

# Safe recovery, neutralization, and destruction of bulk explosives

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## Introduction

The destruction of excess, obsolete, or unserviceable munitions and commercial energetic materials by chemical neutralization and destruction methods offers an environmentally friendlier alternative solution to disposal by open burning and open detonation (OB/OD). MuniRem® reagents offer a scalable and versatile solution to safely neutralize and destroy explosives and chemical warfare agents, while stabilizing heavy metals as the insoluble metal sulfides. The MuniRem reagents are shipped worldwide in powder form. At the time of use, the MuniRem reagent is dissolved in fresh or salt water and applied to the explosives to initiate a rapid chemical neutralization and reduction reaction. Chemical reduction of nitroorganic explosives avoids the formation of nitrate as an end product. Contrarily, the destruction of nitroorganic explosives by chemical oxidation produces high concentrations of nitrates. The pH of MuniRem reagent solution in freshwater is alkaline but decreases to circum-neutral pH when the reaction with explosives is complete. Level C personal protective equipment (PPE) is required when applying MuniRem to destroy explosives. The MuniRem solution is applied at military ammunition manufacturing and demilitarization plants, commercial explosives manufacturing plants, and many other sites needing explosives decontamination and disposal worldwide.

It is well documented that OB/OD is a source of pollution of air, soil, and water. Incomplete combustion of explosives can lead to their spread beyond the immediate vicinity of the OB/OD site by the kick-out that these operations generate and have led to the pollution of soil and water resources. Additionally, it is now confirmed that even small explosions may change the molecular structure of the brain and increase the risk of Alzheimer's disease, Army-funded researchers said in a paper published by the journal *Brain Pathology*, Feb. 25, 2021. Our development and application of the MuniRem solution as an alternative to the disposal of explosives by OB/OD benefits both human health and the environment.

## Case Studies

A sample of case studies of bulk explosives disposal using MuniRem reagents are provided below. Specifically, the four selected case studies demonstrate the application of MuniRem reagents to chemically destroy primary and secondary explosives, sweating dynamite (i.e., dynamite sweating out nitroglycerine), and nitrocellulose propellants. For each case study, which has been selected to address a different type of explosive, the background, methodology, and results are provided. Client names are withheld in compliance with nondisclosure agreements between MuniRem Environmental, LLC (MRE) and its clients.

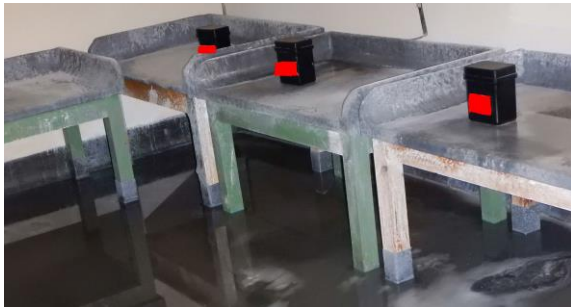
### A. Primary Explosives

**Background:** Lead Styphnate (LS) and tetrazene were stored in magazines for more than a decade under unsuitable conditions. One of the two magazines contained 25 kg of LS in five plastic buckets while the second magazine was used to store 3 kg of Tetrazene in six plastic cups. The average daily temperature in the client's country at the time of performance of this work was between 35°C to 45°C. There were many storage magazines and production buildings inside the safety arc and a few meters from the

magazines with the unstable explosives. The condition of the primary explosives as well as the storage conditions inside the magazines had deteriorated to what can be described as extremely hazardous. The client engaged MRE to safely recover and destroy the explosives chemically with MuniRem reagents and decontaminate the magazines for future use.

