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**A REVIEW OF EXPLOSIVES USED IN
EXPLOSIVE EXCAVATION RESEARCH
LABORATORY**

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Livermore, California**

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**TID-4500, UC-35
Peaceful Applications
of Explosions**

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**A REVIEW OF EXPLOSIVES USED IN EXPLOSIVE EXCAVATION
RESEARCH LABORATORY PROJECTS SINCE 1969**

CPT Howard H. Reed

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EXPLOSIVE EXCAVATION RESEARCH LABORATORY
Livermore, California**

MS. date: June 1974

PREFACE

The U. S. Army Engineer Waterways Experiment Station (USAEWES) Explosive Excavation Research Laboratory (EERL) was the USAEWES Explosive Excavation Research Office (EERO) prior to 21 April 1972. Prior to 1 August 1971, the organization was known as the USAE Nuclear Cratering Group (NCG).

This is an open-ended report on the selected explosives and blasting agents used by EERL since 1969. It describes the explosives used on various projects conducted by EERL. These projects have been funded primarily by the Office, Chief of Engineers.

The Director of USAEWES during the preparation of this report was COL G. H. Hilt; the Director of EERL was LTC R. R. Mills, Jr.

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ABSTRACT

Since 1969 the Explosive Excavation Research Laboratory has been engaged primarily in using commercially developed explosives and blasting agents in a variety of explosives excavation jobs and experiments. Dry and wet (slurry) explosives and blasting agents have comprised the bulk of these products, which are generally fuel-oxidizer mixes with an ammonium nitrate base. General properties of these explosives are covered. The specific products used by EERL are discussed in detail as are the media in which they were used. The present techniques available for procuring explosives are also discussed.

CONVERSION FACTORS

Metric units of measurement used in this report can be converted to English units as follows:

Multiply	By	To obtain
centimeters (cm)	0.3937	inches (in.)
meters (m)	3.2808	feet (ft)
cubic meters (m ³)	35.311	cubic feet (ft ³)
cubic meters (m ³)	1.30795	cubic yards (yd ³)
kilograms (kg)	2.204622	pounds (lb)
kilograms per square meter (kg/m ²)	1.422×10^{-3}	pounds per square inch (psi)
pounds per cubic foot (lb/ft ³)	0.062522	kilograms per cubic meter (kg/m ³)
Fahrenheit degrees (F)	- ^a	Celsius or Kelvin degrees (C, K)
ton (nuclear equivalent of TNT) ^b	4.2×10^9	joules (J)

^aTo obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

^bAll references to yield are in terms of energy; therefore, joules will be the primary value in accordance with the International System of Units (SI) and the alternate will be tons (nuclear equivalent of TNT).

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SECTION I. INTRODUCTION

Since 1969 the Explosive Excavation Research Laboratory (EERL) has been principally concerned with the development of chemical explosive excavation design techniques and engineering procedures that can be used on a wide range of civil engineering excavation projects. Military-related explosive excavation research emphasizes high-priority military requirements especially in the areas of nuclear simulation and military engineering applications of commercial explosives. A number of experimental modelling projects have been accomplished using commercial dry blasting agents and slurries or water gels. Each project has been thoroughly documented by a technical report and various supporting memorandums and papers. It is not the intent of this report to review these projects. The focus will be on the explosives used for these various projects. It is intended that this report provide not only a history of the variety of explosives used, but also a general background on the types of explosives currently available from commercial sources. Additionally, the evolution of explosives specifications for those projects will be traced so that a permanent record is available to guide future specification writers.

It is deemed desirable that this report be updated periodically as new explosives are used on future projects. Those seeking further information on the general properties of dry blasting agents and slurries are encouraged to consult the references listed in the bibliography. It is hoped that the reader will be able to gain not only an appreciation of the explosives used at EERL, but an understanding of the basic technology involved in using these explosives.

SECTION II. EXPLOSIVES AND BLASTING AGENTS

A. Scope

The large-scale use of ammonium nitrate as a primary explosive ingredient has produced changes in the explosives field that rank with the original development of dynamite in significance. Of all the explosives produced in the United States in 1972, ammonium nitrate and dry or wet ammonium nitrate-based products accounted for better than 85%.¹ Ammonium nitrate has been used in the explosives industry for many years but it wasn't until the 1950's with the introduction of a mixture of ammonium nitrate and fuel oil (ANFO) that its impact was felt. Subsequent development of water-based ammonium nitrate slurries or water gels has revolutionized the blasting industry. Economic and efficient bulk-explosive-handling methods, coupled with improved drilling and hauling equipment, have resulted in a progressive reduction in the cost of blasting while related mining and construction costs have risen.² The use, handling, and performance of dry blasting agents and slurries vary significantly from conventional dynamites and military explosives. This section will cover those variations and what is currently known of the general properties of these ammonium nitrate-based explosives. It presupposes a knowledge of the basic properties of explosives.

B. General Considerations

The majority of bulk ammonium nitrate-based explosives are classified as blasting agents. A blasting agent has been defined as any material or mixture, consisting of a fuel and oxidizer, intended for blasting, not otherwise classed as an explosive and in which none of the ingredients are classified as an explosive, provided that the finished product, as mixed and packaged for use or shipment, cannot be detonated by means of a No. 8 blasting cap.³ All blasting agents contain an oxidizer and a reducer or fuel. In the dry blasting agent, ammonium nitrate serves as the oxidizer while a carbonaceous fuel,

such as fuel oil, acts as the reducer. For slurries, the ingredients are more varied. Ammonium nitrate is the primary oxidizer, though it is often supplemented by sodium or calcium nitrate or one of the perchlorates. Reducer-fuels may be carbon, sulphur, or a metal. The slurry may also contain other agents to control density, sensitivity, pH, and stability.

Blasting agents undergo a non-ideal detonation. This means that the explosive's detonation properties depend upon the charge size, degree of confinement, and type of priming. The critical diameter, that diameter below which detonation cannot be maintained, is generally several inches for blasting agents. Blasting agents require confinement to detonate efficiently. Blasting agents do enjoy less stringent storage and transportation regulations and are considered much safer than dynamites in that they are insensitive to impact, blasting caps, and heat. The pressure-time histories, which correlate with energy released, are much different for blasting agents when compared to high explosives. Instead of exhibiting a very strong detonation pressure that rapidly decays with time as TNT or other high explosives do, blasting agents have reduced detonation pressures followed by a sustained explosion pressure. This sustained pressure pulse results from the expanding gases produced by the relatively slow aluminum-oxidation reaction and the other large ingredient particles. This must be kept in mind when comparing explosives. Standard tests tend to overrate the high-detonation-pressure explosives. At present only the underwater energy test is able to provide an accurate evaluation of the total energy developed by blasting agents.

Because of their low cost and inherent safety, blasting agents have proven ideally suited for use as bulk explosives that may be poured or pumped into relatively large boreholes: >100 mm (>4 in.). Blasting agents are used in smaller boreholes with adequate results but at present their primary impact is as a bulk explosive.

