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DEVELOPMENT OF ARMY HIGH-ENERGY FUEL FOR DIESEL/ TURBINE-POWERED SURFACE EQUIPMENT—PHASE II

INTERIM REPORT
AFLRL No. 147

By

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This document reports on the second phase of the U.S. Army's ongoing program for high-energy fuels for diesel/turbine-powered surface equipment. The first phase was reported in AFLRL No. 120, AD A091318, February 1980, and covers the period from October 1977 to October 1979.

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The Army is interested in those fuels that have a high-energy content per unit volume and therefore result in increased payload capabilities and/or extended operational range of the vehicle. A series of screening processes are being used to identify those fuels and/or fuel components that could result in an increase of 10 percent in the range of the vehicle without an increase in the fuel tank size, i.e., fuels with a high-energy content percent volume. The chemical and physical properties of various candidate

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20. ABSTRACT (Cont'd)

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fuels and fuel components are described. The fuel components included both liquids and solids (at room temperature). The blending of the various components and the characterization of the resulting fuels are outlined. Solubility studies were done on some of the solid components to assist in obtaining the resulting fuel in the more desirable liquid state. Those solid components, such as anthracene, that were insoluble in the tests conducted but judged to have good high-energy potential, were studied as slurries.

Catalyzed "carbon black" was investigated. Settling studies with carbonaceous fuels included the effect of temperature upon the stability, the stability of FRF-carbon slurries, and the refinement of the previously reported "Freezing Tube Technique" for measuring stability.

Impact dispersion tests were conducted to study the fire-safety characteristics of energy-augmented fuels. The screening of candidate fuels with the Petter engine is described in detail. Other engine studies with the CLR engine are also included.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, San Antonio, TX under Contracts DAAK70-80-C-0001 and DAAK70-82-C-0001. The work was funded by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, VA. Contracting Officer's representative was Mr. F.W. Schaekel, Fuels and Lubricants Division, Energy and Water Resources Laboratory (DRDME-GL).

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TABLE OF CONTENTS

				Page
I.	INTRODUCTION			[illegible]
II.	APPROACH			10
III.	TECHNICAL PROGRAM			12
	A.	LIQUID HIGH-ENERGY COMPONENTS		12
		1.	RJ-5	14
		2.	JP-10	14
		3.	RJ-6M	15
		4.	Tetrahydronaphthalene (Tetralin)	16
		5.	Extract From Furfural Unit	17
		6.	SRC-II	18
		7.	Polycyclic Aromatic Blending Stock	20
		8.	Burner Oil No. 5	21
		9.	No. 6 Fuel Oil (Bunker C)	21
		10.	JP-9	22
	B.	SOLID HIGH-ENERGY COMPONENTS		22
		1.	Naphthalene	22
		2.	Anthracene	24
		3.	Phenanthrene	24
		4.	SRC-I	24
		5.	Carbon Black	25
	C.	BLENDING AND CHARACTERIZATION OF LIQUID FUELS		25
		1.	SRC-II	27
			a. Augmenting SRC-II with RJ-5	27
			b. Augmenting SRC-II with JP-10	27
			c. Augmenting SRC-II with RJ-6M	32
		2.	Tetralin	32
			a. Blends with DF-2	32
			b. Blends with No. 6 Burner Fuel	32
		3.	No. 6 Burner Fuel	34
			a. Blend of No. 6 Burner Fuel With Cat-1H Diesel	34
		4.	RJ-6M	34
		5.	Furfural Extract	34
	D.	FUEL PREPARATION AND CHARACTERIZATION WITH SOLID HIGH-ENERGY COMPONENTS		34
		1.	Insoluble Components Used in Slurries	34
			a. Anthracene	34
			b. Carbon Black	36
			c. SRC-I	42
		2.	Solid High-Energy Components That Have Appreciable Solubility	43
			a. Solubility Measurements of Naphthalene and Phenanthrene	43
			b. Blending of Solid Components into Liquid Fuels	45

Page

E. IMPACT DISPERSION TESTS TO STUDY FIRE-SAFETY CHARACTERISTICS OF ENERGY-AUGMENTED FUELS.................... 45
1. RJ-5.. 45
2. DF-2.. 47
3. SRC-II.. 49
4. Other Fuels [JP-10 (neat), JP-9, and JP-10/H_2O Microemulsion]............................ 49
5. FRF-Type Fuels Augmented With RJ-5.................... 50

IV. ENGINE STUDIES.. 51
A. CLR Engine Studies...................................... 51
1. Screening Studies................................... 51
a. JP-10/H_2O Microemulsion........................ 51
b. Carbon Black Slurries in FRF.................... 53
c. Catalyzed Carbon Black.......................... 57
B. Petter Engine.. 62
1. Baseline No. 1...................................... 64
a. Fuel Blends..................................... 64
b. Energy-Augmented FRF Blends..................... 65
2. Baseline No. 2...................................... 68
a. Fuel Blends..................................... 68
b. Energy-Augmented FRF Blends..................... 74

V. CONCLUSIONS AND RECOMMENDATIONS.............................. 74
A. Conclusions.. 74
B. Recommendations.. 77

VI. REFERENCES.. 78

APPENDICES
A-1 Inspection Data on SRC-II, Middle Distillate.................. A-3
A-2 Materials Safety Data Sheet SRC-II Material................... A-4
B-1 AFLRL Fuel No. AL-10115-F (Cat-1H)............................ B-3
B-2 AFLRL Fuel No. AL-8821-F (DF-2)............................... B-4
B-3 AFLRL Fuel No. AL-7225-F...................................... B-5
C Freezing Tube Technique... C-3
D Impact Dispersion Test.. D-3
E Data Correction Program for Petter Engine Data.................. E-3
F Data for Baseline No. 1 (Petter Engine)......................... F-3
G Data for Baseline No. 2 (Petter Engine)......................... G-3
H-1 Carbon Black (Raven 1170)..................................... H-3
H-2 Carbon Black (SL-90).. H-4
H-3 Carbon Black (Mogul L).. H-5

LIST OF TABLES

Table		Page
1	Liquid High-Energy Components	13
2	Typical Properties of RJ-5	14
3	Typical Properties of JP-10	15
4	Properties of RJ-6M	15
5	Experimentally Determined Cetane Numbers of RJ-6M With and Without Cetane Improvers	16
6	Typical Properties of Tetralin Solvent	16
7	Properties of Furfural Extract	17
8	Properties of SRC-II (2.9 to 1, Middle Distillate to Heavy Distillate)	18
9	Cetane Determinations of SRC-II With Various Concentrations of Cetane Improver and Blended With DF-2	19
10	Properties of SRC-II (Middle Distillate)	20
11	Properties of Polycyclic Aromatic Blending Stock	20
12	Properties of No. 5 Burner Oil	21
13	Properties of No. 6 Fuel Oil	22
14	Solid High-Energy Components	23
15	Typical Properties of SRC-I	25
16	Laboratory Inspection of Baseline Fuel (Control Fuel)	26
17	Experimental Results Showing the Effect of Augmenting SRC-II Middle Distillate Fuel With RJ-5	30
18	SRC-II Augmented With JP-10 and RJ-6M	31
19	Liquid Fuel Blends Containing No. 6 Burner Fuel, Tetralin, and DF-2	33
20	Anthracene Slurries	35
21	Properties of SL-90 Carbon Slurry Fuel	37
22	Solubilities of Naphthalene and Phenanthrene In Various Organic Hydrocarbons and Related Compounds at 20°C (68°F)	44
23	Comparison of the Volumetric Heats of Combustion of Various Liquid Fuels Containing Naphthalene or Phenanthrene With DF-2 (Control)	46
24	Cetane Number of Fuel Blends Containing Naphthalene or Phenanthrene	47
25	Impact Dispersion Test Results and Fuel Properties	48
26	Properties of DF-2, RJ-5, and Their Equal Blends	49
27	The Effect of RJ-5 Substitution in FRF-Type Fuels and Their Resulting Properties	52
28	CLR Engine Performance Comparison of JP-10 Microemulsion With DF-2	54
29	CLR Engine Performance Comparison of Carbon Black (10 wt%) Slurried in FRF With DF-2	58
30	Comparison of "Catalyzed" Mogul L Carbon Black in a 10 Percent Slurry With Base Diesel Fuel Using REC Values as the Criterion	62

Table		Page
31	Petter Engine Configuration	63
32	Comparison of High-Energy Fuel Candidates to Cat 1-H (Baseline No. 1)	66
33	Comparison of FRF and Energy-Augmented FRF Blends to Cat 1-H (Baseline No. 1)	69
34	Relative Values of Specific Range and Volumetric Heats of Combustion Compared to Cat 1-H	70
35	Comparison of High-Energy Fuel Candidates to Cat 1-H (Baseline No. 2)	72
36	Comparison of Energy-Augmented FRF Blends to Base FRF and Cat 1-H (Baseline No. 2)	75

LIST OF ILLUSTRATIONS

Figure		Page
1	Flow Chart of Testing Procedures for Qualifying High-Energy Fuel	12
2	Conversion Chart: Btu/lb to Btu/gal	28
3	Heat of Combustion of Fuels--Approximate Btu-Gravity Relation	29
4	Photomicrographs of 48 wt% Carbon Black Slurry in JP-10	38
5	Effect of Temperature on the Stability of Slurried Fuels	42
6	Settling Data: 20% Carbon Black in FRF	43
7	RJ-5 Microemulsions	50
8a	BSFC Versus BMEP for Base and Test Fuels at 1000 rpm. Test Fuel-JP-10 Emulsion	55
8b	RFC and REC Versus BMEP for JP-10 Emulsion at 1000 rpm	55
8c	BSFC Versus BMEP for Base and Test Fuels at 1500 rpm. Test Fuel-JP-10 Emulsion	55
8d	RFC and REC Versus BMEP for JP-10 Emulsion at 1500 rpm	56
8e	BSFC Versus BMEP for Base and Test Fuels at 2000 rpm. Test Fuel-JP-10 Emulsion	56
8f	RFC and REC Versus BMEP for JP-10 Emulsion at 2000 rpm	56
9a	BSFC Versus BMEP for Base and Test Fuels at 1000 rpm. Test Fuel-DF-2 Emulsion With 10% Carbon	59
9b	RFC and REC Versus BMEP for DF-2 Emulsions With 10% Carbon at 1000 rpm	59
9c	BSFC Versus BMEP for Base and Test Fuels at 1500 rpm. Test Fuel-DF-2 Emulsion With 10% Carbon	59
9d	RFC and REC Versus BMEP for DF-2 Emulsion With 10% Carbon at 1500 rpm	60
9e	BSFC Versus BMEP for Base and Test Fuels at 2000 rpm. Test Fuel-DF-2 Emulsion With 10% Carbon	60

Figure | Page

9f RFC and REC Versus BMEP for DF-2 Emulsion With 10% Carbon at 2000 rpm 60
10 REC Averaged Over the Load Range Versus Injection Timing.......... 61
11 Petter Screening Engine Installation.......................... 63
12 Specific Range of Various Energy-Augmented Blends Compared to Cat 1-H (Baseline No. 1)........................ 67
13 Specific Range of Various FRF Energy-Augmented Blends Compared to Cat 1-H (Baseline No. 1)........................ 70
14 Comparison of Change in Specific Range to Change in Volumetric Heats of Combustion of Various Tetralin Fuels From Cat 1-H.. 71
15 Specific Range of Various Energy-Augmented Blends Compared to Cat 1-H (Baseline No. 2)........................ 73
16 Comparison of Energy-Augmented FRF Blends to Cat 1-H (Baseline No. 2).. 76

I. INTRODUCTION

The Army Scientific Advisory Panel, in its Summer Study 76 (1)*, recommended a research program on high-energy fuels, i.e., fuels that could increase the payload capabilities and/or extend the operational range of both its tactical and combat vehicles. The development of such a fuel or fuels would need to be conventional enough that they could be used in present and future Army vehicles, yet novel enough that they contain the high-energy (per unit volume) requirement necessary to fulfill the need.

The Air Force and Navy are also interested in high-energy (high-density) fuel development. The Air Force at its Aero Propulsion Laboratory at Wright-Patterson Air Force Base has been actively evaluating hydrocarbon blends that are potential performance improvers for its air-breathing type missile systems. This class of fuel would be exceptionally good for use in the strategic cruise missile whose maximum effectiveness depends on maximum range, minimum time to reach the target, and minimum weight. Since small missiles, such as the cruise, are volume-limited, it is imperative that the fuel contains a high-energy content per unit volume. In general, an increase in the volumetric energy content of a fuel will result in the range of the missile being increased by a like percentage. Although several ways are available to increase the energy content of a given quantity of fuel, the most applicable for missile use is to increase the fuel's density. Research on high-density, high-energy liquid hydrocarbon fuels by the Air Force and Navy continues. This work is being closely monitored by the U.S. Army. A few of these fuels that may be of interest to the Army are described later. The purpose of this program was recently reaffirmed and summarized in a letter from U.S. Army Mobility Equipment Research and Development Command (USAMERADCOM) to Army Fuels and Lubricants Research Laboratory (AFLRL).(2) The letter stated that the purpose of the High-Energy Fuel Program is to provide the user with a fuel having the following characteristics:

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*Underscored numbers in parentheses refer to the list of references given at the end of this report.

- Increases range by 10 percent without any increase in fuel tank volume;
- Does not require any engine modification;
- Is in liquid form for use in existing equipment (two-phase fuel acceptable);
- Has no detrimental effect on the engine;
- Is able to use the existing fuel-handling and transportation equipment;
- Displays no unusual toxicology problems (compared to existing petroleum fuels);
- Considers cost when the above-mentioned requirements are achieved;
- Is available for user acceptance test by FY83;
- Is not considered as a booster for the PRF only, but should perform by itself, as specified.

An interim report,(3) released in October 1979, covered the progress made on the Army High-Energy Fuels Program from October 1977 until October 1979. The current report covers the period from October 1979 through September 1981.

II. APPROACH

The approach has been to identify those fuels and fuel components that have the potential of being high-energy fuel candidates or components for preparing such fuels. A series of screening processes were used to single out these fuels.

The initial screening uses the volumetric heat of combustion (ΔHc) as the main criterion. The physical and chemical properties of the fuel and fuel components are determined in the laboratory whenever possible or values from the chemical literature are used. Density and percent hydrogen are determined on the fuel whenever feasible since they are used to convert the gravimetric determined (ASTM D 240-76) gross ΔHc to the net volumetric ΔHc value.

The experimental gross gravimetric heat of combustion, as measured by ASTM Method D 240, is usually reported in British thermal units (Btu) per pound. If the hydrogen content of the sample is known, this value can be converted to the net gravimetric heat of combustion. Knowing the density of the sample, the volumetric heat of combustion can be obtained. In this report, this value will be expressed in Btu per gallon.

ASTM Method D 240 states that duplicate results by the same operator should be considered suspect if they differ by more than 55 Btu per pound and the results by two or more laboratories should be considered suspect if they differ by more than 175 Btu per pound.

In this report, as a matter of convenience in presenting and comparing the data, the last digit in the gravimetric heat of combustion value is adjusted to the nearest multiple of five. This can be done since the last digit is an order of magnitude less than the precision of the method.

Most of the fuels and fuel blends described in this report are liquids at room temperature. The selection was intentional, as liquid fuels are easier to handle and transport in existing fuel equipment and would undoubtedly run with less problems in diesel and turbine type engines than slurried fuels. However, promising slurried fuels were also tested. The second screening process uses a Petter engine as the screening tool. This engine, described in detail later, was adequate for this use. A highly instrumented CLR engine was used in a few of the screening tests, but because of the uncertainty of its availability when needed and its time-consuming operation, a simple screening device was needed. The Petter engine proved to be a suitable choice. This CLR engine will be used henceforth only in testing those fuels showing the greatest promise from the results of the first two screening tests. Only after passing this final screening with the CLR engine was the candidate fuel considered for the extensive engine tests necessary for qualifying it as a high-energy fuel.

Figure 1 illustrates the steps in the testing procedure for qualifying a high-energy fuel.

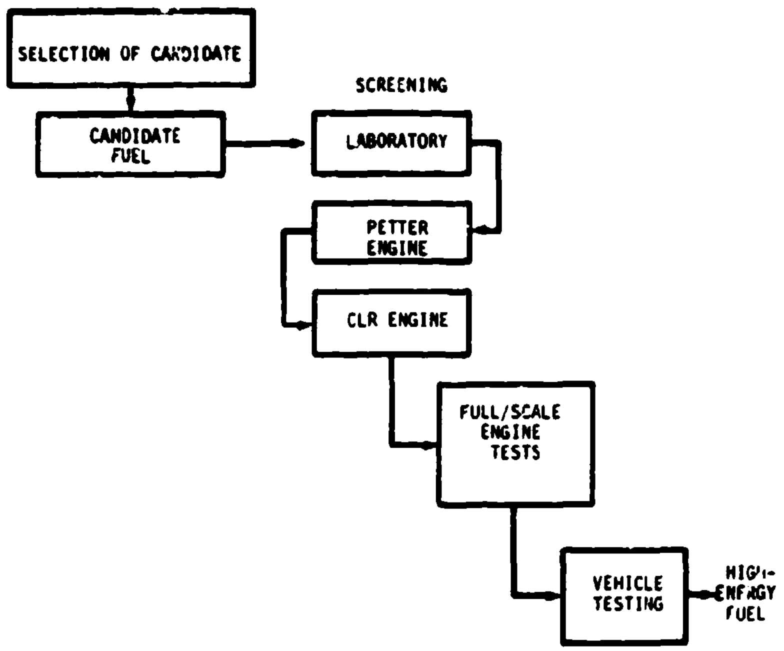


FIGURE 1. FLOW CHART OF TESTING PROCEDURE FOR EVALUATING HIGH-ENERGY FUEL

MERADCOM Commander, during a visit to AFLRL 13 March 1978, commented on the desirability of developing a high-energy fuel that was fire safe, and that the High-Energy Fuel (HEF) Program and the Fire-Resistant Fuel (FRF) Program should eventually merge.

Efforts have been made during the last 2 years to interface the HEF and FRF programs whenever possible, without diluting the goal of achieving a high-energy fuel that meets the characteristics described earlier.

III. TECHNICAL PROGRAM

A. Liquid High-Energy Components

Some of the liquid components described below and listed in Table 1 could

TABLE 1. LIQUID HIGH-ENERGY COMPONENTS

Component	Density 15.56°C (60°F) (g/ml)	ΔHc (net) Btu/gal.	ΔHc (net) Btu/lb	$/Gal.
RJ-5	1.089	160,390	17,735	86.00(a)
JP-10	0.940	144,615	18,435	15.15(a)
RJ-6M	1.001	150,070	17,970	40.00(a)
Tetralin (Tetrahydronaphthalene)	0.972	140,990	17,580	13.90(b)
Furfural Extract	0.987	143,415	17,565	1.25(c)
SRC-II				
(a) 2.9:1 middle distillate to heavy distillate	0.999	137,895	16,540	0.62 to 0.69(d)
(b) middle distillate	0.984	134,755	16,410	0.61 to 0.69(d)
Polycyclic Aromatic Blending Stock	1.017	140,340	16,340	1.38(e)
No. 5 Burner Oil	0.917	137,700	17,995	1.90 to 1.93 (f)
No. 6 Fuel Oil	0.978	141,575	17,350	0.80 to 0.82
DF-2 (Cat 1-H)	0.8504	132,365	18,665	1.69(h)
DF-2 (Typical)	0.8484	130,615	18,450	1.00

(a) Estimated price in quantities of 5000/6000 gal. (Ashland Chemical Co.)
(b) Estimated price in 40,000 gal. quantities (DuPont)
(c) Estimated price--Ashland Chemical Co.
(d) Wholesale net back to the plant: Bulk shipment. Excludes transportation, tax, handling, sales margin, distribution costs.(4)
(e) Tank car; tank truck FOB W. VA.
(f) Truck transport, FOB Chicago
(g) Truck transport, FOB Baltimore (0.5% sulfur)
(h) 8,000-10,000 gallons

possibly be used as fuels without further modification or blending with other materials; some may require a small amount of cetane improver; and some may be too costly to use neat but are desirable as a component because of some beneficial property, such as a very high volumetric heat content, viscosity improver, etc.

1. RJ-5

This synthetic liquid hydrocarbon fuel was described in an earlier report.(3) It was one of the first high-density fuels of the polycondensed cycloparaffic type studied and is currently being produced by Ashland Chemical Company. The typical properties of this fuel, as supplied by the manufacturer, are listed in Table 2. RJ-5 has the highest volumetric heat

TABLE 2. TYPICAL PROPERTIES OF RJ-5

Specific Gravity, 15.56°C (60°F)	1.06 (min)
Existent Gum, mg/100 ml	7.0 (max)
Aromatics, vol%	1.0 (max)
Sulfur, total, wt%	0.06 (max)
Pour Point, °C (°F)	-28.9 (-20)
Net heat of combustion, Btu/lb	17,750
Net heat of combustion, Btu/gal.	160,000 (min)
Viscosity, cSt	
at -53.9°C (-65°F)	20,000 (max)
at -1.1°C (-30°F)	1,400 (max)
at 37.7°C (100°F)	15 (max)
Flash Point, °C (°F)	65.6 (150)

of combustion of any liquid component tested (~160,000 Btu/gal.), but is expensive. Impact dispersion tests (5) using fuel blends of RJ-5 with DF-2 and with FRF indicated that RJ-5 had fire-resistance properties under the conditions of the test. The result of these tests are described in Section III. E. of this report.

2. JP-10 (Exo-Tetrahydrodicyclopentadiene)

JP-10 was also described in Reference 3. The typical properties of JP-10 are shown in Table 3.

TABLE 3. TYPICAL PROPERTIES OF JP-10

Exo-tetrahydrodicyclopentadiene ($C_{10}H_{16}$)

Molecular Weight	136.2
C:H Ratio	0.62
Specific Gravity @ 15.6°C (60°F)	0.94
Heating Value, Btu/gal.	142,000
Viscosity, cSt @ -40°C (-104°F)	19
Freezing Point, °C (°F)	-78.9 (-110)
Flash Point, °C, (°F)	57.2 (135)

3. RJ-6M

This high-energy candidate is the latest to emerge. It has been tested in the laboratory and later screened using the Petter engine. RJ-6M was developed by Ashland Chemical Company, and its composition at present is proprietary. Table 4 lists the typical properties of this fuel as supplied

TABLE 4. PROPERTIES OF RJ-6M

Density @ 15.56°C (60°F)	1.001 g/ml (8.352 lb/gal.)
Net Heat of Combustion	
Btu/lb	17,968
Btu/gal.	150,069
Viscosity @	
-17.8°C (0°F)	68.5 cSt
-31.7°C (-25°F)	110 cSt
-34.4°C (-30°F)	240 cSt
-40.0°C (-104°F)	360 cSt
Flash Point, °C (°F)	65 (140)

by the manufacturer.* The AFLRL experimentally determined cetane numbers, with and without cetane improver, are listed in Table 5. This fuel is a good high-energy candidate.

*Ashland Chemical Co., Dublin, Ohio

TABLE 5. EXPERIMENTALLY DETERMINED CETANE NUMBERS OF RJ-6M WITH AND WITHOUT CETANE IMPROVER

	Cetane No.
RJ-6M (neat)	30
RJ-6M + 0.4 wt% amyl nitrate	39
RJ-6M + 0.8 wt% amyl nitrate	45

4. Tetrahydronaphthalene (Tetralin*)

1,2,3,4—tetrahydronaphthalene, commonly referred to as tetralin, is the product of the partial hydrogenation of naphthalene and is a solvent for oils, resins, asphalt, rubber, and waxes. The typical properties of tetralin solvent as supplied by the manufacturer are shown in Table 6. The ΔHc and elemental analysis were determined at AFLRL.

Certain safety precautions are necessary with its use. On a one-time exposure, it may cause a mild irritation to the skin and eyes. Repeat

TABLE 6. TYPICAL PROPERTIES OF TETRALIN SOLVENT

Molecular Weight	132.2
Boiling Point (760 mm Hg), °C (°F)	207 (405)
Freezing Point, °C (°F)	-31 (-24)
Specific Gravity, 20°C	0.970
Vapor Pressure, mm Hg	
@ 100°C	27
@160°C	221
Solubility in water	Negligible
Flash Point, tag closed cup, °C (°F)	82 (180)
ΔHc Btu/lb (net)	17,578
ΔHc Btu/gal. (net)	140,295
Elemental Analysis, wt%	
Carbon	90.84
Hydrogen	9.16

*Du Pont Co., Wilmington, Delaware

exposure is more hazardous, as it can defat the skin, causing it to crack and lead to secondary infection. Studies with animals have caused liver and kidney damage and cataract formation by repeated oral or inhalation exposure.

5. Extract From Furfural Unit

It was noted in a recent report (6) that the extract from the furfural unit in a lube plant has a relatively high heating value (154,000 Btu/gal.), but will probably vary, depending on the type of lube stock being processed. Several refineries in the United States use the furfural unit in their processes. Samples were requested from two of these refineries.

One sample (Nuflex®) has been received from its manufacturer* with a data sheet containing its typical properties. The ΔHc was determined at AFLRL and found to be somewhat lower than expected. However, the extract would be expected to vary, depending on the lube oil being treated. The properties of the furfural extract are listed in Table 7. This product should be

TABLE 7. PROPERTIES OF FURFURAL EXTRACT

API Gravity @ 15.6°C (60°F)	11.8
Density, lb/gal. @ 15.6°C (60°F)	8.223
Viscosity @ 37.8°C (100°F), SUS	288
Viscosity @ 98.9°C (210°F), SUS	44.4
Aniline Point, °C (°F)	19.4 (67)
Flash Point, COC, °C (°F)	207.2 (405)
Refractive Index, 20°C (68°F)	1.5645
Pour Point, °C (°F)	1.7 (35)
Clay Gel Analysis	
Saturates, wt%	12.0
Polar Compounds, wt%	8.6
Aromatics, wt%	79.4
Asphaltenes, wt%	0
Elemental Analysis	
Sulfur, wt%	2.5-3.0
Nitrogen, ppm	1500-2000
Hydrogen, wt%	7.5-8.0
Carbon, wt%	89-90
Net ΔHc	
Btu/lb (net)	17,540-17,590**
Btu/gal. (net)	144,455-142,375

**Range given; actual value depends on percent of hydrogen present

*Ashland Chemical, Dublin, OH

relatively inexpensive, and further testing of the product is planned.

