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Technical Report
DRDC Valcartier TR 2009-420
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Abstract

Extensive research indicates that propellant residues accumulate at firing positions and represent a concern for the environment and human health. To better understand the impacts of live firing at firing positions, a series of characterizations was conducted to measure the deposition of propellant residues from many sources. The present study was conducted three times with Leopard tanks firing 105-mm tank gun ammunition. The first trial was carried out at CFB Gagetown where no propellant residues were identified. For validation purposes, two additional trials were conducted at CFB Valcartier. DRDC Valcartier assessed the particles emitted, the gaseous emissions, and the particles size distribution during these live-fire events. Gases were collected in front of and inside the tank and the results from the gaseous emissions study will be described in another report. This paper describes the results obtained on the deposition of propellant residues during tank live firings. In November 2008, the setup consisted of half circles of particle traps disposed at 1, 5, 10, 15, 20, 30 and 40 m in front of the tank. Ethanol was poured inside the traps to contain the particles emitted during firing. Following the first set of firings, many traps were destroyed, some caught fire, and the experiment had to be stopped. During this event, since the gaseous collection system was adequate, it was decided to continue the firing to measure the gaseous emissions. The particle collection experiment was postponed until February 2009 when a more robust setup could be put in place. During the February 2009 test, two methods of residues collection were compared: the snow collection and the particle trap methods. For this trial, the new traps were placed in front of the tank using a square pattern at 3, 5, 10, 15, 20, 25, 30, 40 and 45 m. This time, the particle trap setup was efficient and robust enough to collect the residues. Results from both collection methods were compared. It was found that firing 105-mm tank gun ammunition leads to the accumulation of solid propellant residues in the vicinity of the gun at 0.00263 % by weight of unburned 2,4-DNT. Similar results were obtained by both methods, confirming the validity of these results. It was also found that most of the particles are deposited at 20-25 m in front of the tank. This paper describes the sampling strategy, the laboratory procedure, and the results obtained.

Résumé

Une recherche intense a indiqué que des résidus de propergol s'accumulent aux positions de tir et représentent une source de préoccupation pour l'environnement et pour la santé humaine. Afin de mieux comprendre les impacts des tirs réels aux positions de tir, une série de caractérisations a été effectuée pour mesurer la déposition de résidus de propergol provenant de nombreuses sources. La présente étude a été conduite à trois reprises avec des chars d'assaut Léopard faisant feu avec des obus de 105 mm. Le premier essai a été réalisé à la base de Gagetown (BFC Gagetown) où aucun résidu de propergol n'avait été identifié. À des fins de validation, deux essais additionnels ont été réalisés à la BFC Valcartier. RDDC Valcartier a évalué la dispersion des particules émises, les émissions de gaz et la distribution granulométrique des particules durant ces essais à tir réel. Les gaz ont été recueillis à l'avant et à l'intérieur du char d'assaut et ces résultats de l'étude des émissions gazeuses seront décrits dans un autre rapport. Ce rapport décrit les résultats obtenus sur la déposition des résidus de propergol durant les tirs réels effectués par le char d'assaut. En novembre 2008, la disposition des pièges à particules a consisté en des demi-cercles de pièges disposés à des distances de 1, 5, 10, 15, 20, 30 et 40 m en avant du char. De l'éthanol a été versé dans ces pièges pour contenir les particules émises par les tirs. Suite à la première série de tirs, plusieurs pièges ont été détruits, certains ont pris feu et l'expérience a dû être arrêtée. Lors de cet événement, puisque le système de collecte des gaz était adéquat, il a été décidé de poursuivre les tirs et de mesurer les émissions de gaz. L'expérience de collecte des particules a dû être reportée en février 2009 où un ensemble de pièges plus robustes a pu être mis en place. Au cours de l'essai de février 2009, deux méthodes de collecte des résidus ont été comparées: la collection des particules sur la neige et la méthode des pièges à particules. Pour cet essai, les nouveaux pièges ont été placés en avant du char en utilisant un patron carré à des distances de 3, 5, 10, 15, 20, 25, 30, 40 et 45 m. Cette fois-ci, notre ensemble de pièges a été efficace et suffisamment robuste pour capturer les résidus. Les résultats des deux méthodes de collecte ont été comparés. Il a été constaté que le tir de munitions de 105 mm du canon des chars conduit à l'accumulation de résidus de propergol solide dans le voisinage du canon à 0.00263 % en poids de 2,4-DNT non brûlé. Des résultats similaires ont été obtenus par les deux méthodes confirmant la validité de ces résultats. Il a également été trouvé que la majorité des particules sont déposées à 20-25 m en face du char. Ce document décrit la stratégie d'échantillonnage, la procédure de laboratoire et les résultats obtenus.

Executive summary

Evaluation of the propellant residues emitted during 105-mm Leopard tank live firing at CFB Valcartier, Canada

Guy Ampleman; Sonia Thiboutot; André Marois; Annie Gagnon; Denis Gilbert; Michael R. Walsh; Marianne E. Walsh; Peter Woods; DRDC Valcartier TR 2009-420; Defence R&D Canada – Valcartier; December 2009.

Introduction or background: For years, DRDC Valcartier has invested efforts to understand the environmental impacts of the live firing of munitions. Originally, it was thought that the target positions should be the most contaminated areas. Many target areas in many training ranges such as anti-tank, artillery, tank, grenade ranges, etc. were sampled and the highest levels of explosives were identified in anti-tank ranges (5,000 ppm HMX). It was also found that the detonation of normally functioning weapons leads to almost no contamination when high-order detonation is observed. Later on, it was found that the land between the firing positions and the targets is little or simply not contaminated, the contamination coming mainly from the malfunctioning munitions (UXO) that are found and destroyed in place by open detonation leading on some occasions to low-order detonations that are polluting. More recently, it was discovered that the firing positions are the areas most contaminated by energetic materials in the training ranges. Concentrations of nitroglycerin as high as 10,000 ppm were found in anti-tank ranges behind the firing lines. Since then, DRDC Valcartier has decided to investigate more deeply the firing positions especially since the users are always at the firing line possibly exposed to contaminants of concern. So far, anti-tank with Carl-Gustav and M-72 weapons, small arms, artillery with 105 and 155-mm and Navy guns firing positions were studied. Tank firings were studied once at CFB Valcartier (but this was a preliminary study) and a second time at CFB Gagetown. For validation purposes, DRDC Valcartier sampled once more a Leopard tank firing 105-mm shells during an exercise in CFB Valcartier in November 2008 and February 2009. The objective of this exercise was to validate the results obtained at CFB Gagetown and compare with the firing of artillery 105-mm that projects 0.3-0.5% by weight of 2,4-dinitrotoluene residues in the environment.

Results: In November 2008, the setup consisted of half circles of particle traps disposed at 1, 5, 10, 15, 20, 30 and 40 m in front of the tank. Ethanol was poured inside the traps to catch and trap the particles emitted during the firings. Following the first set of firings, many traps were destroyed, some caught fire and the experiment had to be stopped and postponed until February 2009 when a more robust setup was put in place. During the February 2009 event, two methods of particles collection were compared; the snow collection and the particle traps method. For this trial, the new traps were disposed in front of the tank using a square pattern at 3, 5, 10, 15, 20, 25, 30, 40 and 45 m. This time, our particle traps setup was efficient and robust enough to withstand the firing blast and to collect the particles. Results from both collection methods were compared. It was found that firing 105-mm tank gun ammunition leads to the accumulation of solid propellant residues in the vicinity of the gun at 0.00263 % by weight of unburned 2,4-DNT. The same results were obtained by both methods confirming the validity of these results. It was also found that most of the particles are deposited at 20-25 m in front of the tank.

Significance: These results indicated that the tank firings are cleaner than the artillery firings and lead to little contamination by 2,4-DNT. This could be explained by the larger amount of

propellant fired in tank munitions compared to artillery munitions. The amount of propellant in tank 105-mm munitions being twice the amount used for firing 105-mm artillery shells leads to increased pressures and temperatures inside the gun barrel. This results in a better combustion in the tank gun and consequently leads to less residues and a less polluting military activity. This is of significant importance considering that it may help understand and eventually solve the artillery problems by adjusting the propellant charge to get zero emissions of 2,4-DNT.

Future plans: DRDC Valcartier has already accumulated a lot of data concerning the propellant particles emitted at firing positions during live fire exercises. Combined with the expertise developed at sampling the target and impact areas and also based on our knowledge of munitions development and energetic materials in general, we are now in a good position to propose mitigation solutions and try to address the issues encountered with specific weapon systems. Projects to design new training ranges are ongoing and they will address and try to find solutions to the identified issues. More importantly, the development of better green weapons that will not have the same weaknesses as conventional weapons was initiated. It is highly probable that solutions will be identified to address specific problems with these specific weapon platforms.

