

Occupational Exposure to Atmospheric Emissions Produced During Live Gun Firing

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Abstract

A pilot study was performed in Quebec in 2006 and 2007 to estimate occupational exposure of soldiers during live gun firing. For this project three different weapons were tested; the C3 105 mm howitzer, the M777 155 mm howitzer, and the Carl Gustav 84 mm anti-tank. Only area samples were collected and, for safety reasons, samples were collected from 8 to 22 m away from the weapons approximately 90 cm above ground. Results showed that concentrations of total particulates were 1.25 mg/m³, 4.02 mg/m³ and 32.1 mg/m³ for the 105 mm howitzer, the 155 mm howitzer, and the Carl Gustav anti-tank respectively. In addition, estimation on the size distribution determined that most particles were smaller than 4 µm. Hydrogen cyanide was detected from the 105 mm howitzer and the Carl Gustav anti-tank, and formaldehyde was detected from the 155 mm howitzer and the Carl Gustav anti-tank. Although observed concentrations were low for both compounds, it is believed that concentrations around the guns are higher than what was measured during this study. In addition, ambient temperature during trials seemed to have an influence of the dispersion of gases. Although concentrations observed were low, further investigations are needed to better determine soldiers' exposure during live gun firing, and the influence of environmental conditions on this exposure.

Keywords: occupational exposure, artillery, infantry, howitzer, atmospheric emissions, live gun firing

1. Introduction

During the course of their career, members of the Canadian Forces spend time on firing ranges for training purposes. Most soldiers train with small arms but infantry, armored and artillery soldiers train with heavier weapons such as howitzers, anti-tanks, and weapons mounted on armoured vehicles. Exposure to various chemicals has been described in the literature for people practicing in small arms firing ranges either recreationally or for occupational reasons (Bonnano, Robson, Buckley, & Modica, 2002; Gulson, Palmer, & Bryce, 2002; Mancuso, McCoy, Pelka, Kahn, & Gaydos, 2008; Demmeler, Nowak, & Schierl, 2009; Di Lorenzo et al., 2010; Diaz, Sariks, Viebig, & Saldiva, 2012).

Most of the studies looked at lead exposure in indoor ranges (Gulson et al., 2002; Mancuso et al., 2008; Demmeler et al., 2009; Di Lorenzo et al., 2010), although a few studies looked at outdoor ranges (Bonnano et al., 2002; Gulson et al., 2002; Mancuso et al., 2008). Mancuso et al. (2008) also looked at other chemicals such as silica, benzene, ethylbenzene, xylenes, toluene, carbon monoxide, nitrogen dioxide, and hydrogen cyanide. Diaz and Poulin (2012) looked at lead, antimony and barium in a ballistic laboratory.

All studies that measured personal samples showed elevated levels of lead (Bonnano et al., 2002; Mancuso et al., 2008; Diaz et al., 2012). In addition, Bonnano et al. (2002), Mancuso et al. (2008) and Demmeler et al. (2009) found elevated levels of lead in the blood of the shooters, some exceeding the ACGIH recommended BEI value of 30 µg/100 ml.

It has been shown that soils and pore water at military ranges are contaminated with various types of contaminants such as metals and explosive materials (Bennett, Kaufman, Koch, Sova, & Reimer, 2007; Berthelot, Valton, Auroy, Trottier, & Robidoux, 2008; Clausen & Korte, 2009; Martel et al., 2009; Laporte-Saumure, Martel, & Mercier, 2011; Lewis, Sjöström, Skyllberg, & Häggglund, 2010; Etim & Onianwa, 2012; Laporte-Saumure, Martel, & Mercier, 2012; M. R. Walsh, M. E. Walsh, & Ramsey, 2012). Recent work from Du et al. (2011) and Gillies et al. (2007) showed that artillery back blast resulted in fugitive emission of particulate

matter (PM_{2.5} and PM₁₀) from soils.

