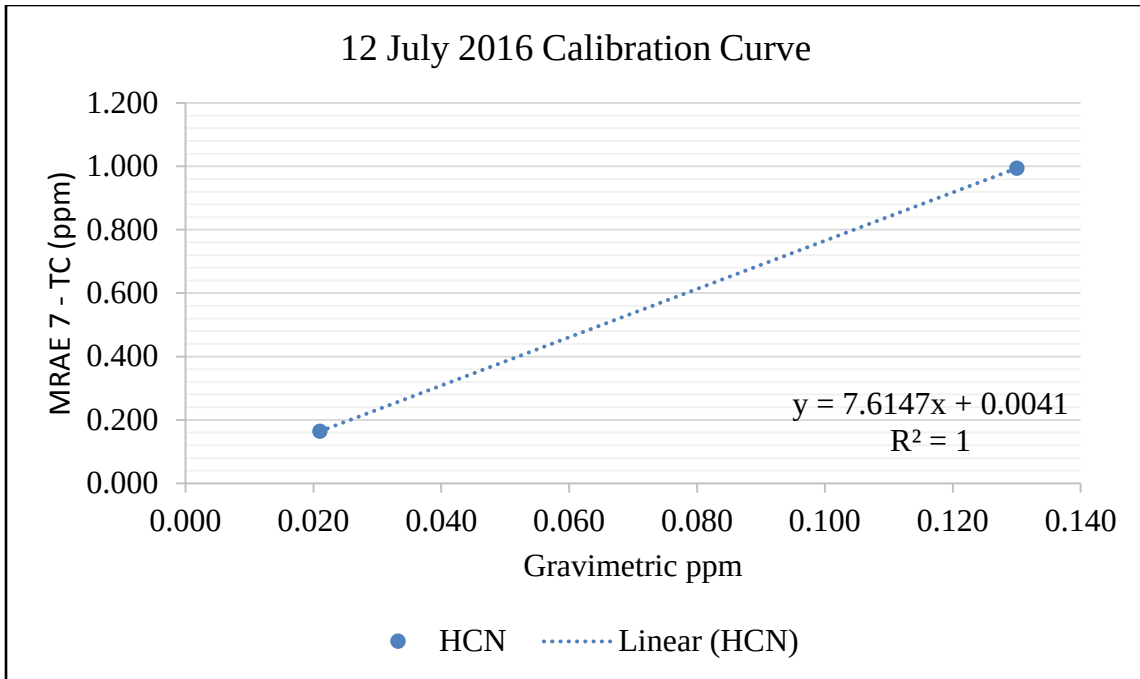


Figure 25: 12 July 2016 HCN Calibration Curve

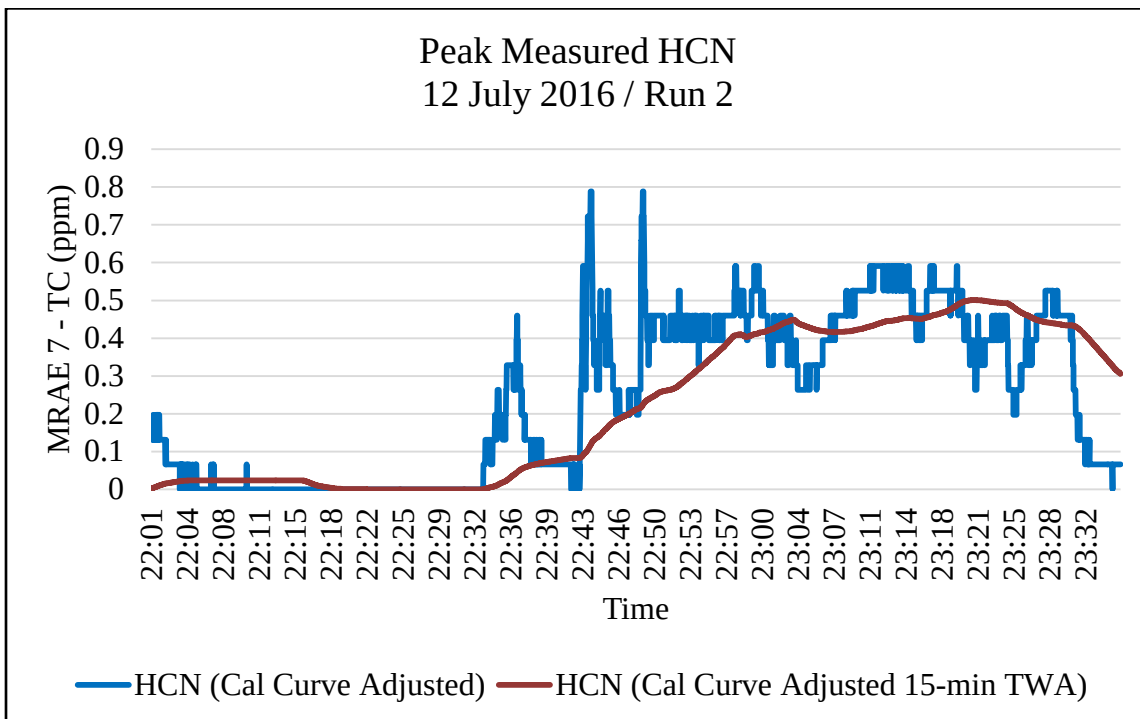


Figure 26: 12 July 2016, Run 2 - Calibration Curve Adjusted Results

This resulted in a peak measured HCN concentration of 0.79 ppm, with a peak 15-minute TWA of 0.5 ppm. Thus, both ACGIH®'s TLV-C® of 4.7 ppm, and NIOSH's 15-minute short-term REL of 4.7 ppm were most likely not exceeded. However, BV annotated a possible breakthrough on the 12 July 2016, Run 2, TC's sample as 1.5 µg of the total 5.1 µg collected was contained in the back section of the sorbent tube. This indicates the results of that sample may be unreliable. However, a comparison of the MRAE average reading to gravimetric result ratios for both runs on 12 July 2016, suggests the calibration correction factor is reasonably accurate, Table 28.

Table 28: MRAE to Gravimetric Ratios

Run	MRAE Average	Gravimetric Result	Ratio
1	0.164 ppm	0.021 ppm	7.809 : 1
2	0.994 ppm	0.130 ppm	7.646 : 1

Using the procedures outlined in Appendix A, summarized in Table 29, given two exposure routes, inhalation and absorption, an estimated peak concentration of 0.79 ppm, and an estimated peak 15-minute exposure of 0.5 ppm, crewmember HCN exposure during semi-annual gunnery is given a RAC of 4, Minor.

Table 29: HCN RAC Analysis

Area:	Points:
Exposure Condition	4
Medical Effects Points Assessed	1
Determined HHSC	III
Exposure Duration	5
Exposure Frequency	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = III, EPC = C)	4

Both the corrected and raw data collected by the author are comparable to those obtained from tests conducted by USAPHC, which ranged from less than 1.0 ppm to a maximum of 8.6 ppm. The data collected by USAPHC was obtained using real time Fourier Transform Infrared Spectroscopy (DoA, 2014a; DoA, 2014b).

Ammonia

A total of 27 gravimetric samples were collected for NH₃ analysis, 10 from the driver's station, 10 from the TC's station, 3 field blanks, 1 trip blank, 1 media blanks, and 2 environmental background. The results of all 27 are shown in Table 30.

Table 30: NH₃ Gravimetric Results

M1A1 MBT Samples			Blanks	
Event	TC's Station	Driver's Station		
D1-1	< 0.19	< 0.20	Field Blank 1	“__“
D2-1	< 0.53	< 0.60	Field Blank 2	“__“
D2-2	< 0.16	< 0.17	Field Blank 3	“__“
D3-1	< 0.10	< 0.10	Trip Blank	“__“
D3-2	0.36	0.40	Media Blank	“__“
D4-1	< 0.40	< 0.42	Environmental Background 1	< 0.23
D4-2	< 0.14	< 0.14	Environmental Background 2	< 0.24
D4-3	0.41	0.87		
D5-1	0.14	0.21		
D5-2	< 0.47	< 0.46		
All results reported in ppm				

MRAE Calibration Curves

One MRAE direct reading instrument was used to collect data on NH₃ concentrations within the turret. The MRAE was set-up in the general breathing zone of the Loader. Two calibration curves were created, Figures 27 and 28, using the gravimetric results from both the TC's and Driver's locations to account for the MRAE's NH₃

electrochemical sensor cross-sensitivity. The specific NH₃ electrochemical cross-sensitivity data is shown in Table 31 (RAE, 2013).

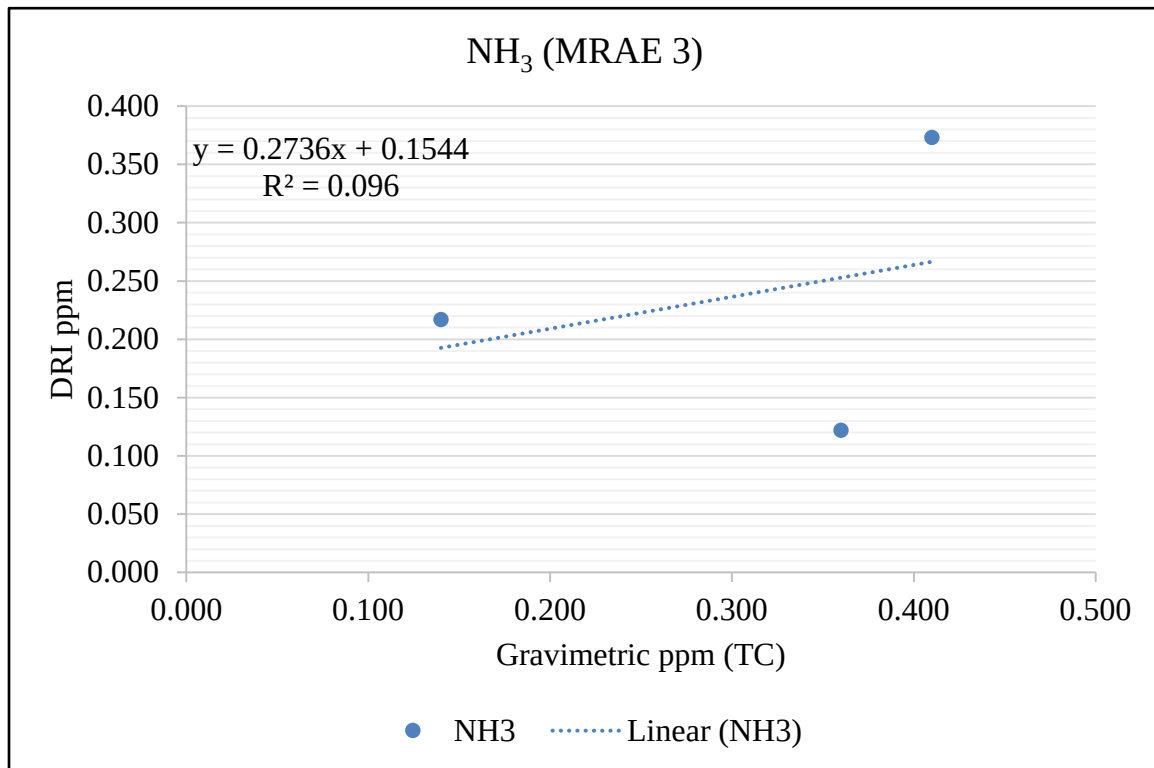


Figure 27: MRAE / TC Gravimetric NH₃ Calibration Curve

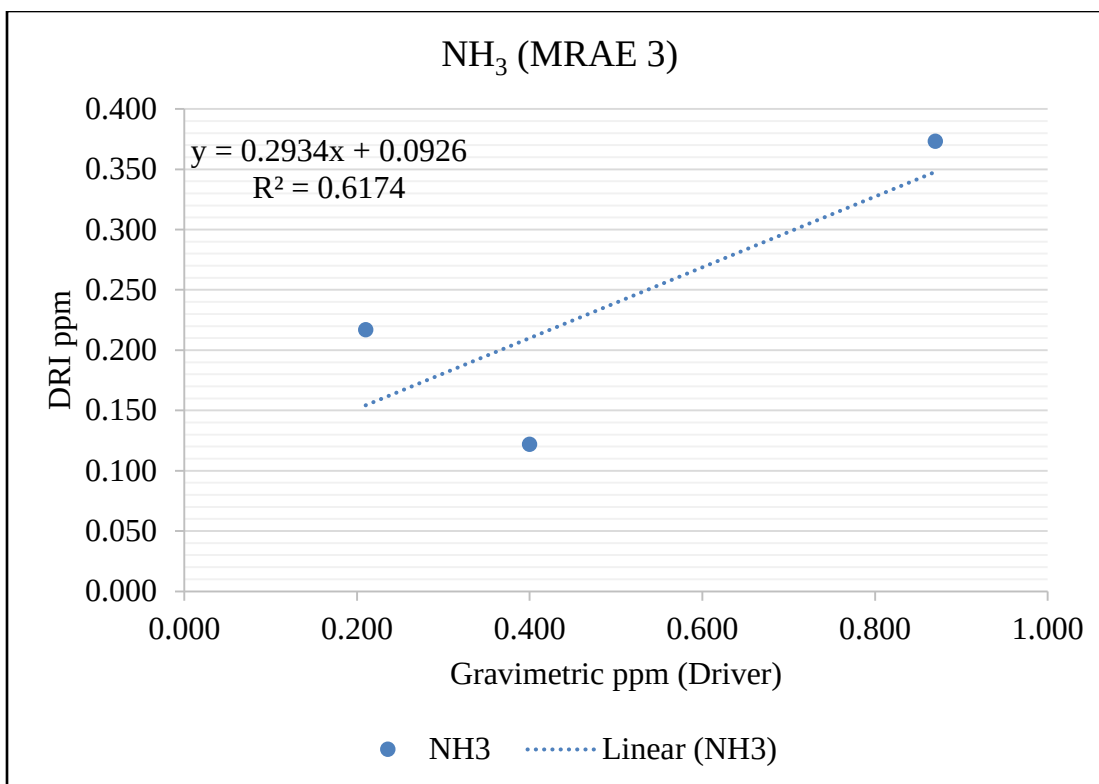


Figure 28: MRAE / Driver Gravimetric NH₃ Calibration Curve

Table 31: NH₃ Cross-Sensitivity Data

Gas	Concentration	Response
Alcohols	1,000 ppm	0 ppm
CO	100 ppm	0 ppm
CO ₂	5,000 ppm	0 ppm
H ₂	10,000 ppm	0 ppm
H ₂ S	20 ppm	~ 2 ppm ¹
Hydrocarbons	% range	0 ppm
1 – Short exposures less than a few minutes.		

