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Characterization of atmospheric emissions produced by live gun firing:

Test on the Carl Gustav anti-tank, 84 mm weapon

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Technical Report
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Canada

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Abstract

Airborne substances emitted during live gun firing of the anti-tank Carl Gustav 84 mm weapon were characterized during a live firing training exercise in Canadian Forces Base (CFB) Valcartier in February 2007. Sampling was performed continuously for two hours throughout the exercise during which particles and chemicals accumulated on sampling media. In total, seventy-one rounds were fired at two firing bays. Established occupational health methods were used to collect and analyze samples for particulate matter, hydrogen cyanide, polycyclic aromatic hydrocarbons (PAHs), dinitrotoluene compounds, benzene, toluene, ethylbenzene and xylene, metals, aldehydes, nitric acid (HNO_3), nitric oxide (NO), nitrogen dioxide (NO_2), hydrogen sulphide (H_2S) and sulphur dioxide (SO_2). Two sets of samples were collected at two sampling stations. Both sampling stations were located behind Firing Bay #2. Most of the chemicals were not detected during the trial. For both sets of samples, particles were found at concentrations much higher than the recommended environmental standards. These findings suggest that there is a potential risk to health associated with exposure to particles for artillery soldiers. For contaminants, concentrations were detected at higher levels at Station #1 than at Station #2 since the first station was closer to the firing bay. Hydrogen cyanide was detected at concentrations of 26.7 and 21.7 $\mu g/m^3$ for Stations #1 and #2, respectively. Lead was detected at concentrations of 2.8 and 2.1 $\mu g/m^3$ for Stations #1 and #2, respectively. Acetaldehyde was detected at concentrations of 12.7 and 9.3 $\mu g/m^3$, respectively, and formaldehyde was also detected at concentrations of 8.2 and 5.8 $\mu g/m^3$ for Stations #1 and #2, respectively. Although iron and propionaldehyde were also detected, it is believed that the concentrations observed were too low to create a potential risk for the soldiers. Concentrations for all contaminants were similar to the reference concentration (RfC) from the United States Environmental Protection Agency (US EPA), which is based on a lifetime exposure. Since gunners are not exposed on a daily basis to the levels observed during this study, their risk is likely to be lower than the EPA estimate. However, these findings suggest that there is a need to conduct personal sampling to assess the health risk, if any, to artillery soldiers. For all substances it is recommended that further investigations of air concentrations be made to properly assess personal exposure. It is also recommended that more sensitive environmental methods be used to collect and analyse the samples.

Résumé

Les composés gazeux et particulaires émis lors des tirs d'anti-char Carl Gustav 84 mm ont été caractérisés lors d'un exercice d'entraînement à la Base des Forces Canadiennes (BFC) Valcartier en février 2007. L'échantillonnage a été effectué en continu pendant deux heures lors de l'exercice, les particules et émissions gazeuses s'accumulant sur les media d'échantillonnage. Au total, soixante et onze tirs ont été effectués à deux baies de tirs. Des méthodes reconnues en hygiène du travail ont été utilisées pour collecter et analyser les échantillons pour les particules en suspension, le cyanure d'hydrogène, les hydrocarbures aromatiques polycycliques (HAP), les composés dinitrotoluène, le benzène, le toluène, l'éthylbenzène et le xylène, les métaux, les aldéhydes, l'acide nitrique (HNO_3), le monoxyde d'azote (NO), le dioxyde d'azote (NO_2), le sulfure d'hydrogène (H_2S) et le dioxyde de soufre (SO_2). Deux lots d'échantillons ont été collectés à deux stations d'échantillonnage. Les deux stations étaient localisées en arrière de la baie de tir #2. La plupart des composés n'ont pas été détectés lors de l'exercice. Pour les deux sets d'échantillons, les particules ont été mesurées à des concentrations beaucoup plus élevées que les normes environnementales. Ces résultats suggèrent que les particules représentent un risque potentiel pour la santé des soldats. Pour les autres contaminants, les niveaux étaient plus élevés à la station #1 qu'à la station #2 car la station #1 était localisée plus proche des baies de tir. Le cyanure d'hydrogène a été détecté à des concentrations respectives de 26.7 et 21.7 µg/m^3 pour les stations #1 et #2. Le plomb a été détecté à des concentrations de 2.8 et 2.1 µg/m^3 pour les stations #1 et #2 respectivement. L'acétaldéhyde a été détecté à des concentrations de 12.7 et 9.3 µg/m^3 respectivement, et le formaldéhyde a également été détecté à des concentrations de 8.2 et 5.8 µg/m^3 pour les stations #1 et #2 respectivement. Bien que le fer et le propionaldéhyde aient aussi été détectés, il est estimé que les niveaux observés étaient trop faibles pour créer un risque pour la santé des soldats. Les concentrations pour tous les contaminants étaient similaires à la concentration de référence (RfC) de l'agence de protection de l'environnement des États-unis (US EPA), qui est basée sur une exposition durant toute la vie. Puisque les artilleurs ne sont pas exposés tous les jours aux concentrations observés lors de cette étude, le risque pour leur santé est probablement plus faible que ce qui est estimé par le US EPA. Cependant, ces résultats suggèrent qu'il est nécessaire de mesurer l'exposition personnelle afin d'évaluer le risque, s'il y a lieu, pour la santé des artilleurs. Il est donc recommandé de poursuivre les études sur la qualité de l'air lors des tirs d'artillerie, en particulier que l'exposition personnelle soit évaluée. Il est également recommandé d'utiliser des méthodes environnementales plus sensibles pour la récolte et l'analyse des échantillons.

Executive summary

Characterization of atmospheric emissions produced by live gun firing: Test on the Carl Gustav anti-tank, 84 mm weapon

Quémerais, B., Diaz, E., Poulin, I., Marois, A.; DRDC Toronto TR 2007-103; Defence R&D Canada – Toronto; March 2008.

Introduction or background: For many years, Defence Research and Development Canada (DRDC) Valcartier has performed environmental site assessments on the live ranges of the major Canadian Forces training bases to evaluate the contamination by explosives at target and firing points. It was found that most of the fixed firing positions are contaminated with propellant residues. Two years ago, DRDC Valcartier began to assess the dispersion of residues at firing points during 105 mm howitzer live firing exercises. Residues of nitrocellulose fibres collected in front of the muzzle showed measurable amount of 2,4-Dinitrotoluene (2,4-DNT). After discussion with the soldiers, it was determined that the gunners may be affected by the gaseous emissions. In the Spring of 2006, researchers from DRDC Valcartier contacted researchers from DRDC Toronto to do further investigations on airborne substances emitted during live gun firing. Preliminary tests were conducted in September 2006 at the muffler installation of the Munitions Experimental Testing Centre (METC) in Nicolet (Quebec) both inside the muffler and outdoors on the C3 105 mm howitzer. Samples were analyzed for particulate matter, hydrogen cyanide, nitroaromatic compounds, dinitrotoluene compounds, benzene, toluene, ethylbenzene and xylene. Direct reading instruments were used to determine levels of nitric oxide (NO), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). In January 2007, DRDC Toronto and DRDC Valcartier collected air samples during a live training exercise on the M777 155 mm howitzer. Metals, polycyclic aromatic hydrocarbons (PAHs), aldehydes, hydrogen sulphide (H_2S), and nitric acid (HNO_3) were added to the previous list of compounds. New testing was performed in February 2007 at Canadian Forces Base (CFB) Valcartier during a live training exercise on the anti-tank Carl Gustav 84 mm weapon for the same parameters.