Since 2000, Defence Research and Development Canada Valcartier (DRDC Valcartier) in conjunction with the Army Corps of Engineers has done intensive work on the contamination of firing ranges in Canadian Forces and US Army Bases (Ampleman, Thiboutot, Desilets, Gagnon, & Marois, 2000; Ampleman et al., 2003; Dube, Thiboutot, Ampleman, Marois, & Bouchard, 2006; Jenkins et al., 2006; Marois, Gagnon, Thiboutot, Ampleman, & Bouchard, 2004; Thiboutot et al., 2004; Walsh et al., 2012) and have found that firing positions are contaminated with explosive materials.

Considering that energetic materials can result in health effects such as headaches, DRDC Valcartier researchers felt that gunners may be affected by gaseous emissions produced by live gun firing. In addition, the researchers were concerned about the size of the particles emitted during this activity. It was decided to characterize gaseous emissions, as well as particle size distribution and composition during live artillery and infantry gun firing. In 2006, DRDC Valcartier initiated a joint project with DRDC Toronto researchers to evaluate potential exposure and health risks for infantry and artillery soldiers.

This paper presents the main results obtained during this pilot study of measured area samples from live artillery gun firing. Subsequent studies have been performed by DRDC Valcartier on airborne emissions produced during live gun firing and collected at the muzzle of the gun (Diaz & Poulin, 2012) or from open burning of artillery propellant (Thiboutot, Ampleman, Pantea, Whitwell, & Sparks, 2012) but they were looking only at the environmental aspect. To our knowledge this is the only publication and study that looked at the occupational health aspect of live heavy gun firing.

2. Methods

2.1 Trials

In total three trials were conducted in Quebec, Canada, from September 2006 to February 2007. The first trial was conducted at the Munitions Experimental Testing Centre (METC) in Nicolet, Quebec, on the C3 howitzer 105 mm using the C60 Squash Head Practice projectile. The facility is equipped with a muffler which allows for accumulation of concentrated emissions making the determination of toxic substances easier. The second trial was conducted at Canadian Forces Base Valcartier (CFB Valcartier), Quebec, on 12th January 2007 during a live firing training exercise on the M777 howitzer 155 mm. The final trial was conducted at CFB Valcartier on 7th February 2007 during a live firing training exercise on the Carl-Gustav anti-tank 84 mm.

Detailed descriptions of the facilities and set-up, the weapons, the ammunitions, and physical and chemical composition of the propellants are given in the references from Table 1.

Table 1. Information on the trials

Date	Location	Weapon	Reference
19/20 September 2006	METC Nicolet	C3 Howitzer 105 mm	Quémerais et al. (2007)
12 January 2007	CFB Valcartier	M777 Howitzer 155 mm	Quémerais, Diaz, Poulin, and Marois (2007a)
7 February 2007	CFB Valcartier	Carl Gustav 84 mm	Quémerais, Diaz, Poulin, and Marois (2007b)

In the September trial, tests were conducted indoor as well as outdoor. The indoor set-up at the METC is shown in Figures 1 and 2 while the outdoor set-up is shown in Figure 3. Because of the pressure inside the muffler during gun firing it was impossible to leave the sampling equipment inside the muffler; a sampling hatch was designed specifically to allow sampling of gases and airborne particles inside the muffler (Figure 2). In each case the sampling equipment was installed on a table approximately 90 cm above ground. The C60 Squash Head Practice uses M67 propellant in up to six charge bags. Both indoor and outdoor tests were conducted at charge 4 and 6. Charge 4 contains 475 g of propellant while charge 6 contains 850 g of propellant.