Given the consistency of the MRAE to read 0.0 ppm during all non-live fire sampling runs, the calibration curve was created using only the live-fire gravimetric results above the reporting limit. This comparison is necessary to determine the feasibility of using direct reading instruments for future NH₃ occupational exposure analyses.

The resulting R^2 values for concentrations at both the TC's and driver's stations, 0.1 and 0.61 respectively, indicate the DRI is more closely correlated with concentrations in the vicinity of the driver's station. This is accounted for the MRAE's position being in closer proximity to the driver's station, than the TC's station

Environmental and Tank Background

The gravimetric results for all environmental background and M1A1 MBT non-live-fire samples below their respective reporting limits, Table 32, combined with the lack of detection by the MRAE, strongly suggest background NH_3 concentrations are negligible.

Table 32: Live-Fire Results

Date / Run	11 July / 2	12 July / 1	12 July / 2	13 July / 2	13 July / 3	14 July / 1
NH_3 (ppm) - TC	< 0.16	< 0.10	0.36	< 0.14	0.41	0.14
NH_3 (ppm) - Driver	< 0.17	< 0.10	0.40	< 0.14	0.87	0.21

As the MRAE's reading are more closely correlated with the gravimetric results collected at the driver's station, a discreet correction factor was calculated for 13 July 2016, Run 3, to evaluate the potential risk during live-fire operations. This correction factor is shown in Equation 2.

Equation 2: NH₃ 13 July 2016, Run 3, Correction Factor

$$CF = \frac{MRAE_{ppm,avg}}{Grav_{ppm}} \rightarrow \frac{0.373 ppm}{0.870 ppm} = 0.43$$

As shown in Figure 29, this estimation resulted in a peak concentration, peak 15-minute TWA, and peak 8-hour TWA of approximately 4.65 ppm, 2.36 ppm, and 0.48 ppm respectively. It is unlikely ACGIH®'s TLV-TWA® and TLV-STEL®, 25 ppm and 35 ppm respectively were exceeded during these events.

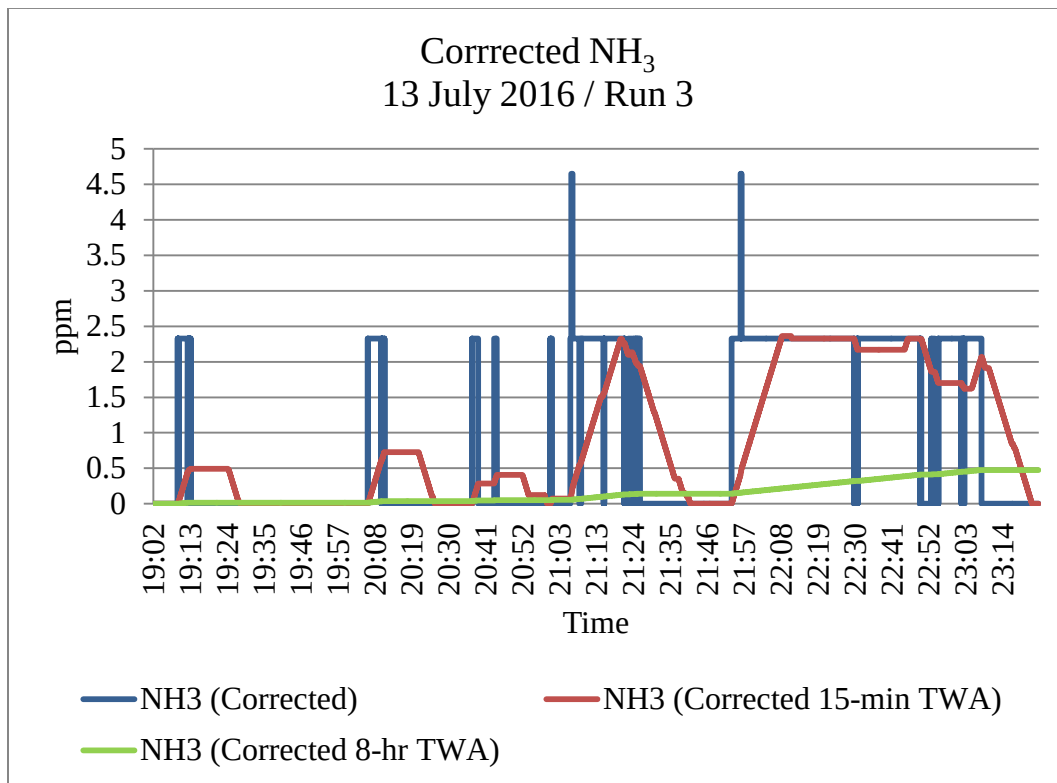


Figure 29: Corrected NH₃ Live-Fire Concentrations

Using the procedures outlined in Appendix A, summarized in Table 33, and given one exposure route, inhalation, and the above mentioned estimated peak exposures, crewmember NH₃ exposure during semi-annual gunnery is given a RAC of 5, Negligible.

Table 33: NH₃ RAC Analysis

Area:	Points:
Exposure Condition	0
Medical Effects Points Assessed	1
Determined HHSC	IV
Exposure Duration	5
Exposure Frequency	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Nitrogen Oxides

Nitric Oxide

A total of 36 gravimetric samples were collected for NO analysis, 10 from the TC's location, 10 from the Driver's location, 10 media blanks, 3 field blanks, 1 trip blank, and 2 environmental background. All 36 samples came back as either below the analytical method's reporting limit or not detected, Table 34. Thus, the ACGIH® TLV-TWA® of 25 ppm was not exceeded.

Table 34: NO Gravimetric Results

M1A1 MBT Samples			Blanks			
Event	TC's Station	Driver's Station				
D1-1	< 0.44	< 0.45	Media Blank 1	--	Field Blank 1	--
D2-1	< 1.2	< 1.4	Media Blank 2	--	Field Blank 2	--
D2-2	< 0.35	< 0.38	Media Blank 3	--	Field Blank 3	--
D3-1	< 0.23	< 0.24	Media Blank 4	--	Trip Blank	--
D3-2	< 0.37	< 0.38	Media Blank 5	--	Environmental Background 1	< 0.53
D4-1	< 0.91	< 0.95	Media Blank 6	--	Environmental Background 2	< 0.53
D4-2	< 0.33	< 0.32	Media Blank 7	--		
D4-3	< 0.25	< 0.25	Media Blank 8	--		
D5-1	< 0.24	< 0.24	Media Blank 9	--		
D5-2	< 1.1	< 1.0	Media Blank 10	--		
All results reported in ppm						

One MRAE DRI, in the general breathing zone of the TC, was used to collect data on NO concentrations within the turret. However, without definitive gravimetric results it is not possible to account for the MRAE's NO electrochemical sensor's cross-sensitivity. The specific NO electrochemical cross-sensitivity data is shown in Table 35 (RAE, 2013).

Table 35: NO Cross-Sensitivity Data

Gas	Concentration	Response
ClO ₂	1 ppm	-0.2 ppm ¹
CO	300 ppm	0 ppm
H ₂ S	15 ppm	-1.5 ppm ¹
HCl	10 ppm	~ 0.5 ppm
NH ₃	50 ppm	0 ppm
NO ₂	5 ppm	~ 1.5 ppm
SO ₂	5 ppm	0 ppm
1 – Negative cross-sensitivities may result in readings lower than the true concentration present.		

Noting that all of the gases listed in Table 35 were well below concentrations eliciting a response from the sensor, the author assumes the raw data collected by the MRAE presents a reasonable representation of NO concentrations present. The highest estimated NO concentration and TWA, 3.0 ppm and 0.05 ppm respectively, were recorded during 13 July 2016, Run 1, and are shown Figure 30.

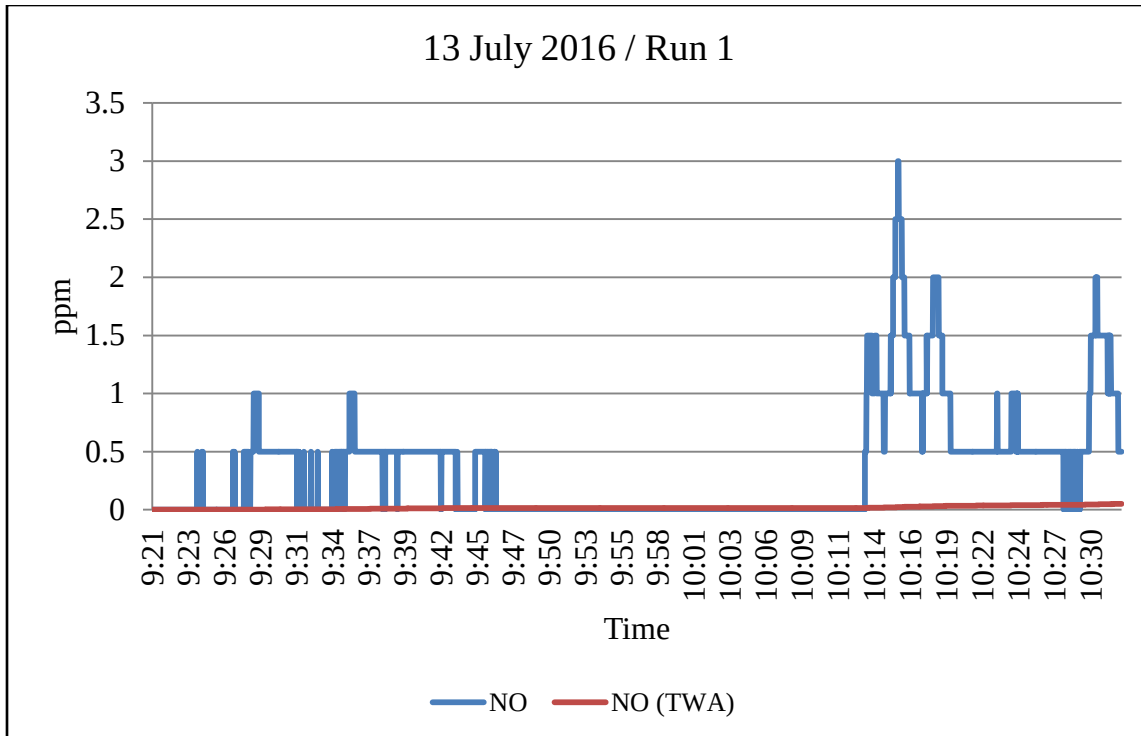


Figure 30: Peak Measured NO

As this was a non-live-fire operation due to a mechanical issue with the M1A1 MBT, these results suggest the primary source of NO within the M1A1 MBT's turret is not the weapon systems. Additionally, these results do not indicate a significant health concern to the M1A1 MBT crew members.

Using the procedures outlined in Appendix A, summarized in Table 36, given one exposure route, inhalation, and a maximum estimated TWA exposure of 0.05 ppm, crewmember NO exposure during semi-annual gunnery is given a RAC of 5, Negligible.

Table 36: NO RAC Analysis

Area:	Points:
Exposure Condition	0
Medical Effects Points Assessed	1
Determined HHSC	IV
Exposure Duration (During Gunnery)	5
Exposure Frequency (During Gunnery)	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Nitrogen Dioxide

A total of 36 gravimetric samples were collected for NO₂ analysis, 10 from the TC's location, 10 from the Driver's location, 10 media blanks, 3 field blanks, 1 trip blank, and 2 environmental background. However, as all 36 samples came back as either below the analytical method's reporting limit or not detected, see Table 37, it is not known if ACGIH®'s TLV-TWA® of 0.2 ppm was exceeded during these events.

Table 37: NO₂ Gravimetric Results

M1A1 MBT Samples			Blanks			
Event	TC's Station	Driver's Station				
D1-1	< 0.43	< 0.44	Media Blank 1	--	Field Blank 1	--
D2-1	< 1.2	< 1.3	Media Blank 2	--	Field Blank 2	--
D2-2	< 0.35	< 0.38	Media Blank 3	--	Field Blank 3	--
D3-1	< 0.23	< 0.23	Media Blank 4	--	Trip Blank	--
D3-2	< 0.36	< 0.37	Media Blank 5	--	Environmental Background 1	< 0.52
D4-1	< 0.89	< 0.93	Media Blank 6	--	Environmental Background 2	< 0.52
D4-2	< 0.32	< 0.32	Media Blank 7	--		
D4-3	< 0.24	< 0.24	Media Blank 8	--		
D5-1	< 0.23	< 0.23	Media Blank 9	--		
D5-2	< 1.0	< 1.0	Media Blank 10	--		
All results reported in ppm						

Two MRAE DRIs were used to collect data on NO₂ concentrations within the M1A1 MBT turret. However, without definitive gravimetric results it is not possible to account for the MRAE's NO₂ electrochemical sensor's cross-sensitivity. The specific NO₂ electrochemical cross-sensitivity data is shown in Table 38 (RAE, 2013).

Table 38: NO₂ Cross-Sensitivity Data

Gas	Concentration	Response
Cl ₂	1 ppm	-1 ppm ¹
CO	300 ppm	0 ppm
H ₂ S	15 ppm	-1.2 ppm ¹
NO	35 ppm	0 ppm
SO ₂	5 ppm	-5 ppm ¹
1 – Negative cross-sensitivities may result in readings lower than the true concentration present.		

Noting that all of the gases listed in Table 38 were well below concentrations eliciting a response from the sensor, the author assumes the raw data collected by the MRAE presents a reasonable representation of NO₂ concentrations present. The highest estimated NO₂ concentration and TWA, 0.5 ppm and 0.004 ppm respectively, were recorded by the MRAE at the TC's position during 13 July 2016, Run 3, and are shown in Figure 31. The MRAE in the loader's position only detected the presence of NO₂ during 14 July 2016, Run 1, for 64 seconds, at a concentration of 0.1 ppm.