C. Bulk Dry Blasting Agents

While various explosive formulations of ammonium nitrate and carbonaceous fuel have been developed, the most predominant dry blasting agent is a 94%-ammonium-nitrate, 6%-fuel-oil mixture known as ANFO. This mixture is the least expensive blasting agent used today. The ammonium nitrate used in ANFO is formed into porous prills or pellets, which are lightly coated with a surfactant to reduce caking. The prill's particle size is from -6 mesh to +20 mesh.* Normally, No. 2 diesel or home heating oil is used as the carbonaceous fuel.

As ANFO is a non-ideal explosive, it is difficult to define its explosive properties exactly. These properties are affected by density, charge diameter, confinement, priming, water conditions, and particle size. Generally, ANFO has a density that is less than water. Its detonation velocity varies from 2300 to 4600 m/s (7545 to 15,091 ft/sec). Theoretically, the energy release of ANFO at oxygen balance is 3906 kJ/kg (930 cal/g). Oxygen balance is defined as that condition in which there is sufficient oxygen to oxidize completely all the fuels in a mixture but a condition in which there is no extra oxygen to react with nitrogen to form nitrous oxides. For oxygen balance, 5.5% fuel oil is needed. In practice, ANFO contains 6% fuel oil, resulting in an oxygen negative reaction and a slight reduction in energy. The desirability of this formulation is that it lessens the possibility of forming poisonous nitrous oxides. Yancik's work⁴ provides a detailed analysis of the performance of ANFO based on several variables that affect its blasting performance. He uses detonation velocity and sensitivity measurements to define the efficiency of the detonation reaction and the ease of initiation.

ANFO has been used extensively in all areas of the mining and blasting industry. It has been especially effective in those areas in which easy blasting conditions and large borehole use are prevalent,

* U. S. Standard Sieve numbers.

such as strip mining. The economies introduced by ANFO, though, have caused its widespread use especially as a bulk system. Even in quarrying and other smaller diameter borehole work, ANFO has been used especially as a top load in the borehole.

ANFO can be obtained in several product forms, either as bulk separate ingredients for on-site mixing or as a bulk premixed explosive. The ANFO is stored on site or delivered on site for direct borehole loading. For smaller jobs, premixed ANFO can be obtained in paper, polyethylene, or burlap packages and rigid cartridges. It is easily loaded into the borehole either by pouring by hand or mechanically. Several mechanical systems are available for loading. For larger holes, increased efficiency is possible through bulk loading with both pneumatic units and auger feeds. Both units have the capacity to deliver either premix explosive or to mix just prior to emplacement. By loading pneumatically, either by a pressure vessel or ejector-type system, the efficiency of ANFO is improved in small diameter holes.

By far the primary advantage of ANFO is its low cost. In large blasting operations, producers were able to buy bulk ANFO for as little as 4 ct a pound as late as the early 70's. Since the fuel crisis and the lifting of price controls in October 1973, minimum prices have risen to at least 10 ct/lb. Not only is ANFO inexpensive but it provides good-to-adequate fragmentation for a wide variety of rocks. The product lends itself to bulk loading techniques, which reduce handling and loading time considerably. As a free-flowing explosive, it is able to fill the borehole completely, insuring 100% coupling with the surrounding medium. It has been demonstrated that the efficiency of a given explosive in fragmenting rock depends in part on how well it transmits energy to the surrounding medium. ANFO produces gaseous products, and increased pressure in the explosive cavity results due to the expansion of these gases. This process is considered instrumental in the capability of ANFO to fracture rock.

Despite its excellent characteristics as a blasting agent, ANFO is not without its drawbacks. Its low density requires that more

volume be loaded to get sufficient energy downhole. ANFO is also susceptible to environmental factors, especially moisture. Water tends to desensitize ammonium nitrate prills. If ANFO is left in contact with water too long, it will not detonate. In industry, ANFO is not used in wet holes unless the hole has been dewatered and a dependable external protection is available, such as plastic sleeves placed downhole. This method increases both the time and cost of the operation and increases safety problems and misfires. ANFO is often used as a top load after the water table has been cleared. ANFO also requires protection from water in storage, and the premixed product cannot be stored too long without fuel segregation.

ANFO requires a high-explosive booster for proper initiation. These are usually cast boosters of pentolite, Composition B, or TNT. In large-diameter holes and under adverse field conditions there is a tendency to underprime. In smaller holes it is common for the primer to be a charge of high-velocity explosive of an equal diameter to that of the borehole. To accomplish the same objective in large boreholes, many blasters make it a practice to use a secondary primer of high-energy slurry or dynamite in conjunction with the cast primer. For long charge lengths it is common practice to space cast primers along the length of the borehole. In small holes, heavy-duty detonation cord that runs through the length of the charge before initiating the booster should not be employed because it will tend to compress the surrounding ANFO causing possible misfires.

D. Slurries

The terms "slurry" and "water gel" are used interchangeably, though a water gel is usually considered a slurry that has been cross-linked to provide better water protection. Its consistency is more like rubber than the more fluid slurries. Another confusion that exists is the technical difference between a slurry explosive and a slurry blasting agent. A slurry explosive either contains an ingredient that is by itself classified as a high explosive or is cap sensitive

(No. 8 cap). A slurry blasting agent does not meet either of these two criteria and is therefore under less restrictive storage and transportation regulations. This section will deal only with slurry blasting agents.

Slurries were originally designed to overcome the problems of ANFO and to produce a denser explosive. As mentioned previously, a slurry is essentially a mixture of an oxidizer and a fuel or sensitizer in a liquid medium, thickened with a gum, and gelled with a cross-linking agent. The earliest slurries used Government surplus TNT as a fuel-sensitizer, but the majority of slurries today do not use high-explosive ingredients. Great advances have been made in slurry formulations since they were first introduced. Many different ingredients have been used to produce a variety of slurry formulations as shown in Fig. 1.⁵

To review the main functions of each ingredient in detail would be very complex. In general, the oxidizer-fuel sensitizer reaction is primarily responsible for the energy produced by the explosion. The gelling agent serves to thicken the mixture to insure homogeneity, nonsettling of components, and ease of handling. The cross-linker causes the slurry to set to varying consistency and improves the explosive's protection against water. Water and various organic solvents are used to provide the liquid medium and improve the stability of the explosive. Aerating and gas forming agents are used to increase the sensitivity of the slurry. In less sensitive slurries, it is essential that microbubbles be available in the explosive to insure adequate detonation through hot-spot initiation.

Slurries are also non-ideal explosives. With the wide variety of products available it is difficult to quantify their explosive properties. Slurries differ from dry blasting agents in that they are water-resistant, denser, and usually more energetic on a volume basis. Among individual slurries significant property changes can be achieved through the variation of particle sizes of the oxidizer, particle size and surface coatings of the aluminum, and the amount and type of aerating agent used. Generally, they equal or exceed the properties

Oxidizers

Ammonium nitrate
Sodium nitrate
Nitric acid
Calcium nitrate
Chlorates
Perchlorates

Cross-Linking Agents

Boron compounds
Potassium dichromate
Antimony compounds
Bismuth compounds
Periodates
Litharge

Gelling Agents

Guar gum
(polysaccharide)
Starch
Acrylamide
polymers

Gas Formers

Peroxides
Acetone and creosote
Sodium and
potassium nitrites
Sodium bicarbonate

Aerating Agents

Fibrous pulps and meals
Vermiculite
Resin microballoons
Perlite
Glass microballoons
Cork

Liquid Medium

Water
Ethylene glycol
Formamide

Fuel-Sensitizers

<u>Explosive</u>	<u>Nonexplosive</u>
TNT	Aluminum
PETN	Sugar
RDX	Urea
Pentolite	Ferrosilicon
Composition B	Ferrophosphorus
Guanidine nitrate	Wood pulp
Smokeless powder	Dinitrotoluene
Nitrostick	Hexamine
Alkylamine nitrates	Ethylene glycol
Nitromannite	Fuel oil
	Paraffin
	Coal
	Carbon
	Sulfur
	Lignosulphonates
	Plant fibers and meals
	Glycerin
	Nitrocellulose
	Gilsonite

Fig. 1. Some ingredients claimed to have been used in slurries.⁵

of ANFO relative to the energy available in a given weight of explosive.