Sommaire

Evaluation of the propellant residues emitted during 105-mm Leopard tank live firing at CFB Valcartier, Canada

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Introduction ou contexte: Depuis plusieurs années, RDDC Valcartier a investi des efforts pour comprendre les impacts environnementaux du tir réel de munitions. À l'origine, on pensait que les zones les plus contaminées devaient être les zones d'impact comme les cibles. Plusieurs cibles dans de nombreuses aires d'entraînement telles que d'antichar, de l'artillerie, de chars, de grenades, etc. ont été échantillonnées et il a été constaté que les concentrations les plus élevées d'explosifs ont été trouvées dans les sites de tir antichar (5000 ppm en HMX). Il a été également constaté que les munitions qui fonctionnent normalement conduisent à une contamination presque nulle lorsque des détonations de premier ordre sont observées. Plus tard, on a constaté que les sols entre les positions de tir et les cibles sont simplement peu ou pas contaminés, la contamination provenant essentiellement du mauvais fonctionnements de munitions (UXO) qui sont trouvées et détruites sur place par détonation extérieure conduisant dans certains cas à des détonations du second ordre qui sont polluantes. Plus récemment, on a découvert que les positions de tir des secteurs d'entraînement sont les zones les plus contaminées par des résidus énergétiques. Des concentrations de nitroglycérine aussi élevées que 10000 ppm ont été trouvées aux positions de tir antichar derrière la ligne de feu. Depuis, RDDC Valcartier a décidé d'investiguer les positions de tir considérant que les utilisateurs y sont toujours présents et peuvent éventuellement être exposés à des contaminants. Jusqu'à maintenant, les positions de tir d'antichar avec Carl Gustav et M-72, d'armes légères, d'artillerie de 105 et 155 mm et de la marine ont été échantillonnées. Le tir à partir de chars d'assaut a été étudié une fois à la BFC Valcartier, mais il ne s'agissait d'une étude préliminaire, et une seconde fois à la BFC Gagetown où aucune particule n'avait été identifiée. À des fins de validation, RDDC Valcartier a échantillonné à nouveau les tirs d'un char d'assaut Léopard utilisant des obus de 105 mm lors d'un exercice à la BFC Valcartier en novembre 2008 et en février 2009. Le but de cet exercice était de valider les résultats obtenus à la BFC Gagetown et de comparer avec les tirs d'artillerie de 105 mm qui projettent 0,3-0,5% en poids de résidus de 2,4-dinitrotoluène dans l'environnement.

Résultats: Le montage était constitué de demi-cercles de pièges à particules disposés à 1, 5, 10, 15, 20, 30, 40 m en avant du char d'assaut. De l'éthanol a été versé dans ces pièges afin d'attraper et de capturer les particules émises par les tirs. En novembre 2008, à la suite de la première série de tirs, plusieurs pièges ont été détruits et certains ont pris feu et l'expérience a dû être interrompue et reportée en février 2009 où un ensemble plus robuste a été mis en place. Au cours de l'essai de février 2009, deux méthodes de collecte des particules ont été comparées: la collection sur la neige et la méthode des pièges à particules. Pour cet essai, les nouveaux pièges ont été disposés en avant du char en utilisant un patron carré à des distances de 3, 5, 10, 15, 20, 25, 30, 40 et 45 m. Cette fois-ci, l'ensemble de pièges à particules a été efficace et suffisamment robuste pour capturer les particules. Les résultats des deux méthodes de collecte ont été comparés. Il a été constaté que le tir de munitions de 105 mm conduit à l'accumulation de résidus de

propergol solide dans le voisinage de l'arme à 0.00263 % en poids. Les mêmes résultats ont été obtenus par les deux méthodes ce qui confirme la validité de ces résultats. Il a également été démontré que la majorité des particules sont déposées à 20-25 m en face du char.

Importance: Ces résultats indiquent que les tirs de char d'assaut sont plus propres que les tirs d'artillerie et ne conduisent qu'à une faible contamination par le 2,4-DNT. Cela peut être expliqué par la quantité de propergol plus importante qui est utilisée dans les munitions de char d'assaut comparativement aux munitions d'artillerie. La quantité de propergol dans la munition de 105 mm char d'assaut étant deux fois plus importante que la quantité de propergol utilisée dans la munition de 105 mm d'artillerie conduit à des pressions et des températures plus élevées dans le canon. Il en résulte une meilleure combustion dans le canon du char d'assaut donc, moins de résidus et une activité militaire moins polluante. Ces résultats sont d'une très grande importance compte tenu qu'ils nous aident à mieux comprendre et possiblement résoudre les problèmes rencontrés durant les tirs d'artillerie en ajustant la charge propulsive pour ne plus produire les émissions de 2,4-DNT.

Perspectives: RDDC Valcartier a déjà accumulé beaucoup de données concernant les particules de propergol émises aux positions de tir lors d'exercices à tir réel. Combiné avec l'expertise développée durant l'échantillonnage des cibles et des zones d'impacts et également basée sur notre connaissance dans le développement des munitions et dans les matériaux énergétiques en général, nous sommes maintenant en bonne position pour proposer des solutions d'atténuation et essayer de résoudre les problèmes rencontrés avec les différents systèmes d'armes. Des projets pour la conception de nouveaux sites d'entraînement sont en cours qui tenteront de comprendre et solutionner les problèmes identifiés. Plus particulièrement le développement de meilleures armes vertes qui n'auront pas les mêmes faiblesses que les armes conventionnelles ont été initiés. Il est fort probable que des solutions seront identifiées pour résoudre les problèmes spécifiques de ces différents systèmes d'armes.

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Acknowledgements

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1 Introduction

For many years, Defence Research and Development Canada (DRDC) Valcartier has been involved in the evaluation of the environmental impacts of the live-fire training to characterize and mitigate adverse effects on training ranges and thereby sustain ongoing military activities (Refs. 1-6). Over the years, many efforts were conducted to assess the environmental loading of explosives at most of the Canadian Forces bases (CFB). To date, these efforts have addressed mainly heavily used target areas (Refs. 7-17). Many of these studies were conducted in collaboration with the US Army Corps of Engineers, Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire and the Environmental Laboratory (EL) in Vicksburg, Mississippi, USA (Refs. 4-6, 14, 18-21). Walsh et al. (Ref. 22) observed that the firing positions were also experiencing a build-up of energetic residues, and since then many studies have been dedicated to the characterization of the firing positions (Refs. 20, 23-26). This research determined that nitroglycerin (NG) and/or 2,4-dinitrotoluene (2,4-DNT) embedded in nitrocellulose fibres are deposited in front and around firing positions (Refs. 11, 22-27). Moreover, it is a common practice in the United States and in Canada to burn excess propellant bags that are removed from the munitions to adjust the ballistic parameters directly on the ground. This practice results in the incomplete combustion of the propellants, therefore leaving high concentrations of propellant compounds on the soils. This practice is currently being assessed by DRDC Valcartier and Director Land Environment and will hopefully soon be replaced by an environmentally friendly alternative.

Four years ago, DRDC Valcartier assessed the dispersion of propellant residues following 105-mm artillery and tank gun firings at CFB Valcartier by placing aluminum witness plates in front of the muzzles of the guns (Ref. 28). At CRREL, similar trials were conducted using snow as a collection media (Ref. 29). Both studies demonstrated that propellant residues comprised of nitrocellulose fibres containing 2,4-DNT were deposited in front of the muzzle of artillery guns, but in a similar test, no residues were found after firing tank ammunition in Valcartier (Ref. 28). The conditions for the trial in Valcartier were not ideal and it was decided to repeat this trial in Gagetown (Ref. 24). During the trial in Gagetown, no residues were detected in any of the particle traps in front of the tank but it was realized that our setup was not adequate. It was concluded that the experiment would have to be repeated another time. Moreover, Walsh et al. studied residues at mortar firing positions and found NG at elevated concentrations for 81-mm mortars (Ref. 30).

During an artillery trial in CFB Valcartier, it came to our attention that gunners often suffered from headaches after gun firing exercises (Ref. 31). Furthermore, in some case, the headaches persisted for days. One potential explanation was the intake of airborne chemicals by the gunners during the exercise. Artillery gaseous emissions were studied and collected during the firing of 155-mm munitions using the new Canadian M777 Howitzer gun (Ref. 32-34) or in a close environment at the muffler installation in Lac St-Pierre using a 105-mm howitzer (Refs. 25, 35). All these studies were undertaken to further understand the emission of propellant particles and gases in the area where gunners normally stand while firing. Of particular interest is the size of the particles emitted during the firing, since sub-micron particles represent an adverse impact for human health. Sub-micron particles, toxic gases, and 2,4-DNT were identified during the study of the firing of a howitzer 105 mm gun in the muffler at Nicolet, Lac St-Pierre and it was concluded

that up to 0.39% of 2,4-DNT is ejected into the environment (Ref. 25, 35). Results also indicated that the gunners' positions are exposed to high concentrations of 2,4-DNT when firing Howitzers.

