Development of a High-Temperature Two-Component Explosive for Geothermal Stimulation

A STATUS REVIEW

CONTRACT EY-76-C-06-2336
DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY

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Presented by:

ROCKET RESEARCH COMPANY

REDMOND, WASHINGTON 98052

A DIVISION OF **ROCKCOR**

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REDMOND, WASH.

LARSE CORPORATION
PALO ALTO, CALIF.

- TELEPHONE DIAL OFFICE
FAULT REPORTING AND
CONTROL SYSTEMS
- MICROWAVE RADIO FAULT
REPORTING AND
CONTROL SYSTEMS
- FIRE AND BURGLAR ALARM
COMMUNICATION SYSTEMS

946-1

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- CHEMICAL TECHNOLOGY
- ENERGY R&D
- MANUFACTURING AND
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- LICENSOR FOR CIRCUIT
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- NUCLEAR WEAPONS EFFECTS
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- PIEZOELECTRIC ACTUATORS
- THERMONUCLEAR FUSION
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**PETROLEUM TECHNOLOGY
CORPORATION**
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- OIL AND GAS WELL
EXPLOSIVE
STIMULATION
- UNDERGROUND EXPLOSIVE
FRACTURING FOR
RESOURCE EXTRACTION

**ROCKET RESEARCH COMPANY
YORK CENTER FACILITY, REDMOND, WASHINGTON**

11087-38

ROCKET RESEARCH COMPANY ORGANIZATION

ROCKET RESEARCH COMPANY PRODUCT/TECHNICAL MIX

SPACE, AIRCRAFT AND STRATEGIC/TACTICAL
SYSTEMS

ROCKET PROPULSION SYSTEMS

253-3

TRANSTAGE REM

GAS GENERATORS

643-1

747 COOL GAS
INFLATION
SYSTEM

1840-1

WPAFB HYDRAZINE
FUELED CARTRIDGE
STARTER

LOW COST STRATEGIC/ TACTICAL HARDWARE

1954-13

HAS LOW COST THRUSTERS

RRC

CHEMICAL ENERGY STORAGE (CES)

1993

H₂SO₄
CES SYSTEM

ENERGY

TIRE SEALANT

1842-32

SEALANT APPLICATOR

PASSIVE RESTRAINT

1707-2

RSFS ALL-PYRO
INFLATOR

AUTOMOTIVE PRODUCTS

SPACE SHUTTLE APU GAS GENERATOR

VIKING LANDER PROGRAM

VIEW OF RRC TERMINAL DESCENT ENGINE FROM MARS

747 SHIPSET OF SLIDE INFLATION SYSTEMS

24296 643-1

747 WITH ESCAPE SLIDES DEPLOYED – BANGOR, MAINE

20073

ROCKCOR, INC.
ENERGY TECHNOLOGY

	CURRENT RESOURCES				FUTURE RESOURCES		
	OIL & GAS	COAL	FISSION	POWER TRANSMISSION/ CONVERSION	SOLAR	GEOTHERMAL	FUSION
ROCKET RESEARCH COMPANY	WASTE HEAT RECOVERY ○	CATALYST R&D FOR METHANATION ○ WASTE HEAT RECOVERY	WASTE HEAT RECOVERY	EXPLOSIVE SWITCHES ○ EXPANSION ENGINES ○ WASTE HEAT RECOVERY ●	ENERGY STORAGE CHEMICAL PHASE CHANGE ○ FUEL CELL ○	HIGH TEMP EXPLOSIVE FOR STIMU- LATION ●	
PHYSICS INTERNATIONAL COMPANY	DYNAFRAC PROCESS ● SONIC JET IGNITION ●	COAL FRAC - RECOVERY OF METHANE ○ EB PROCESSING ○	ELECTRIC BREEDER FOR FUEL SUPPLY ○ PICSES ANALY- SIS OF NUCLEAR REACTOR SAFETY ●	HIGH SPEED SWITCHING			ADVANCED CONCEPTS INCLUDING E BEAM HEATED SOLENOID AND PELLET COMPRESSION ●
PETROLEUM TECHNOLOGY CORPORATION	CHEMICAL EX- PLOSIVE STIMULATION ●		IN SITU LEACH MINING OF URANIUM ORES			EXPLOSIVE STIMULATION PROCESS ○	
LARSE CORPORATION	PIPELINE MONITORING AND CONTROL SYSTEMS ●			STATUS MONITORING SYSTEMS ○			

○ PROPOSALS
● UNDER CONTRACT

LARSE CORPORATION PRODUCTS

**LARSE 3002
MULTIPOINT ALARM SYSTEM
MASTER TERMINAL UNITS**

**LARSE DATA
COMMUNICATOR
MODULE**

**LARSE 3009
COMPUTER BASED FAULT
REPORTING AND
CONTROL SYSTEM**

PETROLEUM TECHNOLOGY CORPORATION
ASTRO FLOW II CHEMICAL EXPLOSIVE FRACTURING EQUIPMENT

PTC REMOTE CONTROL WELL HEAD "CHRISTMAS TREE"

ASTRO FLOW II PROCESS

**EXPLOSIVES
MANUFACTURED
DOWNHOLE**

**INJECTED INTO THE
FORMATION**

PHYSICS INTERNATIONAL PRODUCTS

AURORA FLASH X-RAY MACHINE INSTANTANEOUS
POWER LEVEL OF 25 MILLION-MILLION WATTS

TEMPS GENERATOR PRODUCES ELECTROMAGNETIC
PULSE TO SIMULATE NUCLEAR ENVIRONMENT FOR
ELECTRONIC COMPONENT TESTING

PULSERAD 1480 BUILT FOR FRENCH GOVERNMENT.
POWER OUTPUT EXCEEDS 1 TRILLION WATTS.