With a wide variety of ingredients to choose from, the slurries available on the market today are quite diverse. Aluminized slurries, depending on the amount and particle size aluminum used, are able to achieve extremely high energy outputs. These have proven quite effective in fracturing hard rock such as the taconite found in the Iron Ranges. They have also been used as toe loads or where difficult rock conditions exist. Less energetic slurries have been used as a replacement for ANFO where water is present in the borehole. Recent developments have resulted in the formulation of slurries that will detonate in small diameter holes. These have the potential of replacing most dynamites in operations where small boreholes are preferred. Like ANFO, slurries come in both bulk mix and bagged products. Mixing and pumping units for slurries are quite sophisticated and greatly simplify loading operations.

Slurries have the advantage of being a dense waterproof product, which can be used despite any field conditions that might arise. The higher density and higher energy slurries work well where difficult blasting conditions exist. The increased energy found in slurry has permitted increased spacing between boreholes in blasting patterns. As a free-flowing product, slurry is easy to handle and load, and offers the same coupling advantage that ANFO does. The ability to formulate products with varying detonation properties offers the potential for tailoring an explosive to a particular medium or requirement.

Slurries are more costly than ANFO, especially if an aluminized product is used. Close control must be exercised over mixing and gelling to insure proper product consistency. Like ANFO, slurries require boosting to insure proper initiation. Depending on the degree of sensitivity of the product being used, slurries may require more boosting than a similar ANFO charge. Premixed slurries are not formulated to withstand long storage; therefore they should be used within six months to one year after they are manufactured. Some

premixed slurries will affect various metals and care should be taken to insure that storage containers are compatible.

E. Suggested Precautions

The U. S. Bureau of Mines² suggests that, because blasting agents differ from the high explosives used before by industry, certain precautions should be taken during their use. This list is not final but covers the main considerations.

1. Dry Blasting Agents

- a. Dry blasting agents should not be used in the presence of excessive water unless external protection in the form of a rigid cartridge or a plastic borehole liner is supplied.
- b. Close control must be exercised in ingredient mixing to maximize energy release and to minimize toxic fume generation. A colored dye may be added to the fuel to provide a visual check on mixing.
- c. The charge diameter must exceed the critical diameter, preferably with a good safety margin. The critical diameter is influenced by several conditions, which have been discussed previously. The manufacturer should be consulted to obtain the recommended minimum diameter of a specific product.
- d. Adequate priming is essential. When in doubt, overprime. Heavy priming will partially overcome many unfavorable field conditions.
- e. In marginal situations add boosters up the borehole to assure propagation.
- f. When electric blasting caps are in use, approved equipment should be used for pneumatic loading, and precautions against static electricity should be taken. The use of nonconductive protective plastic tubing increases static electricity hazards by insulating the charge from the ground.
- g. The hazard of ANFO's reactivity with rock, particularly rock with a high sulfide content, should be investigated.

h. Even an oxygen-balanced mixture can produce noxious fumes if inefficient detonation occurs because of water deterioration, separation of ingredients, poor confinement, insufficient compaction, inadequate charge diameter, or inadequate initiation. These conditions also cause poor explosive performance. The use of plastic borehole liners can increase fume production.

i. The low air-gap sensitivity of dry blasting agents makes them susceptible to misfires if the charge column is not continuous.

j. Holes loaded with dry blasting agents should not be allowed to stand for excessive periods after loading because of their susceptibility to water deterioration and segregation of liquid fuels.

2. Slurries

Several of the precautions mentioned for dry blasting agents also apply to slurries.

a. Close control of ingredient mixing is important to insure that the product will detonate properly with the desired properties.

b. Adequate charge diameter and priming are essential and boosters spaced up the borehole are an inexpensive insurance against inadequate detonation.

c. Loading equipment should be designed to avoid metal-to-metal contact even when the most insensitive slurries are being pumped or mixed.

d. Acids or other reactive ingredients in slurries may cause dangerous reactions in rocks. Many slurries do not have these ingredients, but this safety precaution should be kept in mind when new product formulations are used.

e. Noxious fumes may result from inefficient detonation, even in oxygen-balanced mixtures.

f. Low air-gap sensitivity makes some cartridge slurries susceptible to misfires if the charges are physically separated after loading.

g. The sensitivity of some slurries, particularly sugar slurries or other low-energy types, is seriously impaired by low temperatures and would require additional boosting.

h. Depending on their sensitizing system, some slurries have an increased sensitivity at high temperatures and at high altitudes.

i. Premixed slurries should be used on a first-in, first-out basis.

j. If extreme conditions of temperature arise the explosive manufacturer should be contacted to determine how his product will be affected and what remedial actions are appropriate.

F. Summary

Dry blasting agents and slurries are presently the most widely used explosives in industry today. These explosives differ from conventional high explosives in their safety and handling characteristics. They are non-ideal explosives whose performance depends primarily on charge diameter, degree of confinement, and priming system employed. Because of this, standard comparative explosion and performance properties are not available at this time. They are free-flowing bulk explosives that lend themselves to rapid mechanical loading techniques and couple well with the surrounding medium. The primary dry blasting agent is ANFO, a mixture of 94% ammonium nitrate and 6% fuel oil. ANFO is very inexpensive and has proved efficient in many applications. Slurries encompass a wide variety of products, which offer denser, more energetic, formulations. By changing the ingredients, their particle sizes, and the sensitizers, the explosive properties of the resulting slurry can be varied considerably. The Bureau of Mines has suggested certain precautions in the use of these blasting agents that are helpful to the field user.

SECTION III. EXPLOSIVES USED IN EERL PROJECTS

A. Scope

This section deals with the various explosives that have been used by EERL on specific projects. Each explosive will be described in some detail, as will the medium in which each was detonated. Only brief reference will be made to the particular projects. For rapid reference the explosives used to date are shown in Table 1. In referring to this table one must realize that explosives costs may be inflated due to the explosives being procured by a contractor or by limitations imposed by the contract specifications. The specific properties of the different explosives used are listed in Table 2.

B. Dry Blasting Agents

The only dry blasting agent used by EERL to date has been ANFO. Several commercial products have been used, each consisting of 94% ammonium nitrate and 6% fuel oil. No difference was noted in using the products of the various manufacturers. All ANFO detonations were loaded either by pouring the ANFO downhole by hand or by a truck-mounted pumping unit. The hole sizes used in the projects described below ranged from 254 to 762 mm (10 to 30 in.) in diameter. No problems were encountered in using ANFO either in the loading of the holes or in the ANFO itself. There was no evidence of oil segregation or caking.