Results: Most of the chemicals were not detected during the trial. For both sets of samples, particles were found at concentrations much higher than the recommended environmental standards. These findings suggest that there is a potential risk to health associated with exposure to particles for artillery soldiers. For contaminants, concentrations were detected at higher levels at Station #1 than at Station #2 since the first station was closer to the gun. Hydrogen cyanide was detected at concentrations of 26.7 and 21.7 $\mu g/m^3$ for Stations #1 and #2, respectively. Lead was detected at concentrations of 2.8 and 2.1 $\mu g/m^3$ for Stations #1 and #2, respectively. Acetaldehyde was detected at concentrations of 12.7 and 9.3 $\mu g/m^3$, respectively, and formaldehyde was also detected at concentrations of 8.2 and 5.8 $\mu g/m^3$ for Stations #1 and #2, respectively. Although iron and propionaldehyde were also detected, it is believed that the concentrations observed were too low to create a potential risk for the soldiers. Concentrations for all contaminants were similar to the Reference Concentration (RfC) from the United States Environmental Protection Agency (US EPA), which is based on a lifetime exposure. Since gunners are not exposed on a daily basis to the levels observed during this study, their risk is likely to be lower than the EPA estimate.

Future plans: It is recommended that further investigations of air concentrations be made to properly assess personal exposure. It is also recommended that more sensitive environmental methods be used to collect and analyse the samples.

Sommaire

Characterization of atmospheric emissions produced by live gun firing: Test on the Carl Gustav anti-tank, 84 mm weapon

Quémerais, B., Diaz, E., Poulin, I., Marois, A.; DRDC Toronto TR 2007-103; R & D pour la défense Canada – Toronto; Mars 2008.

Introduction ou contexte : Depuis plusieurs années, DRDC Valcartier a réalisé des évaluations environnementales sur les champs de tir des principales bases des Forces Canadiennes afin d'évaluer la contamination par les explosifs des points de tir et des points cibles. Les résultats ont montrés que la plupart des points de tir sont contaminés par des résidus de poudre propulsive. Il y a deux ans, DRDC Valcartier a commencé à étudier la dispersion des résidus au point de tir lors d'un exercice d'entraînement avec l'obusier C3 105 mm. Les résidus de fibres de nitrocellulose prélevés devant la bouche du canon ont montré des concentrations non négligeables en 2,4-dinitrotoluène. Après discussion avec les soldats, les chercheurs se sont aperçus que les artilleurs pouvaient être affectés par les émissions gazeuses. Au printemps 2006, les chercheurs de DRDC Valcartier ont contacté les chercheurs de DRDC Toronto afin d'étudier les substances gazeuses émises lors des tirs d'artillerie. Des tests préliminaires ont été effectués au silencieux du Centre Expérimental de Test des Munitions à Nicolet (Québec), à l'intérieur du silencieux et à l'extérieur sur l'obusier de 105 mm. Les échantillons ont été analysés pour les particules en suspension, le cyanure d'hydrogène, les composés nitroaromatiques, les composés de dinitrotoluène, le benzène, le toluène, l'éthylbenzène et le xylène. Des instruments à lecture directe ont été utilisés pour déterminer les niveaux de monoxyde d'azote, de dioxyde d'azote et de dioxyde de soufre. En janvier 2007, DRDC Toronto et DRDC Valcartier ont collecté des échantillons d'air lors d'un tir d'entraînement sur l'obusier M777 155 mm. Les métaux, les hydrocarbures aromatiques polycycliques, les aldéhydes, le sulfure d'hydrogène et l'acide nitrique ont été ajoutés à la liste précédente. D'autres tests ont été effectués en février 2007 à la BFC Valcartier lors d'un exercice d'entraînement sur l'anti-char Carl Gustav 84 mm pour les mêmes composés.

Résultats : La plupart des composés n'ont pas été détectés lors de l'exercice. Pour les deux sets d'échantillons, les particules ont été mesurées à des concentrations beaucoup plus élevées que les normes environnementales. Ces résultats suggèrent que les particules représentent un risque potentiel pour la santé des soldats. Pour les autres contaminants, les niveaux étaient plus élevés à la station #1 qu'à la station #2 car la station #1 était localisée plus proche des baies de tir. Le cyanure d'hydrogène a été détecté à des concentrations respectives de 26.7 et 21.7 $\mu g/m^3$ pour les stations #1 et #2. le plomb a été détecté à des concentrations de 2.8 et 2.1 $\mu g/m^3$ pour les stations #1 et #2 respectivement. L'acétaldéhyde a été détecté à des concentrations de 12.7 et 9.3 $\mu g/m^3$ respectivement, et le formaldéhyde a également été détecté à des concentrations de 8.2 et 5.8 $\mu g/m^3$ pour les stations #1 et #2 respectivement. Bien que le fer et le propionaldéhyde aient aussi été détectés, il est estimé que les niveaux observés étaient trop faibles pour créer un risque pour la santé des soldats. Les concentrations pour tous les contaminants étaient similaires à la RfC de l'US EPA, qui est basée sur une exposition durant toute la vie. Puisque les artilleurs ne sont pas exposés tous les jours aux concentrations observés lors de cette étude, le risque pour leur santé est probablement plus faible que ce qui est estimé par l'US EPA.

Perspectives : Il est recommandé de poursuivre les études sur la qualité de l'air lors des tirs d'artillerie, en particulier que l'exposition personnelle soit évaluée. Il est également recommandé d'utiliser des méthodes environnementales plus sensibles pour la récolte et l'analyse des échantillons.

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1 Introduction

For many years Defence Research and Development (DRDC) Valcartier has been involved in the study of environmental impacts due to gun firing activities on live firing training ranges ([1] to [8]). Environmental site assessments were performed on the major training bases to evaluate the contamination by explosives at target and firing points ([5]). It was found that most of the fixed firing positions are contaminated with propellant residues such as nitroglycerine (NG) or 2,4-dinitrotoluene (2,4-DNT) embedded in nitrocellulose fibres deposited in front and around the gun after artillery or tank firing exercises ([7]).

