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Assessment of ANFO on the environment

Technical Investigation 09-01

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Defence R&D Canada – Valcartier

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Abstract

In September 2008, DRDC Valcartier was tasked by Director Ammunition and Explosives Management and Engineering (DAEME 3-4) to perform a literature review to assess the effect of Ammonium Nitrate Fuel Oil (ANFO) on the environment and to determine its suitability for service. The Canadian Forces are concerned about the high solubility of ammonium nitrate (AN) that could represent a potential threat to the environment. For example, the detonation of ANFO is often incomplete in a wet environment, leaving behind by-products of unreacted AN as nitrate, nitrite and ammonia into the soil and groundwater. Since groundwater is a critical water source for many humans and animals in isolated locations, all efforts should be directed in preventing water supply contamination. Proper measures must therefore be followed when ANFO is used as a blasting explosive. General guidelines found in the literature are reviewed in this memorandum.

Résumé

En septembre 2008, RDDC Valcartier a été mandaté par le Directeur gestion et technique des munitions et explosifs (D Gest TME 3-4) de réaliser une étude de littérature pour évaluer l'effet du mélange de nitrate d'ammonium et de mazout (ANFO) sur l'environnement et de déterminer son aptitude au service. Les Forces canadiennes sont préoccupées par la grande solubilité du nitrate d'ammonium (AN) qui pourrait constituer une menace potentielle pour l'environnement. Par exemple, la détonation d'ANFO en présence d'humidité est souvent incomplète et conduit à la dispersion dans le sol et les eaux souterraines de sous-produits d'AN n'ayant pas réagi, tels que le nitrate, le nitrite et l'ammoniac. Étant donné que les eaux souterraines représentent une source d'eau essentielle pour de nombreux êtres humains et animaux dans des endroits isolés, tous les efforts devraient être concertés pour éviter la contamination des systèmes d'approvisionnement en eau. Des mesures adéquates doivent donc être suivies lorsque l'ANFO est utilisé comme explosif de minage. Le présent mémorandum résume les lignes directrices générales trouvées dans la littérature.

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Executive summary

Assessment of ANFO on the environment - Technical Investigation 09-01

Sylvie Brochu; DRDC Valcartier TM 2009-195; Defence R&D Canada – Valcartier; January 2010.

Introduction or background: The detonation of Ammonium Nitrate Fuel Oil (ANFO) is often incomplete in a wet environment, leaving behind toxic and water-soluble by-products of unreacted AN as nitrate, nitrite and ammonia into the environment. The Canadian Forces (CF) are concerned about the potential for these contaminants to reach groundwater and contaminate the water supply. There was thus a need to perform a risk assessment study to properly evaluate the hazard of using ANFO and to propose appropriate recommendations to the CF. It was decided to perform this study in two steps, with a literature review as a start, and continue with a laboratory study if necessary.

Results: The most common environmental issues associated with the use of ANFO are related to dissolution of AN and to oil wicking, which lead to heterogeneities in the ANFO composition that will in turn decrease the detonation velocity of the explosive and thus, adversely affect the detonation performance of ANFO. Non stoichiometric ANFO composition will also lead to non-ideal detonations producing more toxic fumes of NO, NO₂, CO and methane. The leaching of nitrates from the explosive occurs rapidly, 25% of nitrates being lost after a six-minute exposure and 50% after a one-hour exposure. ANFO can no longer detonate after the loss of 25% nitrates.

Significance: ANFO should be used with extreme care. Approaches to prevent the contamination of surface water and groundwater with ammonia and nitrate, as well as reduce the production of toxic gases, must be preferred. The use of bulk ANFO should be avoided because of lack of confinement. The use of packaged ANFO and ANFO/emulsion mixtures containing less than 60% emulsion is acceptable only in very dry conditions; therefore, this kind of ANFO should not be used in wet/humid soils and on snow/ice. When these latter conditions are encountered, the use of water-resistant emulsions seems more appropriate. Care should be taken to use only stoichiometric mixtures of ANFO. The duration and degree of confinement must be kept as high as possible, and ANFO must be used immediately after being poured onto or into the ground. Long intervals between explosive loading and firing must be avoided. To increase the detonation efficiency, the user should select the smallest possible AN particles, with a diameter preferentially lower than 0.85 mm, having a pore diameter smaller than 8 µm, and an oil absorption capacity larger than 19%. Also, an environmental assessment of the soil where ANFO will be used should be carried out, and appropriate monitoring of ammonia, nitrates, and the BTEX suite (benzene, toluene, ethylbenzene and xylenes) should be performed if necessary.

Future plans: The next step of this project would be to perform specific environmental assessment where significant amounts of ANFO are planned to be used. DRDC Valcartier has the in-house expertise to perform specific laboratory studies to evaluate the effects of the use of

ANFO on typical soils from the ranges and training areas. Alternatively, the risk could also be evaluated using the hydrogeological assessments performed by DRDC Valcartier on most major Canadian military bases.

Sommaire

Assessment of ANFO on the environment - Technical Investigation 09-01

Sylvie Brochu; DRDC Valcartier TM 2009-195; R & D pour la défense Canada – Valcartier; Janvier 2010.

Introduction ou contexte: La détonation du mélange de nitrate d'ammonium et de mazout (ANFO) est souvent incomplète en présence d'humidité et entraîne la dispersion dans l'environnement de sous-produits d'AN toxiques et hydrosolubles n'ayant pas réagi, tels que le nitrate, le nitrite et l'ammoniac. Les Forces canadiennes (FC) sont préoccupées par le potentiel de contamination des eaux souterraines et du système d'approvisionnement en eau. Il était donc nécessaire de procéder à une étude d'évaluation des risques pour estimer correctement les dangers reliés à l'utilisation d'ANFO et de proposer des recommandations appropriées aux FC. On a décidé d'effectuer cette étude en deux étapes, en débutant par une revue de la littérature, suivie si nécessaire par une étude en laboratoire.

Résultats: Les problèmes environnementaux les plus couramment associés à l'utilisation d'ANFO sont liés à la dissolution de l'AN et à l'exsudation du fuel, qui aboutissent à une composition d'ANFO hétérogène qui, à son tour, entraîne une diminution de la vitesse de détonation de l'explosif et, par conséquent, nuit aux performances de détonation de l'ANFO. Les compositions d'ANFO non stœchiométriques entraînent également des détonations non idéales produisant plus de fumées toxiques de NO, NO₂, CO et de méthane. La lixiviation des nitrates de l'explosif est rapide, la perte de nitrates atteignant 25 % après une exposition de six minutes, et 50 % après une heure d'exposition. L'ANFO ne peut plus détoner après une perte de nitrates supérieure à 25 %.

Importance: L'ANFO devrait être utilisé avec une extrême prudence. Les approches à privilégier doivent permettre d'éviter la contamination des eaux de surface et des eaux souterraines par de l'ammoniac et des nitrates, ainsi que de réduire la production de gaz toxiques. L'utilisation d'ANFO en vrac doit être évitée en raison du manque de confinement. L'utilisation d'ANFO ensaché et de mélanges ANFO / émulsion contenant moins de 60 % d'émulsion est acceptable uniquement dans des conditions très sèches; par conséquent, ce type d'ANFO ne doit pas être utilisé sur des sols détrempés ou humides, sur la neige ou sur la glace. Dans ces conditions, l'utilisation d'émulsions résistantes à l'eau semble plus appropriée. Seuls des mélanges stœchiométriques d'ANFO devraient être utilisés. La durée et le degré de confinement devraient être aussi élevés que possible, et l'ANFO doit être utilisé immédiatement après avoir été déposé sur ou dans le sol. Il faut éviter les longs délais entre le chargement des explosifs et leur détonation. Pour augmenter l'efficacité de la détonation, l'utilisateur devrait sélectionner les particules d'AN les plus petites possible, avec un diamètre de préférence inférieur à 0,85 mm, ayant des pores d'un diamètre inférieur à 8 µm et une capacité d'absorption d'huile de plus de 19 %. En outre, une évaluation environnementale devrait être effectuée sur les lieux d'utilisation.

d'ANFO, comprenant, si nécessaire, la surveillance de l'ammoniac, des nitrates et du BTEX (benzène, toluène, éthylbenzène et xylènes).

Perspectives: La prochaine étape de ce projet serait d'effectuer une évaluation environnementale spécifique à des endroits où l'utilisation de quantités importantes d'ANFO est prévue. RDDC Valcartier possède l'expertise interne pour procéder à des études de laboratoire permettant d'évaluer les effets de l'utilisation d'ANFO sur des sols typiques de sites d'entraînement. Alternativement, le risque pourrait aussi être évalué en utilisant les études hydrogéologiques réalisées par RDDC Valcartier sur la plupart des bases militaires canadiennes d'importance.

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1 Introduction

The aim of this work was to perform a literature review to:

1. Evaluate the effects of the use of ANFO on typical soils of Canadian ranges and training areas.
2. Evaluate the potential for oil and nitrates to leach out of the ANFO mixture and into the soil prior to initiation, and at which rate this happens between preparation and detonation. Determine if special site preparation is required before setting ANFO into place.
3. Evaluate potential short and long-term effects on the environment. Estimate the amount of ANFO that can be used before too much damage is done to the environment.
4. Identify the correct ratio of mixture of AN with fuel oil, which must be consistent to prevent incomplete detonation and the spreading of contaminants. Therefore, identification of these ratios and recommendations as to proper handling, preparation and use of ANFO will be crucial and could minimize the chances of contamination.

Most of the information reported in this work is associated to the mining industry, which uses large quantities of ANFO. Each of these above-mentioned subjects will be addressed separately in the following text. This will be followed by a conclusion and recommendations on the use of ANFO. A reference section is also included, and the initial statement of work is annexed (see annex A).

2 Results

2.1 Effects of ANFO on typical soils of Canadian ranges and training areas (RTAs).

2.1.1 Composition

ANFO is known as a mixture of ammonium nitrate (AN) and fuel oil (FO) appreciated in the mining industry for its low cost. Just in 2005, one billion pounds of ANFO were used in the United States. Ammonium nitrate is a white crystalline solid at room temperature, well known in the explosive community for its oxidizing properties. Fuel oils are a variety of yellowish to light brown liquid mixtures that come from crude petroleum products. Some commonly found fuel oils include kerosene, diesel fuel, jet fuel, range oil, and home heating oil. These fuel oils differ from one another by their hydrocarbon compositions, boiling point ranges, chemical additives and uses. Some chemicals found in fuel oils may evaporate easily, while others may more easily dissolve in water.