**Methodology:**

- i. MRE staff mobilized to the site after the three different MuniRem products (MuniRem-R811E-D, MuniRem-R532E-D, and MuniRem-FE) shipped to the client were received.
- ii. MRE staff included EOD Technicians and Chemists experienced in the application of MuniRem reagents for explosives disposal.
- iii. Prior to the start of the explosives recovery, neutralization, and destruction work, MRE staff met with the client staff and discussed the work and safety plans.
- iv. After approval of the work and safety plans by the client, MRE staff mobilized to the magazine location and setup its PPE, MuniRem products, water, explosives neutralization, and wastewater storage tanks, spray system with pumps and hoses of the desired lengths, lights, and fans, and other accessories.
- v. A dry run of the procedures to be followed was performed in a magazine that contained the same plastic buckets and cups in which the explosives were stored.
- vi. Wooden frames were constructed to hold the plastic storage containers in place so they will not tip over during the spraying of aqueous MuniRem solutions to neutralize the explosives in place (see below).



*Figure 1. Plastic cups in a storage magazine, each holding 0.5 kg of tetrazene. Aqueous solution of MuniRem was sprayed to render safe areas around the containers (left), and a customized soaking system to neutralize the explosives in the storage cups to enable safe recovery (right) were installed.*



*Figure 2. Before and after project photos*

- vii. Police secured entry and exit routes, the fire department mobilized and staged outside the safety arc, and multiple ambulances and the nearest hospital were placed on alert.

- viii. Nonessential personnel were stationed in the yellow zone, leaving only three MuniRem personnel in the red zone.
- ix. MRE staff gained entrance into the magazines to begin work by first spraying the entrance and interior of the magazines with multiple batches of an aqueous solution of MuniRem reagent.
- x. Once the magazines were rendered safe for entry, the primary explosives were neutralized in place, transferred to the magazine exterior, and chemically destroyed with additional MuniRem reagents in open-top plastic pails.
- xi. The wastewater from the neutralization and destruction process was collected into storage tanks and confirmed as negative for explosives using QTest and laboratory analysis before being transported to the onsite wastewater evaporation ponds.

**Result:**

The explosives were safely neutralized, recovered, and destroyed chemically without a site-wide safety shutdown that would have disrupted all work. The magazine was rendered safe for use by spray decontamination of the interior surface of the magazine and entrance with an aqueous solution of MuniRem-R811E. The decontaminated storage magazines were confirmed as free of residual explosives and put back into use. The effective timeline from project initiation to conclusion was six working days. The MuniRem solution mitigated an extremely hazardous situation that lingered for 14 years, during which the client looked around the world for a solution.

At another client site and under subzero temperatures during the winter months, the MuniRem solution was equally safe and effective for the recovery of LS, Primer Mix, Tetrazene, PETN, DDNP stored under unsuitable conditions for nine months following a fatal accident. In another application, the MuniRem solution was applied to neutralize and destroy old bulk Lead Azide stored in drums, with the Lead precipitated as Lead Sulfide. Therefore, the MuniRem solution is effective in both freezing and extremely hot weather.

## B. Secondary Explosives

### Background

MuniRem Environmental LLC was funded to demonstrate and validate the efficacy of its MuniRem reagents to destroy bulk explosives recovered from Navy projectile rounds, as would support demilitarization. The bomb filler was Composition D (picrate-based explosive). The tasks included the destruction of the bulk explosives and decontamination of the bomb casing for recycling.

