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Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

memorandum

TO: Distribution

DATE: August 28, 1992

FROM: M. J. Barr

MAIL STOP/TELEPHONE: C930/7-6866

SYMBOL: WX-3-92-720

SUBJECT: EXPLOSIVE - CONTAMINATED SOIL REACTIVITY

The attached paper on reactivity of explosive-contaminated soils was presented at the 25th DOD explosives safety seminar recently held in Anaheim California. The authors, Ewing and Kristoff, attempted to define the reactive/non-reactive contamination level for explosive contaminated soil to assist in compliance with RCRA requirements. This transition point is quite important as waste handling procedures transportation requirements, disposal permits, etc., all use reactivity data. This study used prepared samples of RDX, in a sand/soil mix and in both a wet and dry mode. As tests to determine explosive reactivity of wastes are not yet specified the authors selected the Bureau of Mines (BOM) protocols which are more severe than Department of Transportation tests specified in EPA SW-846 (1980). Also, their use of straight RDX (no binder) should produce a more conservative reactivity/non-reactive level than that which would be obtained from explosives commonly used at LANL (contained "Desensitizing" binders).

Would the explosives review committee please review this paper and either 1) schedule verification tests, 2) accept Ewings data and limit (15%) on a provisional basis or adjust his limit with a statistically/technically supportable safety factor, 3) define a LANL test protocol and establish defendable limits and safety factors. As DOE does not define tests or limits this could be an opportunity for LANL to take the lead in this area.

I would hope that we can avoid arbitrary limits based on doubt, worry or ultra-conservatism as we are all aware of the costs or administrative hassle associated with overly conservative limits or specifications.

MJB/kfm

Attachment: a/s

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J. B. Ramsay, M-8, MS J960
B. A. Stine, M-7, MS P950
D. L. Jaeger, WX-DO, MS A113
R. L. Rabie, M-7, MS P952
G. A. Buntain, M-1, MS C920
W. A. Bradley, WX-DO, MS P945
R. H. Goldie, HS-5, MS C930
L. B. Chapman, M-1, MS C920
M. J. Barr, WX-3, MS C930
J. C. Corpion, EM-8, MS K490
L. A. Stretz, WX-3, C930
J. M. McAfee, M-7, MS P950
A. S. Vigil, WX-11, MS C931
W. L. Seitz, M-7, MS P952
H. L. Flaugh, WX-DO, MS P945
D. B. Griechen, M-DO, MS P915
Hatler/Gonzales, WX-3, MS C930
WX-3 Group Ofc File, MS C930
J. L. White, EM-8, MS K490

REACTIVITY OF EXPLOSIVE - CONTAMINATED SOILS TO FLAME AND SHOCK STIMULI

By

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ABSTRACT

Extensive testing was conducted by Hercules Incorporated for Arthur D. Little, Inc. and the United States Army Toxic and Hazardous Materials Agency (USATHAMA) to investigate and define the reactivity of explosive-contaminated soils to flame and shock stimuli. These tests were conducted with laboratory prepared, water-wet and dry samples of the explosives RDX or TNT mixed with sand. The flame and shock tests were conducted using Bureau of Mines (BOM) protocols and determined that explosive-contaminated soils containing ≤12% explosive will not react explosively to induced shock or submerged flame initiation stimuli (Figure 1). This study resulted in a technical data base suitable for use as reactivity criteria for assessing the explosive reactivity of contaminated soils to flame and shock stimuli on the basis of soil composition.

Since completion of this study, 86 process waste samples containing up to 4.4% NC or <1% of other explosives (DNT, DEGDN, NG, TNT, RDX, etc.) were tested and determined to be non-reactive to the BOM flame and shock protocols (see Appendix C). These waste samples are now being classified as non-reactive by chemical analysis.

INTRODUCTION

Explosives manufacture and ammunition load, assembly and pack (LAP) operations result in the generation of explosives-contaminated wastewater. Over the years, the Department of the Army has used lagoons for treatment of these wastewaters by evaporation/percolation. Chemical analyses by others[1] determined that the principal sludge components at Savanna Army Depot (SAD) and Louisiana Army Ammunition Plant (LAAP) are TNT, RDX, HMX, water, sand and clay. Other solid, reactive materials and heavy metals are present in concentrations of 0.1% or less. These explosives-contaminated waters and sludges are listed as hazardous wastes under federal regulations promulgated under the Resource Conservation and Recovery Act (RCRA). The basis for this listing is the assumed explosive reactivity of these wastes if subjected to a strong initiating source or if heated under confinement (Refer to 40 CFR 261.23).[2] Presently, tests to determine the explosive reactivity of wastes are not specified. Different tests have been

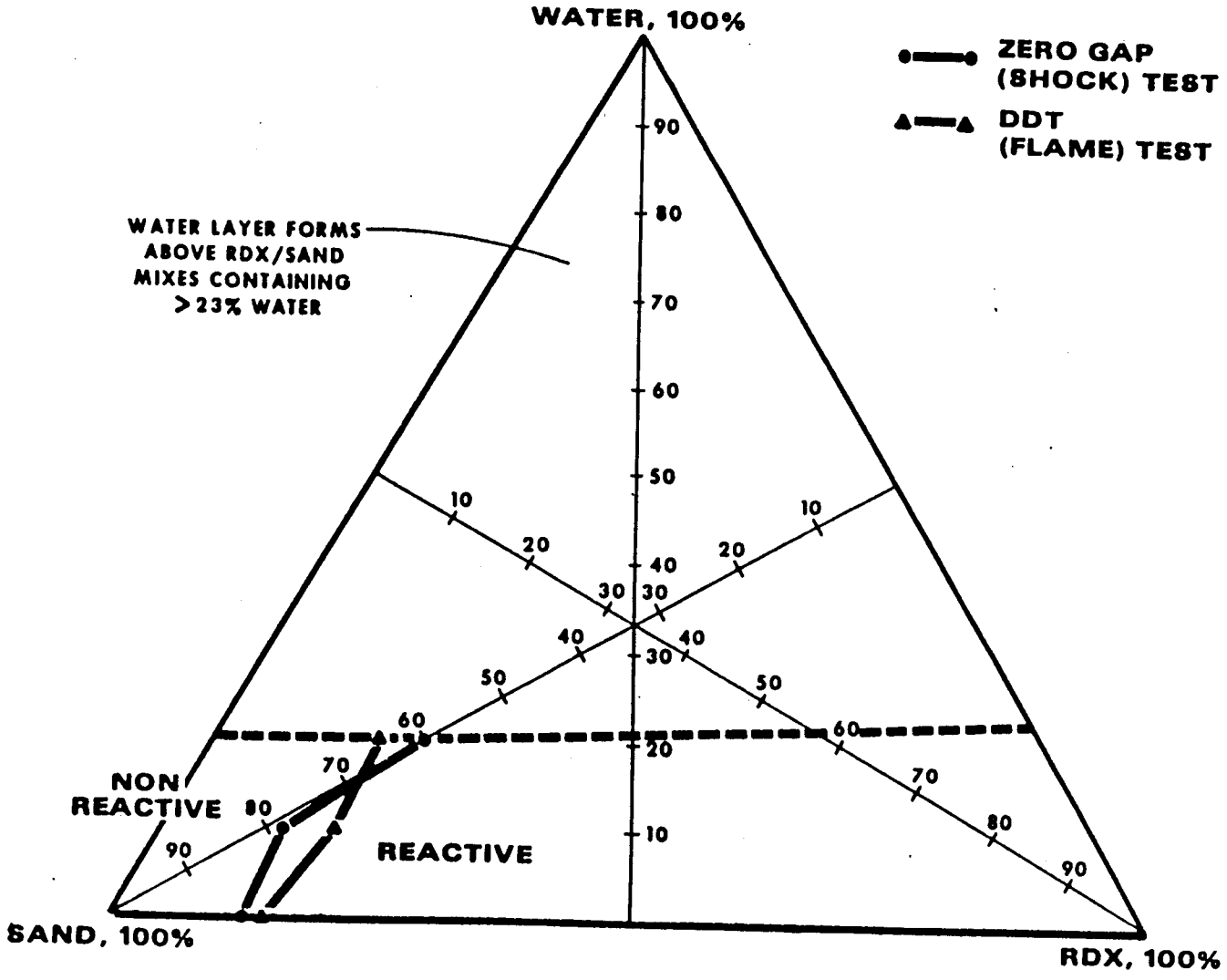

Figure 1. Combined P lts of DDT and Zero Gap Tests

Source: ; les Incorporated (Radford Army Ammunition Plant)

under consideration. Two of these test series are discussed in the following.

The first series of tests are similar to those used by the Department of Transportation (DOT) to determine the shipping classifications for hazardous materials. These inexpensive, small-scale tests determine if a material will burn or explode when subjected to an elevated temperature of 167°F for 48 hours, flame, shock of a No. 8 blasting cap, and BOE Impact Apparatus at 10 and 4-inch drop heights. These tests were listed in U. S. Environmental Protection Agency SW-846 (1980) "Test Methods for Evaluating Solid Waste."[3]

Another series of tests were developed by the BOM in cooperation with DOT to assist the United Nations (UN) Group of Experts on Explosives in preparing recommendations for the international transport of dangerous goods. These test protocols are known as the Zero Gap shock and Deflagration to Detonation Transition (DDT) flame tests (Appendix A). These tests are more expensive and time consuming than the EPA SW-846 tests mentioned previously. One advantage of these tests is that test samples are subjected to greater shock and flame energy in stronger (steel) confinement than in EPA SW-846 tests and therefore test results are more safety conservative.

USATHAMA funded this project for the purpose of investigation and defining the relationship between explosive-contaminated soil reactivity to BOM flame and shock tests, and explosive content. This study provides data for the development of a technical data base that may be used to predict the reactivity of explosive contaminated soils to flame and shock stimuli on the basis of compositional analyses of explosive(s) content. Substitution of laboratory analyses of explosive contaminated sludges for Zero Gap and DDT testing of sludge compositions would result in lower costs for determining the reactivity of contaminated soils.

DISCUSSION

Overall Test Plan

Major explosive contaminates and type of soil in Army lagoons were identified from available analyses (Table 1). The initiation sensitivity and explosive reactivity of the major solid explosive components were assembled from Hercules data files and the literature, and compared to establish which are more sensitive/reactive than the others (Table 2). Based upon these analyses and data the most sensitive/reactive explosive and typical inert test materials were selected for BOM flame and shock tests. Laboratory prepared compositions were then tested using BOM Zero Gap test protocols to determine compositions which were reactive and non-reactive in this test. Various compositions were then tested using BOM DDT test protocols to determine if compositions

Table 1

Typical Army Lagoon Sludge Compositions[a]

Component	Range, % (Dry Basis)[b]
A. Explosive:	
1. TNT	5-41
2. RDX	0.1-10
3. HMX	0.5-1.5
4. TNB, DNB, 2-Amino, DNT	ND -0.1
Total Explosives Content	9-41
B. Inerts:	
1. Sand 2. Clay	⩾ 52

[a]Based upon analyses from Reference 1.