All fuel oils consist of complex mixtures of aliphatic and aromatic hydrocarbons. The aliphatic alkanes (paraffins) and cycloalkanes (naphthenes) are hydrogen-saturated and compose approximately 80 to 90% of the fuel oils. Aromatics (e.g., benzene) and olefins (e.g., styrene and indene) compose 10 to 20% and 1%, respectively, of the fuel oils. The oil most often used in ANFO is fuel oil no. 2 or diesel fuel no. 2. Fuel oil no. 2 is a middle, usually blended, distillate with hydrocarbons in the C_{11} - C_{20} range. Diesel fuel no. 2 is similar in chemical composition to fuel oil no. 2, with the exception of the additives. Diesel fuels predominantly contain a mixture of C_{10} through C_{19} hydrocarbons, which include approximately 64% aliphatic hydrocarbons, 1 to 2% olefinic hydrocarbons, and 35% aromatic hydrocarbons. Diesel oils, as well as typical heating oil, fall under the broader category of Fuel Oil Number 2 (CAS 68476-30-2).

The stoichiometric composition of ANFO is 94.5% AN and 5.5% FO. However, the composition of commercial ANFO formulations will vary depending on the manufacturer. For example, Dynobel manufactures a mixture of AN (92 to 95%), fuel oil no. 2 (4 to 7%) and guar gum (0 to 3%). AMEX™ from Orica is made of 60 to 82% AN and 5 to 10% fuel oil no. 2, and NorAnfo™ from Nordex is composed of 94.33% AN and 5.67% fuel oil. For information, the Material Safety Data Sheet (MSDS) of each of these products is provided in annex B, as well as those of the specific FO used in the mixtures.

2.1.2 Undetonated ANFO

Both undetonated and detonated ANFO can cause adverse effects on the environment. Ammonium nitrate in undetonated ANFO is readily soluble in water and gets easily to surrounding surface water and groundwater. Fuel oil wicking from ANFO can also cause a local environmental problem. In addition, some of the combustion products can also cause adverse environmental impacts. This Subsection will summarize the effects of the main products of concern related to the use of ANFO.

The nitrate ion (NO_3^-) serves as the primary source of nitrogen for aquatic plants in well oxygenated systems. As nitrate levels increase, there is an increasing risk of algal blooms and eutrophication in surface waters according to the Canadian Council of Ministers of the Environment (CCME) (2003). Nitrate is considerably less toxic than ammonia or nitrite. Infants younger than 4 months of age are at particular risk of nitrate toxicity from contaminated well water. Elevated levels of nitrates are toxic to aquatic freshwater animals due to the methaemoglobin formation that results in a reduction in the oxygen carrying capacity of blood and to the inability of the organisms to maintain proper osmoregulation under high salt contents associated with elevated nitrate levels. For marine life, mortality, reduction in feeding and growth, and cellular changes have been reported. To protect the freshwater and marine life, CCME (2003) has set the guidelines to 13 and 16 mg NO_3^-/L , respectively. It is worth noting that the goal of these guidelines is not to prevent eutrophication, which can happen at lower nitrate concentrations. The drinking water guideline for nitrate has been set at 45 mg/L (Health Canada, 2008); it is currently under revision.

The ammonium ion (NH_4^+) is readily soluble in water, in which it is in equilibrium with ammonia (NH_3), depending on the pH, the temperature and the ionic strength of water. Raising pH by one unit can cause the concentration of NH_3 to increase nearly tenfold, while a 5 °C temperature rise can cause an increase of 40-50% (CCME, 2000). The toxicity of NH_3 is much higher than that of NH_4^+ . CCME prescribes a guideline of 0.019 mg/L of NH_3 for the protection of aquatic life in freshwater. There are currently no guidelines for the protection of marine life from NH_3 , or for NH_4^+ .

Ammonia is also a threat to human health. Reported symptoms are irritation of eyes, nose and throat, breathing difficulty, wheezing, chest pain, pulmonary edema, skin burns, vesiculation, and frostbite from liquid ammonia. The National Institute for Occupational Safety and Health (NIOSH) (2007) recommends that average workplace air levels do not exceed 25 mg/m³ for a 15-minute period. Ammonia is immediately dangerous to life and health (IDLH) above 210 mg/m³.

Breathing some fuel oils for short periods may cause nausea, eye irritation, increased blood pressure, headache, light-headedness, loss of appetite, poor coordination, and difficulty concentrating. According to the Agency for Toxic Substances and Disease Registry (ATDSR)

(1995), breathing diesel fuel vapors for long periods may cause kidney damage and lower the blood's ability to clot.

Short-term hazards of some of the lighter, more volatile and water soluble compounds (such as toluene, ethylbenzene, and xylenes) in diesels include potential acute toxicity to aquatic life in the water column (especially in relatively confined areas) as well as potential inhalation hazards. Diesel fuels have moderate volatility and moderate solubility. Diesel products possess moderate to high acute toxicity to biota with product-specific toxicity related to the type and concentration of aromatic compounds. Diesel spills could result in potential acute toxicity to some forms of aquatic life. Oil coating of birds, sea otters, or other aquatic life which come in direct contact with the spilled oil is another potential short-term hazard. In the short term, spilled oil will tend to float on the surface; water uses threatened by spills include: recreation, fisheries, industrial, potable supply and irrigation.

Long-term potential hazards of some of the lighter, more volatile and water soluble compounds (such as toluene and xylenes) in diesel fuels include contamination of groundwater. Long-term water uses threatened by spills include potable (ground) water supply. Chronic effects associated with middle distillates are mainly due to exposure to aromatic compounds.

The International Agency for Research on Cancer (IARC) has determined that some fuel oils (heavy) may possibly cause cancer in humans, but for other fuel oils (light) there is not enough information to make a determination. IARC has also determined that occupational exposures to fuel oils during petroleum refining are probably carcinogenic in humans. The Occupational Safety and Health Administration (OSHA) and the Air Force Office of Safety and Health (AFOSH) have set a permissible exposure level (PEL) of 400 parts of petroleum distillates per million parts of air (400 ppm) for an 8-hour workday, 40-hour workweek (ATDSR, 1995). NIOSH (2007) recommends that average workplace air levels not exceed 350 mg/m³ of petroleum distillates for a 40-hour workweek.

Because of the potential adverse environmental effects of ANFO, its use in Canada is regulated by Section 36(3) of the Fisheries Act (1985), which prohibits *the deposit of deleterious substances into waters frequented by fish, unless otherwise permitted by regulation. There is no regulation pursuant to the Fisheries Act that permits the deposit of by-products resulting from the use of ammonium nitrate-fuel oil mixtures.* Also, the use of ANFO near bodies of water is not recommended by the Institute of Makers of Explosives, which stipulates that *No use of ammonium nitrate-fuel oil mixtures occurs in or near water due to the production of toxic by-products (ammonia)* (Wright and Hopky, 1998).

2.1.3 Combustion products

The detonation of ANFO produces a cloud of reaction products comprising various amounts of nitrogen (N₂), water vapor (H₂O), hydrogen (H₂), oxygen (O₂), carbon monoxide (CO), carbon dioxide (CO₂), methane (CH₄), nitrogen dioxide (NO₂), nitric oxide (NO) and ammonia (NH₃) (Farnfield et al., 2004; Sapko et al., 2002). For every kilogram of ANFO that is detonated,

approximately 1000 liters of gas are produced (Martel et al., 2004). These are reported in Table 1.

Table 1: Combustion products of ANFO, obtained from detonation in calorimeter (Martel et al., 2004)

Combustion Product	Volume of gas
	L/kg
H ₂ O	588
N ₂	230
CO ₂	67.6
CO	13.2
H ₂	4.2
N ₂ O	9.9
NO	<d ¹
CH ₄	0.13
C ₂ H ₆	0.07

¹Detection limit

Under ideal conditions, these reaction gases principally consist of CO₂, N₂ and H₂O. However, most detonations do not occur under ideal conditions, leading thus to the formation of other more toxic gases, such as CO, NO and NO₂ (Farnfield et al., 2004; DND, 1998). Of these, NO₂ is one of the most toxic products, with an OSHA PEL of 9 mg/m³ and a IDHL of 37.6 mg/m³ (NIOSH, 2007). Symptoms of exposure include irritation of eyes, nose and throat, cough, mucoid frothy sputum, decreases pulmonary function, chronic bronchitis, breathing difficulty, chest pain, pulmonary edema, cyanosis, tachypnea, and tachycardia. The generation of orange/red post-blast NO₂ clouds, more commonly referred to as yellow or orange smoke, is common in the commercial explosives' industry. The occurrence of such post-detonation fumes has historically been associates with wet condition and had not been viewed with alarm due to the rapid dispersion of the gas into the air.

The exposure to NO is known to induce irritation of eyes, wet skin, nose and throat, drowsiness, unconsciousness, and methemoglobinemia. The OSHA PEL and the IDHL are of 30 and 123 mg/m³, respectively. CO exposure produces a variety of symptoms, from headache, tachypnea, nausea, lassitude, dizziness, confusion, hallucination, to angina and even syncope. The OSHA PEL and the IDHL are 55 and 1380 mg/m³, respectively. In addition, NO and CO are well known greenhouse gases, as well as methane. NO_x will also contribute to the production of acid rain.

Other combustion products of ANFO have also been detected. Garcia and Harpalani (1989) performed a study in an underground mine to characterize the volatile by-products adsorbed on airborne particulates following the detonation of ANFO. These by-products were adsorbed on the particulates generated and remained airborne following the detonation of explosives. The major ones were bis(2-ethylhexyl)phthalate and C₁₂ to C₂₈ aliphatic hydrocarbons. Also, recent groundwater quality monitoring related to limestone mining activities in Miami-Dade County have revealed benzene residues associated with this material in concentrations of concern (Sierra Club et al. v. Strock and Hall 2007). Benzene residues in aquatic field and laboratory studies have been demonstrated to have both chronic and acute toxicity effects on study organisms (CCME, 1999).