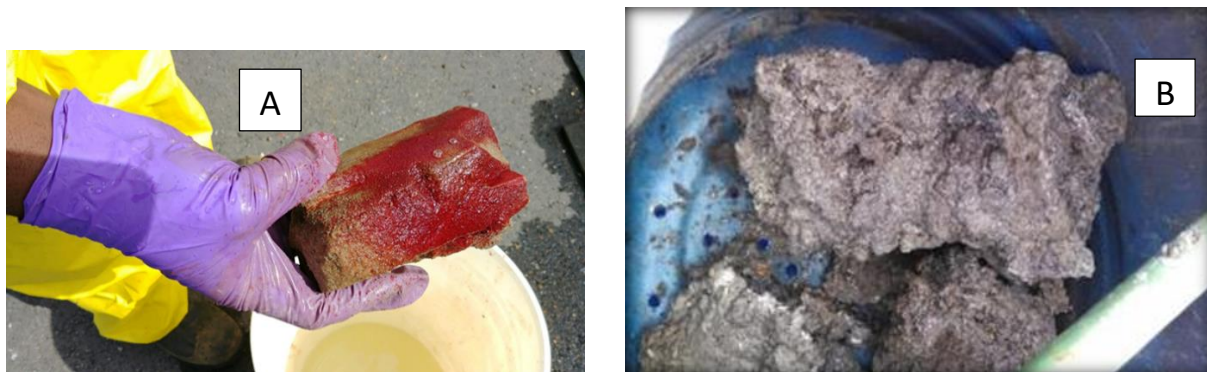


Figure 3. Pentolite (A) and Comp-H6 (B) chunks recovered and neutralized using MuniRem reagents. The color of the pentolite is from its reaction with MuniRem reagent in the pail.

Following the success of this demonstration/validation study, MRE has been contracted at many sites to destroy bulk quantities of other secondary explosives, including the Comp-H6 explosives (i.e., Aluminum, TNT, and wax) and pentolite (50% PETN and 50% TNT) shown in Figure 3.

### Methodology.

- I. A waterjet was used to breach the projectile rounds and the recovered Comp-D and bomb casings were transferred to MRE personnel.
- II. An optimum dose of MuniRem reagent solution was prepared and used to destroy multiple 10-pound (4.54 kg) batches of explosives in the reactor. Additional MuniRem reagent powder was added incrementally to destroy the explosives to the desired effluent explosive concentration.
- III. The 4.54 kg of Comp-D was added incrementally over a 5 minutes duration to 345 L of the solution of MuniRem reagent (MuniRem-R541E) in the reactor. The MuniRem-R541E is an effective but not the most effective MuniRem reagent for rapid neutralization and destruction of Comp-D.
- IV. A mechanical mixer agitated the contents of the reactor while the temperature of the reaction was monitored.
- V. The Comp-D was destroyed to 2 mg/L in the reactor for under two hours. Confirmation was by laboratory analysis.
- VI. The generated wastewater was treated in a sorption/reactive column containing black carbon and iron filings to further decrease the concentration of the end products.
- VII. The projectile metal casings coated with creosote were soaked in an aqueous solution of MuniRem reagent and decontaminated to the desired non-detectable explosives level (U.S. DoD material documented as safe) in 30 minutes. Creosote was destroyed by MuniRem reagent.