Indoor sampling was carried out on 19th September 2006. The sampling valve was opened after firing two rounds at each charge and before ventilation was activated. Sample collection lasted only for few minutes to avoid clogging of the sampling media since concentration of emissions inside the muffler were extremely high. Outdoor sampling was carried out on 20th September 2006. To avoid damage from the blast effect the sampling

station had to be located at a certain distance from the gun. Sampling location was selected according to wind direction in order to capture the plume of atmospheric emissions from the gun muzzle. Sample collection was performed continuously while firing ten rounds at each charge. Sampling times varied from 35 to 43 minutes. All indoor and outdoor sampling was carried out in duplicates.



Figure 1. Side view of the muffler



Figure 2. Sampling hatch with pressure valve and sampling equipment



Figure 3. Outdoor set-up with C3 howitzer 105 mm and sampling equipment

Sampling set-up for the second trial on January 2007 is shown in Figure 4. Two tables were setup with the sampling equipment: one on the left side of the gun at approximately 8 m, and 90 cm above ground (identified as Table #1), and the second one in the firing direction at approximately 22 m, and 90 cm above ground (identified as Table #2). The M777 155 mm projectile uses M1 propellant in up to five charge bags. Samples were collected continuously for a total of 170 minutes. In total, 72 rounds were fired, 69 at charge 4 plus 3 rounds at charge 5. Charge 4 represents 1.814 kg of propellant while charge 5 represents 2.523 kg of propellant.



Figure 4. Location of the sampling equipment around the M777 155 mm howitzer

Sampling set-up for the third trial in February 2007 is shown in Figure 5. Two coolers were located in line with firing bay #2 at 8 m (noted Station #1) and at 13 m (noted Station #2) from the firing bay. Sampling was carried out approximately 30 cm above ground. Coolers were protected from the back blast by a pile of salt bags. When firing full calibre ammunition, the danger zone created by the back blast is approximately 60 m. The propellant used is the AKB 204 and has a weight of 380 g. Sampling was carried out continuously for 105 minutes. In total 71 rounds were fired: 39 at bay #1 and 32 at bay #2.



Figure 5. Positions of the sampling stations around the firing bays

2.2 Analytes

Atmospheric emissions were analyzed for total particulates, size distribution of particles, hydrogen cyanide, dinitrotoluene compounds, benzene, toluene, ethylbenzene, xylene, nitrogen oxide and iodide, sulphur dioxide for all trials. Hydrogen sulphide, nitric acid, polycyclic aromatic hydrocarbons, metals, and aldehydes were added for trials #2 and #3. Nitroaromatic compounds were analyzed during the first trial but since they were never detected they were not analyzed in the following trials.

2.3 Sampling and Analytical Methods

Parameters were sampled and analyzed according to standardized NIOSH and OSHA methods using appropriate filters and sorbent tubes. Detailed methods are given in Qu  merais et al. (2007) and Qu  merais, Diaz, Poulin, and Marois (2007a). Blank filters and sorbent tubes were analyzed for each trial as controls.

Size distribution of particles was analyzed by scanning electron microscopy for trial #1 and then using a cascade impactor for trials #2 and #3. The impactor used was the Maple Personal Cascade Impactor (Series 290) from Thermo Electron Corporation and it was connected to a GilAir5 sampling pump from Sensidyne operating at a flow rate of 2 L/min. Since only one impactor was available it was located on Table #1 and Station #1 for the second and third trials respectively.

For all trials sampling pumps were calibrated prior to and just after sampling to ensure sampling flow remained constant during sample collection.

Analyses for dinitrotoluene compounds were performed at DRDC Valcartier. Size distribution for the first trial was determined directly on the filter collected for total particulates using a TSI DS-130 scanning electron microscope (SEM) equipped with a Gresham light element detector and an integrated X-Ray fluorescence (IXRF) digital imaging system calibrated with magnification standards on the SEM. These analyses were performed in a private laboratory accredited by the American Industrial Hygiene Association (AIHA) in the United States.

For the last two trials morphology and chemical composition of the particles were analyzed using a JEOL LSM-840A SEM equipped with a NORAN energy dispersive X-ray (EDX) spectrometer. All other analyses were performed in a private AIHA accredited laboratory in the United States.