INTERIOR OF AURORA X-RAY MACHINE

PULSERAD 225-W ELECTRON BEAM ACCELERATOR.
OUTPUT OF 1 MILLION ELECTRON VOLTS AT
200,000 AMPERES.

**A HIGH-TEMPERATURE EXPLOSIVE FOR EXPLORATION AND
DEVELOPMENT OF GEOTHERMAL ENERGY SOURCES**

OBJECTIVE

- **TWO-COMPONENT LIQUID EXPLOSIVE**
- **NONDETONABLE COMPONENTS**
- **CAPABLE OF WITHSTANDING TEMPERATURE ENVIRONMENT
IN GEOTHERMAL WELLS**
- **STABLE FOR AT LEAST 24 HOURS AT 477°K (400°F) OR
SHORTER PERIODS AT UP TO 561°K (550°F)**

APPLICATIONS OF HIGH-TEMPERATURE EXPLOSIVE

VAPOR-DOMINATED RESERVOIRS

- INCREASE FLOW RATE IN PRODUCING WELLS
- STIMULATE MARGINAL WELLS
- SAVE DRILLING TIME BY STIMULATING SHALLOW WELLS

LIQUID-DOMINATED RESERVOIRS

- INCREASE PERMEABILITY IN PRODUCING WELLS
- REMOVE SCALE DEPOSITS IN REINJECTION WELLS

DRY HOT ROCK BEDS

- CONNECTING INJECTION AND PRODUCTION WELLS
- "RUBBLIZING" OF ROCK TO INCREASE SURFACE AREA AND ACCELERATE RATE OF HEAT TRANSFER

PUBLISHED RESULTS OF EXPLOSIVE STIMULATION TREATMENTS

Area or Company	No. of Wells	Average Production Before Shot	Average Production After Shot	Improvement Ratio Avg & Max
Kentucky	6,370	53 MCF/D	253 MCF/D	4.8 - 250
Western Co.	8	21 BBL/D	80.5 BBL/D	3.8 - 12
Dowell	4	Oil Wells		13.6 - 25
	6	Oil Wells		14.4 - 23
Talley	3	260 MCF/D	998 MCF/D	3.8 - 9
	4	11.6 BBL/D	30.3 BBL/D	2.6 - 14

**USBM/ERDA CHEMICAL EXPLOSIVE FRACTURING OF GAS WELLS
SUMMARY OF RESULTS**

Well Designation	Amount of Explosive Injected kg lb	Well History	Results
Hampshire No. 10	9,149 20,170	Drilled 1964, acidized once,	No change. Hole diameter increased from 6 inches (15 cm) to 9-10 inches (22 to 25 cm)
Hampshire No. 18	10,333 22,780	Drilled 1968, acidized twice, no improvement as result of previous treatments	Inflow improved by factor of 1.66
Columbia No. 20117-T	13,753 30,320	Completed 1975, no previous stimulation attempts	Productivity increased. Well could not be cleaned out

EXPLOSIVES SELECTION FOR GEOTHERMAL WELL STIMULATION

PHYSICAL STATE	ADVANTAGES	DISADVANTAGES
SOLID	HIGH ENERGY DENSITY. EXISTING HIGH-TEMPERATURE RESISTANT SOLID EXPLOSIVES.	EXPLOSIVE HAZARD ABOVE GROUND. EXPENSIVE. HOLE CANNOT BE ENTIRELY FILLED WITH SOLIDS.
LIQUID	HIGH ENERGY DENSITY. CLOSE COUPLING POSSIBLE.	NOT ALL LIQUIDS ARE READILY MISCIBLE. LIQUIDS ARE GENERALLY THERMALLY LESS STABLE THAN SOLIDS.
GASEOUS	READILY MIXED. CLOSE COUPLING POSSIBLE	LOW ENERGY DENSITY. ONLY FEW COMBINATIONS KNOWN.