Two years ago, DRDC Valcartier began to assess the dispersion of gun residues at firing points during a 105 mm howitzer live firing exercise ([8]). Residues of nitrocellulose fibres collected in front of the gun muzzle showed measurable amounts of 2,4-DNT ([8]).

After discussions with the gunners, DRDC Valcartier researchers felt that the gunners may be affected by the gaseous emissions produced by gun firings. In addition, the researchers were concerned about the size of the particles emitted during gun firing. It was then decided to characterize the gaseous emissions, as well as the particle size distribution and composition during live artillery gun firing.

Since researchers at DRDC Valcartier did not have the capability to perform gas sampling and analysis, they initiated a joint project with DRDC Toronto researchers, who are specialized in Occupational Health. The Deployable Health Hazards Assessment Team (DHHAT) at DRDC Toronto has the capacity to perform airborne measurements for a variety of substances using sorbent tubes, filters or direct reading instruments.

In September 2006, a first test was performed at the Munitions Experimental Testing Centre (METC) in Nicolet, Québec, on the C3 howitzer 105 mm ([9]). Samples were analyzed for hydrogen cyanide, nitroaromatic compounds, dinitrotoluene compounds (2,4-DNT), benzene, ethyl benzene, toluene and xylene, nitrogen oxides (NO and NO_2) and sulphur dioxide (SO_2), and particulate matter, including size distribution ([9]). Results showed that the atmospheric emissions contain toxic compounds that can induce a potential health risk for the soldiers. It was therefore decided to further investigate atmospheric emissions due to live gun firing ([9]).

In January 2007, DRDC Toronto and DRDC Valcartier collected air samples during a live training exercise at Valcartier on the new M777 155 mm howitzer ([10]). In February 2007, similar testing was performed on the anti-tank Carl Gustav 84 mm weapon. This report describes the results on the gaseous emissions produced during the training exercise. It is important to note that personal exposure was not assessed during the exercise.

2 Experimental design

The training exercise was conducted at Canadian Forces Base (CFB) Valcartier on February 7th 2007 in CFB Valcartier. DRDC Valcartier was in charge of coordinating with the infantry unit, of the particulate matter sampling and analysis, and of the 2,4-DNT analysis. DRDC Toronto was in charge of airborne contaminants sampling and analysis (except for 2,4-DNT).

2.1 Equipment and munitions

Tests were performed on the Carl Gustav 84 mm anti-tank gun L14A1. The gun is of Swedish design and manufacture. It is a recoilless, low velocity weapon, which is breech loaded and percussion fired. Two versions of the weapon are in use, namely the original M2 gun (L14A1; see Figure 1 and Figure 2) and the lightweight M3 gun (which is lighter by 6 kg). The gun can be fired from the standing, kneeling, sitting or prone position. The gun mount, housed in the shoulder pad, can be used to support the weapon when firing. Open sights are secured to the barrel; however a telescopic sight can be fitted if needed. In common with other recoilless weapons, it has a danger zone to the immediate rear of the weapon. When firing full calibre ammunition, the danger zone (back blast) is approximately 60 meters ([11]).

The sampling was performed during an exercise performed by the Voltigeurs de Québec (Reserve Force). Thirty-six students participated in the exercise. During the exercise, each student was assigned to fire at minimum one (1) cartridge, 7.62 mm, with tracer FFV 553 (sub-calibre round) plus two (2) cartridges, 84 mm, Target Practice (TP), Rocket-Assisted Projectile (RAP), FFV 552. The 84 mm, TP, RAP, FFV 552 is shown in Figure 3 and Figure 4 ([11]).

A 6.5 mm sub-calibre adaptor is provided to use with the 84 mm gun as well as the 7.62 mm ammunition. Each adaptor is designed to enable practice firing to be carried out on small arm ranges. Modified small arms cartridges are used in conjunction with the adapters and the loading into the chamber on the weapon is exactly the same as for the normal round of ammunition. Reloading of the adapter takes place outside the weapon.

The propellant charge consists of a nominal weight of 0.38 kg of the double base propellant AKB 204 in strip form. Each strip is 0.40 mm thick by 15 mm wide. The central core of the charge, consisting of about 50 g weight, measures 145 mm in length whereas the periphery of the charge is 167 mm in length ([11]).

Table 1. Composition of the double base AKB 204 propellant charge

Component	Proportions of propellant (%)
Nitrocellulose	61.0
Nitroglycerine (NG)	37.5
Ethyl Centralite	1.5

2.2 Parameters and sampling methods

As for the 155 mm howitzer ([10]), samples were collected for the following parameters: total particulates and size distribution, hydrogen cyanide, 2,4-DNT, benzene, toluene, ethyl benzene and xylene, nitrogen dioxide (NO_2), nitric oxide (NO), SO_2, nitric acid (HNO_3), hydrogen sulphide (H_2S), polycyclic aromatic hydrocarbons (PAHs), metals and aldehydes. Nitroaromatic compounds were not analyzed as they were never detected in the preliminary trial in Nicolet ([9]). Collection and sampling methods are described in detail in a previous report ([10]).

2.3 Sampling strategy

Sampling was carried on February 7, 2007 from 9:30 am to 11:15 am. Weather data were obtained from the meteorological station at Jean Lesage International Airport in Quebec City ([12]) and are shown in Annex B. The temperature for the sampling day varied from – 17.8 ºC to – 13.0 ºC during the sampling period. Wind speed was low and varied from 15 to 20 km/hr while the wind was coming from the West-South-West. Relative humidity varied from 68 to 55 %. Average atmospheric pressure was 99.8 kPa.

The class was composed of 36 students divided into 9 groups of 4 persons each. There were 2 firing bays with 2 persons per station. Distribution of students at the firing bays is shown inTable 2. In total, 39 rounds were fired at Bay #1 and 32 rounds at Bay #2 for an overall of 71 rounds.

As we had almost all the sampling material in duplicate, two sampling stations were prepared. Therefore, there was one sampling kit for every compound on each station. The exercise was planned to progress very quickly, and because of the danger zone behind the personnel caused by the back blast of the firing, the positions available for the sampling stations were limited. It was not possible to move the sampling stations from one position to another and even though it would have been better to sample material closer to the rear end of the gun, the back blast surely would have been too strong for the sampling media. As there was no or only little wind during the exercise, it was decided to place the sampling stations in line with Firing Bay #2, protected from the back blast by sand bags as shown on Figure 5 and Figure 6. Sampling Station #1 was closer to the gun and the gunners. After sampling, the tubes and cassettes were closed hermetically and brought back to the laboratory in coolers.