[b]Moisture content ranged from 11 to 30%.

ND - None Detected

Table 2

Comparison of RDX, HMX and TNT Initiation, Flame and Shock Sensitivity Characteristics[a]

Initiation Stimuli	Units	Test Conditions	TNT	RDX	HMX
1. Mechanical					
a. Impact, TIL[b]	ft-lb/in.^{2}	Steel/steel	10.2	13.3	3
b. Sliding Friction, TIL[b]	psi @ 8 fps	Steel/steel	70,000	21,000	23,000
2. Electrostatic Spark Discharge, TIL[b]	Joules	N/A	0.025	0.024	0.065
3. Thermal					
a. Differential Thermal Analysis	°C	-	300	232	~ 280
b. Explosion Temperature	°C	Ignition in 1 s	520	316	327 (in 5 s)
4. Flame					
a. Critical Height to Explosion		Schedule 40 Steel Pipe			
2-in. diameter	In.		12	2	3
4-in. diameter	In.		⩾ 24	5	7
5. Shock					
a. Detonation Velocity	m/s	-	6,825	8,180[c]	9,124
b. Critical diameter for explosive propagation	In.	Schedule 40 Steel Pipe	⩽ 0.27	⩽ 0.27	⩽ 0.27
c. Rifle Bullet Impact	N/A	30 caliber	40% Expl. 60% Unaff.	100% Expl.	-

[a]See Glossary in Appendix D for definitions and test criteria.

[b]Lowest values included only. Higher values available reflect effect of sample thickness, particle size, density, etc.

[c]Pressed pellet; density = 1.65 g/cc.

NA - not applicable

Source: RAAP materials sensitivity laboratory files and AMC Pamphlet 706-177, "Explosive Series, Properties of

were reactive or non-reactive in this test. Test results we evaluated statistically and presented for use in determining explosive-contaminated soil compositions which can be classified as reactive or non-reactive to the BOM tests based upon chemical analysis.

·Selection of Test Sample Materials

1. General

The reactivity of Army lagoon sludges will depend upon the type of explosive present, its concentration in the non-reactive (inert) components and the degree of confinement afforded by the inerts in handling and storage containers. Typical soil analyses from two Army lagoons are shown in Table 1. The data is based upon chemical analyses of explosives-contaminated sludges from Savanna Army Depot (SAD) and Louisiana Army Ammunition Plant (LAAP).[1] These analyses show that the principal solid explosives present are TNT, RDX and HMX. Other solid components include water, sand, clay and low (≤0.1%) concentrations of other explosives and heavy metals.

2. Explosive Component

A review of initiation sensitivity and explosive reactivity data summarized in Table 2 shows that RDX and HMX exhibit simila initiation characteristics when subjected to mechanical, electrostatic and thermal stimuli. When confined and subjected to submerged flame initiation (critical height test), each transits from burning to an explosion reaction at low sample heights. Both materials sustain a detonation reaction and have critical diameters for explosive propagation of ≤0.27 inch in schedule 40 steel pipe. For purposes of this study, it is concluded that RDX and HMX are equivalent in initiation sensitivity and explosive reactivity.

A comparison of RDX, TNT and HMX initiation sensitivity and explosive reactivity data in Table 2 shows that TNT reacts similarly to impact and electrostatic discharge stimuli. However, TNT is much less sensitive to sliding friction and thermal stimuli as it requires greater energy for initiation. Flaked TNT is also less likely to transit to detonation as evidenced by a critical height of ≈24 inches in 4 inch diameter confinement. In contrast, RDX and HMX have critical heights of 5 and 7 inches, respectively, in the same confinement.

TNT, RDX and HMX are all capable of detonation in small diameters (≤0.27 inch). The TNT shock wave propagation rate is slower (6,825 m/s) than those of RDX and HMX (8,180 and 9,120 m/s), respectively). From this comparison, it is concluded that TNT is no more initiation sensitive and a less reactive explosive than RDX and HMX.

It is concluded that the selection of either RDX or HMX, rather than TNT, for BOM flame and shock testing will result in a conservative estimate of explosive reactivity for compositions containing TNT or other secondary explosives of equal sensitivity in these tests. Since typical lagoon analyses indicate that there is up to 6 times more RDX than HMX in the lagoons, RDX was selected as the candidate explosive for use in this study. The presence of small concentrations (≤0.1%) of explosives other than TNT, RDX or HMX will have a negligible effect upon the overall reactivity of sludge.

Type II, Class 1 RDX[4] was purchased from Holston Defense Corporation for use in this study. A RAAP chemical analysis of the Type II RDX determined that it also contained 8.6% HMX and 2.8% of other nitramine variations formed during RDX manufacture.

Limited testing was also conducted with TNT fines obtained from the RAAP TNT Plant. Chemical analysis determined it to contain 99.84% 2, 4, 6 TNT, 0.2% 2, 3, 4 TNT, and small amounts (0.06% total) of DNT and water. The TNT particle size distribution was determined microscopically. Most TNT particles fell in the range of 3μm to 200 μm (average ≈14 μm). Some of the larger particles measured were agglomerates instead of single crystals.

3. Inert Components

(a) Soil

Soil samples from SAD and LAAP were characterized by sieve analysis. Using U. S. Bureau of Public Roads soil-classification protocol, the LAAP soil was identified as loamy sand and the SAD soil as sand.

Several graded and ungraded sand and soil samples taken and analyzed at RAAP identified a New River sand bar sample which closely matches the SAD soil sample. Approximately 2,000 lb of New River ungraded sand was placed in cotton bags, air dried at 140°F for 48 hours, passed through a 20-mesh screen to remove foreign material (grass, branches, roots, rocks) and used in this study.

(b) Water

Since Army lagoon sludges also contain up to 30% water, both water-wet and dry RDX/sand mixtures were investigated in this study. Support laboratory tests conducted with a one liter graduated cylinder and beam balance determined that settled beds of sand or Type II, Class 1 RDX in water contain 20.0% and 22.9% (wt. basis) water, respectively. The addition of more water results in a layer of water above the settled RDX/sand mixture (two phases). The presence of a water head above a settled RDX/sand/water mixture should have little effect upon the reactivity of the settled RDX/sand mixture to flame or shock. Furthermore, Zero Gap and DDT

test configurations are not very well suited for testing two phas systems. Since most flame and shock tests were conducted with RDX/sand mixtures containing more sand than RDX, all trials conducted with settled RDX/sand in water mixtures were conducted with 20% (wt) water added. Visual inspection of 20% water-wet RDX/sand mixtures after loading into test pipes showed a thin water layer on top of samples indicating that all intergranular voids were full of water. Partly water-wet beds of RDX/sand mixtures were also tested with 10% water added.

4. Mix Preparation

Portions of RDX or TNT, sand and water (when required) were weighed to ± 1 gram and manually tumbled together to achieve a uniform mixture immediately before loading in test pipes. Mixes weighing up to 30 lb were prepared in sealed, conductive plastic bags in contact with a grounded, conductive surface to minimize the risk of electrostatic initiation of the explosive. Mixes were kept sealed in the plastic bags until used in tests to preclude loss of moisture by evaporation.

·Test Results

The following sections discuss the results of flame and shock sensitivity tests conducted with RDX/sand/water mixtures and the results of the flame and shock confirmatory tests conducted wit TNT/sand mixtures.

1. Zero Gap Shock Test Results

Wet and dry RDX/sand mixtures were tested to define mixture shock reactivity as a function of RDX content. Testing was conducted using the BOM developed Zero Gap test described in Appendix A and shown in Figure A1. In this test, samples were confined in 1.44-inch diameter steel tubing and subjected to an explosive shock wave induced at one end by two Pentolite pellets. RDX/sand/water compositions reacting explosively were identified using BOM test protocols. Standard probit statistical techniques[5] were used to establish an RDX level in wet and dry sand that has a low (0.5%) probability of reacting explosively to shock in the BOM test configuration.

(a) Initial Trials

Initial trials were conducted using 100% RDX, 100% sand, 100% water and an 80% sand/20% water mixture to verify that the Zero Gap shock test is capable of identifying material samples reactive or non-reactive to shock. These test results are presented in Appendix B, Table B1 and verified that the test is capable of identifying samples reactive or non-reactive to shock in the BOM test configuration.

Trials with RDX produced a positive result and demonstrated RDX reactivity to shock. In both the water and sand trials (three each), end-to-end pipe fragmentation occurred during one trial. Both materials also transmitted a fairly stable shock wave in one or more trials at velocities just below the >1,500 m/s criterion for an explosive reactive material. Water and probably any continuous phase (liquid or solid) material should be expected to transmit the donor induced shock wave effectively to the end of the comparatively short, 16-inch long pipe. It is suspected that much longer pipes would be required to detect shock wave degradation (decaying reaction) in continuous phase materials. Although sand is not a continuous phase material (contains air in granular interstices), another mechanism is thought to have caused the test container to fragment into long strips or appear to propagate the shock wave (positive results). In one sand trial, sand remaining within the undamaged portion of the pipe had been compressed and wedged into the pipe. It is theorized that in other trials with sand, a slug of tightly compressed sand was driven up the steel tube with sufficient force to rupture and fragment the tube and indicate propagation of a shock wave to the end of the 16-inch long test container. It is not likely that both tube fragmentation and indication of a shock wave by mechanical force of sand on the velocity probe would occur at the same time. A plug of sand hard enough to rupture the pipe would be expected to push the velocity probe out ahead of it and no velocity trace would result.

Zero Gap tests with 20% water filling spaces between sand granules gave indications of a pressure wave propagation velocity of ≤770 m/s. None of the sand and/or water (inert) trials transmitted sufficient shock to puncture the 1/8 inch thick, mild steel witness plate.

Zero Gap tests with inerts (sand and water) indicate that positive velocity and/or fragmentation results may occur with inerts in the BOM test configuration. It is speculated that this is why the BOM protocols require at least 2 of 3 different reaction criteria (velocity, pipe fragmentation and/or hole in the witness plate) be met before declaring a positive test result. If a trial with inert material resulted in a positive test result, the resulting data and test conclusions would be safety conservative. It appears unlikely that a shock sensitive material would not react positively in the Zero Gap test.

(b) RDX/Sand/Water Trials

Zero Gap tests were conducted with 0, 10 and 20% water-wet RDX/sand mixtures containing 15-25% RDX. These test results are presented in Appendix B, Table B1.