The first EERL use of ANFO was in the excavation of two railroad cuts at the Trinidad Dam and Lake Project, Trinidad, Colorado.⁶ The first detonation was a mounding shot in which the material was broken in place. A total of 9071 kg (10 tons) of ANFO fragmented an estimated 6880 m³ (9000 yd³) of rock. The second detonation was designed as a cratering excavation. It involved 62.1 Mg (68.5 tons) and excavated a total to 21,400 m³ (28,000 yd³) of material. The boreholes used on these two projects ranged from 305 to 914 mm (12 to 36 in.) in diameter.

Table 1. Explosive data chart.

Explosive	Manufacturer	Project	Explosive/ booster	Cost ^a	Rock type	Excavation design
ANFO	Phillips 66	Trinidad	Dry blasting agent/cast	~\$0.09/lb	Sandstone/ shale	Railroad cuts, RR-2, 3
ANFO	Du Pont	Lost Creek	Dry blasting agent/cast	~\$0.10/lb	Basaltic andesite	Model spill- way cut
ANFO	Austin Powder Co.	R. D. Bailey	Dry blasting agenc/cast	~\$0.06/lb	Shale and sandstone	Spillway
DBA-22M	IRECO	Pre-Gondola II, Phase III	Aluminized slurry/cast	~\$0.21/lb	Bearpaw clay shale	Channel connector
TD2	IRECO	Trinidad	Aluminized slurry/cast	~\$0.21/lb	Sandstone/ shale	Railroad cut, RR-1
Iregel 435	IRECO	Labby	Aluminized slurry/cast	~\$0.42/lb	Siliceous argillite	Sidehill road cut
MS-80-20	Dow Chemical	Tugboat	Aluminized slurry/cast	~\$0.26/lb	Coral	Harbor
MS-80-10	Dow Chemical	Armor Obstacle II	Aluminized slurry/cast	~\$0.17/lb	Bearpaw clay shale	Road craters
MS-80-25	Dow Chemical	R. D. Bailey	Aluminized slurry/cast	~\$0.28/lb	Shale and sandstone	Spillway
Diamond Ore	Dow Chemical	Diamond Ore, Phase II A	Aluminized slurry/cast	~\$0.42/lb	Bearpaw clay shale	Craters
Slurran 615	Gulf Oil	Drum Inlet	Aluminized slurry/cast	~\$0.165/lb	Saturated sand	Channel plug
Trojel WS-7	Trojan Powder	Lost Creek	Nitrostarch slurry/cast	~\$0.35/lb	Basaltic andesite	Model spill- way cut
Zerite	Oriard Powder	Lost Creek	Sulfur slurry/cast	~\$0.45/lb	Basaltic andesite	Model spill- way cut

^aCosts based on contract costs and on amounts used on project.

Table 2. Explosive properties chart.

Explosive	Density g/cm ³	Detonation velocity, ^a m/s	Detonation pressure, GPa	Energy, ^a kJ/kg	Primary ingredients ^b
ANFO	0.85	4560	6.0	3738	AN #2 diesel fuel oil
DBA-22M	1.5	5000	8.1	8190	AN, SN, H ₂ O 30% Al
TD2	1.35	4450	7.5	6300	AN, SN, H ₂ O 18% Al
Iregel 435	1.2	3904	- ^c	2743 ^d	AN, SN, H ₂ O Al/O ₂ = 0.14
MS-80-20	1.56	5700	8.5	6090	AN, SN, H ₂ O 20% Al
MS-80-10	1.3	4660	- ^c	3410	AN, H ₂ O 10% Al
MS-80-25	1.1	4783	3.197	5586	AN, SN, H ₂ O 22.5% Al
Diamond Ore	1.64	4700	8.0	5926	AN, SN, H ₂ O 30% Al, 10% sand
Slurran 615	1.38	4300	- ^c	2730 ^d	AN, H ₂ O perchlorate 8-15% Al
Trojel WS-7	1.22	4923 ^e	12.0	3360 ^f	AN, H ₂ O wet nitrostarch
Zerite	1.34	3660 ^e	6.5	4305	AN, SN, S, H ₂ O

^a Measured. ^b AN - Ammonium nitrate; SN - Sodium nitrate; H₂O - Water; Al - Aluminum; O₂ - Oxygen. ^c Unknown. ^d Gas bubble energy only. ^e Minimum confinement. ^f Theoretical.

The media involved in the Trinidad projects were termed interbedded sandstones and shales, which were classified as weak-to-intermediate-strength rock. The bedding was thin-to-massive and tended to be very lenticular and irregular. The sandstone was highly friable and contained carbonized plant remains. The shale was mostly nonfissile and had a wide range of sand and carbon content. The rock tended to be moderate-to-highly fractured. The unconfined compressive strength of the intact rock ranged from 3102 kPa (450 lb/in.²) for the shale to 54,900 kPa (8000 lb/in.²) for the sandstone. The degree of saturation ranged from 58.3 to 99.6%, with an average of about 78%. The average in situ density of the rock was 2503.9 kg/m³ (156.3 lb/ft³).

ANFO was also used in a spillway modelling project at Project Lost Creek, in Oregon. This project included a number of detonations to determine which of three candidate explosives performed best in a mounding configuration. ANFO proved best and it was used to excavate a model spillway cut in conjunction with controlled blasting techniques. In all, a total of 1497 kg (3300 lb) was used to excavate approximately 6270 m³ (8200 yd³) of rock.

The rock involved in Project Lost Creek was a fine-grained, dense, porphyritic igneous rock. It had the appearance of a basalt, but was classified as basaltic andesite. The rock was characterized by columnar jointing and an extensive network of fracturing with no apparent preferred orientation. The average unconfined compressive strength was 220 MPa (32,420 lb/in.²). The rock had a natural moisture content of 0.8%, and an apparent specific gravity of 2.70.

ANFO was also used at Project R. D. Bailey, a pilot excavation in sandstones and shales in West Virginia. A total of 12,784 kg (28,183 lb) was detonated in 76-mm (3-in.), 160-mm (6 1/4-in.), 170-mm (6 3/4-in.) and 225-mm (9-in.) holes. Cast boosters were used for initiation. A complete description of the geology encountered is presented in Section III C. 6.

C. Slurries

1. DBA-22M

DBA-22M is an aluminized slurry produced by IRECO Chemicals. This dense blasting agent is a high-energy aluminized slurry. The aluminum is specially treated by a coating material to produce an artificial lyophobic surface. This process is performed to increase the aluminum's normal repellency to the liquid solvent. This explosive contains 30% aluminum consisting of a mixture of finely divided metal, 90% passing through 100 mesh, and coarse metal of 4 to 10 mesh. Thus, the quantity of metal and its surface condition effectively create substantial increases in the detonation properties of the total composition. The oxidizer in this case is primarily ammonium nitrate and sodium nitrate, while small quantities of various nitrates, chlorates, perchlorates, or sulfur are present depending on the formulation. (U. S. Patents 3282752, 3249474, 3121036.)

