Chapter 21

Residual Dinitrotoluenes from Open Burning of Gun Propellant

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Following military live fire artillery training, excess propellant bags are routinely open-burned at the firing site. Combustion of these propellants are typically incomplete under these conditions in the field, resulting in residues deposited on the soil surface, such as nitroglycerine and dinitrotoluenes. To better assess the amount of contaminants released during this process, burning tests were conducted with propellant bags from 105- and 155-mm munitions used for howitzer guns. Three different "activities" or burning tests were performed to achieve this study, which are described here. Residual 2,4- and 2,6-dinitrotoluene (DNTs) were analysed in all collected samples.

Introduction

At the end of most military exercises involving large caliber ammunition, such as 105- and 155-mm howitzers, trainees are usually left with a surplus quantity of unused gun propellant. Propellant charges for various large caliber ammunition are supplied in bags of known propellant quantity, from which a certain number are chosen for selective targeting at various distances. Propellant bags not used during the training exercise are destroyed on-site by open burning. For example, the firing of 30,000 rounds of 105-mm ammunition results in the burning of approximately 20,000 kg of single base propellant. If the propellant used were designated with bag numbers 6 and 7, this results in 641 g per round or 50 % in mass of the propelling charge (given that the single base propellant formulation contains 10 %

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of dinitrotoluene compounds (DNTs) (*1*), resulting in 2000 kg of DNTs burned). As the combustion is not complete during open burning of surplus propellant stocks, this quantity is considered a potential source of pollution for ranges and training aeas (RTAs).

In Canada, open burning of excess gun propellant was prohibited in 2010. Prior to this policy (and when this study was executed), excess propellant bags were routinely disposed of through open burning. Although outlawed in Canada, nevertheless, this method of disposal continues to be employed in other countries. Figure 1 shows the visual trace of this disposal technique when conducted on ice, snow and on bare soil.

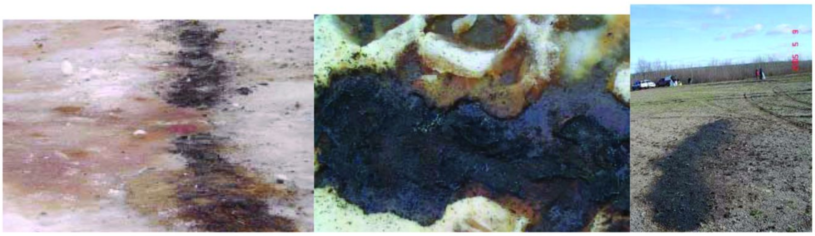

Figure 1. Residual contamination from open burning on ice, snow and soil.

The main pollutants released from burned propellants are 2,4- and 2,6-DNT, nitroglycerine (NG) and Pb. Soil contamination by DNTs and Pb are legislatively controlled by limit thresholds (see Table 1). Past studies have demonstrated that open burning of gun propellant can serve as a source of contamination and, consequently, potentially impact the environment (*2–4*). In fact, concrete burning pads were constructed for burning excess gun propellant at fixed locations in training areas to avoid deposition of unburned residues on soil. Pb and 2,4- and 2,6-DNT were measured in the soil as 60,000, 490 and 30 mg kg^{-1}, respectively (*4*). In another study, 40 burning points were sampled for propellants in soil over a 50 x 100 m area (*3*) with special care taken to remove all unburned propellant grains before analysis as to not affect the measurements. Concentrations of 770 and 30 mg kg^{-1} soil for 2,4- and 2,6-DNT were measured, respectively.

Badger Army Ammunition Plant was used intermittently over a 33-year period to produce single and double base propellants for gun, rocket and small arms ammunition. The disposal area used between 1942 and 1983 to burn waste propellant and as well as other process chemicals, created a point source of 2,4-, 2,6-DNT and Pb that resulted in a three-mile long plume of contaminated groundwater. This plume has migrated offsite of the facility and has been detected in private drinking water wells. Currently, a decontamination process is underway by the U.S. government to cleanup this disposal site, at an estimated cost of $250 million U.S. dollars (*5*).