Considering that tank gunners can be exposed to gases inside the turret and because of the growing interest in the contamination of firing positions, it was decided to reinvestigate emissions resulting from the firing of a 105-mm gunned Leopard tank. One of the aspects that was covered during the tank trial in Gagetown was the collection of gases in front of the tank and inside the tank during the firing (Refs. 24, 36). During this trial, the gaseous sampling equipment suffered extreme damage during the firing and it was decided to repeat the air sampling during the CFB Valcartier tank trial in November 2008. During this trial, the air emission collection system was carefully protected from the blast and incurred no damage (Ref. 37). However, our setup of particle traps was inadequate to resist the blast in these winter conditions: some traps were completely destroyed, some were expelled from the site by the blast, and other traps caught fire. The experiment had to be stopped and postponed until February 2009.

This paper describes the two tank trials of November 2008 and February 2009 at CFB Valcartier where particle traps were installed using different setups and where two sample collection methods were used and compared. This work was co-funded by the Sustain Thrust from Defence Research and Development Canada and by the Strategic Environmental Research and Development Program of the United States through project ER-1481.

2 Background

2.1 Logistics

The first trial was organized and conducted at CFB Valcartier by DRDC Valcartier in conjunction with the 12e Régiment Blindé du Canada (12e RBC) during one of their exercises in November 2008. We tried to minimize the impact of our presence during that exercise because it was an extremely busy day for the soldiers. A Leopard tank was used to fire 105-mm practice rounds in the Termoli range and propellant residues were collected using particle traps containing ethanol to improve the capture of the propellant residues. During this trial, the soil was frozen, no snow had accumulated yet making the blast of the firings even stronger on the particle traps (Fig. 1). From the very beginning of the trial, some traps were destroyed, some were expelled by the blast, and others caught on fire, the ethanol being ignited by the flame of the firings (Figs. 2, 3). It was decided to stop this experiment and to postpone it until February 2009 when we installed a more robust setup of more resistant particle traps. The air emissions collectors (Figure 2 on the left) were strong enough to withstand the blast, so this part of the study continued and the results are described in another report (Ref. 37). The military offered us an opportunity to repeat our experiment outside of their busy schedule, leaving us with a chance of having a Leopard tank for our specific needs. It was decided to repeat the trial in February 2009 with a new setup of stronger particle traps. Our trial of February 2009 was conducted at night due to other range priorities, leading to spectacular firings (Fig. 4). After 80 Squash Head Practice 105 mm rounds were fired DRDC Valcartier and CRREL started collecting snow and traps from 2100 hrs and it was completed by 2300 hrs (Fig. 5). Two methods of sampling for the particles were used, one by collecting the snow cover and the other by collecting the residues in the particle traps at the end of the firings (Figs. 6-9).

2.2 Equipment and Munitions

The 105-mm tank gun is the main armament of the Canadian Forces Leopard C2 Main Battle Tank (Fig. 1). This tank provides close and direct fire support and anti-tank defence for the mechanized battle group. The turret of the Leopard tank is the spaced armour, welded type and carries a crew of three: the Commander, the Gunner and the Loader. The main armament consists of the 105-mm QF gun, either the British L7A3 or the American M68, with semi-automatic, horizontal sliding breechblock. The tube is 51 calibres in length and is equipped with a bore evacuator (fume extractor) and a thermal tube jacket. The barrel is rifled for 471 cm (185.5 inches) with a uniform twist of one turn in 18 calibres. The fire control equipment for this system is the SABCA TFCS with laser range finder.

All available ammunition for the 105-mm gun was described in the Gagetown study (Ref. 24). Operational ammunition consists of three types: Armour Piercing Fin Stabilized Discarding Sabot (APFSDS), Smoke White Phosphorous (WP), and High Explosive Squash Head (HESH), while practice (training) ammunition consists of Short Range Target Practice Discarding Sabot (SRTPDS), Target Practice Fin Stabilised Discarding Sabot (TPFSDS), Squash Head Practice (SH Practice) and Blank. The Leopard C2 tank can carry 59 rounds of ammunition. Most of theses rounds contain a tracer composition to help aim at the target. These rounds have a T at the

end of their designation. As an example, APFSDS-T would be the operational weapon containing the tracer composition.

The High Explosive Squash Head (HESH-T) cartridge is a base detonated, thin walled, high explosive filled cartridge of British manufacture, that is designed to defeat armoured targets and fortified structures such as concrete emplacements by blast, spalling, and shock wave effect. There are also secondary anti-personnel effects caused by blast and fragmentation. The projectile is spin stabilised and is effective at both large and small angles of attack and at relatively low striking velocities. The projectile, when fired, has a muzzle velocity of 731 m/s. The charge consists of 2.857 kg of single base type M1 NH .033 propellants contained in three longitudinal pockets within a silk cloth bag. A tin/lead foil decoppering strip 298 mm by 178 mm by 0.05 mm thick is sewn inside the bag at the top. The projectile filling consists of approximately 2.1 kg of RDX/wax 88/12 pressed explosive.

For the need of the February 2009 trial, 90 Squash head practice rounds with a tracer (SH/P-T, C109 A1) were fired. This is a training round designed as a ballistic match for the current HESH L35 cartridges. The C109A1 differs from the C109 only in the simplified projectile design to reduce production costs (Figs. 10, 11). Our rounds were stock number 1315 21 914 3294-0654 lot CA-06H11-01. The nominal propellant load consists of 3.0 kg of M1 (NH .034) propellant divided into three equal pockets within a viscose rayon cloth bag. A tin/lead foil strip is sewn into the upper section of the bag to act as a decoppering agent. The projectile is similar in external configuration to the HESH projectile and contains an inert load of castor oil filler with a density of 1.6 g/mL in a plastic container. Table 1 contains all the propelling charges and types of propellants for all the available 105-mm tank ammunition.

Table 1: 105-mm Tank Gun Ammunition Propelling Charges

Ammunition	***Weight of propellants (g)***	***Type of propellants***
APFSDS-T, M111	5800	M30 triple base
APFSDS-T, DM23A1	5800	M30 triple base
APFSDS-T, DM63C	6000	M26 double base
APFSDS-T, C76	5350	NQ/M triple base
APFSDS-T, M428	5800	M26 double base
HESH-T, L35	2857	M1 single base
WP-T M416*	2780	M1 single base
SR/TPDS-T, C148*	5120	M6 single base
TP/FSDS-T, C71*	5075	M6 single base
SH/PRACT, C109*	3000	M1 single base

* Ammunition studied in this report

Table 2 shows the composition of propellant types normally found in practice 105-mm tank ammunition squash head and fin stabilised discarding sabot. M1 is the propellant found in our practices rounds.

Table 2: Composition of Single Base Propellants M1 and M6

Chemical	***Weight percentage in the propellant (%)***	
	M1	**M6**
Nitrocellulose	85% ± 2%	86% ± 2%
2,4-DNT	10% ± 2%	10% ± 2%
Dibutylphtalate	5% ± 1%	3% ± 1%
Potassium sulphate	1% ± 0.3%	0%
Diphenylamine	0.9% ± 1.2%	1% ± 1%

3 Experimental

3.1 Sampling Strategy and Nomenclature

3.1.1 Propellant residues in particle traps

In November 2008, particle traps were placed in half circles at 1, 5, 10, 15, 20, 30 and 40 m in front of a Leopard tank firing 105-mm ammunition at CFB Valcartier, Termoli range (Figs. 12, 13). A total of 70 traps were installed in front of the tank in holders with weights to stabilise them (Fig. 14). Ethanol was poured in each of them to improve the adhesion and capture of the propellant residues emitted. As mentioned, following the first series of firings, some plates were destroyed, some caught fire and the experiment was stopped and postponed to February 2009 (Figs. 2, 3). These particle traps acquired at the grocery store were made of thin aluminum and their main usage was more at re-heating food than cooking food. For this, they were very thin and definitely not robust enough to withstand a tank blast pressure (Fig. 3). The DRDC built trap holders were made of stainless steel and were not destroyed during the November 08 trial (Fig. 3).

In February 2009, stronger heavier- gauge traps were acquired from a commercial dealer. Their main usage was for cooking on a large scale in industries or restaurants. They measured 53 x 48 cm, were 2.5 mm thick with a height of 8 cm (Fig. 15). The same holders were used and new V-shaped holders were also tried (Fig. 16). Figure 16 showed that a plume was formed after a few firings. The holders and traps can also be seen in this figure. For this trial, a total of 57 traps were set out in a series of transects at fixed distances in front of the tank. A rectangular shape was obtained using 3 traps disposed at 3 meters in front of the muzzle of the gun, 5 traps at 5 m and then 7 traps per row at 10, 15, 20, 25, 30, 40 and 45 m in front of the muzzle of the gun. This resulted in a rectangle where the longest axe of the rectangle was in the direction of firing. At the end of the firing, it was found that our setup resisted the firings of the 80 rounds. Some of the traps, especially those close to the muzzle of the gun, were displaced but not flipped over. At the end of the trial, our traps were collected for analyses. At the end of the exercise, each row was combined to represent what was expelled at a specific distance. These samples were labelled row 1 to row 9. Most of the traps contained snow that was recovered and put in plastic containers (Fig. 17) for further analyses in the laboratory. Some of the traps were displaced by the blast and these were combined with the closest row for analysis.