3. Results

Many of the analytes were detected only during the September trial inside the muffler where emissions were concentrated. The analytes detected discussed in this paper comprise hydrogen cyanide, formaldehyde, and particulates which were identified most commonly.

Blanks were never detected for all analytes.

3.1 Weather Data

Weather data for each sampling day are shown in Table 2. There was approximately 30   C difference between

the warmest and the coldest day. Relative humidity was the lowest when the temperature was also the lowest. Wind speed was lowest during the 155 mm howitzer trial and highest during the 105 mm howitzer trial.

Table 2. Weather data (average during the sampling period)

	Temperature (°C)	Relative humidity (%)	Pressure (kPa)	Wind speed (km/hr)	Wind direction
20/09/2006	16	70	100.1	22	SW
12/01/2007	-0.5	100	100.8	10	WSW
07/02/2007	-15	65	99.8	18	WSW

3.2 Pump Calibration

Differences between pre and post calibration flow for each trial were below 15%. These differences were considered as acceptable and average pump flow was used to calculate sample concentration.

3.3 Concentration of Particles

Results for particle concentrations are shown in Table 3.

Table 3. Particle concentrations measured for each trial

Date	Test	Concentration (mg/m ³)
19/09/2006	Muffler-6 bags	320.00
		310.00
	Muffler-4 bags	180.00
		150.00
20/09/2006	Outdoor-6 bags	1.50
		0.99
	Outdoor-4 bags	1.10
		1.40
12/12/2007	Table #1	3.42
	Table #2	4.62
07/02/2007	Station #1	31.6
	Station #2	32.6

Duplicate samples collected during the first trial in Nicolet showed experiments were reasonably reproducible (2 to 20% difference between duplicates). Total particle concentrations inside the muffler potentially included fugitive emissions of residues present in the muffler before our tests. However this contribution should be minimal since the first section of the muffler was cleaned prior to each test (Ampleman et al., 2008). Outdoor tests gave average concentrations of 1.25 mg/m³ for both charges 4 and 6. The fact that there was no difference between charges 4 and 6 is probably due to rapid dispersion and dilution of the plume.

During the trial with the M777 howitzer, particle concentration was higher at Table #2, located in line with the muzzle, than at Table #1, located on the left side of the gun. Average particle concentration was 4.04 mg/m³ for this trial. Concentrations observed are higher than for the C3 105 mm howitzer likely because 72 rounds were fired in the second trial as compared to only 10 rounds in the first one, and consequently considerably more propellant was burned during the second trial. However, particle concentrations remained low considering that approximately 117 kg of propellant was burned during the exercise. This is probably due to the fact that the gun muzzle was higher than in the first trial (Figures 3 and 4) and that the plume was dispersed. However, smoke was

observed at the gun muzzle directly after firing but also each time the breech was opened to insert a new round.

Results were quite different for the Carl Gustav anti-tank weapon. Particle concentrations were much higher than in the previous two trials giving an average of 32.1 mg/m^3 . It is possibly due to the fact that the emissions produced by combustion of the propellant are expelled at the back of the weapon. The samplers were located 8 and 13 m directly behind one of the firing bay therefore, they were in-line with the emissions. Particle concentrations at each station are similar suggesting that atmospheric emissions were not diluted between stations and that sampling stations were located in the plume.

3.4 Size Distribution of Particles

Results for size distribution obtained using scanning electron microscopy are shown in Table 4. Results for the outdoor 4 bags in trial #1 and all results for trials #2 and #3 have been discarded since there were discrepancies between the weigh and the electron microscopy analysis of the filters. It was concluded that the filters may have been affected by humidity and that weighing was not accurate, therefore results obtained were discarded.