Table 1. Soil contaminant standards from U.S. Environmental Protection Agency (EPA), Quebec, Ontario and Canada.[a]

Soil standards					
Residential/Parkland, mg/kg					
	Quebec	*Ontario*	*Canada (CCME[b])*	*Maryland*	*Region 3[c] USA*
2,4-DNT	0.04	1.1	N.A.	16	1.6
2,6-DNT	2 x 10^{-4}	N.A.	N.A.	7.8	61
Dibutylphtalate	6	N.A.	N.A.	780	6.1 x 10^{3}
Lead	500	200	140	400	400
Industrial, mg/kg					
2,4-DNT	1.7	N.A.	N.A.	200	5.5
2,6-DNT	3 x 10^{-2}	N.A.	N.A.	100	620
Dibutylphtalate	7 x 10^{4}	N.A.	N.A.	1.0 x 10^{4}	6.2 x 10^{4}
Lead	1000	1000	600	1000	800

[a] N.A. = not available. [b] CCME for Canadian Council of Ministers of the Environment. [c] Region 3 corresponds to the mid-Altantic states (Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia).

The objective of this study was to measure the residual concentration of 2,4- and 2,6-DNT after open burning of single base gun propellant. Three activities were performed: (1) February 2005 at Canadian Forces Base (CFB) Valcartier; (2) March 2005 at CFB Valcartier (DRDC experimental test site) and; (3) May 2005 at CFB Gagetown. Activities 1 and 3 consisted of collecting samples after the burning of an unknown number of bags during live firing events, while Activity 2 was a trial planned by DRDC where various experimental tests were performed on snow-covered ground to evaluate the mass of residues generated. Activities 1 and 2 were performed over snow-covered ground while sampling during Activity 3 was performed on the soil surface (*6*).

Experimental

Propellant Charges

The gun propellant used in 105- and 155-mm munitions during soldier training exercises was a single base formulation named M1, which is composed of 85 % nitrocellulose, 10 % 2,4-DNT, approximately 5 % dibutlyphtalate and 1 % potassium sulphate. M1 also contains 2,6-DNT, a by-product of 2,4-DNT synthesis. For both gun calibers, the propellant is separated into charges of various weight and loaded into a polyester-viscose rayon cloth bag marked with the

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increment or charge number (*1*). This system allows the soldier to withdraw one or more bags to adjust the charge depending on the target position. The propelling charge for the 105-mm munitions was M67, which consists of approximately 1.28 kg of gun propellant divided into 7 increment charges. Increment charge 5 incorporates a piece of Pb foil as a decoppering agent for the barrel of the Howitzer. The propelling charge for the 155-mm caliber was the M4A1 (M4 series), which is divided in 5 bags (numbers 3 to 7) and their total weight is 6.098 kg (*7*). No Pb is added to bags for the 155-mm munitions.

Experimental Design and Sampling Approach

Three main "activities" defined as propellant burn tests were performed in this study: burn tests for Activities 1 and 2 were conducted over snow-covered ground while Activity 3 was conducted over bare soil. Burn tests in Activities 1 and 3 (described in the following paragraphs) were conducted in conjunction with pace and tempo of live-fire training exercises. Thus, the exact number of propellant bags was not known, but estimated from a photography taken before burning commence. In contrast, Activity 2 was carried out by the DRDC team under more controlled conditions, where the exact quantity of propellant burned was known.

Activities 1 and 3

Activity 1 took place during an artillery exercise where 105-mm munitions were fired. Sample collection was adapted to interfere as little as possible with military training. For this reason, it was not possible to exactly count the number of propellant bags they were burned by the soldiers.

However, the number of bags were estimated from a digital image of the propellant stacks taken before the burning. From this image, we estimated that approximately 45 bags of charges numbers 5, 6 and 7 were placed along the ground in a line or row of approximately 1.8 m before burning, equaling a total gun propellant mass of 11.7 kg. After the propellant burn, and active training was concluded, the DRDC team divided the disposal "line" into three segments of 60 cm length for sampling. Snow cover remaining in each 60-cm segment after the propellant burn was collected in plastic bags and sealed until further processing (see Figure 2).

For Activity 3, propellant was burned following active artillery training with 105-mm howitzer ammunition (*8*). Images of the stacked propellant bags before and after burning are shown in Figure 3. Propellant residue grains were collected by sampling at 25 to 30 increments along the length of the burned row, taking great care to collect only residues and avoid incorporating soil into the sample.