PROPERTIES OF EXPLOSIVES UNDER CONSIDERATION FOR GEOTHERMAL APPLICATION

Explosive	Density gm/cm ³	Melting Point °K	Current Thermal Application Range °K	Detonation Velocity m/sec	Detonation Pressure K bar	Impact(1) Sensitivity cm (solids) Joules/sec (liquids)	Comments
<u>Solids</u>							
Z-TACOT	1.85	683	561-589	7,200	180		Commercially available. Sole source supply until patent expires
HNS	1.74	591	533-561	7,100	230	39	Commercially available
PYX	1.77	—	561-589	7,800	270	63	Developed by LASL, currently no commercial source
PATO	1.94	593	505-533	-	307	320	Developed by LASL, currently no commercial source
DATB	1.84	562	505-533	7,700	282	320	Used in military service, commercially available
TATB	1.94	(2)	533-561	7,970	313	320	May be commercially available in near future. ERDA-controlled supply

Notes:

(1) Type 12 impact tool for solid explosives

(2) Does not melt prior to decomposition

LOGIC DIAGRAM -- HIGH TEMPERATURE EXPLOSIVE

PHYSICAL PROPERTIES OF INORGANIC OXIDIZERS

Compound	Formula	Molecular Weight	Melting Point °K	Temp. for Density °K	Density g/cm ³	Useful Oxygen % by Wt.	Useful Oxygen g/cm ³	Heat of Formation at 298°K	
								kcal/mol	kJ/mol
Nitric acid (100%)	HNO ₃	63.013	231	298	L* 1.5027	63.48	0.954	-41.40	-173.2
Lithium nitrate	LiNO ₃	68.944	537	293	S* 2.388	58.02	1.385	-115.3	-482.4
				631.6	L 1.723		1.000		
				882.5	L 1.586		0.920		
Lithium perchlorate	LiClO ₄	106.390	509	293	S 2.428	60.15	1.460	-90.89	-380.3
Calcium perchlorate	Ca(ClO ₄) ₂	238.98	543	293	S 2.651	53.56	1.420	-178.0	-744.0
Sodium perchlorate	NaClO ₄	122.44	755 (d)	298	S 2.536	52.27	1.326	-91.48	-382.7
Calcium nitrate	Ca(NO ₃) ₂	164.09	834	291	S 2.651	53.56	1.420	-178.0	-744.0
Sodium nitrate	NaNO ₃	84.995	580	293	S 2.261	47.06	1.064	-101.5	-424.7
				594.6	L 1.900		0.894		
				1011.4	L 1.620		0.762		
Nitric acid (68%)	HNO ₃ · H ₂ O			293	L 1.41	43.17	0.609		
Potassium perchlorate	KClO ₄	138.55	883	283	S 2.55	40.42	1.018	-103.6	-433.0
Potassium nitrate	KNO ₃	101.11	607	293	S 2.10	39.6	0.832	-117.7	-492.0
				653.1	L 1.837		0.727		
				1044.7	L 1.537		0.609		
Sodium nitrite	NaNO ₂	68.995	544	273	S 2.168	34.78		-85.9	-359.4
Calcium nitrate tetrahydrate	Ca(NO ₃) ₂ · 4H ₂ O	236.15	315.8	293	S 1.896	33.87	0.642	-509.37	-2131
Ammonium perchlorate	NH ₄ ClO ₄	117.49	dec.	293	S 1.95	34.04	0.664	-70.74	-296.0
Ammonium nitrate	NH ₄ NO ₃	80.043	442.8	298	S 1.725	19.99	0.345	-87.93	-367.9

* L = Liquid S = Solid

COMPATIBILITY TESTING EQUIPMENT SET-UP

ANALYTICAL RESULTS OF POST-TEST THERMAL STABILITY SAMPLES – 24 HOURS

<u>Sample¹</u>	<u>Test Temp. (°K)</u>	<u>% Nitrate Loss</u>	<u>Gases Detected</u>
HTS + Guanidinium Nitrate (GuNO ₃)	505	8	
HTS + Ethyleneglycol (EG)	505	34	
HTS + Sulfolane	505	12	
HTS + Diethyleneglycol (DEG)	505	40	
(LiNaK)NO ₃ + Formamide	505	14	
(LiNaK)NO ₃ + GuNO ₃	505	21	
(LiNaK)NO ₃ + EG	505	28	
(LiNaK)NO ₃ + Sulfolane	505	23	
(NaKCa)NO ₃ · 4H ₂ O + GuNO ₃	505	12	
(NaKCa)NO ₃ · 4H ₂ O + Acetamide	505	38	
(NaKCa)NO ₃ + Acetamide	533	35	CH ₄ , CO, CO ₂ , NO _x
(NaKCa)NO ₃ · 4H ₂ O + EG	505	32	
(NaKCa)NO ₃ + Dimethylformamide	505	45	H ₂ , CH ₄ , CO, CO ₂ , NO _x
(NaKCa)NO ₃ + Sulfolane	505	31	CO ₂ , NO _x
(NaKCa)NO ₃ + Sulfolane	533	57	
(NaKCa)NO ₃ · 4H ₂ O + DEG	505	25	
(NaKCa)NO ₃ + M-Pyrol	533	50	CO ₂ , NO _x
(NaKCa)NO ₃ + DEGDME	533	40	
(NaKCa)NO ₃ + DEGMEE	533	60	
(NaKCa)NO ₃ + Triethyleneglycol	533	43	
(NaKCa)NO ₃ + Phthalonitrile	533	7	
(NaKCa)NO ₃ + Phthalimide	533	13	
(NaKCa)NO ₃ + Dibutylphthalate	533	10	
(NaKCa)NO ₃ + Triphenylphosphate	533	55	CO, CO ₂ , NO _x
(NaKCa)NO ₃ only	533	16	

