BRITISH COLUMBIA

Ministry of Environment and Climate Change Strategy

Technical Guidance 9

Environmental Management Act

Guidance on Preparing Nitrogen Management Plans for Mines using Ammonium Nitrate Fuel Oil Products for Blasting

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Contents

1.0 Introduction

Nitrogen compounds (ammonia, nitrate and nitrite) are often released on mine sites during the detonation of nitrogen-based explosives, including Ammonium Nitrate Fuel Oil (ANFO) which is commonly used for blasting at mine sites in British Columbia and around the world. In order to protect the receiving environment from impacts related to the release of these nitrogen compounds, management of nitrogen-based explosives during the storage, handling, transporting, bore-hole loading, and detonating phases of blasting and management of surface water runoff from mine areas may be necessary at some mines sites. Approaches to prevent the contamination of surface water and groundwater with ammonia, nitrate and nitrite as well as reduce the production of toxic gases, should be proactively planned and implemented at mine sites.

The intent of this document is to serve as a guide to be used when developing a site-specific nitrogen management plan either as a proactive step initiated by a mine owner or in response to fulfilling a regulatory requirement (i.e. a condition in a permit under either the *Environmental Management Act* (EMA) or the *Mines Act* (MA)).

Under authority of EMA, a Ministry of Environment and Climate Change Strategy (ENV) Statutory Decision Maker may establish limits for nitrogen compounds in the receiving environment, set requirements for authorized discharges or establish additional conditions to ensure protection of the environment. As part of an EMA permit, a Statutory Decision Maker can require a mine owner to submit a Nitrogen Management Plan. The Plan is meant to be the vehicle for identifying the specific management measures needed to ensure permit limits/conditions will be met.

2.0 Nitrogen in the Environment

ANFO (see Appendix A for more information on ANFO) can cause deleterious environmental effects in both detonated and undetonated states. In high-moisture settings, detonation of ANFO can be inefficient, leading to incomplete combustion and toxic residuals. The undetonated ammonium nitrate (AN) is highly water-soluble and can result in releases of nitrate, nitrite and ammonia into the environment, including both surface water and groundwater. Dissolution of AN is a common issue affecting the detonation performance of ANFO and, depending on site-specific conditions, can lead to environmental issues from the releases of nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO) and methane (CH_4) due to poorly detonated ANFO. According to some literature sources, this dissolution can happen very quickly, as 25% of nitrates can leach from the explosives after 6 minutes of exposure to moisture, and 50% after a one-hour exposure. Following the loss of 25% of nitrates, the ANFO will not be able to properly detonate.

While nitrogen in a well-oxygenated aquatic environment, in the form of the nitrate ion (NO_3^-), is an important nutrient to aquatic plants, excess nitrogen compounds including nitrate, nitrite and ammonia can potentially harm receptors in the receiving environment. Depending on how they are managed, the use of explosives at a mine site can cause the release of large quantities of nitrogen compounds and increase the risk of impacts. Potential effects of rising nitrate levels include algal blooms, reduced oxygen and eutrophication of surface water bodies. Though nitrates are significantly less toxic to freshwater aquatic life than ammonia or nitrite, elevated levels of nitrates may still be toxic. In addition, effects to humans may occur: risk of nitrate toxicity, usually from elevated levels of nitrates in contaminated well water, is higher for infants younger than 4 months, and ammonia can also impact human health.

Fuel oil wicking from the blasthole is another common problem leading to poor detonation and the associated AN release issues noted above as well as direct environmental issues from the release of fuel oil. If hydrocarbon fuels in the “diesel-fuel” range are used in the ANFO mixture the fuel oil component has moderate volatility and moderate solubility. These diesel-range fuel products may be acutely toxic to biota, depending on the precise type of fuel and the concentration of aromatic compounds, though in general acute toxicity will be moderate to high. Less potentially harmful mineral oils can also be used as the fuel oil component in ANFO.

3.0 Storage of Explosives

The minimum requirements for siting, construction, equipment standards, safety, operation and licensing of explosive facilities are regulated under the *Explosives Act* (Canada) and the Health, Safety and Reclamation Code for Mines in British Columbia (the Code). Guidance for meeting the federal *Explosives Act* requirements are provided in the Natural Resources Canada Guidelines for Bulk Explosives Facilities G05-01 February 2014 document.

This Nitrogen Management Plan guidance document is not intended to replace or duplicate the requirements of the above mentioned documents. For completeness, a Nitrogen Management Plan should describe the actions taken to meet regulatory requirements that contribute to meeting nitrogen management goals (i.e., siting an explosive facility away from any water sources).