Test results summarized in Table 3 and shown in Figure 2 indicate that dry RDX/sand mixes containing 15% RDX are not reactive to induced shock in the BOM test configuration at the 0.5%

Table 3

Summary of Zero Gap Shock Test Results

Composition Tested, %			Average Bulk Density, g/cc	No. Trials	Average Shock Propagation Rate,[b] m/s	Positive Reactions[c] %
RDX	Sand[a]	Water				
20	80	0	1.342	11	2,220	73
18.75	81.25	0	1.294	10	3,030	20
17.5	82.5	0	1.339	10	2,670	20
15	85	0	1.345	20	1,864	0
25	65	10	1.285	5	2,550	100
23.5	66.5	10	1.262	10	2,760	60
22	68	10	1.289	10	2,480	30
19	71	10	1.273	10	2,620	10
18.5	61.5	20	1.760	2	3,960	100
17	63	20	1.752	10	3,120[d]	50
16.5	63.5	20	1.746	10	1,140	10
16	64	20	1.768	20	887	0

[a] Sand 0.8 to 0.2% water-wet.

[b] Shock propagation rate recorded by velocity probe in the upper half of the test sample (shock was induced into the bottom of the test sample).

[c] Two of the three following positive test result criteria are recorded: (A) Clean hole punched through, 1/8-in. thick steel plate; (B) Pipe fragmented along its entire length; (C) Stable propagation velocity > 1,500 m/s. Refer to Appendix B, Table B1 for complete listing of tests.

[d] Five trials averaged. Others were decaying reactions (variable rates).

[illegible]ce: Hercules Incorporated (Radford Army Ammuni[illegible] Plant)

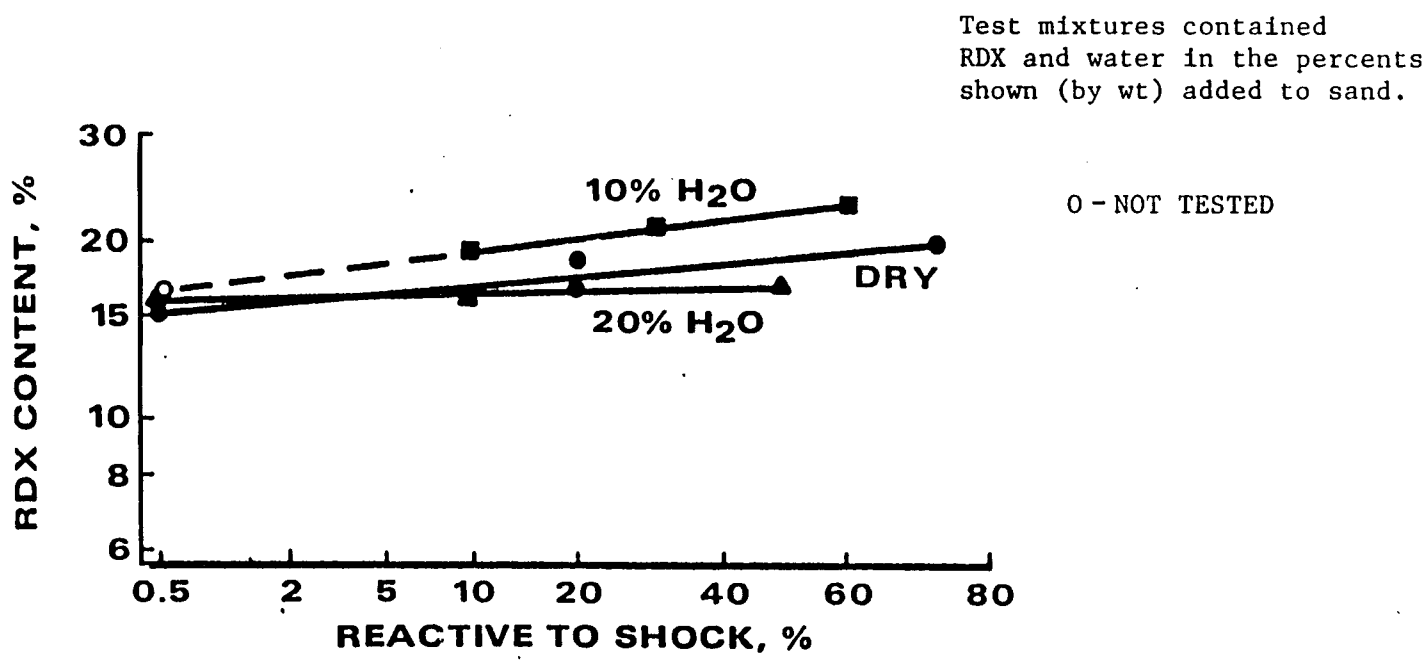

Figure 2. RDX/Sand/Water Shock Reactivity in Zero Gap Tests.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

reactivity level. Twenty consecutive trials with 15% RDX in sand tested negatively and verified at the 90% confidence level that this RDX/sand composition is unreactive at the 0.5% reactivity level.

Zero Gap tests with 20% water-wet RDX/sand mixes determined that mixes containing 16.0% RDX are also 0.5% reactive at the 90% confidence level. A comparison of 0 and 20% water-wet test results indicate that the substitution of up to 20% sand with water has little effect upon sample reactivity at the 0.5% reactivity level.

The predicted 0.5% reactive RDX concentration (16.5%) in the 10% water-wet RDX/sand mixes was nearly the same at those obtained at the 0 and 20% water-wet levels. Figure 2 shows the results of all RDX/sand samples tested in the Zero Gap test configuration.

Comparing the results of RDX/sand Zero Gap tests at higher reactivity levels (Figure 2), it can be seen that substitution of 10% sand with water reduces sample reactivity. However, substitution of an additional 10% sand with water (20% water content) has the opposite effect. The reason for these results is likely changes in bulk density. Experiments by others have demonstrated that, for a given explosive in cylinders of large diameter, the detonation velocity is nearly a linear function of the initial bulk density.[6] A more recent report of critical diameter (C_d) studies with loose, crystalline explosives concluded that increase of the explosive charge density as a result of pressing (charge consolidation) or filling voids with water decreases the charge air content, improves the conditions for shock wave propagation in a given medium and results in lower C_d.[4] An examination of the measured bulk densities of test mixtures shows that the bulk density of dry and 10% water-wet RDX/sand mixtures were essentially the same and averaged 1.2 g/cc. However, the bulk density of 20% water-wet RDX/sand mixtures was significantly higher and averaged 1.7 g/cc. The higher bulk density apparently caused the observed shift between the 10% and 20% moisture parameters.

It is concluded that water-wet or dry RDX/sand mixtures containing ≤15% RDX are not likely to sustain propagation of a shock wave in the BOM Zero Gap test. In contrast, RDX contaminated soils containing >15% RDX may be desensitized to shock stimuli by adding uncontaminated soil to reduce the RDX content to ≤15% RDX.

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2. Deflagration to Detonation Transition (DDT) Test Results

Wet and dry RDX/sand mixtures were also tested to define mixture flame reactivity as a function of RDX content. Testing was conducted using the BOM DDT test described in Appendix A and shown in Figure A2. In this test, samples are confined in 3-inch, schedule 80 steel pipe and subjected to flame from a 20-gram

igniter. RDX/sand/water compositions reacting explosively were identified using BOM test protocols. Standard probit analysis techniques[5] were used to establish an RDX level in wet and dry sand that has a low (0.5%) probability of reacting to flame in the BOM DDT test configuration.

(a) RDX/Sand/Water Trials

The DDT flame test results are summarized in Table 4 and plotted in Figure 3. All individual trial results are listed in Appendix B, Table B2 for reference. The DDT tests were conducted with 0, 10 and 20% water-wet RDX/sand mixes containing 12 to 28% RDX. Figure 3 shows that dry RDX/sand mixes containing ≤13% RDX should not react explosively when subjected to submerged flame initiation in the BOM test configuration. Twenty consecutive trials with 13% RDX in sand gave negative results, and verified at the 90% confidence level that this RDX/sand composition is unreactive at the ≤0.5% reactivity level.

DDT tests with 10% water-wet RDX/sand mixtures reacted about the same as tests with dry RDX/sand mixtures. Twenty consecutive trials with 10% water-wet RDX/sand mixes containing 12% RDX gave negative results, and verified at the 90% confidence level that this RDX/sand/water composition is also unreactive at the 0.5% reactivity level.

DDT tests conducted with 20% water-wet RDX/sand mixtures determined that these mixtures are not as reactive to flame as other moisture levels tested. Figure 3 indicates that a 20% RDX/60% sand/20% water composition should be 0.5% reactive in the BOM DDT test configuration. Verification tests were not conducted since previous verification tests have consistently been successful in demonstrating low (≤0.5%) reactivity for projected low reactivity compositions. However, all DDT trials conducted with 20% water-wet RDX/sand mixtures containing 25% RDX generated sufficient pressurization to rupture the schedule 80 pipe. Many pipes were split end-to-end and flattened. It is apparent that the 25% RDX/55% sand/20% water composition is reactive to flame in the steel pipe confinement, but that water at the 20% level moderated (slowed down) and prevented a DDT reaction most of the time. Fragmentation of the pipe or cap into two or more separate pieces (BOM criteria) occurred in only three of 10 trials conducted (30% reactive).

During DDT testing, 2 out of 10 trials were negative for dry 25% RDX/75% sand samples. This result is not in agreement with 20% RDX/80% sand tests resulting in 10 positive results out of 10 trials, or the correlation between RDX/sand compositions and percent positive reactions shown in Figure 3. A review of test records show nothing abnormal to indicate the cause of the two negative results. It is concluded that these results may be indicative of test variability.

Table 4

Summary of DDT Test Results for RDX/Sand Mixtures

Composition Tested, %			Average Bulk Density g/cc	No. Trials	Positive Reactions,[b] %
RDX	Sand[a]	Water			
50	50	0	-	1	100
30	70	0	-	1	100
25	75	0	1.28	10	80
20	80	0	1.32	10	100
17.5	82.5	0	1.34	10	70
15	85	0	1.33	10	10
13	87	0	1.43	20	0
19	71	10	1.34	3	100
15	75	10	1.41	10	30
12	78	10	1.49	20	0
28	52	20	1.70	10	80
26.5	53.5	20	1.71	4	25
25	55	20	1.73	10	30
13	67	20	1.77	5	0

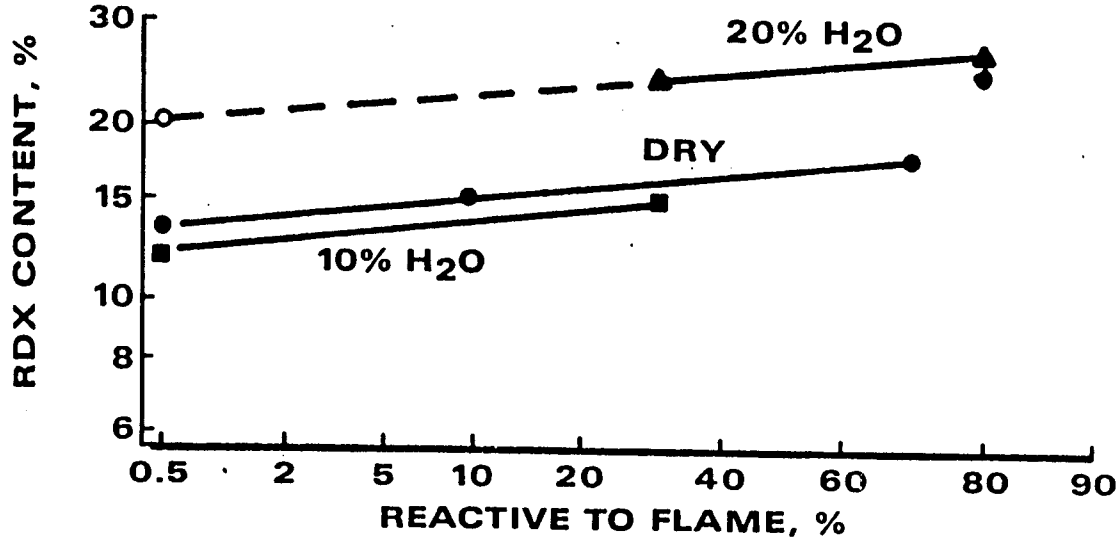
[a]Sand ≈ 0.25% water wet.