The impactor was placed in sampling Station #1. The SKC 224-PCXR8 pumps and the LFS-113 DC pumps can be used in the temperature range from -20°C to 45°C, but the technical specifications of the GilAir 5 state an operating range from 0°C to 40°C. Also, due to the presence of a solution of potassium hydroxide (KOH) in the bubbler for cyanide sampling, it was decided to use a heating system to ensure the proper work of the pumps and we avoid the freezing of the solution. An isolated box covered with glass wool and containing hot pads was used. The pumps were plugged with their respective sampling kits, turned on and deposited on the hot pads. Free space was filled with glass wool. Sampling media were placed outside the box and the cover was closed in a way to keep most of the heat inside the box and to ensure that the tubes were not squeezed or kinked (Figure 7).

Table 2. Number of rounds fired by firing bay and by team

Team	Firing bay	Number of rounds per bay	Total rounds per Team
1	#1	4	8
	#2	4	
2	#1	4	10
	#2	6	
3	#1	4	9
	#2	5	
4	#1	5	10
	#2	5	
5	#1	4	8
	#2	4	
6	#1	4	8
	#2	4	
7	#1	6	10
	#2	4	
8	#1	4	8
	#2	4	
9	#1	4	6
	#2	2	

One blank per parameter was brought to the field and send for analysis along with the samples. Samples were not taken in duplicates. All the pumps were calibrated the day before the outside at -20 ºC to account for the expected cool temperature. They were calibrated again immediately after sampling at the same temperature. Samples were kept refrigerated and send to the laboratory for analysis. Size distribution analyses and 2,4-DNT analyses were performed in the laboratory at DRDC Valcartier. All other analyses were done by Clayton Group Services Inc. (Novi, Michigan and Atlanta, Georgia).

3 Results and discussion

For data interpretation, environmental standards and toxicology reports from the US EPA, Health Canada, and the Canadian Council of the Ministry of Environment (CCME) were used. (Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienists (ACGIH) were not considered applicable as there was no evaluation of personal exposure over an 8-hour period as required by the ACGIH. Data interpretation is mainly based on possible rather than actual health risks due to exposure to emissions compounds.)

Contrary to the previous trial ([10]), gaseous cyanide, iron, lead, and three aldehydes were detected.

3.1 Pump calibration

Results for the pumps calibration are shown in Table 3 for each type of substance. The last column shows the difference between pre and post sampling.

Unfortunately some pumps topped during sampling, probably due to the cold temperature, and one sampling tube was broken, maybe because of the back blast. In fact, the coolers moved backward during the exercise due to the back blast.

For all parameters the difference between pre and post sampling is always lower than 10 %, except for one sample for SO_2, which is considered as acceptable. Average pump flow was used for further calculations.

Table 3. Pump calibration for each type of substances

Parameter	Table #	Pre-flow (cc/min)	Post-flow (cc/min)	Average (cc/min)	Difference %
PAHs	1	2163	1950	2056.5	5.2
PAHs	2	2057	1896	1976.5	4.1
Cyanide	1	1000	1054	1027.0	2.6
Cyanide	2	1046	905.3	975.7	7.2
Metals	1	3940	3815	3877.5	1.6
Metals	2	3932	3846	3889.0	1.1
Particles	1	3980	3911	3945.5	0.9
Particles	2	4007	3963	3985.0	0.6
2,4-DNT	1	1021	1014	1017.5	0.3
2,4-DNT	2	1003	1037	1020.0	1.7
Benzene/toluene	1	212.2	192.0	202.1	5.0
Benzene/toluene	2	198.2	193.8	196.4	1.3
Aldehydes	1	510.9	483.0	497.0	2.8
Aldehydes	2	506.3	476.1	491.2	3.1
HNO_3	1	483.6	n/a[1]	n/a	n/a
HNO_3	2	472.8	489.6	481.2	1.8
H_2S	1	1452	n/a[2]	n/a	n/a
H_2S	2	1358	n/a[1]	n/a	n/a
SO_2	1	119.7	106.1	112.9	6.0
SO_2	2	125.5	93.6	109.6	14.6
NO/NO_2	1	25.1	21.1	23.1	8.7
NO/NO_2	2	28.2	28.0	28.1	0.4
Impactor	1	1782	2091	1936.5.5	8.0

[1] The pump stopped during sampling

[2] The pump stopped during sampling and the sampling tube was broken

3.2 Particle concentration and size distribution

Particle concentrations at Station #1 and #2 (Figure 6) were 31.6 and 32.6 mg/m^3, respectively. This is much higher than the concentrations observed during the first trials ([9], [10]). This can be explained by the fact that the smoke is released through the rear of the Carl Gustav weapon where the coolers were located. Therefore, the sampling equipment was closer to the smoke than in the previous trials.

Evaluation of size distribution was not possible in this study as the masses on the filters of the impactor were too low to allow for proper weighing. However, it is reasonable to estimate that, as for the previous trials, most of the particles are less than 4 µm ([9], [10]).

Fine particles are considered to be the most hazardous ([13]). Particles under 4 µm are known to be deposited in the gas-exchange region of the lungs ([17]). Health effects related to chronic exposure to fine particles include cardiac-related and respiratory effects ([16]).

Table 4. Recommendations for particulate matter concentration in ambient air

Particle size	**US EPA (mg/m^3) ([14])**	**Health Canada (mg/m^3) ([15])**	**CCME (mg/m^3) ([13])**
PM10[1]	0.15		
PM2.5[2]	0.015		
PM2.5[3]	0.035		0.03
TSP[4]		0.07	
TSP[5]		0.12	
TSP[6]		0.40	

[1] Particulate Matter < 10 µm, 24-hour standard

[2] Particulate Matter < 2.5 µm, annual standard

[3] Particulate Matter < 2.5 µm, 24-hour standard

[4] Total Suspended Particulate, annual standard, maximum acceptable level

[5] Total Suspended Particulate, 24-hour standard, maximum acceptable level

[6] Total Suspended Particulate, 24-hour standard, maximum tolerable level

From the previous trial, we can estimate that approximately 30 % of the particles were less than 2.5 µm, which gives an estimated PM2.5 concentration of approximately 10 mg/m^3. This is much higher than recommended environmental standards. Fine particles are therefore considered to be a potential risk for the soldier's health.

It is therefore recommended to assess personal exposure to fine particles and to properly evaluate PM2.5.

3.3 Hydrogen cyanide

Total hydrogen cyanide levels are shown in Table 5, which includes the US EPA Reference Concentration (RfC) for chronic inhalation exposure ([18]). The RfC for the US EPA is "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" ([18]).