4.0 Waste Disposal and Discharges to the Environment

Effluent discharges from a mine site to the receiving environment are authorized by permits issued under the EMA. Some effluent streams may contain nitrogen compounds including: pit water, water runoff from waste rock, surface water runoff at explosive facilities, wash bays used for decontaminating explosive mobile equipment and waste soil recovered from spill sites.

Water management activities on the mine site are regulated under the EMA, the MA, and the Code. Contaminant sources on mine sites are required to have planned water management and pollution control works and apply best management practices. (See Joint *Mines Act/Environmental Management Act* Permit Application Information Requirements Guidance Document[1], Section 5)

Effluent and air emissions from explosives facilities are potential sources of nitrogen releases to the environment and therefore discharges to the receiving environment needs to be regulated by an EMA permit. Surface water runoff management, spill contingency and water monitoring at explosive facilities are regulated by MA and EMA permits, as well as wash water and sump sediment disposal from where explosive mobile equipment are washed.

Under the Natural Resources Canada Guidelines for Bulk Explosives Facilities G05-01 February 2014 document "scrap" explosive is defined in two key places. First, there is the residual explosive ("heel") which is collected from inside mobile explosive equipment that is used to transport product to the blast holes. This is a form of scrap explosive which, when collected, is a viable explosive product. The federal guidance document outlines that it can be bagged, labelled and stored with other explosives for future blasting. Secondly, there is type of scrap explosive which is collected from the washing and decontamination of mobile equipment in the explosive facility wash bays. The disposal of scrap explosive from the "washing systems" is to be authorized by the province.

Under the *Hazardous Waste Regulation* it is the responsibility of the waste generator to classify its waste. Hazardous waste is not authorized for discharge under EMA effluent discharge permits. Because effluent from washing explosive trucks will contain nitrates and nitrites as well as other products and waste characteristics at levels that could potentially exceed hazardous waste thresholds it is recommended that mines retain Qualified Professionals to screen wash bay wastes against the *Hazardous Waste Regulation*. Wash bay wash water, sump solids and the leachates should be individually classified prior to applying for an EMA discharge permit. During the waste characterization steps, consideration must also be given to extractable petroleum hydrocarbon (EPH) concentrations and toxicity associated with the chemical detergent neutralizers used during the decontamination of explosive mobile equipment.

Waste ANFO which has been altered from exposure to water or neutralized in the decontamination steps of washing explosive mobile equipment will not be authorized by ENV for disposal in blast holes prior to a blast. ANFO that has been exposed to water or neutralizer will not detonate properly which will lead to increased levels of potentially harmful nitrogen compounds being released from the waste rock if it is disposed of in bore holes prior to a blast. All waste ANFO must be properly disposed of according to its waste classification (hazardous or non-hazardous) and, if discharged on the mine site, be authorized in an EMA permit otherwise it must be transported off site for disposal at a licensed waste facility.

[1] https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/documents/permitting/minesact-ema_application_information_requirements_feb2016.pdf

5.0 Recommended Nitrogen Management Plan Content

The overarching goal of a Nitrogen Management Plan (NMP) should be to control nitrogen losses from a mine site using a purposely planned and executed management process. This process needs to be designed so it provides an understanding of each aspect of a mine's operation where nitrogen compounds (nitrate, nitrite and ammonia) can be created and released, where nitrogen compounds can potentially impact the receiving environment and the specific management strategies needed to control / mitigate nitrogen losses to the receiving environment within the context of each mine's unique site-specific conditions and risks to the environment.

Each nitrogen management strategy should be coupled with measurable key performance indicators (KPIs) and management performance metrics that will allow the success of each management strategy to be measured. Setting management performance metrics and measuring KPIs will facilitate continuous improvement of the nitrogen management plan.

The matrix in Table 1 can be used to guide the development of a site-specific nitrogen management plan. Site-specific and unique site factors should also drive the direction that each NMP takes. Nitrogen Management Plans should be dynamic documents with sufficient detail to allow for the effective implementation of strategies and the timely monitoring of performance indicators all with the framework of a management feedback loop that drives iterative improvements to blasting and nitrogen management activities. In addition to *ad hoc* changes made to a NMP, pre-defined timeframes requiring formal review and updates should be included.