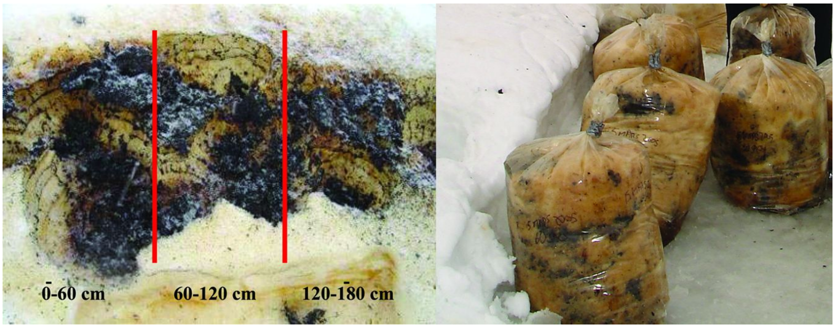

Figure 2. Row of gun propellant bags residues (left) and sampling in plastic bags (right).

Figure 3. Line of bags before (left) and after (right) the burning on the ground.

Activity 2

Activity 2 involved burning tests of stacks of propellant which were placed by the DRDC team over areas of snow cover. Since these tests were not performed as part of a military training exercise, we were better able to control experimental conditions and parameters related to testing. For these tests, we had available sixty complete cartridges of propellant for 155-mm munitions to study the effect of different patterns of burning on the quantity of residual material. All burnings were conducted on pristine snow cover. Although the sampling team attempted to exhaustively collect the majority of residual material on the test area, a yellow color was still apparent in the snow afterwards.

Activity 2 was conducted in two parts: first, tests were conducted with individual bags of propellant, as shown in Figure 4a. We performed one burning per bag (number 3, 4, 5, 6 and 7) totalling five burnings.The second part of Activity 2 involved the simultaneous burning of multiple propellant bags placed in line as shown in Figure 4b, similar to what is done following live-fire exercises. For this part of Activity 2, five replicate rows containing 15 bags of gun propellant each were burned, while only one row composed of 30 propellant bags and

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another row composed of 60 propellant bags were burned, with the length of each row ranging from 5 to 8 m.

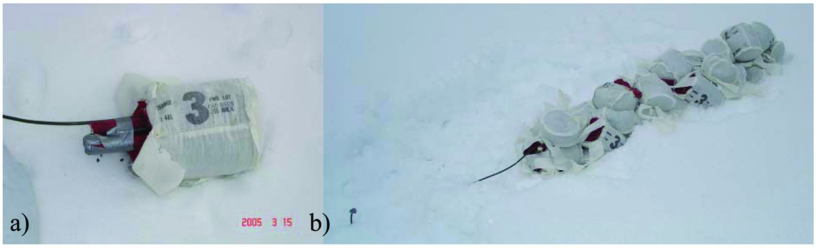

Figure 4. a) Individual bag; b) Row of 30 bags before their burning.

Burning the propellant over the snow-covered ground presented some unique challenges. The burning area was easily noticeable in the snow by its yellow color. However, sampling this clearly visible area provided difficulties since the heat of the reaction melted the overlying snow cover. This resulted in the ready leaching of propellant contaminants into the underlaying soil material. This yellow color was visually apparent to a depth of 65 cm below the soil surface, therefore samples were collected down to this depth as well. The yellow color is observed after propellant burning over ice and in snow, arising from the incomplete combustion of the gun propellant. This color was not observed when burning was performed over bare soil.

As burning tests for the rows of propellant containing 15 bags was replicated five times, we were able to calculate meaningful statiscial parameters. Calculations showed that the variance of the mean residual 2,4-DNT can be calculated to estimate the error associated with the mean percentage of residual 2,4-DNT. The result obtained is 0.0003 as the variance on the mean percentage that is 0.08%. However, this error is underestimated since the area of contamination was not completely collected. Thus, a significant error can be associated to the residues left on the snow after the collection of samples. We concluded to not provide an estimated error to this work for these reasons. Yet, this problem does not detract from the larger aim of this study, which is to determine if open burning of gun propellant leaves residual contamination. The contamination was probably more underestimated for the burning of several bags as compared to the individual bag burnings, since the extent of the burn area was more significant in this first case. In fact, the extent of contamination, i.e. the yellow contamination trace, was lower for individual bag burning than for the burning of several bags.