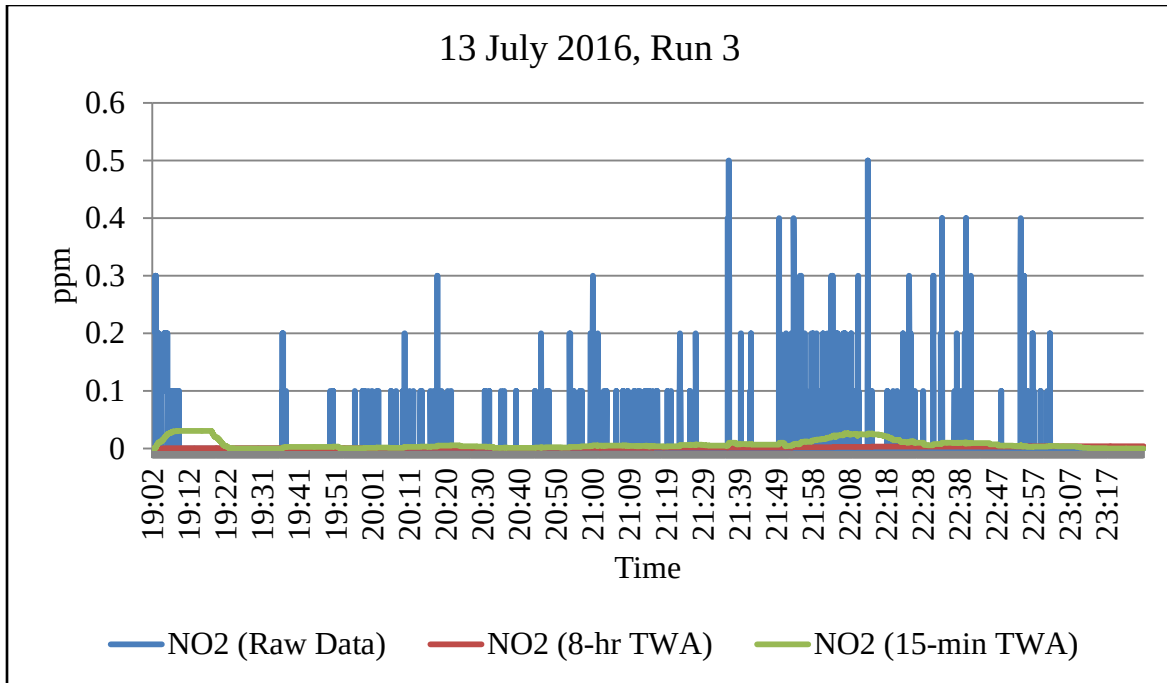


Figure 31: Peak Measured NO₂ Concentration

These results do not indicate a significant health concern to the M1A1 MBT crew members. Therefore, using the procedures outlined in Appendix A, summarized in Table 39, given inhalation as the most likely sole exposure route, and a maximum estimated TWA of 0.004 ppm, M1A1 MBT crew member NO₂ exposure during semi-annual gunnery is assigned a RAC of 5, negligible.

Table 39: NO₂ RAC Analysis

Area:	Points:
Exposure Condition	0
Medical Effects Points Assessed	1
Determined HHSC	IV
Exposure Duration	5
Exposure Frequency	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Sulfur Dioxide

A total of 27 gravimetric samples were collected for SO₂ analysis, 10 from the gunner's location, 10 from the driver's location, 1 media blank, 3 field blanks, 1 trip blank, and 2 environmental background. All 27 samples came back as either below the analytical method's reporting limit or not detected, see Table 40. Thus, NIOSH's TWA REL of 2.0 ppm was not exceeded during these events.

Table 40: SO₂ Gravimetric Results

M1A1 MBT Samples			Blanks	
Event	Gunner's Station	Driver's Station		
D1-1	< 0.0068	< 0.007	Field Blank 1	“--“
D2-1	< 0.018	< 0.022	Field Blank 2	“--“
D2-2	< 0.0055	< 0.006	Field Blank 3	“--“
D3-1	< 0.0037	< 0.0037	Trip Blank	“--“
D3-2	< 0.0057	< 0.0059	Media Blank	“--“
D4-1	< 0.043	< 0.045	Environmental Background 1	< 0.025
D4-2	< 0.015	< 0.015	Environmental Background 2	< 0.025
D4-3	< 0.012	< 0.012		
D5-1	< 0.011	< 0.011		
D5-2	< 0.05	< 0.049		
All results reported in ppm				

Two MRAE DRIs were used to collect data on SO₂ concentrations within the M1A1 MBT turret. However, without definitive gravimetric results it is not possible to account for the MRAE's SO₂ electrochemical sensor's cross-sensitivity. The specific SO₂ electrochemical cross-sensitivity data is shown in Table 41 (RAE, 2013).

Table 41: SO₂ Cross-Sensitivity Data

Gas	Concentration	Response
CO	300 ppm	< 1 ppm
NO	50 ppm	0 – 5 ppm
NO ₂	6 ppm	< 10 ppm
NH ₃	20 ppm	0 ppm
H ₂ S	25 ppm	< 0.1 ppm
H ₂	400 ppm	< 1 ppm
HCN	10 ppm	< 5 ppm
C ₂ H ₂	10 ppm	< 30 ppm
C ₂ H ₄	50 ppm	< 45 ppm
Note: This table is not exclusive and other gases present may present an undetermined cross-sensitivity response.		

Noting that all of the gases listed in Table 41 known to be present were well below concentrations eliciting a response from the sensor, the author assumes the raw data collected by the MRAE presents a reasonable representation of SO₂ concentrations present. The highest estimated SO₂ concentration and 15-minute TWA, 0.2 ppm and 0.02 ppm respectively, were recorded by the MRAE at the TC's position during 12 July 2016, Run 2, and are shown in Figure 32. The MRAE in the loader's position only detected the presence of SO₂ during 12 July 2016, Run 2, for 7 seconds, at a concentration of 0.1 ppm.

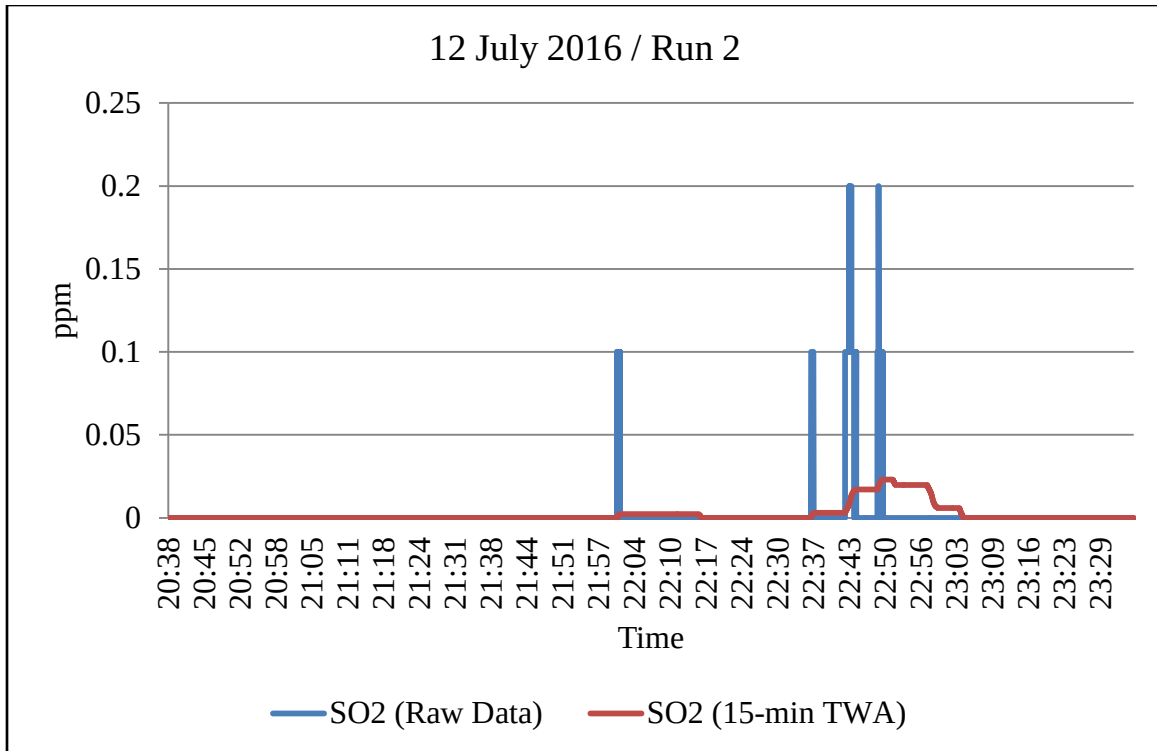


Figure 32: Peak Measured SO₂ Concentration

These results do not indicate a significant health concern to the M1A1 MBT crew members, and it is unlikely ACGIH®'s TLV-STEL® of 0.25 ppm was exceeded during these runs. Therefore, using the procedures outlined in Appendix A, summarized in Table 42, given one exposure route, inhalation, and a maximum estimated 15-minute TWA exposure of 0.02 ppm, crewmember SO₂ exposure during semi-annual gunnery is given a RAC of 5, negligible.

Table 42: SO₂ RAC Analysis

Area:	Points:
Exposure Condition	0
Medical Effects Points Assessed	1
Determined HHSC	IV
Exposure Duration	5
Exposure Frequency	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Hydrogen Sulfide

The presence of H₂S was only detected during Run 3, on 13 July for a period of 17 seconds, Figure 33, at a measured concentration between 0.6 and 0.9 ppm. Thus, ACGIH®'s TLV-TWA® and TLV-STEL® of 1.0 ppm and 5.0 ppm respectively, were not exceed during these events. Given this isolated detection and a lack of gravimetric samples, crewmember H₂S exposure during semi-annual gunnery is assigned a RAC of 5, negligible.

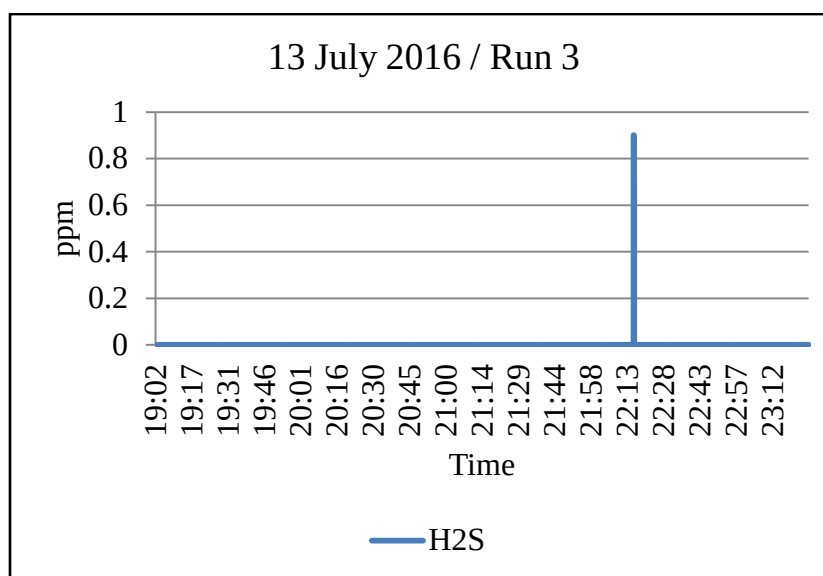


Figure 33: H₂S Concentration

Metal / Metalloid Particles

A total of 25 gravimetric samples were collected for metal / metalloid analysis, 8 total metal / metalloid samples from the central location, 5 Pb from the TC's location, 5 Pb from the driver's location, 1 media blank, 4 field blanks, 1 trip blank, and 1 environmental background. All total metal / metalloid particle samples were collected on a 0.8 μm MCE filter connected either directly to the HazDust-IV or to a GilAir Plus personal sampling pump via Tygon[®] tubing. The 8 total metal / metalloid samples, 2 field blanks, trip blank, and environmental background sample were screened for all 28 metals listed in Table 43.

Table 43: Total Metals / Metalloids Screened

Metals / Metalloids Screened			
Aluminum	Antimony	Arsenic	Barium
Beryllium	Cadmium	Calcium	Chromium
Cobalt	Copper	Iron	Lead
Lithium	Magnesium	Manganese	Molybdenum
Nickel	Phosphorus	Potassium	Selenium
Silver	Sodium	Strontium	Thallium
Tin	Titanium	Vanadium	Zinc

Of these metals / metalloids, all but Antimony, Calcium, Copper, Iron, Lead, Manganese (Mn), and Zinc were not detected above the analytical method's reporting limit.

Therefore, the author assumes the concentrations of those metals listed in Table 43, except for the seven mentioned above, are negligible and can be assigned a RAC of 5, negligible.

A contingency analysis conducted using John's Macintosh Program statistical software, developed by the SAS Institute, of element by live fire yes or no, Figure 34,

shows that during non-live-fire runs only Cu and Mn were present. Additionally it shows that Mn was only present during non-live-fire runs. The author expects the copper present during these runs is from both residual particles from the previous live fire runs and from particles present in the soil on the range itself. As only one tank was sampled during non-live-fire runs, serial number 632676, it is unknown if the Mn is uniquely isolated to this tank or not.

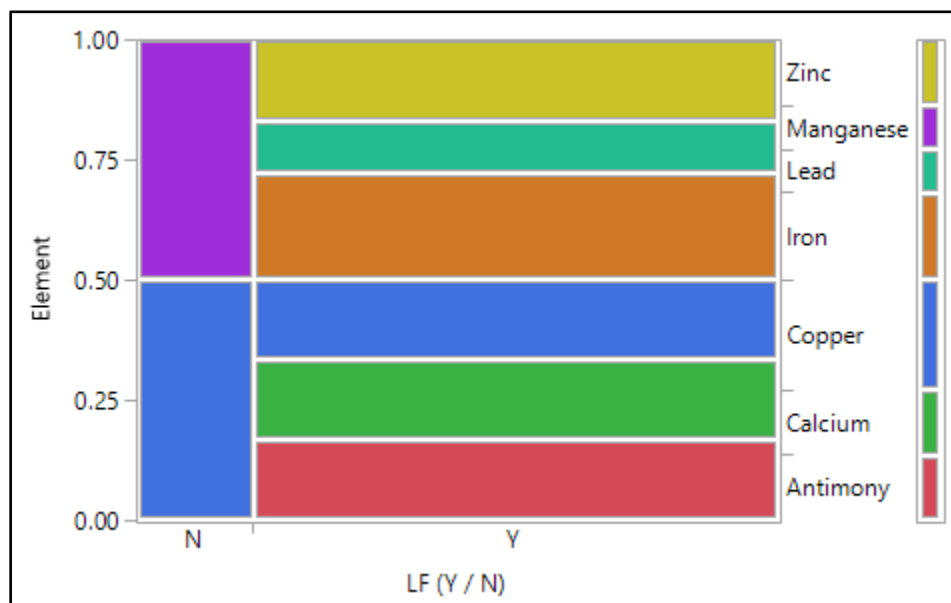


Figure 34: Contingency Analysis of Elements

extrapolated to an 8-hr TWA using Equation 3, of each elemental mean to its most restrictive respective EL, Table 44, showed that all concentrations were less than or equal to 1.7% of their EL, with the exception of Pb which presents the greatest risk at 14% of its EL.