Table 1. Suggested Content for Nitrogen Management Plans at a Mine Site

Section #	Section	Plan Content
1.0	Project / Site Overview	Project description – Brief description for context of: • background information of the mine site • location • type of mine • mine processes • general operations • geographic setting • climate
2.0	Purpose	Provide context on the reason behind preparing a NMP – i.e., required under an EMA Permit, compliance order or continuous improvement process.
3.0	Overview of Explosive Use and Management	Overview of the mine's • use & type of explosives • existing protocols/procedures • blast simulations • methods of drilling • loading • type of rock material • goals and objectives for blasting • frequency of blasting • Roles and responsibilities of the mine staff that play key roles in nitrogen management The intent of this section is to provide the operational contextual setting for explosive use at the mine site. The scale of operations and approach to blasting management described in this section set the stage for the other report section since the above suggested items will, in part, drive the nitrogen control management strategies.
3.1	Location of Facilities	Description of all explosive related facilities at the mine site: • manufacturing facilities • bulk storage sites • emulsion & prill silos • fuel oil tank farms • equipment wash bays This section defines where potential sources of nitrogen release in addition to the active mine areas as well where EMA effluent and emission discharge authorizations may be needed.

3.2	Quantities and Types of Explosives	Overview of the types of explosives and explosive related products used and stored on site as well as typical monthly/annual inventory. This section helps to rationalize the level of risk of nitrogen releases that may exist at given mine site. Risk is partly related to the types and quantities of explosives on site.
3.3	Hazard Classes	Overview of industry hazard classifications of all explosive related products stored and used on site. Include explosives, emulsions, fuel oil, and decontamination neutralizers. The classification of waste explosive products should be identified in this section. This section will rationalize EMA permit discharge and waste disposal authorizations / strategies need to meet nitrogen control strategies.
4.0	Risk Assessment	A conceptual site model should be presented that demonstrates the current state of management knowledge on nitrogen sources, release rates and mechanisms, effects pathways and receptors. Where available, quantifiable data should be used to define the potential risk (i.e., extent/duration/magnitude/direction of impacts). In the case where there is a high risk to sensitive receptors (i.e. human health or species-at-risk) a more detailed risk assessment may be warranted prior to developing specific nitrogen management control strategies.
4.1	Receiving Environment	All surface receiving aquatic environments, groundwater, aquifers and drinking water sources should be described and where practical, presented spatially on maps.
5.0	Management Strategies	Strategies to control nitrogen losses can fall into two general categories: 1) Explosives Management (source control) 2) Water Management (mitigation / prevention)

5.1	Explosives Management – *Source Control*	This section should describe the best management practices, protocols and procedures in place or that will be implemented to ensure the optimal use and minimal loss of explosive products. Strategies that lead to optimal or even reductions in the amount of ANFO needed to accomplish mining objectives will directly correlate to the risk of nitrogen-related impacts to the receiving environment and the types of management strategies necessary to meet environmental protection goals. Strategies that should be presented include: • Explosive product selection (i.e., type of ANFO) • powder factor optimization • practices for explosive storage (preventing contact with water/moisture) • Practices to prevent water contacting explosive in blast holes (i.e., blast hole liners, bench dewatering) • drill pattern optimization • blast optimization simulations • sleep time • explosive loading • spill response/reporting • incident management/investigation • training and inspections • blast monitoring • dealing with misfires • handling and disposal waste explosive products All the above factors in some manner can play a role in optimal explosive use as well as the quantity of nitrogen released to the environment.
5.2	Water Management – *Mitigation / Prevention*	Outline all the measures the mine is or will undertake to manage water and its ability to come in contact with explosive residue on waste rock. This should cover the mine's overall system of perimeter ditches, surface water collection and treatment, settling/infiltration structures as well as clean water diversion and site water balance. Other water management strategies that should be presented include surface water runoff control at the explosive facilities, including contingency structures in case of spill during inclement weather, bench de-watering, waste rock storage areas and water diversion/interception at waste rock dumps. Including data on factors such as precipitation, frequency of storm events, and annual volume of water captured, stored, and released, and a comparison of changes from year to year would demonstrate the magnitude that weather related factors might have on nitrogen management at the site.