3.1.2 Snow collection method

In addition to the collection of propellant residues on trays, researchers from CRREL collected samples from the snow surface. Multi-increment sampling with replicates and quality assurance procedures were carried out. The protocol used follows Walsh, M.R., et al. (Ref. 38). The primary purpose of this redundant sampling was to directly compare the results of the two different sampling and analysis protocols.

3.1.2.1 Baseline sampling

Prior to the initiation of the trial, a snow sample was taken downrange of the tank position. A 20-cm x 20-cm flat polytetrafluoroethylene (PTFE) coated aluminum scoop was used to take 10 increments to a depth of 2.5 cm. The increments were collected in a single bag and kept separate from the post-firing samples prior to processing and analysis. The increments were taken downrange from the tank firing position along a centerline out to the sixth line of trays, 25 m from the firing position. Snow depths along this line varied from 11 cm up to 19.5 cm at the base of the snow berm. The average depth was 14 cm.

3.1.2.2 Post-firing decision unit delineations

The tank firing exercise concluded late on a dark, foggy night. Light stanchions and the headlights of several vehicles were used to delineate the main plume area between the firing position and the snow berm. Even so, it was difficult to determine the extent of the plume (Fig. 18). Sampling snow was accomplished using frontal light (Fig. 19). A wedge-shaped area 6-m across at the firing position, 26-m across at the berm 27-m away and uneven sides of 28- and 30-m was outlined as the main plume area (Fig. 20). The area was outlined by packing the snow along the boundary edges and placing flags at the corners. Beyond this area, we outlined an additional downrange area that we designated as over the bank as it was on a down slope. The sides of these areas were measured following the completion of sampling. The OTP (outside-the-plume) decision units encompass the areas up to 3-m from the edges of the main decision units. This strategy was previously used at Alaskan training areas (Ref. 39).

3.1.2.3 Snow sampling

Sampling started shortly after the completion of the designations of the decision units. The main plume area was sampled first. Two OTP samples were then taken along the long edges of the main plume area. Three replicate samples were then taken in the down slope area, followed by a single OTP along the edges and far end of the down slope area.

A systematic random approach was used when sampling the main plume area. The initial sampling locations were randomly determined and then systematically carried through over the whole of the decision unit. The decision unit shape was not rectangular, so we sampled parallel to the 28-m side, working our way from the firing position to the top of the berm, then shifting towards the 30-m edge about 5 m to sample along a line parallel to the previous line. Four samples were built by collecting snow samples every five meters: three surface samples and one subsurface sample beneath the same surface sample location at each stop (Figs. 7, 8). The surface samples were taken with a 20 x 20 x 2.5 cm PTFE-covered aluminum scoop. The subsurface sample was taken with a similar scoop 10-cm on a side. Samples were taken simultaneously at each sampling location. The increments for each sample were placed in a clean polyethylene (PE) bag that was labelled, tagged, and cinched with a tie-wrap following sampling. All samples from the same decision unit were stored and transported together.

The OTP samples for the main plume area were taken with a 10 cm scoop in a random-walk fashion along the outside edges of the decision unit. Two samples were separately taken. All

increments were taken at the surface to a depth of 2.5 cm (Table 3). Bagging, labelling, storage, and transportation followed the procedure outlined above.

The down slope area decision unit proved a bit of a challenge for sampling. Previous drifting of snow resulted in snow depths in some areas in excess of a meter. However, we persevered and collected three plume samples and an OTP sample as outlined above (Fig. 21). A list of samples is given in Table 3. Sampling started at 2100 hrs and was completed by 2300 hrs. The flags located at all the snow depth measurement points were blown away, so post-firing snow depth measurements could not be taken.

Table 3: Sampling Data Coming from Snow Collection

Sample Description	Scoop Size (cm X cm)	Number of Increments	Sampled Area (m^2)
Snow Background in front of tank before firing	20 x 20 x 2.5	10	0.4
Main Plume - Surface - Tank to berm - Rep 1	20 x 20 x 2.5	29	1.2
Main Plume - Surface - Tank to berm - Rep 2	20 x 20 x 2.5	29	1.2
Main Plume - Surface - Tank to berm - Rep 3	20 x 20 x 2.5	29	1.2
Main Plume - Subsurface of sample 09 DRDC-04	10 x 10 x 2.5	29	0.3
OTP* - 0-3 m - Tank side of berm - Rep 1	10 x 10 x 2.5	39	0.4
OTP* - 0-3 m - Tank side of berm - Rep 2	10 x 10 x 2.5	39	0.4
Plume - Surface – Down slope area - Rep 1	20 x 20 x 2.5	25	1.0
Plume - Surface - Down slope area - Rep 2	20 x 20 x 2.5	25	1.0
Plume - Surface - Down slope area - Rep 3	20 x 20 x 2.5	25	1.0
OTP* - 0-3 m- Down slope area	15 x 15 x 2.5	30	1.2

*OTP Outside the delineated plume

3.2 Parameter, Sample Treatment and Analytical Methods

3.2.1 Collection and treatment of samples in particle traps

To avoid the degradation of the energetic material residues, particle traps were sampled immediately after the firing was completed around 2100 hrs. All traps on a specific row were combined as row 1 to row 9. Nevertheless, no traps were turned over and all the 57 traps were

collected and analysed. The snow and particles in the traps were transferred into plastic pails and each trap was then thoroughly rinsed with ethanol and combined in the pail. All the pails were sealed for transport and named according to the nomenclature explained earlier. Since the weather was very cold, no specific precautions were needed to protect the samples during transport to DRDC Valcartier. Upon arrival at the lab, the pails were kept at -20°C until extraction.

To prepare the samples for Reverse Phase-High Performance Liquid Chromatography (RP-HPLC) analysis, the snow was melted and evaporated to dryness under a fume hood in the dark. Acetone was used to rinse the pail to completely extract the particles and transferred to a small beaker where it was evaporated to dryness again. The residues were recovered by adding acetonitrile (100 mL) (Fig. 22). Usually, acetonitrile (15 mL) from this solution was recuperated, evaporated to dryness, re-extracted with acetonitrile (2.5 mL), diluted with water (2.5 mL) and injected into the HPLC for analysis. However, it was observed that in all the samples, a green solid formed during the evaporation of the acetonitrile solution (Fig. 23) and this solid introduced interferences during the analyses. It was decided to get rid of this solid by evaporating the acetonitrile solution (15 mL) to dryness, recuperating the energetic residues with ethyl acetate (50 mL) and crushing the crystals using a glass spatula to try breaking them into smaller pieces. The solid was then filtered and the organic solution was washed three times with water (40 mL). The organic phase was dried over magnesium sulphate and evaporated to dryness. The energetic residues were recuperated with acetonitrile (2.5 mL). This extract was combined with water (2.5 mL) and the solution was filtered on a 0.45 microns filter and was ready to be analyzed by HPLC.

Prior to the HPLC analyses, extracts were maintained at 4°C according to Method EPA 8330 update SW 846 (1994) (ref. 40). Analyses were performed with a HPLC Agilent HP 1100 equipped with a degasser G1322A, a quaternary pump model G1311A, an autosampler G1313A and a UV diode array detector model G1315A monitoring at 210, 220 and 254 nm. The injection volume was 20 µL and the column was a Supelcosil LC-8 (25 cm x 3 mm x 5 µm) eluted with 15:85 isopropanol/water (v/v) at a flow rate of 0.75 mL/min. The column temperature was maintained at 25°C during the analysis. Standards and solvents were diluted 1:1, acetonitrile to water (0.5 mL Acn /0.5 mL water).

The green residue was recuperated and dried (Fig. 24). It was analysed by Fourier Transform Infrared (FT-IR) and Raman spectroscopy. These FTIR and Raman analyses revealed the presence of cyanide and thiocyanate as the anion of this insoluble ionic compound. Combustion of gun propellants generates hydrogen cyanide (Refs. 34, 35, 41) that may easily react with metals leading to metal cyanides that typically form green compounds. Metals analyses were performed by EXOVA Laboratories using Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) and revealed that copper, boron and potassium were the three main constituents of the metallic green compound. Copper was at the highest concentration at 180,000 ppm while potassium and boron were respectively at 250,000 and 3,100 ppm. Boron and potassium are often chemical components of the igniter while copper is coming from the rotating band. Consequently, it can be assumed that the green compound is a mixture of these chemicals most probably a mixture of copper cyanide or cuprous thiocyanate.