To summarize, undetonated ANFO can lead to the dispersion of ammonia and nitrate in the environment, which could have either short or long-term toxic effects on fish and wildlife resources if they were released in sufficient concentrations. The detonation of ANFO releases variable amounts of greenhouses and toxic gases that could also affect nearby workers. There is thus a need to execute detonations with ANFO in ways that will minimize the release of contaminants to the environment.

2.2 Potential for leaching of nitrates and oil, rate of leaching and site preparation.

2.2.1 Dissolution of AN

The concentration of nitrates in mine effluents is site specific and varies widely from 25 to 300 mg/L, which is well above the CCME criteria for the protection of aquatic life of 13 to 16 mg/L. The concentration of ammonia was found to vary from 10 to 40 mg/L (Koren et al., 2000), which is also well above the CCME criteria for the protection of aquatic life of 0.019 mg/L.

Pommen (1983) evaluated that up to 1% of the nitrogen content of ANFO used at the Fording coal mine in British Columbia in 1979-80 was released to the receiving environment. However, Ferguson and Leask (1988) in a later analysis of water quality near coal mines in the Kootenay coal fields, indicated that Pommen's results (1983) were likely an overestimate of the nitrogen release. Mines that used ANFO explosives in dry conditions released 0.2% of the nitrogen from blasting, as compared to the 1% predicted by the Pommen (1983) formula. Wiber et al. (1991) evaluated that, even with good practices, there is a significant (5 to 15%) loss during the use of ANFO.

Field evidence and studies show that ANFO often fails to ignite or burn completely in shot holes. Laboratory procedures for predicting nitrate concentrations in effluent after the disposal of spent ore at heap-leach gold processing operations were investigated by Davis et al. (1996). Laboratory tests were performed to define the concentrations of nitrate and nitrite in leachate as a function of time. Nitrate and nitrite were easily observed during the column testing of spent and blasted, unreacted ore. Levels of both contaminants decrease monotonically as a function of time. Nitrate

levels in spent ore went from approximately 40 mg/kg during the first day of leaching, to approximately 12 mg/kg after 10 days. In the blasted ore, nitrate went from more than 140 mg/kg, to approximately 20 mg/kg after 10 days. Nitrite was not detected.

According to Revey (1996), exposure of ANFO to water leads to a loss of nitrate of approximately 25% after 10 minutes and 50% after one hour. ANFO is no longer detonable after the loss of 25% nitrates. The use of water resistant (WR) ANFO is slightly better, leading to a loss of water of approximately 25% after a one-hour exposure (Revey, 1996).

2.2.2 Loss of fuel oil in ANFO from wicking

Several experiments were conducted to assess the amount of fuel oil loss due to wicking of the fuel oil in ANFO. In one of these, AN prills were mixed with diesel fuel no. 2 and set for 24 hours (Sapko et al., 2002). They were then placed in simulated boreholes consisting of 2.5-, 5-, 6- and 11-cm cylindrical holes in porous cement blocks that were dried at 110 °C for 7 days before loading. The ANFO was weighed, placed in a hole, sealed, and kept at 55 °C during testing, after which it was removed from the boreholes and weighed at 1-, 2-, 6-, 8-, 9-, and 13-day intervals. The mass loss was found to be relatively constant at 0.0048 g/in²/day. For the 7.6-cm diameter boreholes, after 30 days the average fuel oil concentration in the mixture decreased from 6% to 4.5%. Such a loss of fuel oil would result in under-fueled explosives in blasting situations, leading to an increase in NO and NO₂ production.

Similar tests were conducted with boreholes containing 8% moisture (Sapke et al., 2002). Eight percent was chosen since the drill cuttings from a mine in Wyoming that had experienced red cloud formation after blasting, contained from 7% to 8% water. The drill cuttings, with 8% bound moisture, seemed dry to the touch. To perform the experiment, the water was added to the borehole and let standing for about 24 hours while the moisture was drawn into the walls of the simulated cementitious borehole. ANFO was weighed and added to the empty 5-cm diameter borehole and sealed. In these tests, the hygroscopic AN drew the water from the cement, which dissolved some AN, and the column height decreased as the AN solution was drawn into the cementitious walls. The height of the column was recorded and the mass loss was calculated from the change in prill height and initial density. About 50% (½ the column height) was lost to the cementitious borehole in 10 days. Similar tests were also conducted with the borehole cased with 12 parts drill cuttings and one part cement. There was no significant difference in loss rate between the sand/cement borehole and the one fabricated with drill cuttings of similar particle size. Without borehole liners, there can be a significant loss of AN. Even with holes that appear dry to the touch, a significant loss of AN can result with time.

2.2.3 Site preparation

Revey (1996) mentions that there is a direct relationship between the ammonia and nitrate levels in water and the amount of undetonated explosives in the rock through which water flows. Moreover, the loss of nitrate, ammonia and oil will increase the heterogeneity in the composition of oil, leading to a formulation that will contain both oxygen-negative and oxygen-positive

portions. The detonation of such a product will in turn lead to non ideal detonations and to the production of more toxic gases (Farnfield et al., 2004; Sapko et al., 2002).

Consequently, it is imperative to develop approaches that will reduce the ammonia and nitrate levels in water. Explosives losses can be controlled at the source by avoiding working in wet conditions. Water-filled holes should be emptied with compressed air before pneumatically loading ANFO (Revey, 1996). If practical for field use, borehole liners should reduce the wicking of fuel oil and AN dissolution during long sleep times.

Even with stoichiometrically balanced explosives, the ground conditions do not provide good confinement, thus resulting in non-ideal detonations. The degree and duration of explosive confinement should be kept as high as possible (Sapko et al., 2002) to reduce the ANFO loss and decrease the NO_x concentration. Laboratory results indicate that dry, soft, and porous overburden may wick away significant amount of fuel oil from ANFO during long intervals between explosive loading and firing (“sleep times”). The degree of wicking was more pronounced with smaller diameter holes. In addition, ANFO in the presence of overburden containing only 8% bound moisture caused significant AN dissolution over time. If practical for field use, borehole liners should reduce the wicking of fuel oil and AN dissolution during long sleep times.

Long explosives columns which produce bottom hole hydrostatic pressures that decrease the probability of successful detonation propagation should be avoided (Sapko et al., 2002). Care should be taken to avoid explosive precompression caused by hole-to-hole shock propagation due to wet overburden and clay veins (Sapko et al., 2002). Explosives admixture with drill cuttings that will reduce the temperature of the detonation should also be avoided. Significant water infiltration during long intervals between loading and firing, which changes the explosive composition (Sapko et al., 2002), should also be avoided.

The type of explosive used can have a significant effect on overall losses. For instance, if bulk explosives are used instead of packaged explosives, spillage losses will be relatively high. If bulk ANFO is used in wet holes, losses caused by complete failure or partial detonation will be high. When conditions that cause very high hole-to-hole shock pressures exist, only explosives that can resist precompression should be used.

2.3 Evaluation of the potential short and long-term effects on the environment and estimation of the maximum amount of ANFO that can be used before without damaging the environment.

As mentioned in the previous section, the loss of AN by exposure of ANFO to water will lead to an increase of nitrate and ammonia concentrations in surface water and groundwater, up to concentrations that could exceed the CCME criteria and be detrimental to the flora, the fauna and/or lead to health hazards. In addition, oil wicking and AN dissolution will both lead to heterogeneities in the ANFO mixtures, that will in turn lead to non-ideal detonations, and to the

production of more toxic gases, such as CO and NO_x, that will contribute to increase the production of greenhouse gases and acid rain.

The damage to the environment is site-specific and is related to characteristics such as the type of soil, the depth of the groundwater, the presence of surface water, and the yearly amount of precipitation. Each type of soil has different characteristics, and will have different effects on water infiltration rates, water holding capacity, evapotranspiration rate, and other soil characteristics. For example, the permeability of clay-rich and silt-rich soils is very low; these types of soils will prevent the explosives residues from reaching groundwater. On the contrary, sandy and coarse-grain soils are very permeable and will allow the infiltration of explosives residues. However, a combination of sandy soils, deep groundwater table, and low precipitation is enough to preserve the groundwater from contamination. At the opposite, a fine clay-rich layer on top of fractured bedrock, such as the Canadian Shield for example, does not prevent the explosives residues to reach groundwater. Vegetation can also decrease the infiltration of contaminants by absorbing part of it.

Consequently, the estimation of the damage to the environment cannot be done at this point in time. However, DRDC has made a hydrogeological assessment for most of the major Canadian military bases (Valcartier, Shilo, Gagetown, Petawawa, Wainwright, Meaford and Cold Lake) (Ampleman et al., 2003; Brochu et al., 2009; Diaz et al., 2008; Marois et al., 2004; Thiboutot et al., 2004), and thus already has data on local soil characteristics and depth to groundwater. DRDC is also in the process of building risk maps and vulnerability maps of the Canadian RTAs, which will help evaluate the risk associated with the use of ANFO. DRDC can also perform specific laboratory studies to evaluate the effects of the use of ANFO on typical soils from the RTAs.

2.4 Identification of the correct ratio of mixture of AN with fuel oil and recommendations as to proper handling, preparation and use of ANFO.

The detonation performance of ANFO can be influenced by many parameters that will lead to a decrease in the detonation performance, to a slower detonation velocity, and to the production of more toxic fumes due to the occurrence of non-ideal detonations. The effects of various parameters on the detonation of ANFO have been studied extensively in the mining industry. The most relevant of these studies are discussed here.

Besides soil preparation, AN losses by dissolution, and oil wicking, which have been discussed in Chapter 2, several other factors have been identified as contributing to the non-ideal detonation behavior of ANFO. These include (Forsyth et al., 1995; Sapko et al., 2002; Farnfield et al., 2004):

- Type of ANFO
- Physical characteristics of AN particles

- Storage and handling controls
- Blast considerations
- Loading controls

2.4.1 Type of ANFO

ANFO can be found in bulk or packaged granules, or in the form of an emulsion in a cartridge, in which AN is surrounded by an oil or a wax fuel phase. Granules of ANFO should be used only in dry boreholes (Revey, 1996; Martel et al., 2004). Bulk ANFO should never be loaded into wet holes or delayed too long before detonation. Packaged ANFO is also not effective in wet holes because the ANFO will sift past the packaged ANFO and dissolve in the water. The water will cause further ANFO loss when it wicks up the sifting ANFO into the main column. This problem is a common cause of misfires in bench-blasting applications. To prevent this, holes should be sealed with a fully coupled and water-resistant cartridge of emulsion explosives before loading ANFO.