6. SRC-II (Solvent-Refined Coal II)

A process is under development for transforming high-sulfur coal into distillate fuels and various gaseous products. Plans have been made to construct a 6000-ton per day demonstration plant for DOE near Morgantown, WV, but as of this date these plans have been temporarily suspended. The use of SRC-II fuels for steam was expected to become competitive with petroleum-based fuels within 10 years.(7) A sample of a fuel oil blend (2.9:1 middle distillate:heavy distillate) was obtained from a solvent-refined coal pilot plant at Fort Lewis, WA. The analyses received with the sample were for a batch blend; not for the specific sample reported here. These analyses are listed in Table 8. Tests conducted at AFLRL indicated that the sample received was a representative one.

TABLE 8. PROPERTIES OF SRC-II
(2.9 to 1, Middle Distillate to Heavy Distillate)

Specific Gravity, 15.6°C (60°C)	0.999
°API at 15.6°C (60°C)	10.14
Viscosity	
@ 43.3°C (110°F), cSt	4.527
@ 98.9°C (210°F), cSt	1.289
Flash Point, ASTM D 93, °C (°F)	71.1 (160)
Heat Content	
Btu/lb (net)	16,540
Btu/gal.	137,895
Coal Tar Acid, ml/100 g	25.9
Sulfur, wt%	0.21
Ash, %	0.02
IBP, °C (°F), ASTM D 86	170 (338)
End Point, °C (°F)	371 (700)
Hydrogen*, wt%	8.64

*Determined at AFLRL

The fuel listed in Table 8 was known to be highly aromatic and to have a very low cetane number. The cetane test engine would not run on SRC-II neat. Therefore, 3 wt% and 5 wt% amyl nitrate (a cetane improver) was added to samples of the above fuel oil blend, and cetane determinations were made at AFLRL. The results are shown in Table 9.

TABLE 9. CETANE DETERMINATIONS OF SRC-II WITH VARIOUS CONCENTRATIONS OF CETANE IMPROVER AND BLENDED WITH DF-2

Wt% SRC (AL-8321-F)	DF-2 (AL-7225)	Wt% Amyl Nitrate	Resulting Cetane Number
100.0	---	---	Engine would not run
---	100.0	---	49
97.0	---	3.0	18
95.0	---	5.0	27
48.5	48.5	3.0	37
48.5	50.0	1.5	29

--- Indicates none of this material used in the blend.

Even with the amyl nitrate added, the cetane number of this SRC-II was still relatively low. A sample from this fuel (without cetane improver) was run in a CLR engine as a 50:50 mixture with diesel fuel on another program at Southwest Research Institute (SwRI). No difficulties were experienced on this brief run.

Another sample of SRC-II from the same source was almost entirely middle distillate. Cetane number was determined to be 16. The properties of this fuel, determined at AFLRL, which related to the high-energy fuel program are summarized in Table 10, and the complete inspection data on this SRC-II middle distillate sample can be found in Appendix A, No. 1. The safety and toxicological aspects of solvent-refined fuels are given in Appendix A, No. 2.

TABLE 10. PROPERTIES OF SRC-II (Middle Distillate)

Specific Gravity, 15.6/15.6°C (60°C)	0.9840
Viscosity	
@ 37.8°C (100°F), cSt	3.83
@ 40.0°C (104°F), cSt	3.68
Flash Point, ASTM D 93, °C (°F)	80 (176)
Heat of Combustion	
Btu/lb	16,410
Btu/gal.	134,755
Hydrogen, wt%	8.64
Ash, wt%	0.0023
Cetane No.	16

7. Polycyclic Aromatic Blending Stock

Another refinery product that is relatively inexpensive and has a fairly high volumetric heat of combustion is a polycyclic aromatic blending stock. Its properties, as determined at AFLRL, are listed in Table 11.

TABLE 11. PROPERTIES OF POLYCYCLIC AROMATIC BLENDING STOCK

Specific Gravity, 15.6/15.6°C (60°C)	1.0173
Heat of Combustion	
Btu/lb (net)	16,535
Btu/gal. (net)	140,340
Carbon, wt%	90.89
Hydrogen, wt%	7.70
FIA (Aromatics), wt%	97
Monoaromatics, wt%	7.2
Diaromatics, wt%	75.2
Triaromatics, wt%	1.4
Olefin, wt%	1.4
Saturates, wt%	1.5

8. Burner Oil No. 5

This fuel is included as a blending component because of its moderately high volumetric heat content and relatively low cost. Its properties, as determined at AFLRL, are listed in Table 12.

TABLE 12. PROPERTIES OF NO. 5 BURNER OIL

Cetane No.	41.0
Viscosity, 40°C (104°F), cSt	185.9
API Gravity, 15.6°C (60°F)	22.8
Density, g/ml, 15.6°C (60°F)	0.9170
Flash Point, ASTM D 93, °C (°F)	108 (227)
Sulfur, wt%	0.66
Pour Point, °C (°F)	21 (70)
Ash, wt%	0.248
Hydrogen, wt%*	13.86
Heat of Combustion	
Btu/lb (net)	17,995
Btu/gal. (net)	137,700
Copper Strip Corrosion, 50°C (122°F)	
ASTM D 130	1a

*Calculated

9. No. 6 Fuel Oil (Bunker C)

This is a heavy residual oil that requires preheating before it can be burned. It is used as a fuel for industry and ships, and can be obtained from straight-run or cracked residiums in the refinery operation. This oil is comparatively inexpensive with a relatively high volumetric heat of combustion. The properties are listed in Table 13.

TABLE 13. PROPERTIES OF NO. 6 FUEL OIL

Cetane No.	26
Viscosity, 40°C (104°F), cSt	137.89
°API Gravity, 15.6°C (60°F)	13.2
Density, 15.6°C (60°F)	0.978
Sulfur, wt%	1.5
Pour Point, °C (°F)	-3 (27)
Ash, wt%	0.47
Hydrogen, wt%	10.58
Heat of Combustion	
Btu/lb (net)	17,350
Btu/gal. (net)	141,575

10. JP-9

This is a three-component blend of JP-10 (65-70 wt%), RJ-5 (20-25 wt%), and methylcyclohexane (10-12 wt%). It has a net volumetric heating value of approximately 142,000 Btu/gal. with a flash point of 24°C. Only a limited amount of testing was done with this fuel.

B. Solid High-Energy Components

Some of the solid components described below and listed in Table 14 are materials that are soluble in other liquid components or in DF-2. They can be used to augment the energy content of the component or fuel in which they are dissolved. In cases where the solubility is not appreciable, slurries are a definite possibility, although one-phase liquid fuels are the more desirable.

1. Naphthalene

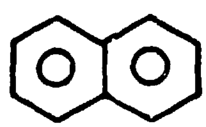


TABLE 14. SOLID HIGH-ENERGY COMPONENTS

Solid Component[a]	Density, °C	Net Heat of Combustion, Btu/lb
Naphthalene	$1.178 \frac{15.56}{15.56}$ (b)(c)	16,720 (b)(c)
	$1.162 \frac{20}{4}$ (d)	16,725 (e)
Phenanthrene	1.179 25 (d)	15,935 (g)
	$1.063 \frac{15.56}{15.56}$ (f)	
Anthracene	$1.283 \frac{25}{4}$ (h)(i)	16,695 (g)
	$1.25 \frac{27}{4}$ (d)(j)	16,725 (k)
		16,770 (c)
SRC-I	1.2 (k)	15,215 (g)
Carbon Black (n) (Raven 1170)	$1.80 \frac{15.56}{15.56}$ (e)	13,875 (g)

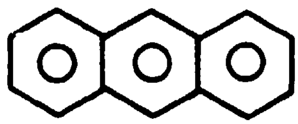
Notes:

(a) Solid at room temperature.
(b) Technical Data Book - Petroleum Refining, 2nd Edition, 1970, American Petroleum Institute, Washington, D.C.
(c) Extrapolated from higher temperature.
(d) The Merck Index, Ninth Edition, Merck & Co., Inc., Rahway, N.J.
(e) Calculated from data in CRC Handbook of Chemistry & Physics, 59th Edition, CRC Press, West Palm Beach, FL.
(f) The Condensed Chemical Dictionary, Fifth Edition, 1958, Reinhold Publishing Co., NY
(g) Experimentally determined at AFLRL.
(h) CRC Handbook of Chemistry & Physics, 59th Edition, CRC Press, West Palm Beach, FL.
(i) Dictionary of Organic Compounds, Revised Edition, 1953, Oxford University Press, NY.
(j) Calculated from data in note (h) and corrected to net value. Literature value at 25°C.
(k) Calculated from data in note (i) and corrected to net value. Literature value at constant pressure.
(l) Temperature of measurement not given in reference; from Table of Typical Properties of SRC-I Product, Coal, Feed-Western Kentucky Bituminous, Synthetic Fuels Data Handbook, 2nd Edition, Cameron Engineers, Inc., Denver, CO.
(m) Manufacturer (Cities Service Co., Columbian Div., Akron, OH) suggests this density for practical purposes in calculating formulations.
(n) See Appendix H for the properties of the carbon blacks used in this report.

Naphthalene can be derived from coal-tar oils or produced by dealkylation of a refinery stream containing heavy aromatics such as those found in a heavy reformate or from cycle stock from a catalytic cracker.

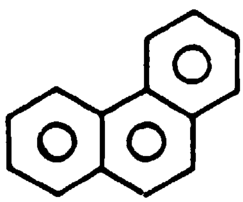
Naphthalene is used in the manufacturing of phthalic anhydride and 2-naphthol. It is the raw material used in the preparation of various pharmaceutical products and the making of synthetic organic dyes, and is also used as an intermediate in the preparation of tetralin and decalin. Its use as a moth repellant and insecticide has declined since chlorinated compounds were introduced for that purpose.

2. Anthracene



Anthracene is obtained from coal tar distillation. It is either insoluble or has very limited solubility in most organic liquids. The solubility of anthracene is discussed in Section III. D. 1a of this report.

3. Phenanthrene



Phenanthrene is an isomer of anthracene that is also obtained from coal tar. As discussed in Section III. D. 2a, it is more soluble than anthracene in all of the material tested at AFLRL.

4. SRC-I

The process for converting a high-sulfur, high-ash coal to a low-sulfur, low-ash solid fuel is known as the SRC-I process. The typical properties of SRC-I prepared from a western Kentucky bituminous coal are shown in Table 15.

TABLE 15. TYPICAL PROPERTIES OF SRC-I (7)

Carbon, wt%	88.0
Hydrogen, wt%	5.9
Nitrogen, wt%	2.2
Sulfur, wt%	0.7
Oxygen, wt% by difference	3.1
Ash, wt%	0.2
Forms of Sulfur	
Sulfate, wt%	--
Pyritic, wt%	--
Organic, wt%	0.7
Heating Value, Btu/lb	16,250
Fusion Point, °F (gradient bar)	350
Density, gm/cm^3	1.2

It is assumed that the heating value listed in Table 15 is the gross heating value. The gross ΔHc was determined by running a sample of SRC-I at AFLRL. The sample had a gross ΔHc of 15,750 Btu/lb and a net value of 15,215 Btu/lb.

5. Carbon Black

The use of carbon black in preparing slurries with various liquid hydrocarbons to increase the vol : energy content is still a good possibility. The properties of carbon blacks and the slurry technology have been described in Reference 3.

C. Blending and Characterization of Liquid Fuels

The properties of the blended fuels prepared from the various components were compared to a DF-2 Diesel Control Fuel* that meets the Environmental Protection Agency (EPA) specification for emission testing**. The properties of this baseline fuel are listed in Table 16, while the properties of

* From Phillips Chemical Company, Bartlesville, OK
**As described in Chapter One, EPA, Part 86.177.6

TABLE 16. LABORATORY INSPECTION OF BASELINE FUEL*
(CONTROL FUEL)

Gravity, °API	34.8
Specific Gravity	0.8509
Distillation, D 86 °C (°F)	
IBP	196 (384)
5	212 (414)
10	222 (432)
20	234 (454)
50	266 (510)
90	301 (574)
95	309 (588)
EP	320 (608)
Recovery, %	98.5
Viscosity, cSt @ 40°C	2.48
Flash Point, °C (°F)	71.7 (161)
Pour Point, °C (°F)	-21.7 (-7)
Hydrocarbon Type (FIA), vol%	
Aromatics	29.6
Olefins	1.6
Saturates	68.8
Elemental Analysis, wt%	
Carbon	86.63
Hydrogen	12.85
Sulfur	0.34
H:C Atom Ratio	1.78
Heat of Combustion	
Gross, Btu/lb	19,265
mg/kg	44.81
Net, Btu/lb	18,095
mg/kg	42.08
Btu/gal.	128,465
Accelerated Stability, mg/100 ml	0.3
Existent Gum, mg/200 ml	3.9
Cetane No.	48.0

*AFLRL Fuel No. AL-9649-F.

other diesel fuels used in this report can be found in Appendix B. The volumetric heat content of a fuel serves as a guide to forecast the fuel's ability to increase the range of a vehicle in which it is used, and should be a useful tool in deciding which fuels should advance to the next screening stage, i.e., engine testing.

The composition of the fuel blends in this report are listed as weight percent. In the blending of fuels, it is sometimes more convenient to measure the fuel components by volume and then weigh them. For this reason, the weight percents usually result in fractions of whole numbers.

Since a high-energy fuel candidate should have a high volumetric heat of combustion, and heats of combustion are usually expressed in Btu's per pound, it would be convenient to have a conversion chart that would indicate quickly if a fuel might qualify as a high-energy fuel (knowing the density and Btu's/lb). Figures 2 and 3 can be used for this purpose. These figures illustrate the large effect that slight changes in density make upon the volumetric heat content of the fuel.

1. SRC-II

SRC-II, middle distillate, has a volumetric ΔHc of approximately 134,750 Btu/gal. Since the goal of the high-energy fuel program is a 10-percent increase in range without any increase in fuel tank volume, SRC-II needs to be augmented with a component of higher volumetric heat content such as RJ-5.

a. Augmenting SRC-II With RJ-5

Table 17 shows the experimental results of augmenting SRC-II fuel with RJ-5. Since both components have low cetane ratings, it would probably be necessary to add a cetane improver, such as amyl nitrate, when using it in a diesel engine. The disadvantage of using RJ-5 is its high price.

b. Augmenting SRC-II With JP-10

Blending SRC-II (middle distillate) with JP-10 had only a slight effect on increasing its energy content (volumetric heat of combustion). For example, an equal mixture by weight of JP-10 and SRC-II, with 1 percent amyl nitrate added, increased the energy content by only 0.3 percent. The low heat content of amyl nitrate (10,600 Btu/lb) contributed to hindering the increase in energy. This cursory study is included in Table 18.

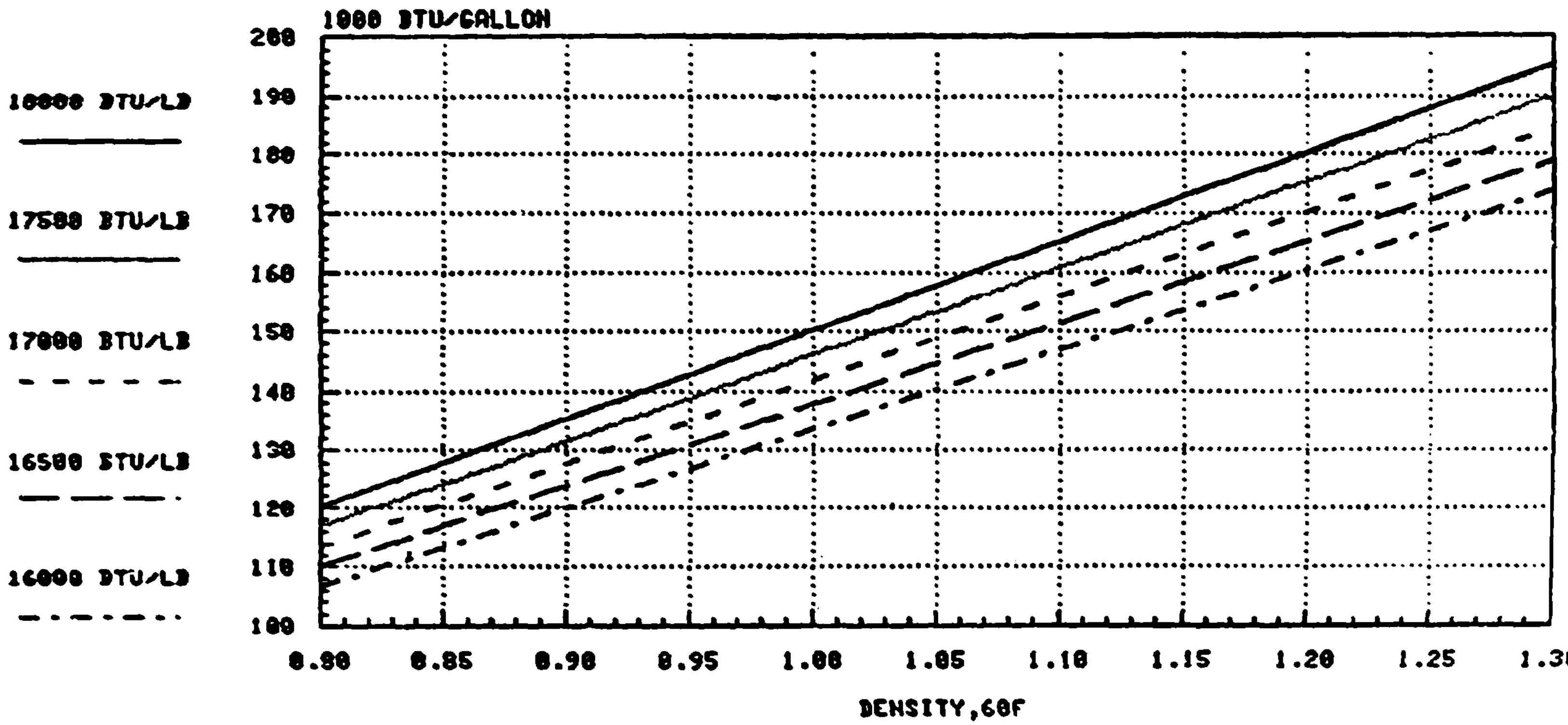


FIGURE 2. CONVERSION CHART: BTU/LB TO BTU/GAL.

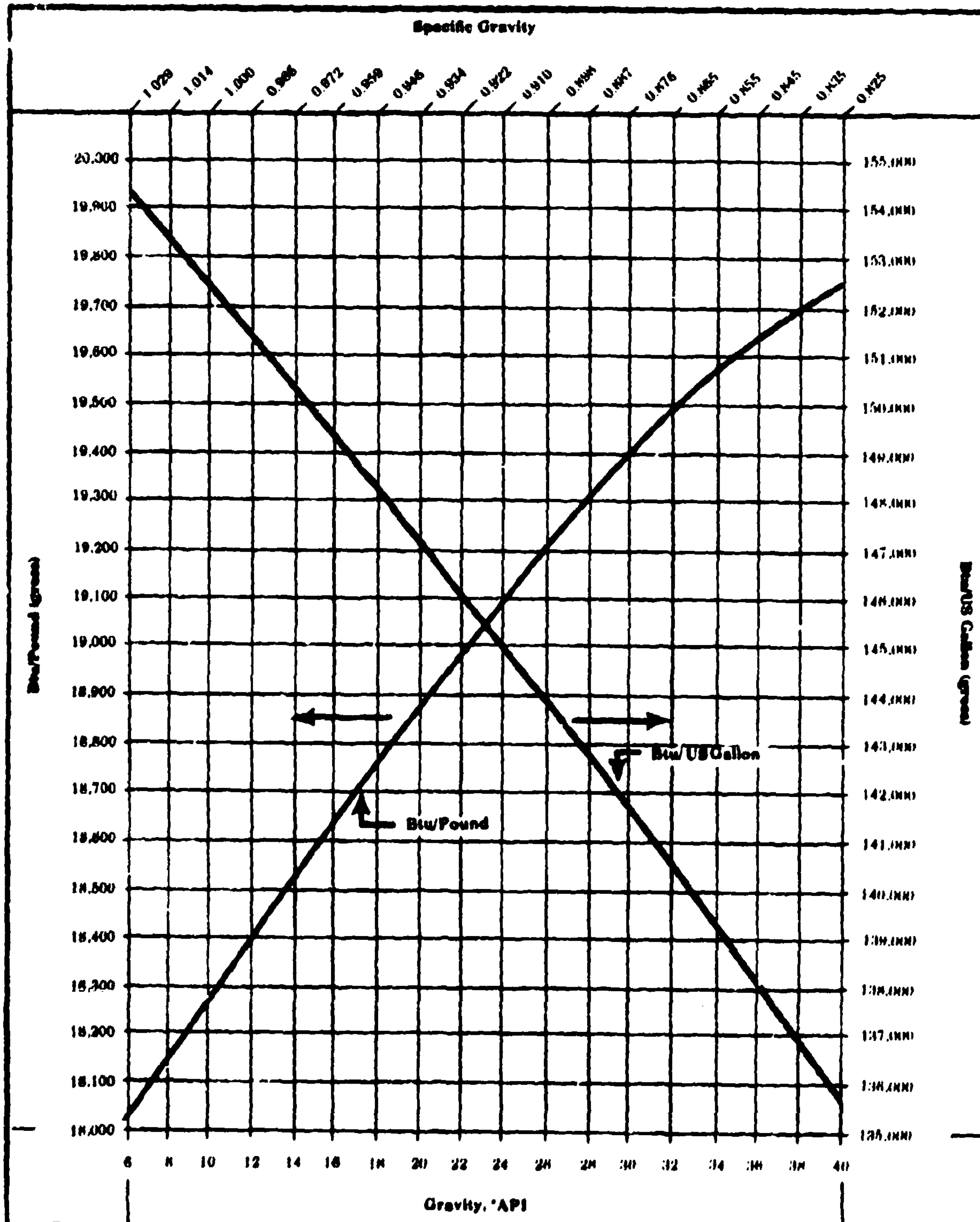


FIGURE 3. HEAT OF COMBUSTION OF FUELS-
APPROXIMATE BTU-GRAVITY RELATION (FROM "TABLES OF USEFUL INFORMATION," EXXON CORP., LUBETEXT D 400, JANUARY 3, 1973)

TABLE 17. EXPERIMENTAL RESULTS SHOWING THE EFFECT OF AUGMENTING SRC-II MIDDLE DISTILLATE FUEL WITH RJ-5

SRC-II(a), Wt%	RJ-5, Wt%	Amyl Nitrate, Wt%	Density, 15.56°C (60°F) g/ml	Hydrogen, Wt%	Viscosity @ 40°C, cSt	Heat of Combustion (net) Btu/lb	Heat of Combustion (net) Btu/gal.	Heat Content, % Improvement Over Control Fuel(b)
100.0	—	—	0.9840	8.64	—	16,412	134,755	4.9
89.11	10.89	—	0.9934	8.75(c)	3.97	16,540	137,090	6.7
74.50	24.50	1.00	1.0585	8.08(c)	—	16,595	139,430	8.5
73.18	26.82	—	1.0084	8.93(c)	—	16,835	141,660	10.3
71.78	25.24	2.98	1.0093	9.16	4.03	16,484	138,830	8.1
61.42	35.64	2.94	—	—	—	—	141,955(c)	10.5
49.50	49.50	1.00	1.0319	9.16(c)	5.26	17,025	146,585	14.1
24.50	74.50	1.00	1.0585	9.45(c)	—	17,330	153,050	19.1
—	100.00	—	1.0820	9.74	1	17,735	160,390	24.9

(a) AFLRL Fuel No. 8321F.
(b) Control Fuel, ΔHc (net) 128,465 Btu/gal.
(c) Calculated from the individual components.

TABLE 18. SRC-II AUGMENTED WITH JP-10 AND RJ-6M

RJ-6M, Wt%	SRC-II, Wt%	JP-10, Wt%	Amyl Nitrate, Wt%	ΔHc (net) Btu/lb	ΔHc (net) Btu/gal.	% Improvement Volumetric ΔHc Over Control Fuel	Cetane No.(a)
---	49.5	49.5	1.0	17,030	136,215	6.0	---(c)
---	74.5	24.5	1.0	16,545	134,080	4.4	---(c)
---	---	100.0	---	18,290	143,450	11.7	---(c)
---	---	---	100	10,600	88,450	-31.1	---(c)
100	---	---	---	17,970	150,070	16.8	30
99.6	---	---	0.4	17,490(b)	149,850(b)	16.6	39
99.2	---	---	0.8	17,911(b)	149,605(b)	16.5	45
50.0	50.0	---	---	17,190(b)	142,365(b)	10.8	---(c)
25.0	75.0	---	---	16,801(b)	138,555(b)	7.8	---(c)

(a) Determined at AFLRL.
(b) Calculated from the individual components.
(c) Not determined.

c. Augmenting SRC-II With RJ-6M

In Section III.A.3, RJ-6M was discussed. Only a limited amount of work has been done with this fuel since it was received just prior to the writing of this report. It is much less costly than RJ-5 and has a rather high heat content of 150,070 Btu/gal. (16.8 percent improvement compared to control fuel).

Some calculated values of blends of RJ-6M with SRC-II are listed in Table 18. For example, a 50:50 mixture by weight results in a blend having a 10.8 percent increase in volumetric heat content when compared to the control fuel. The cetane number on RJ-6M was determined at AFLRL and found to be 30. Addition of 0.4 and 0.8 wt% amyl nitrate increased the cetane number to 39 and 45, respectively.

RJ-6M must be considered as an excellent candidate fuel at this point in its testing.

2. Tetralin

a. Blends With DF-2

Tetralin has a low cetane number and would require either a substantial amount of cetane improver or would need to be blended with another component in order for it to be run in a diesel engine. Blends of tetralin with DF-2 are shown in Table 19. The blend containing 75 wt% tetralin, 24 wt% DF-2 (Cat 1-H; 53 cetane number) and 1.0 wt% cetane improver was run in the Petter engine without difficulty.

b. Blends With No. 6 Burner Fuel

A 50:50 blend by weight of tetralin and No. 6 burner fuel would probably need a cetane improver, but indications are that it would have a 10-percent improvement in heat content over that of the control fuel.