6.0	Performance Monitoring	Key performance indicators (KPIs) in the form of leading indicators should be developed for each nitrogen control strategy along with a performance metric that defines the target the mine is trying to achieve with its NMP. Leading indicators will assess effectiveness of the management strategies. Lagging indicators, such as nitrogen concentration in receiving environment water, is measuring the impact after it has happened. Leading indicators, if effectively structured, can also serve as early warning indicators that the risk of receiving environment impacts or permit exceedances is escalating. Some examples of leading KPIs include: powder factor, velocity of detonation, number of dry and wet holes at the time of blasting, quantity of explosive spilled and quantity recovered, sleep time, and nitrogen concentrations in mine contact water.
7.0	Environmental Monitoring	Describe the applicable site permits and locations where monitoring for nitrogen compounds will take place. Monitoring sites, frequency of sampling and sampling protocols may be part of a mine's existing environmental monitoring program; therefore, not necessary to duplicate in detail in the NMP. If nitrogen compounds are not addressed through routine site monitoring programs, the NMP may need to identify where permit amendments will be required to monitor compliance with nitrogen management requirements.
8.0	Data Analysis and Reporting	Annual reporting summarizing the results of the NMP's implementation may be required by an EMA permit. The annual report, if required, should present the results of the previous year's nitrogen control efforts including comparison between measured KPIs and management performance metrics. Trends in water monitoring and discussion of nitrogen management successes, failures, and lessons-learned should also be included.
9.0	Authorized Discharges	Identify authorized discharges of nitrogen affected contact water and explosives wastes. If additional discharge permits will be required in the upcoming planning year – identify the permits requiring amendments and expected submission timeframes.
10.0	Continuous Improvement / Research and Development	Present the management feedback process that will be used to drive continuous improvement in the NMP. Identify where research and development initiatives are needed or being undertaken to address specific management questions or uncertainties related to nitrogen management.

6.0 References

Assessment of ANFO on the Environment. Technical Investigation 09-01 Defence Research and Development Canada – Valcartier. Technical Memorandum 2009-195. January 2010.

ANFO, Emulsion and Heavy ANFO Blends – Useful Explosive and Blasting Agent for Modern Day Blasting. Partha Das Sharma, B.Tech. May 2010. https://miningandblasting.wordpress.com/2010/05/03/anfo-emulsion-and-heavy-anfo-blends-%E2%80%93-useful-explosive-and-blasting-agent-for-modern-day-blasting/

Appendix A – General Overview of Ammonium Nitrate Fuel Oil

Ammonium Nitrate Fuel Oil is a mixture of ammonium nitrate (AN) and fuel oil (FO). ANFO is commonly used in the mining industry as an explosive because of its low cost and is estimated to comprise 80% of all explosives used annually in North America.

Ammonium nitrate (AN) is a weak explosive base and it is technically classified as a blasting agent rather than an explosive because it cannot be detonated with a #8 strength detonator. ANFO requires a primer assembly to be detonated. Compared to other classes of explosives ANFO is an inefficient explosive as it releases large volumes of gases during the detonation process. However, ANFO's advantage is found in its heaving ability when it is confined to relatively tight blast holes. The heaving action of ANFO breaks rock into manageable sizes for mine equipment to handle efficiently, without causing excessive displacement during the blast.

All fuel oils contain mixtures of varying proportions and types of hydrocarbons. The fuel oils used most commonly for ANFO is number 2 fuel oil or number 2 diesel fuel. These two fuels are very similar in chemical composition, but differ in the additives used.

There are three types or grades of explosive-grade ANFO and each has different explosive and water resistant properties. During the manufacture of explosive-grade ANFO, an ammonium nitrate solution is turned into prills (droplets). Water added to the AN solution creates pores in the prills after the water has evaporated out. The pores hold the fuel oil when the AN prill is soaked in fuel oil during the final steps of the manufacturing process. AN prills are not waterproof or water resistant which leads to failed or inefficient detonation after they absorbs moisture, usually from contact. In addition, AN prill properties allow it to absorb moisture from the atmosphere.

Emulsion can be added to ANFO to make it more water resistant. Emulsions are water–oil solutions comprised of oxidizers suspended in an oil medium such as mineral oil. A bulking agent in the form of ultra-fine air, glass, resin, or plastic bubbles is injected into the mixture to control the bulk density of the final explosive product. Explosives with high levels of emulsion are more water resistant and safer to handle, use and store. The high velocity of detonation of emulsion explosives makes it effective for very hard rock conditions. The energy levels of emulsion explosives are similar to those of nitroglycerine-based explosives. Emulsion explosives are well-oxygenated and generate less noxious fumes and smoke compared to low or no-emulsion ANFO.

High bulk density blends of ANFO and emulsion are classed as Heavy ANFO (HANFO). The consistency of HANFO allows it to be pumped which makes it easier to load into blast holes than dry products. HANFO has more energy in the bore hole than ANFO, provides better water resistance and is priced in the middle between ANFO and high emulsion explosives. The composition of ANFO is typically around 94.5% AN and 5.5% FO. HANFO contains 60-70% emulsion. The water resistance of HANFO allows the *sleep time*[2] to be extended and it can be used in wet rock formations with less risk of degradation, misfires or inefficient detonation.

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 or on snow/ice. When these latter conditions are encountered, the use of water-resistant emulsions or plastic liners is more appropriate.

[2] The time between when blast holes are loaded with explosive and when they are detonated.