3.2.2 Snow samples processing and analysis

Samples were stored in a cold area away from sunlight prior to transportation to the analytical chemistry lab at CRREL in Hanover, NH. At CRREL, the samples were processed following the

procedure described in Walsh et al. (Ref. 38). The samples were melted, taking care not to allow the sample temperature to exceed 10°C or to refreeze. Using a vacuum filtration unit, the aqueous phase was separated from the soot or particulate fraction. The number of filters used and filtrate generated were tracked. The filters were placed in a labelled jar and set out to dry. After drying, the sealed jars were refrigerated. The filtrate fractions were mixed by vigorously shaking and two or four 500-mL aliquots were taken and placed in labelled bottles in a refrigerator after logging in the sample. All the glassware and reusable containers were carefully washed.

Filtration blanks were obtained by running 1000 mL of deionised water periodically through a freshly-cleaned filtration apparatus and collecting filter and filtrate fractions. The aliquots in labelled bottles were pre-concentrated by passing through a Porapak RDX cartridge. Spikes or blanks were run at this time. The cartridges were eluted with acetonitrile (5 mL) to give a 100:1 concentration solution, and they were split into 3.5-mL and 1.5-mL fractions.

The filters were processed by adding acetonitrile in 10-mL increments until the filters were covered and the closed jars were shaken for 18 hours. The acetonitrile volumes were recorded. Prior to the HPLC analysis, the acetonitrile extracts (1 mL) were mixed with reagent grade water (3.0 mL).

Following processing, the sample extracts were analyzed on a HPLC system for nitroaromatics and nitroamines, specifically 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), and nitroglycerine (NG). The HPLC was a modular system from Thermo Electron Corporation composed of a Finnigan SpectraSYSTEM Model P4000 pump, a Finnigan SpectraSYSTEM UV2000 dual wavelength UV/VS absorbance detector set at 210 and 254 nm (cell path 1 cm), and a Finnigan SpectraSYSTEM AS300 autosampler. Samples were introduced with a 100-µL sample loop. Separations were achieved on a 15-cm × 3.9-mm (4-µm) NovaPak C8 column (Waters Chromatography Division, Milford, Massachusetts) at 28°C and eluted with 1.4 mL/min of 15:85 isopropanol/water (v/v).

4 Results and Discussion

4.1 Propellant Residues in Particle traps

During the tank trial in February 2009, 90 Squash Head Practice rounds were fired between 1600 and 2100 hrs. One can see in Table 4 that some traps were moved by the blast from the original setup. Nevertheless, none of the traps were flipped over and still represent an area of capture for the particles. By looking at Table 4, it can be seen that most of the particles are deposited at 20-25 meters in front of the muzzle of the gun. It is also observed that more traps than originally installed at these distances are found in these lines coming from other rows. The particle traps dimensions were 53 cm x 48 cm, meaning a surface of 0.2544 square meters. Taking into account that 57 traps were collected, this represents a surface of 14.5 m^2. By examining Figure 20 and doing the mathematics, the entire area was calculated to be 929 m^2. A total of 11.06 mg of 2,4-DNT was deposited in our 57 traps so by extrapolation, a total of 709 mg was deposited on the entire area following the firings of the 90 Squash head practice rounds. This means that each round deposited 7.89 mg of 2,4-DNT. Considering that one round contains 3 kg of M1 propellant and 10% of 2,4-DNT (meaning 300 g of 2,4-DNT), the rate of deposition of 7.89 mg /round represents 0.00263 % W/W of the original concentration of 2,4-DNT for this weapon platform.

Table 4: DNT Concentrations Obtained with the Particle Trap Method

Sample	*Distance (m)*	*No of Traps (pre-fire)*	*No of Traps (post-fire)*	*2,4-DNT (mg)*
Row 1	**3**	**3**	**2**	**1.11**
Row 2	**5**	**5**	**4**	**0.14**
Row 3	**10**	**7**	**5**	**0.05**
Row 4 Pail1*	**15**	**7**	**7**	**0.94**
Row 4 Pail 2	**15**			**0.37**
Row 5	**20**	**7**	**8**	**3.08**
Row 6	**25**	**7**	**9**	**3.13**
Row 7	**30**	**7**	**7**	**0.88**
Row 8	**40**	**7**	**8**	**1.01**
Row 9	**45**	**7**	**7**	**0.35**
Total		**57**	**57**	**11.06**

*Two pails were used for Row 4 since there was too much snow for only one pail

In previous studies, it was observed that artillery firings of 105-mm rounds deposited at a rate of 0.5% W/W of the original concentration of 2,4-DNT (Refs. 25, 31). One must say that the propellant charges are smaller in 105-mm artillery rounds than in the 105-mm tank munitions especially when they fired artillery guns at low charges. Having more propellant in the 105-mm tank munitions, it is more likely that their combustion is more complete than with the 105-mm artillery gun ammunition. The artillery is built to attack in an indirect fire and is intended at hitting at long distances. The tank ammunition is built to propel projectiles at high velocity using high kinetic energy to cause lethal effect in a direct fire. To achieve their terminal effects, the

artillery gun ammunition propelling charges contain approximately 1.28 kg of propellant (seven bags) while the 105-mm tank ammunition contains from 3.0 to 6.0 kg of propellant from Practice Squash head to operational APFSDS rounds (Table 1). During the Nicolet trial, C-60 Squash head artillery rounds were fired at charge 6 and charge 4 meaning that only 840 and 467 g of propellant were respectively burned ejecting 0.23 and 0.39% of 2,4-DNT (Ref. 25). The tank Squash Head practice ammunition uses more than three times the amount of propellant compared to the artillery rounds of the Nicolet study (Ref. 25). This means that higher temperature and pressure are resulting in the tank gun barrel, leading to a cleaner combustion with smaller amounts of residues. This could be explained by the fact that the barrel is longer for a tank than for the howitzer leading to more time at elevated pressure and temperature leading to a cleaner combustion.

4.2 Propellant Residues in Snow Samples

The baseline sample taken from the main plume area prior to the start of firing had very high levels of NG. No 2,4- or 2,6-DNT was detectable in the sample. Therefore, all DNT detected at the site can be attributed to the February 2009 tank trial. It was important to verify the presence of 2,4-DNT before our trial since often Leopard tanks fire 7.72 machine gun and their small arms contain 2,4-DNT. The NG detected may have come from previous firing of a light armoured vehicle 20 mm cannon that often use the same training area. The 20-mm TR ammunition contains nitroglycerin at 10% and the Ball 20-mm contains 2,4-DNT at 8 %. Usually, light armoured vehicle exercises are done firing the 20 mm rifle with both types of small arms. It was therefore very important to assess the presence of nitroglycerine and 2,4-DNT on site before doing our trial.

The main plume area contained the bulk of the DNT residues from the propellant. The plume surface sample averaged an estimated 390 mg of 2,4-DNT and 4.1 mg of 2,6-DNT when extrapolated over the complete decision unit. The one subsurface sample had 160 mg of 2,4-DNT and 1.8 mg of 2,6-DNT when extrapolated over the plume area. The down slope decision unit averaged 36 mg of 2,4-DNT and 0.28 mg of 2,6-DNT over the whole area, while the OTPs contained 9.1 mg and 1.0 mg of 2,4-DNT respectively. The bulk of the residues resided in the main plume area: 92% of the combined mass of DNT. Only 1.5% of the total estimated DNT mass was found in the OTP sample adjacent to the main plume area. Beyond the berm, 6.1% of the total estimate mass of deposited DNT residues was found in the down slope area and 0.16% in that area's OTP. These results are summarized in Table 5. A more complete data set can be found in Annex B.

As mentioned in the previous section, 90 rounds were fired, and in each of these rounds, there was a total of about 300 g of 2,4-DNT. Using the results from snow and dividing the total DNT estimated for the area by the number of rounds gives us a deposition rate of 6.7 mg DNT/round. This is 0.0022% of the original DNT load of the rounds, giving a combustion efficiency of 1-0.0022% or 99.9978% efficiency.

Over the course, it is interesting to note that a lot of the residues in the main plume area were found below the surface. Fully 27% of all residues were estimated to reside in a 2.5-cm thick sample layer 2.5-cm below the surface. The muzzle blast from the Leopard tank's 105-mm rifled gun was ferocious, churning up and moving the snow in the first 20 m in front of the tank. In some areas, almost 10 cm of snow were removed from the surface. The muzzle blast from any

direct-fire weapon will cause difficulties in sampling, not only in snow but over soil as well. The subsurface sample concentration was 40% of the surface sample concentration. If the trend with depth is linear, the next lift would have contained about 66 mg, the next 27 mg, and so on. Adding these to the original 610 mg of DNT gives us approximately 720 mg of DNT. If this line of reasoning is valid, the mass of DNT residues per round becomes 8.0 mg/round, or 0.0027% of the original DNT load per round. This agrees very well with the deposition rate of 0.0026% found with the particle traps method.