The effect of water on mixtures of ANFO and emulsion has been evaluated by Schettler and Brashear (1996). Clear PVC 150-mm diameter pipes were filled with 75 to 305 mm of water prior to loading with straight ANFO and emulsion blends with ratios varying from 80/20 to 60/40. The results indicate that straight ANFO and the 80/20 ANFO/emulsion mixture failed to detonate after a one-hour exposure. The 70/30 and 60/40 mixes detonated only in the presence of a maximum of 75 mm of water, and even then the detonation velocities were lower than those measured in dry conditions. The 50/50 ANFO/emulsion blend was the only one providing acceptable detonation velocities after a one-hour exposure, indicating that waterproof products should contain a minimum of 50% emulsion. However, water exposure of one week resulted in the detonation failure of the 50/50 blend (Rowland et al., 2001). The 100% emulsion detonated properly after a two-month exposure, but was characterized by high NO_x production. Rowland et al. (2001) indicate that this finding is usually observed with blasting agents that do not detonate properly, either through degradation by water or some other mechanism, and is not consistent with acceptable detonation velocities.

Sapko et al. (2002) also compared the use of ANFO, emulsion and 50/50 mixtures of ANFO and emulsion. They observed that the ANFO and 50/50 ANFO/emulsion blend produced much more NO_x than the emulsion. They hypothesized that the grain size of the explosive has probably a significant effect on the detonation. Explosives like ANFO contain rather large grains of AN which tend to decompose and yield NO_x. In emulsion explosives, the nitrate is mainly found in solution and is in more intimate contact with the emulsified fuel droplets.

The effectiveness of two thickening agents, fumed silica (Cabosil™) and WR Conditioner 260, was evaluated by Sapko et al. (2002) to reduce the AN and FO loss. It was shown that the addition of two percent Cabosil to the fuel oil before mixing with the AN prills decreased the FO wicking from simulated boreholes, but not the AN loss in the presence of 8% water. The Cabosil may have also prevented the oil from effectively migrating into the prill pores. The addition of

Cabosil to the prills before mixing with the FO appeared to restrict the oil absorption by the prills and prevented uniform distribution of the oil on the outside of the prills.

Sapko et al. (2002) also evaluated WR Conditioner 260, a gelling agent that was added to the ANFO and placed in a simulated 5.1-cm diameter cement-sand borehole containing 8% moisture. The WR Conditioner acts by gelling the water near the wall of the borehole, thereby reducing the rate of AN dissolution. As the gelled water boundary layer between the explosive column and the borehole wall thickened, the better the center explosive core was protected from further erosion. The conditioner effectively delayed the AN loss in simulated 5.1-cm boreholes, and was expected to improve with an increase in borehole diameter. However, this method was not evaluated in the field in larger and deeper holes where hydrostatic effects may become important.

2.4.2 Physical characteristics of AN particles

The detonation velocities, and thus the amount of toxic fumes produced, are influenced by the pore volume, the pore diameter, the particle diameter, the bulk density of ANFO and the oil absorption capacity of AN (Miyake et al., 2001; Sapko et al., 2002). The pores in the blasting prill enable the fuel oil to be retained by the prill in a uniform and intimate manner. They also improve the sensitivity by acting as sites for high temperature "hot spots" or ignition points (DND, 1998). The detonation velocity increases with the decrease of the mode pore diameter. The pores with a diameter of less than 8 μm were more effective than larger pores. Also, for the same total pore volume, the detonation velocity increased with the decrease of the particle diameter, i.e. increases of the specific surface area. The highest detonation velocities (3.85 km/s) were observed for the smallest particles (< 0.85 mm) (Sapko et al., 2002).

Sapko et al. (2002) also studied the effect of the bulk density of ANFO on the detonation velocity and the production of toxic fumes. They compared ANFO prills having a density of 0.86 g/cm³ with pulverized ANFO (< 200 microns) with a density averaging 0.82 g/cm³. The average measured detonation velocity was 3.93 km/s for the pulverized ANFO and 2.74 km/s for prilled ANFO. Also, with the same degree of light confinement, the NO₂ production from pulverized AN was a factor of 4 lower than that produced from standard prills. Both CO and H₂ from the detonation of pulverized AN were about a factor of 2 lower, and the NO was 30% lower than with prills. No significant difference in CO₂ production was detected between the pulverized and prilled AN. The authors hypothesized that there was a more intimate contact of AN and FO in pulverized AN that may lead to a more complete reaction.

The effect of the oil absorption capacity of AN on the detonation velocities of ANFO was studied by Miyake and Ogawa (1998). The material studied was a stoichiometric mixture of 94% AN and 6% of fuel oil no. 2 with particles of diameter ranging from 0.84 to 1.41 mm. The detonation velocity of ANFO was strongly influenced by the oil absorption capacity of AN. The detonation velocities of ANFO prepared with AN having less than 15% of oil absorption capacity ranged from 3.30 to 3.40 km/s, which correspond to 66 to 69% of the ideal detonation velocity. The highest value (3.55 km/s, 75% of the ideal velocity) was obtained with oil having an absorption capacity of 19.6%. Also, the detonation velocities of ANFO containing more than 15% of oil absorption capacity increased with the increase of oil capacity absorption.

The effect of aging at room temperature for ANFO for 12 months was studied by Miyake et al. (2001). No change was observed for most ANFO samples, with the exception of one sample that showed an increase of the detonation velocity. This result supports the hypothesis of the sensitivity of AN to the physical properties of AN.

2.4.3 Storage and handling control

Sloppy handling, storage and loading practices can cause a significant amount of explosive spillage, particularly when bulk explosives are used (Revey, 1996). Bins, tanks, storage trailers and loading equipment should be regularly maintained to prevent explosives spills. When applicable, spill containment and cleanup procedures should be developed. Bulk explosive should be stored in bins on concrete containment tanks following recommendations from explosives manufacturers. In addition, rock-berm should be built around tanks and bins. If necessary, explosives manufacturers can provide mobile clean-up crew and equipments services.

2.4.4 Blast design consideration

Care should be taken to ensure complete detonation of all explosives. Poor drilling and loading practices can cause significant amount of explosives to remain undetonated. Charges are often disrupted or torn away by premature rock movement caused by earlier detonations. Drill patterns, stemming or collar length, explosive selection, priming methods and delay timing can be adjusted to control charge cutoffs or failures. Common causes of misfire are cutoffs and precompression failures (Revey, 1996), which are described in Subsections 2.4.4.1 and 2.4.4.2:

2.4.4.1 Cutoffs

Cutoff is a premature movement of the rock containing adjacent unfired holes due to the presence of weak seams or joints in the ground that are separated by early firing charges. The cutting or separation of the explosive column due to the rock movement during the detonation can be avoided by using multiple in-hole delay primers. The reduction of the delay time between adjacent holes or row of holes can also help prevent cutoffs.

Cutoffs and explosives losses often occur when detonating cord down lines and surface delays are used in bench blasting. When detonating cord is used without a delay detonator in the hole, the ground swell that occurs when the first row of holes fires can tear cord and delay connections before they fire, hence, causing multiple hole failures. This type of cutoff can be prevented by using fully activated sequential timing (FAST) systems that use relatively long in-hole delays in combination with short surface delays. The goal of these systems is to have all of the in-hole initiators sequentially energized before the first charges fire and rock starts moving. In very large shots that cannot be fully energized, one should try to have at least two rows energized behind the row that is firing. FAST sequential timing can be achieved with either nonelectric- or electric-initiation systems.

2.4.4.2 Precompression failures

Several blasting problems can occur when hole-to-hole shock pressures are too high. High blast-induced pressure in rock can cause sympathetic detonation (propagation) of dynamite charges and precompression failure in emulsion and water gel explosives. This precompression is caused by several conditions or combinations of conditions. When the ground is very seamy and wet, the magnitude of hole-to-hole shock is greatly increased. Shock also increases when the holes are very close together, which is always the case in underground tunnel and surface ditch blasting where the application requires tightly spaced holes. If precompression failures occur, one should try spacing the blastholes farther apart or switch to an explosive that can withstand higher pressures.

2.4.5 Loading controls

When bulk ANFO is used without specific controls, the loss of explosives due to spillage and blow back during pneumatic loading is typically around 2 to 5%. Surface auger-loading trucks with poorly designed, aimed discharge hoses spill ANFO prills onto ground around hole collars during loading. Wind can also add to losses by carrying some prills away from the hole if the discharge hose is too high in the air. Most spills can be prevented by simply adjusting the loading practices. Moreover, spills must be cleaned as soon as they occur.

Sometimes during loading, packaged explosive columns are separated by rock chunks falling into the hole or when a cartridge becomes stuck. If that occurs, the separated portion should be independently primed with the same delay detonator used in the initial primer. Using the same delay will prevent one part of the separated charge from disrupting the other, and the desired firing sequence will be maintained.

3 Conclusions

The literature review indicates that the most common environmental issues associated with the use of ANFO are related to dissolution of AN and to oil wicking. Nitrates and ammonium are readily soluble in water, and thus can very easily reach groundwater. Nitrates exceeding the CCME guidelines (2003) of 13 mg NO₃⁻/L for freshwater (or 16 mg NO₃⁻/L for the protection of marine life) are at risk of causing methaemoglobin, especially in babies. In addition, the presence of nitrate in marine water will cause algal blooms and eutrophication. The toxicity of the ammonium ion is low, but the ammonium in water is in equilibrium with ammonia, which is characterized by a much higher toxicity. Aquatic life is affected when concentrations of ammonia exceed 0.019 mg/L (CCME, 2000). In addition, ammonia in concentrations above 25 mg/m³ for a 15-minute period or the IDHL of 210 mg/m³ (NIOSH, 2007) poses a health hazard to humans. However, this situation is not likely to happen to CF members, given the fact that ANFO is usually handled outside.