Equation 3: 8-hr Extrapolation

$$TWA = C \left(\frac{t_{avg, sample}}{480 \text{ min}} \right)$$

Table 44: Concentration vs EL Comparison

Element	Maximum Reported Concentration	EL	% of EL
Antimony	0.0034 mg/m ³	0.5 mg/m ³	0.68 %
Calcium	0.065 mg/m ³	None	N/A
Copper	0.017 mg/m ³	1.0 mg/m ³	1.7 %
Iron	0.0051 mg/m ³	5.0 mg/m ³	0.1 %
Lead	0.007 mg/m ³	0.05 mg/m ³	14 %
Manganese	0.014 mg/m ³	1.0 mg/m ³ *	1.4 %
Zinc	0.0058 mg/m ³	5.0 mg/m ³	0.12 %
* - As the form of Manganese present was indeterminable, the OEL for Manganese compounds and fumes (as Mn) was used.			

Given the amount of Pb contained in the different types of ammunitions' components, additional samples were taken for Pb analysis at both the TC's and diver's stations, their results are shown in Table 45.

Table 45: Additional Pb Sample Results

Date / Run	13 July / 1	13 July / 2	13 July / 3	14 July / 1	14 July / 2
Pb (mg/m ³) - TC	< 0.0070	< 0.0025	0.0042	0.0031	< 0.0079
Pb (mg/m ³) - Driver	< 0.0072	< 0.0025	0.0025	< 0.0018	< 0.0079

The results of the additional samples did not report any concentrations higher than the 0.007 mg/m³ listed in Table 44.

Using the procedures outlined in Appendix A, summarized in Tables 46 and 47, given one exposure route, inhalation, and maximum TWA exposures less than or equal to 1.7%

and 14% of their EL, metals / metalloids other than Pb, and Pb respectively, crewmember total metals / metalloids and Pb exposure during semi-annual gunnery are respectively assigned a RAC of 5, negligible; and 4, minor.

Table 46: Total Metals / Metalloids (Pb Excluded) RAC Analysis

Area:	Points:
Exposure Condition	0
Medical Effects Points Assessed	1
Determined HHSC	IV
Exposure Duration (During Gunnery)	5
Exposure Frequency (During Gunnery)	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = IV, EPC = C)	5

Table 47: Pb RAC Analysis

Area:	Points:
Exposure Condition	3
Medical Effects Points Assessed	2
Determined HHSC	III
Exposure Duration (During Gunnery)	5
Exposure Frequency (During Gunnery)	3
Number of Exposed Personnel (4)	1
Determined EPC	C
Determined RAC (HHSC = III, EPC = C)	4

Particulate Matter

Microscopy / Spectroscopy

Microscopy and spectroscopy, using both a SEM equipped with an EDAX[®]-EDS, and an environmental SEM, was conducted of particles collected in the loader's general breathing zone. These particles were collected using 25 mm, 0.8 μm polycarbonate (PC) filters preloaded in black conductive cassettes connected to a GilAir Plus personal sampling pump via Tygon[®] tubing. The purpose of this analysis was to try and characterize the morphology and chemical composition of particles present in the M1A1 MBT's turret. Figures 35 – 40, present a sample of the various morphologies seen.

Of particular interest were the sub-micron spherical particles, Figures 39 and 40. These suggested the heterogeneous nucleation of vapors into solid particles, whereas gaseous molecules form larger particles as they transition from the gas phase, to the liquid phase, and finally into the solid phase by condensing onto pre-existing condensation nuclei particles. Two SEM samples were prepared from the PC filter collected from July 12, 2016, Run 2. One sample was analyzed using the SEM equipped with EDAX[®]-EDS and the second was analyzed using the environmental SEM. On both samples, the author found particles of similar size and shape for comparison, Figure 41.

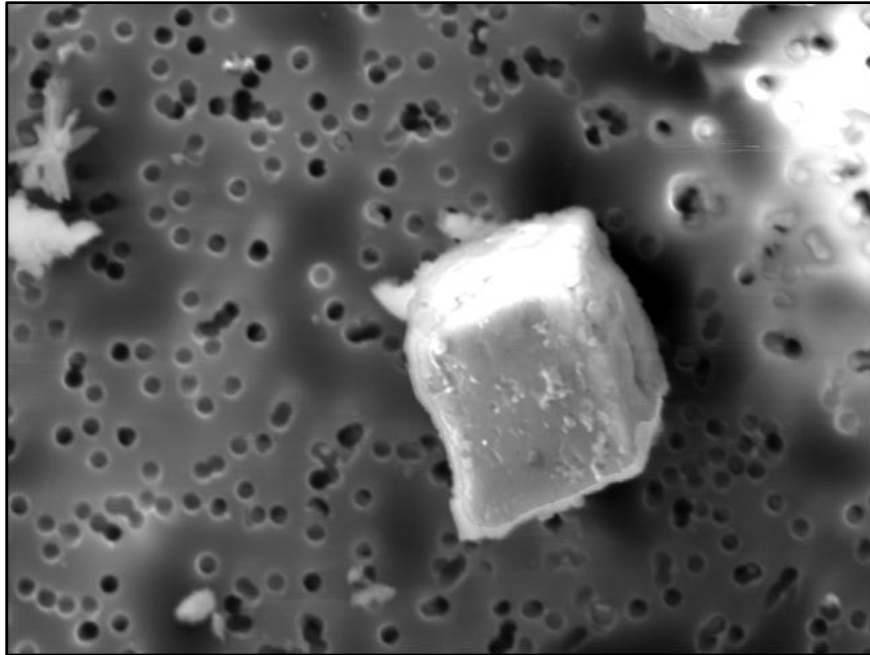


Figure 35: Cubical Morphology

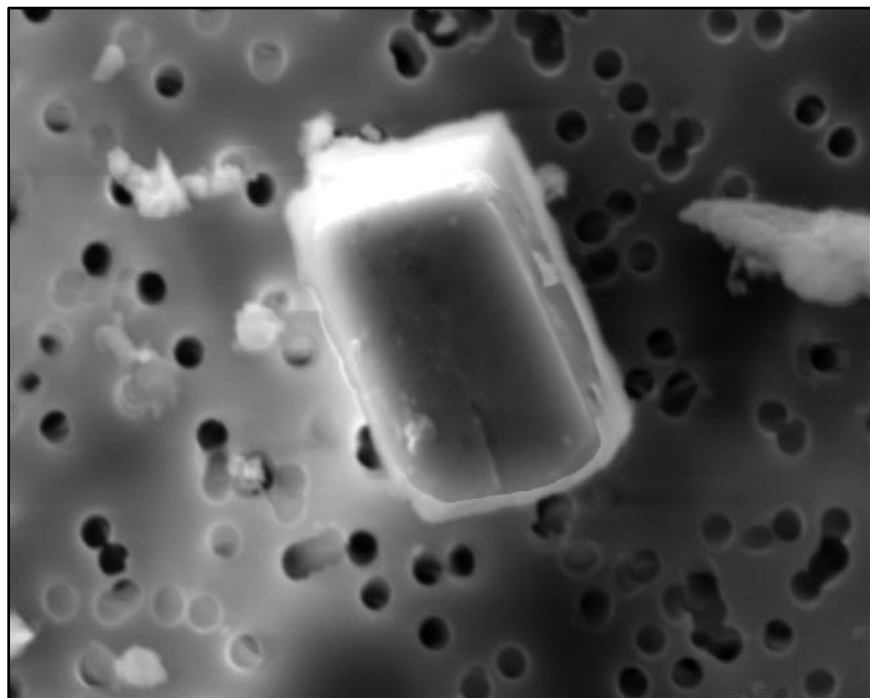


Figure 36: Rectangular Morphology

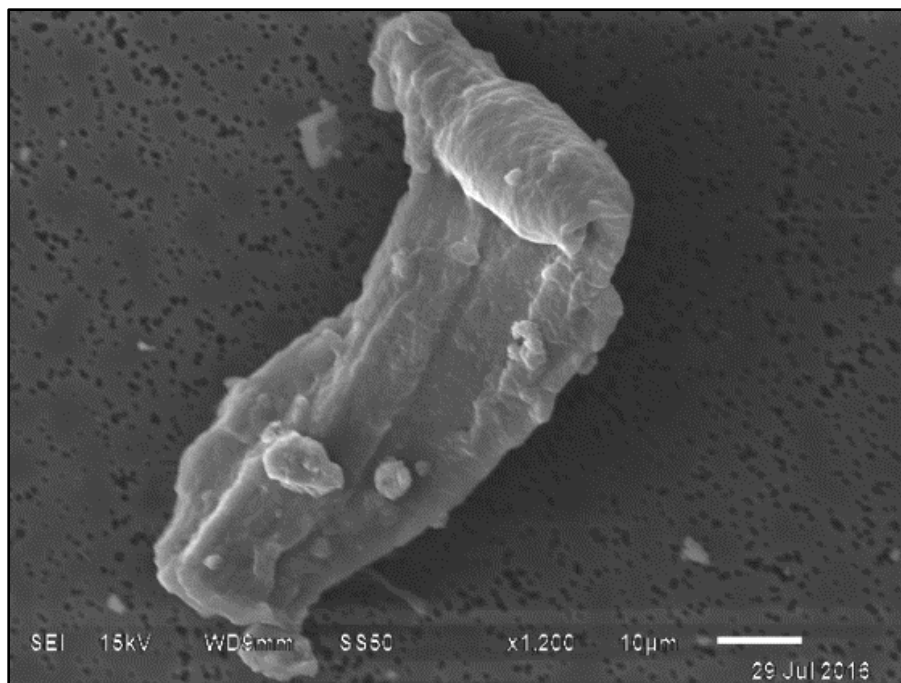


Figure 37: Irregular Morphology

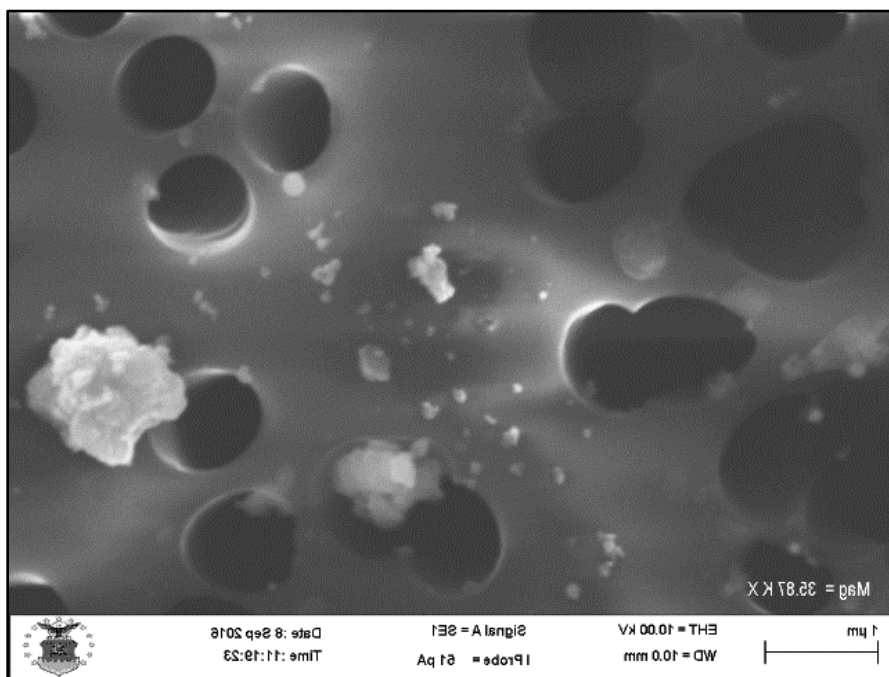


Figure 38: Agglomerate Morphology

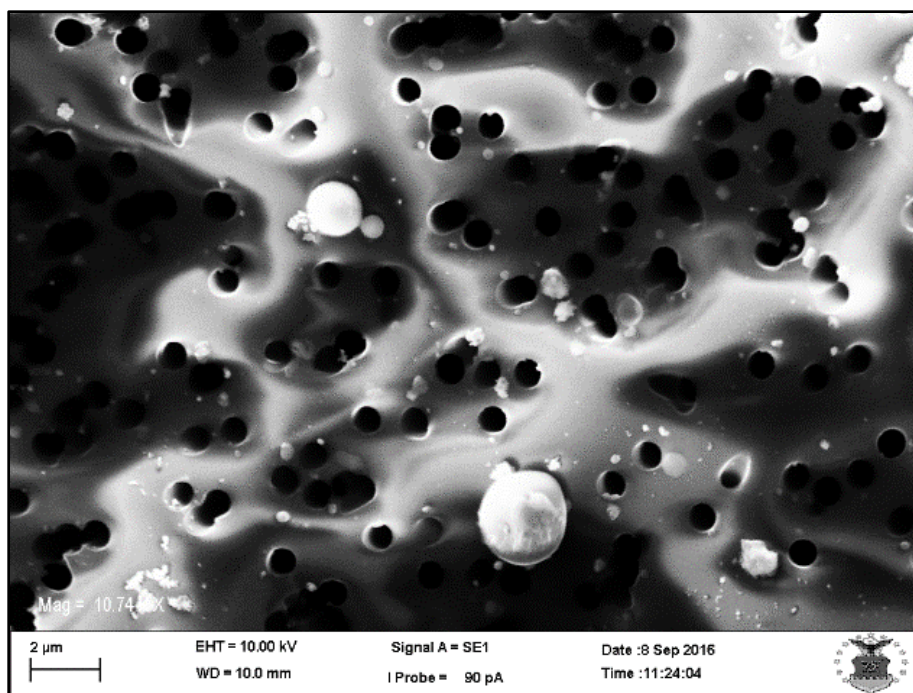


Figure 39: Spherical Morphology (Environmental SEM)