Table 4. Size distribution of particles (% of total number of particles)

Date	Test	< 4 μm (%)	< 10 μm (%)	< 50 μm (%)
19/09/2006	Muffler-6 bags	79.8	98.8	100.0
		78.5	98.3	99.8
	Muffler-4 bags	82.4	98.2	100.0
		76.6	97.9	99.7
20/09/2006	Outdoor-6 bags	98.7	100.0	100.0
		90.6	99.3	100.0

For the first trial, the mass concentration of each fraction (i.e. < 4 μm , < 10 μm , and < 50 μm) was estimated from the total number distribution. For this calculation, it was assumed that all particles in the smaller fraction had a diameter of 4 μm and that all particles in the second fraction had a diameter of 10 μm . Particles were assumed to all be spherical with a mass density of 1 g/cm^3 . Calculations for the mass distribution were done according to the following equations (Walter, 2011).

$$v(d_p) = n(d_p) \times (\pi d_p^3) / 6$$

$$m(d_p) = v(d_p) \times \rho$$

Where $n(d_p)$ is the number distribution, $v(d_p)$ is the volume distribution, d_p is the particle diameter, $m(d_p)$ is the mass distribution, and ρ is the particle density.

Using these calculations the mass distribution of particles with a diameter of 4 μm gives averages of 26.6% and 31.7% for the indoor and outdoor tests respectively.

Particles inside the muffler showed a distribution that tends slightly to larger particles than outside. Using an average of 31.7%, the mass concentrations for the fraction below 4 μm were estimated for the first trial outdoor test at charge 4, and the second and third trials based on the total concentration of particles (Table 5). Since they are not relevant in terms of occupational exposure, data from inside the muffler were not included.

Table 5. Estimated mass concentrations for the fraction below 4 μm

Date	Test	< 4 μm (mg/m^3)
20/09/2006	Outdoor-6 bags	0.5
		0.3
	Outdoor-4 bags	0.4
		0.4
12/01/2007	Table #1	1.1
	Table #2	1.5
07/02/2007	Station #1	10.0
	Station #2	10.3

Results obtained using scanning electron microscopy for the various stages of the impactor showed that there were no particles on the first 6 stages of the impactor for the trial performed in January (Poulin, Diaz, & Qu  merais, 2008a). Since the cut-off point of the stage #6 of the impactor is 1.55 μm , this observation suggests that most particles were smaller than 2 μm , and therefore mostly respirable. Electron microscopy analysis of all stages of the impactor showed that on stage #7 particles originated mainly from soot and potassium sulphate (Poulin et al., 2008a). Stage #8 was composed primarily of soot (Poulin et al., 2008a). The last stage did not show any particle.

For the trial with the Carl Gustav, the first stages of the impactor (i.e. stages #1 to #5, particles over 3.5 μm) showed very few particles when analyzed using scanning electron microscopy. However, the last stages were covered with small particles. Stage #6 showed that many particles were composed of NaCl, likely originating from the salt bags. However, the last three stages of the impactor were covered with submicron particles composed mainly of propellant combustion residues and aluminum. Aluminum is believed to originate from the warhead (Poulin, Diaz, & Qu  merais, 2008b). The last stage of the impactor showed a fairly large area (40 μm) covered with ultrafine particles (<100 nm) (Poulin et al., 2008b).

3.5 Hydrogen Cyanide and Formaldehyde

Results for hydrogen cyanide and formaldehyde are shown in Table 6. Average concentrations for hydrogen cyanide inside the muffler were 17.4 and 20.9 mg/m^3 for charges 4 and 6 respectively. The ratio of charge 4 to charge 6 of 83.3% is much higher than the ratio of propellant suggesting that the sampler may have overloaded at least while sampling at charge 6. There was no significant difference between charge 4 and charge 6 during the outdoor test suggesting dilution of the emissions. Hydrogen cyanide was not detected during the trial with the M777 howitzer 155 mm, and showed much lower concentrations during the trial with the Carl Gustav anti-tank. In addition, the level observed at Station #1 was slightly higher than level at Station #2 suggesting a negative gradient concentration from the firing bay, contrarily to results observed with particles.