[b]Pipe and/or at least one end cap fragmented into two distinct pieces.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

Refer to Appendix B, Table B2 for complete listing of tests.

Test mixtures contained RDX and water in the percents shown (by wt) added to sand.



O - NOT TESTED

Figure 3 RDX/Sand/Water Flame Reactivity in DDT Tests.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

As determined during Zero Gap tests, the bulk density of 20% water-wet RDX/ sand mixtures averaged 1.8 g/cc and was greater than that of dry and 10% water-wet mixtures which ranged from 1.3 to 1.4 g/cc. The effect of increased density upon the sensitivity of RDX/sand mixtures to flame initiation is not clear based upon DDT test results. It is suspected that the decrease in RDX/sand mixture reactivity experienced with 20% water-wet mixtures is due primarily to the flame quenching effect of the water rather than increased bulk density.

DDT tests at the predicted 0.5% reactive composition levels resulted in "no reactions" in 20 consecutive trials and verified that wet or dry mixtures of RDX/sand containing ≤12% RDX are not flame sensitive in the BOM DDT test. Likewise, the DDT test results also show that reactive RDX contaminated soils containing >12% RDX may be desensitized to flame by adding uncontaminated soil and reducing the RDX content to ≤12% RDX.

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·Reactivity Criteria

Predicted 0.5% reactive RDX/sand/water compositions for both the Zero Gap and DDT tests are also plotted on the trimodal plot in Figure 1. This plot identifies dry and settled RDX/sand compositions not reactive to flame and shock in the BOM tests. A dotted line has been drawn to show the maximum percent of water which will be present in settled RDX/sand mixtures and the limits of this study. However, it is likely that any RDX/sand/water composition not reactive to BOM tests in the settled state will also be non-reactive if the same weights of an RDX/sand mixture are suspended in greater amounts of water.

The trimodal plot serves as a quick means to identify explosive-contaminated soils which are reactive or non-reactive to the BOM flame and shock tests based primarily on sample composition. Using this reactivity criteria, comparatively quick and inexpensive chemical analysis of Army lagoon soil samples may be used instead of the more time consuming and expensive BOM Zero Gap and DDT tests to establish the reactivity of soils containing secondary explosives contaminates such as RDX, HMX, TNT, etc.

·Confirmatory Tests With TNT

Dry TNT/sand mixtures were prepared and tested in the BOM DDT and Zero Gap tests to confirm that TNT is no more reactive in these tests (Figure 4) than RDX. Test results are presented in Tables 5 and 6 and discussed in the following.

Zero Gap tests were conducted with a mixture of 19% TNT fines in sand. This composition was selected for comparison with a 19% RDX/81% sand mixture determined previously to react positively to shock 50% of the time in the Zero Gap test configuration (see Figure 4). Test results for this TNT/sand mixture are listed in

Table 5

Summary of Zero Gap Shock Test Results for TNT/Sand Mixtures

Trial No.	Composition, % TNT[a]	Sand[b]	Water	Loading Density, g/cc	Shock Propagation Rate Thru Sample,[c] m/s	BOM Test Criteria[d] Velocity > 1,500 m/s	Hole in Plate	End-to-End Pipe Fragmentation	Type Reaction[e]
1	19	81	0	1.26	g	g	-	+	h
2	19	81	0	1.31	g	g	-	-	-
3	19	81	0	1.26	f	-	-	-	-
4	19	81	0	1.29	3,796	+	-	-	-
5	19	81	0	1.30	2,179	+	-	-	-
6	19	81	0	1.24	1,072	-	-	-	-
7	19	81	0	1.26	1,419	-	-	-	-
8	19	81	0	1.26	1,166	-	-	-	-
9	19	81	0	1.24	1,473	-	-	+	-
10	19	81	0	1.27	2,032	+	-	-	-
11	19	81	0	1.27	2,748	+	-	-	-
				Averages = 1.271	1,921				

[a]Type II, Class 1.

[b]Moisture in sand = 0.25%.

[c]16-in. long steel tubing; 1.44-in. I.D.; 0.22-in. wall thickness.

[d]"+" indicates positive result. "-" indicates negative result. See Appendix A for further description of BOM criteria.

[e]"+" indicates positive result; 2 or 3 criteria are positive and therefore the test indicates sustained propagation of the shock wave through the sample. "-" indicates negative result. See Appendix A for further description of BOM criteria.

[f]Decaying reaction. No steady state velocity in sample.

[g]Propagation rate not recorded - Oscilloscope trigger did not function.

[h]Insufficient criteria to determine if reaction was positive or negative.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

Table 6

Summary of DDT Test Results for TNT/Sand Mixtures

Trial No.	Composition, % TNT[a]	Sand[b]	Water	Loading Density, g/cc	Type Reaction[c]
1	17	83	0	1.32	-
2	17	83	0	1.28	-
3	17	83	0	1.32	-
4	17	83	0	1.33	-
5	17	83	0	1.28	-
6	17	83	0	1.29	-
7	17	83	0	1.32	-
8	17	83	0	1.32	-
9	17	83	0	1.32	-
10	17	83	0	1.30	-
			Average =	1.309	

[a]Type II, Class 1.

[b]Sand ≈ 0.25% water wet.

[c]"+" indicates positive result - that the pipe or an end cap fragmented into 2 or more distinct pieces; "-" indicates negative result. See Appendix A for further description of BOM criteria.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

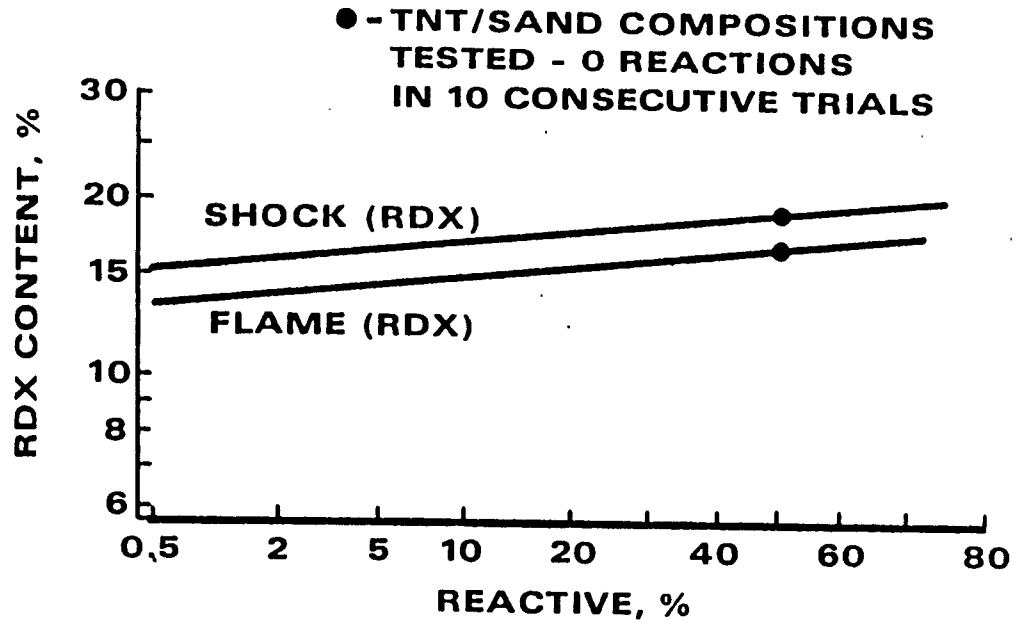


Figure 4 Dry RDX/Sand vs Dry TNT/Sand Reactivity

Source: Hercules Incorporated (Radford Army Ammunition Plant)

Table 5 and show that no positive reactions occurred in 10 consecutive Zero Gap trials. It is concluded that additional (>19%) TNT must be added to TNT/sand mixtures to achieve a reactivity level (50%) equivalent to a 19% RDX/81% sand mixture in the BOM Zero Gap shock test.

Likewise, DDT tests were conducted with a mixture of 17% TNT fines in sand. This composition was selected for comparison with a 17% RDX/83% sand mixture determined previously to react positively to flame initiation 50% of the time in the DDT test configuration (see Figure 4). Test results for this TNT/sand mixture are listed in Table 6 and show that no positive reactions occurred in 10 consecutive trials. It is concluded that TNT is less reactive in the BOM DDT flame initiation test than RDX.

DDT and Zero Gap tests with TNT verified that TNT is less reactive than RDX used to establish Figure 1 reactivity criteria. This study's findings further confirm that the sample reactivity based on compositional analyses can be used to predict the reactivity of contaminated soils in BOM flame and shock tests.

·ANALYSIS

Standard Probit analysis techniques[5] were used to establish an RDX level in wet and dry sand mixtures that has a low (0.5%) probability of reacting to shock in the BOM Zero Gap and DDT test configurations. Ten test trials were conducted for each wet and dry RDX/sand composition tested to obtain percent reaction data; i.e., some of the trials reacted positively. Since only 10 trials were conducted at each RDX level, resulting probabilities of a positive reaction ranged from 10 to 90% in increments of 10. The percent reactive data was plotted on probability paper to convert a logarithmic function between the probability of a positive reaction in the Zero Gap test, and the RDX content in dry and moisture-wet samples tested to a straight line. Then a straight line was drawn through the data and extrapolated to the 0.5% reactive level. The RDX level expected to react positively at the 0.5% reactive level was determined from the extrapolated plot and tested to verify that the wet or dry RDX/sand composition has a low level of reactivity in the BOM Zero Gap test. Verification testing was accomplished by conducting 20 confirmatory trials with the predicted 0.5% reactive composition. Statistically, there was a 90% chance of achieving 0 positive reactions in 20 consecutive trials. Achievement of no reactions in 20 consecutive trials was accepted as proof of low composition reactivity.