TABLE 19. LIQUID FUEL BLENDS CONTAINING NO. 6 BURNER FUEL, TETRALIN, AND DF-2

No. 6 Burner Fuel, Wt%	Tetralin, Wt%	DF-2(a) Wt%	Amyl Nitrate Wt%	Density, 15.56°C (60°F) g/ml	Hydrogen, Wt%	Heat of Combustion (net) Btu/lb	Heat of Combustion (net) Btu/gal.	% Improvement Over Control Fuel(b)
—	100.0	—	—	0.970	9.16	17,580	142,275	11.7
—	97.0	—	3.0	0.9709(b)	—	17,370	140,990(b)	9.5
—	75.0	24.0	1.0	0.9386	10.11	17,815	139,510	8.6
—	80.0	19.0	1.0	0.9491	9.92	17,735(b)	140,440	9.3
100.0	—	—	—	0.9779	10.58	17,350	141,575	10.2
90.0	—	9.0	1.0	0.9642	10.61	17,559	141,275	10.0
50.0	50.0	—	—	0.9740(b)	—	17,465(b)	141,945(b)	10.5

(a) Cat 1-H; See Appendix B-1 for Table of Properties (AFLRL Fuel No. AL-10115).
(b) Calculated from individual components.

3. No. 6 Burner Fuel

a. Blend of No. 6 Burner Fuel With Cat 1-H Diesel

Another possible high-energy fuel is a blend of No. 6 burner fuel with another component that would make the properties of the burner fuel acceptable. For example, a blend containing approximately 90 wt% No. 6 burner fuel, 9.0 wt% DF-2 (Cat 1-H) and 1.0 wt% amyl nitrate resulted in a fuel that had a net volumetric heat of combustion of 141,275, or a 10 percent improvement over the control fuel. The viscosity as measured by ASTM D 445 decreased from 185.9 cSt at 40°C (104°F) in the No. 6 burner fuel to 71.5 cSt at 40°C in the blend. The cetane number of the No. 6 burner fuel was 26, while that of the Cat 1-H was 53, which means the blend would be upgraded in cetane number even without the cetane improver (see Table 19). The properties of the Cat 1-H fuel are in Appendix B, No. 1.

4. RJ-6M

Since this is one of the most recent candidate fuels, blending studies with other fuel components have not yet been started. However, from the limited data available and from the Petter engine tests (to be described later), this synthetic hydrocarbon gives all indications of being an excellent high-energy fuel and/or component.

5. Furfural Extract

This material is also a recent candidate for the high-energy fuel program and its testing has been limited thus far.

D. Fuel Preparation and Characterization With Solid High-Energy Components

1. Insoluble Components Used in Slurries

a. Anthracene

Anthracene is a good candidate for a high-energy component since it has a relatively high density (1.283 g/ml at 25°C) and experimental measured net ΔHc of 16,695 Btu/lb. This experimental value is in fair agreement with the literature value measured at 25°C of 16,770 Btu/lb. Unfortunately, it is not very soluble in most common hydrocarbons.

A brief examination of the chemical literature and cursory solubility studies in the laboratory indicated that anthracene had no appreciable solubility in the various organic hydrocarbons in which it was tested. The laboratory studies included tetralin, DF-2, JP-10, RJ-5, mixed naphthalenes, FRF, and SRC-II.

In the literature examined, no appreciable solubility was found in methyl naphthalene, m-cresol, nitrotoluene, decahydronaphthalene, 1 methyl-2 pyrrolidinone, 1,4 dioxane, dibutyl cellosolve. In nitrobenzene, the solubility is 1.86 g/100 ml. Merck Index (9th Edition) reports 1.0 gram anthracene to be soluble in 67 ml absolute alcohol, in 70 ml methanol, 62 ml benzene, 85 ml chloroform, 200 ml ether, 31 ml carbon disulfide, 86 ml carbon tetrachloride, and 125 ml toluene.

Because of the potential energy content, slurries of anthracene in DF-2, tetralin, and RJ-5 were prepared. Each consisted of 49.85 wt% anthracene and 49.85 wt% of the fuel and 0.3 wt% aluminum octoate to prevent settling. Table 20 shows the resulting experimental heat of combustion of these

TABLE 20. ANTHRACENE SLURRIES[a]

	Density 15.6/15.6 g/ml (Experimental)	Net ΔHc Btu/gal. (Experimental)	% Improvement Over ΔHc in Net Control DF-2 Fuel
Anthracene: DF-2	0.9999	147,415	14.7
Anthracene: Tetralin	1.0583	149,870	16.7
Anthracene: RJ-5	1.1501	165,110	28.5
Control DF-2[b]	0.9874	128,465	---

(a) All slurries have 0.30% aluminum octoate added as suspension agent and are equal wt% (49.85) of anthracene and the other component.
(b) AFLRL Fuel No. AL-9979-F (Control Fuel).

slurried fuels and the percent improvement in the volumetric heating value over a typical DF-2. Because all the slurries in Table 20 show improvement over the "control diesel fuel," slurries of this type should be worthy of further study and testing.

b. Carbon Black

Experience with slurry fuels at AFLRL and other research being conducted at SwRI (a) have indicated several problems that need to be addressed before these fuels can be fully utilized. Difficulties are usually encountered when the carbon concentration in slurries is greater than 10 wt%, and the problem becomes correspondingly more troublesome as the carbon black concentration is increased. The problems alluded to are incomplete combustion, decreased thermal efficiency, degraded atomization, high viscosity, settling, and operational difficulties, such as plugging of the injector nozzle or sticking of the nozzle valve. However, great advances have been made in carbon slurry technology during the past few years, especially by researchers interested in coal slurries and by those working in government-sponsored research on the cruise missile.

Two recent important achievements (see 1 and 2 below) have been made recently to help promote carbon slurried fuels.

(1) High carbon loading at relatively low viscosity

A s[illegible]le c[illegible] fuel containing 48 percent carbon black (SL-90) in JP-10 (with 3 [illegible] surf[illegible]) was received from Ashland Chemical Co. Its viscosity at ambi[illegible] [illegible]e is such that this slurry flows easily. The data furnish[illegible] with [illegible]mple are shown in Table 21. The high volumetric heat of combustion (168,185 Btu/gal.), approximately 31 percent higher heating value than the control DF-2, should make it worthy of consideration as a high-energy fuel candidate. Photomicrographs of the fuel are shown in Figure 4.

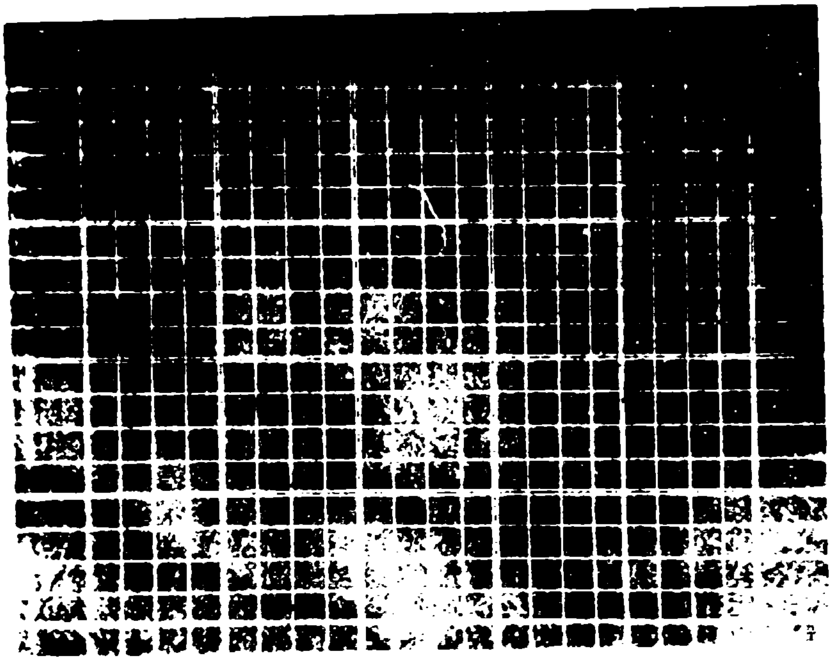
(a) U.S. Department of Energy, Office of Transportation Programs, Contract No. DE-AC04-79CS54240-001.

TABLE 21. PROPERTIES OF SL-90 CARBON SLURRY FUEL

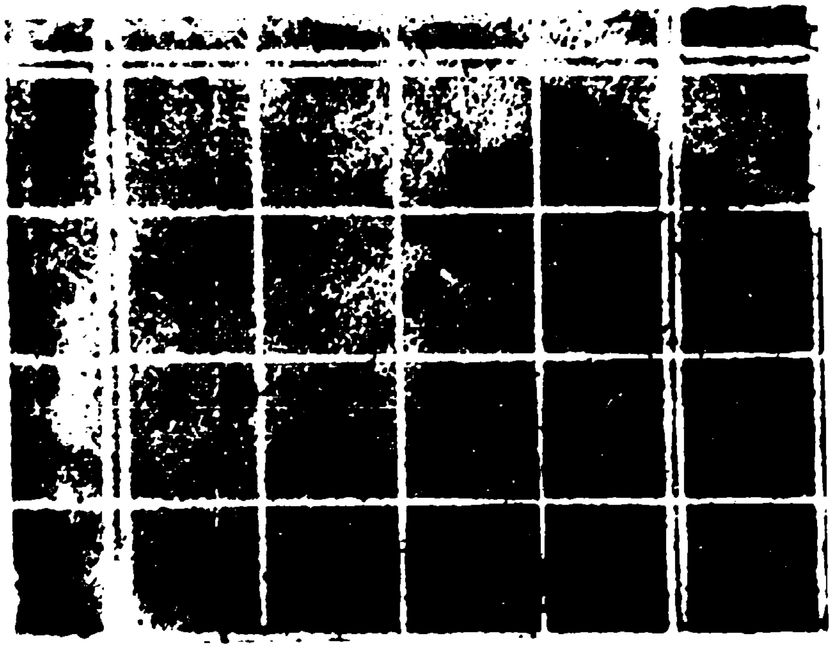
Nominal wt% Carbon Black	48
Nominal wt% JP-10	49
Nominal wt% Surfactant	3
Analyzed wt% Carbon Black	47.2
Density @ 25°C, lb/gal.	10.09
Net Heat of Combustion, Btu/lb	16,371
Net Heat of Combustion, Btu/gal.	165,183
Flash Point, °C (°F)	53.3 (128)

Contraves RM-30 Viscosity:

Temp, °C	Shear Rate, Sec^{-1}	cP
25	1	663
25	10	182
25	100	83
25	600	53
-20	1	1562
-20	10	478
-20	100	241
-20	600	285



a. 100X MAGNIFICATION



b. 430X MAGNIFICATION

FIGURE 4. PHOTOMICROGRAPHS OF 48 WEIGHT PERCENT CARBON BLACK SLURRY IN JP-10

A representative of the manufacturer indicates that a carbon slurry of a similar concentration in DF-2 could easily be prepared using this proprietary method of preparation. If so, this should be a good candidate fuel available at a relatively low cost.

(2) "Catalyzed" carbon black

Previous engine studies have indicated a problem with achieving full utilization of the carbon when running in the CLR engine. Use of a catalyst could possibly aid in its combustion and thus increase carbon utilization. The transition metals iron, nickel, and manganese were originally selected as catalyst candidates. At the recent Workshop on the Combustion of Slurry Fuels at the 17th JANNAF Combustion Meeting, it was stated that lead had been successfully used in the catalysis of carbon particle combustion in a turbine combustion chamber. Therefore, lead (as lead acetate) was added to the list of catalyst candidates. Deposition of the metals on the carbon black was achieved by dissolving the metallic compound in water [in methanol for iron (ferrocene)], adding the carbon black, and stirring for at least 1 hour. The carbon black was removed by filtration and then dried. Since the carbon black was extremely absorbent and the compounds containing the potential catalyst were highly polar, the deposition occurred without difficulty.

If 100 percent of the metal were deposited, the concentration of the carbon black would be 0.30 wt% for the iron, nickel, and lead, and 0.36 wt% for the manganese. The amount deposited has not yet been quantitatively determined, but X-ray fluorescence indicates the amount is relatively large. Washing of the carbon blacks with diesel fuel did not remove the deposits.

The above-described successful deposition work was first done on a relatively small scale (40 grams per test). Afterward, four larger batches (approximately 750 grams each), each containing a different metal, were processed. With this "catalyzed" carbon, four test fuels (8 liters each) were prepared containing 10 wt% carbon black in diesel fuel.

Engine tests with these fuels are described later.

(3) Settling studies

The freezing tube technique for measuring settling in carbon slurries was described in the first interim report on this program and is repeated in Appendix C of this report. The only difficulty encountered with this method thus far is that it tends to give slightly high values for the recovered carbon. These values appear to be high but correct relative to each other. This could be caused by the incomplete removal of the last traces of diesel fuel absorbed by the carbon black. A brief study was conducted to see if this rationale might be correct.

(a) Refinement of the freezing tube technique

A fuel was prepared in the attritor to contain 20.0 wt% carbon black, 1.0 wt% lecithin, and 79.0 wt% diesel fuel. The resulting slurry was placed in a settling tube for 48 hours at ambient temperature. The tube was then frozen and sliced into eight equal sections, and the percent carbon was determined, using the method mentioned above. The carbon recovered from the top four sections contained 20.57, 20.55, 20.58, and 20.58 wt% carbon, respectively. The average is 2.85 percent higher than the 20.0 wt% that was used in the preparation. The carbon samples recovered from the four sections were then placed in a Soxhlet extraction thimble that had been prewashed and dried to constant weight with methylene chloride. The carbon (17.3760 g) in the thimble was then continuously extracted with methylene chloride for eight hours. The carbon was dried and reweighed (16.7320 g) with a loss of 0.6440 g noted. This loss represents 3.7 percent of the total at the start of the extraction. Upon evaporation of the methylene chloride, 0.3888 g of residue was recovered, or 2.2 percent of the total at the start. The 2.2 percent of material recovered from this carbon compared favorably with the 2.85 percent high value that was observed when the carbon was originally determined by the freezing tube method. The residue recovered from the methylene chloride was essentially DF-2.

The four lower sections contained 20.60, 20.60, 20.57, and 20.62 wt% carbon, respectively. The average of these four sections was 20.60 wt% carbon, or

3.0 percent higher than the 20.0 wt% used to make the preparation. The same extracting procedure used with methylene chloride was then used with pentane. A 3.0-percent loss in weight was noted, and a residue was recovered upon evaporation that represented 1.1 percent of the total carbon at the beginning of the extraction. This residue was also found to be DF-2.

It would appear that methylene chloride is more effective in removing the diesel fuel from the carbon and will be used in place of pentane in future studies using the freezing tube technique.

(b) Effect of temperature on the stability of carbon slurries

Prior to the refinement in the freezing tube technique for measuring settling in carbon slurries, the effect of temperature on the stability of these slurries was examined.

A slurry containing 20 percent carbon black, 79 percent DF-2, and 1 percent lecithin was prepared in the attritor. Settling data were collected on a sample of the above fuel that had stood in a 100°C oil bath for 48 hours and a similar sample standing at room temperature (22°C) for the same period of time. The samples were analyzed by the freezing-tube technique.

It would appear from Figure 5 that about 4 percent more carbon had settled out of the top section of the sample at 100°C compared to the room temperature sample. This decrease of carbon in the top section of the 100°C sample is reflected in the increase of the carbon content of the lower sections.

(c) Stability of FRF-carbon slurries

Carbon black was added to a fire-resistant diesel fuel (FRF) so that the resultant fuel contained 20 wt% carbon black, 67.2 wt% DF-2, and 4.8 wt% water. Settling data were collected on samples after approximately 1, 15, and 38 days standing at ambient temperature. The samples were analyzed by the freezing tube technique prior to its refinement. As mentioned above,

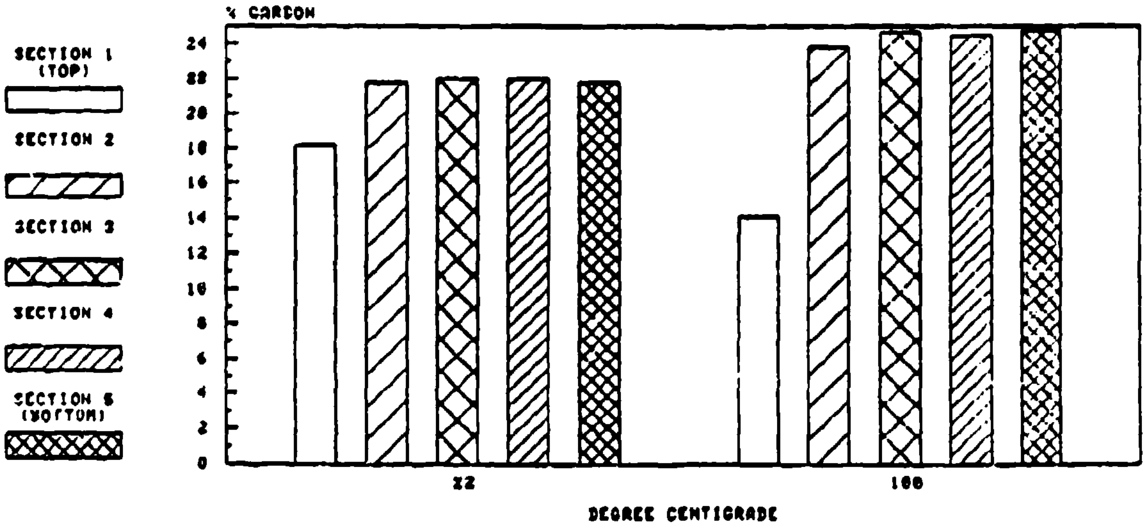


FIGURE 5. EFFECT OF TEMPERATURE ON THE STABILITY OF SLURRIED FUELS (20% Carbon, 1% Lecithin in DF-2, 48 Hour Settling Period)

the original procedure tends to give slightly high values for the recovered carbon. Although these values appear to be somewhat high, they are correct relative to each other. The high value is attributed to the incomplete removal of the last traces of diesel fuel that is absorbed by the carbon black. The refinement to this technique mentioned previously eliminates this problem. Even without the refinement, it is an excellent indicator of stability since all samples are treated in an identical manner.

The data from the FRF/carbon black stability study are plotted and shown in Figure 6. The mixture is fairly stable for at least 1 day as indicated from the carbon content in the six sections. For example, the carbon percentages found after 1 day, from top to bottom, were 22.0, 22.8, 23.1, 23.2, 23.7, and 25.5. It would appear that only slight settling has occurred.

c. SRC-I

A cursory search was made for a hydrocarbon in which SRC-I would have an

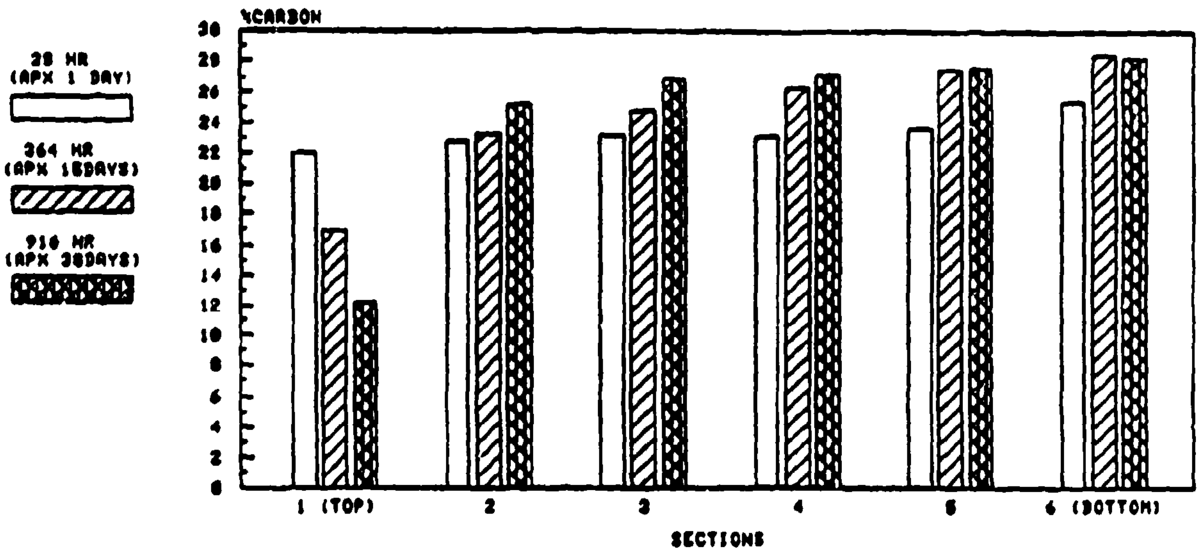


FIGURE 6. SETTLING DATA: 20 PERCENT CARBON BLACK IN FRF

appreciable solubility. No such hydrocarbon was found at that time but the search is continuing.

A slurry containing 20 wt% SRC-I in DF-2 was prepared, and the gross experimental heating value was 18,860 Btu/lb. Using the literature value for the density of SRC-I and the experimental density of DF-2, and assuming the densities are additive, the net volumetric heating value for the slurry was found to be 136,865 Btu/gal., a 6.5-percent improvement over DF-2.

2. Solid High-Energy Components That Have Appreciable Solubility

a. Solubility Measurements of Naphthalene and Phenanthrene

Naphthalene and phenanthrene are two solid (at room temperatures) hydrocarbons that have potential as high-energy fuel components. Phenanthrene is an isomer of anthracene but has the distinct advantage in that it is not as insoluble in organic hydrocarbons as anthracene. For example, in tetralin, anthracene was found to have very little solubility, while the solubility of phenanthrene was experimentally found to be approximately 43.6 grams of phenanthrene per 100 grams of tetralin at 21°C (Table 22). Therefore, a sample containing 30.37 wt% phenanthrene in tetralin (approximately the maximum concentration) was prepared. The gross experimental heat of combustion was 18,135 Btu/lb. Using the experimentally determined density of 0.9930 g/ml at 36°C corrected to 1.006 g/ml at 15.6°C, the net volumetric heating value was calculated to be 146,025 Btu/gal. This would represent a 13.7-percent improvement over the typical diesel fuel. In order for such a mixture to be run in a diesel engine, cetane improver would be necessary. Phenanthrene contribution to the volumetric heat content of a blend or slurry would be less than that of anthracene.

TABLE 22. SOLUBILITIES[(a)] OF NAPHTHALENE AND PHENANTHRENE IN VARIOUS ORGANIC HYDROCARBONS AND RELATED COMPOUNDS AT 20°C (68°F)

	Phenanthrene, g/100 g	Naphthalene, g/100 g
Tetrahydronaphthalene (tetralin)	50.0	43.6
DF-2[(a)]	24.1	9.9
JP-10	29.5	12.0
RJ-5	(c)	15.3
Mixed Naphthalenes[(b)]	29.7	27.4
SRC-II (middle distillate)	29.3	29.2
FRF	15.3	8.2

(a) AFLRL Fuel No. AL-9979-F (Control Fuel).
(b) AFLRL Fuel No. AL-9509-A.
(c) Not determined.

The solubility of phenanthrene in DF-2 (control fuel) was experimentally found to be 9.9 g of phenanthrene per 100 grams of DF-2 at 20°C. A sample was prepared containing 9.0 g phenanthrene in 91.0 g of DF-2 and the experimental ΔHc was determined. Using the experimentally determined density of

0.8693 g/ml at 15.6°C, the net volumetric heating value was found to be 133,160 Btu/gal., an improvement of 3.6 percent over neat diesel fuel. Probably no cetane improver would be required with this fuel. It would be necessary, however, to avoid temperatures much below 20°C, because the phenanthrene would crystallize and settle out.

The solubility of naphthalene and phenanthrene in various organic hydrocarbons and related compounds are shown in Table 22.

b. Blending of Solid Components Into Liquid Fuels

Various fuels have been prepared using these two high-energy components. Table 23 compares these fuels and their AFLRL-determined heats of combustion with the control DF-2. The experimentally determined cetane numbers of fuel blends containing naphthalene and phenanthrene are shown in Table 24.

E. Impact Dispersion Tests to Study Fire-Safety Characteristics of Energy-Augmented Fuels

1. RJ-5

Several high-energy or related fuels were examined for their fire-safety characteristics by the AFLRL Impact Dispersion Test*. The results from these tests indicated that RJ-5 and some of its blends had some good fire-hindering properties.

Impact dispersion tests** were conducted on RJ-5 and some of its blends.

(a) RJ-5 (neat)
(b) RJ-5: DF-2 Blend (50 vol%: 50 vol%)**
(c) RJ-5: FRF Blend (30 vol%: 70 vol%)+

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* = For a description of these tests and the rating system, see Appendix D.
** = 56.05 wt% RJ-5; 43.95 wt% DF-2 (AFLRL Fuel No. AL-8821-F)
\+ = 34.65 wt% RJ-5 and 65.35 wt% FRF (FRF prepared using DF-2 with AFLRL Fuel No. AL-8821-F). The resulting net volumetric ΔHc was 128,570 Btu/gal.; about equal to control fuel (128,465).