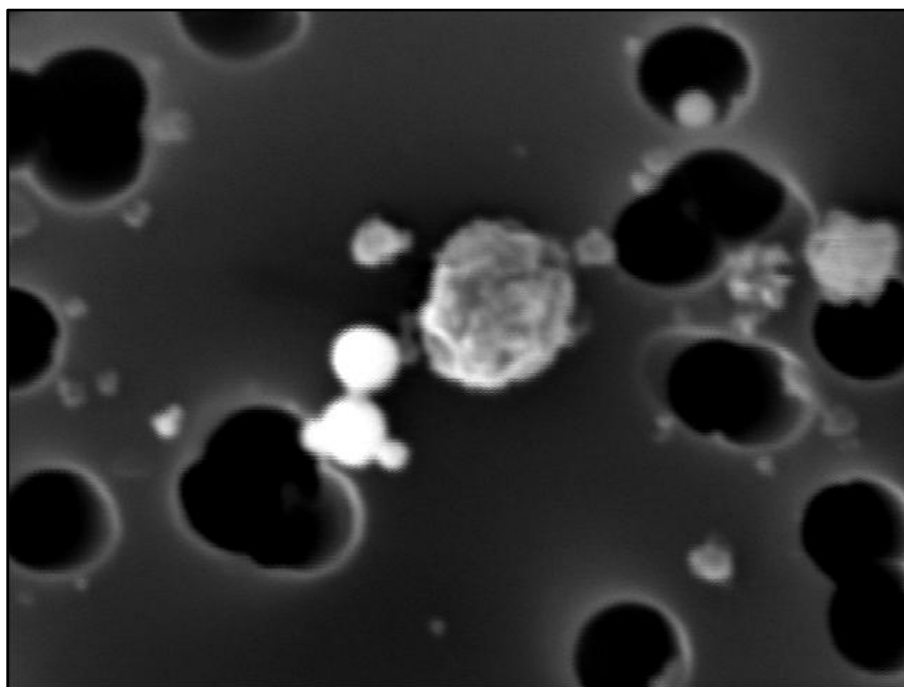


Figure 40: Spherical Morphology (SEM with EDAX[®]-EDS)

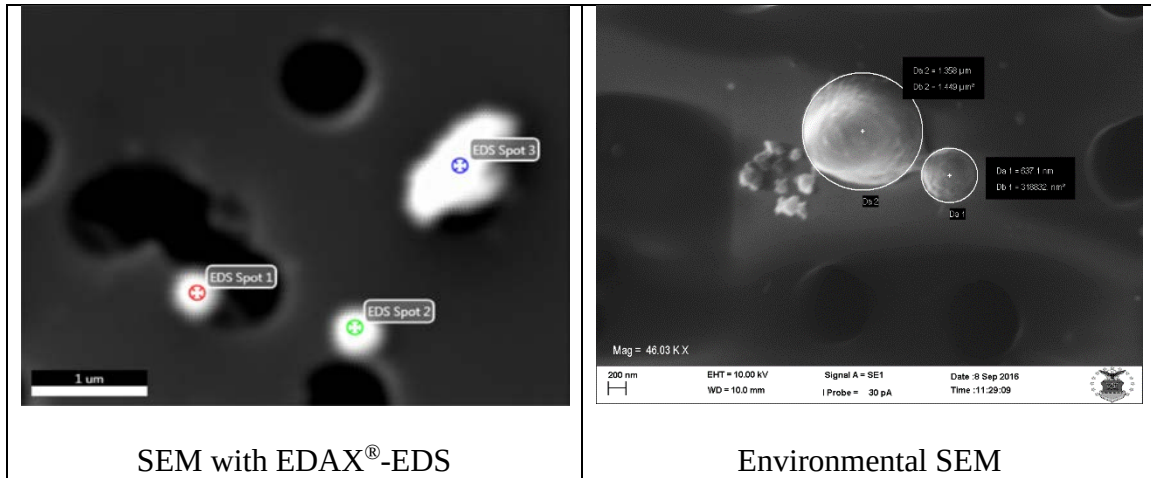


Figure 41: SEM Comparison Particles

The SEM EDAX[®]-EDS revealed a chemical analysis of both particles containing Pb, Sb, and Cu, Figure 42. All three elements are primarily found in the projectile compositions for both the M80 and M62, 7.62 mm rounds (E. Vainchenker, personal communication, September 27, 2016).

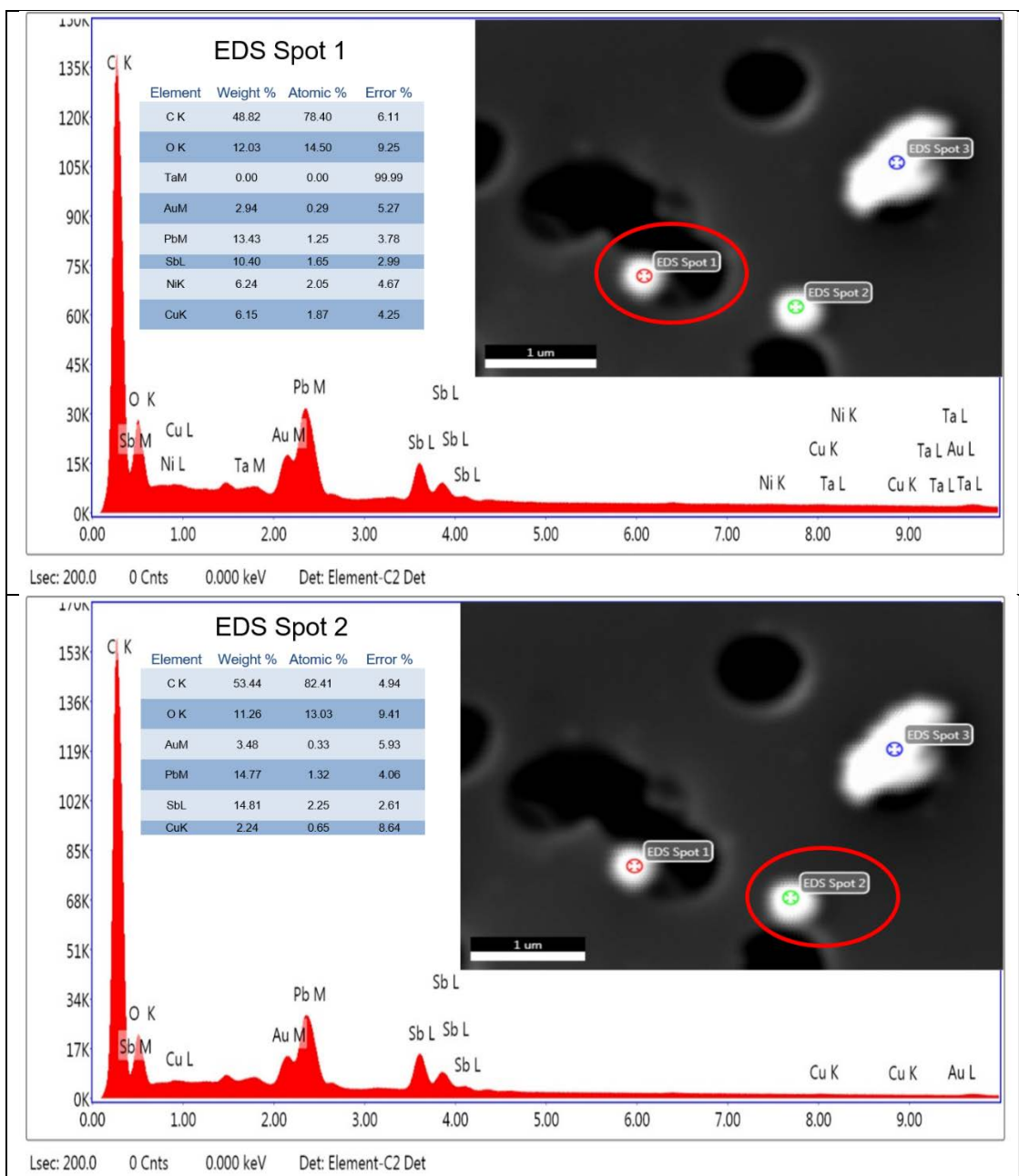


Figure 42: SEM with EDAX®-EDS Particle Analysis

Barium was also identified by the EDAX[®]-EDS, Figure 43.

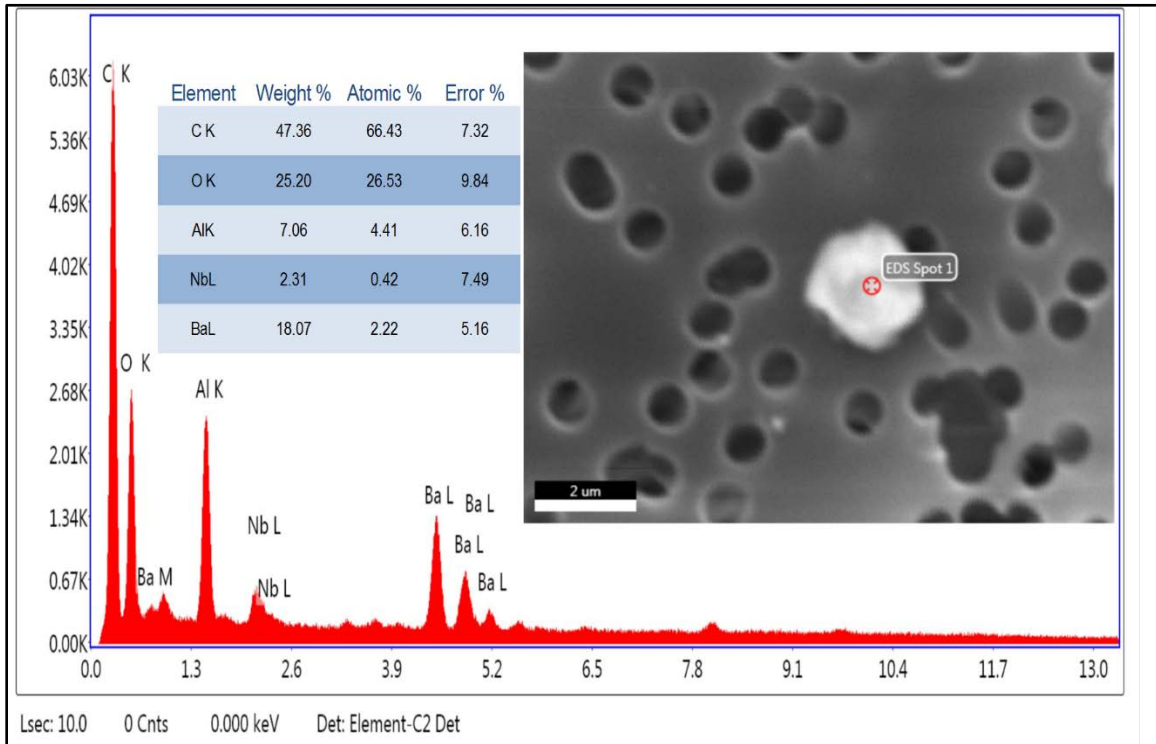


Figure 43: Barium Containing Particle

The deformation of the particle at the point of impact seen under the organic SEM indicates the particle was still malleable and was most likely transitioning from the liquid to solid phase, Figure 44. All three particles are estimated to be in the 0.4 to 0.6 μm range prior to impactation. The SEM-EDS also detected the presence of Aluminum, Barium, Magnesium, Molybdenum, Nickel, Phosphorus, Potassium, Sodium, Strontium, and Titanium; all of which were below their gravimetric analysis reporting limits. This indicates M1A1 MBT crew-members may be exposed to these metals / metalloids as well, but at levels well below their OELs.

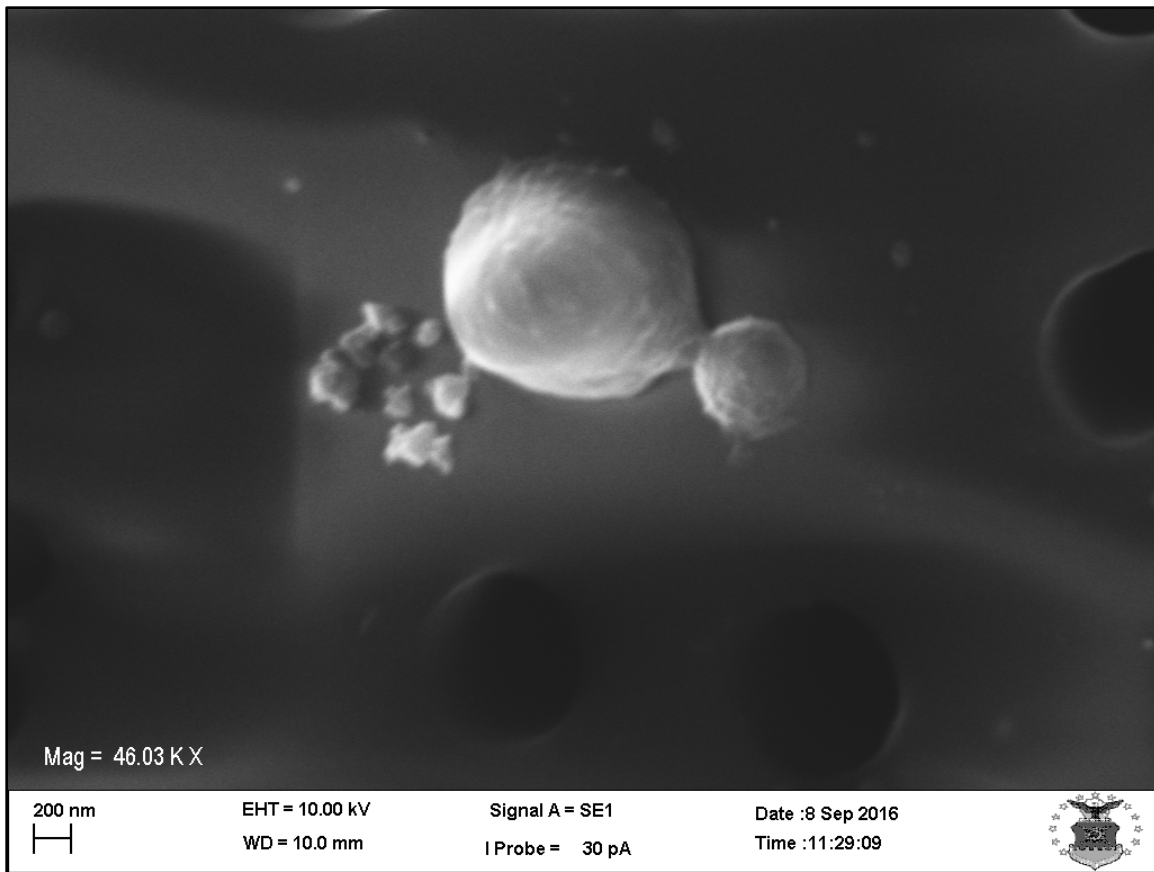


Figure 44: Particle Deformation at Point of Impaction

Concentration and Size Distribution

Overall particle concentration measurements were taken using the DustTrak DRX and HazDust-IV. Given the inconsistent results and configuration change of the HazDust-IV, its results have been omitted from this analysis. 13 July 2016, Run 2, represents the peak respirable particle (PM₄), diameter less than or equal to 4.0 μm , concentrations present during a live fire run, and are summarized in Figures 45 and 46.