¹The initial sample size is 4 g

**ANALYTICAL RESULTS OF POST-TEST THERMAL STABILITY SAMPLES --
6 HOURS AT 505°K**

<u>Sample</u>	<u>% Nitrate Loss</u>	<u>Nitrite as mg NaNO₂</u>	<u>Carbonate as mg CO₂</u>	<u>Gases Detected</u>
(NaKCa)NO ₃ + Acetamide	3.4	0.004	4.3	CO ₂ , NO _x
(NaKCa)NO ₃ + Ethyleneglycol	3.4	0.036	1.6	CO, CO ₂ , NO _x
(NaKCa)NO ₃ + Dimethylformamide	31	0.03	202.5	H ₂ , CH ₄ , CO, CO ₂ , NO _x
(NaKCa)NO ₃ + Sulfolane	21	0.76	58	CO, CO ₂ , NO _x
(NaKCa)NO ₃ + Phthalimide	0	0.003	0.5	CO ₂ , NO _x
(NaKCa)NO ₃ + Dimethylphthalate	0	0.80	—	CO, CO ₂ , NO _x
(NaKCa)NO ₃ + 4,4'-Thiodiphenol	0	0.084	—	CO ₂ , NO _x
(NaKCa)NO ₃ + Triphenylphosphate	9.4	0.80	4.1	CO, CO ₂ , NO _x

RESULTS OF MATERIALS COMPATIBILITY TESTS AT 505°K FOR 24 HOURS

<u>Sample</u>	<u>% Nitrate Loss</u>
HTS + acetamide + graywacke, unidentified	10
[(NaKCa)NO ₃ + acetamide] = X	13
X + graywacke, from Geysers, CA	4
X + LASL EE-1 well sample from Jemez Mt., NM	4
X + Volcanic tuffs from Weiraki, New Zealand	6
[NaKCa)NO ₃ + guanidinium nitrate + acetamide] = Y	7
Y + graywacke, from Geysers, CA	7
Y + LASL EE-1 well sample from Jemez Mt., NM	0
Y + Volcanic tuffs from Weiraki, New Zealand	7
Y + Dextrid - XC polymer KCl mud ⁽¹⁾ /BaSO ₄	7
Y + Carbonox-Q-Broxin mud ⁽¹⁾ /BaSO ₄	11
Y + Invermul mud ⁽¹⁾ BaSO ₄	18
Y + Pipe thread lubricant, UOCS ⁽²⁾ #1	7
Y + Scrapings from an old 13-3/8-inch diameter casing, UOCS #2	14
Y + Scrapings from a rusty 4-1/2-inch diameter drill pipe, UOCS #3	32
Y + Unisteam, UOCS #4	11
Y + Drilling mud, UOCS #5	0
Y + Cement sample, UOCS #6	0
Y + Cement and micrograywacke cuttings, UOCS #7	0
Y + Unwashed greenstone cuttings, UOCS #8	4
Y + Unwashed graywacke cuttings, UOCS #9	7
Y + Unwashed serpentine cuttings, UOCS #10	0
Y + Used bearing from a well, UOCS #11	7
Y + Perlite, UOCS #12a	0
Y + HR-T, UOCS #12b	30
Y + SAA1 silica flour, UOCS #12c	6
Y + HR-12, UOCS #12d	25
Y + POZ, UOCS #12e	11
Y + Class "G" cement, UOCS #12f	6
Y + CFR 2, UOCS #12g	14
Y + Steam condensate, UOCS #13	6

(1) These mud samples were obtained from Dr. A. Spencer. They were combined with 20% by weight BaSO₄.

(2) UOCS = Union Oil Company Sample. These samples were obtained from Union Geothermal Division of Union Oil Company of California, located in Santa Rosa. Additional details of these samples can be found in the correspondence from Jack Hartz of Union Oil Company to Dr. E. Schmidt of ROCKCOR, dated September 21, 1977.