DBA-22M was tested by EERL in a series of small-scale cratering tests: 3.6 kg (8 lb) at the Livermore test site⁷ and in medium-scale cratering tests: 227 kg (500 lb) at Fort Peck, Montana.⁸ These tests indicated that this slurry was an outstanding cratering explosive, outperforming all others tested. As a result, DBA-22M was used in the Pre-Gondola III, Phase III reservoir connection at Fort Peck, Montana, in the fall of 1969.⁹ This project involved excavating a channel to connect the Fort Peck reservoir with previously excavated interconnected row craters. Five charges in a row – a total of 63.5 Mg (70 tons) of explosive – were used to produce a crater approximately 120 m (400 ft) long, 46 m (150 ft) wide, and 7.6 m (25 ft) deep at the centerline. The explosive was pumped into boreholes ranging from 1676 to 2591 mm (66 to 102 in.) in diameter.

The material at Fort Peck is Bearpaw shale. The shale is uniform, dark gray, highly compacted, and uncemented. Weathering extends to depths of 3 to 6 m (10 to 20 ft), and the rock is highly fractured near the surface. The unbroken unweathered shale is essentially impervious. Water content ranges from as much as 30% near the surface to a consistent 16 to 18% at depth. The shale is

generally 100% saturated. The unweathered material has an unconfined compressive strength of less than 2060 kPa (300 lb/in.²), a specific gravity of 2.15, and a compressional wave velocity of approximately 1981 m/s (6500 ft/sec).

DBA-22M was also used in Project Poke Holes in 1973 at Fort Polk, Louisiana. Cratering performance tests were conducted using various explosives in 227-kg (500-lb) charges buried at optimum depth of burial. These detonations were in a silty or sandy soil with a water table near the surface.

2. TD2

TD2 is another IRECO aluminized slurry that has been used by EERL. It is basically a formulation of the products listed for DBA-22M. The major difference is a reduction in the amount of aluminum from 30 to 18% with a corresponding reduction in density and other detonation properties (U. S. Patent 3249474).

TD2 was used by EERL in 1970-71 on the Middle Course II experimental cratering series and on the D-4 railroad cut in conjunction with the previously mentioned Trinidad Dam and Lake Project, near Trinidad, Colorado.⁶ Two parallel rows of charges were used to excavate a 122-m (400-ft) cut. A total of 39.9 Mg (44 tons) of explosive in 32 separate boreholes excavated some 13,760 m³ (18,000 yd³) of material. Hole diameters varied from 760 mm (30 in.) with full diameter drilling to 910 mm (36 in.) with underreaming, and were loaded by a slurry mix truck. The medium for this project was the same interbedded sandstone and shale that was described in Section III. B.

3. Iregel 435

A third IRECO slurry that has been used by EERL is Iregel 435. This particular slurry, while containing the same basic ingredients as the other IRECO slurries mentioned, has benefited from improved research in gelling agents and water content. Iregel has lowered the minimum water requirement by an improved thickening and gelling

process resulting in better strength. The ratio of aluminum to available oxygen for this explosive is 0.14. Total energy is approximately 4769 kJ/kg (1140 cal/g).

Iregel 435 was used on a portion of a road cut in conjunction with the Libby Dam Project, Libby, Montana, in the spring of 1972. The detonation involved some 4040 kg (8900 lb) of explosive.¹⁰ Emplacement holes were 101 mm (4 in.), 127 mm (5 in.) and 229 mm (9 in.) in diameter. The medium at Project Libby was not investigated extensively but was generally classified as a siliceous argillite.

4. MS 80-20

MS 80-20 is a high-energy aluminized slurry manufactured by the Dow Chemical Company. Dow deals primarily in oxidizer-metal explosives, and this represents one of their series of slurries with varying aluminum content. This explosive contains 20% aluminum. The primary oxidizer is ammonium nitrate; to increase its density and sensitivity significant amounts of sodium nitrate and perchlorate have been added.

MS 80-20 was used to excavate a planned small boat harbor on Project Tugboat, conducted in Kawaihae Bay, Island of Hawaii, State of Hawaii, in 1970.¹¹ A total of twelve 9071-kg (10-ton) charges were detonated to create a berthing basin and entrance channel in a coral reef that was overlain with a water layer averaging approximately 1.8 m (6 ft) in depth. The explosive was detonated in 914- to 1727-mm (36- to 68-in.) holes. The explosive was pumped downhole into cylindrical cylinders made of steel conforming to Federal Specification QQ-S-698 and AM-2. When initiated properly, this slurry performed extremely well. Some misfires prompted a change in initiating systems for slurries and dry blasting agents as discussed later.

The Kawaihae coral reef had undergone no secondary calcification or cementation, and was characterized by loosely bound, interlocking, shrub-like branches. The material was soft (for rock), easily crumbling under small loads. It had an unconfined compressive

strength of 7445 kPa (1080 lb/in.²) and an average bulk specific gravity of 1.37. Its water content ranged from 22.5 to 38.4%.

5. MS 80-10

MS 80-10 is another of Dow's aluminized slurries. It contains 10% -40 mesh aluminum. Oxidizers were both ammonium and sodium nitrate, while the liquid phase was water and organic solvents. This explosive was formulated to achieve a higher density than Dow usually uses for their products, resulting in a lower total energy than was expected. The explosives were emplaced in their plastic cartridges in boreholes ranging from 203 to 762 mm (8 to 30 in.). Additionally, this explosive was stored and performed satisfactorily in temperatures below freezing 266 to 272 K (20 to 30°F).

MS 80-10 was used by EERL in some of its military cratering test programs to evaluate its use in small-scale road cratering tests. Charges ranged in size from 109 to 1360 kg (240 to 3000 lb). These tests were conducted as part of Project Armor Obstacle II at Fort Peck, Montana.¹² The Bearpaw clay shale found at this site is covered extensively in Section III. C. 1.

6. MS80-25

A third aluminized slurry from Dow, MS 80-25, was used on Project R. D. Bailey conducted in West Virginia in 1973.¹³ Basically, this was a mixture of an ammonium nitrate, sodium nitrate, and aluminum (22.5% by weight) with 20% water and other organic liquids. The explosive was delivered in plastic sausages, which were slit prior to loading. Cast boosters were used to initiate the explosive. A total of 28,649 Mg (63,160 lb) of MS 80-25 was used.

The project involved drilling and blasting coupled with controlled-blasting techniques to provide a pilot spillway excavation

at the R. D. Bailey Lake Project on the Guyandot River. Emplacement hole sizes were 77 mm (3 in.), 171 mm (6-3/4 in.), 228 mm (9 in.) and 311 mm (12 1/4 in.) in diameter.

The R. D. Bailey project site is located in the maturely dissected Kanaw Section of the Appalachian Plateau physiographic province. The generally flat-lying sedimentary rocks have been strongly eroded to produce a geomorphically mature topography. The bedrock in the upper Guyandot River basin is composed of nearly flat-lying sedimentary rocks, predominantly sandstones and shales, with some coals and underclays. The mineralogy of the sandstone includes quartz, mica, feldspar, chlorite, and kaolinite; that of the shales - illite, quartz, kaolinite, with minor chlorite and feldspar.

MS 80-25 was also used in Project Poke Holes in 1973 at Fort Polk, Louisiana. This project was a cratering comparison experiment. Charge size was 227 kg (500 lb); an optimum depth of burial was used.