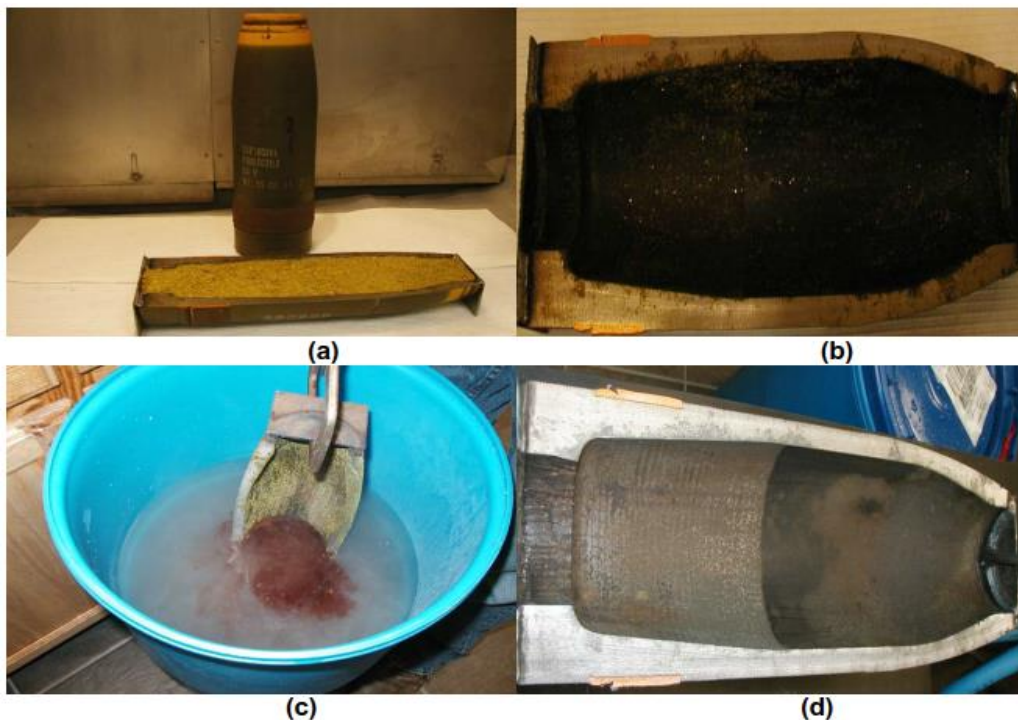


Figure 4. Separate demonstration for halved projectiles treatment: (a) halved shells containing wetted Comp-D; (b) halved shell after removing Comp-D; (c) halved shell being decontaminated in solution of MuniRem® reagent - the purple color is from the reaction of picrate with MuniRem® reagent, (d) clean halved shell after decontamination to MDAS (5X).

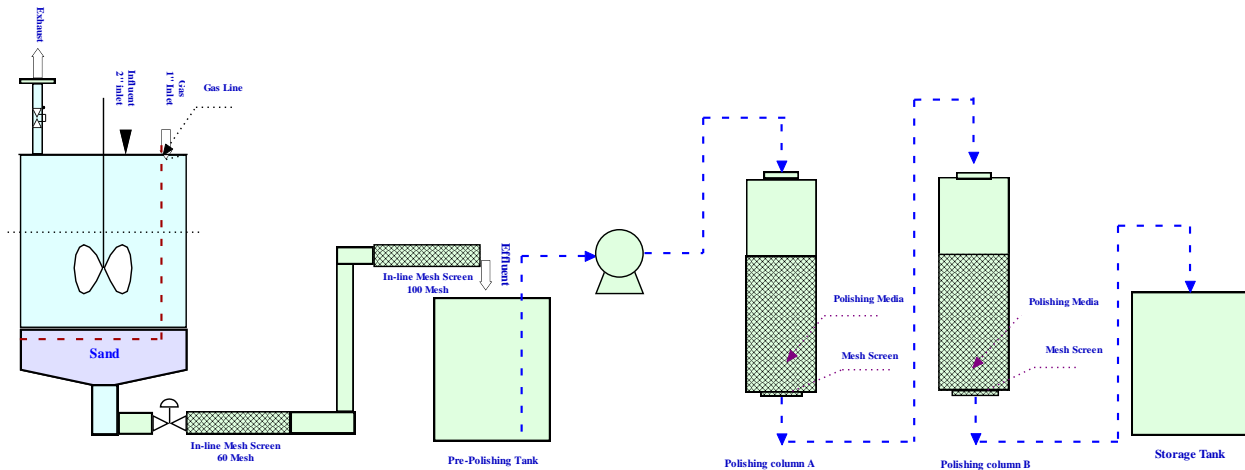


Figure 5. Custom built reactor for chemical destruction of multiple 10 pound (4.5 kg) batches of Comp-D and two columns for polishing the generated wastewater operated in series. The treatment media in the polishing columns was a mixture of Carbon & zerovalent iron.