Table 5: DNT Mass Quantities Obtained with the Snow Collection Method

Sample	2,4-DNT (mg)	2,6-DNT (mg)	DNT[1] (%)
Snow Background in front of tank before firing	—	—	
Inside Plume - Surface – Main plume area - Rep 1	**300**	**3.2**	
Inside Plume - Surface - Main plume area - Rep 2	**290**	**3.0**	
Inside Plume - Surface - Main plume area - Rep 3	**580**	**6.1**	
Inside Plume - Surface - Main plume area - Average:	**390**	**4.1**	**65%**
Inside Plume - Subsurface of sample of 09 DRDC-04	**160**	**1.8**	**27%**
Main Plume Area total:	**550**	**5.9**	**92%**
OTP - 0-3 m - Tank side of snowbank - Rep 1	**5.4**	**0.00**	
OTP - 0-3 m - Tank side of snowbank - Rep 2	**13**	**0.00**	
OTP - 0-3 m - Tank side of snowbank – Average:	**9.1**	**0.00**	**1.5%**
Main Plume and OTP Areas total:	**560**	**5.9**	**93.5%**
Plume - Surface – Down slope area - Rep 1	**29**	**0.27**	
Plume - Surface - Down slope area - Rep 2	**39**	**0.18**	
Plume - Surface - Down slope area - Rep 3	**41**	**0.41**	
Plume - Surface - Down slope area –Average:	**36**	**0.28**	**6.1%**
OTP - 0-3 m- Down slope area	**1.0**	**0.00**	**0.16%**
Down Slope Plume and OTP Areas total:	**37**	**0.3**	**6.3%**
Total estimated mass of analytes:	**600**	**6.2**	**100%**

[1]: The percentages are % of the total mass

During the planning stages of this trial, we hypothesized that the deposition rate for the tank rounds would fall somewhere between those obtained for the 105-mm howitzer and the 155-mm howitzer. The three weapon systems use the same propellant formulation; all have long rifled barrels, and all utilize large amounts of propellants. Previous tests have shown that higher propellant loads and longer barrels are a good indicator of high efficiency rates for the propellants. This test proved our hypothesis true. As can be seen in Table 6, the tank residues fall between the two howitzers.

Table 6: Deposition Rates Obtained with Different Weapon Platforms

Weapon System Howitzer	*Propellant*	*Load/ round (g)*	*Residues/ round (mg)*	*Residues/ load (%)*
105-mm artillery[1]	M1 - I & II	42	34	0.08
105-mm artillery[2]	M1 - I & II	Varied	Varied	0.3 -0.05
155-mm artillery	M1	275	1.2	0.0005

Weapon System Howitzer	*Propellant*	*Load/ round (g)*	*Residues/ round (mg)*	*Residues/ load (%)*
105-mm tank[1]	M1	300	6.7	0.0022
105-mm tank[2]	M1	300	7.8	0.0026

[1] : Performed by CRREL, [2] : Performed by DRDC Valcartier

5 Conclusion

In the context of assessing the contamination of firing positions of different weapon platforms, 105-mm tank gun practice rounds were fired during an exercise using a Leopard tank in CFB Valcartier in February 2009. This trial was performed to validate the results obtained in a previous trial conducted at CFB Gagetown. At CFB Valcartier, the first attempt to perform the trial was done in November 2008, but after firing the first set of munitions, the setup was destroyed and some traps caught on fire and the experiment had to be stopped. It was decided to re-conduct the test in February 2009 with a more robust system capable of withstanding the blast of the tank firings. In February 2009, a total of 90 Squash Head Practice rounds were fired. That represents 300 kg of M1 propellant corresponding to 30 kg of 2,4-DNT burned during that exercise.

During the February 2009 event, two methods of particle collection were compared; the snow collection developed by CRREL and the particle traps method developed by DRDC Valcartier. For this trial, the new traps were disposed in front of the tank using a square pattern at 3, 5, 10, 15, 20, 25, 30, 40 and 45 m. This time, our particle traps setup was efficient and robust enough to collect the particles. Results from both collection methods were compared. It was found that firing 105-mm tank gun ammunition leads to the accumulation of solid propellant residues in the vicinity of the gun at 0.00263 % of 2,4-DNT using the particle trap method. Using the snow collection method gave almost the same result and a value of 0.0022% W/W of unburned 2,4-DNT was obtained, confirming the validity of these results. It was also found that most of the particles are deposited at 20-25 m in front of the tank.

According to the latest results obtained from artillery exercises, it was found that 0.4-0.6% of 2,4-DNT is ejected during the firing of 105-mm artillery gun firing. In our February 2009 study, it was found that 0.0026% of unburned 2,4-DNT are found following the firing of the 90 tank gun ammunition rounds. At CFB Gagetown, no residues were identified but our setup was partly destroyed and it was concluded that our sampling strategy was not adequate. It is for that reason that we wanted to repeat this trial. Considering that residues were identified with the 155-mm artillery gun, it was hypothesized that 105-mm tank gun firings should give values between 155-mm and 105-mm artillery gun firings. This was proven by measuring the residues ejected using two different sampling collection methods.

The combustion of propellants in artillery or tank guns follows laws of physics: the higher the pressure and temperature, the better the combustion and the lesser residues expelled at the muzzle of the gun. The three weapon systems use the same propellant formulation; all have long rifled barrels, and all utilize large amounts of propellants. Previous tests have shown that higher propellant loads and longer barrels are a good indicator of high efficiency rates for the propellants. The artillery is built to attack in an indirect fire mode and is intended at hitting at long distances. The tank ammunition is built to propel projectiles at high velocity using high kinetic energy to cause lethal effect in a direct fire mode. The artillery 105-mm ammunition propelling charges contain approximately 1.28 kg of propellant while the 105-mm tank ammunition contains from 3.0 to 6.0 kg of propellant from practice to operational rounds. The Squash Head practice round used in our study contains almost three times the amount of propellant compared to the artillery Squash head C-60 Practice rounds that were fired at charge 6 in Nicolet, Lac St-Pierre, Canada. This suggests that higher temperature and pressure are

experienced in the tank gun barrel, leading to a more complete or “cleaner” combustion without projection of solid un-reacted residues. This is also observed in the 155-mm artillery gun where the propellant loads are even bigger than the 105 mm artillery and tank ammunition, probably leading to very high pressure and temperature in the barrel. This is why very low percentages of 2,4-DNT (0.0005%) are ejected by 155-mm artillery firings. This was observed for all M1 simple base propellants but this will also be true for the more powerful propellant charges such as the triple base propellant charge used in 155-mm artillery gun or in the 120-mm Challenger tank where higher pressure and temperature are expected. In these cases, it is foreseen that it will be difficult to measure any residues ejected by the platform because the combustion will be more efficient.

Finally, comparing the two sample collection methods was a fruitful exercise since it confirms and validates the results obtained during this trial. Both methods have their strengths and weaknesses. The snow collection method is by far the simplest and quickest method to perform. No need to deploy anything, you just use the scoop to collect the snow before and after, you measure the plume and you analyse the results. The weakness is that you cannot perform this method all year long. On the other hand, the particle trap collection method can be done any time of the year but measurements have to be done to install the traps according to the desired sampling pattern and the setup can suffer cross-contamination from the site if the soils surrounding the setup are very contaminated especially in high blast conditions. This cross-contamination can be evaluated and removed from the results but more analyses are necessary. If we consider the sample treatment and analysis, both methods look similar.

In conclusion, it can be said that this trial was a success and that we accomplished the objective of this study that was to analyse residues expelled by the most difficult weapon platform. The next step in studying the firing positions will be to evaluate the propellant residues ejected by the firing of the tank rifle. As it was seen, nitroglycerin can be found at firing positions of tank ranges and this will have to be evaluated with these medium calibre weapons.