The percentage of residual 2,4-DNT reported in the following tables were calculated by dividing the mass of residual 2,4-DNT by the initial mass of gun propellant burned. This percentage allows an easy calculation of the mass of 2,4-DNT left in snow after the burning of a known quantity of single base gun propellant.

Sample Processing, Extraction, and Analysis

For soil samples, residues were air-dried in the dark, and then homogenized by adding acetone until a slurry was formed after which the acetone was evaporated. For snow samples, the collected snow was melted and the water was evaporated in a pail to recuperate the residues from the burning. The estimated mass loss from the evaporation of sample water and from the collection and transfer of residues from the pail to the extraction media ranged from 2 to 15%. Propellant residues recovered from snow and soil samples were sieved using a 25-mesh sieve (< 710 μm). Afterwards, an 8 g composite subsample was generated by randomly collecting several increments from the entire processed sample. This incremental samping approach was used in order to provide the greatest homogeneity in the subsample. This composite subsample was then placed in an amber vial and mixed with acetonitrile (10 to 20 mL) for 1 min, and then extracted using an ultrasonic water bath for 18 h. The vials were then centrifuged for 60 min at 2000 rpm and the supernatant was collected. The supernatant was diluted with a 1:1 acetonitrile to water mixture. Afterwards, a 2-mL volume of the mixture was removed and then diluted with another 2-mL volume of 1% calcium chloride. This mixture was then filtered through a 0.45 μm filter and the filtrate analyzed by high performance liquid chromatography (HPLC).

High Performance Liquid Chromatography (HPLC) (8)

All extracts were maintained at 4°C in the dark until analyzed by HPLC according to an in-house procedure based on EPA method 8330B (1994) (*9*). Dissolved propellant concentrations were determined using an Agilent HP 1100 HPLC system equipped with an ultraviolet (UV) diode array detector, which was set for simultaneously monitoring absorbances at 210, 220, and 254 nm during the chromatographic separation. During the separation, a 20 μL was injected into 15:85 isopropanol/water (v/v) mobile phase pumped at a flow rate of 0.75 mL min^{-1}. The separation was conducted across a Supelcosil LC-8 column (25 cm x 3 mm x 5 μm) stationary phase. The column temperature was maintained at 25 °C during the analysis. Standards and solvents were diluted 1:1 acetonitrile to water. Sample elutions were compared to a set of 14 standard energetic and propellant compounds, including HMX, RDX, 1,3,5-trinitrobenzene (TNB), 1,3-dinitrobenzene (DNB), nitrobenzene (NB), trinitrotoluene (TNT), tetryl, NG, 2,4-DNT, 2,6-DNT, 2-A-DNT, 2-nitrotoluene (NT), 3-NT, and 4-NT.

Results

Activity 1

Table 2 shows the total mass of 2,4-DNT obtained after burning propellant for 105-mm ammunition over snow following a live-fire training event. In some cases, evaporation of the water from the snow resulted in residue particles that were strongly agglomerated at the bottom of the pail. This made it extremely

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difficult to pass these particles through the 25-mesh sieve as described in experimental methods section. For this reason, some sample collected along the 1.8 m row of propellant bags was not analyzed. In the first 60 cm segment, the two samples of snow collected were analyzed, while for 60-120 cm segment, two of the three samples of snow collected were analyzed. Finally, one of the three samples collected from the 120-160 cm was analyzed.

Table 2. Residual 2,4-DNT quantites detected after burning over pristine snow cover during Activity 1. Distances indicate specific segments collected along the 1.8 m row of stacked propellant bags as described previously.

Sample	*2,4-DNT*	*residual 2,4-DNT*
	g	*%*
0-60 cm bag 1	0.53	0.07
0-60 cm bag 2	2.15	0.07
60-120 cm – bag 1	4.07	0.1
60-120 cm – bag 3	0.13	0.1
120-180 cm	4.94	0.13

When duplicate samples were collected from the same area, it was observed that the mass of 2,4-DNT was greater for the first collected sample (4.07 g) than that collected in the second duplicate (0.13 g). Obviously, this represented the fact that exhaustive sampling for the first duplicate greatly reduced the quantity of residue left for the second duplicate sample.