SEALED MILD STEEL PIPE DETONABILITY TEST SAMPLE HOLDERS

76mm DIAMETER DETONABILITY TESTS BEFORE AND AFTER DETONATION

COMPARISON OF TARGET PLATE PERFORATIONS BY PTC-4 AND A HIGH-TEMPERATURE EXPLOSIVE

DETONATION TEST RESULTS – OPEN PIPE TESTS

Oxidizer	Fuel	Temperature		Initiation	Witness Plate Indentation (mm)
		°K	°F		
C-4	C-4	293	77	Cap	∞
PTC-4 ¹	PTC-4	293	77	Cap + C-4 ²	∞
NaClO ₄	Guanidinium nitrate	561	550	Cap + C-4	∞
NaClO ₄ · H ₂ O	Triethylene glycol	552	534	Autodetonated	∞
(NaKCa) NO ₃	Guanidinium nitrate	561	550	Cap	∞
(NaKCa) NO ₃	Acetamide	480	405	Cap + C-4	37 ³
NaClO ₄	Diethylene glycol	519	475	Cap + C-4	30 ⁴
NaClO ₄	Ethylene glycol	469	385	Cap + C-4	28 ⁴
(NaKCa) NO ₃ · 4H ₂ O	Sulfolane	533	500	Cap	28 ⁴
(LiNaK) NO ₃ + NaClO ₄	Glycerol	555	540	Cap + C-4	25
HNO ₃ + H ₂ O	Nitrobenzene	293	77	Cap	25
NaClO ₄	Ethylene glycol	472	390	Cap	19 ⁴
NaClO ₄	Diethylene glycol	505	450	Cap	18
NaClO ₄	Guanidinium nitrate	561	550	Cap	17
(LiNaK) NO ₃	Ethylene glycol	477	400	Cap + C-4	17
(NaKCa) NO ₃ · 4H ₂ O	Triphenylphosphate	533	500	Cap	16
(NaKCa) NO ₃ · 4H ₂ O + NaClO ₄	Dibutylphthalate	561	550	Cap	14
NaClO ₄ · H ₂ O	Acetamide	505	450	Cap	13
(LiNaK) NO ₃ + NaClO ₄	Glycerol	561	550	Cap	13
None	m-Dinitrobenzene	561	550	Cap	12
KClO ₄	m-Dinitrobenzene	550	530	Cap	10
HTS ⁵	Melamine	561	550	Cap	10
HTS + NaClO ₄	Dibutylphthalate	533+	500+	Cap	9

DETONATION TEST RESULTS – OPEN PIPE TESTS

Oxidizer	Fuel	Temperature		Initiation	Witness Plate Indentation (mm)
		°K	°F		
(NaKCa) NO ₃ • 4H ₂ O	Acetamide	505	450	Cap	8
(LiNaK) NO ₃	Diethylene glycol	505	450	Cap	8
HTS	Dimethylphthalate	550	530	Cap	7
None	2,4-Dinitrotoluene	522	480	Cap + C-4	7
None	2,4-Dinitrotoluene	561	550	Cap	6
(LiNaK) NO ₃	Glycerol	544	520	Cap	6
None	m-Dinitrobenzene	547	525	Cap + C-4	5
(NaKCa) NO ₃	Silicone oil	505	450	Cap	5
HTS	Dibutylphthalate	561	550	Cap	4
HTS	Ethylene glycol	466	380	Cap	3
HTS	Dowtherm G	533	500	Cap + C-4	3
HTS	Dibutylphthalate	561	550	Cap + C-4	3
HTS	Acetamide	505	450	Cap	1
HTS	Dibutylphthalate	293	77	Cap	None
HTS	Glycerol	477	400	Cap	None
HTS	Formamide	477	400	Cap	None
HTS	Mineral oil	505	450	Cap	None
HTS	Dowtherm G	533	500	Cap	None ⁶
HTS	Therminol 55	561	550	Cap	None
HTS	Triphenylphosphate	561	550	Cap	None
HTS	Sulfolane	533	500	Cap	None ⁶
(LiNaK) NO ₃	Ethylene glycol	472	390	Cap	None
(LiNaK) NO ₃	Acetamide	505	450	Cap	None

DETONATION TEST RESULTS – OPEN PIPE TESTS

Oxidizer	Fuel	Temperature		Initiation	Witness Plate Indentation (mm)
		°K	°F		
(LiNaK) NO ₃	Dibutylphthalate	561	550	Cap	None
(LiNaK) NO ₃	Sulfolane	533	500	Cap	None ⁶
(LiNaK) NO ₃ + NaClO ₄	Dibutylphthalate	561	550	Cap	None ⁶
(NaKCa) NO ₃ • 4H ₂ O	Dibutylphthalate	561	550	Cap	None
(NaKCa) NO ₃ • 4H ₂ O	Dimethylphthalate	550	530	Cap	None ⁶
(NaKCa) NO ₃ • 4H ₂ O	Therminol 66	561	550	Cap	None
(NaKCa) NO ₃	Acetamide	293	77	Cap	None
(NaKCa) NO ₃	Guanidinium nitrate + acetamide (70/30)	297	75	Cap	None
NaClO ₄	Melamine	293	77	Cap	None
None	m-Dinitrobenzene	373	212	Cap	None
None	Guanidinium nitrate + H ₂ O	293	77	Cap	None

ANNOTATIONS:

- 1 PTC-4 – Proprietary explosive of Petroleum Technology Corporation, a subsidiary of ROCKCOR, Inc.
- 2 A Hercules No. 8 blasting cap and 20 g booster charge of composition C-4.
- 3 This was a 1-5/8" (dia) x 12" open pipe bomb containing slightly over one pound of the explosive mixture. All the others in the table were 100 g mixtures.
- 4 Witness plate penetrated, but not to the extent that a high order detonation occurred.
- 5 HTS = heat treatment salt = KNO₃ : NaNO₃ : NaNO₂ (53 : 7 : 40% by weight).
- 6 The explosion was somewhat louder than just the blasting cap.

NOTE: All immiscible mixtures contained 2% Cab-O-Sil and were stirred while hot, just prior to initiation, by a remotely activated stirrer.