AN dissolution and oil wicking will lead to heterogeneities in ANFO composition that will in turn decrease the detonation velocity of the explosive and thus, adversely affect the detonation performance of ANFO. Non stoichiometric ANFO composition will also lead to non-ideal detonations that will produce more toxic fumes of NO, NO₂, CO and methane. Of these, NO₂ is one of the most toxic products. In addition, NO, CO and methane are well known greenhouse gases, and NO_x contribute to the production of acid rain. The risk of exposure of CF members to ANFO combustion products is low, because the work is performed outside. However, the production of toxic gases should be kept as low as possible to avoid environmental issues.

Literature data indicate that the leaching of nitrates from explosive occurs rapidly, 25% of nitrates being lost after a six-minute exposure and 50% after a one-hour exposure (Revey, 1996). ANFO is no longer detonable after the loss of 25% nitrates (Revey, 1996). The mass loss of FO from dry boreholes was found to be relatively constant at 0.0048 g/in²/day, leading in a decrease of FO concentration from 6% to 4.5% after 30 days. Ferguson and Leask (1988) evaluated that 0.2% of the nitrogen from ANFO was released from blasting in dry conditions.

Approaches that will reduce the ammonia and nitrate levels in water, as well as reduce the production of toxic gases, include avoiding working in wet conditions, keeping the duration and degree of confinement as high as possible, and avoiding working on weak overburden. Long sleep times, long explosive columns and explosive admixtures with drill cuttings should all be avoided. If appropriate, blast designs and loading controls should be reviewed. The use of bulk ANFO should be avoided because of the absence of confinement. The use of packaged ANFO and ANFO/emulsion mixtures is acceptable only in dry conditions. Literature data also indicate that the performance of emulsions is better than that of ANFO in wet conditions. To achieve the cleanest detonations, an intimate contact at the molecular level should be favoured. This can be achieved by selecting the smallest possible AN particles, with a diameter preferentially lower than 0.85 mm, having a pore diameter smaller than 8 µm, and an oil absorption capacity larger than 19%.

Environmental impacts are site-specific and are related to characteristics such as the type of soil, the depth of the groundwater, the presence of surface water, and the yearly amount of precipitation. The damage to the environment cannot be estimated only from literature data. The hydrogeological assessments performed by DRDC on most major Canadian military bases can help evaluate the risk associated with the use of ANFO on specific bases. Alternatively, DRDC has the in-house expertise to perform specific laboratory studies to evaluate the effects of the use of ANFO on typical soils from the RTAs.

4 Recommendations

ANFO should be used with extreme care. If such a blasting agent has to be used, the user should consider the following:

- a. Carry out an environmental assessment of the soil where ANFO will be used. DRDC's risk and vulnerability maps of the Canadian RTAs could be used as a starting point. If necessary (depending on the soil type, depth of groundwater, amount of ANFO used, etc.), monitor ammonia, nitrates, and the BTEX suite (benzene, toluene, ethylbenzene and xylenes) on the site where ANFO is used;
- b. The use of bulk ANFO should be avoided;
- c. The use of packaged ANFO and ANFO/emulsion mixtures containing less than 60% emulsion is acceptable only in very dry conditions; therefore, ANFO should not be used in wet/humid soils and on snow/ice. When these latter conditions are encountered, the use of water-resistant emulsions seems more appropriate;
- d. Care should be taken to buy stoichiometric mixtures of ANFO;
- e. The duration and degree of confinement must be kept as high as possible;
- f. To increase the detonation efficiency, the user should select the smallest possible AN particles, with a diameter preferentially lower than 0.85 mm, having a pore diameter smaller than 8 μm , and an oil absorption capacity larger than 19%;
- g. ANFO must be used immediately after being poured onto or into the ground. Long intervals between explosive loading and firing must be avoided.

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Annex A Statement of work

STATEMENT OF WORK

FOR TASKING

DEFENCE R&D CANADA - VALCARTIER

STATEMENT OF WORK (SOW)

PROJECT NUMBER: Engineering Assessment 06-13
(DRDC Valcartier internal CPME #12SW03)

PROJECT TITLE: Assessment of ANFO on the Environment

PROJECT TYPE: Assessing the Safety and Suitability for Service of ANFO

PROJECT PRIORITY: *As appropriate to the project (refer to the project priority listing at Annex E of C-02-006-006/AG-001) and approved by the TASKING AUTHORITY.*

F – Normal priority for a project related to new weapons, new methods or systems improvements that will better the National Defence.

REFERENCES: *A list of significant references applicable to the project (such as CFTO's, drawings, project directives, or UCR's Specifications, photographs, etc)*

NA

BACKGROUND:

- a) Ammonium nitrate fuel Oil (ANFO) is an explosive mixture commonly used in the mining industry. The CF also trains in its use as an expedient explosive method. Ammonium nitrate (AN) is highly soluble and could cause a potential threat to the environment if misused. The detonation of ANFO is often incomplete in a wet environment, leaving behind by-products of unreactive AN as nitrate, nitrite and ammonia contaminants into the soil and ground water.
- b) ANFO generally has an explosive efficiency of 80% (0.8) of TNT; and if mixed properly could yield up to 160% (1.6) equivalency of TNT. The mixture of AN/FO consists of 94.3% AN and 5.7% FO by weight. The primary benefit of using ANFO is the fact that it is cheap and fairly powerful making it a cost saving alternative.
- c) Contaminated water from AN by-products when consumed can cause chronic illness such as methemoglobinemia. Since ground water is a critical water source for many humans and animals in isolated locations, all efforts should be directed in preventing contaminants from entering into the water supply.
- d) Proper measures must be followed if ANFO is to be used as an alternative explosive. ANFO must be assessed in all the different types of soil for any anomalies; as the data collected could be useful for future investigative purposes. Guidelines and procedures must be drawn up to provide training and to prevent environmental catastrophes.

AIM:

Assess the effect of ANFO on the environment and to determine its suitability for service.

SCOPE OF WORK:

Perform a literature review to:

- a) Evaluate the effects of the use of ANFO on typical soils of Canadian Range and Training Areas.
- b) Evaluate the potential for oil and nitrates to leach out of the ANFO mixture and into the soil prior to initiation, and at what rate this happens at between preparation and detonation. Determine if special site preparation is required before setting ANFO into place.

- c) Evaluate potential short and long-term effects on the environment. Estimate the amount of ANFO that can be used before too much damage is done to the environment.
- d) Identify the correct ratio of mixture of AN with fuel oil, which must be consistent to prevent incomplete detonation and the spreading of contaminants. Therefore, identification of these ratios and recommendations as to proper handling, preparation and use of ANFO will be crucial and could minimize the chances of contamination.

PROJECT SUPPORT:

a. *ENGINEERING SUPPORT: Specify arrangements made for the provision of personnel, weapon systems, items of equipment, special instrumentation, supplies, etc, required for the project which are not available at the designated Field Unit.*

Technical advice can be sought from DAEME 3-3-6 at 819-997-2624

b. *FINANCIAL SUPPORT: As a minimum provide the FE code, Planning code and Resource code may be issued by the TASKING AUTHORITY. If further details are necessary, include the estimated expenditure for labour. Travel and material as applicable and an upper financial limit not to be exceeded without DGAEPM approval.*

The cost of the project is estimated at \$15000 in labour cost for the academic review and in administration fees for the project.

PROJECT START DATE: 8 September 2008

PROJECT COMPLETION DATE: 21 January 2009

DELIVERABLES AND DUE DATES:

Deliverables such as reports, prototype etc and their estimated delivery dates

ASSB Engineering Assessment draft report will be provided electronically by December 22nd. A final copy of the ASSB report will be provided no later than ten working

days after having received the feedback on the report from the sponsor.

PAYMENT SCHEDULE

Specify how money should be paid such as Milestone payment, Final payment etc (\$\$\$ in FY 07/08 and \$\$\$ in FY08/09)

A payment of \$15000 in FY 08/09 will be paid on receipt of the final ASSB report.

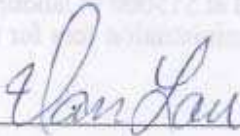
SECURITY CLASSIFICATION: UNCLASSIFIED

DRDC Valcartier PROJECT MANAGER: Name: Mr. Marc Brassard

Phone number: 418-844-4000 (4446)

DAEME POINT OF CONTACT: Name: Maj Ian Lau

Phone number: 819-997-4173



I. Lau
Ammunition Technical Group Officer
DAEME 3-4

DISTRIBUTION LIST

DAEME 3-4

DRDC Valcartier – Energetic Materials Section / Attn: Marc Brassard

Expenditure Initiation

Date: 1 Aug 08

1	ORIGINAL REQUISITION (YES/NO) IF APPLICABLE, AMENDMENT NO.	☒ Yes	☐ No			
2	IF AVAILABLE, PREVIOUS CONTRACT NO					
3	VALUE	\$ 15,000.00	GST/HST	\$ -	TOTAL	\$ 15,000.00
4	REQUIREMENT	DRDC-Valcartier will be conducting an Engineering Assessment on Ammonium Nitrate Fuel Oil (ANFO) to determine: (1) its effects on the environment; and (2) its Safety and Suitability for Service (S3) use in Canada Range and Training Areas.				
5	PART NUMBER	n/a	NCAGE	n/a	AMMOPLAN SERIAL	n/a
6	IS A SUBSTITUTE PRODUCT ACCEPTABLE	☐ Yes	☐ No	n/a		
7	IS A SRCL REQUIRED	☐ Yes	☒ No	If Yes - please attach a completed SRCL document		
8	RDD	n/a				
9	DELIVERY POINT (DEL. DATE)	21 Jan 08				
10	DND STANDARD PALLETIZATION	☐ Yes	☐ No	n/a		
11	AMMUNITION DATA CARD INSTRUCTIONS	☐ IAW Annex A V1.0 or Mil Std 1168 ☐ Mil Std 1168 ☒ Not Applicable				
12	STANDARD LOTTING INSTRUCTIONS	☐ IAW Annex B V1.0 ☐ Contractor's Lotting practices ☐ Mil Std 1168				
13	AMMUNITION PACKAGING MARKINGS INSTRUCTIONS	☐ IAW Annex C V1.0 ☐ IAW DDL ☒ Not Applicable				
14	AVAILABLE COTS	☐ Yes	☐ No	n/a		
15	QAC	n/a				
16	COST CENTRE	☐ 3524 BC ☐ 8484 WA ☒ 8484XA ☐ 8484XA-SDOA ☐ 8484YA				
17	NEW REQUIREMENT	☒ Yes	☐ No			
18	COMMENTS	Nil.				