TABLE 23. COMPARISON OF THE VOLUMETRIC HEATS OF COMBUSTION OF VARIOUS LIQUID FUELS CONTAINING NAPHTHALENE OR PHENANTHRENE WITH DF-2 (CONTROL)

Naphthalene, wt%	Phenanthrene, wt%	Liquid Components,[a] wt%	Density, 15.56°C (60°F), g/ml	Hydrogen, wt%	Experimental ΔHc Combustion Btu/lb	Experimental ΔHc Combustion Btu/gal.	Percent Increase in Volumetric ΔHc Over Control DF-2
20.0	---	A= 80.0	0.9524	10.94	17,810	141,555	10.2
	19.4	A= 77.6 B= 3.0	0.9651	10.66	18,695	142,715	11.1
	20.0	C= 80.0	1.0363	7.01	16,790	145,190	13.0
	19.4	C= 77.6 B= 3.0	1.0394	7.11	16,460	142,755	11.1
	30.37	D= 69.63	1.006	8.10[b]	17,395	146,025	13.7
	9.01	D= 90.99	0.8693	12.20[b]	18,335	133,160	3.7
19.42		E= 80.58	0.8750	11.58[b]	18,155	132,545	3.2
25.0		A= 72.0 B= 3.0	0.9556	10.63	17,525	139,745	8.8
14.4		F= 85.6	0.8894	11.92	16,135	119,765	-6.8
	19.73	G= 80.27	1.0097	8.052[b]	16,545	139,400	8.5
15.0		H= 85.00	0.8[illegible]35[b]	-------	18,375[b]	137,215[b]	6.8
	13.3	I= 86.70	1.0926	9.20[b]	17,996	164,070	27.7
33.33		D= 66.67	0.9864	8.20	17,275	142,200	10.7
22.78		A= 77.22	0.9546	10.58	17,960	143,065	11.4
	22.0	C= 78.00	1.0367	7.39[b]	16,800	145,340	13.1
13.30		F= 86.70	0.8768	11.78	16,985	123,625	-3.8
	7.5	F= 92.50	0.8881	12.26	16,420	121,665	-5.3
	21.5	C= 78.50	1.0385	6.96	16,985	147,185	14.6
	22.6	G= 77.40	1.0134[b]	8.17	16,665	140,920	9.7

(a) See Code Letter

A= JP-10
B= Amyl Nitrate (cetane improver)
C= Aromatic Blending Stock
D= Tetralin
E= DF-2 (control fuel) AFLRL Fuel No. AL-9979-F
F= PRF
G= SRC-II (middle distillate)
H= DF-2 (Cat I-H) AFLRL Fuel No. AL-10115-F
I= RJ-5

(b) Calculated from individual components

TABLE 24. CETANE NUMBERS OF FUEL BLENDS CONTAINING NAPHTHALENE OR PHENANTHRENE

Fuel Composition	wt%	AFLRL Experimental Cetane No.
DF-2[(a)]	91.0	
Phenanthrene	9.0	45
DF-2[(a)]	80.6	
Naphthalene	19.4	43
Tetralin	65.3	
Naphthalene	32.7	
Amyl Nitrate	2.0	24
Tetralin	68.3	
Phenanthrene	29.7	
Amyl Nitrate	2.0	24

[(a)] DF-2 [AFLRL Fuel No. AL 9970 (Control Fuel)]

Examination of the video record of these tests showed no ground fires and only a medium-size fireball which is equal to a "D" rating. This is the rating that all the FRF fuels (84 vol% DF-2; 10 vol% H_2O; 6 vol% surfactant) have received. The fact that these fuels containing RJ-5 did not sustain pool burning could reflect the effect of the high flash point of RJ-5 (111°C), since the fuels were dropped at 77°C onto the impact plate at 93.3°C.

2. DF-2

It is noted in Table 25 that the amount of RJ-5 needed to eliminate pool burning of DF-2 (AL-8821-F) in this test has been found to be between 35 to 50 volume percent. The blend containing 30 vol% RJ-5 and 70 vol% DF-2 has a coalesced fireball with simultaneous light pool burning immediately after impact, thus an "E" rating. The intensity of this ground fire then increased with time. DF-2 (neat) had an "E" rating.

TABLE 25. IMPACT DISPERSION TEST RESULTS AND FUEL PROPERTIES[a]

Fuel	Impact Dispersion Test Rating(b)	ΔHc (net), Btu/gal.	Density (15.56°C), g/ml	Viscosity 40°C, cSt
DF-2 (neat) (c)	E	130,620	0.8484	3.20
SRC-II (neat) (d)	E	134,760	0.9840	3.68
JP-9 (neat)	E	143,445 (e)	0.9444	2.49
JP-10 (neat)	E			
JP-10 microemulsion (f)	E	126,190	0.9533	(g)
RJ-5 (neat)	D	160,390	1.0837	13.27
50 vol% RJ-5; 50 vol% DF-2 (56.05 wt% RJ-5; 43.95 wt% DF-2)	D	144,220	0.9657	5.78
30 vol% RJ-5; 70 vol% DF-2 (35.38 wt% RJ-5; 64.62 wt% DF-2)	E	139,550(h)	0.9316(h)	(g)
35 vol% RJ-5; 65 vol% DF-2 (40.75 wt% RJ-5; 59.25 wt% DF-2)	D	141,140	0.9328	4.73
25 vol% RJ-5; 25 vol% SRC-II (76.77 wt% RJ-5; 73.14 wt% SRC-II)	D	141,630	1.0084	4.40
75 vol% RJ-5; 25 vol% SRC-II (76.77 wt% RJ-5; 23.23 wt% SRC-II)	D	156,080	1.0632	8.14
30 vol% RJ-5; 70 vol% FRF (34.65 wt% RJ-5; 65.35 wt% FRF)	D	128,565	0.9382	(g)
FRF	D(i)	116,825(h)	0.8747(h)	(g)
46 vol% FRF; 54 vol% SRC-II (43.08 wt% FRF; 56.91 wt% SRC-II)	E	126,315(h)	0.9338(h)	(g)
46 vol% FRF; 54 vol% JP-10 (44.24 wt% FRF; 55.76 wt% JP-10)	E	128,135(h)	0.9095(h)	(g)

(a) Experimentally determined at AFLRL except where otherwise indicated.

(b) Impact Dispersion Test Rating

A = No pilot flame enlargement
B = Pilot flame dimentions less than doubled.
C = Pilot flame dimensions more than doubled.
D = Pilot flame totally obscured by transient mist fireball.
E = Coalesced fireball with simultaneous pool burning.

Test Conditions: Sample 76.7°C (170°F)
Impact Plate 93.3°C (200°F)

(c) AFLRL Fuel No. AL-8821-F, Flash Point 72°C (161°F) used in all blends with this table where DF-2 is indicated. See Appendix B, No. 2 for its properties.

(d) Middle Distillate, AFLRL Fuel No. AL-9252-SP-F, Flash Point 80°C (176°F) used in all blends in this table where SRC-II is indicated.

(e) Calculated from AFLRL data.

(f) 83.5 wt% JP-10; 10 wt% H_2O; 6.0 wt% surfactant; 0.5 wt% cetane improver.

(g) Not determined.

(h) Calculated from components.

(i) FRF made with DF-2 having AFLRL No. AL-8821-F not tested. Rating given based on other FRF tests with similar fuels.

The properties of DF-2, RJ-5, and their equal blends are listed in Table 26. It can be seen from this table that a 50:50 volumetric blend of DF-2 and RJ-5 results in a fuel that shows an improvement in the volumetric heat of combustion of 12.3 percent when compared to the control DF-2.

TABLE 26. PROPERTIES OF DF-2, RJ-5, AND THEIR EQUAL BLENDS

	DF-2[(a)]	RJ-5	50 Vol% RJ-5: 50 Vol% DF-2[(b)]
Btu/gal. (net)	130,615	160,390	144,220[(c)]
Btu/lb (net)	18,450	17,740	17,900
Density, 15.6°C (60°F)	0.8484	1.0837	0.9657
Viscosity, cSt, 40°C	3.2	13.27	5.78
Flash Point, °C (°F)	71.7 (161)	111 (232)	86.1 (187)
Freeze Point, °C (°F)	---	-53.9 (-65)[(d)]	2 (36)
Pour Point, °C (°F)	-10 (-14)	---	---

(a) AFLRL Fuel No. 8321-F.--see Appendix B, No. 2 for its properties.
(b) 56.05 wt% RJ-5 and 43.95 wt% DF-2.
(c) This represents a 12.3 percent increase over that of control fuel.
(d) Literature value (exp. value at another lab).

3. SRC-II

The blends of SRC-II and RJ-5 at SRC-II concentrations of 25 and 75 vol%, respectively, received "D" ratings. The data in Table 25 indicate that 25 vol% RJ-5 will eliminate pool burning of SRC-II. Lesser amounts of RJ-5 with SRC-II have not yet been tested. SRC-II (neat) received "E" ratings.

4. Other Fuels [JP-10 (neat), JP-9, JP-10/H_2O Microemulsion]

Other fuels to receive "E" ratings were JP-10 (neat), JP-9 (neat), and JP-10/H_2O microemulsion (see Table 25).

JP-9 is a three-component blend containing JP-10 (65-70 wt%), RJ-5 (20-25 wt%), and methylcyclohexane (10-12 wt%). JP-9 was developed by the Air Force to meet its critical specifications for the fuels used in its Air Launched Cruise Missile. When subjected to the impact dispersion test, an intense fire resulted. No further work is planned with this fuel.

5. FRF-Type Fuels Augmented With RJ-5

FRF fuels and their fire-safety characteristics have been described in detail elsewhere.(8) Because they contain an appreciable amount of water, they suffer by having a reduced energy content. Since RJ-5 has shown the tendency to have fire-hindering properties, and also have a very high volumetric energy content (160,000 Btu/gal.), a blend of FRF and RJ-5 might result in a fuel that still has the fire-safety characteristics of FRF but at a much higher energy content.

Several months after the tests listed in Table 25 were completed, another series of impact dispersion tests were run using the same conditions as in the past. All the fuels containing RJ-5 that were tested in this series received a "D" rating in the impact dispersion test, and all containing water were microemulsions (Figure 7). These fuels are still stable micro-

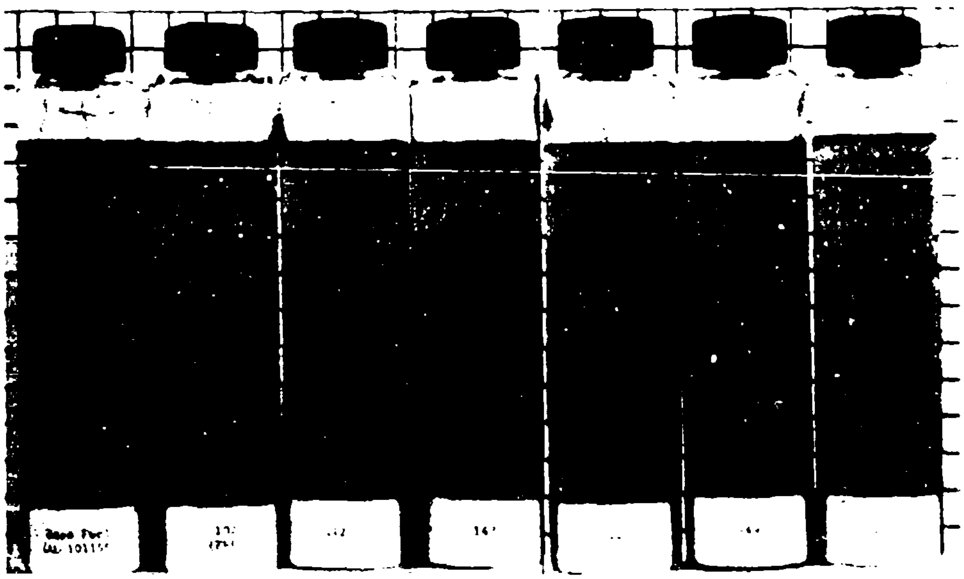

FIGURE 7. RJ-5 MICROEMULSIONS

emulsions to date (after 8 months) upon standing at room temperature. When only 3.0 vol% surfactant was used in attempting to prepare a microemulsion containing 5 vol% water and 5 vol% RJ-5 in 87 vol% DF-2, a trace amount of "cream" was visible at the bottom of the container after standing for several days at room temperature. When the surfactant content was increased to 3.5 vol%, the "cream" was eliminated and a stable microemulsion resulted.

In all cases, the RJ-5 increase in the volumetric ΔHc of the fuel compared to neat FRF without apparent sacrifice to its fire-hindering properties. Since RJ-5 appears to have good fire-resistant properties for exposure temperatures of 93°C (200°F) or less, it was not expected to have any deleterious effects under such exposure conditions when substituted in the FRF formulations. The results are summarized in Table 27. All the fuels, except No. 6, and including the FRF, were prepared using the same DF-2 (AFLRL Fuel No. AL-10115F, Cat 1-H) and all compositions are volumetric percentages.

IV. ENGINE STUDIES

A. CLR Engine Studies

1. Screening Studies

Prior to obtaining the Petter engine as a screening tool for high-energy fuel candidates, the screening tests were conducted using a CLR engine in the engine-testing facilities that were established and operated under a Department of Energy contract. Two of these fuel formulations, both related to the fire-resistant fuel program, are described below.

a. JP-10/H_2O Microemulsion

FRF is a microemulsion consisting of 84 vol% DF-2, 10 vol% water, and 6 vol% surfactant. It has shown great promise as a fire-resistant fuel for the Army's application. It was reasoned that JP-10, with its relatively high

TABLE 27. THE EFFECT OF RJ-5 SUBSTITUTION IN FRF-TYPE FUELS AND THE RESULTING PROPERTIES

Run. No.	Composition, vol%				Impact Dispersion(1) Rating	Density g/ml, 15.56°C (60°F)	Cetane No.	Experimental ΔHc (net), Btu/lb	Experimental ΔHc (net), Btu/gal	Percent Increase in The Volumetric Energy Content Over Typical FRF
	DF-2	Water	Surfactant	RJ-5						
1	84.0	7.5	6.0	2.5	D	0.8752	45	16,680	121,800	4.6
2	84.0	5.0	6.0	5.0	D	0.8762	45	17,100	125,010	7.4
3	79.0	10.0	6.0	5.0	D	0.8856	43	16,105	119,000	2.2
4	86.5	5.0	3.5	5.0	D	0.8730	47	17,290	125,920	8.2
5	81.5	5.0	3.5	10.0	D	0.8845	45	17,310	127,220	9.8
6	50.0	---	000	50.0	D	0.9657	[45](2)	17,900	144,220	23.9
FRF	84.0	10.0	6.0	---	[D](3)	0.[illegible]37	44	15,970	116,395	---
Base Fuel	100.0	---	---	---	[E](3)	0.8504	53	18,665	132,365	13.7

(1) Test Conditions: Sample 76.7°C (170°F)
Impact Plate 93.3°C(200°F)
Code for rating Impact Dispersion Tests:
A = No Pilot flame enlargement.
B = Pilot flame dimensions less than doubled.
C = Pilot flame dimensions more than doubled.
D = Pilot flames totally obscured by transient mist fireball.
E = Coalesced fireball with simultaneous pool buring.

(2) All fuels listed in the table were prepared using a Cat 1-H base fuel (AL-10115F) except No. 6 which used Code No. 8821. All experimental measurements made on Fuel No. 6 were made eight months previous except cetane number. The cetane number determination listed in brackets was made on a sample of the same composition except the Cat 1-H fuel was used. Fuel AL-8821F has a flash point of 71.7°C (161°F); fuel AL-10115F has a flash point of 80°C (176°F). The rating of "D" by the previous impact dispersion test on Fuel No. 6 should be applicable and comparable to the other fuels listed in the table and tested in this apparatus.

(3) This fuel was not tested by the impact dispersion apparatus. Value in brackets indicate a test on a fuel of similar composition.

volumetric energy content [~142,000 Btu/gal. (net)] might be used to replace the DF-2 in the FRF and thus restore some or all of the energy loss caused by the water. Thus, the JP-10/H_2O microemulsion fuels were prepared to see if any fire-resistant properties might be imparted to this fuel.

Several different emulsifying agents were tried. Three microemulsion fuels of this type were prepared; all were stable for one year and one was still stable after two years when the stability test was terminated.

The terms Relative (Specific) Fuel Consumption (RFC), the Relative (Specific) Energy Consumption (REC), and the Relative (Specific) Volumetric Fuel Consumption (RVFC) are defined at the bottom of Table 28.

Screening tests on the latter JP-10/water microemulsion were conducted using the CLR engine. In Table 28, it can be seen that the REC values at 1000, 1500, and 2000 rpm are close to one, indicating that the thermal cycle efficiency when using this fuel is similar to that observed when the base fuel was used. A good comparison of the JP-10/water microemulsion fuel with DF-2 can be made using RVFC, i.e., the ratio of the BSVC of the test fuel to that of the base fuel. RVFC values less than unity are desirable as they would indicate better performance by the test fuel than the base fuel when using the same volume. The JP-10/water microemulsion has RVFC values close to unity over the speed and load range. This indicates a volumetric consumption rate very close to that of the baseline diesel fuel. Comparisons of this microemulsion with the base fuel can also be made using Figure 8a to 8f. It should be noted that the calculated net volumetric heat of combustion of this fuel (127,250 Btu/gal.) is almost that of a typical DF-2 (DF-2 control fuel = 128,465 Btu/gal.).

b. <u>Carbon Black Slurries in FRF</u>

Fire-resistant fuels in general are penalized in their energy content (ΔHc) because of the water present. An attempt was made to reduce some of the loss in energy content by the addition of carbon. A 20 wt% carbon concentration in FRF was first prepared, but rheology problems suggested a lower

TABLE 28. CLR ENGINE PERFORMANCE COMPARISON OF JP-10 MICROEMULSION [(a)] WITH DF-2[(b)]

Test No.	Engine Speed, rpm	Bhp (obs)	Rack Position	Load, lb/ft	Mass Fuel Rate, lb/m	BSFC-Test Fuel lb/bhp-hr	BSFC-Base Fuel lb/bhp-hr	BSVC-Test Fuel gal./bhp-hr	BSVC-Base Fuel gal./bhp-hr	Specific Range hp-hr/gal.	Thermal Eff, %	RFC[(c)]	REC[(d)]	RVFC[(e)]
1	1000	4.57	Full	24.0	2.70	0.591	0.527	0.075	0.750	13.34	26.7	1.121	0.991	1.000
2	1000	3.22	3/4	16.9	2.00	0.622	0.521	0.079	0.074	12.68	25.4	1.194	1.056	1.068
3	1000	2.17	1/2	11.4	1.52	0.700	0.591	0.089	0.084	11.25	22.5	1.184	1.047	1.060
4	1500	6.85	Full	24.0	4.02	0.586	0.491	0.074	0.070	13.44	26.9	1.193	1.055	1.057
5	1500	5.23	3/4	13.8	3.12	0.597	0.513	0.076	0.073	9.95	19.9	1.544	1.366	1.040
6	1500	3.37	1/2	11.8	2.32	0.688	0.579	0.087	0.082	11.45	22.9	1.188	1.051	1.061
7	2000	8.00	Full	21.0	4.72	0.590	0.564	0.075	0.080	13.35	26.8	[illegible].046	0.925	0.938
8	2000	5.94	3/4	15.6	3.93	0.662	0.600	0.084	0.085	11.91	2[illegible]	[illegible]33	0.914	0.988
9	2000	3.81	1/2	10.0	3.17	0.832	0.679	0.106	0.096	9.47	[illegible]	[illegible].225	1.083	1.104

(a) - JP-10/Water Microemulsion 32.73 wt%, JP-10; 10.54 wt% water; 6.20 wt% surfactant; 0.50 wt% cetane improver
Heating Value (net) - 16,115 Btu/lb (calc), 127,250 Btu/gal. (calc) Density - 0.9463 g/ml at 15.56°C (60°F)

(b) - DF-2 (Base fuel) Heating Value (net) 18,220 Btu/lb, 128,300 Btu/gal. Density - 0.8438 g/ml at 15.56°C (60°F)

(c) - Relative (Specific) Fuel Consumption (RFC)
$RFC = BSFC_{test}/BSFC_{base}$

(d) - Relative (Specific Energy Consumption) (REC)
$REC = RFC\ (\text{Heating Value}_{net}\ \text{Test Fuel}/\text{Heating Value}_{net}\ \text{Base Fuel})$

(e) - Relative (Specific) Volumetric Fuel Consumption (RVFC)
RVFC = BSVC (Test Fuel)/BSVC (Base Fuel)

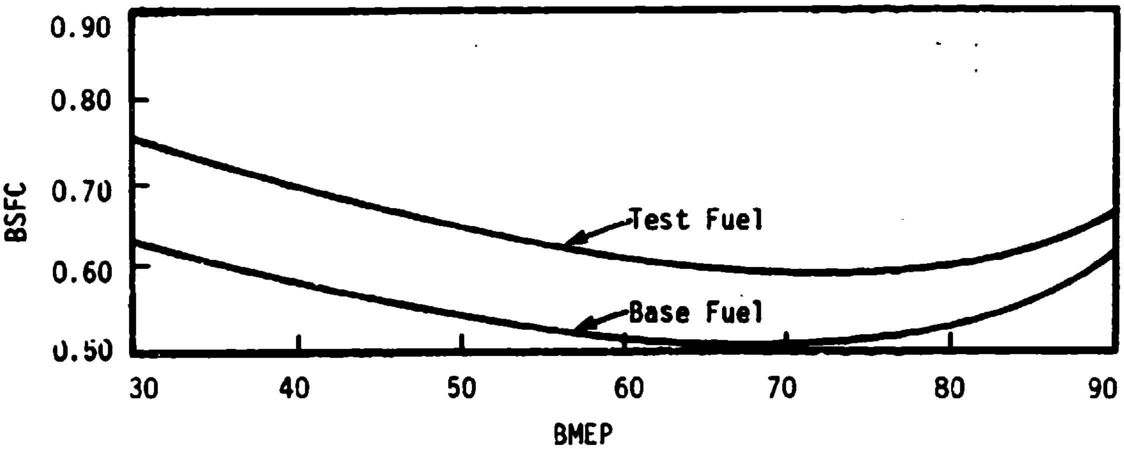

FIGURE 8a. BSFC VERSUS BMEP FOR BASE AND TEST FUELS AT 1000 RPM
TEST FUEL - JP-10 EMULSION

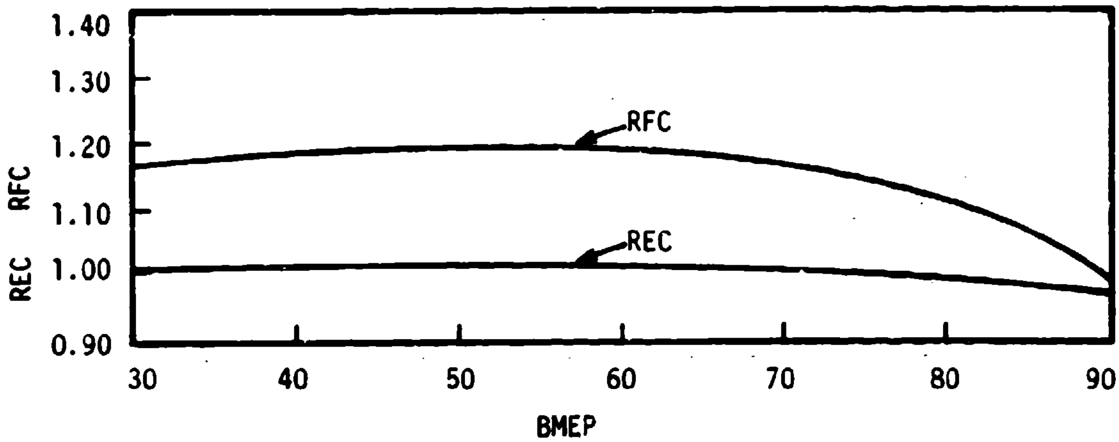

FIGURE 8b. RFC AND REC VERSUS BMEP FOR JP-10 EMULSION AT 1000 RPM

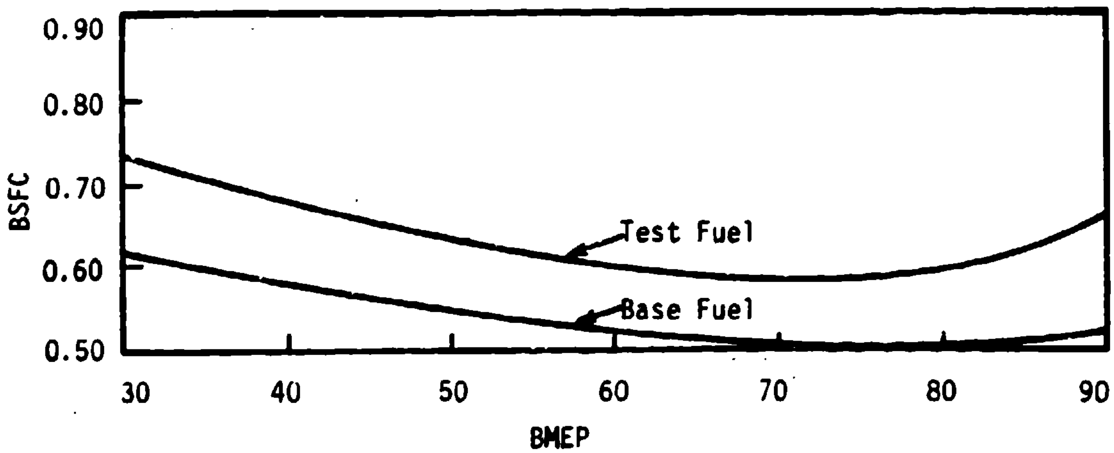

FIGURE 8c. BSFC VERSUS BMEP FOR BASE AND TEST FUEL AT 1500 RPM
TEST FUEL - JP-10 EMULSION

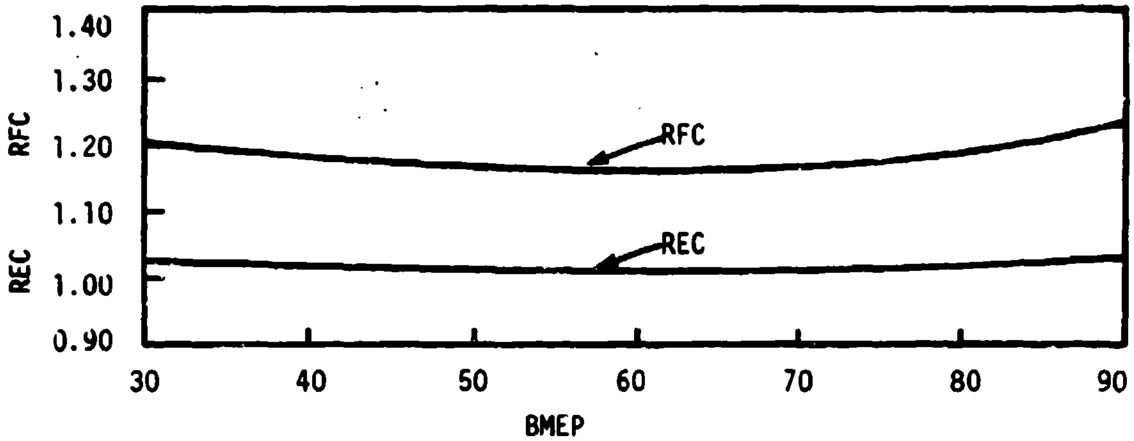

FIGURE 8d. RFC AND REC VERSUS BMEP FOR JP-10 - EMULSION AT 1500 RPM

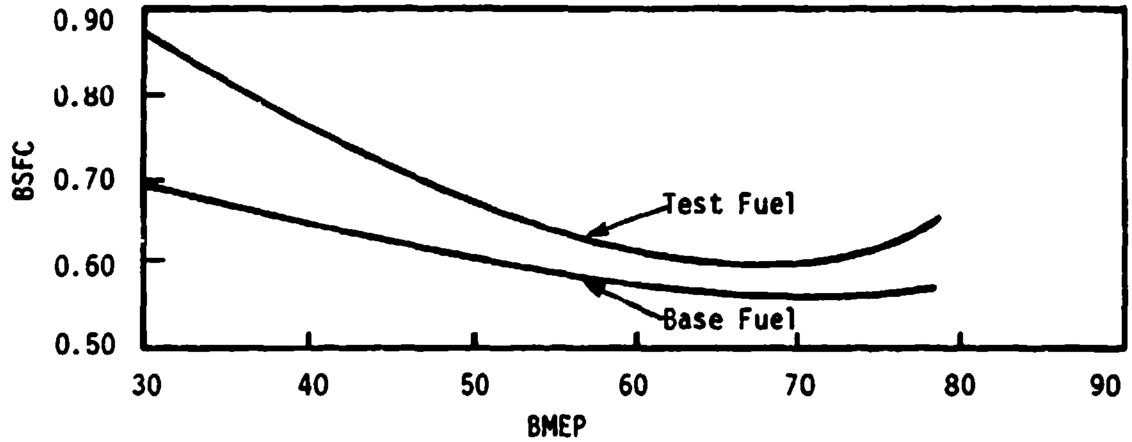

FIGURE 8e. BSFC VERSUS BMEP FOR BASE AND TEST FUEL AT 2000 RPM
Test Fuel - JP-10 Emulsion