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Annex A Figures

Figure 1: Leopard C2 Firing in November 2008 Trial

Figure 2: November 2008 Setup on Fire

Figure 3: Particle traps Destroyed During November 2008 Trial

Figure 4: Leopard Tank Firing Squash Head at Night

Figure 5: Sampling Propellant Residues at Night

Figure 6: Collecting Particles Using the Snow Collection Method

Figure 7: Sampling Snow at the Surface and Below the Surface

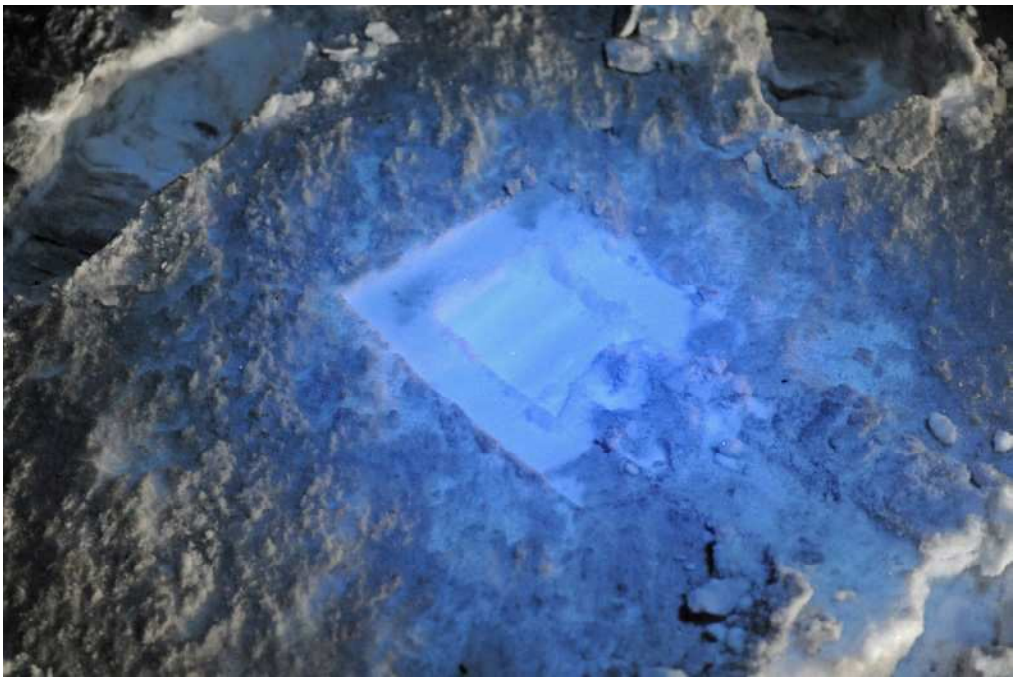

Figure 8: Sampling Snow Using Lights

Figure 9: Collecting Particles in the Traps

Figure 10: Practice Squash Head

Figure 11: Squash Head Brought to the Tank

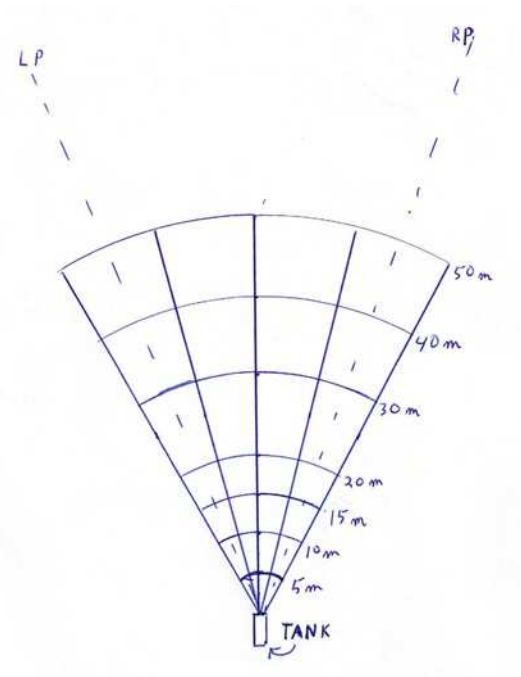

Figure 12: Half Circles Pattern of Trays in Front of the Tank

Figure 13: Trays Placed in Front of the Tank (November 2008)

Figure 14: Particle traps in Holders with Weights

Figure 15: Stronger Particle Traps Installed on a Fresh Snow Cover

Figure 16:Traps in Holders with Weights After a few Firings

Figure 17: Particles Collection for Analyses

Figure 18:Main Plume Area Immediately Following Cessation of Firing

Figure 19:Sampling Snow Using 20 x20 cm Scoop

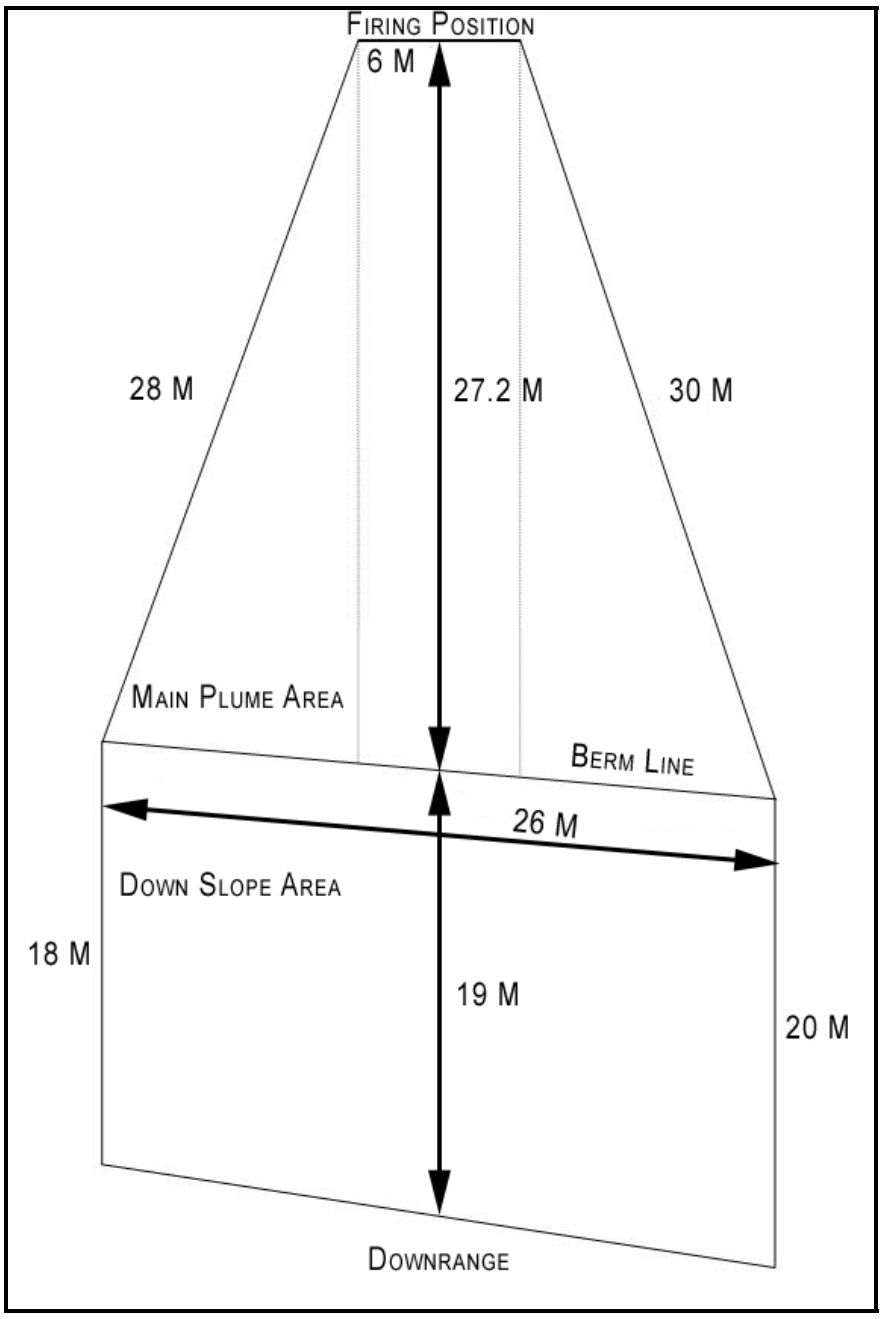

Figure 20: Main Decision Units Layout

Figure 21:Sampling in Down Slope Area Beyond the Berm

Figure 22:Acetonitrile Extraction of the Pails

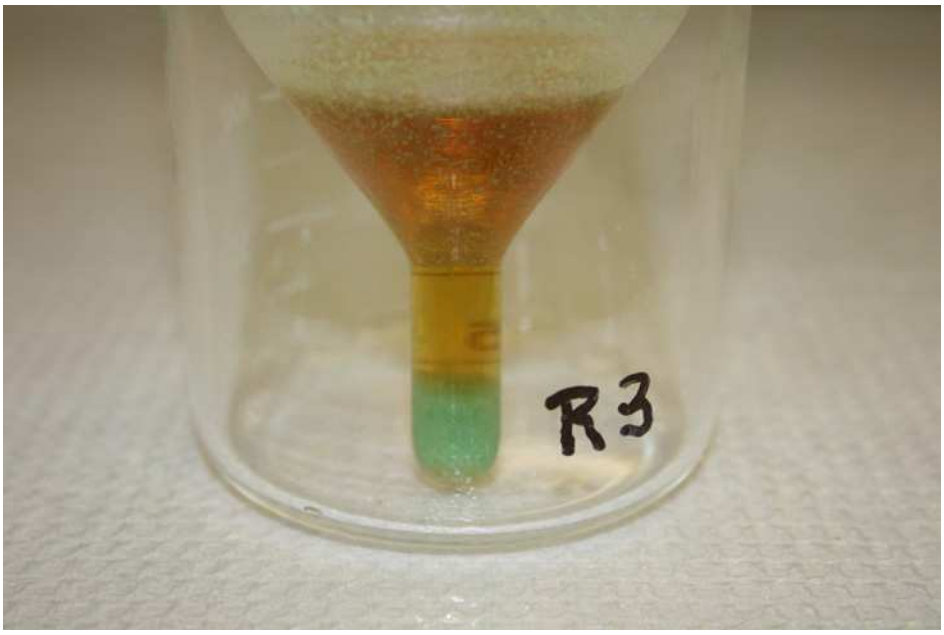

Figure 23: Unknown Solid Crystallization

Figure 24: Green Solid Isolated by Evaporation

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Annex B Snow Results from CRREL