7. Diamond Ore Slurry

The Diamond Ore slurry was a special slurry developed by Dow for use as a modeling explosive for nuclear weapons simulation. The ultimate aim was to have a slurry explosive that could detonate reproducibly enough so that it could be characterized by an equation of state.¹⁴ The slurry selected was an ammonium nitrate, aluminized slurry. The aluminum was given special surface treatment, while the particle sizes of the ammonium nitrate were rigidly controlled. Additional ingredients were used to give the slurry rigid density control. Unfortunately, operational requirements forced the abandonment of the program before a final equation of state was developed. The program did serve to illustrate the difficulty of trying to characterize a non-ideal explosive with its various time-dependent reactions.

Diamond Ore slurry was used during the fall of 1971 in a series of three 9071 kg (10-ton) cratering detonations in conjunction

with Project Diamond Ore II. These shots were in the Bearpaw clay shale previously characterized. The slurry was pumped into 914-mm (36-in.) diameter boreholes. The average crater was 9.1 m (30 ft) deep and 36.6 m (120 ft) in diameter.

8. Slurran 615

Slurran 615 is an aluminized slurry produced by the Chemical Division of Gulf Oil Company. It contains 8 to 15% aluminum and small amounts of perchlorate explosive to increase sensitiveness. Slurran 615 was used to excavate a 114-m (375-ft) plug to complete a dredged channel into the Atlantic Ocean from Drum Inlet on the coast of North Carolina.¹⁵ The cut was 24.3 m (80 ft) wide. The material excavated was a saturated sand. The explosive was placed in 16-gage sheet metal cylinders 610 mm (24 in.) in diameter. Twenty-two 907-kg (1-ton) charges were used. When exploded in seawater, the Slurran 615 tended to produce large quantities of brown smoke, indicating that nitrogen oxides had been formed. Such a result generally means that the detonation was inefficient.

9. Trojel WS-7

Trojel WS-7 was a slurry explosive produced by the Trojan U. S. Powder Company. This explosive was sensitized with wet nitrostarch and uses both ammonium and sodium nitrate as its oxidizers. The use of nitrostarch gives this slurry relatively high detonation velocity and pressure, though the available energy is lower than aluminized slurries.

Trojel WS-7 was used at Project Lost Creek,¹⁶ as described earlier in Section III, B. This slurry was loaded by hand in 254-mm (10-in.) boreholes. Preliminary results indicate that it was not as efficient as ANFO in fracturing the basaltic andesite in place. It did, however, outperform Zerite, which is described below.

19. Zerite

Zerite was a slurry explosive produced by the Oriard Powder Company. This explosive consisted primarily of ammonium and sodium nitrate with 20% water and organic solvents. The sensitizer used in this slurry was sulfur. In addition, the ammonium nitrate used in the mix was coated with wax, which served as a fuel for the explosive. This slurry was hand-loaded into 250-mm (10-in.) bore-holes.

Zerite was the third explosive used at Project Lost Creek, and it performed the poorest of the three explosives in fracturing the rock in place. It was anticipated that an aluminized high-energy slurry would be provided for this project. Zerite did not meet the performance specifications of the project in terms of total explosive energy produced.

1i. Miscellaneous

a. In 1969 a small-scale test program was initiated at the Lawrence Livermore Laboratory high-explosive test facility to evaluate the cratering performance of a number of commercially available chemical explosives with emphasis on those containing ammonium nitrate. Explosives were selected on the basis of cost, availability, energy content, ease of emplacement, and safety and handling limitations. The explosives and their properties are listed in Table 3.⁷ Tests were conducted in a firing pit consisting of fine, well-graded sand with about 4% moisture content. Sand density was held at $1954 \pm 32 \text{ kg/m}^3$ ($122 \pm 2 \text{ lbs/ft}^3$). Charge size varied from 3.6 to 5.89 kg (8 to 13 lb) at various depths of burial.

b. Four slurries designed by Hercules Inc. were tested in Projects Raystown and Poke Holes. These consisted of an ethylene glycol mononitrate, water, and oxidizer salt base with varying amounts of aluminum. Project Poke Holes was conducted in the fall of 1973 at Fort Polk, Louisiana, in a sandy, silty soil with a near-surface water table. Project Raystown was conducted in sedimentary soils near Huntington, Pennsylvania, in the spring of 1973.

Table 3. Site 300 explosives data.⁷

Name ^a	Mfgr.	Density g/cm ³	Detonation pressure, GPa	Detonation velocity, m/s	Heat of detonation, kJ/kg	Gel	Contains aluminum	HE sensitized
MS-80-20	Dow	1.20	8.5 ^b	5700	6090	Yes	Yes	No
ANFO	Du Pont	0.93	6.0 ^b	4560	3738 ^b	No	No	No
Pourvex	Du Pont	1.40	9.9	5850	3150	No	No	Yes
Pourvex Extra	Du Pont	1.40	9.6	6040	2982	No	No	Yes
Pourvex 10% Al	Du Pont	1.40	9.0 ^b	4900	4830 ^b	No	Yes	Yes
Pourvex 20% Al	Du Pont	1.40	8.5 ^b	4700	6090 ^b	No	Yes	Yes
Tovex	Du Pont	1.40	10.4	6050	3066	No	No	Yes
DBA-30	Ireco	1.30	6.0 ^b	4300	3150	Yes	Yes	No
DBA-38	Ireco	1.33	6.6	4500	4662	Yes	Yes	No
DBA-22M	Ireco	1.50	8.1	5000	8190	Yes	Yes	No

^aCommercial trade name.

^bEstimates.

Both experiments involved explosive cratering performance tests.

D. Initiation

As mentioned in Section II, blasting agents are not cap-sensitive and require high-explosive boosters for detonation. The qualities of a good primer are (1) a sufficient high-energy content so that it will release a large quantity of heat quickly, and (2) a high-speed shock effect to insure hot spot compression. The primer should be sensitive to detonation-cord or cap initiation and should be immune to its environment. Lastly, it is desirable that the booster diameter should be approximately equal to that of the main charge. This last requirement is due to the experimental observation that in some charges when small-diameter boosters were used the charge did not fully detonate. This was attributed to the lateral expansion losses of the expanding detonation front being so great that the detonation eventually failed because the ANFO was overly compressed.¹⁷

Current commercial boosters are primarily cast explosives ranging in size from 151 g (1/3 lb) to 2.2 kg (5 lb) with the 454-g (1-lb) size being most prevalent. The 1-lb booster is cylindrical with a diameter of 63.5 mm (2.5 in.) and a 101-mm (4-in.) height.

Except for the Diamond Ore shots, where Composition C4 was molded into a booster due to the spherical nature of the shot cavity, EERL has used commercial cast boosters. This experience has been primarily with relatively large-diameter charges: 203 mm (8 in.) to several feet. Initially, the boosters were placed equidistant along the cylindrical charge axis. After the misfire problems that were encountered with this method during Project Tugboat, full-column boosting along the axis has been used. This booster is made by stringing a series of cast boosters along a detonation cord and placing this through the middle of the charge column. No misfires have resulted. For smaller diameter holes, the practice has been to boost at the bottom of the hole, preferably with a booster that is equal to the charge diameter. The explosive manufacturer should be consulted if adverse conditions arise. The standardization of good initiating practices is

one of the many areas that needs research in the use of blasting agents.