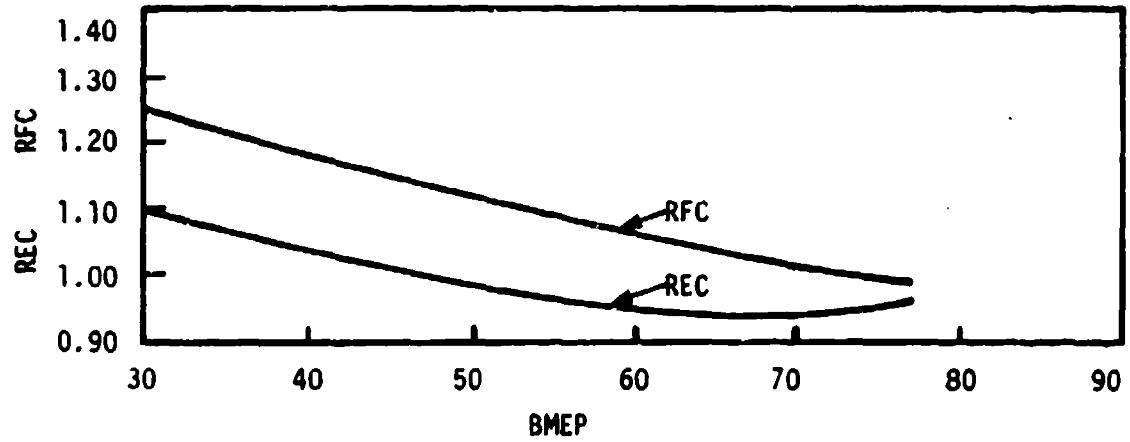

FIGURE 8f. RFC AND REC VERSUS BMEP FOR JP-10 - EMULSION AT 2000 RPM

carbon concentration. The composition of the carbon/PRF slurry that was tested was 10 wt% carbon, 73.55 wt% DF-2, 10.32 wt% deionized water, and 6.13 wt% surfactant. The CLR engine performance comparison of this slurried fuel with base DF-2 is shown in Table 29. Figures 9a to 9f indicate that the suspended carbon caused a reduction in the performance compared to DF-2 over the three speeds and load ranges that were tested. Even at 10 percent carbon black, the viscosity of this test fuel was much higher than that of the base fuel and undoubtedly contributed to its poor performance by the degradation of the injection and atomization processes. As can be noted in the table, the REC's in all runs were greater than one. This was especially evident at the lower speed (1000 rpm).

Figure 10 shows the REC, averaged over all loads, for each plunger diameter plotted versus the injection timing. Except for the 21-degree injection timing using the 9.5-mm plunger, the optimum plunger diameter appears to be the 8.5 mm. One surprising fact is the trend toward reduced energy consumption as the injection timing is retarded. If the carbon particles have long combustion time compared to the liquid fuel, it would be expected that increases in injection rate or advanced injection timings would improve the efficiency.

c. Catalyzed Carbon Black

As mentioned in Section III.D.2., the deposition of four different metals (manganese, iron, lead, and nickel) on carbon black was successfully achieved. Such metals might act as catalysts and aid in the combustion and utilization of the carbon black. The data in Table 30 compare the four "catalyzed" fuels with the base fuel diesel fuel, using REC as the criterion. The percentage of the metals coated on the carbon black listed in the table are those calculated assuming 100 percent of the metal was deposited in each case.

The REC values for the uncoated slurry, using the same injection timing and duration, are also listed in Table 30. Examination of this data indicates that the "catalyzed" carbon black slurries have improved the efficiency over the uncoated black slurry, especially with the nickel nitrate.

TABLE 29. CLR ENGINE PERFORMANCE COMPARISON OF CARBON BLACK (10 wt%) SLURRIED IN FRF[(a)] WITH DF-2[(b)]

Test No.	Engine Speed, rpm	Bhp (obs)	Rack Position	Load, lb/ft	Mass Fuel Rate, lb/m	BSFC-Test Fuel lb/bhp-hr	BSFC-Base Fuel lb/bhp-hr	BSVC-Test Fuel gal./bhp-hr	BSVC-Base Fuel gal./bhp-hr	Specific Range hp-hr/gal.	Thermal Eff, %	RFC[(c)]	REC[(d)]	RVFC[(e)]
1	1000	3.73	Full	19.6	3.49	0.935	0.549	0.123	0.078	8.14	17.2	1.703	1.476	1.511
2	1000	2.97	3/4	15.6	2.85	0.960	0.548	0.126	0.078	7.94	16.8	1.752	1.519	1.615
3	1000	2.09	1/2	11.0	2.28	1.089	0.595	0.143	0.085	6.99	14.8	1.830	1.586	1.682
4	1500	6.51	Full	22.8	4.50	0.691	0.518	0.091	0.074	11.02	25.3	1.334	1.156	1.230
5	1500	4.74	3/4	16.6	3.45	0.728	0.532	0.096	0.075	10.46	22.1	1.368	1.186	1.280
6	1500	3.31	1/2	11.6	2.79	0.842	0.585	0.111	0.083	9.04	19.1	1.439	1.247	1.337
7	2000	7.96	Full	20.9	5.69	0.715	0.532	0.094	0.076	10.65	22.5	1.344	1.165	1.237
8	2000	6.36	3/4	16.7	4.50	0.708	0.553	0.093	0.079	10.76	22.8	1.280	1.110	1.208
9	2000	4.42	1/2	11.6	3.67	0.831	0.606	0.109	0.086	9.16	19.4	1.371	1.189	1.267

(a) - 10 wt% Carbon Black (Raven 1170) slurried in 90 wt% FRF

Composition of Fuel that results is 73.55 wt% DF-2 (AL-8821F); 10 wt% Carbon Black; 10.32 wt% Deionized Water;

6.13 wt% Surfactant (EA-8)

Calculated Heating Value (net) = 15,795 Btu/lb (120,530 Btu/gal.)   Density (Experimental) = 0.9144 g/ml at 1556°C (60°F)

(b) - DF-2 (Base fuel) Heating Value (net) 18,220 Btu/lb (128,300 Btu/gal.)   Density - 0.8438 g/ml at 1556°C(60°F)

(c) - Relative (Specific) Fuel Consumption (RFC)

$RFC = BSFC_{test}/BSFC_{base}$

(d) - Relative (Specific) Energy Consumption (REC)

$REC = RFC\ (Heating\ Value_{net}\ Test\ Fuel/Heating\ Value_{net}\ Base\ Fuel)$

(e) - Relative (Specific) Volumetric Fuel Consumption (RVFC)

RVFC = BSVC (Test Fuel)/FSVC (Base Fuel)

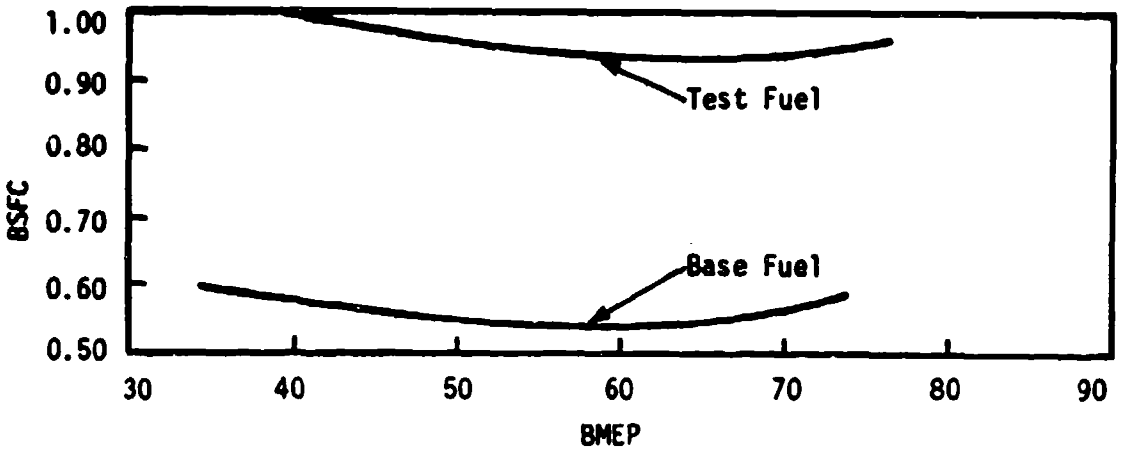

FIGURE 9a. BSFC VERSUS BMEP FOR BASE AND TEST FUEL AT 1000 RPM
Test Fuel DF-2 Emulsion With 10% Carbon

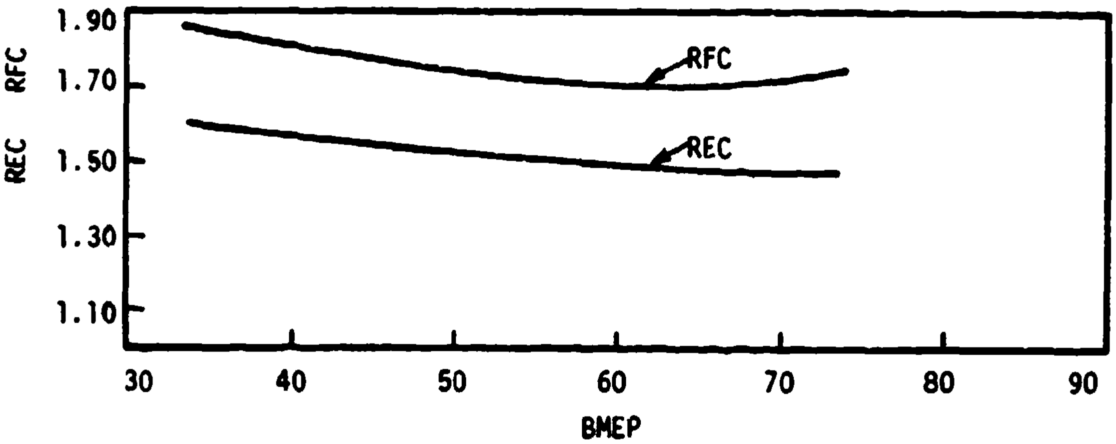

FIGURE 9b. RFC AND REC VERSUS BMEP FOR DF-2 EMULSION WITH 10% CARBON AT 1000 RPM

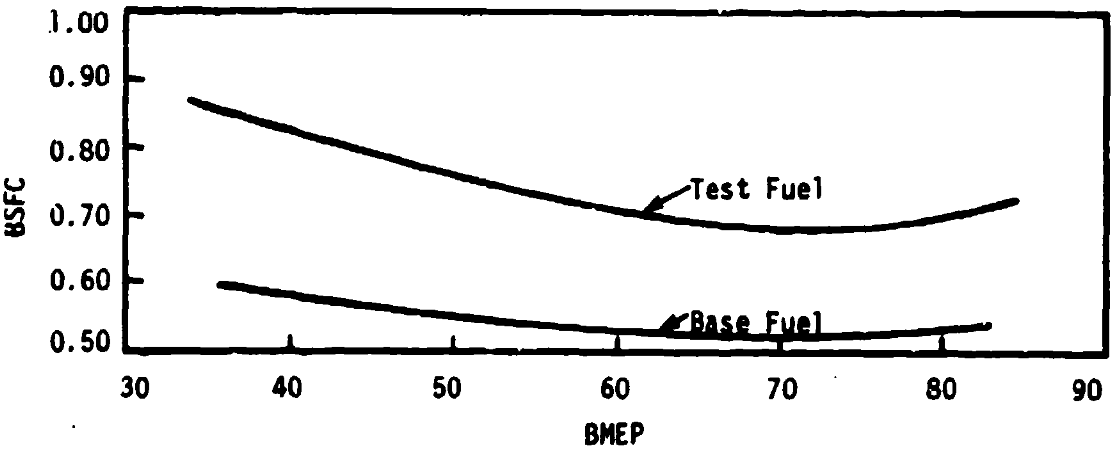

FIGURE 9c. BSFC VERSUS BMEP FOR BASE AND TEST FUEL AT 1500 RPM
Test Fuel DF-2 Emulsion With 10% Carbon

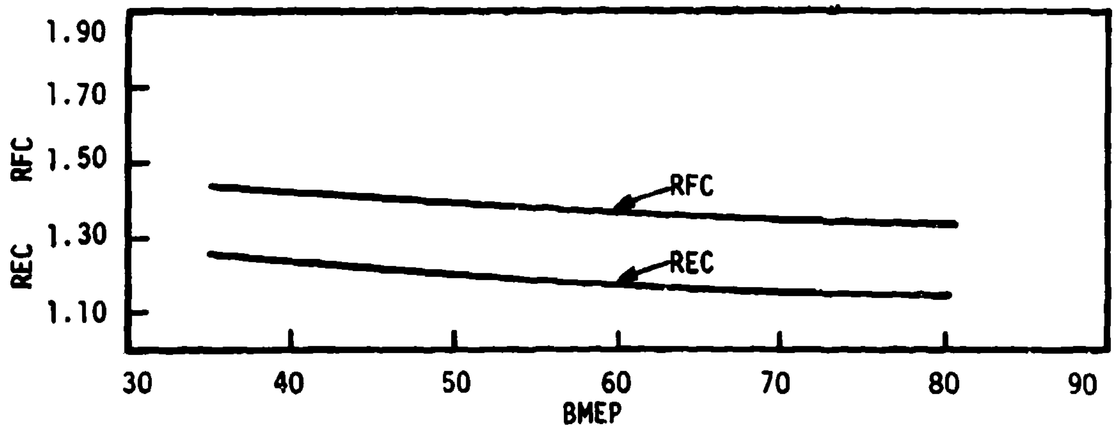

FIGURE 9d. RFC AND REC VERSUS BMEP FOR DF-2 EMULSION WITH 10% CARBON, AT 1500 RPM

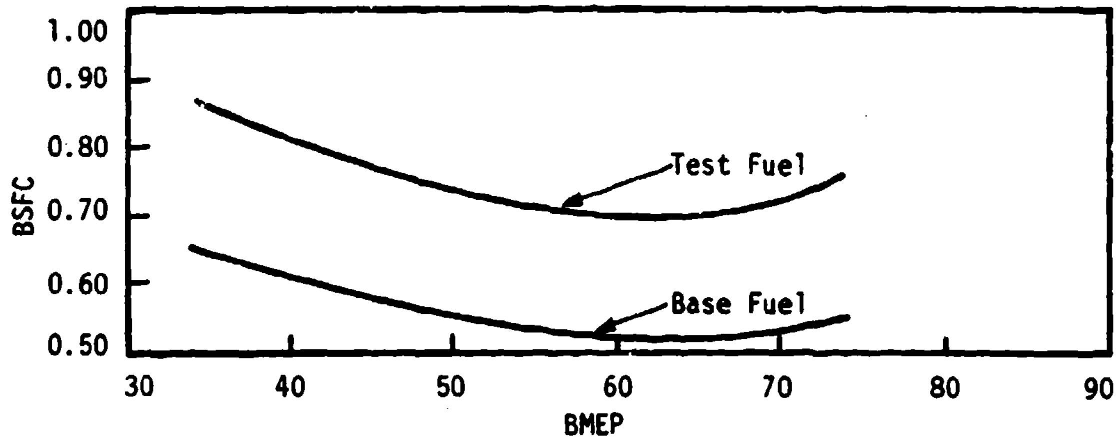

FIGURE 9e. BSFC VERSUS BMEP FOR BASE AND TEST FUEL AT 2000 RPM
Test Fuel - DF-2 Emulsion With 10% Carbon

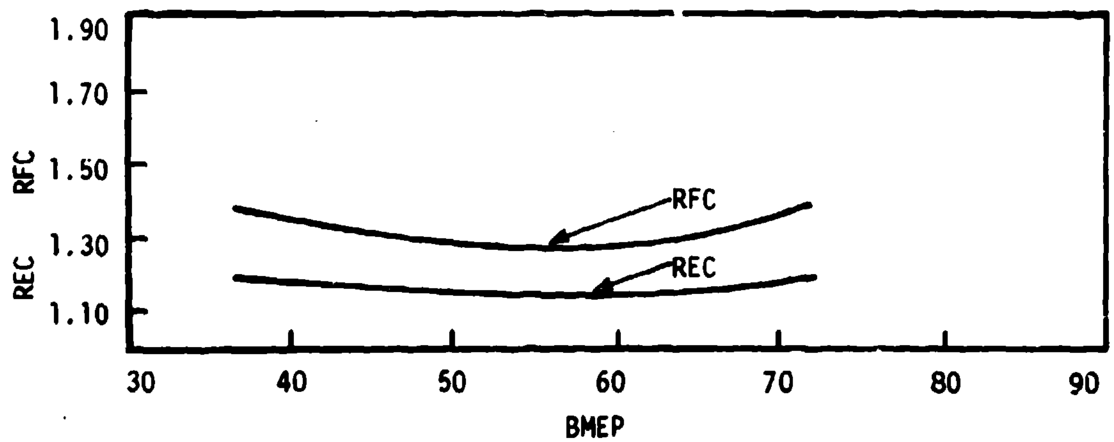

FIGURE 9f. RFC AND REC VERSUS BMEP FOR DF-2 EMULSION WITH 10% CARBON AT 2000 RPM

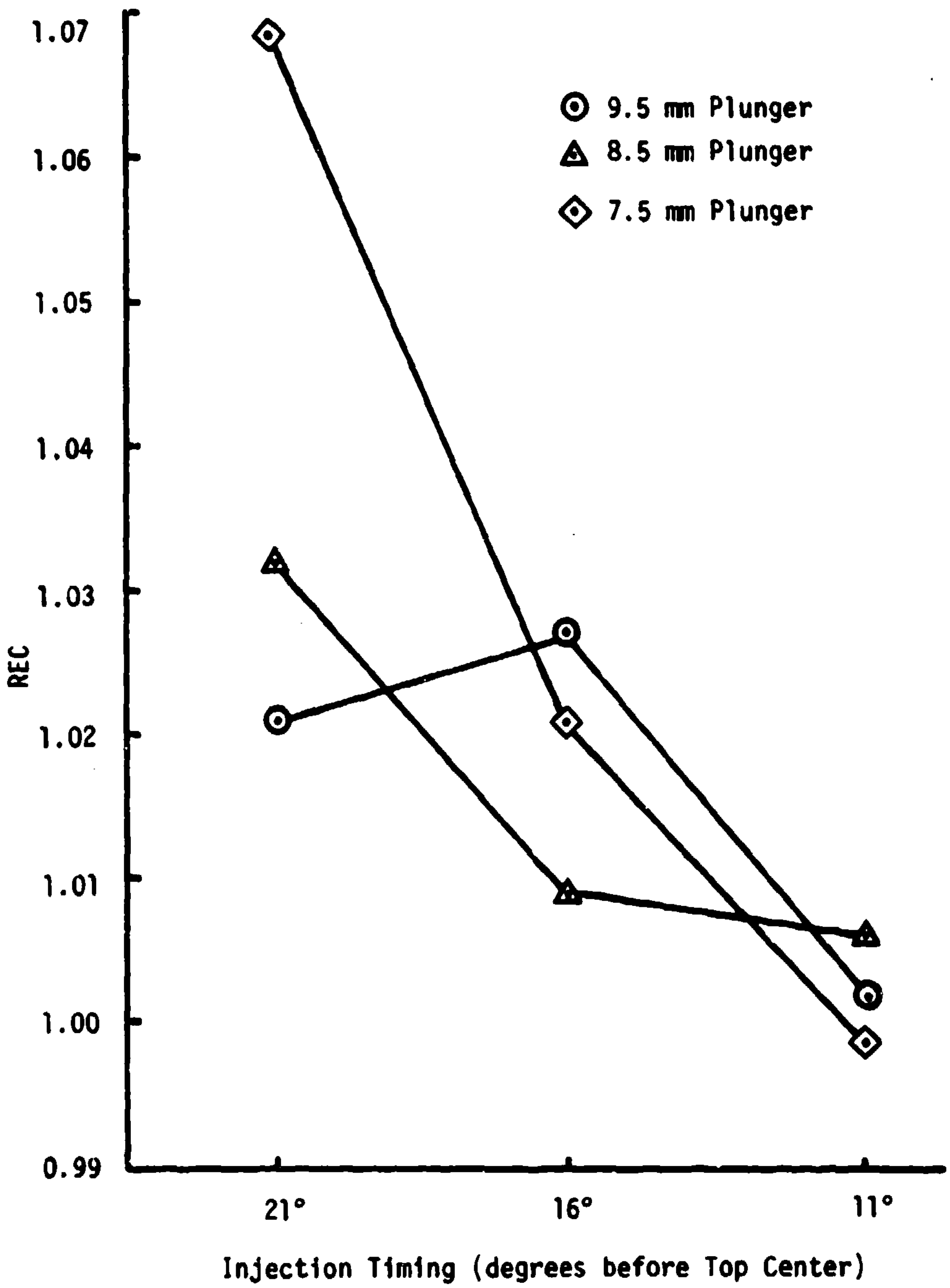

FIGURE 10. REC AVERAGED OVER THE LOAD RANGE VERSUS INJECTION TIMING

TABLE 30. COMPARISON OF "CATALYZED" MOGUL L CARBON BLACK IN A 10 PERCENT SLURRY WITH BASE DIESEL FUEL USING REC VALUES AS THE CRITERION

	REC		
	Full Load	3/4 Load	1/2 Load
No Coating	0.99	1.03	0.99
0.31% Manganese Nitrate	0.84	0.93	1.01
0.1% Ferrocene	0.95	0.96	0.97
0.05% Lead Acetate	0.97	0.99	1.12
0.15% Nickel Nitrate	0.92	0.94	0.88

B. Petter Engine

The majority of the candidate fuels for this program were liquid fuels blended with the engine baseline Cat 1-H. These blends also contained a cetane improver, if initial screening proved them to be of insufficient cetane quality to sustain normal engine operation.

A British-made Petter direct injection engine (Table 31) was used as a tool for comparing the fuel candidates against a baseline DF-2. A 60-cycle, 115/230-volt, 15-ampere, 3500-watt, AC generator was cradled and driven by a cog belt at twice engine speed to provide a load on the engine. The mechanical energy of the engine was converted to electrical energy in the generator, and dissipated as heat through immersion heaters in a drum of water. An electronic load cell and readout was attached, via a torque arm, to the cradled generator to be used as a measure of load (Figure 11).

The engine was governed to operate at 1800 rpm and a constant load of 10 lb in order to maintain a constant power test condition for all fuel blends. The barometric pressure, ambient temperature, and relative humidity were monitored for all fuel trials in order to correct engine performance for atmospheric conditions, as stated by the SAE diesel engine rating code (9). Appendix E is a listing of the data correction program used to reduce the engine data. The specific range (hp-hr/gal.), which is the inverse of the corrected volumetric fuel consumption, was the parameter upon which comparisons were made between the candidate high-energy fuels and the baseline Cat 1-H.