**DETONABILITY TEST RESULTS OF SOME MIXTURES
OF GUANIDINIUM NITRATE AND ACETAMIDE**

Sample ¹	Temperature		Initiation	Result
	°K	°F		
Guanidinium nitrate + acetamide (65/35) ³	505	450	Cap ²	Negative
Guanidinium nitrate + acetamide (75/25)	505	450	Cap	Negative
Guanidinium nitrate + acetamide (85/15)	505	450	Cap	Negative
Guanidinium nitrate	505	450	Cap	Negative
Guanidinium nitrate + acetamide (70/30) ⁴	477+	400+	Cap + C-4 (20g)	Negative

¹ Unless otherwise specified, these were 80 g samples in 37 mm diameter pipes

² Hercules No. 8 detonator squib

³ The numbers in parentheses indicate percent by weight of each, respectively

⁴ This was a 5 lb mixture. It was tested in a 3-inch diameter pipe

COOK-OFF TEST RESULTS¹

Sample	Average Heating Rate		Result	Exotherm	Heating Rate at Exotherm Temp.		DSC Exotherm ²
	°K/min	°F/min			°K/min	°F/min	
1. (NaKCa) NO ₃ + acetamide	5.1	9.2	Blew top at 639°K (690°F)	586°K (596°F)	2.6	4.6	537°K
2. (NaKCa) NO ₃ + phthalimide	5.6	10.0	Blew top at 575°K (575°F)	537°K (508°F)	1.4	2.5	536°K
3. (NaKCa) NO ₃ + sulfolane	7.5	13.5	Deflagrated at 585°K (594°F)	543°K (518°F)	5.9	10.7	410°K
4. (NaKCa) NO ₃ + dimethylformamide	6.4	11.5	Blew top at 525°K (485°F)	516°K (470°F)	2.0	3.7	484°K
5. (NaKCa) NO ₃ + triphenylphosphate	6.5	11.7	Blew top at 581°K (586°F)	553°K (536°F)	5.6	10.0	542°K
6. NaClO ₄ + guanidine nitrate	3.0	5.4	Blew top at 744°K (880°F)	563°K (554°F)	0.6	1.0	568°K
7. (NaKCa) NO ₃ + M-pyrol	6.2	11.0	Burst at 511°K (460°F)	505°K (450°F)	Unknown		495, 537°K
8. (NaKCa) NO ₃ + guanidine nitrate ³	2.8	5.1	Burst at 691°K (785°F)	585°K (593°F)	0.94	1.7	588°K
9. (NaKCa) NO ₃ + guanidine nitrate ³ + acetamide	3.0	5.5	Burst at 592°K (606°F)	568°K (563°F)	0.78	1.4	506°K
10. (NaKCa) NO ₃ + acetamide + unidentified graywacke ⁴	5.0	9.0	Burst at ~639°K (~690°F)	555°K (540°F)	1.3	2.3	531°K

1. These were 175-g samples unless otherwise specified. Each was shaken for 5 minutes after the sample temperature reached 400°F.

2. The DSC exotherms were determined at a heating rate of 20°K/min.

3. These were 150-g samples.

4. This contained 130 g of the explosive mixture (slightly underoxidized due to a mix-up) and 10 g of graywacke.

DETONATION TEST RESULTS – SEALED PIPE

Oxidizer	Fuel	Temperature		Initiation	Result
		°K	°F		
C-4	C-4	293	77	Cap + S.C. ¹	Positive High order detonation
PTC-4	PTC-4	293	77	Cap + S.C.	Positive
(NaKCa) NO ₃ · 4H ₂ O	Formamide ²	>394	>250	Cap + S.C.	Negative ³
(NaKCa) NO ₃ · 4H ₂ O	Acetamide ²	505	450	Cap + S.C.	Negative ³
NaClO ₄	Guanidinium nitrate	550	530	Cap + S.C.	Positive ³
(NaKCa) NO ₃	Dimethylformamide	511	460	Cap + S.C.	Positive
(NaKCa) NO ₃	Acetamide	~519	~475	X-321-K Cap	Positive
(NaKCa) NO ₃	Acetamide	516	470	Cap + S.C. ⁴	Positive
(NaKCa) NO ₃	Acetamide	516	470	Cap + S.C.	Positive
(NaKCa) NO ₃	M-Pyrol	505	450	Cap + S.C.	Negative
(NaKCa) NO ₃	Triethylene glycol	494	430	Cap + S.C.	Positive
(NaKCa) NO ₃	Phthalonitrile	511	460	Cap + S.C.	Negative
(NaKCa) NO ₃	Phthalimide	533	500	Cap + S.C.	Positive

NOTES:

¹ A Hercules No. 8 blasting cap attached to the groove of a shaped charge. The groove of the shaped charge was filled with approximately 2 g of C-4. The shaped charge was aimed through the side of the sealed pipe at a 45° downward angle at the liquid surface.

² The fuel was sealed in a polyethylene bag.

³ These were 100 g mixtures. All the others were 175 g mixtures.

⁴ The shaped charge was initiated through the top of the sealed pipe for this test only.