Unfortunately, formaldehyde was not measured during the first trial. Formaldehyde concentration was higher at Table #1 (left side of the gun) than at Table #2 (in front of the gun muzzle) during the test with the M777 howitzer 155 mm. For the test with the Carl Gustav anti-tank weapon, Station #1 showed a higher concentration than Station #2 suggesting again a negative gradient concentration from the firing bay. It is interesting to note that this behaviour is opposite to the behaviour of particles (Table 3).

Table 6. Concentrations of hydrogen cyanide and formaldehyde

Date	Test	Hydrogen cyanide (mg/m ³)	Formaldehyde (µg/m ³)
19/09/2006	Muffler-6 bags	21.2	NA
		20.5	NA
	Muffler-4 bags	17.87	NA
		16.83	NA
20/09/2006	Outdoor-6 bags	0.21	NA
		0.17	NA
	Outdoor-4 bags	ND	NA
		0.16	NA
12/01/2007	Table #1	ND	7.1
	Table #2	ND	3.6
07/02/2006	Station #1	0.027	8.2
	Station #2	0.022	5.8

NA: non available.

ND: non detected.

4. Discussion

This study has many limitations. Since it was a pilot study, personal exposure samples were not collected and TWA were not calculated, it is quite difficult to estimate health risks for soldiers. In addition, it was not possible to install the sampling stations close to the guns for safety reasons and emissions were diluted and dispersed before reaching the samplers. Finally, only exposure to atmospheric emissions was evaluated. Combustion residues are deposited on the gun itself, on unused projectiles and on soldiers' uniforms. Therefore there is also a risk for dermal exposure that was not evaluated here.

4.1 Concentrations and Size Distribution of Particles

Total average particle concentrations were 1.25, 4.02, and 32.1 mg/m³ for the 105 mm howitzer, the 155 mm howitzer, and the 84 mm Carl Gustav respectively. These concentrations are approximately three orders of magnitude higher than the 22 µg/m³ annual average PM₁₀ concentration in Quebec City in 2008 (WHO, 2013) and than the average ambient level of PM_{2.5} which varied between 6 and 10 µg/m³ in Southern Quebec between 2000 and 2010 (Environment Canada, 2012). It confirms that the particles collected were originated from the combustion of the propellant and not from ambient particles. However, there is a possibility that some of these particles were produced by fugitive emissions produced by the back blast as noted by Du et al. (2011) and Gillies et al. (2007).

Detailed composition of particles was not analyzed during the first trial therefore it is impossible to know what proportion of collected particles may have originated from fugitive emissions in this case. During the last two trials, the ground was frozen and covered with snow therefore fugitive emissions of particles from the ground were unlikely. This was confirmed by the electron microscopy analysis of the filters showing that particles originated mainly from soot and potassium sulfate (Poulin et al., 2008a, 2008b). During the last trial, scanning electron microscopy analysis showed that some of the particles were composed of NaCl and likely originated from the salt bags used to protect the coolers. They may have contributed significantly to the overall mass (Poulin et al., 2008b).

The analysis performed using scanning electron microscopy of the different stages of the impactor (trials #2 and #3) showed that most particles collected were below 2 µm, and a significant amount of ultrafine particles (<100 nm) were also observed in the last trial. Estimated average mass concentrations of particles below 4 µm were 0.4 mg/m³ and 1.3 mg/m³ for the 105 mm and 155 mm howitzers respectively.

It is safe to assume that soldiers may be exposed to high concentration of fine and ultrafine particles. During the second trial with the M777 155 mm howitzer, smoke was observed each time the gunner was opening the breech to insert a new round. In a recent literature review on the health effects on air pollution, Anderson and Thundiyil (2012) noted that increases as low as $10 \mu\text{g}/\text{m}^3$ in PM_{10} and $\text{PM}_{2.5}$ concentrations were found to have significant cardiovascular and respiratory health effects, even during short-term exposure.