WARRANTY AND DISCLAIMER

Within the scope of work, Hercules warrants that it has exercised its best efforts in performing the hazards analysis and testing reported herein, but specifically disclaims any warranty, expressed or implied, that hazards or accidents will be completely eliminated or that any particular standard or criterion of hazard or accident elimination has been achieved if the findings and recommendations of Hercules Incorporated are adopted.

TWE:lmc

abstract

REFERENCES

[1]J. W. Noland, J. R. Marks, P. J. Marks, "Task 2, Incineration Test of Explosives Contaminated Soils at Savanna Army Depot Activity, Savanna, Illinois," Roy F. Weston, Inc., Final Report, DRXTH-TE-CR-84277, April 1984.

[2]Code of Federal Regulations, "40 CFR, Part 261."

[3]U. S. Environmental Protection Agency, "Test Methods for Evaluating Solid Waste," SW-846, 1980.

[4]Department of Defense, "Military Specification RDX," MIL-R-398C with Int. Amendment 5, 1 May 1978.

[5]D. J. Finney, "Probit Analysis," 3rd Edition, Cambridge at the University Press, 1971.

[6]U. S. Material Command, "Principles of Explosive Behavior," Engineering Design Handbook AMCP 706-180, April 1972, p. 7-1.

[7]B. Zygmunt, "The Detonation Properties of Explosive-Water Mixtures," Technical Military Academy, Warsaw 00-908 (Poland): Propellants, Explos. Pyrotech. 7, 107-109 (1982).

APPENDIX A

Procedures for the Classification of Explosive Substances

These tests determine whether the substance is explosive. Two tests are used to determine the response of the substance under test to a strong shock wave and to a strong thermal stimulus: The Bureau of Mines Gap Test and the Bureau's Deflagration/Detonation Transition (DDT) Test. The Gap Test subjects the substance to a strong shock from a pentolite donor charge and indicates whether the substance is able to propagate the detonation. In the DDT test, the substance is ignited inside a steel pipe bomb and an observation is made of whether it will continue to burn or will transit to detonation.

DESCRIPTION OF TESTS

1. GAP TEST FOR SOLID MATERIALS

The experimental arrangement used for the gap test is shown in Figure A1. The test sample is contained in a cylinder consisting of a 40.6 cm (16-inch) length of cold-drawn seamless carbon steel "mechanical" tubing 4.76 cm (1.875 inches) in outside diameter with a thickness of 0.56 cm (0.219 inch) and inside diameter of 3.65 cm (1.438 inch). The sample in this test is a granular solid at room temperature that is loaded to the density attained by tapping the cylinder until further settling becomes imperceptible or clay tamped gently into place. The bottom of the cylinder is closed with two layers of 0.0076-cm (0.003 inch) thick polyethylene sheet tied on with gum rubber bands and polyvinyl chloride electrical insulating tape. The sample is subjected to the shock wave generated by the detonation of two cast pentolite density 1.65 g/cm^3 (50/50 pentaerythritol tetranitrate PETN/TNT) pellets 5.08 cm (2-inches) in diameter and 2.54 cm (1 inch) thick. The pellets will be in direct contact with the bottom of the sample tube ("zero gap"). The pentolite pellet is initiated by a U. S. Army Engineers special detonator having a base charge of 0.935 gram (14.4 grains) of the PETN and a primary charge of 0.35 gram (5.4 grains) of diazo dinitrophenol which is butted against the bottom surface of the pentolite pellets and held in place by a cylinder of wood or a metal chip. Instrumentation consists of a continuous rate probe made of a thin aluminum tube with an inner diameter of 0.051 cm (0.02 inch) and a wall thickness of 0.0038 cm (0.0015 inch) with an axial nylon (skip wound) resistance wire of 0.0079 cm (0.0031 inch) diameter, having a resistance of 3.0 ohms/cm (7.52 ohms/inch). The outer tubing is crimped against the inner wire at the lower end, forming a resistor. When this assembly is inserted in a medium that transmits a shock wave, the outer wall crushes against the inner wire as the wave moves up the tubing, shortening the effective length and changing the resistance. If a constant current (usually 0.06 ampere) is made to flow between the outer and inner conductors, the voltage between them is proportional to the effective length and can be recorded as a function of time using an

oscilloscope. The scope of the oscilloscope trace is thus proportional to the velocity of the shock wave.

Criteria. Results of this test are considered to be positive if a stable propagation velocity greater than 1.5 km/sec is observed. Additional diagnostic information is provided by a mild steel witness plate 15.24 cm (6 inches) square and 0.3175 cm (0.125 inch) thick, mounted at the upper end of the sample tubing and separated from it by spacers 0.16 cm (0.063 inch) thick. A hole punch cleanly through the plate is an indication of a positive result.

A third source of diagnostic information is the fragmentation of the sample tube. The results of the test are considered to be positive only if the tube is fragmented along its entire length. The fragments range, depending on the material tested, from a few long strips to nearly a hundred small fragments; bulging, cracking, or "banana-peeling" of the acceptor is not considered a positive result.

In most cases, the results of the above three diagnostic methods agree. In some they do not, particularly with low-energy material, e.g., benzoyl peroxide, in which the witness plate is not punched through, but the tube is fragmented; also with certain propellants, the witness plate is punched, but little damage is done to the tube, evidently indicating a localized explosion at the upper end of the tube. In such cases, since there are essentially three criteria (witness plate, tube fragmentation, and rate probe), the result is assessed on the basis of the two criteria that agree; i.e., if any two criteria indicate a detonation, the result is considered positive, but not so if only one indicates a detonation. Some cases of doubtful propagation can also be resolved by using a longer sample tube. As applied in Zero Gap test, a negative result in this test is interpreted to mean that the substance does not have significant explosive properties.

2. DDT TEST

The experimental arrangement for the DDT Test is shown in Figure A2. The sample of material to be tested is contained in a 45.7 cm (18-inch) length of 3-inch diameter schedule 80 carbon steel pipe with inside diameter of 7.37 cm (2.9 inches) and wall thickness of 0.75 cm (0.30 inch), capped at both ends with "3000 pound" forged steel pipe caps.

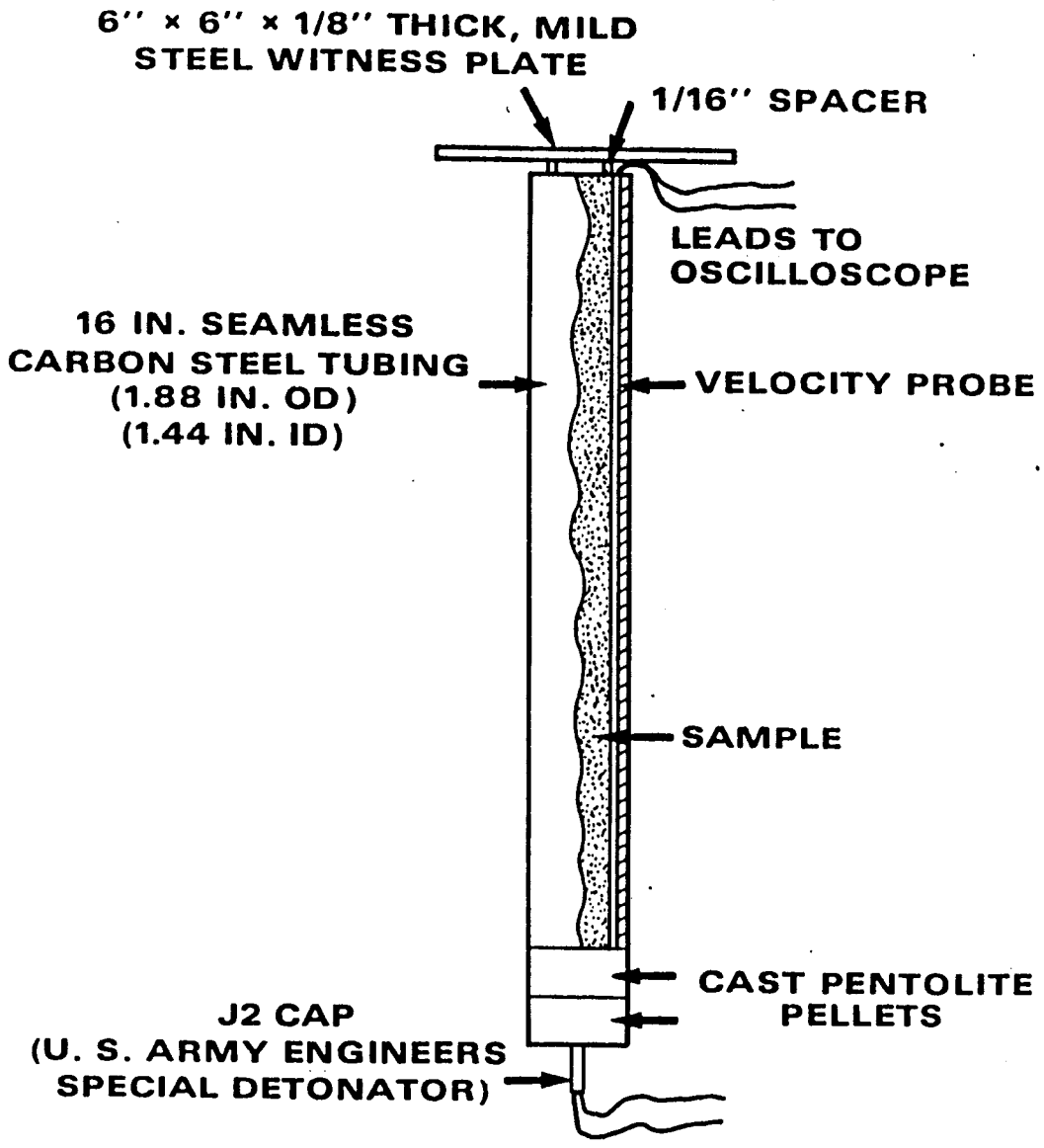
The sample is subjected to the thermal and pressure stimulus generated by an igniter consisting of a mixture of 50 percent RDX and 50 percent grade FFF_g black powder located at the center of the sample vessel. The igniter assembly consists of a cylindrical container 2.06 cm (0.81 inch) in diameter and of variable length, which is made from 0.0254 cm (0.01 inch)

thick cellulose acetate held together by two layers of nylon-filament-reinforced cellulose acetate tape. The length of the igniter capsule is 0.32 cm (0.125 inch) for each gram of igniter material. The igniter capsule contains a small loop formed from a 2.54 cm (1 inch) length of nickel-chromium alloy resistance wire 0.03 cm (0.012 inch) in diameter lead wires 0.066 cm (0.026 inch) in diameter; the overall wire diameter including insulation is 0.127 cm (0.05 inch). These lead wires are fed through small holes in a brass disc approximately 1 cm (0.4 inch) in diameter and 0.08 cm (0.03 inch) thick, which is soldered to the end of 23 cm (9-inch) length of "1/8 inch" steel pipe having a diameter of 1.03 cm (0.405 inch); this pipe is threaded at the outer end and screwed into a threaded hole on the inside of one of the pipe caps. This pipe supports the igniter capsule and serves as channel for the igniter wires. The igniter is fired by a current of 15 amperes obtained from a 20-volt transformer.