DETONABILITY OF $\text{NaClO}_4\text{-GuNO}_3$ MIXTURE UNDER VARIED CONDITIONS

TWENTY-FOUR-HOUR DETONATION TEST RESULTS

Sample ¹	Test Temperature		Duration (hrs)	Result
	(°K)	(°F)		
1. (NaKCa)NO ₃ + acetamide	491 ± 10	425 ± 20	23	Detonated on command ²
2. (NaKCa)NO ₃ + sulfolane	491 ± 10	425 ± 20	21	Detonated on command
3. NaClO ₄ + Guanidinium nitrate (GuNO ₃)	533 ± 10	500 ± 20	24	Detonated on command
4. (NaKCa)NO ₃ + triphenylphosphate	505 ± 10	450 ± 20	24	Negative
5. (NaKCa)NO ₃ + dimethylformamide	478 ± 10	400 ± 20	1.3	Burst by itself
6. (NaKCa)NO ₃ + phthalimide	505 ± 10	450 ± 20	10	Burst by itself
7. (NaKCa)NO ₃ + acetamide	561 ± 10	550 ± 20	24	Burst or deflagrated on command ³
8. NaClO ₄ + GuNO ₃	561 ± 10	550 ± 20	24	Burst or deflagrated on command
9. (NaKCa)NO ₃ + GuNO ₃	561 ± 10	550 ± 20	24	Burst or deflagrated on command
10. (NaKCa) + GuNO ₃ + acetamide	505 ± 10	450 ± 20	24	Detonated on command

¹ Sample sizes varied from 100 g (for No. 3 and No. 9), 150 g (for No. 10), to 175 g (for the rest), depending on the ease of loading the 1.5-inch diameter pipe bombs.

² The top and main body of the pipe were blown into fragments. The threaded bottom cap of the pipe was flared and the witness plate was distorted.

³ The pipe sheared off above the bottom cap leaving it and the witness plate essentially intact with minimal distortion.

ADIABATIC COMPRESSION TEST APPARATUS

ADIABATIC COMPRESSION TEST RESULTS¹

Sample	Sample Size (g)	Temperature °K	Heating Time (min)	Result
N ₂ H ₄	3.2	387 (238°F)	17	—
N ₂ H ₄	3.2	394 (250°F)	14	—
N ₂ H ₄	4.1	422 (300°F)	8.5	+
(NaKCa)NO ₃	3.2	533 (500°F)	12.5	—
GuNO ₃ -AcNH ₂ ²	3.2	533 (500°F)	12	—
(NaKCa)NO ₃ -GuNO ₃ -AcNH ₂ ³	3.2	550 (530°F)	20	+
(NaKCa)NO ₃ -GuNO ₃ -AcNH ₂ ³	3.2	533 (500°F)	8.5	—
(NaKCa)NO ₃ -GuNO ₃ -AcNH ₂ ³	4.1	561 (550°F)	15	—
(NaKCa)NO ₃ -GuNO ₃ -AcNH ₂ ³	4.1	568 (563°F)	15.5	—

¹ Each sample was suddenly compressed with 2,000 psi of N₂ within 3 ms, at an average rate of 670,000 psi/s

² This is 70 to 30% by weight mixture of guanidinium nitrate and acetamide, respectively.

³ This is a 58.7% — 28.9% — 12.4% by weight mixture. The mixture was premolten in a test tube and later transferred to the sample U-tube.

ELECTROSTATIC DISCHARGE (ESD) TEST RESULTS

Sample conditions: Molten. temperature 400°F

Test conditions: Room temperature – 70°F
Relative humidity – 15%

Test Level (Joules)	No. of Shots	Total No. of Trials
5.0	10	10
1.26	8	10
0.50	4	10
0.075	0	20

FRICTION SENSITIVITY TEST RESULTS

Sample conditions: Solid

Test conditions: Temperature – 66°F
Relative humidity – 61°F
Steel components

Test Velocity (mps)	Energy Level (N/m ²)	No. of Shots	Total No. of Trials
3.0	12.1 x 10 ⁸	1	18
	10.2 x 10 ⁸	1	10
	8.8 x 10 ⁸	1	10
	7.5 x 10 ⁸	0	20
2.4	9.9 x 10 ⁸	0	20

NOTE: LIRA infrared analyzer used to detect reaction.

For the 2.4 mps friction test, 9.9 x 10⁸ N/m² was the highest test level attainable consistent with a proper test.

TIL is 7.5 x 10⁸ N/m² for 3 mps friction.

TIL is greater than or equal to 9.9 x 10⁸ N/m² for 2.4 mps friction.

Friction sample was 0.080" thick sheet.

DETONATION ARREST TEST FIXTURE

**CROSS SECTION OF DETONATION ARREST TEST FIXTURE AT DONAR
INTERFACE ACCEPTOR**

DETONATION ARREST FIXTURE AFTER DETONATION OF MIXED UPPER SECTION

HIGH PRESSURE DETONABILITY TEST BOMB

11112-09 2025-4

-ASSY - 301-11-

DETONATION VELOCITY TEST FIXTURES DURING ASSEMBLY

REMAINS OF DETONATION VELOCITY TEST FIXTURES

11111-71

DETONATION VELOCITY TEST RESULTS

Explosive Sample	Average Detonation Velocity (m/s)	Test Designation	Remarks
(NaKCa)NO ₃ /AcNH ₂ + GuNO ₃	6,096	A	Mixed OK
	6,016	B	Mixing problems
	6,000	C	Mixed OK
(NaKCa)NO ₃ /AcNH ₂	3,810	F	Mixed OK
(NaKCa)NO ₃ /Sulfolane	2,454	H	Mixed repeatedly. Detonator not fully inserted.
	4,675		
	5,562