E. Future Research Areas

Continued research is planned in the use of bulk explosives. Additional data will be gathered on the properties of these explosives. Data will be collected on the dependence of the energy release of bulk explosives on field conditions, such as handling and loading procedures, hole size, environmental conditions, and initiation procedures. Field tests will be conducted in conjunction with the EERL experimental excavation projects to provide comparative data on bulk explosive effects in terms of rock fragmentation and excavated volume. The end product of this study should be a source book for Corps of Engineer use that will provide guidance on the use of bulk explosives on Corps projects.

F. Summary

The blasting agents used by EERL represent a small sample of the type of products on the market. They have been used in several media and most often in larger size boreholes. Bulk systems and packaged products have been used, and both are easily handled and transported.

SECTION IV. EXPLOSIVES PROCUREMENT

A. Scope

The explosives covered in Section III were procured by several different methods and the use of various techniques for writing specifications. No method has been devised to insure that an explosive with desired properties will be obtained for a specific project. This Section will cover the problem areas involved in specifying explosives in a construction contract. As we continue to gain experience we are able to avoid or minimize these problem areas. It is hoped that those

who follow can learn from these experiences and add to them in refining the knowledge in this area.

B. Methods of Procurement

Three general methods have been used to procure explosives for experimental work. One method is writing explosive specifications into the contract being let under competitive bidding and having the explosive contractor provide a suitable explosive. Another method is to contract only for explosives. This also requires writing explosive specifications. The third method is to buy explosives on a sole source basis.

1. Sole Source

This procurement method is usually the preferred method when a specific explosive is needed, because it allows for the outright purchase of the explosive desired. Sole source procurement is not applicable to many of the larger scale projects that have been and will be conducted. It has been used primarily to secure explosives for small-scale tests or for comparison tests. Sufficient justification is required before a sole source contract is permissible. Whenever appropriate, however, this method should be considered as it is the only method available for getting a specific explosive.

2. Explosives Contract

Of the two competitive bidding methods for procuring explosives, an explosives contract has been the most effective. The bidders are explosive manufacturers who are intimately familiar with the terms of the specifications, which of their products meet these specifications, and what modifications can be made to any of their off-the-shelf products to meet the specifications. Thus it is possible to procure an off-the-shelf or modified off-the-shelf product that meets the contract requirements. This type of contract can also be used to provide samples of the explosive for independent testing, and to

enable the manufacturer to provide and to certify specific property and performance tests of the explosive. Another important feature to the researcher is that this contract provides direct communication with the explosives manufacturer. This has proved invaluable in the past when difficulties or questions arose.

3. Construction Contract

Procuring explosives in this manner places the burden of selecting the explosive on the contractor who is responsible for the entire operation. While he has the explosive specifications to guide him, he usually has dealt with one or two firms in the past and will go to these, or he tries to use the explosive company that is closest. Such action has led to problems in that either the explosives obtained do not meet specifications, or in that there is pressure to accept products that have been obtained at the last minute in order not to delay the overall project. Another drawback of this method is that we have no direct dealings with the explosive manufacturer should we desire additional information. While this problem is not severe, it can limit direct communication. One of the advantages is that everything is handled with one contract, and the contractor has full responsibility for all explosives operations including the problem of getting rid of excess explosives.

C. Explosives Specifications

1. General

No matter which method is selected to procure explosives for a project, the key to getting what is wanted is to ask for it; this is much easier said than done. The most difficult problem is deciding what is needed. The data bank contained in Section III and an investigation of the products being used in other excavation and mining sites near the project area should provide a good starting point. Assuming this is done, you can write specifications that are geared to the particular set of properties desired.

2. Product Specifications

It is possible to write specifications so that a particular product or products, or their equivalent, are specified. Generally, the specification is written to read: Product A, Product B, or equivalent. Some criteria for the equivalence should be specified. One possibility is that the contracting officer would have to approve an equivalent, or a set of performance properties would have to be equalled or exceeded.

When a particular explosive or explosives seem best-suited for a project, or when explosive comparison tests are being conducted and sole source supply cannot be justified, this method of presenting specifications may be preferred. Care must be taken, however, to insure that what constitutes an equivalent explosive is carefully defined.

3. Performance Specifications

The writing of performance specifications is more difficult. Performance specifications should give a range of values for the different properties desired and be realistically based on previous knowledge of the explosives available.

Generally, the properties that can be specified include density, detonation velocity, detonation pressure, explosive energy, environmental stability, allowable ingredients, and specifics concerning performance in property or safety tests. The first four properties are generally the most important in determining the type of explosive that will be supplied. Density specifications are generally used either when an explosive heavier than water is required, or a dense product is required to maximize explosive charge in each borehole. The detonation velocity and pressure are related in that high-velocity explosives tend to have higher detonation pressures. Energy constraints are usually used when it is believed that higher energy products are required due to hardness or some other property of the rock. Experimentally, the energy specification might be

required to obtain several products with different energies for comparison purposes.

It is usually desirable, when specifying performance characteristics, to give a range of values or to specify that the explosive property will exceed a designated fixed value. It is difficult to say exactly how large the range should be, but generally the lowest acceptable value is chosen for the low end. This is because, in competitive bid contracts, the manufacturers tend to meet minimum specifications to be most competitive. A second consideration in writing performance specifications is to specify whether the explosive property values are to be determined theoretically or experimentally. Usually experimental results are required because these are more in line with what can be expected of the explosive on the actual job. Both the experimental tests and results are usually required from the explosive manufacturer.

Several other techniques are available for writing performance specifications, depending on the planned use of the explosive. If climatic conditions are extreme, specifications should be included to insure that the explosive will function at those extremes. In this same vein any constraints on the explosive used on-site can be used in the specifications. These constraints include such things as wet boreholes, fixed diameter boreholes, prolonged storage, or limited priming explosives. If it is not desirable to use certain explosives, then these may be eliminated by using ingredient specifications or excluding certain Department of Transportation explosives classes. By specifying only certain ingredients or classes of ingredients that can be used, it is possible to control the type of products that will be obtained.

Another essential specification is a requirement that the manufacturer provide all data concerning safety and classification tests performed on the explosive. These are required to assure that use, storage, and transportation of the explosive are in accordance with existing state and local regulations. If the explosive is not classified by Department of Defense regulations and is expected to be used

on DOD land or in a military program, this information is essential in seeking an interim classification. No matter what type of specification is written, safety and classification test data should be required.

D. Summary

The writing of explosives specifications for use at EERI has been a continuing search for the best methods of getting the product required for a job, yet insuring that all available explosive products are considered. Three general methods for accomplishing this have been sole source supply, product or equivalent specifications, and performance specifications. The method used depends on the explosive required and the work to be performed. Several examples of explosives specifications are contained in Appendix A.

For the writing of explosive specifications, the best advice is that the specifications should include whatever the job requires. This applies to specifications for explosive performance, external constraints, and any data that are required for experimental programs or studies. Safety data should also be required. If doubt exists as to the possibility of having too stringent a set of specifications, several explosive manufacturers should be contacted to see whether they can provide products that meet the specification. Proper explosives specifications will insure that the right explosive is used on the job.