Criteria. The criterion currently used in the interpretation of this test is that for a positive result either the pipe or at least one of the end caps be fragmented into at least two distinct pieces, i.e., results in which the pipe is merely split or laid open or in which the pipe or caps are distorted to the point at which the caps are blown off are considered to be negative results. Although it may be argued that a small number of fragments does not indicate the development of a detonation, it at least indicates a very rapidly rising pressure which in a larger sample could lead to development of detonation.

DDT Testing using a 20-gram (308-grain) igniter provides a strong thermal stimulus. Substances that yield a negative result with a 20-gram (308-grain) igniter are interpreted to have no significant explosive properties.

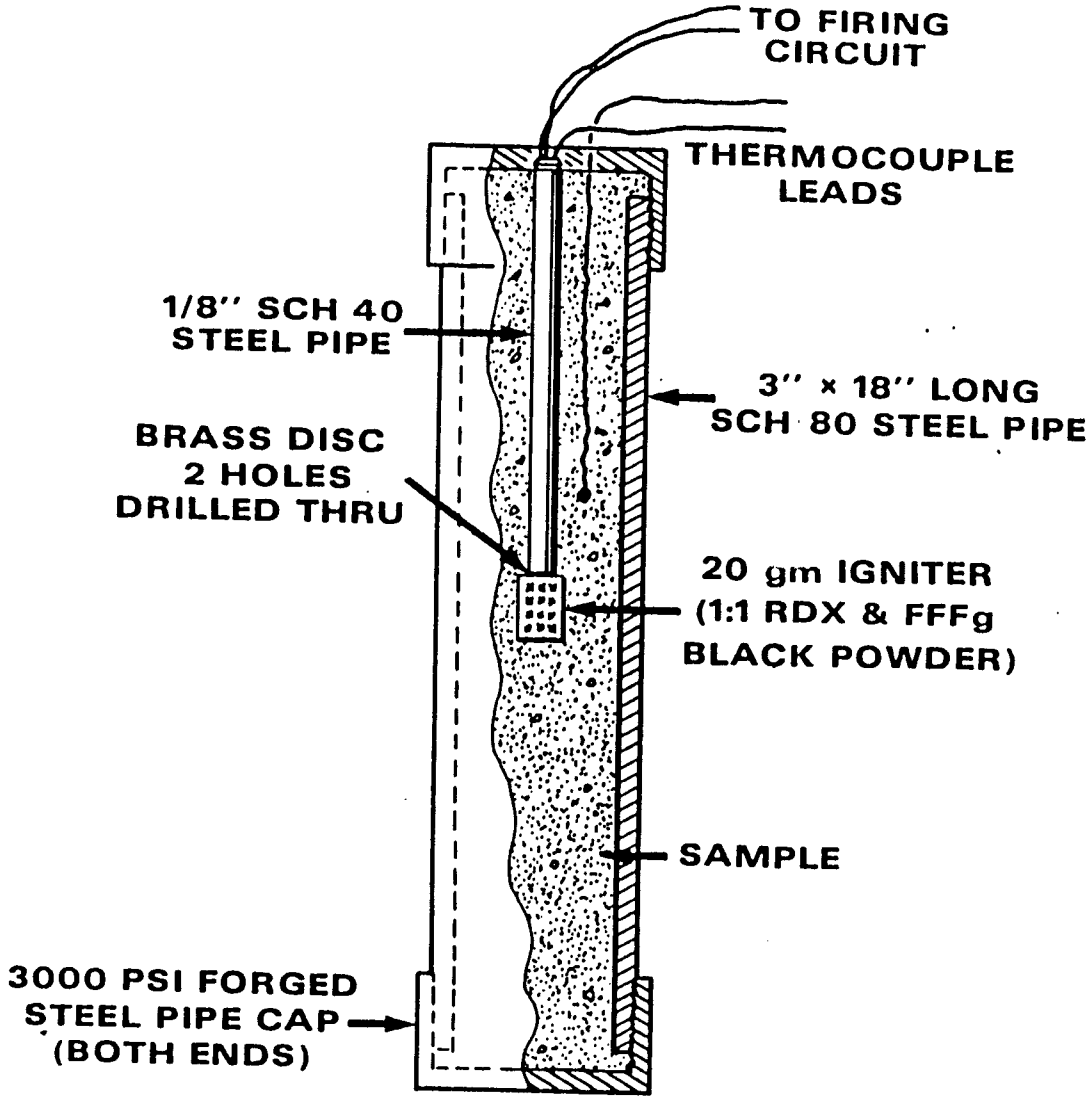
SOURCE: J. Edmund May, Richard W. Watson, and Richard J. Mainiero, U. S. Bureau of Mines, Department of the Interior, Pittsburg, PA 15236.



ZERO GAP SHOCK TEST

Figure A1

Source: U.S. Bureau of Mines, Department of the Interior



DDT TEST

Figure A2

Source: Hercules Incorporated (Radford Army Ammunition Plant)

APPENDIX B

Summary of Bureau of Mines Zero Gap Shock and Deflagration-to-Detonation Test Results for RDX/Sand/Water Mixtures

Table B1

BOM Zero Gap Shock Test Results - RDX/Sand Mixtures

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Shock Propagation Rate Thru Sample,[c] m/s	BOM Test Criteria[d] Velocity > 1,500 m/s	Hole in Plate	End-to-End Pipe Fragmentation	Type Reaction[e]
1	100	0	0	1.088	6,110	+	+	+	+
2	100	0	0	1.096	5,780	+	+	+	+
3	100	0	0	1.191	6,475	+	+	+	+
4	100	0	0	1.079	6,882	+	+	+	+
5	100	0	0	1.088	6,882	+	+	+	+
6	0	100	0	1.422	1,215	-	-	-	-
7	0	100	0	1.446	f	-	-	-	-
8	0	100	0	1.417	f	-	-	+	-
9	0	0	100	0.997	1,364	-	-	-	-
10	0	0	100	0.981	1,366	-	-	-	-
11	0	0	100	0.981	1,419	-	-	+	-
12	0	80	20	1.879	766	-	-	-	-
13	0	80	20	1.854	f	-	-	-	-
14	0	80	20	1.862	724	-	-	-	-
15	50	50	0	1.207	3,362	+	+	+	+
16	30	70	0	1.306	1,826	+	+	+	+
17	20	80	0	1.294	3,790	+	-	+	+
18	20	80	0	1.352	2,788	+	-	+	+
19	20	80	0	1.352	1,763	+	-	+	+
20	20	80	0	1.372	1,959	+	-	+	+
21	20	80	0	1.347	2,504	+	-	+	+
22	20	80	0	1.310	> 2,500	+	-	-	-
23	20	80	0	1.347	1,763	+	-	+	+
24	20	80	0	1.335	2,101	+	-	+	+
25	20	80	0	1.347	1,417	-	-	-	-
26	20	80	0	1.352	1,826	+	-	+	+
27	20	80	0	1.352	2,029	+	-	-	-
28	18.75	81.25	0	1.298	2,337	+	-	-	-
29	18.75	81.25	0	1.277	3,240	+	-	+	+
30	18.75	81.25	0	1.286	3,644	+	-	-	-
31	18.75	81.25	0	1.273	3,644	+	-	-	-
32	18.75	81.25	0	1.282	3,644	+	-	-	-
33	18.75	81.25	0	1.331	1,829	+	-	+	+
34	18.75	81.25	0	1.261	4,129	+	-	-	-
35	18.75	81.25	0	1.286	4,129	+	-	-	-
36	18.75	81.25	0	1.339	1,419	-	-	-	-
37	18.75	81.25	0	1.306	2,256	+	-	-	-
38	17.5	82.5	0	1.339	> 3,900	+	-	+	+
39	17.5	82.5	0	1.339	> 2,800	+	-	-	-
40	17.5	82.5	0	1.343	g	g	-	-	-
41	17.5	82.5	0	1.343	g	g	-	-	-
42	17.5	82.5	0	1.327	g	g	-	-	-
43	17.5	82.5	0	1.323	2,253	+	-	-	-
44	17.5	82.5	0	1.364	1,892	+	-	+	+
45	17.5	82.5	0	1.335	2,101	+	-	-	-
46	17.5	82.5	0	1.347	3,000	+	-	-	-
47	17.5	82.5	0	1.327	2,594	+	-	-	-
48	15	85	0	1.359	1,313	-	-	-	-
49	15	85	0	1.384	1,471	-	-	-	-
50	15	85	0	1.310	> 3,400	+	-	-	-
51	15	85	0	1.380	> 2,500	+	-	-	-
52	15	85	0	1.331	> 3,000	+	-	-	-
53	15	85	0	1.327	2,891	+	-	-	-
54	15	85	0	1.364	765	-	-	-	-
55	15	85	0	1.319	3,951	+	-	-	-
56	15	85	0	1.393	1,701	+	-	-	-
57	15	85	0	1.372	g	g	-	-	-
58	15	85	0	1.389	g	g	-	-	-
59	15	85	0	1.368	f	-	-	-	-
60	15	85	0	1.347	g	g	-	+	h

Table B1 (cont)