ORIGINATOR (PRINT & SIGN)


Maj I. Lau

DESIGNATION

DAEME 3-4

PHONE (819) 997-4173

DATE

1 Aug 08

TEAM LEADER (PRINT & SIGN)


L. Albon

DESIGNATION

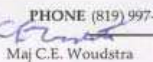
DAEME 3

PHONE (819) 997-1975

DATE

1 Aug 08

APPROVAL (PRINT & SIGN)


Maj C.E. Woudstra

DESIGNATION

DAEME 5

PHONE (819) 994-9420

DATE

1 Aug 08

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Annex B Material Safety Data Sheets of ANFO from Dynobel, Orica and Nordex

Material Safety Data Sheet

Dyno Nobel Inc.
2650 Decker Lake Boulevard, Suite 300
Salt Lake City, Utah 84119
Phone: 801-364-4800 Fax: 801-321-6703
E-Mail: dyna.hse@am.dynobel.com

FOR 24 HOUR EMERGENCY, CALL CHEMTREC (USA) 800-424-9300
CANUTEC (CANADA) 613-996-6666

MSDS # 1009
Date 04/26/07

Supersedes
MSDS # 1009 01/31/05

SECTION I - PRODUCT IDENTIFICATION

Trade Name(s): ANFO
DYNOMIX™, DYNOMIX™ (U.G.)
DYNOMIX™ WR
DYNOMIX™ HD
FRAGMAX™

Product Class: ANFO, Bulk or Packaged

Product Appearance & Odor: White, free-flowing solid prills with fuel oil odor. May be tinged pink or other color to distinguish from solid prills without fuel.

Hazard Shipping Description (U.S. DOT and Canada TDGR)

For ANFO, DYNOMIX™, DYNOMIX™ (U.G.), FRAGMAX™ : Ammonium nitrate-fuel oil mixture 1.5D NA0331 II
Or Explosive, blasting, type B 1.5D UN0331 II

Note: Either description is acceptable, but if already packaged, refer to packaging for which description to use.

For DYNOMIX™ WR: Explosive blasting, type B 1.5D UN0331 II
For DYNOMIX™ HD (Canada only): Explosive blasting, type B 1.1D UN0082 II

NFPA Hazard Classification: Not Available (See Section IV - Special Fire Fighting Procedures)

SECTION II - HAZARDOUS INGREDIENTS

Ingredients:	CAS#	% (Range)	Occupational Exposure Limits	
			ACGIH TLV-TWA	OSHA PEL-TWA
Ammonium Nitrate	6484-52-2	92-95	None ¹	None ²
Fuel Oil	68476-34-6	4-7	100 ppm	None
Guar Gum*	9000-30-0	0-3	None ¹	None ²

¹ Use limit for particulates not otherwise regulated (PNOR): Total dust, 15 mg/m³; respirable fraction, 5 mg/m³.

² Use limit for particulates not otherwise classified (PNOC): Inhalable particulate, 10 mg/m³; respirable part., 3 mg/m³.

* DYNOMIX™ WR is the only product containing guar gum.

Ingredients, other than those mentioned above, as used in this product are not hazardous as defined under current Department of Labor regulations, or are present in de minimus concentrations (less than 0.1% for carcinogens, less than 1.0% for other hazardous materials).

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DYNO
Dyno Nobel

Groundbreaking Performance

Material Safety Data Sheet

SECTION III - PHYSICAL DATA

Boiling Point: Not Applicable

Vapor Density: > 1

Percent Volatile by Volume: < 8 (Fuel oil)

Evaporation Rate (Butyl Acetate = 1): < 1

Vapor Pressure: <5 mm Hg @ 75° F

Density: 0.8 to 1.1 g/cc bulk density

Solubility in Water: Ammonium Nitrate component completely soluble

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flash Point: >120° F (49°C)

Flammable Limits: Not Available

Extinguishing Media: (See Special Fire Fighting Procedures section.)

Special Fire Fighting Procedures: Do not attempt to fight fires involving explosive materials. Evacuate all personnel to a predetermined safe location, no less than 2,500 feet in all directions.

Unusual Fire and Explosion Hazards: Can explode or detonate under fire conditions. Burning material may produce toxic vapors.

SECTION V - HEALTH HAZARD DATA

Effects of Overexposure

Eyes: May cause irritation, redness and tearing.

Skin: Prolonged contact may cause irritation.

Ingestion: Large amounts may be harmful if swallowed.

Inhalation: May cause dizziness, nausea or intestinal upset.

Systemic or Other Effects: None known.

Emergency and First Aid Procedures

Eyes: Irrigate with running water for at least 15 minutes. If irritation persists, seek medical attention.

Skin: Wash with soap and water.

Ingestion: Seek medical attention.

Inhalation: Remove to fresh air.

Special Considerations: None.

SECTION VI - REACTIVITY DATA

Stability: Stable under normal conditions. May explode when subjected to fire, supersonic shock or high-energy projectile impact, especially when confined or in large quantities.

Conditions to Avoid: Keep away from heat, flame, ignition sources and strong shock.

Materials to Avoid (Incompatibility): Corrosives (strong acids and strong bases or alkalis).

Hazardous Decomposition Products: Carbon Monoxide (CO) and Nitrogen Oxides (NO_x)

Hazardous Polymerization: Will not occur.

SECTION VII - SPILL OR LEAK PROCEDURES

Steps to be taken in Case Material is Released or Spilled: In case of fire evacuate area not less than 2,500 feet in all directions. Protect from all ignition sources. Notify authorities in accordance with emergency response procedures. Only personnel trained in emergency response should respond. If no fire danger is present, and product is undamaged and/or uncontaminated, repackage product in original packaging or other clean DOT approved container. Ensure that a

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complete account of product has been made and is verified. If possible, plug drains or dike channels to prevent either material or water runoff from entering storm drains or surface waters. Follow applicable Federal; State and local spill reporting requirements.

Waste Disposal Method: Disposal must comply with Federal, State and local regulations. If product becomes a waste, it is potentially regulated as a hazardous waste as defined under the Resource Conservation and Recovery Act (RCRA) 40 CFR, part 261. Review disposal requirements with a person knowledgeable with applicable environmental law (RCRA) before disposing of any explosive material.

SECTION VIII - SPECIAL PROTECTION INFORMATION

Ventilation: Not required for normal handling. Forced ventilation may be necessary where natural ventilation is limited.

Respiratory Protection: None normally required. In a dusty environment, or in hot, enclosed areas, respiratory protection may be needed.

Protective Clothing: Gloves and work clothing that reduce skin contact are suggested.

Eye Protection: Safety glasses are recommended.

Other Precautions Required: None.

SECTION IX - SPECIAL PRECAUTIONS

Precautions to be taken in handling and storage: Store in cool, dry, well-ventilated locations. Store in compliance with Federal, State, and local regulations. Keep away from heat, flame, ignition sources and strong shock.

Precautions to be taken during use: Avoid breathing the fumes from detonation of explosives. Use accepted safe industry practices when using explosive materials. Unintended detonation of explosives or explosive devices can cause serious injury or death.

Other Precautions: It is recommended that users of explosive materials be familiar with the Institute of Makers of Explosives Safety Library publications.

SECTION X - SPECIAL INFORMATION

The reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR 372 may become applicable if the physical state of this product is changed to an aqueous solution. If an aqueous solution of this product is manufactured, processed, or otherwise used, the nitrate compounds category and ammonia listing of the previously referenced regulation should be reviewed.

Disclaimer

Dyno Nobel Inc. and its subsidiaries disclaim any warranties with respect to this product, the safety or suitability thereof, the information contained herein, or the results to be obtained, whether express or implied, INCLUDING WITHOUT LIMITATION, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE AND/OR OTHER WARRANTY. The information contained herein is provided for reference purposes only and is intended only for persons having relevant technical skills. Because conditions and manner of use are outside of our control, the user is responsible for determining the conditions of safe use of the product. Buyers and users assume all risk, responsibility and liability whatsoever from any and all injuries (including death), losses, or damages to persons or property arising from the use of this product or information. Under no circumstances shall either Dyno Nobel Inc. or any of its subsidiaries be liable for special, consequential or incidental damages or for anticipated loss of profits.

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DYNO
Dyno Nobel

Groundbreaking Performance



Material Safety Data Sheet

Preparation Date: 16-Jun-2004

Revision Date: 30-Jul-2008

Revision Number: 1

SECTION 1 – PRODUCT AND COMPANY IDENTIFICATION

Supplier(s):
Orica Canada Inc.
Maple Street
Brownsburg, QC
For MSDS Requests: 1-450-533-4201

Orica USA Inc.
33101 E. Quincy Avenue
Watkins, CO 80137-8406
For MSDS Requests: 1-303-268-5000

Product Name: **Ammonium Nitrate Fuel Oil**
Product Code: 125
Alternate Name(s): AMEXTM, AMEX HDTM, ANFO
UN-No: UN0331
Recommended Use: A booster sensitive blasting agent.

Emergency Telephone Number: FOR CHEMICAL EMERGENCIES (24 HOUR) INVOLVING TRANSPORTATION, SPILL, LEAK, RELEASE, FIRE OR ACCIDENTS: **IN CANADA CALL: THE ORICA TRANSPORTATION EMERGENCY RESPONSE SYSTEM AT 1-877-561-3636. IN THE U.S. CALL: CHEMTREC 1-800-424-9300. IN THE U.S.: FOR LOST, STOLEN, OR MISPLACED EXPLOSIVES CALL: BATF 1-800-800-3855. FORM ATF F 5400.0 MUST BE COMPLETED AND LOCAL AUTHORITIES (STATE/MUNICIPAL POLICE, ETC.) MUST BE ADVISED.**

SECTION 2 – HAZARD IDENTIFICATION

Emergency Overview:

Risk of explosion by shock, fire of other sources of ignition. If misused or disposed of improperly, material could explode and cause death or serious injury. This product contains one or more substances, which are classified in the EU as carcinogenic, mutagenic and/ or reprotoxic, Irritating to eyes, respiratory system and skin. Harmful if swallowed. Oxidizing agent.