The calculated total mass of 2,4-DNT found in the propellant residues was 12 g. It was estimated that this mass represented approximately 45 bags of gun propellant that were burned. Assuming that 15 bags per row were burned, i.e. 3900 g of gun propellant with a homogeneous distribution of bags # 5, 6 and 7 (*1*), then we calculate that on average, the burned residue contained 0.1 % 2,4-DNT (i.e., 0-60 cm contained 0.07 %; 60-120 cm: 0.1 % and 120-180 cm: 0.13 %). Note that this calculation of the mass of 2,4-DNT in the burning residues was normalized by the initial mass of gun propellant, multiplied by 100. It was calculated that the proportion of 2,6-DNT in the residues varied from 0 to 4 %.

Activity 2

Activity 2 involved burning tests of 155-mm ammunition on snow cover under more controlled conditions than Activities 1 and 3, since the number of bags burned was known exactly and different strategies of burning conditions were experimented. The first stage of this test was to burn the individual bags of propellant (bags # 3, 4, 5, 6 and 7) on a pristince snow cover (see Figure 4a). The results obtained for each charge are presented in Table 3. The quantity of 2,4-DNT recovered ranged from 0.04 to 0.13% (or an average 0.08%) of the total residue mass. We attempted to relate the quantity of 2,4-DNT remaining in the burned residues to the initial quantity of propellant contained in each particular bag (e.g., # 3, 4, 5, 6, 7), but in the end, found no relationship between these parameters. Therefore, the quantity of 2,4-DNT contained within the residual material collected over the snow cover cannot be statistically correlated with the initial quantity of propellant before burning. Measurements of 2,6-DNT (data not shown) demonstrated that the quantity of this compound ranged from 2 to 3 %.

Table 3. Quantity of residue and 2,4-DNT recovered following burning of individual bags of propellant over a pristine snow cover.

Charge number (mass of the bag)	*solid residues*	*solid residues*	*2,4-DNT*	*residual 2,4-DNT*
	g	*%*	*g*	*%*
4 (0.524 kg of gun propellant)	91.8	17	0.40	0.08
5 (0.779 kg of gun propellant)	12.5	2	0.28	0.04
6 (1.261 kg of gun propellant)	54.2	4	0.48	0.04
7 (1.530 kg of gun propellant)	36.3	2	2.01	0.13
3 (1.814 kg of gun propellant)	37.9	2	1.59	0.09

Our inability to correlate initial mass of DNT with residual quantity left in unburned propellant particles suggests a link between the different scenarios in which propellant bags are stacked and oriented before burning. Thus, the second stage of Activity 2 involved determining the quantity of residue material and the concentration of 2,4-DNT remaining with that material under different burning scenarios. In particular, propellant bags are typically stacked in a row by soliders after live-fire exercises and burned all at once, as opposed to burned individually as performed in the first stage of Activity 2. For this work, three different scenarios were tested. First, five replicate rows consisting of 15 bags of propellant each were burned. Afterwards, these rows were sampled and analyzed as previously described. The data (Table 4) shows that quantity of 2,4-DNT measured within the residue material was statiscially reproducible. Measured quantities of 2,4-DNT ranged from 0.04 to 0.09% total mass of the burned residue material.

The second scenario involved burning one row consisting of 30 bags of propellant, while the third experimental scenario involved burning of one row consisting of 60 propellant bags. The quantity of residual 2,4-DNT (Table 4) after burning the row with 30 bags of propellant was 36.3 g (0.1% total residue mass), while the residual 2,4-DNT concentration from the row with 60 bags was 22.1 g (0.03% total residue mass). The lower quantity of 2,4-DNT recovered from the row with 60 propellant bags may be in part explained by the fact that the residue material was spread out over a larger area than expected, making it more difficult to exhaustively sample the site. Thus, this difficulty must be resolved before a more extensive interpretation of the data can be offered. In addition, we again did not observe any correlation between the initial and final concentrations of 2,4-DNT remaining in the residue material.

Table 4. Quantity of total residue material and 2,4-DNT recovered after burning bags of propellant over a pristine snow cover.