Cyanide is well absorbed by the gastrointestinal tract and the skin, and is rapidly absorbed by the respiratory tract ([19]). Cyanide is rapidly distributed throughout the body, although there is no accumulation of cyanide in the blood or tissues following chronic exposure. Approximately 80 % of cyanide is metabolized to thiocyanate in the liver which is excreted in the urine ([19]). Chronic hydrogen cyanide exposure is known to induce neurological, respiratory, cardiovascular, and thyroid effects ([18], [19]). Occasionally, irritation to the skin and eyes may be observed ([19]). Typical exposure for the general population is from tobacco smoke, automobile exhaust and waste incinerators ([19]). A lethal dose is estimated to be 50 mg for an average adult ([19]).

Table 5. Gaseous hydrogen cyanide concentrations for the two stations

	Concentration (µg/m3)
Station #1	26.7
Station #2	21.7
RfC[1] ([18])	**3.0**

[1] Lifetime exposure

Outside temperature during this study was very low. All the pumps and the bubbler containing the KOH were installed inside a cooler with a heating system (see Section 2.3). Unfortunately, approximately half of the KOH solution was lost during sampling due to overflow of the bubbler. It is believe that the difference between the temperature inside and outside the cooler was responsible for the overflow. The cool air expanded while entering the warm cooler, creating an overflow of the bubbler. Therefore, hydrogen cyanide concentrations are likely to be underestimated.

Concentration was higher at Station #1 than at Station #2 due to the fact that the first station was closer to the firing bays (Figure 6). Concentrations are higher than the recommended RfC from the US EPA ([18]), which is based on a lifetime exposure, and is not the case herein. Some studies have shown that workers exposed to chronic concentrations of 0.2 mg/m^3 of hydrogen cyanide suffer typical health effects such as headache and nausea ([18], [19]). In normal operations, artillery soldiers are not exposed in this manner and the risk of any health effect is very small. Further investigation will be needed to assess personal exposure as it is expected that concentrations closer to the gun will be higher than those observed in this study, and as these concentrations were likely underestimated.

3.4 Metals

Amongst the list of metals, only iron and lead were detected at both Stations. Results are shown in Table 6. The US EPA does not have any RfC for these two compounds but it does have a National Ambient Air Quality Standard (NAAQS).

Lead is classified as a probable human carcinogen by the US EPA ([21]). Other health effects include, but are not limited to, neurotoxicity, hypertension, impaired haemoglobin synthesis and male reproductive impairment ([21], [22]).

Table 6. Iron and lead concentrations at both sampling stations

	Iron (µg/m3)	**Lead (µg/m3)**
Station #1	2.7	2.8
Station #2	4.3	2.1
NAAQS[1]	**-**	**1.5**

[1] [14]

Both iron and lead concentrations are low. Iron is only toxic at high concentrations ([20]). Therefore, concentrations observed during this study suggest that iron is not a potential health risk for gunners.

Lead concentrations observed at Stations #1 and #2 are higher than the NAAQS, the concentration at Station #1 being almost twice the level of the standard, which is based on a lifetime exposure. As gunners are not exposed to these concentrations on a daily basis, their risk is far lower than the estimated US EPA risk and no more than the risk of the general population. However, as gunners are closer to the emissions than the sampling stations, it is reasonable to believe that they are exposed to higher concentrations. Therefore it is highly recommended to properly assess personal exposure.

3.5 Aldehydes

Acetaldehyde, formaldehyde and propionaldehyde were detected during this study. Results are shown in Table 7. The US EPA has a RfC for chronic inhalation exposure only for acetaldehyde ([23]).

Table 7. Concentrations of aldehydes for each sampling location

	Acetaldehyde ($\mu g/m^3$)	**Formaldehyde ($\mu g/m^3$)**	**Propionaldehyde ($\mu g/m^3$)**
Station #1	12.7	8.2	10.6
Station #2	9.3	5.8	8.5
RfC	**9.0**[1]	**-**	**-**

[1] [23]

Acetaldehyde is known to be irritating to the eyes and the upper respiratory tract during short exposure ([24]). It may cause pulmonary oedema at high concentrations ([24]). It is classified as a probable carcinogen by the US EPA ([23], [24]). Environmental exposure to acetaldehyde is through inhalation of ambient air, cigarette smoke and ingestion of food containing acetaldehyde ([24]). As acetaldehyde is a metabolite of ethyl alcohol, it is believed that it is associated with liver damage, facial flushing and developmental effects ([24]). The risk level for cancer is 1 in 10,000 for a concentration of 5 $\mu g/m^3$ ([23]).

Acetaldehyde concentrations are higher at Station #1 than at Station #2 as the first station was closer to the firing bay. Concentrations are at a similar level than the RfC from the US EPA and about two times higher than the risk level of 1 in 10,000 ([23]). However, these concentrations are based on a daily lifetime exposure for the general population. Therefore, the health risk for artillery soldiers is likely to be lower than the EPA estimate. However, as gunners are closer to the gaseous emissions than the sampling stations, it is believed that they are exposed to higher concentrations. As acetaldehyde can be irritating for the upper respiratory tract even for short time exposure, it is highly recommended that personal exposure and health risk to the gunners be properly assessed.

Formaldehyde is known to cause irritation of the mucosa in the eyes and upper airways ([25]). Formaldehyde is also considered as a probable carcinogen by the US EPA ([25]). Nasopharyngeal and lung cancers have been observed in workers exposed to formaldehyde ([25]). Formaldehyde can be found in combustion products such as diesel exhaust and cigarette smoke ([25], [27]).

According to the US EPA, a formaldehyde concentration of 8 $\mu g/m^3$ gives a carcinogenic risk level of 1 in 10,000 ([26]). This level is similar to formaldehyde concentration observed at the two stations. Since the soldiers are not exposed on a daily basis for a lifetime their risk is likely far lower than the EPA estimate and likely no more than the general population. However, the gunners are working closer to the gun and it is therefore recommended that personal exposure be assessed in order to properly estimate the health risk.

Propionaldehyde is known as an irritant to the eyes and the upper respiratory tract ([28]). Environmental exposure may occur from ambient air and tobacco smoke ([29]). Although there is no RfC for propionaldehyde, it is unlikely that concentrations observed during our study constitute a health risk for the gunners. However, its irritating effects may be added to the effects of other contaminants and it is therefore recommended that personal exposure be properly assessed.

4 Conclusion

This study was performed following a preliminary study on the 105 mm howitzer done at Nicolet, Québec and a more complete study performed during a live firing exercise on the howitzer 155 mm. In total, 71 rounds were fired at Firing Bays #1 and #2. Samples were collected at two sampling stations located behind Firing Bay #2.

Samples collected during this study showed significant concentrations for particles, hydrogen cyanide, iron, lead, acetaldehyde, formaldehyde and propionaldehyde. However, no other contaminants were detected. This might be due to dilution of the gaseous emissions.