Appearance:	Physical State:	Odor:
Off-white prills	Solid	Diesel fuel oil

SECTION 3 – COMPOSITION/ INFORMATION ON INGREDIENTS

Chemical Name	CAS-No	Weight %
Ammonium Nitrate	6484-52-2	60-82
Fuels, Diesel, no. 2	68476-34-6	5-10

SECTION 4 – FIRST AID MEASURES

General Advice:	In case of accident or if you feel unwell, seek medical advice IMMEDIATELY (show the product label where possible).
Eye Contact:	Immediately flush with plenty of water. After initial flushing, remove any contact lenses and continue flushing for at least 15 minutes. Immediate medical attention is required.
Skin Contact:	Wash off immediately with soap and plenty of water, removing all contaminated clothes and shoes. If skin irritation persists, call a physician.
Inhalation:	Move victim to fresh air. Give artificial respiration ONLY if breathing has stopped. Give cardiopulmonary resuscitation (CPR) if there is no breathing AND no pulse. Obtain medical advice IMMEDIATELY.
Ingestion:	Immediate medical attention is required. Do not induce vomiting. Clean mouth with water and afterwards drink plenty of water. If spontaneous vomiting occurs, have victim lean forward with head

125- Ammonium Nitrate Fuel Oil

1/5

Notes to physician: positioned to avoid breathing in of vomitus, rinse mouth and administer more water. Never give anything by mouth to and unconscious person. Symptomatic. Administer oxygen if there are signs of cyanosis. If clinical condition deteriorates, administer 10cc Methylene Blue intravenously. It is unlikely for this to be required with methemoglobin level of less than 40%.

SECTION 5 – FIRE-FIGHTING MEASURES

Flammable properties: Not itself combustible but assists fire in burning materials. The product does not flash. Rate of burning: does not sustain burning at atmospheric pressure.

Suitable extinguishing media: DO NOT FIGHT FIRES INVOLVING EXPLOSIVES. Evacuate surrounding areas. When controlling fire before involvement of explosives, fire-fighters should wear positive pressure self-containing breathing apparatus (SCBA) and full turnout gear. Water may be applied through fixed extinguishing system (sprinklers) as long as people need not be present for the system to operate.

Unsuitable extinguishing media: DO NOT FIGHT FIRES INVOLVING EXPLOSIVES. Attempts to smother a fire involving this product will be ineffective as it is its own oxygen source. Smother this product could lead to decomposition and explosion. This product is more sensitive to detonation if contaminated with organic or oxidisable material or if heated while confined. Unless the mass of product on fire is flooded with water, re-ignition is possible.

Specific hazards arising from the chemical: This product is a high explosive with mass detonation hazard. DO NOT FIGHT FIRES INVOLVING EXPLOSIVE MATERIALS. Immediately evacuate all personnel from the area to a safe distance. Guard against re-entry. Thermal decomposition can lead to release of irritating gases and vapors.

Protective equipment and precautions for firefighters: As in any fire, wear self-contained breathing apparatus pressure-demand, NIOSH approved (or equivalent) and full protective gear.

SECTION 6 – ACCIDENTAL RELEASE MEASURES

Methods for containment: Avoid dust formation. Do not breathe dust.

Methods for cleaning up: Avoid the use of metal tools containing iron and/or copper. Be careful to avoid shock, friction, and contact with grit. Collect product for recovery or disposal. For release to land, contain discharge by constructing dykes or applying inert absorbent; for release to water, utilize damming and/or water diversion to minimize the spread of contamination. Collect contaminated soil and water, and absorbent for proper disposal. Notify applicable government authority if release is reportable or could adversely affect the environment.

Other information: Deactivating chemicals: Not applicable.

SECTION 7 – HANDLING AND STORAGE

Handling: This product is an explosive and should only be used under the supervision of trained personnel. The use of coveralls is recommended. Use good industrial hygiene and housekeeping practices. Keep away from open flames, hot surfaces and sources of ignition.

Storage: Store under moderate temperatures recommended by a technical services representative. Store under dry conditions in a well ventilated magazine that has been approved for either detonator storage or explosive storage. Do NOT store explosives in a detonator magazine or detonators in an explosive magazine. Keep away from heat, spark and flames. Keep containers closed. Explosives should be kept well away from initiating explosives; protected from physical damage; separated from oxidizing materials; combustibles, and sources of heat. Keep away from incompatibles. Ideal storage temperature is 10-27°C (50-80°F). Do not expose sealed containers to temperatures above 40°C (104°F).

SECTION 8 – EXPOSURE CONTROLS/PERSONAL PROTECTION

Chemical Name	ACGIH TLV	OSHA PEL	NIOSH IDLH
Fuels, Diesel, no. 2	TWA: 100 mg/ m ³ Skin		

Other exposure guidelines: Ammonium Nitrate: ORICA Guideline 5 mg/m³ (internal TWA).

Engineering Measures: No information available.

Personal Protective Equipment

Eye/Face Protection: Tightly fitting safety goggles.

Skin Protection: User should verify impermeability under normal conditions of use prior to general use. Impervious butyl rubber gloves.

Respiratory Protection: In case of insufficient ventilation wear suitable respiratory equipment. A NIOSH-approved respirator, if required.

Hygiene Measures: Handle in accordance with good industrial hygiene and safety practice. Recommendations listed in this section indicate the type of equipment, which will provide protection against over exposure to this product. Conditions of use, adequacy of engineering or other control measures, and actual exposures will dictate the need for specific protective devices at your workplace.

SECTION 9 – PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	Off-white prills	Odor:	Diesel fuel oil
Physical State:	Solid	Viscosity:	No information available
pH:	No data available	Flash Point:	52°C/ 126°F (Diesel fuel)
Autoignition Temperature:	230- 265 °C	Boiling Point/Range:	None
Melting Point/Range:	170°C/ 338°F	Flammable Limits (Upper):	Not Applicable
Flammable Limits (Lower):	Not Applicable	Explosion Power:	350-400 kJ/ 100g
Specific Gravity:	No data available	Water Solubility:	Dissolves slowly with prolonged exposure to water
Other Solubility:	Not available	Vapor Pressure:	0.4 mmHg @ 20°C /68°F (diesel fuel oil)
Oxidizing Properties:	Oxidizer	Partition Coefficient (n-octanol/water):	No data available

SECTION 10 – STABILITY AND REACTIVITY

Stability:	Stable under normal conditions. Decomposition Temperature: Ammonium Nitrate will spontaneously decompose at 210°C (410°F).
Conditions to avoid:	Keep away from open flames, hot surfaces and sources of ignition. Not expected to be sensitive to static discharge. Not expected to be sensitive to mechanical impact.
Incompatible materials:	Avoid oxidizable materials, metal powder, bronze & copper alloys, fuels (e.g. lubricants, machine oils), fluorocarbon lubricants, acids, corrosive liquids, chlorate, sulphur, sodium nitrite, charcoal, coke and other finely divided combustibles. Strong oxidizing and reducing agents.
Hazardous decomposition products:	The following toxic decomposition products may be released. At temperatures above 210°C, decomposition may be explosive, especially if confined. Nitrogen oxides (NOx). Carbon oxide. Hydrocarbons.
Hazardous Polymerization:	None under normal processing. Hazardous polymerization does not occur. Explosive material under shock conditions.

SECTION 11 – TOXICOLOGICAL INFORMATION

Acute Toxicity

Product Information: Irritating to eyes. May cause skin irritation. Harmful if swallowed.

Chemical name	LD50 Oral	LD50 Dermal	LC50 Inhalation
Ammonium Nitrate	2217 mg/kg Rat	3000 mg/kg Rabbit	88.8 mg/L Rat 4 h
Fuels, Diesel, no. 2	> 5000 mg/kg Rat	>5000 mg/kg Rabbit	

Subchronic Toxicity (28 Days): Ammonium Nitrate: Ingestion may cause methemoglobinemia. Initial manifestation of methemoglobinemia is cyanosis, characterized by navy lips, tongue and mucous membranes, with skin color being slate grey. Further manifestation is characterized by headache, weakness, dyspnea, dizziness, stupor, respiratory distress and death due to anoxia. If ingested, nitrates may be reduced to nitrites by bacteria in the digestive tract. Signs and symptoms of nitrite poisoning include methemoglobinemia, nausea, dizziness, increased heart rate, hypotension, fainting and, possibly shock.

Chronic Toxicity: May cause methemoglobinemia.
Carcinogenicity: The table below lists whether each agency has listed any ingredient as a carcinogen.

Chemical Name	ACGIH	IARC	NTP	OSHA
Fuels, Diesel, no. 2	A3			

Legend: A3: Confirmed animal carcinogen.
Mutagenic effects: There is no evidence of mutagenic potential.
Irritation: Irritating to eyes. May cause irritation of respiratory tract. May cause skin irritation in susceptible persons.
Reproductive effects: No information is available and no adverse reproductive effects are anticipated.
Developmental effects: No information is available and no adverse developmental effects are anticipated.
Target Organ: Eyes, skin, respiratory system, blood, kidney, liver, urinary tract, blood, endocrine system, immune system & gastrointestinal tract (GI).

SECTION 12 – ECOLOGICAL INFORMATION

Ecotoxicity effects: Dissolves slowly in water. Harmful to aquatic life at low concentrations.
Environmental Effects: Can be dangerous if allowed to enter drinking water intakes. Do not contaminate domestic or irrigation water supplies, lakes, streams, ponds, or rivers.

Persistence/Degradability: Some water resistance but soluble with extended time periods.
Mobility in Environmental media: Dissolves slowly in water.

SECTION 13 – DISPOSAL CONSIDERATIONS

Waste Disposal Method: Burn under supervision of an expert at an explosive burning ground or destroy by detonation in boreholes, in accordance with applicable local, provincial and federal regulations. Call upon the services of an Orica Technical Representative.