WEDGE TEST FIXTURE DURING ASSEMBLY

11112-08 2025-3

HITEX DETONATION VELOCITY AS A FUNCTION OF WEDGE GAP WIDTH

REMAINS OF THIN FILM PROPAGATION TEST-WEDGE TEST FIXTURE

111111-70 2025-7

DETONATOR COOK-OFF TEST RESULTS

Detonator	Manufacturer	Explosive Charge, g	Heating Rate °K/min	Temperature at Autoignition		Temperature		Time at Temperature, Minutes	Fired On Command
				°K	°F	°K	°F		
E-97	DuPont	0.356 RDX	5.6	460	368	---	---	---	---
E-97	DuPont		3.4	464	376	---	---	---	---
E-97	DuPont		3.6	466	379	---	---	---	---
E-97	DuPont		2.7	461	371	---	---	---	---
E-97	DuPont		1.1	---	---	435	324	30	Yes
E-97	DuPont	Pb(N ₃) ₂	2.3	---	---	454	358	30	Yes
Number 8	Hercules		3.7	420	297	---	---	---	---
MS-250-9	DuPont		3.7	435	324	---	---	---	---
Lead azide squib	Atlas		3.6	587	597 (605)	---	---	---	---
X-321-K	DuPont		4.7	585	593	---	---	---	---

HIGH-TEMPERATURE EXPLOSIVE FOR GEOTHERMAL WELL STIMULATION

- **PHASE I — EXPLOSIVE DEVELOPMENT. CONTRACT EY-76-C-06-2336 COMPLETED**
- **PHASE Ia — EXTENDED EXPLOSIVE DEVELOPMENT. PROPOSED NOVEMBER 1977. IMMEDIATE PROGRAM START POSSIBLE.**
- **PHASE II — CONSTRUCTION OF AND ABOVE-GROUND TEST WITH MOBILE MIXING UNIT.**
- **PHASE III — LOW-PRESSURE, HIGH-TEMPERATURE GEOTHERMAL WELL DEMONSTRATION TEST**
- **PHASE IV — HIGH-PRESSURE, HIGH-TEMPERATURE MOBILE MIXING UNIT DEVELOPMENT AND CONSTRUCTION.**

**PHASE Ia – EXTENDED HIGH-TEMPERATURE EXPLOSIVE EVALUATION
FOR GEOTHERMAL WELL STIMULATION***

- COMPATIBILITY WITH MATERIALS OF CONSTRUCTION
- PHYSICAL PROPERTIES
- ENVIRONMENTAL IMPACT ASSESSMENT
- ANALYSIS OF EXPLOSIVE RESIDUES
- DETONATION VELOCITY AT HIGH PRESSURE
- FAILURE DIAMETER AT HIGH PRESSURE
- EFFECT OF STEAM OR BRINE DILUTION
- HIGH-TEMPERATURE DETONATOR/BOOSTER DEVELOPMENT
- PROGRAM PLAN FOR FIELD DEMONSTRATION TEST

***RRC 78-P-826 Submitted November 11, 1977**

PHASE II – DESIGN OF LOW-PRESSURE MOBILE MIXING UNIT

- **SELECT MATERIALS**
- **SELECT COMPONENTS**
- **DESIGN FLOW DIAGRAM AND CONTROLS**
- **ENGINEERING DRAWINGS**
- **PROCUREMENT OF COMPONENTS AND HARDWARE**
- **INSTALLATION OF TANKS, AGITATORS, PUMPS, VALVES, METERS ON MIXER/PUMPER TRAILER**
- **INSTALLATION OF METERING AND CONTROL EQUIPMENT IN DATA CONTROL TRAILER (DCT)**
- **CHECKOUT RUNS WITH INERT COMPONENTS**
- **EXTENDED CLOSED LOOP OPERATION WITH ONE COMPONENT AT A TIME**
- **SELECTION OF REMOTE TEST SITE**
- **INSTALLATION OF ABOVE-GROUND SIMULATED BORE HOLE AND DISPOSAL UNIT**
- **ABOVE-GROUND DEMONSTRATION TEST WITH INVITED OBSERVERS (POTENTIAL USERS)**

PETROLEUM TECHNOLOGY CORPORATION TEST AREA AND EQUIPMENT

GENERAL LAYOUT

TRAILER-MOUNTED LOW PRESSURE RIG

RIG AND DELIVERY LINES FOR TWO COMPONENTS

EXPLOSIVE MIXING TEST SETUP AND CATCH TANK

LOCATION: ATOMIC ENERGY COMMISSION HANFORD RESERVATION WASHINGTON STATE

PETROLEUM TECHNOLOGY CORPORATION
ASTRO FLOW II CHEMICAL EXPLOSIVE FRACTURING EQUIPMENT

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ON-SITE ORIENTATION OF EQUIPMENT