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Shock Propagation Rate Thru Sample,[c] m/s	BOM Test Criteria[d] Velocity > 1,500 m/s	Hole in Plate	End-to-End Pipe Fragmentation	Re[illegible]n[e]
61	15	85	0	1.327	g	g	-	+	h
62	15	85	0	1.327	f	-	-	+	-
63	15	85	0	1.335	f	-	-	-	-
64	15	85	0	1.323	g	g	-	-	-
65	15	85	0	1.352	f	-	-	-	-
66	15	85	0	1.319	f	-	-	-	-
67	15	85	0	1.327	2,029	+	-	-	-
68	15	85	0	1.327	f	-	-	-	-
69	15	85	0	1.319	f	-	-	-	-
70	25	65	10	1.261	3,644	+	-	+	+
71	25	65	10	1.269	1,894	+	-	+	+
72	25	65	10	1.310	2,256	+	-	+	+
73	25	65	10	1.335	2,693	+	-	+	+
74	25	65	10	1.249	2,256	+	-	+	+
75	23.5	66.5	10	1.306	2,256	+	-	+	+
76	23.5	66.5	10	1.269	3,240	+	-	+	+
77	23.5	66.5	10	1.269	4,314	+	-	+	+
78	23.5	66.5	10	1.286	1,829	+	-	+	+
79	23.5	66.5	10	1.265	3,502	+	-	-	-
80	23.5	66.5	10	1.265	2,604	+	-	+	+
81	23.5	66.5	10	1.224	2,890	+	-	-	-
82	23.5	66.5	10	1.257	1,765	+	-	-	-
83	23.5	66.5	10	1.265	2,420	+	-	+	+
84	23.5	66.5	10	1.219	g	g	-	-	-
85	22	68	10	1.273	3,502	+	-	+	+
86	22	68	10	1.277	2,337	+	-	+	+
87	22	68	10	1.339	2,337	+	-	-	-
88	22	68	10	1.287	1,473	-	-	-	-
89	22	68	10	1.269	3,502	+	-	-	
90	22	68	10	1.228	3,235	+	-	-	
91	22	68	10	1.277	1,641	+	-	-	
92	22	68	10	1.319	2,417	+	-	-	-
93	22	68	10	1.294	1,763	+	-	+	+
94	22	68	10	1.327	2,594	+	-	-	-
95	19	71	10	1.261	3,790	+	-	-	-
96	19	71	10	1.306	1,526	+	-	+	+
97	19	71	10	1.306	2,689	+	-	-	-
98	19	71	10	1.302	1,213	-	-	+	-
99	19	71	10	1.310	3,115	+	-	-	-
100	19	71	10	1.249	1,473	-	-	-	-
101	19	71	10	1.265	1,166	-	-	-	-
102	19	71	10	1.236	4,957	+	-	-	-
103	19	71	10	1.249	2,896	+	-	-	-
104	19	71	10	1.244	3,367	+	-	-	-
105	18.5	61.5	20	1.755	3,957	+	+	+	+
106	18.5	61.5	20	1.764	3,957	+	+	+	+
107	17	63	20	1.784	g	g	+	+	+
108	17	63	20	1.759	3,957	+	+	+	+
109	17	63	20	1.780	3,957	+	+	+	+
110	17	63	20	1.714	603	-	-	-	-
111	17	63	20	1.751	3,441	+	-	+	+
112	17	63	20	1.784	f	-	-	+	-
113	17	63	20	1.677	f	-	-	+	-
114	17	63	20	1.776	f	-	-	+	-
115	17	63	20	1.731	f	-	-	-	-
116	17	63	20	1.764	3,644	+	-	+	+

Table B1 (cont)

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Shock Propagation Rate Thru Sample,[c] m/s	BOM Test Criteria[d] Velocity > 1,500 m/s	Hole in Plate	End-to-End Pipe Fragmentation	Type Reaction[e]
117	16.5	63.5	20	1.739	564	-	-	-	-
118	16.5	63.5	20	1.722	893	-	-	-	-
119	16.5	63.5	20	1.731	724	-	-	-	-
120	16.5	63.5	20	1.751	766	-	-	-	-
121	16.5	63.5	20	1.743	g	g	-	-	-
122	16.5	63.5	20	1.743	564	-	-	-	-
123	16.5	63.5	20	1.784	4,129	+	+	+	+
124	16.5	63.5	20	1.739	684	-	-	-	-
125	16.5	63.5	20	1.751	850	-	-	-	-
126	16.5	63.5	20	1.755	1,119	-	-	+	-
127	16	64	20	1.755	643	-	-	-	-
128	16	64	20	1.764	981	-	-	-	-
129	16	64	20	1.804	850	-	-	-	-
130	16	64	20	1.751	1,315	-	-	-	-
131	16	64	20	1.776	808	-	-	-	-
132	16	64	20	1.772	643	-	-	-	-
133	16	64	20	1.751	766	-	-	-	-
134	16	64	20	1.743	525	-	-	-	-
135	16	64	20	1.755	564	-	-	-	-
136	16	64	20	1.817	808	-	-	+	-
137	16	64	20	1.780	1,072	-	-	+	-
138	16	64	20	1.776	1,116	-	-	+	-
139	16	64	20	1.755	g	g	-	-	-
140	16	64	20	1.747	1,215	-	-	+	-
141	16	64	20	1.764	f	-	-	+	-
142	16	64	20	1.776	f	-	-	+	-
143	16	64	20	1.768	g	g	-	-	-
144	16	64	20	1.764	g	g	-	-	-
145	16	64	20	1.768	937	-	-	+	-
146	16	64	20	1.764	1,072	-	-	+	-

[a]Type II, Class 1.

[b]Moisture in sand ranged from 0.8 to 0.2%.

[c]16-in. long steel tubing; 1.44-in. ID; 0.22-in. wall thickness.

[d]"+" indicates positive result. "-" indicates negative result. See Appendix A for further description of BOM criteria.

[e]"+" indicates positive result; 2 or 3 criteria are positive and therefore the test indicates sustained propagation of the shock wave through the sample. "-" indicates negative result. See Appendix A for further description of BOM criteria.

[f]Decaying reaction. No steady state velocity in sample.

[g]Propagation rate not recorded - Oscilloscope trigger did not function.

[h]Insufficient criteria to determine if reaction was positive.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

Table B2

BOM Deflagration to Detonation Transition Test Results - RDX/Sand Mixtures

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Type Reaction[c]
1	50	50	0	d	+
2	30	70	0	d	+
3	25	75	0	1.23	+
4	25	75	0	1.39	+
5	25	75	0	1.19	-
6	25	75	0	1.28	+
7	25	75	0	1.27	-
8	25	75	0	1.35	+
9	25	75	0	1.27	+
10	25	75	0	1.26	+
11	25	75	0	1.29	+
12	25	75	0	1.28	+
13	20	80	0	1.42	+
14	20	80	0	1.31	+
15	20	80	0	1.29	+
16	20	80	0	1.32	+
17	20	80	0	1.31	+
18	20	80	0	1.33	+
19	20	80	0	1.30	+
20	20	80	0	1.32	+
21	20	80	0	1.32	+
22	20	80	0	1.28	+
23	17.5	82.5	0	1.29	-
24	17.5	82.5	0	1.33	-
25	17.5	82.5	0	1.35	+
26	17.5	82.5	0	1.33	+
27	17.5	82.5	0	1.34	+
28	17.5	82.5	0	1.36	+
29	17.5	82.5	0	1.34	+
30	17.5	82.5	0	1.35	+
31	17.5	82.5	0	1.35	-
32	17.5	82.5	0	1.34	+
33	15	85	0	1.26	-
34	15	85	0	1.38	-
35	15	85	0	1.34	+
36	15	85	0	1.32	-
37	15	85	0	1.32	-
38	15	85	0	1.32	-
39	15	85	0	1.34	-
40	15	85	0	1.36	-
41	15	85	0	1.30	-
42	15	85	0	1.35	-
43	13	87	0	1.44	-
44	13	87	0	1.43	-
45	13	87	0	1.44	-
46	13	87	0	1.44	-
47	13	87	0	1.47	-
48	13	87	0	1.46	-
49	13	87	0	1.44	-
50	13	87	0	1.40	-
51	13	87	0	1.43	-
52	13	87	0	1.37	-
53	13	87	0	1.42	-
54	13	87	0	1.46	-
55	13	87	0	1.39	-
56	13	87	0	1.39	-
57	13	87	0	1.47	-
58	13	87	0	1.39	-
59	13	87	0	1.45	-
60	13	87	0	1.48	-
61	13	87	0	1.46	-
62	13	87	0	1.35	-

Table B2 (cont)

Trial No.	Composition, % RDX[a]	Sand[b]	Water	Loading Density, g/cc	Type Reaction[c]
63	19	71	10	1.32	+
64	19	71	10	1.37	+
65	19	71	10	1.32	+
66	15	75	10	1.33	-
67	15	75	10	1.43	-
68	15	75	10	1.42	+
69	15	75	10	1.36	-
70	15	75	10	1.45	-
71	15	75	10	1.43	-
72	15	75	10	1.46	+
73	15	75	10	1.41	-
74	15	75	10	1.43	-
75	15	75	10	1.42	+
76	12	78	10	1.47	-
77	12	78	10	1.51	-
78	12	78	10	1.50	-
79	12	78	10	1.45	-
80	12	78	10	1.51	-
81	12	78	10	1.53	-
82	12	78	10	1.50	-
83	12	78	10	1.44	-
84	12	78	10	1.53	-
85	12	78	10	1.52	-
86	12	78	10	1.50	-
87	12	78	10	1.48	-
88	12	78	10	1.44	-
89	12	78	10	1.48	-
90	12	78	10	1.50	-
91	12	78	10	1.47	-
92	12	78	10	1.55	-
93	12	78	10	1.47	-
94	12	78	10	1.44	-
95	12	78	10	1.53	-
96	28	52	20	1.72	+
97	28	52	20	1.71	+
98	28	52	20	1.69	+
99	28	52	20	1.72	+
100	28	52	20	1.74	-
101	28	52	20	1.71	+
102	28	52	20	1.70	+
103	28	52	20	1.67	-
104	28	52	20	1.67	+
105	28	52	20	1.70	+
106	26.5	53.5	20	1.70	+
107	26.5	53.5	20	1.74	-
108	26.5	53.5	20	1.68	-
109	26.5	53.5	20	1.73	-
110	25	55	20	1.74	-
111	25	55	20	1.66	-
112	25	55	20	1.77	+
113	25	55	20	1.74	+
114	25	55	20	1.74	+
115	25	55	20	1.75	-
116	25	55	20	1.71	-
117	25	55	20	1.76	-
118	25	55	20	1.70	-
119	25	55	20	1.71	-
120	13	67	20	1.85	-
121	13	67	20	1.82	-
122	13	67	20	1.79	-
123	13	67	20	1.66	-
124	13	67	20	1.72	-

Table B2 (cont)

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[a]Type II, Class 1.

[b]Sand ≈ 0.25% water wet.

[c]"+" indicates positive result - that the pipe or an end cap fragmented into two or more distinct pieces; "-" indicates negative result. See Appendix A for further description of BOM criteria.

[d]Not determined.

Source: Hercules Incorporated (Radford Army Ammunition Plant)

APPENDIX C

The attached is a summary of tests conducted at Radford AAP, during the period of 1986 to 1991, to determine the reactivity of explosive contaminated wastes (dirt and ash mixtures) to flame and shock stimuli. These tests used the Bureau of Mines (BOM) Flame and Shock Test Protocols. Each sample listed was subjected to 3 shock and 3 flame tests. If the sample showed reactivity in any single test, it would have been listed as reactive. None of the samples tested showed evidence of reactivity.

As a result of these tests, and the previous tests conducted with RDX, sand and water, it was concluded that all Radford process wastes with very low explosive content are not reactive to the BOM flame and shock protocols. Currently, these process wastes are not tested using the BOM protocols. Reactivity is determined by chemical analysis of the waste samples to verify the low explosive content.