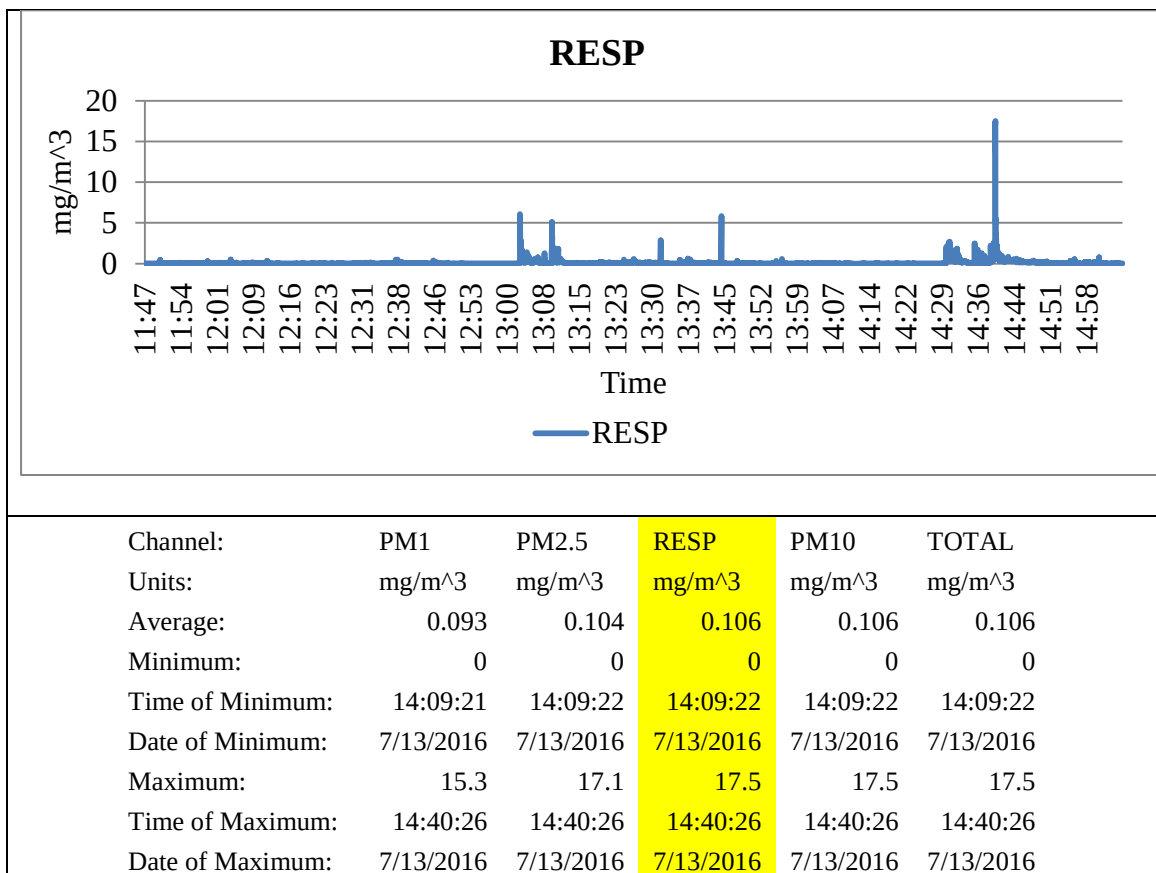


Figure 45: Peak Respirable Particle Measurement

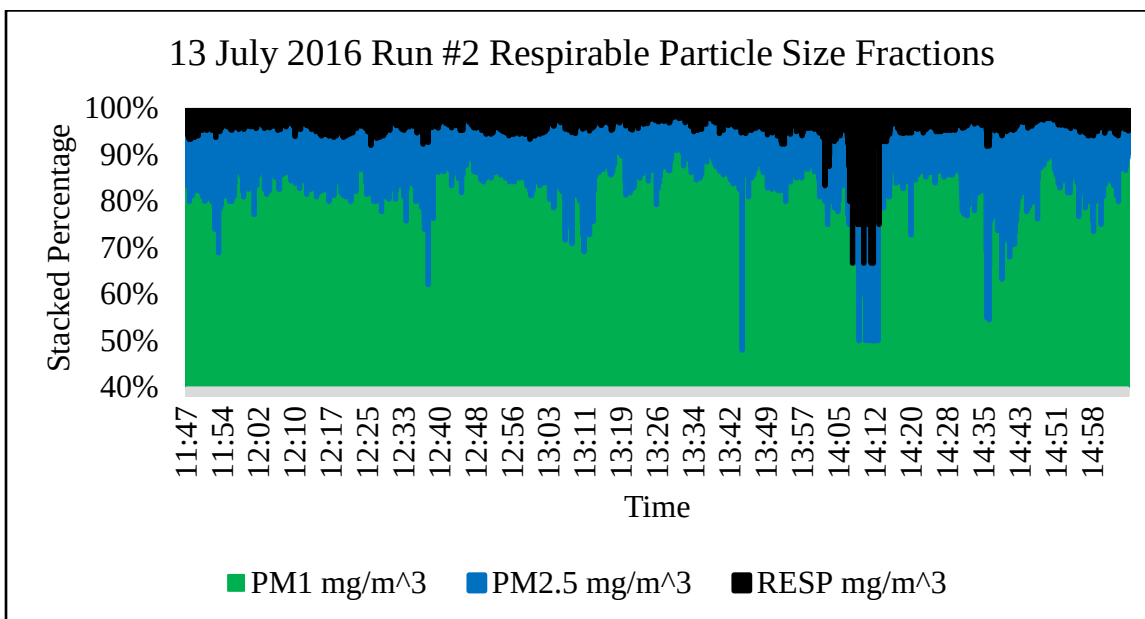


Figure 46: PM₄ Size Distribution Cumulative Percentages

The spikes in concentration coincide with the firing of the 120 mm main gun at times: 13:03, 13:04, 13:10, 14:30, 14:32, and 14:40 (two rounds fired in rapid succession); as well as with the crew change and ammunition reload conducted from 13:20 to 13:45. As shown in Figure 46, greater than 60% of PM₄ is PM₁. However, without a full characterization of these particles it is not possible to ascertain the true nature of the risk presented. Without knowing how these particles will behave aerodynamically, the author is unable to determine where these particles are likely to deposit within the respiratory system.

When compared to the ACGIH[®] recommended TLV for respirable particles not otherwise specified, 3.0 mg/m³, the average exposure concentration, 0.106 mg/m³, is well below the TLV. However, this TLV is momentarily exceeded immediately following firing of the 120 mm main gun. Accordingly, using the procedures outlined in Appendix A, summarized in Table 48, given one exposure route, inhalation, and maximum TWA exposures 0.106 mg/m³, crewmember PM₄ exposure during semi-annual gunnery is assigned a RAC of 3, moderate.

Table 48: PM₄ RAC Analysis

Area:	Points:
Exposure Condition	3
Medical Effects Points Assessed	2
Determined HHSC	III
Exposure Duration	5
Exposure Frequency	3
Number of Exposed Personnel (4)	2
Determined EPC	B
Determined RAC (HHSC = III, EPC = B)	3

V. Conclusions and Recommendations

Summary of Analytical Results

As anticipated, and summarized in Table 49, all exposures were below their respective ELs, and all but one present either a minor or negligible risk to M1A1 MBT crew members during semi-annual gunnery qualifications. Many of the analytes sampled were below their respective analytical method's reporting limits, but their presence was indicated through either DRIs (gases) or SEM EDAX[®]-EDS (metals / metalloids) analysis. It was noted that CO levels did momentarily exceed the NIOSH REL ceiling of 200 ppm during two collection events, 12 July 2016, Run 2, and 14 July 2016, Run 1. In both instances CO levels returned to acceptable levels within approximately one minute. Based on the total data collected, PM₄, HCN, and Pb present the greatest health risks to M1A1 MBT crew members.

Table 49: Hazard Summary

Chemical	Overall Risk
PM ₄	Moderate
HCN	Minor
Pb	Minor
Cl ₂	Negligible
CO	Negligible
CO ₂	Negligible
HCl	Negligible
H ₂ S	Negligible
NH ₃	Negligible
NO	Negligible
NO ₂	Negligible
SO ₂	Negligible
Metals / Metalloids other than Pb	Negligible

Many of the run TWAs reported by BVNA under represent the true exposure levels present during the live-fire portions of training due to each sampling event involving a non-live-fire dry-run immediately proceeded by the live-fire event. Running these events back-to-back significantly increased the total air volume sampled. While this increased volume allowed for greater collection, a significant portion of the air sampled most likely did not contain combustion by-products — diluting the overall concentration. The condensed time line the supporting unit had to complete all of its training requirements, due to numerous mechanical issues and low M1A1 MBT availability, precluded the author's ability to either replace sample media between events, or start the sampling equipment upon completion of the non-live-fire dry-run. The low tank availability also negated the author's ability to collect samples from a large percentage of the tanks present.

While the presence of direct reading instruments greatly enhanced the author's ability to analyze exposures over time, the cross-sensitivity of electrochemical sensors precludes their feasibility for use as a stand-alone instrument for future occupational exposure assessments at this time. However, when paired with co-located gravimetric sampling techniques, a more accurate representation of what is happening inside the tank is obtained.

Significance of Research

The analytical results of this research project were commensurate with results of previous HHARs (DoA, 2014a; DoA, 2014b; DoA, 2006; DoA, 2004). For those analytes presenting a negligible risk, the author concurs with USAPHC in that future

monitoring may not be required for routine exposures such as semi-annual gunnery. The author does however recommend these analytes receive additional monitoring during non-routine exposures such as combined arms breaching operations, where M1A1 MBT configurations may allow for increased concentrations through reduced ventilation rates.

A new health risk this research projected addressed, which was not addressed in previous HHARs, was PM. With delayed manifestation of adverse health effects related to combustion by-products becoming a serious topic again — exposure to open burn pits (VA, 2017) — it is paramount this risk be addressed. Given the multitude of potential adverse health risks of inhalation hazards, the author concludes PM presents a moderate health risk potential, both acute and chronic, to M1A1 MBT crew members and should be further evaluated for mitigation.

Recommendations for Action

In accordance with DoDI 6055.01, Appendix to Enclosure 4, Paragraph a., the author identifies M1A1 MBT live fire operations as an operation which generates a lead containing aerosol (DoDI, 2014). Accordingly, the author makes the recommendation that M1A1 MBT crew members' blood lead levels be monitored pre- and post-live fire to both document any service related lead exposure and obtain medical determination of possible enrollment in a blood lead level monitoring program. Additionally, the collected blood lead level data will facilitate evaluation of the risk presented by the inhalation of aerosolized sub-micron lead containing particles over time.

Medical monitoring could also be extended to include a full blood metal screening to evaluate potential bioaccumulation of other metals (i.e. Cu, Ba, Cr, etc). While not

detected gravimetrically, metals such as Al, Ba, and Ni were identified as possible particle constituents by the EDAX[®]-EDS. This identification allows for the possibility other metals may be present as well, and may possess potential long-term health risks.

Three identified analytes, CO, NO, and Pb, possess properties which may require biological monitoring as well. Future CO monitoring should include COH_b measurements taken either by blood or breathalyzer. Biological monitoring for both NO and Pb require blood sampling. Although NO presents a negligible risk to crew members, it is a methemoglobin inducer. This biological aspect of NO should be evaluated to determine the true risk potential.

Recommendations for Future Research

Further sampling of all gases / particles assigned a RAC of 4 or higher should be conducted to better define the risk they present over time. In regards to HCN, the author recommends the use of a second sorbent tube inline behind the initial sorbent tube. This will help minimize uncertainty in the event the primary sorbent tube experiences breakthrough. While this will theoretically double sorbent tube expense, it will have a minimal impact on overall analytical costs. This is because the second sorbent tube only requires analysis in the event the primary sorbent tube experiences breakthrough. For NO₂ the author recommends to only sample live fire evolutions, not sample for NO simultaneously, and increase the flow rate from 0.025 L/min to a rate which will result in a sample size as close to the NIOSH 6014 maximum of 6.0 L. Doing this should minimize the number of sample results below the LOD, or substantiate NO₂ being assigned as a negligible risk.

For future occupational exposure analyses, the author recommends the inclusion of bloodwork. This will provide useable / actionable COHb data, for evaluation of CO exposure, and provide documentation on service related lead exposure. Additionally, when collecting particle samples for microscopy analysis, the author recommends the addition of a collection device capable of collecting particles directly on a transmission electron microscope (TEM) grid. This will significantly both reduce the required sample preparation time and increase the quality of the sample's image through the use of a TEM.

Based on the inability to accurately account for electrochemical sensor cross-sensitivity, the author recommends future controlled experiments to determine feasibility and usefulness of conducting occupational exposure assessments solely with direct reading instruments. The ability to accurately conduct these assessments without the need for laboratory analysis would greatly reduce both time and cost. Additionally, direct reading instruments allow for researchers to visually depict concentrations over time, vice relying solely on overall averages. This is increasingly important in evaluating short-term exposures and ceilings.

The author also recommends an aerosol characterization study be carried out for ammunition generated aerosols within enclosed firing spaces. This will provide more clarification on the aerosolized particles, specifically particle composition and size distribution. This is applicable to a wide variety of organizations and equipment.

Finally, the author recommends the evaluation of a personal filtration device for M1A1 MBT crew-members. The addition of a personal filtration device which could be attached to the existing Combat Vehicle Crewman's helmet could greatly reduce the

inhalation of aerosolized particles. The author recommends forced air perpendicular to the crew members' general breathing zones or personal electrostatic filtration devices/masks as possible solutions.

Appendix A

(DoDI 6055.01, October 14, 2014, pp. 28 – 31)

DETERMINING RACs

1. DETERMINING RACs FOR SAFETY AND FIRE HAZARDS. Use the matrix in Table 1 to determine the Risk Assessment Codes (RACs) for safety and fire hazards.