Scenario (initial mass of gun propellant)	*solid residue*	*2,4-DNT*	*residual 2,4-DNT*
	g	*g*	*%*
15 bags, burn 1 (18.294 kg)	406.0	11.5	0.06
15 bags, burn 2 (18.294 kg)	427.0	16.8	0.09
15 bags, burn 3 (18.294 kg)	394.3	13.4	0.07
15 bags, burn 4 (18.294 kg)	538.6	12.2	0.07
15 bags, burn 5 (18.294 kg)	275.7	7.3	0.04
30 bags (36.588 kg)	808.7	36.3	0.10
60 bags (73.176 kg)	1681.0	22.1	0.03

From the mean percentage, i.e. 0.07 %, it is possible to estimate the amount of 2,4-DNT left on snow after the burning of a known mass of single base gun propellant. For example, if 10 kg of gun propellant is burned on snow, approximatively 7 g of 2,4-DNT will be released in the environment. As we failed to exhaustively recover the residue from the burn area, , we believe the results are underestimated as mentioned earlier in the text. The proportion of 2,6-DNT of the total DNTs recovered varied from 1 to 3 %.

Activity 3

Activity 3 consisted of the open burning of gun propellant bags during live fire exercises, where the exact number of propellant bags that were burned was unknown. However, burns were conducted over bare soil as opposed to pristine snow cover . Two different sites were sampled following live-fire exercises. For this particular test, soil samples were collected from the burn area in duplicate, processed, and anlayzed as described previously, however, care was taken to remove the propellant residue from the collected soil sample. The results from these tests are presented in Table 5. The mean concentrations of 2,4-DNT detected at the two sites were 700 ± 100 and 345 ± 5 mg kg^{-1} soil, respectively, This can be explained by the fact that a larger number of propellant bags were burned at Site 1 than Site 2, which, of course, is a sensible result. Also, we measured for the first time, quantities of 1,3-DNB in the soil samples – something not found in the tests over pristine snow cover. . The proportion of 2,6-DNT of the total DNTs in the soil ranged from 4 to 5 %.

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Table 5. Energetic materials detected in samples collected at Sites 1 and 2 during Activity 3.[a]

Sample	*1,3-DNB*	*2,4-DNT*	*2,6-DNT*
	mg/kg	*mg/kg*	*mg/kg*
Gun propellant burning-Site 1	1.7	740	39
Gun propellant burning-Site 1 DUP	1.2	550	25
Gun propellant burning-Site 2	1.0	340	14
Gun propellant burning-Site 2 DUP	1.0	350	13

[a] DUP = field duplicate

Discussion

Alternative Methods to the Burning of Gun Propellant

DRDC Valcartier studied the effect of burning composition M1 single base propellant directly over soil and a pristine snow cover. Burning of the propellant material was overwhelmingly incomplete, as demonstrated by Activities 1 and 2, leaving behind significant quantities of residue particles, and relatively high concentrations of dintrotoluene compounds. Incomplete combustion of the propellant over the snow cover seemed to be in part, attributed to the melting and subsequent consumption of the energy by the resulting water, resulting in a less complete combustion. The following discussion explains briefly the different approaches suggested by DRDC Valcartier to minimize the accumulation of toxic compounds, such as 2,4-DNT and NG (if double base propellant is used) in the environment from propellant burning.

Incorporation of Modular Charge Artillery System

The Modular Charge Artillery System (MACS) was developed to increase the efficiency of propellant use for weapons, while minimizing the excess left over after training. "MACS uses a "build-a-charge" concept in which all M231 and M232 increments are identical in the lot, eliminating the need to dispose of unused increments. Unused increments are retained for future use. MACS propellants are transported and handled in the same manner as other conventional propellants" (*10*). This system has been available for 155-mm howitzer guns since 2003. Military personnel confirmed to DRDC scientists that no burning of excess propellant occurs with the use of the MACS.

Recycling of the Excess of Gun Propellant

Excess bags of propellant following live firing exercises can be returned from the field and placed in a secure magazine, for later collection, reprocessing, and use as new gun propellant.