Particle concentrations observed during this study were a lot higher than during the two previous studies. Unfortunately, we were unable to measure particle distribution but it is likely that most of the particles are fine particles as observed previously. Our estimation gave a fine particle concentration a lot higher than environmental standards. Therefore, particles are considered to be a potential health risk for gunners.

Iron concentrations observed during this study are considered to be too low to be a health risk for artillery soldiers. However, lead concentrations were almost two times higher than the ambient air standard from the US EPA for a lifetime exposure. Although as soldiers' exposure is very short, it is likely that their risk is lower than the EPA estimate. However, as concentrations close to the gun are likely to be higher than those observed here, further investigation should be performed to verify the health risk to the soldiers.

Acetaldehyde, formaldehyde and propionaldehyde were detected at concentrations similar to RfC or to a cancer risk level estimated by the US EPA. However, as for the other contaminants, soldiers' exposure to these concentrations is very short; therefore their risk level is likely to be similar to the risk level of the general population. However, the concentrations closer to the guns are likely to be higher than the ones observed in the study. As aldehydes are irritating to the upper respiratory tract even during short time exposure, it is highly recommended that further investigations be made on aldehydes concentrations, particularly to assess personal exposure.

As few contaminants were detected, it is recommended that methods are used that are more appropriate for sample collection and analysis for the area samples. It is also recommended that both area and personal exposure samples be collected as there may be soldiers located further away from the guns.

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Annex A Sampling installation

A.1 Equipment and munitions

Figure 1. The Carl Gustav 84 mm weapon (L14A1) and ammunition

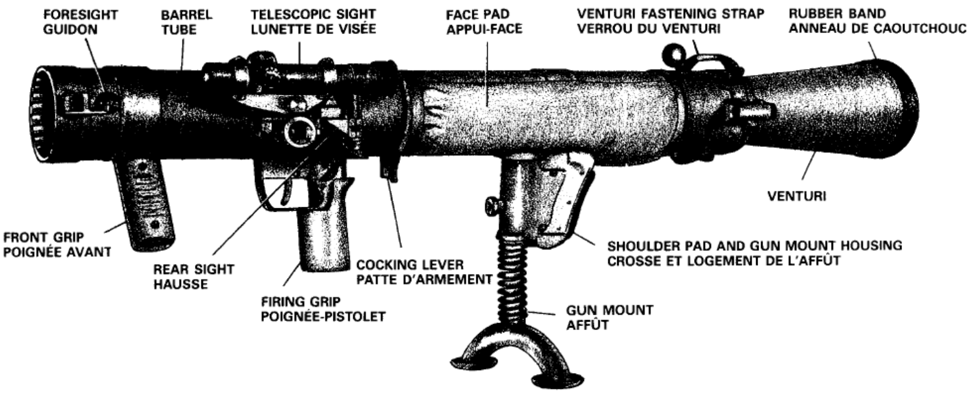

Figure 2. The anti-tank 84 mm L14A1 gun

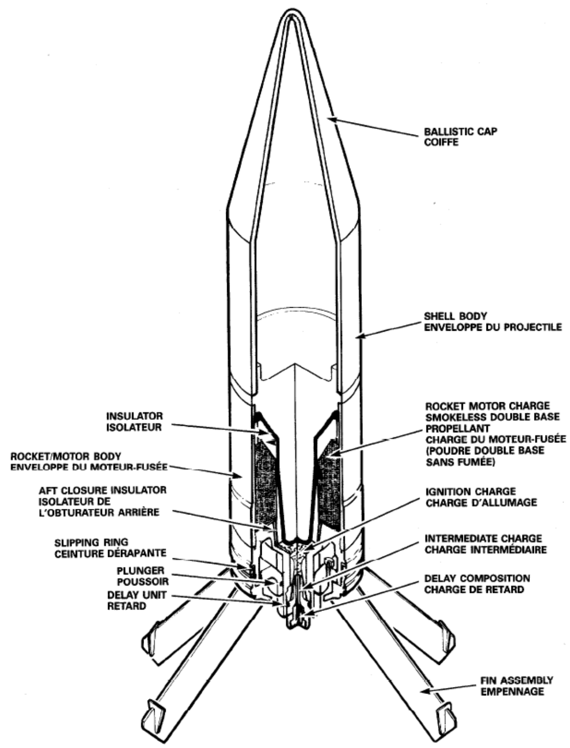

Figure 3. Shell 84 mm, TP, RAP, FFV 552 (with fins deployed)