Table 1. RAC Matrix

Hazard Severity		Mishap Probability			
Description	Code	A Likely to occur immediately	B Probably will occur in time	C Possible to occur in time	D Unlikely to occur
Death, permanent total disability, or loss of facility or asset	I	1 Critical	1 Critical	2 Serious	4 Minor
Permanent partial disability or major property damage	II	1 Critical	2 Serious	3 Moderate	4 Minor
Lost workday injury or compensable injury, or minor property damage	III	2 Serious	3 Moderate	4 Minor	5 Negligible
Injury involving first aid or minor supportive medical treatment, a minimal threat to personnel or property, or a violation of a standard	IV	4 Minor	4 Minor	5 Negligible	5 Negligible

2. DETERMINING RACs FOR CHRONIC HAZARDS. Use the Table 1 matrix and descriptions in Tables 2 through 8 to determine the RAC for chronic hazards.

a. Determining the Health Hazard Severity Category (HHSC). The HHSC reflects the magnitude of exposure to a single physical, chemical, or biological agent and the effects of chronic exposure.

- (1) Use the procedures in Tables 2 and 3 to assess exposure points.
- (2) Total the exposure points assessed in Tables 2 and 3.
- (3) Use Table 4 to determine the HHSC based on the total points assessed.

Table 2. Exposure Points Assessed

Alternate Exposure Route?	Exposure Condition			
	95 th percentile < 0.1 occupational exposure limit (OEL)	95 th percentile between 0.1 OEL and 0.5 OEL	95 th percentile between 0.5 OEL and OEL	95 th percentile > OEL
No	0	3	5	7
Yes	1 - 2	4	6	9

Table 3. Medical Effects Points Assessed

Condition	Points
No medical effect, such as nuisance noise and nuisance odor	0
Temporary reversible illness requiring supportive treatment, such as eye irritation	1 - 2
Temporary reversible illness with a variable but limited period of disability, such as metal fume fever	3 - 4
Permanent, non-severe illness or loss of capacity, such as permanent hearing loss	5 - 6
Permanent, severe, disabling, irreversible illness, such as asbestosis, lung cancer, or death	7 - 8

Table 4. Determining the HHSC

Total Points (sum of exposure and medical effects points)	HHSC
13 – 17	I
9 – 12	II
5 – 8	III
0 – 4	IV

2. Determining the Effect Probability Category (EPC). The EPC is a function of the duration and frequency of exposure and the number of exposed personnel.

- a. Use the guides in Tables 5 and 6 to assess the frequency and duration of exposure points assessed.
- b. Sum the points in Table 5 for exposure duration and exposure frequency, divide by 2, then round up. Add those points with the exposed personnel points assessed in Table 6.
- c. Use Table 7 to determine the EPC for chronic hazards based on the points totaled from Tables 5 and 6.

Table 5. Duration and Frequency of Exposure Points Assessed

Point s	Exposure Duration							
	> 8 hours/day	6 – 8 hours/day	4 – 6 hours/day	2 – 4 hours/day	1 – 2 hours/day	30 – 60 minutes/ day	15 – 30 minutes / day	0 – 15 minutes / day
	8	8	6	5	4	3	2	1
Point s	Exposure Frequency							
	Daily	2 – 3 times/ week	Weekly	2 – 3 times/ month	Monthly	Quarterly or 2 – 3 times/year	Annual	Less Than Annual
	8	7	6	5	4	3	2	1

Table 6. Number of Exposed Personnel Points Assessed

Number of Exposed Workers	Points
< 5	1 – 2
5 – 9	3 – 4
10 – 49	5 – 6
> 49	7 – 8

Table 7. Determining the EPC

Total Points from Tables 5 and 6	EPC
14 – 16	A
10 – 13	B
5 – 9	C
< 5	D

c. **Determining the RAC for Health Hazards.** Determine the RAC for chronic hazards by using the matrix in Table 8 to account for HHSC and EPC.

Table 8. Determining the RAC for Health Hazards

HHSC	EPC			
	A	B	C	D
I	1	1	2	3
II	1	2	3	4
III	2	3	4	5
IV	3	4	5	5

3. COMPUTING THE ESTIMATED COST EFFECTIVENESS INDEX (CEI). To compute the CEI:

- a. Find the severity and probability multiplier using Table 9.

Table 9. Severity and Probability Multiplier

Severity	Probability			
	A	B	C	D
I	188	63	21	7
II	63	21	7	2
III	21	7	2	1
IV	7	2	1	0.26

- b. Record the average or equivalent number of persons exposed daily to the hazard during the course of the year.
- c. Compute the Effectiveness Index using the formula (Severity and Probability Multiplier) x (Number of Persons) = Effectiveness Index.
- d. Obtain the estimated cost of the abatement project.
- e. Compute the CEI using the formula (Abatement Cost)/(Effectiveness Index) = CEI.

4. PRIORITIZING FOR MITIGATION

- a. Prioritize hazard mitigation first by RAC.
- b. Prioritize hazard mitigation within a RAC by CEI.

Appendix B

Ammunition Data:

Nomenclature	Lot Number	Year Manufactured	Propellant
M865	ORI14J718M002	2014	M14
M1028	ORI08G955-001	2008	JA-2
A131	LC-13L333L013	2013	WC846
A576	LC-11K686L077	2011	WC860
	LC-13K377L005	2013	

Appendix C

Sample Equipment:

MultiRAE Pro (3):

Vendor: RAE Systems

Item Number: PGM-6248

Unit Serial Number: MCB3Z020P3

Unit Firmware Version: V 1.02A

Running Mode: Hygiene

Datalog Mode: Auto

Diagnostic Mode: No

Datalog Interval: 1 second

Sensor Information:

Sensor	Serial Number	Pre-Calibration	Post-Calibration	Calibration By
SO ₂	SC03AF0024P6	8 July 2016	18 July 2016	USAFSAM
NH ₃	SC03500075RA	8 July 2016	18 July 2016	USAFSAM
NO ₂	SC03750011P4	8 July 2016	18 July 2016	USAFSAM
HCN	SC03490028P4	8 July 2016	18 July 2016	USAFSAM
CO ₂	SC03610077NA	8 July 2016	18 July 2016	USAFSAM

MultiRAE Pro (7):

Vendor: RAE Systems

Item Number: PGM-6248

Unit Serial Number: MCB3Z019P3

Unit Firmware Version: V 1.02A

Running Mode: Hygiene

Datalog Mode: Auto

Diagnostic Mode: No

Datalog Interval: 1 second

Sensor Information:

Sensor	Serial Number	Pre-Calibration	Post-Calibration	Calibration By
NO ₂	SC03750008P2	8 July 2016	18 July 2016	USAFSAM
NO	SC03740008QC	8 July 2016	18 July 2016	USAFSAM
H ₂ S / CO	SC03130100P2	8 July 2016	18 July 2016	USAFSAM
SO ₂	SC03AF0060P2	8 July 2016	18 July 2016	USAFSAM
HCN	SC03490047P2	8 July 2016	18 July 2016	USAFSAM

Dräger Pac[®] 7000:

Vendor: Dräger

Item Number: 831-8970

Unit Serial Number: ARJC-7202

Sensor Information:

Gas Type: CO

Part Number: 681-1082

Calibration Date: 31 March 2016

Calibration By: Dräger

Haz-Dust IV:

Vendor: SKC, Inc
Vendor Item Number: 770-4004

Manufacturer: Environmental Devices Corporation
Manufacturer Model Number: HD-1004
Unit Serial Number: 06164841

Data Type: Inhalable
Datalog Interval: 10 seconds

Calibration Date: June 2016
Calibration By: Environmental Devices Corporation

Zeroed pre- and post-run using zeroing accessory (SKC Catalog Number: 770-4202A)
by author.

DustTrak DRX:

Vendor: TSI

Model Number: 8534
Model Serial Number: 8534161502
Datalog Interval: 1 second

Calibration Date: 5 April 2016
Calibration By: USAFSAM

Sobent Tubes (By Event):

10 July 2016 – Run 1:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
SO2-DVR-D1-1	10589	May 2017	N/A	1.5	1502.500	1498.700	1500.600
HCl-LDR-D1-1	10597	May 2018	N/A	2.0	2001.200	1997.400	1999.300
SO2-D1-TCG-1	10589	May 2017	N/A	1.5	1501.700	1502.500	1502.100
PVC-TC-D1-1	17054-7E0-110	5/2019	N/A	2.0	1999.300	2001.400	2000.350
CL2-DVR-D1-1	10601	May 2017	N/A	0.5	499.500	502.130	500.815
NH3-DVR-D1-1	10461	Mar 2018	6517900433	0.5	498.700	499.310	499.005
HCN-DVR-D1-1	10602	May 2021	6409400436	0.2	195.200	202.750	198.975
NO2-DVR-D1-1	10221	Oct 2017	6351200458	0.025	25.487	26.154	25.821
NO-DVR-D1-1	10221	Oct 2017	6351200654				
CL2-TC-D1-1	10601	May 2017	N/A	0.5	501.420	497.780	499.600
NH3-TC-D1-1	10461	Mar 2018	6517900436	0.5	497.230	502.150	499.690
HCN-TC-D1-1	10602	May 2021	6409400441	0.2	197.460	199.430	198.445
NO2-TC-D1-1	10221	Oct 2017	6351200459	0.025	25.781	25.943	25.862
NO-TC-D1-1	10221	Oct 2017	6351200651				

11 July 2016 – Run 1:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
SO2-DVR-D2-1	10589	May 2017	N/A	1.5	1499.200	1503.800	1501.500
HCl-LDR-D2-1	10597	May 2018	N/A	2.0	2002.900	1995.200	1999.050
SO2-D2-TCG-1	10589	May 2017	N/A	1.5	1503.700	1497.400	1500.550
PVC-TC-D2-1	17054-7E0-110	5/2019	N/A	2.0	2001.100	1998.200	1999.650
CL2-DVR-D2-1	10601	May 2017	N/A	0.5	499.800	501.350	500.575
NH3-DVR-D2-1	10461	Mar 2018	6517900439	0.5	496.890	507.220	502.055
HCN-DVR-D2-1	10602	May 2021	6409400439	0.2	196.180	199.760	197.970
NO2-DVR-D2-1	10221	Oct 2017	6351200462	0.025	25.523	25.671	25.597
NO-DVR-D2-1	10221	Oct 2017	6351200645				
CL2-TC-D2-1	10601	May 2017	N/A	0.5	501.960	489.740	495.850
NH3-TC-D2-1	10461	Mar 2018	6517900441	0.5	515.020	492.070	503.545
HCN-TC-D2-1	10602	May 2021	6409400443	0.2	205.910	193.350	199.630
NO2-TC-D2-1	10221	Oct 2017	6351200460	0.025	26.316	24.018	25.167
NO-TC-D2-1	10221	Oct 2017	6351200649				

11 July 2016 – Run 2:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
SO2-DVR-D2-2	10589	May 2017	N/A	1.5	1503.700	1483.500	1493.600
HCl-LDR-D2-2	10597	May 2018	N/A	2.0	1995.400	1975.300	1985.350
SO2-D2-TCG-2	10589	May 2017	N/A	1.5	1497.800	1476.900	1487.350
PVC-TC-D2-2	17054-7E0-110	5/2019	N/A	2.0	1998.000	1981.200	1989.600
CL2-DVR-D2-2	10601	May 2017	N/A	0.5	501.530	502.690	502.110
NH3-DVR-D2-2	10461	Mar 2018	6517900435	0.5	507.490	486.610	497.050
HCN-DVR-D2-2	10602	May 2021	6409400437	0.2	199.920	195.960	197.940
NO2-DVR-D2-2	10221	Oct 2017	6351200455	0.025	25.683	25.759	25.721
NO-DVR-D2-2	10221	Oct 2017	6351200648				
CL2-TC-D2-2	10601	May 2017	N/A	0.5	490.280	505.530	497.905
NH3-TC-D2-2	10461	Mar 2018	6517900440	0.5	492.130	456.960	474.545
HCN-TC-D2-2	10602	May 2021	6409400442	0.2	193.220	239.990	216.605
NO2-TC-D2-2	10221	Oct 2017	6351200461	0.025	24.007	28.669	26.338
NO-TC-D2-2	10221	Oct 2017	6351200652				

12 July 2016 – Run 1:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
SO2-DVR-D3-1	10589	May 2017	N/A	1.5	1500.600	1497.600	1499.100
HCl-LDR-D3-1	10597	May 2018	N/A	2.0	2000.300	1995.700	1998.000
SO2-D3-TCG-1	10589	May 2017	N/A	1.5	1499.800	1490.200	1495.000
PVC-TC-D3-1	17054-7E0-110	5/2019	N/A	2.0	1999.300	1993.900	1996.600
CL2-DVR-D3-1	10601	May 2017	N/A	0.5	507.070	502.370	504.720
NH3-DVR-D3-1	10461	Mar 2018	6517900432	0.5	499.260	495.680	497.470
HCN-DVR-D3-1	10602	May 2021	6409400435	0.2	204.470	201.220	202.845
NO2-DVR-D3-1	10221	Oct 2017	6351200058	0.025	23.986	24.872	24.429
NO-DVR-D3-1	10221	Oct 2017	6351200019				
CL2-TC-D3-1	10601	May 2017	N/A	0.5	497.800	492.100	494.950
NH3-TC-D3-1	10461	Mar 2018	6517900455	0.5	499.030	510.200	504.615
HCN-TC-D3-1	10602	May 2021	6409400434	0.2	202.890	198.960	200.925
NO2-TC-D3-1	10221	Oct 2017	6351200063	0.025	24.947	23.578	24.263
NO-TC-D3-1	10221	Oct 2017	6351200016				

12 July 2016 – Run 2:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
SO2-DVR-D3-2	10589	May 2017	N/A	1.5	1497.800	1485.100	1491.450
HCl-LDR-D3-2	10597	May 2018	N/A	2.0	1999.900	1971.300	1985.600
SO2-D3-TCG-2	10589	May 2017	N/A	1.5	1498.300	1473.500	1485.900
PVC-TC-D3-2	17054-7E0-110	5/2019	N/A	2.0	1998.600	1966.500	1982.550
CL2-DVR-D3-2	10601	May 2017	N/A	0.5	502.280	502.160	502.220
NH3-DVR-D3-2	10461	Mar 2018	6517900409	0.5	495.810	481.430	488.620
HCN-DVR-D3-2	10602	May 2021	6409400490	0.2	201.180	197.530	199.355
NO2-DVR-D3-2	10221	Oct 2017	6351200057	0.025	24.916	23.293	24.105
NO-DVR-D3-2	10221	Oct 2017	6351200018				
CL2-TC-D3-2	10601	May 2017	N/A	0.5	499.500	465.890	482.695
NH3-TC-D3-2	10461	Mar 2018	6517900452	0.5	502.100	539.280	520.690
HCN-TC-D3-2	10602	May 2021	6409400493	0.2	217.300	180.540	198.920
NO2-TC-D3-2	10221	Oct 2017	6351200062	0.025	24.951	22.663	23.807
NO-TC-D3-2	10221	Oct 2017	6351200020				