A New Burning Scenario

It is obvious that the current scenario of open burning does not promote the complete combustion of the propellant compounds. A new scenario should be designed to ensure more complete combustion. For example, the propellants could be burned using a field reactor, engineered for more complete combustion under higher temperature and pressure. However, such an engineering solution is probably not feasible or conducive to field situations, where the warfighter may be required to stringently follow a particular protocol or require additional equipment to achieve this. Moreover, with such an approach, no detonation will occur if the mass of gun propellant bags burned does not exceed the critical mass needed to obtain a deflagration to detonation transition.

Burning Gun Propellant in Metal Pans Placed in the Field

In some installations, excess of gun propellant after live-fire exercise are burned after placing the material in large metal pans (*11*). Under this scenario, propellant residues after the burn are concentrated in a single location, avoiding the potential for dispersing the materials onto the soil or surface waters. Althought deployed on a number of military bases, burning propellant on concrete pad is not recommended since the concrete can fracture with seasonal fluctuations, allowing for leaching of the residues with rainfall, and migration into the environment.

Incinerator

The excess of gun propellant could also be simply burned in an incinerator. Such conditions could ensure more complete control of burn conditions, while catching residue material and prevent spread into the environment. Moreover, an incinerator can reduce the gaseous or particulate emissions during the burning process when equipped with the proper gaseous emissions scrubbers (*12*).

Conclusion

Activity 1 demonstrated that open burning of excess gun propellant bags was incomplete, resulting in leftover residue material containing relatively high concentrations of dinitrotoluenes. 2,4-DNT quantities were on average 0.1 %. In Activity 2, different scenarios of burning were tested, showing that there was little difference in the quantity of residue and dinitrotoluenes whether the propellant bags were burned or in stacks or rows. Activity 3 represented a sampling event following live-fire exercises, where propellant burning was tested over bare soil as opposed to a pristine cover of snow.

In general, burning the excess bags of propellant over the pristine snow cover seemed to result in greater concentrations of residual dinitrotoluene than when burned over bare soil. It was hypothesized that this was a result of the energy loss attributed to the absorption and metling of the snow during the burn. Thus, less energy was available to combust the propellant itself. This melting, coupled with the permeation of the snow melt into the soil, made complete sampling of the snow material impossible. Thus, we expect that dinitrotoluene concentrations measured from open burning over snow are underestimates.

A similar study, conducted by Walsh et al. (*13*), showed that the burning of single base propellant over bare soil (wet and dry moisture conditions) of single base propellant left approximately 0.9 % of residual 2,4-DNT relative to the initial mass of 2,4-DNT present in the formulation (note that in this study, the percentage is calculated by dividing the mass of 2,4-DNT detected with the total mass of gun propellant burned). Given that the proportion of 2,4-DNT in single base propellant is 10%, a similar percentage was obtained if our result is converted to obtain the residual 2,4-DNT over the initial 2,4-DNT (0.8%), as Walsh et al. reported. However, this similarity is surprising since in this study the burning was performed on snow while their tests were performed over clean sand. No reason was found to explain why the residual 2,4-DNT is similar in both cases, as the combustion was supposed to be affected by the snow and, consequently, the water produced during the melting of the snow. This reaction should decrease the rate of the combustion inducing a less complete combustion.

Future work should be carried out with known quantities of gun propellant bags burned over bare soil to obtain more accurate estimates of dinitrotoluenes remaining in the residual material. In this study, the unburned residues seemed less dispersed on the soil than on the pristine snow cover. We hypothesized that the snow covered absorbed the heat energy intended for burning the excess propellant by melting the snow, thus reducing the efficiency of combustion of the propellant bags.

Finally, we recommend that in order to avoid or limit the residual contamination due to the burning of excess propellant, some important alternatives should be considered, as discussed previously. These alternatives include: 1) employing modular charges (e.g., MACS) for weapons, such as the 155-mm munitions; 2) establish recycling programs allowing for the reuse of excess of gun propellant; 3) burning of gun propellant over metal pans either carried out by the soliders or placed strategically in the field; 4) develop more efficient burning scenarios, such as possibly a field-portable reactor, and ; 5) collection and transport of excess propellant to be burned in a base incinerator. It is to be noted that solutions 1 and 2 would be ideal, for not only decreasing waste and enhancing efficiency, but also does not rely on the burning at all.

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