SECTION 14 – TRANSPORT INFORMATION

DOT Proper Shipping Name: Explosive, blasting type B
Hazard Class: 1.5D
UN-No: UN0331
Packing group: II
TDG Proper Shipping Name: Explosive, blasting type B
Hazard Class: 1.5D
UN-No: UN0331
Packing group: II

Transportation Emergency Telephone Number: 1-877-561-3636 or CHEMTREC: 1-800-424-9300

SECTION 15 – REGULATORY INFORMATION

CANADIAN CLASSIFICATION: This product has been classified in accordance with the hazard criteria of the CPR (Controlled Products Regulations) and this MSDS contains all the information required by the CPR.

WHMIS hazard class: This product is an explosive and is not regulated by WHMIS.

USA CLASSIFICATION:

SARA Regulations Sections 313 and 40 CFR 372: This product contains the following toxic chemical(s) subject to reporting requirements, Ammonium Nitrate (6484-52-2) & Fuels, Diesel no.2 (68476-34-6).

SARA 311/312 Hazardous Categorization

Acute Health Hazard: Yes
Chronic Health Hazard: Yes
Fire Hazard: Yes
Reactive Hazard: Yes
Sudden Release of Pressure Hazard: No

Ozone Protection and 40 CFR 42: No reportable quantities of ozone depleting agents

Other Regulations/Legislations which apply to this product: New Jersey Right-to-Know, Pennsylvania Right-to-Know, Massachusetts Right-to-Know, Rhode Island Right-to-Know, Florida, New Jersey Special Health Hazard Substance List, Minnesota Hazardous Substance List, California Director's List of Hazardous Substances, California Proposition 65.

TSCA: Complies

DSL: Complies

NDSL: Complies

The components in the product are on the following international inventory lists:

Chemical Name	TSCA	DSL	NDSL	ENCS	EINECS	ELINCS	CHINA	KECL	PICCS	AICS
Ammonium Nitrate	X	X	-	-	X	-	X	X	X	X
Fuels, Diesel, no. 2	X	X	-	X	X	-	X	X	X	X

Legend: X – Listed

SECTION 16 – OTHER INFORMATION

Prepared by: Safety Health & Environment
303-268-5000

Preparation Date: 16-Jun-2004
Revision Date: 30-Jul-2008

The information contained herein is offered only as guide to the handling of this specific material and has been prepared in good faith by technically knowledgeable personnel. It is not intended to be all-inclusive and the manner and conditions of use and handling may involve other and additional considerations. No warranty of any kind is given or implied and Crica will not be liable for any damages, losses, injuries or consequential damages which may result from the use of or reliance on any information contained herein.

End of MSDS

Material Safety Data Sheet February 2003 **MSDS 9701**

NorAnfo

Section I - Material Identification and Use

Product Name <i>NorAnfo</i>	Product Family <i>ANFO Mixture</i>	Chemical Name <i>Organic Explosive</i>	Chemical Formula <i>3 (NH4NO3) CH2</i>
Manufacturer's Name <i>Nordex Explosives Ltd.</i>		Manufacturer's Address <i>(Dane, Ontario) P.O. Box 790 Kirkland Lake, Ontario, Canada P2N 3K4</i>	
Emergency Telephone <i>705-642-3265</i> <i>705-668-0429</i> <i>705-668-0439</i>	Fax Number <i>705-642-3266</i>		
Trade Name and Synonyms <i>NorAnfo Amex Anfo</i>			
Chemical Family <i>Organic Nitrate Explosive</i>		Material Usage <i>Blasting Agent</i>	

Section II - Hazardous Ingredients of Material

Hazardous Ingredients <i>Ammonium Nitrate Fuel Oil</i>	Concentration <i>94.33% 5.67%</i>	C.A.S or U.N. Numbers <i>UN0222 CAS68334-30-5 UN 1233</i>	L.D. Lo Oral L. D. 50 <i>Oral - 4820 mg /kg (rats) 5000 mg /kg (rats)</i>
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Section III - Physical Data for Material

Physical, Odor & Appearance <i>Solid, Granular, Slightly Oily, Pinkish Gray</i>	Density <i>0.84gr/cc</i>	Solubility <i>Water Soluble</i>	PH <i>5.6 - 6.0</i>
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Section IV - Fire and Explosion Hazard of the Material

Flammability <i>Yes</i>	Conditions <i>Non-Spontaneous, will decompose In fire and may explode if confined</i>	Means of Extinction <i>Do Not Fight Fire - Evacuate **MAY EXPLODE**</i>
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Special Procedure in Case of Fire
Evacuate Area Immediately

Flammability Classification

1.5D Hazardous Combustion Products --- Oxides of Nitrogen and Carbon

Explosion Data

Insensitive to Static Discharge

Sensitivity to Impact greater than 1 meter	Rate of Burning won't sustain	Explosive Power 0.74 Kc/gram	Sensitivity to Static Discharge only if ground into fine particles
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Section V - Reactivity Data

Chemical Stability

Do not mix with strong Acids, Alkalis, Gases

Incompatibly to Other Substances

Acids, Alkalis, Chlorates

Reactivity

Yields a powerful Explosion in contact with high shock &/or high heat

Hazardous Decomposition of Products

CO C02 NH3 NO N02

Section V1 - Toxicological Properties of the Material

Possible Routes of Entry

<i>Skin Contact (no)</i>	<i>Skin Absorption (no)</i>	<i>Eve Contact (yes)</i>	<i>Inhalation Acute (no)</i>
--------------------------	-----------------------------	--------------------------	------------------------------

Effect of Acute Exposure

Concentrated solutions or dust may be irritating to the eyes, skin or gastro intestinal tract

Effects of Chronic Exposure

Nil if proper gloves worn and /or cleanliness is followed.

L.D. 50 Reproductivity 45 gm /kg (in rats)	Exposure Limit .05 mgm/m3	Irritant Nil	Sensitivity by grinding	Carcinogenicity Mutagenicity Affect - Nil
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Section VII - Preventive Measures

Gloves (specify) recommended	Respiratory (specify) face mask (if blown)	Eye (specify) safety glasses	Footwear N/A	Clothing(specify) N/A
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Other (specify)

follow the Explosive Act & Department of Labour

Engineering Controls (i.e. Ventilation & Enclosure Process)

handle as an Explosive

Leak and Spill Procedure

sweep up and dispose in a blast hole, do not burn, AN component will dissolve in water

Waste Disposal

use in blast

Handling Procedures and Equipment

Refer to Natural Resources Canada – Explosives Regulatory Division

Storage Requirements

store only in an Approved & Licensed High Explosives Magazine

Special Shipping Information

UN0331 1.5 D Explosive, Blasting Type B
permit required for transportation with proper placards displayed on vehicle

Section VIII - First Aid Measures

For Skin Contact

wash with soap and water

For Eye Contact

irrigate the eye for 15 minutes

For Ingestion

if victim is alert and not convulsing, give two glasses of water to dilute material
and induce vomiting (obtain immediate medical attention)

Further Information

refer to Nordex Technical Bulletin "NorAnfo"

Section IX - Date of M.S.D.S. (not a Technical Bulletin)

Prepared By

Nordex Explosives Ltd April 2004

705-642-3265

EMERGENCY CONTACT: Joe Rozon, Plant Manager
705-642-3265
705-668-0429

List of symbols/abbreviations/acronyms/initialisms

AFOSH	Air Force Office of Safety and Health
AN	Ammonium nitrate
ANFO	Ammonium nitrate fuel oil
ATDSR	Agency for Toxic Substances and Disease Registry
CAS	Chemical Abstract Service
CCME	Canadian Council of Ministers of the Environment
BTEX	Benzene, toluene, ethylbenzene and xylenes
DAEME	Directorate Ammunition & Explosives Management and Engineering
D Gest TME 3-4	Directeur gestion et technique des munitions et explosifs
DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
FAST	Fully activated sequential timing
FO	Fuel oil
IARC	International Agency for Research on Cancer
IDHL	Immediately dangerous to life and health
MSDS	Material Safety Data Sheet
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure level
ppm	Parts per million
R&D	Research & Development
RTA	Ranges and training area
WR	Water resistant

DOCUMENT CONTROL DATA		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)		
1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence R&D Canada – Valcartier 2459 Pie-XI Blvd North Quebec (Quebec) G3J 1X5 Canada	2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED	
3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.) Assessment of ANFO on the environment: Technical Investigation 09-01		
4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used) Brochu, S.		
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In September 2008, DRDC Valcartier was tasked by Director Ammunition and Explosives Management and Engineering (DAEME 3-4) to perform a literature review to assess the effect of Ammonium Nitrate Fuel Oil (ANFO) on the environment and to determine its suitability for service. The Canadian Forces are concerned about the high solubility of ammonium nitrate (AN) that could represent a potential threat to the environment. For example, the detonation of ANFO is often incomplete in a wet environment, leaving behind by-products of unreacted AN as nitrate, nitrite and ammonia into the soil and groundwater. Since groundwater is a critical water source for many humans and animals in isolated locations, all efforts should be directed in preventing water supply contamination. Proper measures must therefore be followed when ANFO is used as a blasting explosive. General guidelines found in the literature are reviewed in this memorandum.

En Septembre 2008, RDDC Valcartier a été chargé par Directeur gestion et technique des munitions et explosifs (D Gest TME 3-4) de réaliser une étude de littérature pour évaluer l'effet du mélange de nitrate d'ammonium et de mazout (ANFO) sur l'environnement et de déterminer son aptitude au service. Les Forces canadiennes sont préoccupées par la grande solubilité du nitrate d'ammonium (AN) qui pourrait constituer une menace potentielle pour l'environnement. Par exemple, la détonation d'ANFO en présence d'humidité est souvent incomplète et conduit à la dispersion dans le sol et les eaux souterraines de sous-produits d'AN n'ayant pas réagi, tels que le nitrate, le nitrite et l'ammoniaque. Étant donné que les eaux souterraines représentent une source d'eau essentielle pour de nombreux êtres humains et animaux dans des endroits isolés, tous les efforts devraient être concertés pour éviter la contamination des systèmes d'approvisionnement en eau. Des mesures adéquates doivent donc être suivies lorsque l'ANFO est utilisé comme explosif de minage. Le présent memorandum résume les lignes directrices générales trouvées dans la littérature.

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ANFO; Ammonium nitrate; fuel oil; environment; nitrate leaching; groundwater contamination;

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