TABLE 31. PETTER ENGINE CONFIGURATION

Engine Type	Normally aspirated, Single-Cylinder, Compression Ignition, Direct Injection 4-Stroke Cycle
Bore, cm (in.)	8.73 (3.44)
Stroke, cm (in.)	11.0 (4.33)
Displacement, cm^3 ($in.^3$)	659 (40.2)
Compression Ratio	16.5:1
Rated Power, kW (bhp)	5.6 (7.5)
Rated Speed, rpm	1800
Injection Timing	28° BTC
Valve Timing (intake) (exhaust)	4.5°BTC to 35.5° ABC 35.5° BBC to 4.5° ATC
Fuel	B.S. Specification No. 2869: 1967 Class A1 or A2

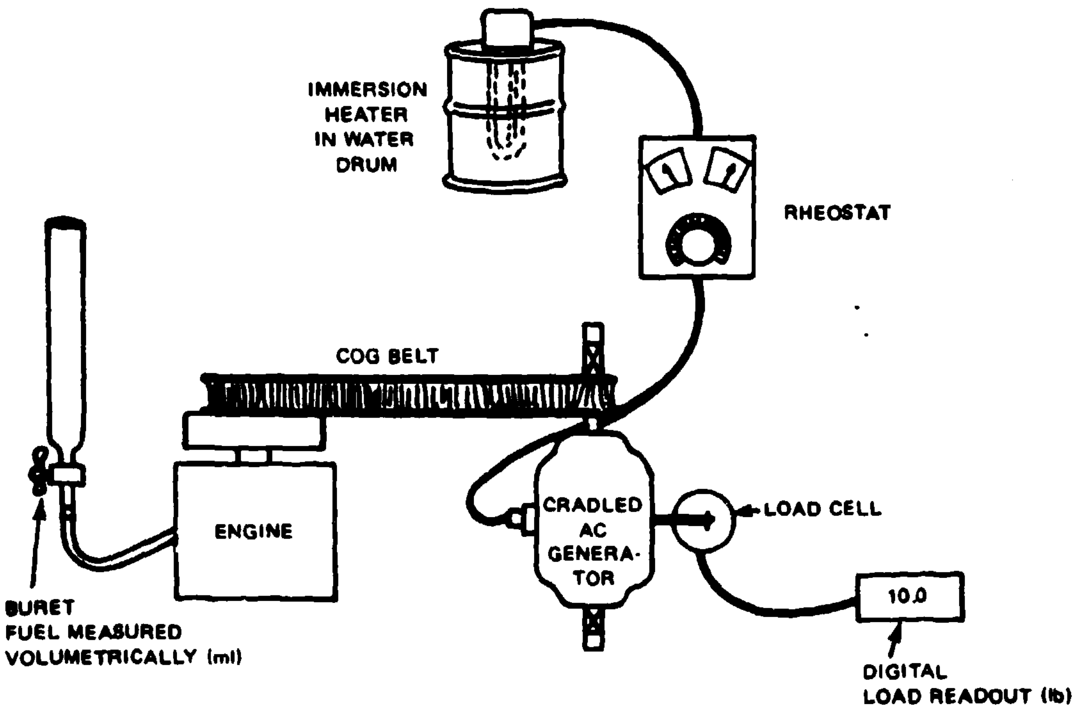

FIGURE 11. PETTER SCREENING ENGINE INSTALLATION

The results from the screening procedures are presented in two different sets, due to a baseline drift after the Petter engine was idle for several months. The consistency of the results within each set of baseline data was very good, so there are no problems associated with the significance of the data collected. A comparison of the relative diffnrences between two fuels that were examined in each baseline set allowed valid comparisons of the specific range based on the span of the 95-percent confidence intervals of the relative difference between these two fuels. The two fuels were Cat 1-H and FRF.

1. Baseline No. 1

The results from the screening tests performed on the Petter engine are presented in two categories; one is high-energy fuel blends, and the other is the energy-augmented FRF blends. All corrected data are presented in Appendix E.

a. Fuel Blends

During the screening process, there were seven high-energy fuel candidates whose performances were examined with the Petter engine. Of the fuels blended, most ran very well in the engine, except for the naphthalene blends and the anthracene slurry. With the naphthalene blends, if the ambient temperature dropped below 20°C (68°F), the naphthalene would crystalize in the burret, and the engine would stall due to fuel starvation. The anthracene slurry proved to be too large in particle size to run through the Petter engine's gravity feed fuel system. Because of this, no data were available for comparison to baseline performance with the anthracene slurry.

Since the guidelines for a high-energy fuel require an approximate 10-percent increase in range over a typical DF-2, there were only two fuels which met this criteria. A blend of 50/50 vol% Cat 1-H and RJ-5 exhibited a 13.5-percent improvement in specific range (hp-hr/gal.) compared to Cat 1-H. The specific range of this blend was 16.77 ± 0.18 hp-hr/gal., compared to a specific range of 14.78 ± 0.1 hp-hr/gal. for the baseline Cat 1-H. The 95-

percent confidence intervals for the two fuels show that the comparison is statistically valid, with their deviation from the mean being 2.2 percent and 1.3 percent for the blend and Cat 1-H, respectively. Another candidate fuel which improved on baseline performance was a 75/24/1 wt% mixture of tetralin, Cat 1-H, and amyl nitrate. The calculated specific range of 16.16 ± 0.01 hp-hr/gal. represents a 9.3-percent improvement over baseline performance with this blend. Due to cost consideration, and the performance evaluations, the tetralin fuel appears to be one of the more attractive high-energy fuel candidates. Table 32 and Figure 12 are comparisons of various high-energy fuel blends to the baseline.

b. Energy-Augmented FRF Blends

The energy augmentation of FRF to a performance level equal to the base Cat 1-H was considered an aspect of the High-Energy Fuels Program. There were three blends screened in the Petter engine, two of which exhibited a performance level comparable to the Cat 1-H. The third blend, which was an 85.6/14.4 wt% mixture of FRF and naphthalene, encountered the same operational difficulties associated with the other naphthalene blends. The performance increase of the FRF/naphthalene blend over the base FRF was insignificant in this study.

The first of the two blends which displayed a considerable improvement over the base FRF was a 50/50 vol% mixture of FRF and JP-10. The increase in specific range was from 13.06 hp-hr/gal. for FRF to 14.71 ± 0.01 hp-hr/gal. for the blend. This represents an 11.1-percent increase over base FRF, while falling a slight 0.5 percent from the Cat 1-H value of 14.78 ± 0.1 hp-hr/gal. The second was a 63/37 vol% mixture of FRF and RJ-5, which displayed an 11.8-percent increase in specific range over base FRF. The specific range for this blend was 14.81 ± 0.9 hp-hr/gal., which is actually a slight improvement over Cat 1-H at 14.78 ± 0.1 hp-hr/gal. The comparison of the performance of these blends to baseline is statistically valid, due to the small span of the 95-percent confidence intervals for the specific range of these blends and baseline. Both of the blends performed extremely well in the Petter engine, without any engine modifications or operating

TABLE 32. COMPARISON OF HIGH-ENERGY FUEL CANDIDATES TO CAT 1-H (BASELINE NO. 1)

Fuel Blend	BHP*	BSFC, lb/hp-hr	BSVC, gal./hp-hr	Specific Range, hp-hr/gal.	Span of 95% confidence Intervals as % Of Specific Range	% Change in Range From Baseline, Cat 1-H	% Thermal Efficiency
Cat 1-H	5.15	0.479	0.068	14.78	± 0.65	---	28.5
50% Cat 1-H 50% RJ-5	5.28	0.483	0.060	16.77	± 1.1	13.6	28.6
75% Tetralin 24% Cat 1-H 1% Amyl Nitrate	5.23	0.484	0.062	16.16	± 0.05	9.3	29.5
99% JP-10 1% Amyl Nitrate	5.12	0.498	0.064	15.70	± 0.80	6.2	27.7
72% JP-10 25% Naphthalene 3% Amyl Nitrate	5.12	0.520	0.065	15.34	± 2.40	3.8	27.9
90.99% DF-2 9.01% Phenanthrene	5.26	0.486	0.067	14.84	± 0.50	0.4	28.5
80.58% DF-2 19.42 Naphthalene	5.15	0.493	0.068	14.78	± 2.45	0.0	28.4

* All values represent data corrected for atmospheric conditions during the blend testing in the Petter Engine. The engine itself was run at constant power, i.e., constant speed and constant load.

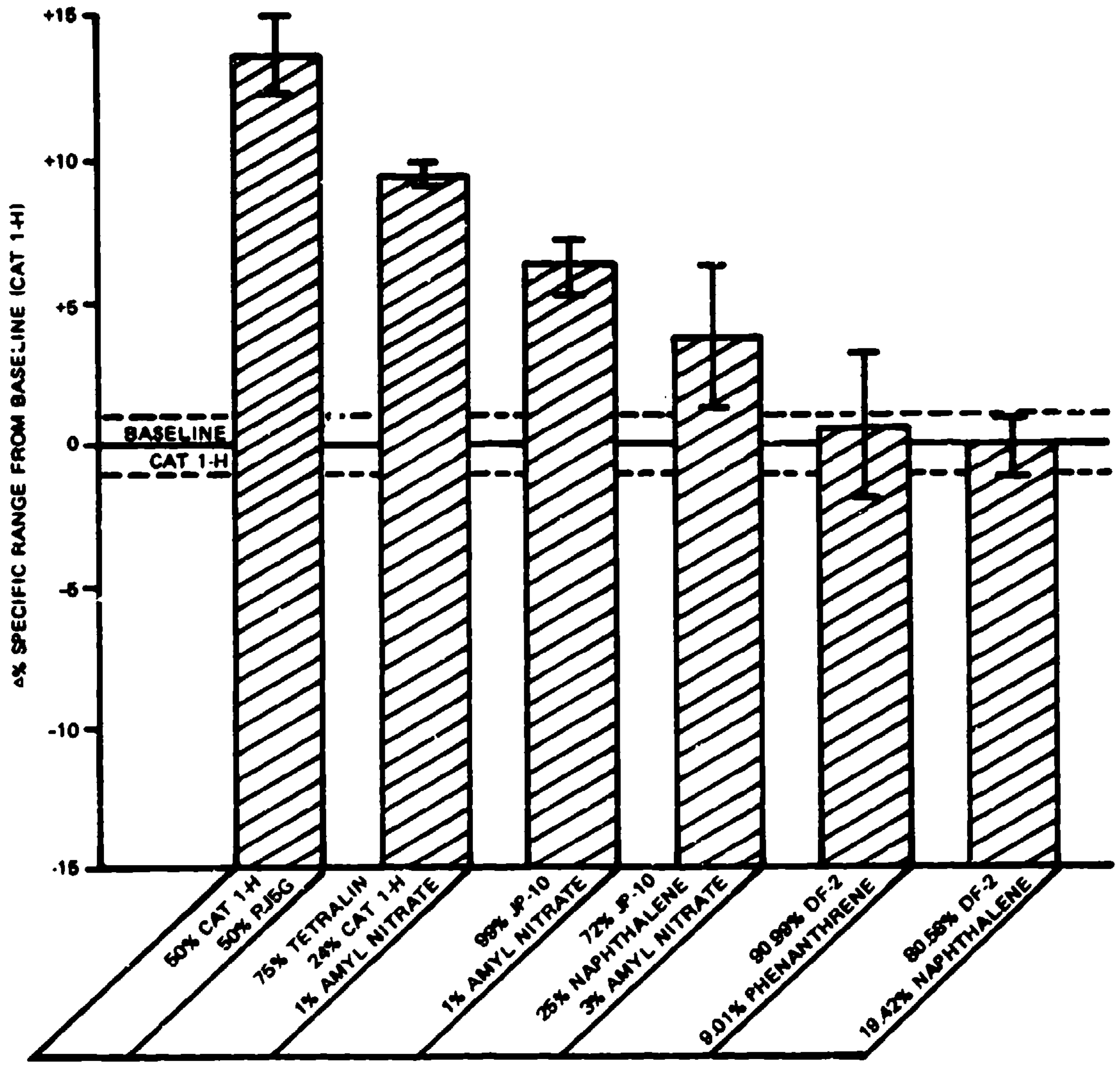

FIGURE 12. SPECIFIC RANGE OF VARIOUS ENERGY-AUGMENTED BLENDS COMPARED TO CAT 1-H (BASELINE NO. 1)

difficulties. The performance evaluations of the various energy-augmented FRF blends are listed in Table 33 along with the graphical results in Figure 13.

2. Baseline No. 2

a. Fuel Blends

All corrected data for this baseline set are presented in Appendix F. During the screening process with this baseline set, nine separate high-energy fuel blend candidates were examined in the Petter engine. Of the nine fuel candidates, only one displayed an improvement of greater than 10 percent, while two others showed promise. The fuel which exhibited the largest increase in specific range for this baseline set was 99.6/0.4 wt% mixture of RJ-6M and amyl nitrate. The blend showed an increase in specific range of 11.9 percent at 17.15 ± 0.03 hp-hr/gal. compared to 15.32 ± 0.08 hp-hr/gal. for the Cat 1-H fuel. With this fuel, the operator noticed slight engine surging, although speed and load set points could be maintained. The surging may be due to the cetane number being below the engine manufacturer's specification of 45. The AFLRL experimental cetane number determined for this particular blend was 39. The potential of RJ-6M may be further realized with blend preparation based on increasing the cetane number.

One of the fuels that produced an increase in specific range, but fell below the 10-percent improvement level was a tetralin fuel. The blend was 97/3 wt% combination of tetralin and amyl nitrate, which exhibited a 7.7-percent increase in specific range at a value of 16.50 ± 0.09 hp-hr/gal. Another tetralin blend screened in this baseline set, an 80/19/1 wt% mixture of tetralin/Cat 1-H/amyl nitrate, displayed only a 4.2-percent increase in specific range. As reported earlier, a 75/24/1 wt% mixture of tetralin/Cat 1-H/amyl nitrate showed a 9.3-percent increase over its respective baseline value. Table 34 and Figure 14 are a listing and visual representation of the anomaly that appeared in the data from the various tetralin blends. It is felt that this anomaly may be due to interrelated effects of the volu-

TABLE 33. COMPARISON OF FRF AND ENERGY-AUGMENTED FRF BLENDS TO CAT 1-H (BASELINE NO. 1)

Fuel Blend	BHP*	BSFC, lb-fuel/ hp-hr	BSVC, gal-fuel/ hp-hr	Specific Range hp-hr/gal	Span of 95% confidence Intervals as % Of Specific Range	% of Specific Range From Base FRF	% of Specifc Range From Cat 1-H	% Thermal Efficiency
FRF	5.17	.558	.077	13.06	± 0.35	---	-11.6	28.6
85.6% FRF + 14.4% Napthalene	5.15	.557	0.75	13.33	± 0.55	1.6	-10.0	28.5
50% FRF + 50% JP-10	5.27	.516	0.68	14.71	± 0.01	11.1	- 0.5	28.7
63% FRF + 37% RJ-5	5.29	.538	0.675	14.81	± 0.60	11.8	0.2	28.6
Cat 1-H	5.10	.481	0.68	14.78	± 0.65	11.6	---	28.3

* All values represent data corrected for atmospheric conditions during the blend testing in the Petter engine. The engine itself was run at constant power, i.e., constant speed and constant load.

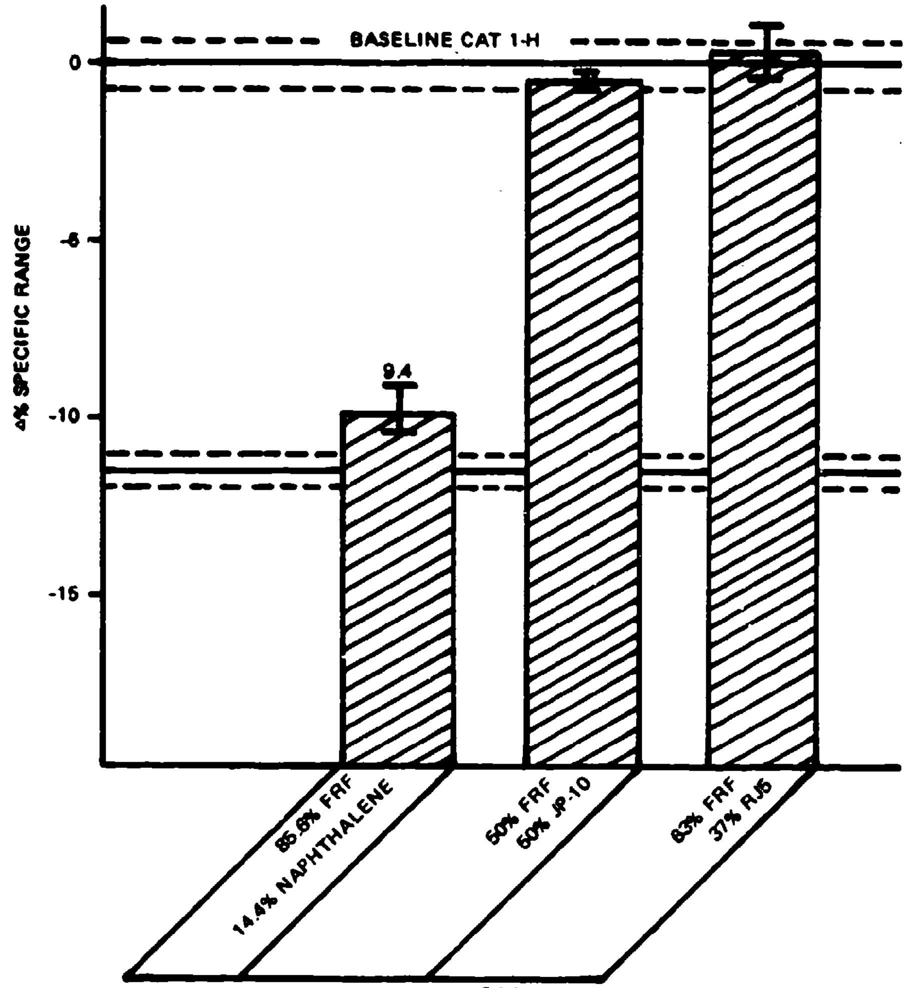

FIGURE 13. SPECIFIC RANGE OF VARIOUS FRF ENERGY-AUGMENTED BLENDS COMPARED TO CAT 1-H (BASELINE NO. 1)

TABLE 34. RELATIVE VALUES OF SPECIFIC RANGE AND VOLUMETRIC HEAT OF COMBUSTION COMPARED TO CAT 1-H

Fuel Blend	% Specific Range	Vol% Heat Of Combustion
Cat 1-H	---	---
97% Tetralin 3% Amyl Nitrate	7.7 ± 0.6	6.7
80% Tetralin 19% Cat 1-H 1% Amyl Nitrate	4.2 ± 1.05	6.2
75% Tetralin 24% Cat 1-H 1% Amyl Nitrate	9.3 ± 0.05	5.6

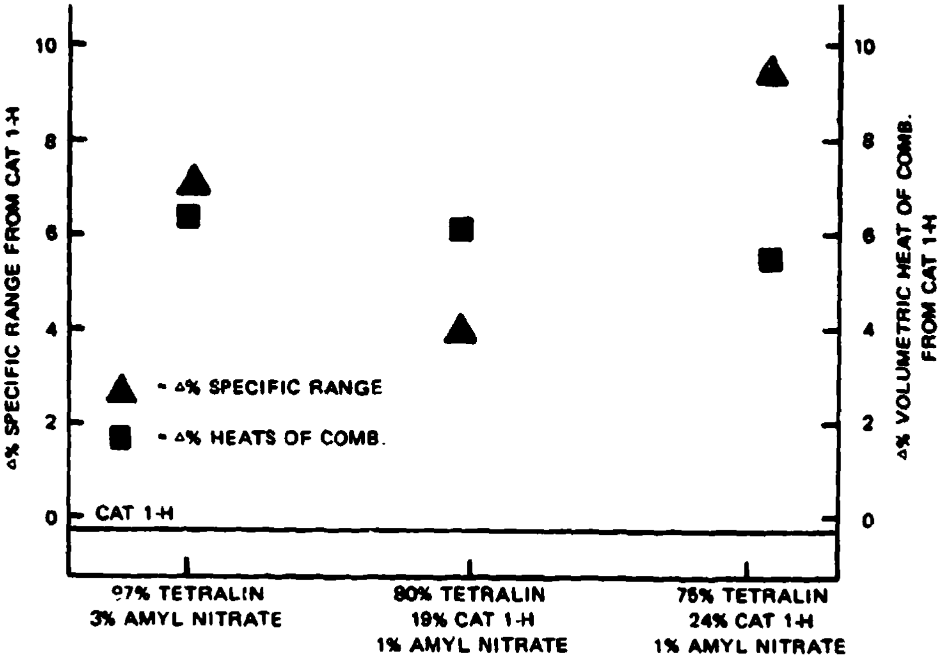

FIGURE 14. COMPARISON OF CHANGE IN SPECIFIC RANGE TO CHANGE IN VOLUMETRIC HEAT OF COMBUSTION OF VARIOUS TETRALIN FUELS FROM CAT 1-H

metric heat of combustion and cetane number. The cetane numbers of these various blends had not been determined, but due to the chemical structure of the base tetralin, its cetane number is predicted to be around 10 or 12. The promise shown by the tetralin blend warrants further attention in developing its high-energy capabilities.

The other blend which showed improvement was a JP-10/naphthalene blend. A 77.6/19.4/3.0 wt% mixture of JP-10/naphthalene/amyl nitrate (AN) increased the specific range of the Petter direct injection engine by 7.1 percent. The value of the specific range was 16.41 ± 0.16 hp-hr/gal., versus 15.32 ± 0.08 hp-hr/gal. for the Cat 1-H baseline fuel. Initial problems in screening this fuel developed due to the extremely low cetane numbers of the basestock fuels; however, the addition of the amyl nitrate improved fuel performance adequately so that the test could be completed. The problems associated with all previous naphthanlene blends were also evident in this high-energy fuel candidate. Table 35 and Figure 15 display the results for the various blends tested during this phase of the program.

TABLE 35. COMPARISON OF HIGH-ENERGY FUEL CANDIDATES TO CAT-1H (BASELINE NO. 2)

Fuel Blend	BHP*	BSFC, lb/hp-hr	BSVC, gal/hp-hr	Specific Range, hp-hr/gal.	Span of 95% Confidence Intervals as % Of Specific Range	% Change in Range From Baseline	% Thermal Efficiency
Cat 1-H	5.21	0.462	0.065	15.32	± 0.55	---	29.5
RJ-6M	5.13	0.487	0.058	17.15	± 0.20	11.9	29.1
97% Tetralin 3% Amyl Nitrate	5.25	0.492	0.0606	16.50	± 0.60	7.7	29.8
77.6% JP-10 19.4% Naphthalene 3.0% Amyl Nitrate	5.19	0.484	0.061	16.41	± 1.00	7.1	29.5
89% No. 6 Burner Oil 10% Cat 1-H 1% Amyl Nitrate	5.23	0.498	0.062	16.15	± 0.45	5.4	29.1
79% No. 6 Burner Oil 20% JP-10 1% Amyl Nitrate	5.23	0.504	0.0623	16.05	± 0.25	4.8	29.0
80% Tetralin 19% Cat 1-H 1% Amyl Nitrate	5.21	0.496	0.063	15.97	± 1.05	4.2	28.9
90% No. 5 Burner Oil 10% Cat 1-H	5.18	0.490	0.064	15.67	± 0.50	2.3	28.7
80% NO. 5 Burner Oil 20% JP-10	5.21	0.499	0.065	15.41	± 0.40	0.6	28.6
85% Cat 1-H 15% Naphthalene	5.18	0.476	0.065	15.36	± 0.35	0.3	28.9

* All values represent data corrected for atmospheric conditions during the blend testing in the Petter engine. The engine itself was run at a constant power, i.e., constant speed and constant load.

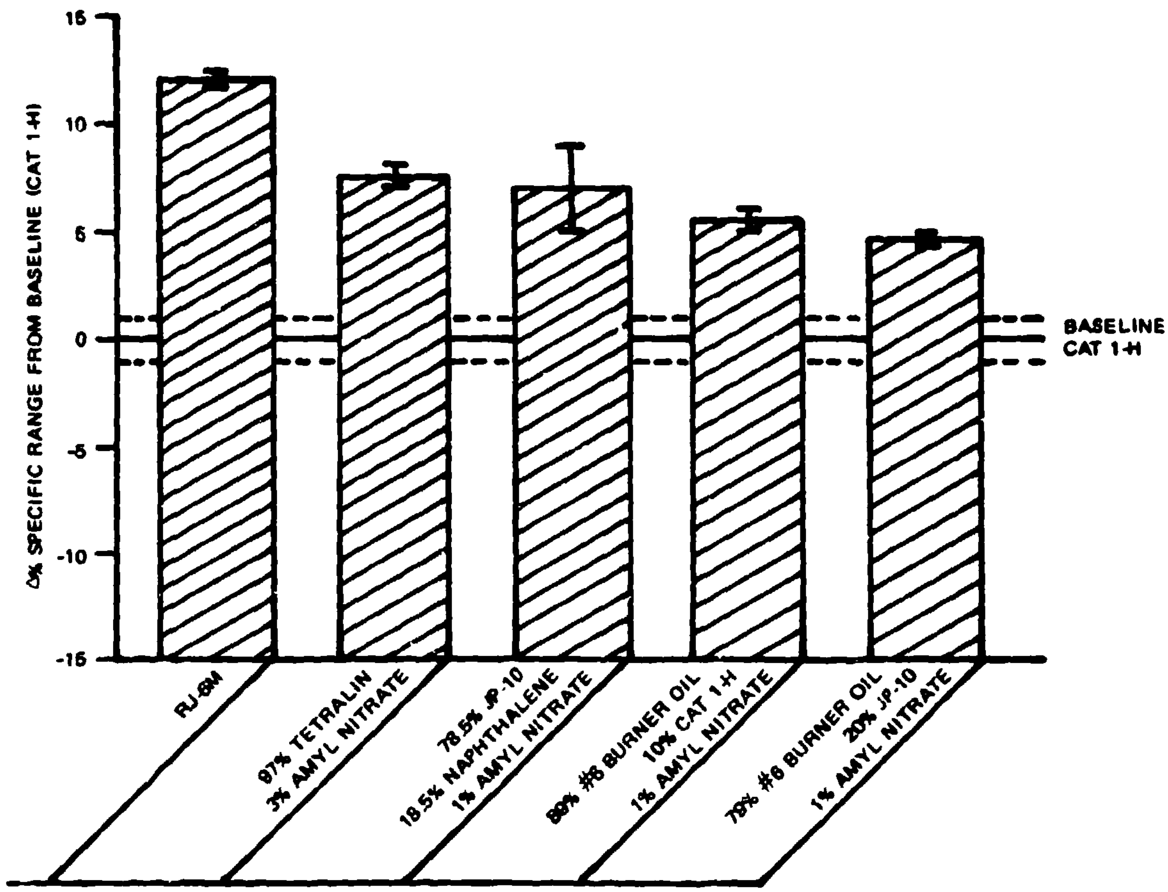

FIGURE 15. SPECIFIC RANGE OF VARIOUS ENERGY-AUGMENTED BLENDS COMPARED TO CAT 1-H (BASELINE NO. 2)

b. Energy-Augmented FRF Blends

Further screening of energy-augmented FRF blends revealed two blends which showed parity with the baseline diesel fuel. The first blend exceeded the performance of the Cat 1-H by 2.6 percent based on specific range. This fuel was an 86.5/5/5/3.5 vol% blend of Cat 1-H/deionized H_2O/RJ-5/EA78 surfactant. The specific range for this fuel was 15.72 ± 0.08 hp-hr/gal., which is a 15.1-percent increase over the base FRF value of 13.41 ± 0.26 hp-hr/gal. For comparisons, the Cat 1-H has a specific range of 15.32 ± 0.08 hp-hr/gal. Another energy-augmented blend which showed promise was 84/6/5/5 vol% mixture of Cat 1-H/surfactant/deionized H_2O/RJ-5. This combination of fuels increased the specific range of FRF by 10.4 percent to a value of 15.00 ± 0.04 hp-hr/gal., but fell short of baseline performance by a small 2.1 percent. Several other blends were tested, but results indicated relatively minor improvements. Table 36 and Figure 16 display the results for all augmented FRF blends examined.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

- Several of the screened candidates showed good potential for meeting the objective of improving range/power capabilities.
- The Petter engine has worked exceptionally well as a screening device.
- Several synthesized hydrocarbons, with cetane improver added, are feasible HEF candidates. These include RJ-5, RJ-6M, JP-10, and tetralin.
- A synthetically derived hydrocarbon, RJ-6M, improved the range of the screening engine by 11.9 percent over the baseline.
- The tetralin-based fuels are probably the most realistic high-energy fuels due to cost consideration and performance evaluations. The full potential of these fuels has probably not yet been realized, since cetane effects have not been fully evaluated.