13 July 2016 – Run 1:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
MTL-DVR-D4-1	16967-7E0-138	Jun 2019	N/A	2.0	2000.700	1994.200	1997.450
HCl-LDR-D4-1	10597	May 2018	N/A	2.0	1999.400	1995.500	1997.450
MTL-TC-D4-1	16967-7E0-138	Jun 2019	N/A	2.0	1999.600	2001.700	2000.650
PVC-TC-D4-1	17054-7E0-110	5/2019	N/A	2.0	2002.200	1998.500	2000.350
SO2-DVR-D4-1	10589	May 2017	N/A	0.5	497.870	499.250	498.560
NH3-DVR-D4-1	10461	Mar 2018	6517900458	0.5	490.720	502.760	496.740
HCN-DVR-D4-1	10602	May 2021	6409400492	0.2	200.880	197.150	199.015
NO2-DVR-D4-1	10221	Oct 2017	6351200055	0.025	25.608	24.529	25.069
NO-DVR-D4-1	10221	Oct 2017	6351200646				
SO2-D4-TCG-1	10589	May 2017	N/A	0.5	483.600	497.100	490.350
NH3-TC-D4-1	10461	Mar 2018	6517900456	0.5	492.830	502.090	497.460
HCN-TC-D4-1	10602	May 2021	6409400485	0.2	207.550	202.650	205.100
NO2-TC-D4-1	10221	Oct 2017	6351200061	0.025	25.995	24.837	25.416
NO-TC-D4-1	10221	Oct 2017	6351200015				

13 July 2016 – Run 2:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
MTL-DVR-D4-2	16967-7E0-138	Jun 2019	N/A	2.0	1997.500	2002.200	1999.850
HCl-LDR-D4-2	10597	May 2018	N/A	2.0	1998.300	1999.200	1998.750
MTL-TC-D4-2	16967-7E0-138	Jun 2019	N/A	2.0	2002.800	2001.500	2002.150
PVC-TC-D4-2	17054-7E0-110	5/2019	N/A	2.0	1999.100	1995.800	1997.450
SO2-DVR-D4-2	10589	May 2017	N/A	0.5	499.450	492.180	495.815
NH3-DVR-D4-2	10461	Mar 2018	6517900457	0.5	497.800	491.400	494.600
HCN-DVR-D4-2	10602	May 2021	6409400490	0.2	201.510	195.870	198.690
NO2-DVR-D4-2	10221	Oct 2017	6351200059	0.025	24.911	24.583	24.747
NO-DVR-D4-2	10221	Oct 2017	6351200022				
SO2-D4-TCG-2	10589	May 2017	N/A	0.5	498.300	495.700	497.000
NH3-TC-D4-2	10461	Mar 2018	6517900460	0.5	499.600	502.900	501.250
HCN-TC-D4-2	10602	May 2021	6409400487	0.2	189.862	205.063	197.463
NO2-TC-D4-2	10221	Oct 2017	6351200060	0.025	26.207	24.719	25.463
NO-TC-D4-2	10221	Oct 2017	6351200024				

13 July 2016 – Run 3:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
MTL-DVR-D4-3	16967-7E0-138	Jun 2019	N/A	2.0	2001.800	1993.300	1997.550
HCl-LDR-D4-3	10597	May 2018	N/A	2.0	1999.100	1991.600	1995.350
MTL-TC-D4-3	16967-7E0-138	Jun 2019	N/A	2.0	2000.900	1984.300	1992.600
PVC-TC-D4-3	17054-7E0-110	5/2019	N/A	2.0	1996.300	1991.700	1994.000
SO2-DVR-D4-3	10589	May 2017	N/A	0.5	497.410	490.980	494.195
NH3-DVR-D4-3	10461	Mar 2018	6517900453	0.5	498.280	495.050	496.665
HCN-DVR-D4-3	10602	May 2021	6409400488	0.2	499.820	206.060	352.940
NO2-DVR-D4-3	10221	Oct 2017	6351200454	0.025	24.671	24.264	24.468
NO-DVR-D4-3	10221	Oct 2017	6351200026				
SO2-D4-TCG-3	10589	May 2017	N/A	0.5	499.300	482.030	490.665
NH3-TC-D4-3	10461	Mar 2018	6517900454	0.5	497.900	489.530	493.715
HCN-TC-D4-3	10602	May 2021	6409400484	0.2	206.345	190.392	198.369
NO2-TC-D4-3	10221	Oct 2017	6351200054	0.025	24.916	25.748	25.332
NO-TC-D4-3	10221	Oct 2017	6351200027				

14 July 2016 – Run 1:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
MTL-DVR-D5-1	16967-7E0-138	Jun 2019	N/A	2.0	2000.100	2002.500	2001.300
HCl-LDR-D5-1	10597	May 2018	N/A	2.0	2001.300	2010.300	2005.800
MTL-TC-D5-1	16967-7E0-138	Jun 2019	N/A	2.0	1999.500	2005.300	2002.400
PVC-TC-D5-1	17054-7E0-110	5/2019	N/A	2.0	1998.900	2006.800	2002.850
SO2-DVR-D5-1	10589	May 2017	N/A	0.5	499.530	502.180	500.855
NH3-DVR-D5-1	10461	Mar 2018	6517900408	0.5	501.250	497.830	499.540
HCN-DVR-D5-1	10602	May 2021	6409400545	0.2	199.820	203.720	201.770
NO2-DVR-D5-1	10221	Oct 2017	6351200132	0.025	24.712	26.108	25.410
NO-DVR-D5-1	10221	Oct 2017	6351200047				
SO2-D5-TCG-1	10589	May 2017	N/A	0.5	502.810	499.600	501.205
NH3-TC-D5-1	10461	Mar 2018	6517900406	0.5	500.080	496.560	498.320
HCN-TC-D5-1	10602	May 2021	6409400546	0.2	194.290	201.110	197.700
NO2-TC-D5-1	10221	Oct 2017	6351200125	0.025	23.982	24.537	24.260
NO-TC-D5-1	10221	Oct 2017	6351200049				

14 July 2016 – Run 2:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
MTL-DVR-D5-2	16967-7E0-138	Jun 2019	N/A	2.0	2004.300	2007.800	2006.050
HCl-LDR-D5-2	10597	May 2018	N/A	2.0	2008.700	2011.200	2009.950
MTL-TC-D5-2	16967-7E0-138	Jun 2019	N/A	2.0	2004.900	2002.100	2003.500
PVC-TC-D5-2	17054-7E0-110	5/2019	N/A	2.0	2006.600	2000.900	2003.750
SO2-DVR-D5-2	10589	May 2017	N/A	0.5	503.380	501.900	502.640
NH3-DVR-D5-2	10461	Mar 2018	6517900411	0.5	505.180	507.240	506.210
HCN-DVR-D5-2	10602	May 2021	6409400550	0.2	199.800	200.220	200.010
NO2-DVR-D5-2	10221	Oct 2017	6351200702	0.025	25.661	24.585	25.123
NO-DVR-D5-2	10221	Oct 2017	6351200499				
SO2-D5-TCG-2	10589	May 2017	N/A	0.5	496.800	492.390	494.595
NH3-TC-D5-2	10461	Mar 2018	6517900402	0.5	500.580	499.290	499.935
HCN-TC-D5-2	10602	May 2021	6409400559	0.2	202.470	198.960	200.715
NO2-TC-D5-2	10221	Oct 2017	6351200695	0.025	25.309	24.270	24.790
NO-TC-D5-2	10221	Oct 2017	6351200309				

14 July 2016 – Environmental Background:

Sample Number	Lot Number	Exp Date	Serial Number	Target Flow Rate (LPM)	Pre-Cal (ml/min)	Post-Cal (ml/min)	Average Flow Rate (ml/min)
PVC-BKGND-1	17054-7E0-110	5/2019	N/A	2.0	2007.800	2008.400	2008.100
HCl-BKGND	10597	May 2018	N/A	2.0	2011.200	2021.600	2016.400
PVC-BKGND-2	17054-7E0-110	5/2019	N/A	2.0	2002.100	2000.700	2001.400
PVC-BKGND-3	17054-7E0-110	5/2019	N/A	2.0	2000.900	2001.900	2001.400
SO2-BKGND-2	10589	May 2017	N/A	0.5	501.900	498.800	500.350
NH3-BKGND-2	10461	Mar 2018	6517900404	0.5	507.240	511.590	509.415
HCN-BKGND-2	10602	May 2021	6409400544	0.2	200.220	200.400	200.310
NO2-BKGND-2	10221	Oct 2017	6351200697	0.025	24.585	24.084	24.335
NO-BKGND-2	10221	Oct 2017	6351200506				
SO2-BKGND-1	10589	May 2017	N/A	0.5	492.390	488.690	490.540
NH3-BKGND-1	10461	Mar 2018	6517900407	0.5	499.290	497.760	498.525
HCN-BKGND-1	10602	May 2021	6409400548	0.2	198.960	200.550	199.755
NO2-BKGND-1	10221	Oct 2017	6351200701	0.025	24.270	23.105	23.688
NO-BKGND-1	10221	Oct 2017	6351200498				
Time did not allow pre-run calibration adjustments, previous run post-run calibration data used for pre-run calibration.							

Appendix D

Analytical Methods:

OSHA ID 209: <https://www.osha.gov/dts/sltc/methods/inorganic/id209/id209.html>

NIOSH 6004: <https://www.cdc.gov/niosh/docs/2003-154/pdfs/6004.pdf>

NIOSH 6011: <https://www.cdc.gov/niosh/docs/2003-154/pdfs/6011.pdf>

NIOSH 6014: <https://www.cdc.gov/niosh/docs/2003-154/pdfs/6014-1.pdf>

NIOSH 6016: <https://www.cdc.gov/niosh/docs/2003-154/pdfs/6016.pdf>

NIOSH 6017: <https://www.cdc.gov/niosh/docs/2003-154/pdfs/6017.pdf>

NIOSH 7303: <https://www.cdc.gov/niosh/docs/2003-154/pdfs/7303.pdf>

NIOSH 7907: <https://www.cdc.gov/niosh/docs/2003-154/pdfs/7907.pdf>

Acronyms

ACGIH – American Conference of Governmental Industrial Hygienists

ASTM – American Society for Testing and Materials

Ba – Barium

BVNA – Bureau Veritas North America

CDA – Censored Data Analysis

CEI – Cost Effectiveness Index

CI – Confidence Interval

Cl₂ – Chlorine

CO – Carbon Monoxide

CO₂ – Carbon Dioxide

d_{ae} – Aerodynamic Diameter

DoA – Department of the Army

DoD – Department of Defense

DoDI – Department of Defense Instruction

DoN – Department of the Navy

DRI – Direct Reading Instrument

EL – Exposure Limit

EPC – Effect Probability Category

ESRL – Earth System Research Laboratory

GMD – Global Monitoring Division

GT – Gun Table

HCl – Hydrogen Chloride

HCN – Hydrogen Cyanide

HHAR – Health Hazard Assessment Report

HHSC – Health Hazard Severity Category

IC – Ion Chromatography

ICP-AES – Inductively Coupled Plasma, Atomic Emission Spectroscopy

ICRP – International Commission on Radiological Protection

IOM – Institute of Occupational Medicine

MAGTF – Marine Air-Ground Task Force

MBT – Main Battle Tank, M1A1 Abrams

MCE – Mixed Cellulose Ester

Mg – Magnesium

MU – Miami University, Oxford, Ohio

Na – Sodium

NH₃ – Ammonia

NIOSH – National Institute for Occupational Safety and Health

NO – Nitric Oxide

NO₂ – Nitrogen Dioxide

NOAA – National Oceanic and Atmospheric Administration

ODP – Ocean Drilling Program, Texas A&M University

OEH – Occupational and Environmental Health

OSHA – Occupational Safety and Health Administration

Pb – Lead

PEL – Permissible Exposure Limit (OSHA)

PM – Particulate Matter

PPE – Personal Protective Equipment

PTFE – Polytetrafluoroethylene

RAC – Risk Assessment Code

REL – Recommended Exposure Limit (NIOSH)

RSO – Range Safety Officer

SEM – Scanning Electron Microscope

SO₂ – Sulfur Dioxide

SOP – Standard Operating Procedures

Sr – Strontium

STEL – Short-Term Exposure Limit

TC – Tank Commander

TLV – Threshold Limit Value

TLV-C[®] – Threshold Limit Value – Ceiling

TLV-STEL[®] – Threshold Limit Value – Short-Term Exposure Limit (15-minute)

TLV-TWA[®] – Threshold Limit Value – Time-Weighted Average (8-hour)

TPCSDS-T – Target Practice, Cone Stabilized Discarding Sabot with Tracer

TPMP-T – Target Practice, Multi-Purpose with Tracer

TTPs – Techniques, Tactics, and Procedures

TWA – Time Weighted Average

UCI – University of California, Irvine

USEPA – United States Environmental Protection Agency

USMC – United States Marine Corps

USAPHC – United States Army Public Health Center

VA – Department of Veteran’s Affairs

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14. ABSTRACT Currently, the U.S. Army Public Health Center possesses limited data on M1A1 Abrams Main Battle Tank crew member occupational exposures. While not directly related to M1A1 crew member occupational exposures, current research has established a relationship between chronic exposure to pollutants below exposure guidelines and adverse health effects, which exposure to in a confined space may exacerbate. Additionally, inhalation of particulate matter has continually been referenced as a probable cause in delayed manifestation of adverse health effects related to military service. As such, advances in sampling and analytical technology may illuminate exposures previously considered not significant as significant. This research project aims to address two primary questions: what current occupational health hazard risks are M1A1 crew members subjected to during live-fire operations, and do any of these exposures present more than a negligible health hazard risk? Using current sampling equipment positioned in five separate locations within the tank, the author evaluates multiple inhalation exposures. Based on the total data collected, particulate matter, hydrogen cyanide, and lead present the greatest potential health risks. Recommendations from these results include continued monitoring to establish health risk potentials over time, future biological monitoring of crew members, and evaluation of personal filtration devices.					
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