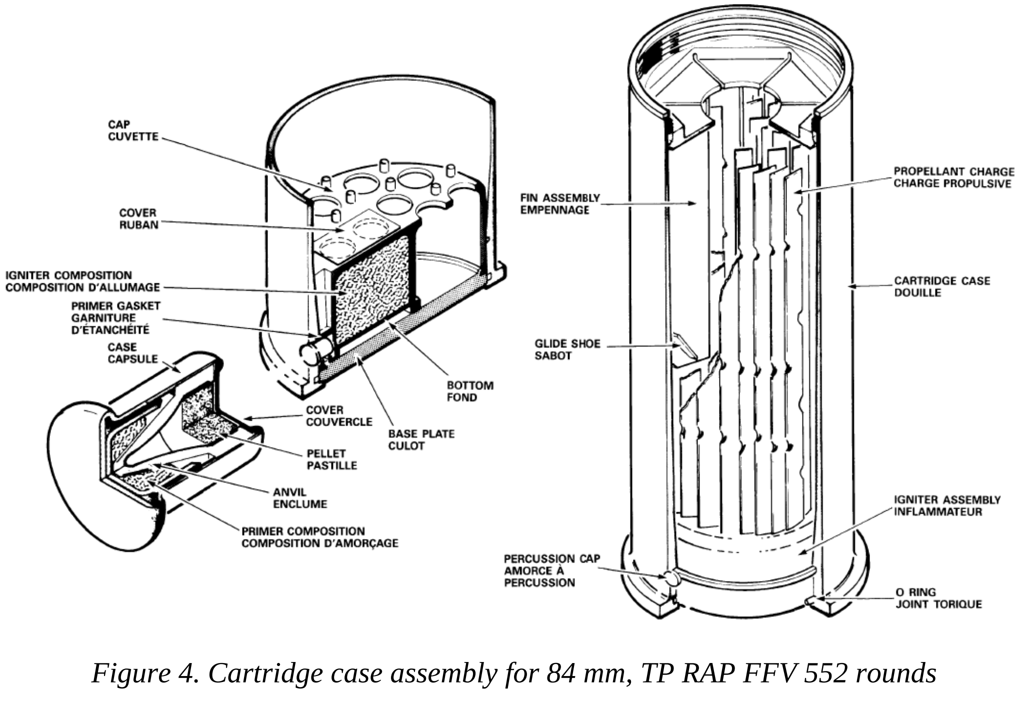

Figure 4. Cartridge case assembly for 84 mm, TP RAP FFV 552 rounds

A.2 Sampling strategy

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

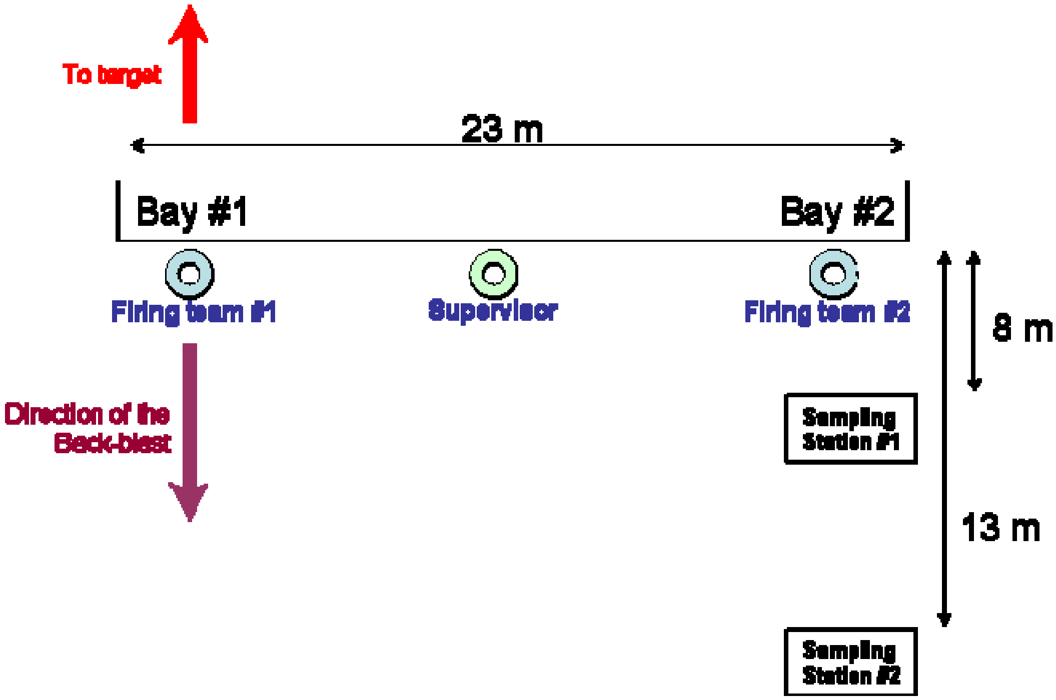

Figure 6. Positions of the sampling stations and the personnel during the exercise

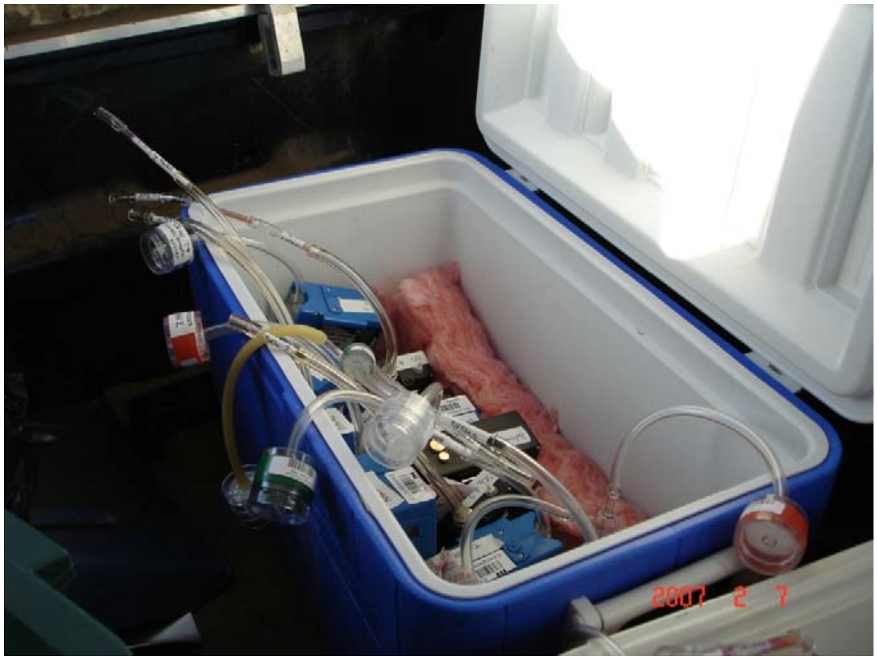

Figure 7. Sampling equipment inside the cooler

Annex B Climate data

Hourly Data Report for February 7, 2007										
Time	Temp °C	Dew Point Temp °C	Rel Hum %	Wind Dir 10's deg	Wind Spd km/h	Visibility km	Stn Press kPa	Hmdx	Wind Chill	Weather
00:00	-18.5	-22.3	72	25	17	M	100.04		-28	NA
01:00	-18.4	-22.1	73	24	15	M	99.99		-27	NA
02:00	-18.1	-22.0	71	26	19	M	99.97		-28	NA
03:00	-18.9	-22.9	71	24	15	M	99.93		-28	NA
04:00	-19.4	-23.2	72	25	19	M	99.89		-29	NA
05:00	-19.1	-22.6	74	24	15	M	99.88		-28	NA
06:00	-22.6	-25.8	75	35	4	M	99.86			NA
07:00	-23.3	-26.1	78	24	7	M	99.84			NA
08:00	-19.9	-22.5	80	24	13	M	99.84		-28	NA
09:00	-17.8	-22.3	68	24	20	M	99.83		-28	NA
10:00	-16.7	-21.3	67	21	15	M	99.80		-25	NA
11:00	-15.2	-19.9	67	23	17	M	99.79		-24	NA
12:00	-13.0	-20.1	55	25	20	M	99.69		-22	NA
13:00	-12.6	-19.5	56	24	22	M	99.61		-22	NA
14:00	-12.6	-20.9	50	25	28	M	99.59		-23	NA
15:00	-12.4	-18.3	61	23	19	M	99.61		-21	NA
16:00	-13.1	-17.5	69	24	19	M	99.63		-22	NA
17:00	-13.4	-19.7	59	24	22	M	99.65		-23	NA
18:00	-14.8	-20.2	63	26	17	M	99.67		-23	NA
19:00	-14.9	-19.1	70	25	19	M	99.69		-24	NA
20:00	-16.1	-19.7	74	26	17	M	99.69		-25	NA
21:00	-15.8	-19.9	71	25	19	M	99.72		-25	NA
22:00	-16.6	-21.3	67	24	15	M	99.73		-25	NA
23:00	-16.0	-19.1	77	25	19	M	99.69		-25	NA