Considering that, during this study, soldiers were exposed to higher concentrations of particulates, personal exposure should be collected to clarify potential health risks to the soldiers. Size distribution should also be determined more precisely to know the importance of fine ($<2.5 \mu\text{m}$) and ultrafine particles ($<100 \text{nm}$) since these are the most important in terms of health effects (Martins et al., 2010).

4.2 Hydrogen Cyanide and Formaldehyde

Results for these gases show a different behaviour than the behaviour of particles. The fact that hydrogen cyanide was detected at much higher concentrations in September than in February contrarily to what was observed for particles suggest that temperature may have an influence on the behaviour of gases. Combustion of propellants produces extremely high temperatures (Lengellé, Duterque, & Trubert, 2002). Gases expelled from the weapons are at a much higher temperature than the ambient air.

It is then safe to assume that the density of gases is lower than the density of air and that these gases likely rise. This will be even more pronounced in winter when the temperatures are below zero. This could explain why the concentration of hydrogen cyanide was one order of magnitude lower in February than in September since the temperature in February was $31 \text{ }^\circ\text{C}$ lower than in September. It also explains the negative gradient in concentration between Station #1 and #2 in the February trial. In contrast to particles that were projected at the back of the weapon, gases appear to have risen away from the gun due to their low density. This implies that concentrations close to the weapons are probably much higher, at least for a short period of time. It also means that concentrations of gaseous compounds around the guns may be quite different in winter and in summer.

Formaldehyde is an irritant of the upper respiratory tract and is considered a human carcinogen (IARC, 2012). Background levels in rural areas are around $1 \mu\text{g}/\text{m}^3$, levels slightly lower than what was measured during our study (European Commission, 2004). The European Union recommends a level of $30 \mu\text{g}/\text{m}^3$ for a 30-min exposure (European Commission, 2004) and ACGIH recommends a level of $370 \mu\text{g}/\text{m}^3$ for a 15-min exposure (ACGIH, 2012). Levels measured here are lower than the recommended limits but they were not personal exposure samples and it is likely that soldiers were exposed to values higher than those measured during the study.

According to the US Environmental Protection Agency, most people would experience discomfort at concentrations of hydrogen cyanide of $1.44 \text{ mg}/\text{m}^3$ for a 4-hours exposure (USEPA, 2013). Although these levels are much higher than the concentrations measured during the study, it would be important to know the exact exposure level of the soldiers. In addition, since both formaldehyde and hydrogen cyanide are irritants of the upper respiratory tract, exposure to both of these compounds may have a combined effect (ACGIH, 2012).

5. Conclusion

Although this study had many limitations, it underlines potential health risks for artillery and infantry soldiers. The combustion of propellant produces many toxic compounds that are released through the muzzle of the gun or when the breech is opened to insert a new projectile. Soldiers working around these guns are exposed to these compounds.

This pilot study showed that there is a potential for significant exposures to particles, hydrogen cyanide, and formaldehyde. In fact, results showed that most particles produced during live gun firing are below $4 \mu\text{m}$ and that soldiers may be exposed to high concentrations of these particles. Fine ($<2.5 \mu\text{m}$) and ultrafine particles ($<100 \text{nm}$) are associated with premature death, aggravated asthma, and chronic bronchitis (Martins et al., 2010). For gaseous emissions, both hydrogen cyanide and formaldehyde are irritants of the upper respiratory tract (ACGIH, 2012). Hydrogen cyanide may also give headaches, nausea and has effect on the thyroid while formaldehyde is a human carcinogen (IARC, 2012).

Therefore it is essential to characterize soldiers' exposure to fine and ultrafine particles as well as to gaseous emissions by collecting personal exposure samples. Further investigations are needed to better estimate soldiers' exposure to these chemicals. Since it would be difficult to collect samples for all compounds, the use of biomarkers may be an alternative for this type of study when they exist.

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