TABLE 36. COMPARISON OF ENERGY-AUGMENTED FRF BLENDS TO BASE FRF AND CAT 1-H (BASELINE NO. 2)
(Petter Single-Cylinder Diesel Engine)

Fuel Blend	BHP*	BSFC, lb/hp-hr	BSVC, gal./hp-hr	Specific Range, hp-hr/gal.	Span of 95% Confidence Intervals as a Percent of Specific Range	Percent Specific Range From Base FRF	Percent Specific Range From Baseline Cat 1-H	Percent Thermal Efficiency
FRF	5.21	0.544	0.075	13.41	± 1.9	---	-12.5	29.3
79% DF-2 10% (DI) H_2O 6% EA78 5% RJ-5	5.25	0.543	0.073	13.67	± 0.5	1.7	-10.8	29.0
81% DF-2 10% RJ-5 5% H_2O 4% EA78	5.19	0.507	0.068	14.67	± 0.25	8.3	- 4.2	28.9
84% Cat 1-H 6% EA78 5% (DI) H_2O 5% RJ-5	5.31	0.487	0.067	15.00	± 0.25	10.4	- 2.1	30.5
86.5% Cat 1-H 5% (DI) H_2O 5% RJ-5 3.5% EA78	5.24	0.466	0.064	15.72	± 0.45	15.1	2.6	31.5
Cat 1-H	5.21	0.462	0.065	15.32	± 0.55	12.5	---	29.5

* All values represent data corrected for atmospheric conditions during the blend testing in the Petter engine. The engine itself was run at a constant power, i.e., constant speed and constant load.

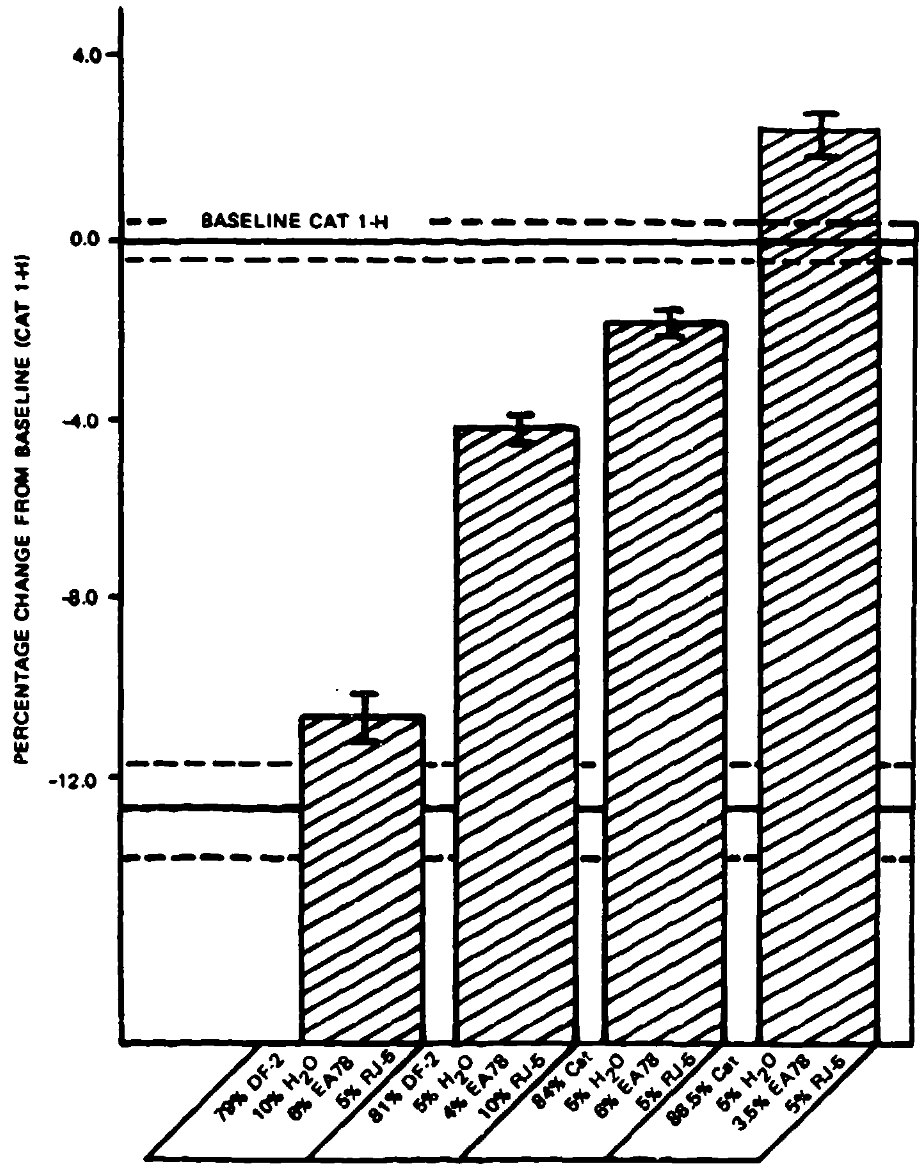

FIGURE 16. COMPARISON OF ENERGY-AUGMENTED FRF BLENDS TO CAT 1-H (BASELINE NO. 2)

- A 75/24/1 wt% blend of tetralin/Cat 1-H/amyl nitrate increased the specific range by 9.3 percent.
- Certain low-cost refinery products and streams have potential as high-energy fuel blending components, such as No. 6 Fuel Oil, furfural extract, and a polycyclic aromatic blending stock.
- The HEF and FRF programs have been brought closer together without diluting the effort of either.
- RJ-5, although costly, has an extremely high volumetric heat content and has shown fire-safety characteristics. It could be useful as a blending component.
- Blends have been prepared which show potential for high-energy, fire-resistant fuels.
- A 86.5/5/5/3.5 vol% blend of Cat 1-H, dionized H_2O, RJ-5, and EA78 surfactant improved upon FRF performance by 15.1 percent, which is a 2.6-percent improvement over the reference fuel.
- A 63/37 vol% mixture of FRF and RJ-5 increased the range of the base FRF to a parity with the reference fuel.
- A 50/50 vol% blend of Cat 1-H and RJ-5 displayed a 13.5-percent improvement over the reference diesel fuel (Cat 1-H).

B. Recommendations

- RJ-6M, one of the latest high-energy fuel candidates to emerge, shows great promise. Studies with this fuel should be vigorously pursued.
- Studies with the more promising fuel and fuel components should continue.
- Studies of the cetane effect on the performance of the high-energy fuels in the engine, especially with tetralin and its blends, should be initiated.
- Further work should be expended on developing blending criterion based on cetane number, due to inherent low cetane numbers of many of the basestock.
- All fuel blends which display improvements in range that meet the project guidelines should be further examined for performance optimization.

- Laboratory and engine studies with "catalyzed" carbon black should be pursued.
- Some promising fuel and fuel blends have not yet been screened with the Petter engine. This should be done.
- Cognizance should be maintained with other high-energy fuel research, especially that conducted for the Air Force and Navy.
- Wherever feasible, efforts should continue to interface the HEF and FRP programs.

VI. REFERENCES

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2. LePera, M.E., Letter from Mr. Maurice E. LePera, Chief, Fuels and Lubricants Division, Energy and Water Resources Laboratory, U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, VA to Mr. S.J. Lestz, Director, U.S. Army Fuels and Lubricants Research Laboratory, San Antonio, TX dated 8 April 1981.

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4. Schmid, B.K. and Jackson, D.M., "The SRC-II Process," Phil. Trans. R. Soc. Land. A300, 129-139, (1981).

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APPENDIX A

NO. 1 INSPECTION DATA ON SRC-II, MIDDLE DISTILLATE

NO. 2 MATERIALS SAFETY DATA SHEET SRC-II MATERIAL

APPENDIX A NO. 1

SRC-II Middle Distillate Inspections

Specific Gravity	
15.5°C/15.5°C	0.9840
Gravity, °API	12.3
Viscosity	
cSt at 37.8°C(100°F)	3.83
cSt at 40°C(104°F)	3.68
Flash Point, (D 93), °C(°F)	80(176)
Aniline Point, °C(°F)	-9(16)
Pour Point, °C(°F)	-48(-54)
Cloud Point, °C(°F)	Too dark
Hydrocarbon Type FIA, vol%	
Aromatics	91.2
Saturates	8.1
Olefins	0.7
Elemental Analysis, wt%	
Carbon	86.15
Hydrogen	8.64
Oxygen	3.9
Nitrogen	0.82
Sulfur	0.26
Ring Carbons, wt%	
Monoaromatic	30.5
Diaromatic	22.6
Triaromatic	0.95

Ash, wt%	0.0023
Steam Jet Gum, mg/100 ml	25.1
Accelerated Stability, mg/100 ml	10.5
Particulate Matter, mg/l	77.5
Total Acid No., mg KOH/gm	0.31
Cetane Number	16
Carbon Residue, 10% Btms, wt%	0.52
Water, wt%	0.08
Copper Strip Corrosion, 50°C (122°F)	1a
Net Heat of Combustion	
MJ/kg	40.007
Btu/lb	17,200
Visual	
Color (D 1500)	8.0
Appearance	Dark gray, turns opaque. Black
IR Curve	Spectrum indicates mixture of aromatic compounds with significant hydroxyl substitutions on aromatic rings. No organic acids.

Distillation	ASTM D 86 °C	ASTM D 86 °F	GC Distribution °C	GC Distribution °F
IBP	187	368	151	304
5% Recovered	204	400	187	368
10	211	412	197	387
15	216	420	210	410
20	220	428	216	420
30	228	442	232	450
40	237	459	244	471
50	245	473	258	497
60	254	489	268	514
70	262	504	280	536
80	274	525	295	563
90	289	553	311	592
95	303	577	324	615
EP	323	613	377	710

APPENDIX A NO. 2

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration
MATERIAL SAFETY DATA SHEET

SRC II MATERIAL — Revised 8/79, Replaces 4/79 CRH

SECTION I

MANUFACTURER'S NAME: The Pittsburg & Midway Coal Mining Co.	EMERGENCY TELEPHONE NO.: (713) 228-1011
ADDRESS (NUMBER, STREET, CITY, STATE & ZIP CODE): North Fort Lewis, WA 98433	
CHEMICAL NAME & SYNONYMS: NA	TRADE NAMES & SYNONYMS: Naphtha
CHEMICAL FAMILY: Coal derived aromatic naphtha	FORMULA: ND
CAS NUMBER: ND	TSCA REGISTRY ENTRY: ND

SECTION II – HAZARDOUS INGREDIENTS

MATERIALS	%	TLV (Units)	MATERIALS	%	TLV (Units)
Naphtha	99+	*	Hydrogen Sulfide	< 0.1	10 ppm
Phenols & Cresols	5-10	5 ppm	Benzene	< 1.0	10 ppm

*No information is currently available on the long-term toxicity and/or carcinogenic potential of this particular material. However, the health hazards, particularly skin lesions, associated with coal liquefaction processes are recognized as potential health problems. Therefore, it is recommended that inhalation and skin exposure be kept to a minimum. See Section V and IX.

DOT HAZARD CLASS: Flammable liquid.

SECTION III – PHYSICAL DATA

BOILING POINT °C (°F)	60-177°C (140-350°F)	SPECIFIC GRAVITY (H_2O=1) 15.6 / 15.6 C	0.81
VAPOR PRESSURE (mm Hg.)	ND	PERCENT, VOLATILE BY VOLUME (%)	99
VAPOR DENSITY (AIR = 1)	ND	EVAPORATION RATE	ND
SOLUBILITY IN WATER	Negligible		
APPEARANCE AND ODOR	Colorless to dark amber (darkens with age and air contact).		

SECTION IV – FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	FLAMMABLE LIMITS	LEL	UEL
-35.6°C (-32°F) closed cup	ND		

EXTINGUISHING MEDIA

- [ ] ALCOHOL FOAM
- [x] CARBON DIOXIDE
- [x] DRY CHEMICAL
- [x] FOAM
- [x] WATER SPRAY (FOG)
- [ ] OTHER

SPECIAL FIRE FIGHTING PROCEDURES: Treat like gasoline or light petroleum naphtha. Floats on water. Use water to cool fire-exposed containers, disperse vapors, and protect personnel. Use air-supplied rescue equipment for enclosed areas.

FIRE AND EXPLOSION HAZARDS: Highly volatile and flammable. Material can be ignited by flame or incendiary spark under almost all normal atmospheric temperature conditions due to its low flash point.

NA = Not Applicable   ND = No Data Available   Gulf Modified Form OSHA-20

SECTION V – HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE See Section II.

EFFECTS OF OVEREXPOSURE Severe eye irritant. Vapor is irritating to the eyes and mucous membranes. High concentrations of H_2S in an enclosed space such as a tankcar will produce depression, unconsciousness & death. Systemic toxicity, particularly CNS & resp. effects, can occur from the possible skin absorption, inhalation, and ingestion of this material due to the presence of phenolic compounds.

EMERGENCY AND FIRST AID PROCEDURES SKIN CONTACT: Immed. water deluge shower. Follow by rinsing with castor or olive oil for large skin surface exposures. EYE CONTACT-Flush immed. with water for 15 min. INHA: Remove from exposure, give artif. resp. if necessary. INGES: DO NOT INDUCE VOMITING (aspira. hazard) Give 1-2 oz act. charcoal followed by 1-2 glasses of milk or 2-4 oz olive or veg. oil. Obtain immed. med. aid for all cases of contact.

SECTION VI – REACTIVITY DATA

STABILITY:	UNSTABLE		STABLE	X	CONDITIONS TO AVOID

INCOMPATABILITY (Materials to avoid) Reacts with strong oxidizing materials.

HAZARDOUS DECOMPOSITION PRODUCTS When heated to decomposition, it may emit irritating and toxic fumes.

HAZARDOUS POLYMERIZATION:	MAY OCCUR		WILL NOT OCCUR	X	CONDITIONS TO AVOID

SECTION VII – SPILL OR LEAK PROCEDURES

- [ ] EVACUATE AREA
- [x] STOP FLOW
- [x] ELIMINATE ALL SOURCES OF IGNITION, FLAMMABLES
- [x] AVOID INHALATION
- [x] AVOID DERMAL CONTACT
- [x] RESPIRATORY PROTECTION (AS PER SECTION VIII)
- [x] SKIN PROTECTION (AS PER SECTION VIII)
- [x] ABSORB OR SCRAPE UP
- [ ] VACUUM UP
- [ ] EVAPORATE SMALL AMOUNTS IN HOOD
- [x] INCINERATE UNDER CONTROLLED CONDITIONS
- [ ] INCINERATE USING AFTER BURNER & SCRUBBER
- [ ] BURY IN REMOTE AREA OR USE AS LANDFILL
- [ ] NEUTRALIZE AND WASH AWAY WITH WATER
- [x] OBSERVE GOVERNMENTAL SPILL & WATER QUALITY REGULATIONS
- [x] REMOVE SOILED CLOTHING
- [ ] OTHER

SECTION VIII – SPECIAL PROTECTION INFORMATION

	DURING NORMAL USE	FOR GASES, VAPORS, DUSTS, FUMES, MISTS EXCEEDING TLV	SPECIAL (E.G. THERMAL PROCESSING, SPRAY APPLICATIONS)
GENERAL VENTILATION	Yes	Yes	
LOCAL EXHAUST	Yes	Yes	
RESPIRATORY PROTECTION (1-3)		2, if needed	3, large spills

1. Particle-Removing Air Purifying Air Respirator (Mechanical Filter) *2. Gas and Vapor-Removing Air Purifying Respirator (Canister)* *3. Full Face Mask Positive Pressure-Demand Type Supplied Air*

EYE PROTECTION	SAFETY GLASSES	X	CHEMICAL GOGGLES	X	FACE SHIELD		*(E) EXCELLENT*
PROTECTIVE GLOVES	NEOPRENE	G	POLYVINYL ALCOHOL	NR	POLYETHYLENE	NR	*(G) GOOD* *(F) FAIR*
	NATURAL RUBBER	P	BUTYL RUBBER	NR	POLYVINYL CHLORIDE	NR	*(P) POOR* *(NR) NOT RECOMMENDED*

OTHER PROTECTIVE EQUIPMENT The application of a skin barrier cream before work and several times during work is recommended.

SECTION IX – SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING: Avoid skin and eye contact. Avoid the inhalation of mists, fumes, or vapors. Maintain good ventilation. Fresh change of work clothes daily. Showering and clothes change recommended at the end of each shift. [illegible], empty drums may contain flammable vapors. Wash out drums with water before discarding. May dissolve paint, plastics and rubbers. Do not transfer [illegible] or storage vessels made of these materials. Upon standing or being cooled a [illegible], [illegible] water layer may settle out. This layer should be discarded before u[illegible]

OTHER PRECAUTIONS: Animal data suggest that SRC materials have the potential of producing fetotoxic effects. Therefore, it is prudent to prevent fertile females from receiving significant exposure to this material.

NOTICE

The data and recommendations presented herein are based upon our research and the research of others, and are believed to be accurate. No guarantee of their accuracy is made; however, and the products discussed are distributed without warranty, express or implied, and the person receiving them shall make his own determination of the suitability thereof for his particular purpose.

FOR TRANSPORTATION SPILLS OR LEAK EMERGENCIES, CALL: CHEMTREC - 800-424-9300 (CHEMICAL TRANSPORTATION EMERGENCY CENTER).

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

MATERIAL SAFETY DATA SHEET

SRC II MATERIAL — Revised 8/79, Replaces 7/79 CRH

SECTION I

MANUFACTURER'S NAME: The Pittsburg & Midway Coal Mining Co.	EMERGENCY TELEPHONE NO.: (713) 228-1011
ADDRESS (NUMBER, STREET, CITY, STATE & ZIP CODE): Nort Fort Lewis, WA 98433	
CHEMICAL NAME & SYNONYMS: NA	TRADE NAMES & SYNONYMS: Heavy Distillate
CHEMICAL FAMILY: Coal derived heavy distillate	FORMULA: NA
CAS NUMBER: ND	TSCA REGISTRY ENTRY: ND

SECTION II – HAZARDOUS INGREDIENTS

MATERIALS	%	TLV (Units)	MATERIALS	%	TLV (Units)
Heavy Distillate	100	*			

*The health hazards, particularly skin lesions associated with coal liquefaction processes are recognized as potential health problems. Therefore, it is strongly recommended that inhalation and skin exposure be kept to a minimum and that all recommended precautions be observed when handling this material. See Section V and IX.

DOT HAZARD CLASS: Excepted from regulations

SECTION III – PHYSICAL DATA

BOILING POINT °C (°F)	288–454°C (550–850°F)	SPECIFIC GRAVITY (H_2O=1) 15.6°/15.6°C	1.08
VAPOR PRESSURE (mm Hg.)	ND	PERCENT, VOLATILE BY VOLUME (%)	97
VAPOR DENSITY (AIR = 1)	ND	EVAPORATION RATE	ND
SOLUBILITY IN WATER	Negligible		
APPEARANCE AND ODOR	Amber to black oil, oily odor.		

SECTION IV – FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	FLAMMABLE LIMITS	LEL	UEL
> 121°C (250°F) closed cup	ND		

EXTINGUISHING MEDIA
- [ ] ALCOHOL FOAM
- [x] CARBON DIOXIDE
- [x] DRY CHEMICAL
- [x] FOAM
- [x] WATER SPRAY (FOG)
- [ ] OTHER

SPECIAL FIRE FIGHTING PROCEDURES: Use water spray to keep fire-exposed containers cool, flush spills away from fire exposure, and to disperse vapors. Use air-supplied rescue equipment for enclosed areas. This material sinks in water.

FIRE AND EXPLOSION HAZARDS: Combustible. Heating this material to its flash point is likely to give sufficient vapors for ignition upon exposure to flame or incendiary sparks.

NA = Not Applicable   ND = No Data Available   Gulf Modified Form OSHA-20

SECTION V – HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE: Suggested guideline for airborne exposure to coal derived materials: 0.2 mg/m³ as benzene solubles. See Section II.

EFFECTS OF OVEREXPOSURE: Mildly irritating to the eyes. Minor irritation may occur after prolonged or repeated contact with the skin. Although the inhalation hazard is low due to the relatively low volatility of the products, inhalation of mists or vapors released upon heating should be avoided. Prolonged and repeated exposures may lead to dermatitis, more serious skin disorders, and possibly skin cancer. CAUTION: High pressure skin injection may occur when working with fuel injectors. Injury will not appear serious at first; within a few hours tissue will become swollen, discolored, and extremely painful.

EMERGENCY AND FIRST AID PROCEDURES – SKIN CONTACT: Wash thoroughly with soap and water or waterless hand cleaner. EYE CONTACT: Flush with copious amounts of water. If irritation persists, seek medical aid. INHALATION: Remove from exposure. HIGH PRESSURE SKIN INJECTION: Emergency medical treatment must be obtained immediately after accidental injection. Physician must be familiar with local procedures for treatment of this type of wound (i.e., incision, saline irrigation, removal of necrotic tissue, and wound dressing).

SECTION VI – REACTIVITY DATA

STABILITY	UNSTABLE		STABLE	X	CONDITIONS TO AVOID

INCOMPATABILITY (Materials to avoid): Reacts with strong oxidizing materials

HAZARDOUS DECOMPOSITION PRODUCTS: When heated to decomposition, it will emit irritating and toxic fumes.

HAZARDOUS POLYMERIZATION	MAY OCCUR		WILL NOT OCCUR	X	CONDITIONS TO AVOID

SECTION VII – SPILL OR LEAK PROCEDURES

☐ EVACUATE AREA	☐ RESPIRATORY PROTECTION (AS PER SECTION VIII)	☐ EVAPORATE SMALL AMOUNTS IN HOOD	☐ NEUTRALIZE AND WASH AWAY WITH WATER
☒ STOP FLOW	☐ SKIN PROTECTION (AS PER SECTION VIII)	☒ INCINERATE UNDER CONTROLLED CONDITIONS	☒ OBSERVE GOVERNMENTAL SPILL & WATER QUALITY REGULATIONS
☒ ELIMINATE ALL SOURCES OF IGNITION, FLAMMABLES	☒ ABSORB OR SCRAPE UP	☐ INCINERATE USING AFTER BURNER & SCRUBBER	☒ REMOVE SOILED CLOTHING
☒ AVOID INHALATION	☒ VACUUM UP	☐ BURY IN REMOTE AREA OR USE AS LANDFILL	☐ OTHER
☒ AVOID DERMAL CONTACT			

SECTION VIII – SPECIAL PROTECTION INFORMATION

	DURING NORMAL USE	FOR GASES, VAPORS, DUSTS, FUMES, MISTS EXCEEDING TLV	SPECIAL (E.G. THERMAL PROCESSING, SPRAY APPLICATIONS)
GENERAL VENTILATION	Yes	Yes	
LOCAL EXHAUST	Preferred	Yes	
RESPIRATORY PROTECTION (1-3)		1, if needed	

1. Particle-Removing Air Purifying Air Respirator (Mechanical Filter) *2. Gas and Vapor-Removing Air Purifying Respirator (Canister)* *3. Full Face Mask Positive Pressure-Demand Type Supplied Air*

EYE PROTECTION	SAFETY GLASSES	X	CHEMICAL GOGGLES		FACE SHIELD		*(E) EXCELLENT*
PROTECTIVE GLOVES	NEOPRENE	G	POLYVINYL ALCOHOL	NR	POLYETHYLENE	NR	*(G) GOOD* *(F) FAIR*
	NATURAL RUBBER	P	BUTYL RUBBER	NR	POLYVINYL CHLORIDE	NR	*(P) POOR* *(NR) NOT RECOMMENDED*

OTHER PROTECTIVE EQUIPMENT: The application of a skin barrier cream before work and several times during work is recommended.

SECTION IX – SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING: Avoid skin and eye contact. Avoid the inhalation of mists, fumes, or vapors. Maintain good ventilation. Fresh change of work clothes daily. Showering and clothes change recommended at the end of each shift. Combustible hydrocarbons, empty drums may contain combustible vapors. Wash out drums with water before discarding.

OTHER PRECAUTIONS: Animal data suggest that SRC materials have the potential of producing fetotoxic effects. Therefore, it is prudent to prevent fertile females from receiving significant exposure to this material.

NOTICE

The data and recommendations presented herein are based upon our research and the research of others, and are believed to be accurate. No guarantee of their accuracy is made, however, and the products discussed are distributed without warranty, express or implied, and the person receiving them shall make his own determination of the suitability thereof for his particular purpose.

FOR TRANSPORTATION SPILLS OR LEAK EMERGENCIES, CALL CHEMTREC – 800-424-9300 (CHEMICAL TRANSPORTATION EMERGENCY CENTER).