## Results.

Multiple batches of the US military explosive Comp-D were neutralized rapidly and subsequently destroyed into organic anions (formate and acetate) with nitrogen, ammonia, and carbon dioxide as gaseous products. Formate and acetate are used by bacteria as both carbon and electron sources in wastewater treatment processes. In a reactor configuration, the destruction of 4.54 kg of Comp-D was achieved in under two hours. In an open-top reactor exposed to oxygen in the air, the reaction takes longer and consumes more MuniRem reagent. MuniRem-R811E-D and MuniRem-FE (booster) are the most effective MuniRem reagents with a dose of reagent to Comp-D of about 2:1 (mass:mass). The wastewater was polished in a sorption and reactive column of black carbon and zero-valent iron; an option for sites that desire to dispose of the wastewater at a publicly owned wastewater treatment facility. The pilot study data was used to develop a protocol for neutralization of bulk explosives and decontamination of metal casings with MuniRem solution.

Following the success of this pilot test, MuniRem reagents have been approved and applied to dispose of multiple other secondary explosives, including PETN, TNT, RDX, HMX, pentolite (PETN plus TNT), Tetryl, NC, NG, etc.

## C. Nitrocellulose Fines and Propellants

### Background.

Demilitarization operations at a former ammunition plant generated nitrocellulose propellants that the client desired to dispose of by a nonthermal method. Also, the manufacturer of commercial blasting explosives needed to dispose of over thirty (30) tons of nitrocellulose fines at a remote location. The chemical destruction options were either alkaline hydrolysis or the MuniRem solution. The MuniRem solution was preferred because it generates wastewater with a circum-neutral pH and low nitrate concentration. Alkaline hydrolysis was not selected because of the exothermic reaction, high pH, and nitrate of the generated wastewater. The option to convert the NC fines to fertilizer was not considered because the site conditions were unsuitable.

## Methodology.

- I. MuniRem reagents (MuniRem-R811E-D, MuniRem-FE, MuniRem-R532E) and organic solvents were shipped to the project site.
- II. Equipment and supplies required included: HDPE neutralization tanks, wastewater tanks, water, mixer, PPE, field explosives detection kits (EXPRAY® and QTest®).
- III. Nitrocellulose propellant was pretreated with organic solvent (acetone or ethyl acetate) to increase its solubility in water.
- IV. Nitrocellulose fines do not require pretreatment with organic solvent because of the large surface area available to react with MuniRem reagent in solution.
- V. MuniRem reagent plus water were added incrementally to the neutralization reactor to initiate the reaction between the MuniRem reagent and the NC in solution.
- VI. Because the reaction is moderately exothermic with a temperature high of 60 degrees Celsius, a jacketed reactor or open-top reactor is recommended. As the volume of water increases, the maximum temperature of the degradation reaction decreases. Water has a high heat capacity.
- VII. A color change and increased temperature of the solution are initial confirmations that the reaction is occurring.
- VIII. The pH of the wastewater generated is between 7.52 to 9.5, depending on the formulation of MuniRem reagent selected. MuniRem-R532E produces the highest pH at the end of the destruction reaction.
- IX. The ratio of MuniRem reagent to NC was 2:1. When zero-valent iron is added to the reactor, less MuniRem reagent is required to completely degrade the NC.
- X. The complete destruction of NC was confirmed by EXPRAY® and QTest®.
- XI. The complete destruction of NC and concentration of nitrite, nitrate, and sulfate in the wastewater were determined at an analytical laboratory.

## Results.

The NC was transformed to glucose and mannose primarily, with smaller amounts of arabinose and xylose. Other breakdown products were sulfate and small amounts of nitrate and nitrite. The transformation of NC to monosaccharides (sugars) offers a potential source of raw material for cellulosic ethanol production. The wastewater may be disposed of as non-hazardous waste after polishing by biodegradation. In bioreactors or constructed wetlands, the sugars and nitrogen compounds in the wastewater generated should be consumed by bacteria and plants.

MuniRem Environmental has also developed a method for converting NC and biochar into fertilizer for plant growth. This solution requires that the NC be free of pollutants such as heavy metals and other explosives.