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List of symbols/abbreviations/acronyms/initialisms

2,4-DNPH	2,4-Dinitrophenylhydrazine
2,4-DNT	2,4-Dinitrotoluene
ACGIH	American Conference of Governmental Industrial Hygienists
BFC	Base des Forces Canadiennes
CCME	Canadian Council of the Ministry of Environment
CFB	Canadian Forces Base
D FHP	Directorate of Force Health Protection
DHHAT	Deployable Health Hazard Assessment Team
DRDC	Defence Research and Development Canada
EPA	Environmental Protection Agency
HAP	Hydrocarbures aromatiques polycycliques
HNO_3	Nitric acid
H_2S	Hydrogen sulphide
KOH	Potassium hydroxide
METC	Munitions Experimental Testing Centre
NAAQS	National Ambient Air Quality Standard
NATO	North Atlantic Treaty Organization
NG	Nitroglycerine
NO	Nitric oxide
NO_2	Nitrogen dioxide
PAHs	Polycyclic aromatic hydrocarbons
PM	Particulate matter
RAP	Rocket-assisted projectile
R&D	Research & Development
RfC	Reference concentration
SO_2	Sulphur dioxide
TLV	Treshold Limit Values
TP	Target practice
TSP	Total Suspended Particulate
US	United States

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Airborne substances emitted during live gun firing of the anti-tank Carl Gustav 84 mm weapon were characterized during a live firing training exercise in Canadian Forces Base (CFB) Valcartier in February 2007. Sampling was performed continuously for two hours throughout the exercise during which particles and chemicals accumulated on sampling media. In total, seventy-one rounds were fired at two firing bays. Established occupational health methods were used to collect and analyze samples for particulate matter, hydrogen cyanide, polycyclic aromatic hydrocarbons (PAHs), dinitrotoluene compounds, benzene, toluene, ethylbenzene and xylene, metals, aldehydes, nitric acid (HNO_3), nitric oxide (NO), nitrogen dioxide (NO_2), hydrogen sulphide (H_2S) and sulphur dioxide (SO_2). Two sets of samples were collected at two sampling stations. Both sampling stations were located behind Firing Bay #2. Most of the chemicals were not detected during the trial. For both sets of samples, particles were found at concentrations much higher than the recommended environmental standards. These findings suggest that there is a potential risk to health associated with exposure to particles for artillery soldiers. For contaminants, concentrations were detected at higher levels at Station #1 than at Station #2 since the first station was closer to the firing bay. Hydrogen cyanide was detected at concentrations of 26.7 and 21.7 µg/m^3 for Stations #1 and #2, respectively. Lead was detected at concentrations of 2.8 and 2.1 µg/m^3 for Stations #1 and #2, respectively. Acetaldehyde was detected at concentrations of 12.7 and 9.3 µg/m^3, respectively, and formaldehyde was also detected at concentrations of 8.2 and 5.8 µg/m^3 for Stations #1 and #2, respectively. Although iron and propionaldehyde were also detected, it is believed that the concentrations observed were too low to create a potential risk for the soldiers. Concentrations for all contaminants were similar to the reference concentration (RfC) from the United States Environmental Protection Agency (US EPA), which is based on a lifetime exposure. Since gunners are not exposed on a daily basis to the levels observed during this study, their risk is likely to be lower than the EPA estimate. However, these findings suggest that there is a need to conduct personal sampling to assess the health risk, if any, to artillery soldiers. For all substances it is recommended that further investigations of air concentrations be made to properly assess personal exposure. It is also recommended that more sensitive environmental methods be used to collect and analyse the samples.

Les composés gazeux et particulaires émis lors des tirs d’anti-char Carl Gustav 84 mm ont été caractérisés lors d’un exercice d’entraînement à la Base des Forces Canadiennes (BFC) Valcartier en février 2007. L’échantillonnage a été effectué en continu pendant deux heures lors de l’exercice, les particules et émissions gazeuses s’accumulant sur les media d’échantillonnage. Au total, soixante et onze tirs ont été effectués à deux baies de tirs. Des méthodes reconnues en hygiène du travail ont été utilisées pour collecter et analyser les échantillons pour les particules en suspension, le cyanure d’hydrogène, les hydrocarbures aromatiques polycycliques (HAP), les composés dinitrotoluène, le benzène, le toluène, l’éthylbenzène et le xylène, les métaux, les aldéhydes, l’acide nitrique (HNO_3), le monoxyde d’azote (NO), le dioxyde d’azote (NO_2), le sulfure d’hydrogène (H_2S) et le dioxyde de soufre (SO_2). Deux lots d’échantillons ont été collectés à deux stations d’échantillonnage. Les deux stations étaient localisées en arrière de la baie de tir #2. La plupart des composés n’ont pas été détectés lors de l’exercice. Pour les deux sets d’échantillons, les particules ont été mesurées à des concentrations beaucoup plus élevées que les normes environnementales. Ces résultats suggèrent que les particules représentent un risque potentiel pour la santé des soldats. Pour les autres contaminants, les niveaux étaient plus élevés à la station #1 qu'à la station #2 car la station #1 était localisée plus proche des baies de tir. Le cyanure d'hydrogène a été détecté à des concentrations respectives de 26.7 et 21.7 $\mu g/m^3$ pour les stations #1 et #2. Le plomb a été détecté à des concentrations de 2.8 et 2.1 $\mu g/m^3$ pour les stations #1 et #2 respectivement. L'acétaldéhyde a été détecté à des concentrations de 12.7 et 9.3 $\mu g/m^3$ respectivement, et le formaldéhyde a également été détecté à des concentrations de 8.2 et 5.8 $\mu g/m^3$ pour les stations #1 et #2 respectivement. Bien que le fer et le propionaldéhyde aient aussi été détectés, il est estimé que les niveaux observés étaient trop faibles pour créer un risque pour la santé des soldats. Les concentrations pour tous les contaminants étaient similaires à la concentration de référence (RfC) de l'agence de protection de l'environnement des États-unis (US EPA), qui est basée sur une exposition durant toute la vie. Puisque les artilleurs ne sont pas exposés tous les jours aux concentrations observés lors de cette étude, le risque pour leur santé est probablement plus faible que ce qui est estimé par le US EPA. Cependant, ces résultats suggèrent qu'il est nécessaire de mesurer l'exposition personnelle afin d'évaluer le risque, s'il y a lieu, pour la santé des artilleurs. Il est donc recommandé de poursuivre les études sur la qualité de l'air lors des tirs d'artillerie, en particulier que l'exposition personnelle soit évaluée. Il est également recommandé d'utiliser des méthodes environnementales plus sensibles pour la récolte et l'analyse des échantillons.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Atmospheric emissions, health effects, artillery gun firing, Carl Gustav, anti tank, 84 mm

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