APPENDIX C

Table C1

Compilation of Reactivity Test Results for Contaminated Dirt/Ash/Residue at RAAP [a]

Burning Ground Ash	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
1.	-		X	.05	<.005	<.005	<.005	<.005	-	<.005	NC Trace	12/09/85
2.	-		X	.01	<.005	<.005	<.005	<.005	-	<.005	-	12/09/85
3.	-		X	<.005	.02	.05	<.005	<.005	-	<.005	NC Trace	12/09/85
4.	-		X	.04	.05	.28	.01	.11	-	ND	NC Trace 1,2-DNG-.02	07/16/86
5.	-		X	<.001	<.0005	<.0005	.0005	.0005	-	.0005	NC Trace	09/09/86
6.	-		X	.002	.002	.002	.002	.002	-	.002	1-3 DNG-.002 1-2 DNG-.002	09/10/86
7.	-		X	.0607	.014	ND	ND	ND	ND	.095	-	12/09/86
8.	-		X	ND	.001	.001	ND	.01	.001	.001	-	12/22/86
9.	-		X	ND	ND	ND	ND	ND	ND	ND	-	12/28/86
10.	-		X	.014	.004	ND	.0005	.0003	ND	.016	-	12/29/86
11.	-		X	ND	.003	.001	ND	.01	ND	.03	-	01/00/87
12.	-		X	.024	ND	ND	ND	ND	ND	ND	NC Trace	02/00/87
13.	10		X	ND	.2822	.008	.003	.004	.0038	.0066	-	03/00/87
14.	12		X	.004	.067	ND	ND	.007	ND	ND	-	04/08/87
15.	13		X	.03	ND	.02	ND	ND	ND	ND	-	05/05/87

[a] Composit samples of contaminated dirt/ash were subjected to flame and shock tests. Testing was accomplished in accordance with guidelines and criteria described in Bureau Of mines (BOM) report "Procedures for the Classification of Explosive Substances."

Table C1 (cont)

	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
Burning Ground Ash (cont)												
16.	14		X	.01	.004	<.001	<.001	<.001	<.001	<.001	-	06/02/87
17.	15		X	.001	.007	<.001	<.001	<.002	ND	.020	-	06/22/87
18.	16		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	07/17/87
19.	18		X	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	NC-<.001	08/25/87
20.	19		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	09/17/87
21.	21		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	09/30/87
22.	22		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	11/03/87
23.	23		X	<.013	<.012	<.0002	<.001	<.001	<.003	<.001	NC-<.001	11/12/87
24.	24		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	12/17/87
25.	25		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	12/10/87
26.	26		X	.009	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	02/01/88
27.	27		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	02/18/88
28.	29		X	<.01	<.01	<.01	<.01	<.01	<.01	<.01	NC-<.01	03/23/88
29.	30		X	.18	.0018	.005	<.01	<.01	<.01	<0.1	-	04/14/88
30.	31		X	.09	<.01	<.01	<.01	<.01	<.01	<0.1	-	05/16/88
31.	32		X	<.01	<.01	<.01	<.01	<.01	<.01	<0.1	-	05/19/88
32.	33		X	.27	.04	<.01	<.01	<.01	<.01	<.01	NC-<.01	05/16/88

Table C1 (cont)

	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
Burning Ground Ash (cont)												
33.	34		X	.011	<.01	<.01	<.01	<.01	<.01	ND	-	06/16/88
34.	35		X	<.01	<.01	<.01	<.01	<.01	<.01	ND	-	07/12/88
35.	37		X	.027	.018	.015	<.01	<.01	<.01	<.01	-	08/18/88
36.	38		X	.0068	.0107	.0107	ND	ND	ND	ND	-	09/01/88
37.	41		X	.03	<.01	<.01	<.01	<.01	<.01	<.01	-	10/10/88
38.	43		X	.88	<.01	<.01	<.01	<.01	<.01	<.01	-	11/08/88
39.	44		X	ND	ND	ND	ND	ND	ND	ND	-	12/20/88
40.	46		X	ND	ND	0.18	ND	ND	ND	ND	-	01/25/89
41.	47		X	.045	ND	.18	ND	ND	ND	ND	-	03/02/89
42.	48		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	-	03/22/89
43.	49		X	<.001	.0018	.0025	<.001	<.001	<.001	<.001	-	04/13/89
44.	50		X	0	0.03	ND	ND	ND	ND	ND	-	05/11/89
45.	51		X	ND	ND	.19	ND	ND	ND	ND	-	06/09/89
46.	52		X	0.02	ND	ND	ND	ND	ND	ND	-	07/19/89
47.	53		X	ND	.0002	.03	ND	ND	ND	ND	-	07/17/89
48.	54		X	.06	ND	ND	ND	ND	ND	ND	-	08/16/89
49.	55		X	ND	ND	ND	.04	ND	ND	ND	-	08/21/89
50.	56		X	ND	.20	.12	ND	ND	ND	ND	-	10/06/89
51.	57		X	.001	.04	ND	ND	ND	ND	ND	-	10/06/89
52.	58		X	ND	ND	ND	ND	ND	ND	ND	-	10/19/89
53.	59		X	.02	ND	.17	ND	ND	ND	ND	-	12/01/89
54.	60		X	ND	.03	.01	ND	ND	ND	ND	-	12/01/89
55.	61		X	.02	ND	ND	ND	ND	ND	ND	-	12/24/89

Table C1 (cont)

	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
Burning Ground Ash (cont)												
56.	62		X	ND	ND	ND	ND	ND	ND	ND	-	02/01/90
57.	63		X	ND	ND	ND	ND	ND	ND	ND	-	02/01/90
58.	64		X	.02	ND	ND	ND	ND	ND	ND	-	02/15/90
59.	65		X	.002	ND	ND	ND	ND	ND	ND	-	02/15/90
60.	66		X	.02	ND	ND	ND	ND	ND	ND	-	04/05/90
61.	67		X	ND	ND	ND	ND	ND	ND	ND	-	05/01/90
62.	68		X	ND	ND	ND	ND	ND	ND	ND	-	05/03/90
63.	69		X	.02	ND	ND	ND	ND	ND	ND	-	05/10/90
64.	71		X	ND	ND	ND	ND	ND	ND	ND	-	07/25/90
65.	73		X	.0001	.0006	.023	.0003	.0003	ND	ND	-	08/16/90
66.	74		X	.008	ND	ND	ND	ND	ND	ND	-	08/22/90
67.	75		X	0.03	.004	.008	ND	ND	ND	ND	-	09/17/90
68.	76		X	0.004	ND	ND	ND	ND	ND	ND	-	10/04/90
69.	77		X	ND	ND	ND	ND	ND	ND	ND	-	11/02/90
70.	78		X	ND	.02	.06	ND	ND	ND	ND	-	11/29/90
Incinerator Ash												
1.	11		X	ND	ND	ND	ND	ND	ND	ND	-	03/00/87
2.	17		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	07/17/87
3.	28		X	<.001	<.001	<.001	<.001	<.001	<.001	<.001	NC-<.001	02/23/88
4.	36		X	.01	<.01	<.01	<.01	<.01	<.01	<.01	ND	08/12/88
5.	40		X	<.01	<.01	<.01	<.01	<.01	<.01	<.01	ND	09/22/88
6.	42		X	<.01	<.01	<.01	<.01	<.01	<.01	<.01	NC-<.01	11/08/88

Table C1 (cont)

	Test No.	Test Results Expl	Test Results Non Expl	Percent Explosive Ingredients Detected 2,4 DNT	DEDGN	NG	HMX	RDX	AKII	2,4,6 TNT	Other	Date Tested
Nitrocellulose												
1. Lagoon #403-2	-		X	ND	ND	ND	ND	ND	ND	ND	NC-4.4	01/09/89
2. Lagoon #403-3	-		X	ND	ND	ND	ND	ND	ND	ND	NC-1.1	01/09/89
Hazards Test Area												
1. Sand Recovered After Hazards Stack Test on NOSIH-AA2	-		X	<.0005	<.0005	<.0005	<.0005	<.0005	-	<.0005	1,2 DNG <.0005 1,3 DNG <.0005	-
2. Crushed Stone From Hazards Test Pit	20		X	<.001	<.011	.034	.009	.185	<.001	<.001	NC-<.001	09/17/87
3. Crushed Stone From Hazards Test Pit	39		X	.002	.02	.02	.01	.19	.003	.013	ND	09/07/88
Miscellaneous												
1. Hazards Waste Mgt Site 4	45		X	ND	ND	ND	ND	ND	ND	ND	NC-<.01[c] NO_2-320 Mgm[34] NO_3-108 Mgm[34] Cyanide-.0052 Mgm[36]	01/16/89
2. Lagoon	-		X	ND	ND	ND	ND	ND	ND	ND	ND	04/19/89
3. Clarifer Tank Study	-		X	ND	.01	.03	ND	ND	.12	ND	NC-.07	12/27/89
4. Activated Carbon from Building 3555	70		X	ND	ND	ND	ND	ND	ND	ND	0.4 Acetone Extractables	06/19/90
5. Incinerator Sludge Tanker #TTL-26	72		X	ND	ND	ND	ND	ND	ND	ND	ND	08/06/90

APPENDIX D

Glossary

Critical Diameter Test	Defined as the greatest container diameter tested which did not sustain propagation of a shock wave introduced at one end of the sample by a high-energy donor.
Critical Height to Explosion	Defined as the greatest material height tested in a given container diameter which did not result in transition from burning to an explosive reaction.
Deflagration to Detonation (DDT) Test	See Appendix A.
Detonation Velocity	Rate at which a shock wave induced at one end of a sample travels through and is sustained by the sample.
Differential Thermal Analysis	A test used to determine at what temperature propellant and explosive samples begin to thermally decompose.
Electrostatic Spark Discharge Threshold Initiation Level	The maximum electrostatic discharge energy which will not ignite propellant or explosive samples.
Explosion Temperature	The temperature which produces an explosion, ignition or decomposition of a sample in 5 seconds.
Frictional Threshold Initiation Level	The maximum frictional (sliding) energy which will not ignite propellant or explosive material.

HMX	Cyclotetramethylene-tetranitramine (also known as Homocyclomite or octagen).
Impact - Threshold Initiation Level	The maximum impact (falling weight) energy which will not ignite propellant or explosive materials.
RDX	Cyclotrimethylene trinitramine (also known as Cyclonite, Hexogen or T4).
Rifle Bullet Test	Determines the reactivity of a sample loaded into a 3 inch pipe nipple and subjected to the impact of a caliber .30 bullet.
TNT	Trinitrotoluene
USATHAMA	United States Army Toxic and Hazardous Materials Agency.
Zero Gap Test	See Appendix A