Sample Description	Snow Melt Volume (L)	2,4-DNT			2,6-DNT		Reporting Limits		
		Mass in Snowmelt (mg)	Mass in Soot (mg)	Total Mass in Sample (mg)	Mass in Soot (mg)	Total Mass in Sample (mg)	Mass in Snowmelt (mg)	Mass in Soot (mg)	Mass/m^2
Snow Background in front of tank before firing	1.26	0.000	0.000	0.000	0.0000	0.0000	0.0006	0.0005	0.003
Inside Plume - Surface - Main Area - Rep 1	5.30	0.015	0.815	0.830	0.0090	0.0090	0.0027	0.0015	0.004
Inside Plume - Surface - Main Area - Rep 2	5.98	0.021	0.782	0.804	0.0085	0.0085	0.0030	0.0015	0.004
Inside Plume - Surface - Main Area - Rep 3									
Solid phase extraction (SPE 1)	5.80	0.024	1.586	1.610	0.0171	0.0171	0.0029	0.0015	0.004
Solid phase extraction (SPE 2)	5.80	0.025		1.612					
Solid phase extraction (SPE 3)	5.80	0.025		1.612					
		0.025		1.611					
Inside Plume - Subsurface of 09 DRDC-04	1.42	0.001	0.113	0.114	0.0012	0.0012	0.0007	0.0005	0.004
OTP - 0-3 m - Tank side of berm - Rep 1	1.66	0.000	0.012	0.013	0.0000	0.0000	0.0008	0.0005	0.003
OTP - 0-3 m - Tank side of berm - Rep 2	1.54	0.001	0.030	0.030	0.0000	0.0000	0.0008	0.0005	0.003
Plume - Surface - Down slope area - Rep 1	3.22	0.002	0.057	0.059	0.0005	0.0005	0.0016	0.0005	0.002
Plume - Surface - Down slope area - Rep 2	3.16	0.002	0.077	0.079	0.0004	0.0004	0.0016	0.001	0.003
Plume - Surface - Down slope area - Rep 3	3.20	0.002	0.082	0.084	0.0008	0.0008	0.0016	0.0005	0.002
OTP - 0-3 m- Down slope area	2.28	0.000	0.006	0.006	0.0000	0.0000	0.0011	0.0005	0.001
SPE Blank	0.50								

Reporting Limits (mg/L): Aqueous Concentration (mg/L): 0.0005 ; Mass in Snow Melt (mg) : Snow Melt Vol (L) x 0.0005 ; Solvent Extract Conc (mg/L): 0.05; Mass in Soot (mg) : Extract Volume (L) x 0.05

List of symbols/abbreviations/acronyms/initialisms

ACN	Acetonitrile
APFSDS	Armour Piercing Fin Stabilised Discarding Sabot
°C	Degree Celsius
CFB	Canadian Forces Base
CRREL	Cold Regions Research Engineering Laboratory
2,4-DNT	2,4-Dinitrotoluene
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
EL	Environmental Laboratory
FTIR	Fourier Transform Infrared
HESH	High Energy Squash Head
HPLC	High Pressure Liquid Chromatography
ICP/MS	Inductively Coupled Plasma/ Mass Spectrometry
Kg	Kilogram
mL	Milliliter
Mm	Millimeter
M/S	Meter per second
NG	Nitroglycerin
OTP	Outside the plume
ppm	Parts Per Million
PTFE	Polytretrafluoroethylene
PE	polyethylene
12^{th} RBC	12^{th} Régiment Blindé du Canada
RDDC	Recherche et développement pour la défense Canada
R&D	Research & Development
RDX	Research Development Explosive, Heaxahydro-1,3,5-Trinitro-1,3,5-Triazine
RP-HPLC	Reverse Phase High Pressure Liquid Chromatography
SERDP	Strategic Environmental R&D Programme
SH	Squash Head

SRTPDS	Short Range Target Practice Discarding Sabot
TPFSDS	Target Practice Fin Stabilised Discarding Sabot
UXO	Unexploded Ordnance
V/V	Volume/volume
W/W	Weight/weight

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Extensive research indicates that propellant residues accumulate at firing positions and represent a concern for the environment and human health. To better understand the impacts of live firing at firing positions, a series of characterizations was conducted to measure the deposition of propellant residues from many sources. The present study was conducted three times with Leopard tanks firing 105-mm tank gun ammunition. The first trial was carried out at CFB Gagetown where no propellant residues were identified. For validation purposes, two additional trials were conducted at CFB Valcartier. DRDC Valcartier assessed the particles emitted, the gaseous emissions, and the particles size distribution during these live-fire events. Gases were collected in front of and inside the tank and the results from the gaseous emissions study will be described in another report. This paper describes the results obtained on the deposition of propellant residues during tank live firings. In November 2008, the setup consisted of half circles of particle traps disposed at 1, 5, 10, 15, 20, 30 and 40 m in front of the tank. Ethanol was poured inside the traps to contain the particles emitted during firing. Following the first set of firings, many traps were destroyed, some caught fire, and the experiment had to be stopped. During this event, since the gaseous collection system was adequate, it was decided to continue the firing to measure the gaseous emissions. The particle collection experiment was postponed until February 2009 when a more robust setup could be put in place. During the February 2009 test, two methods of residues collection were compared: the snow collection and the particle trap methods. For this trial, the new traps were placed in front of the tank using a square pattern at 3, 5, 10, 15, 20, 25, 30, 40 and 45 m. This time, the particle trap setup was efficient and robust enough to collect the residues. Results from both collection methods were compared. It was found that firing 105-mm tank gun ammunition leads to the accumulation of solid propellant residues in the vicinity of the gun at 0.00263 % by weight of unburned 2,4-DNT. Similar results were obtained by both methods, confirming the validity of these results. It was also found that most of the particles are deposited at 20-25 m in front of the tank. This paper describes the sampling strategy, the laboratory procedure, and the results obtained.

Une recherche intense a indiqué que des résidus de propergol s'accumulent aux positions de tir et représentent une source de préoccupation pour l'environnement et pour la santé humaine. Afin de mieux comprendre les impacts des tirs réels aux positions de tir, une série de caractérisations a été effectuée pour mesurer la déposition de résidus de propergol provenant de nombreuses sources. La présente étude a été conduite à trois reprises avec des chars d'assaut Léopard faisant feu avec des obus de 105 mm. Le premier essai a été réalisé à la base de Gagetown (BFC Gagetown) où aucun résidu de propergol n'avait été identifié. À des fins de validation, deux essais additionnels ont été réalisés à la BFC Valcartier. RDDC Valcartier a évalué la dispersion des particules émises, les émissions de gaz et la distribution granulométrique des particules durant ces essais à tir réel. Les gaz ont été recueillis à l'avant et à l'intérieur du char d'assaut et ces résultats de l'étude des émissions gazeuses seront décrits dans un autre rapport. Ce rapport décrit les résultats obtenus sur la déposition des résidus de propergol durant les tirs réels effectués par le char d'assaut. En novembre 2008, la disposition des pièges à particules a consisté en des demi-cercles de pièges disposés à des distances de 1, 5, 10, 15, 20, 30 et 40 m en avant du char. De l'éthanol a été versé dans ces pièges pour contenir les particules émises par les tirs. Suite à la première série de tirs, plusieurs pièges ont été détruits, certains ont pris feu et l'expérience a dû être arrêtée. Lors de cet événement, puisque le système de collecte des gaz était adéquat, il a été décidé de poursuivre les tirs et de mesurer les émissions de gaz. L'expérience de collecte des particules a dû être reportée en février 2009 où

un ensemble de pièges plus robustes a pu être mis en place. Au cours de l'essai de février 2009, deux méthodes de collecte des résidus ont été comparées: la collection des particules sur la neige et la méthode des pièges à particules. Pour cet essai, les nouveaux pièges ont été placés en avant du char en utilisant un patron carré à des distances de 3, 5, 10, 15, 20, 25, 30, 40 et 45 m. Cette fois-ci, notre ensemble de pièges a été efficace et suffisamment robuste pour capturer les résidus. Les résultats des deux méthodes de collecte ont été comparés. Il a été constaté que le tir de munitions de 105 mm du canon des chars conduit à l'accumulation de résidus de propergol solide dans le voisinage du canon à 0.00263 % en poids de 2,4-DNT non brûlé. Des résultats similaires ont été obtenus par les deux méthodes confirmant la validité de ces résultats. Il a également été trouvé que la majorité des particules sont déposées à 20-25 m en face du char. Ce document décrit la stratégie d'échantillonnage, la procédure de laboratoire et les résultats obtenus

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Environment; explosives; residues; tank; live firing; demolition

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