## D. Dynamite

### Background

Abandoned and deteriorated dynamite was found in multiple magazines at closed coal mine sites from the 1960s and 1970s. The largest quantity was in magazines that held more than a ton of deteriorated dynamite. The dynamite sticks had over the years leaked out nitroglycerin which pooled within the packaging/floor and soaked the shelving. Disposal of the dynamite by use of age-old dilution and desensitization chemicals including nitro-killers, acetone, alcohol, and diesel was deemed unacceptable because they generate hazardous and flammable wastes. Additionally, one of the magazines was in a residential area (Figure 3) and next to a state highway. Therefore, the MuniRem solution was selected as the safest and most environmentally friendly option.

## Methodology

- i. The neighboring community was informed and evacuated during the three days when the chemical neutralization and destruction were performed.
- ii. MuniRem reagents and blasting mats were shipped to the site.
- iii. Equipment and supplies required included: HDPE neutralization tanks, wastewater tanks, water, mixer, PPE, and field explosives detection kits (EXPRAY® and QTest®).
- iv. Engineering controls consisting of soil berms and blasting mats were installed to minimize air-blast and shrapnel danger.
- v. The population in the residential areas within the safety arc was evacuated, and roads were closed by law enforcement.
- vi. Aqueous solution of MuniRem reagents was prepared and sprayed on the pooled NG and the entire interior of the magazines.
- vii. The reaction between MuniRem reagent and NG was accompanied by a temperature increase and color change.
- viii. The air quality inside the magazine was monitored by an installed multi gas monitor installed inside the magazine.



Figure 6. Location of the magazine containing half a ton of dynamite within a residential area (left) and magazine with >1 ton of dynamite(right). Photos are courtesy Ram Inc, Ohio, USA



Figure 7. Sweating dynamite without (left) and with a solution of MuniRem reagent applied (right) to neutralize and destroy the nitroglycerin. Photos are courtesy Ram Inc, Ohio, USA

- ix. After 4 hours, the dynamite sticks were picked up and placed in a pail of aqueous MuniRem solution, one stick at a time, as a steady mist of the solution was sprayed.
- x. The recovered dynamite sticks were breached in a neutralization reactor under a solution of MuniRem reagent.
- xi. The dynamite fillers were destroyed in the neutralization reactor, while the packaging was soaked in tanks containing an aqueous solution of MuniRem reagent.
- xii. The complete destruction of the explosives was confirmed by EXPRAY® and QTest®.
- xiii. The wastewater was analyzed at an analytical laboratory and the results were used to determine the disposal of the wastewater, after characterization as a nonhazardous waste.
- xiv. The decontaminated packaging was burnt on-site.

**Result.**

The net explosive weight was quickly reduced in situ by applying a copious amount of aqueous solution of MuniRem reagent to the bulk dynamite in the magazine. The rapid neutralization and destruction of the NG by spraying the MuniRem solution on the dynamite mitigated the explosive hazard so that the remaining dynamite sticks could be recovered and destroyed in reactors made of open-top drums. The wastewater from this and multiple sites has been characterized as nonhazardous waste for disposal purposes. The MuniRem solution offers a safe and environmentally friendly option for the disposal of unstable dynamite in urban and remote locations. Thus, at many sites environmental polluting practice of pouring diesel into abandoned magazines containing sweating dynamite and burning has been replaced by the MuniRem solution.

## Conclusion

The rapid chemical neutralization and destruction of bulk explosives and energetic hazardous waste provides a safe, environmentally friendly, and cost-competitive alternative to countercharging, incineration, or bioremediation technologies. The MuniRem solution offers an environmentally friendly alternative to OD/OB and is applied to support projects at various Army Ammunition Plants, Commercial Explosive Manufacturing Facilities, Law Enforcement Response Actions, demilitarization, and cleanup of explosive storage magazines.