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APPENDIX A

EXAMPLE EXPLOSIVES SPECIFICATIONS

A. Introduction

This appendix contains extracts from two contracts used to obtain explosives. One is a product specification, and the second is a performance specification. They are presented merely as illustrations of the techniques described in Section IV. They are now somewhat out of date and are not intended to be examples to be copied. Persons interested in assistance in the preparation of explosive specifications should contact the Waterways Experiment Station Explosive Excavation Research Laboratory.*

B. Product Specifications

These specifications were used on Project R. D. Bailey in West Virginia in 1973:

1. ANFO

ANFO will be a commercially available, homogeneous mixture of prilled ammonium nitrate and No. 2 fuel oil, such as ANFO-HD or equal.

2. Slurry

The slurry blasting agent shall be Dow MS-80-25 or equal and a commercially available product. The slurry may contain the following components: ammonium and/or sodium nitrate and/or perchlorate, water, solvents, gelling or cross-linking agents, stabilizing agents as required for storage and water resistance, and sensitizers as required for complete detonation using the

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specified boosters. The slurry will contain at least 5% by weight of aluminum granules, powder, or flakes (particle size shall not exceed 0.5 mm, or 40 mesh, in its smallest dimension).

The slurry shall be capable of complete detonation in boreholes of 3 to 12 in. in diameter using the booster system specified under "Boosters" below, after being emplaced for a period of 3 days at temperatures ranging from 10 to 80°F. The blasting agent, its components, and its detonation products shall be sufficiently non-toxic and nonirritant that they do not present any undue hazard to personnel engaged in explosives handling and emplacement. Special safety equipment for personnel must not be required.

C. Performance Specifications

These specifications were used for a proposed project in Alaska in 1973.

1. Slurry

a. Composition - The slurry blasting agent may contain the following components: ammonium and/or sodium nitrate and/or perchlorate, aluminum, water, solvents, gelling or cross-linking agents, stabilizing agents as required for storage requirements and water resistance, and sensitizers for complete detonation using the specified boosters while the subject to the environment prescribed. The explosive will contain at least 10% by weight of aluminum granules, powder, or flakes; particle size shall not exceed 0.5 mm or 40 mesh in its smallest dimension.

The blasting agent components and the resulting mixture shall fall under only the following classifications (DFR Title 49, Part 146.04-5): Explosive B, oxidizing material, hazardous article, inflammable liquid, and inflammable solid. Additives classified as Explosive A by the CFR Title M, Part 146.20-7 are not permitted except by the express permission of the contracting officer.

The slurry shall be capable of complete detonation in 18-in. holes using the booster system specified under "Boosters" below

after being in place for a period of 7 days at temperatures ranging from 20 to 70°F. The slurry must be capable of storage in outdoor magazines where ambient temperatures will range from -40 to 70°F. While freezing of the slurry is not objectionable, it must be capable of returning to a workable consistency when heated to the expected emplacement temperatures (0 to 70°F). Any freezing and thawing cycle should result in no changes in explosive performance, workability, water resistance, and sensitivity to detonation. The blasting agent, its components, and its detonation products shall be sufficiently nontoxic and nonirritant as not to present any undue hazard to personnel engaged in explosives handling and emplacement. Special safety equipment for personnel must not be required.

The slurry may be site-mixed, delivered by mixing and/or pumping trucks, or delivered in prepackaged sausages weighing between 40 and 60 lb. Packaging material must be such that it is unaffected by temperatures down to -40°F.

b. Performance Specification – The performance specifications of the slurry blasting agent are as follows:

(1) Bulk Density – The density of the formulated mixture shall be 1.2 g/cm³ or greater at standard temperature and pressure.

(2) Detonation Velocity – The detonation velocity of the blasting agent shall be greater than 3500 m/sec (confined velocity).

(3) Total Energy – The total energy of the blasting agent will be greater than 1100 cal/g, this to be determined experimentally.

2. Blasting Caps

The blasting caps will be electric, No. 6 or better, with 30-ft leads.

3. Boosters

The boosters will be high-strength, water-resistant, non-nitroglycerin explosives, such as 50/50 pentolite or the equivalent. The boosters shall have a through hole to accept plastic reinforced detonating cord. The booster will also have a cap well to accept a blasting cap.

4. Detonating Cord

The detonating cord will be a 54-grain PETN core plastic reinforced primacord such as that manufactured by Ensign Bickford Co., or the equivalent.

5. Explosives Quality Control

The explosives supplier shall establish and maintain quality control including, but not limited to, furnishing the contracting officer two copies of the manufacturer's declaration, which will include the following:

a. Performance

- (1) Confined detonation velocity (m/sec)
- (2) Detonation pressure (kbar)
- (3) Density (g/cm^3)
- (4) Total energy (cal/g) (both calculated and experimental).

The contractor shall also furnish a description of the manufacturer's procedure for determining the above data.

b. Composition

- (1) Amount and type of oxidizer
- (2) Amount and type of liquid vehicle
- (3) Amount of aluminum, fuel, or sensitizer
- (4) Amount and type of gelling agent and stabilizer
- (5) Amount and type of other ingredients such as cross-linking agents using general descriptions
- (6) Oxygen balance

c. Safety – The contractor will supply all safety data from the manufacturer:

- (1) Impact sensitivity
- (2) Thermal stability
- (3) Spark sensitivity
- (4) DOT class
- (5) Compatibility

6. Information for Environmental Impact from Explosives Excavation.

In addition to the disruption of the ground in the blast area, and the accompanying noise, dust, airblast, and ground shock, the products of the explosive are released to the atmosphere. The type of products produced depend on the compounds used in the explosive, the environment in which the explosive is placed, and the condition of the explosive itself. Of paramount importance is the oxygen balance of the explosive.

The term, oxygen balance, is meant to denote the amount of oxygen available to react in the explosive. Zero oxygen balance is defined as the point at which there is sufficient oxygen to completely oxidize all the fuels in the mixture, but the point at which there is no excess oxygen to react with the nitrogen in the mixture to form nitrogen oxides.

The explosives planned for use on this project are formed mainly from the elements of carbon, hydrogen, nitrogen, and oxygen. Generally, the only other primary ingredient is sodium or fine aluminum particles. Trace amounts of other materials such as silicon, chromium, zinc, or potassium may also be used to help stabilize, sensitize, or preserve the gel. The explosives will not contain any ingredients that are classified as Class A explosives. The blasting agent, its components, and its detonation products shall be sufficiently nontoxic and nonirritant so as not to present any undue hazard to personnel engaged in explosives handling and emplacement.

Upon detonation, the gases produced will be primarily CO_2 , H_2O , and N_2 , with small traces of NO , CO , NH_3 , CH_4 , and traces of other combinations of the elements involved. If aluminum is present it will

react with oxygen to form aluminum oxide. Sodium also reacts with oxygen to form sodium oxide. If the explosive is oxygen-poor, less CO_2 is formed and more CO and C are developed. If too much oxygen is present, oxides of nitrogen are present.

Both CO and the oxides of nitrogen are poisonous if taken in large enough quantities. The nature of the cratering operation is such, however, that there is sufficient oxidation and dispersal of the gases to remove any toxicity risks to humans or any adverse effects upon the environment.