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration
MATERIAL SAFETY DATA SHEET

SRC II MATERIAL | Revised 8/79, Replaces 7/79 CRH

SECTION I

MANUFACTURER'S NAME The Pittsburg & Midway Coal Mining Co.	EMERGENCY TELEPHONE NO. (713) 228-1811
ADDRESS (NUMBER, STREET, CITY, STATE & ZIP CODE) North Fort Lewis, WA 98433	
CHEMICAL NAME & SYNONYMS NA	TRADE NAMES & SYNONYMS Middle Distillate
CHEMICAL FAMILY Coal derived middle distillate	FORMULA NA
CAS NUMBER ND	TSCA REGISTRY ENTRY ND

SECTION II – HAZARDOUS INGREDIENTS

MATERIALS	%	TLV (Units)	MATERIALS	%	TLV (Units)
Middle Distillate	99+	*	Benzene	< 1	10 ppm

*The health hazards, particularly skin lesions associated with coal liquefaction processes, are recognized as potential health problems. Therefore, it is strongly recommended that inhalation and skin exposure be kept to a minimum and that all recommended precautions be observed when handling this material. See Section V and IX.

DOT HAZARD CLASS: Combustible liquid

SECTION III – PHYSICAL DATA

BOILING POINT °C (°F)	177-288°C (350-550°F)	SPECIFIC GRAVITY (H_2O=1) 15.6 / 15.6 C	0.97
VAPOR PRESSURE (mm Hg.)	ND	PERCENT, VOLATILE BY VOLUME (%)	97
VAPOR DENSITY (Air = 1)	ND	EVAPORATION RATE	ND
SOLUBILITY IN WATER	Slightly soluble		
APPEARANCE AND ODOR	Amber to black oil, strong creosotelike odor		

SECTION IV – FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	FLAMMABLE LIMITS	LEL	UEL
> 71°C (160°F) closed cup	ND		

EXTINGUISHING MEDIA

- ☐ ALCOHOL FOAM
- ☒ CARBON DIOXIDE
- ☒ DRY CHEMICAL
- ☒ FOAM
- ☒ WATER SPRAY (FOG)
- ☐ OTHER

SPECIAL FIRE FIGHTING PROCEDURES: Use water spray to keep fire-exposed containers cool, flush spills away from fire exposures and to disperse vapors. Use air-supplied rescue equipment for enclosed areas. This material floats and emulsifies with water.

FIRE AND EXPLOSION HAZARDS: Combustible. Flammability similar to diesel fuel or kerosene. Either misting of the material through handling or heating to its flash point is likely to give sufficient vapors for ignition upon exposure to flame or incendiary sparks.

NA = Not Applicable   ND = No Data Available   Gulf Modified Form OSHA-20

SECTION V – HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE Suggested guideline for airborne exposure to coal derived materials: 0.2 mg/m^3 as benzene solubles. See Section II.

EFFECTS OF OVEREXPOSURE: Severely irritating to the eyes; strongly irrit. to the skin. Systemic toxicity, particularly CNS & resp. effects, can occur from the possible skin absorp., inhalation, and ingest. of this material due to the presence of phenolic compounds. Prolonged & repeated exposures may lead to dermatitis & possibly to skin tumor formation. CAUTION: High press. skin injection may occur when working with fuel injectors. Injury will not appear serious at first; within a few hours tissue will become swollen, discolored, and extremely painful.

EMERGENCY AND FIRST AID PROCEDURES - SKIN CONTACT: Immed. water deluge shower. Follow by washing with castor or olive oil for large skin surface exposures. EYE CONTACT: Flush immed. with water for 15 min. INHALATION: Remove from exposure, give artif. resp. if necessary. INGESTION: DO NOT INDUCE VOMITING (aspiration hazard). Give 1-2 oz act. charcoal followed by 1-2 glasses of milk or 2-4 oz veg or olive oil. Obtain immed. med. aid for all cases of contact. HIGH PRESS. SKIN INJECTION: Emerg. med. treat. must be obtained immed. after accidental injection. Physician must be familiar with local procedures for treatment of this type of wound (i.e., incision, saline irrigation, removal of necrotic tissue, & wound dressing).

SECTION VI – REACTIVITY DATA

STABILITY:	UNSTABLE		STABLE	X	CONDITIONS TO AVOID

INCOMPATABILITY (Materials to avoid) Reacts with strong oxidizing materials.

HAZARDOUS DECOMPOSITION PRODUCTS When heated to decomposition, it will emit irritating and toxic fumes.

HAZARDOUS POLYMERIZATION:	MAY OCCUR		WILL NOT OCCUR	X	CONDITIONS TO AVOID

SECTION VII – SPILL OR LEAK PROCEDURES

- [ ] EVACUATE AREA
- [x] STOP FLOW
- [x] ELIMINATE ALL SOURCES OF IGNITION, FLAMMABLES
- [x] AVOID INHALATION
- [x] AVOID DERMAL CONTACT
- [x] RESPIRATORY PROTECTION (AS PER SECTION VIII)
- [x] SKIN PROTECTION (AS PER SECTION VIII)
- [x] ABSORB OR SCRAPE UP
- [x] VACUUM UP
- [ ] EVAPORATE SMALL AMOUNTS IN HOOD
- [x] INCINERATE UNDER CONTROLLED CONDITIONS
- [ ] INCINERATE USING AFTER BURNER & SCRUBBER
- [ ] BURY IN REMOTE AREA OR USE AS LANDFILL
- [ ] NEUTRALIZE AND WASH AWAY WITH WATER
- [x] OBSERVE GOVERNMENTAL SPILL & WATER QUALITY REGULATIONS
- [x] REMOVE SOILED CLOTHING
- [ ] OTHER

SECTION VIII – SPECIAL PROTECTION INFORMATION

	DURING NORMAL USE	FOR GASES, VAPORS, DUSTS, FUMES, MISTS EXCEEDING TLV	SPECIAL (E.G. THERMAL PROCESSING, SPRAY APPLICATIONS)
GENERAL VENTILATION	Yes	Yes	
LOCAL EXHAUST	Yes	Yes	
RESPIRATORY PROTECTION (1-3)		2, if needed	3, for large spills

1 Particle-Removing Air Purifying Air Respirator (Mechanical Filter) *2. Gas and Vapor-Removing Air Purifying Respirator (Canister)* *3. Full Face Mask Positive Pressure-Demand Type Supplied Air*

							(E) EXCELLENT (G) GOOD (F) FAIR (P) POOR (NR) NOT RECOMMENDED
EYE PROTECTION	SAFETY GLASSES	X	CHEMICAL GOGGLES	X	FACE SHIELD		
PROTECTIVE GLOVES	NEOPRENE	G	POLYVINYL ALCOHOL	NR	POLYETHYLENE	NR	
	NATURAL RUBBER	P	BUTYL RUBBER	NR	POLYVINYL CHLORIDE	NR	

OTHER PROTECTIVE EQUIPMENT The application of a skin barrier cream before work and several times during work is recommended.

SECTION IX – SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING Avoid skin and eye contact. Avoid the inhalation of mists, fumes, or vapors. Maintain good ventilation. Fresh change of work clothes daily. Showering and clothes change recommended at the end of each shift. Combustible hydrocarbons empty drums may contain combustible vapors. Wash out drums with water before discarding.

OTHER PRECAUTIONS

Animal data suggest that SRC materials have the potential of producing fetotoxic effects. Therefore, it is prudent to prevent fertile females from receiving significant exposure to this material.

FOR TRANSPORTATION SPILLS OR LEAK EMERGENCIES, CALL CHEMTREC - 800-424-9300 (CHEMICAL TRANSPORTATION EMERGENCY CENTER).

APPENDIX B

NO. 1 AFLRL FUEL NO. AL-10115-F (CAT-1H)

NO. 2 AFLRL FUEL NO. AL-8821-F (DF-2)

NO. 3 AFLRL FUEL NO. AL-7225-F

APPENDIX B, NO.1

AFLRL FUEL NO. AL-10115-F(CAT-1H)

API Gravity, 15.56°C (60°F)	34.9
Flash Point, Pensky-Martin Closed Cup, °C (°F)	80 (176)
Pour Point, °C (°F)	-16 (+3.2)
Cloud Point, °C (°F)	-4 (+24.8)
Carbon Residue, %	0.14
Coppor Corrosion	1A
Ash,%	0
Lamp Sulfur, %	0.399
Viscosity, 37.8°C (100°F), cSt	3.21
,40.0°C (104°F), cSt	3.12
Saturates, %	71.5
Aromatics, %	28.5
Cetane Number	53
Hydrogen, wt%	13.09
Carbon, wt%	86.46
Nitrogen, ppm	36.5
Net Heat of Combustion, Btu/lb	18,665
H_2O, %	0
Sediment, %	0
TAN	0.03
Aniline Point, °C (°F)	67.7 (153.9)

APPENDIX B, NO. 2

AFLRL FUEL NO. AL 8821-F

API Gravity, 15.56°C (60°F)	35.2
Density, g/ml 15.56°C (60°F)	0.8484
Carbon, wt%	86.66
Hydrogen, wt%	13.34
Flash Point, Pensky-Martin Closed Cup, °C (°F)	71.7 (161)
Fire Point, °C (°F)	84 (183.2)
Viscosity, 40°C (104°F), cSt	3.2
Cetane Number	51.0
Sulfur, wt%	0.47
Copper Corrosion (D-130)	1A
Net Heat of combustion, Btu/lb	18,450
Cloud Point °C (°F)	-1.0 (+30.2)
Pour Point °C (°F)	-10.0 (+14)
Accelerated Stability (D-2274), mg/100 ml	2.7
TAN	0.03
Stream Jet Gum mg/100 ml	3.2
Saturates (FIA), vol%	69.1
Olefins (FIA), vol%	1.5
Aromatics (FIA), vol%	29.4
K.F. Water, %	0.03

APPENDIX B, NO. 3

REFERENCE GRADE DIESEL FUEL, #AL-7225-F

[MIL-F-46162A(MR)]

API 15.56°C (60°F)	36.1
Flash Point, Pensky-Martin Closed Cup °C (°F)	60 (140)
Cloud Point, °C (°F)	-21(-5)
Pour Point, °C (°F)	-24 (-11)
Viscosity, 40°C (104°F), cSt	2.07
37.8°C (100°F), cSt	2.17
Carbon Residue on 10% Bottoms, wt%	0.15
Lamp Sulfur, wt%	0.35
Sulfur (by X-ray) %	0.31
Copper Strip Corrosion	1A
Ash, wt%	0.0009
Water and Sediment, vol%	0.01
TAN	0.01
Cetane Number	48
Saturates, (FIA), vol%	70.9
Olefins, (FIA), vol%	1.6
Aromatics, (FIA), vol%	27.5
Density, 15°C g/ml	0.8438
Gross Heat of Combustion, Btu/lb	19,450

APPENDIX B, NO. 3 (Cont'd)

Boiling Point Distribution, °C	D-86	GC
IBP	167	89
10% evap'd	218	211
20%	228	220
30%	233	232
40%	238	238
50%	242	251
60%	248	258
70%	257	271
80%	270	287
90%	293	312
95%	313	333
E.P.	336	393
Recovered, %	99	
Residue, %	1	
Loss, %	0	

APPENDIX C

FREEZING TUBE TECHNIQUE

APPENDIX C

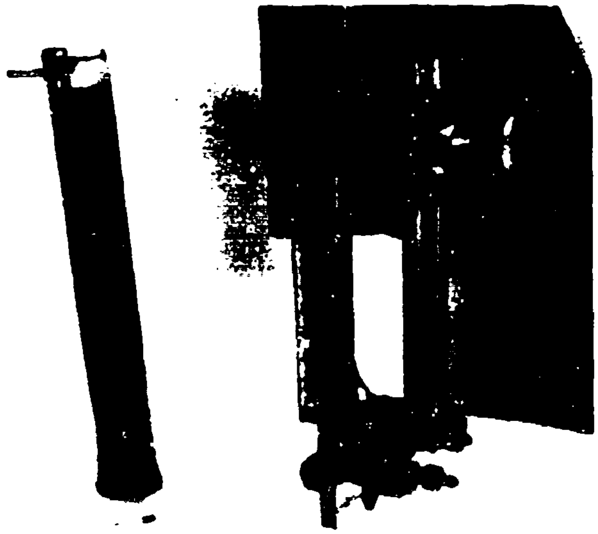
FREEZING TUBE TECHNIQUE[a][b]

In this AFLRL-developed method, the prepared samples of known concentration were placed in plastic tubes (4.5-cm OD, 3.8-cm ID, 0.32-cm wall, and approximately 31 cm in length) which were plugged at the bottom with a No. 8 rubber stopper (Figure a). Almost all the data were taken at room temperature; however, a controlled temperature bath could be used for future samples if settling rates at other temperatures are desired (Figure b). After the desired time period for settling, the tubes were frozen at approximately -80°C (-112°F) (Figure c), and each tube cut into six segments (Figures d and e) and measured by length. After each segment has thawed, it was thoroughly stirred to give a uniform sample. A small 5- to 10-gram sample was removed and then analyzed for solids (carbon) by a modified ASTM D 893-78 procedure, the standard test for insolubles in (used) lubricating oils. The procedure, as modified, consists of weighing the sample in a centrifuge tube, washing it three times with 75 to 100 ml of pentane per wash, and removing the pentane by decanting after centrifugation. The sample is dried in an oven at 104°C (220°F) for at least 30 minutes, cooled in a desiccator, and then weighed.

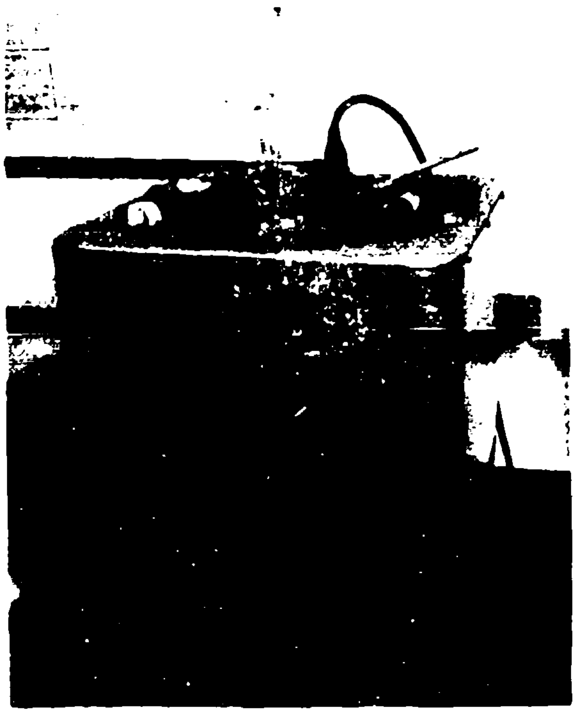
Although a good method, it is time consuming and it tends to give slightly high values for the recovered carbon. Although the values appear to be high, they are correct relative to each other, a phenomenon whch might be caused by the incomplete removal of the last trace of diesel fuel adsorbed by the carbon black. Although the method is not yet quantitative, it is an excellent indicator of stability, since all samples are prepared in an identical fashion.

(a) From Reference 3

(b) For revision to this technique, see this report, III-D-1b(3)(a).



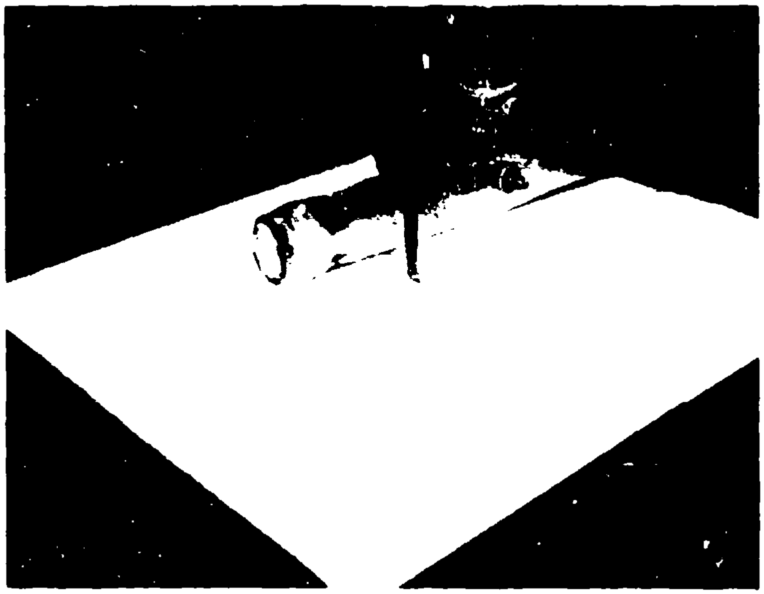
a. Tube Containing the Carbon Slurry



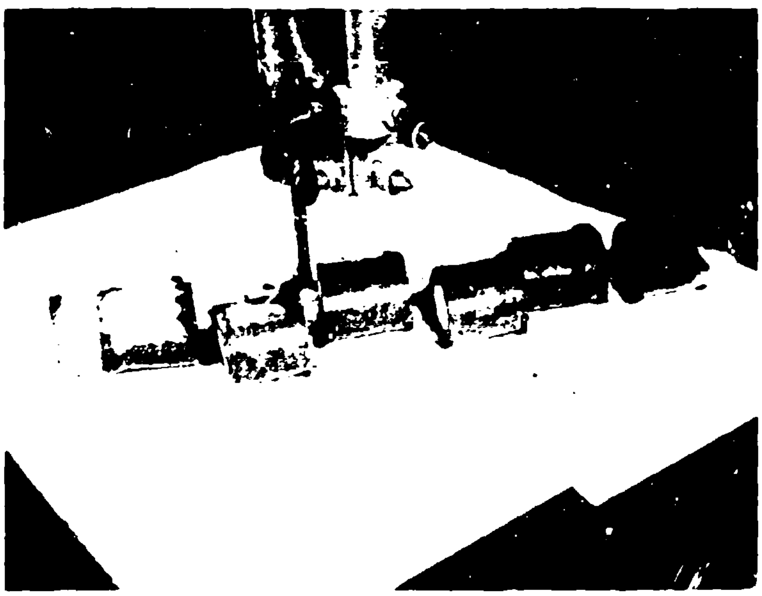
b. Tube in Controlled Temperature Bath

c. Tube Frozen in -80°C Bath

FREEZING TUBE METHOD FOR MEASURING CARBON SEDIMENTATION



d. Frozen Tube Just Prior to Slicing



e. The Six Resulting Segments After Slicing

FREEZING TUBE METHOD FOR MEASURING CARBON SEDIMENTATION (CONT'D)

APPENDIX D

IMPACT DISPERSION TEST

Program Title: Development of Impact Dispersion Fluid Flammability Test

Sponsor: U.S. Army

Contract No.: DAAD05-67-C-0354/DAAD05-70-C-0250/DAAK-73-C-0221/ DAAG53-76-C-0003/DAAK70-78-C-0001

SwRI Project No.: 10-2078/10-2798/10-3630/10-4296/10-5070

Start/Complete Dates: 1969/1978 Continuing Refinement of Facility and Procedures

Reports or Publications: Weatherford, W. D., Jr., and Schaekel, F. W., "Emulsified Fuels and Aircraft Safety," AGARD/NATO 37th PEP Meeting "Aircraft Fuels, Lubricants, and Fire Safety," The Hague, Netherlands, May 1971 (AGARD-CP-84-71, pp. 21, 1-21, 12).

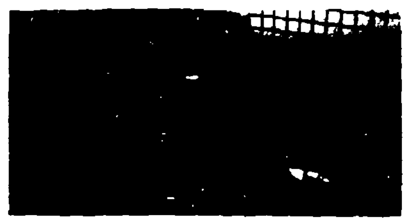
Weatherford, W. D., Jr., and Wright, B. R., "Status of Research on Antimist Aircraft Turbine Engine Fuels in the United States," AGARD/NATO 45th PEP Meeting "Aircraft Fire Safety," Rome, Italy, April 1975 (AGARD-CP-166, pp. 2, 1-2, 12, DDC No. AD-A011341).

Weatherford, W. D. Jr., and Schaekel, F. W., "U.S. Army Helicopter Modified Fuel Development Program—Review of Emulsified and Gelled Fuel Studies," prepared by Southwest Research Institute, U.S. Army Fuels and Lubricants Research Laboratory, under U.S. Army Contract No. DAAK02-73-C-0221, AFLRL No. 69, June 1975 (DDC No. AD-A023848).

PROGRAM SYNOPSIS

Technical Objectives: Develop a repeatable bench-scale laboratory technique for assessing fire-safety characteristics of various flammable liquids.

Approach: Impact dispersion experiments are conducted in a well ventilated enclosed facility developed for this purpose. These tests involve allowing a 2-liter glass vessel, containing about 1.2 kg of fuel, to fall freely 6 meters onto a steel target plate, originally embedded in concrete and surrounded on two sides by gas pilot flames. In the present facility, the target plate comprises a horizontal, elevated 2.5 cm-thick steel plate with electric surface heaters attached to its under side so that its surface temperature can be adjusted and controlled independently.

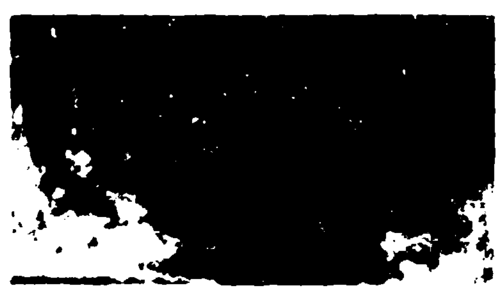


Heated Impact Pad, Gas Pilot Array, and Fluid Container With Solonoid Release (Lowered for Photograph)

The relatively low vertical velocity of 11 meters per second developed by the glass vessel during this free fall corresponds to total occupant survivability during a vertical helicopter crash, but it is near the onset of marginal survivability. The glass containers are filled to an ullage of about 2 percent of the total volume for each test. A television camera (with zoom lens) is located about 6 meters from the impact point, and this is used to document the test results on video tape. A background grid provides a dimensional frame of reference, and subsequent examination of the video tape by slow motion (and stop action) provides reduced data. Tests are conducted at several different temperature levels, from about 25° to 99° by preheating the fuel sample and the steel target plate to the desired temperatures.

Peak Splash With No Fireball (Typical of Antimist Fuels)

Accomplishments: The following data reduction system placed the impact dispersion results on a semiquantitative basis. A rating from "A" through "E" is assigned to the results of each experiment, depending upon the observed flammability characteristics. These range from "no pilot flame enlargement" for highly effective antimist fuels through "pilot dimensions less than doubled," "pilot flames totally obscured by transient mist fireball" (neat, low-volatility fuels), to "coalesced fireball with simultaneous pool burning" (volatile liquid fuels).This method of quantifying the results of impact dispersion tests has proved usable and correlatable with other experimentally measured flammability properties.



Peak Mist Fireball

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APPENDIX E

DATA CORRECTION PROGRAM

FOR PETTER ENGINE DATA

```
$FILES (0,5)
C*********************************************************
C
C  PEDRP-  Petter Engine Data Reduction Program,
C          a program used to correct performance
C          parameters from the PETTER screening
C          engine for atmospheric conditions. The
C          mean and 95% confidence intervals are
C          then calculated for corrected parameters.
C
C*********************************************************
C
      PROGRAM PEDRP
      DIMENSION A(100,7),B(100,5),C(30),D(5)
      DIMENSION NAST(2),LAST(25),NFAC(3),NSRG(3),MAST(25)
C
C
C  OPEN FILE 'ATM' WHICH CONTAINS THE SHE ATMOSPHERIC CORRECTION
C  FACTORS.
C
C        BD = DRY ATMOSPHERIC PRESSURE
C        T  = AMBIENT AIR TEMP.(F)
C        AB = CONVERSION TO ABSOLUTE TEMP.(R)
C
C
      OPEN(501,FILE='ATM')
      READ(501,*)BD,T,AB
      F=T+AB
C
C
C  OPEN FILE 'BTU' WHICH CONTAINS THE NET HEAT OF COMBUSTION OF
C  THE FUEL BLENDS EVALUATED WITH THE PETTER ENGINE.
C
C
      OPEN(504,FILE='BTU')
C
C
      LU=1
450   WRITE(LU,1)
1     FORMAT(1X,'ENTER LU NUMBER FOR PRINTER----')
      READ(LU,*)LP
      L=7
      J=5
      NCJ=J*6
      NBF=100
C
C
C  THE SPECIFIC RANGE FILE IS WERE THE CALCULATIONS FOR
C  SPECIFIC RANGE ARE PLACED IN ORDER TO COMPARE FUELS.
C
C
      WRITE(LU,200)
200   FORMAT(1X,'SPECIFIC RANGE FILE NAME----')
      READ(LU,201)NSRG
201   FORMAT(3A2)
```

```
C
C
C  FUELS CAN BE ACCESSED INDIVIDUALLY OR ACCESSED FROM
C  A FUEL ACCOUNTING FILE FOR A SPECIFIC BASELINE SET.
C
C
       WRITE(LU,2)
2      FORMAT(1X,'A SPECIFIC FUEL FILE ?  Y  OR  N')
       READ(LU,105)LFN
105    FORMAT(1A1)
C
C
       IF(LFN.NE.1HY.AND.LFN.NE.1HN)GO TO 30
       IF(LFN.NE.1HY)GO TO 8
C
C
C  ACCESS FUELS INDIVIDUALLY
C
C
       WRITE(LU,3)
3      FORMAT(1X,'INPUT FUEL FILE NAME-----')
       READ(LU,5)NAST
5      FORMAT(2A2)
       OPEN(502,FILE=NAST)
       WRITE(LU,6)
6      FORMAT(1X,'INPUT FUEL BLEND NUMBER-----')
       READ(LU,*)IFNO
C
C
C  SUBROUTINE FFNO CORRELATES FUEL NUMBER WITH NET HEAT OF
C  COMBUSTION.
C
C
       CALL FFNO(IFNO,504,BTLB,LAST,*23)
C
C
       GO TO 13
8      IF(LFN.EQ.1HN.AND.NUT.EQ.1HY)REWIND 503
C
C
C  FUELS ARE ACCESSED THROUGH A FUEL ACCOUNTING FILE WHICH
C  CORRELATES WITH A SET OF BASELINE DATA.
C
C
       WRITE(LU,9)
9      FORMAT(1X,'NAME OF FUEL ACCOUNTING FILE-----')
       READ(LU,10)NFAC
10     FORMAT(3A2)
       OPEN(503,FILE=NFAC)
       LEG=0
11     READ(503,*,END=300)
       LEG=LEG+1
       GO TO 11
300    REWIND 503
       DO 21 LL=1,LEG
```

```
      READ(503,12)NAST,IFNO
12    FORMAT(2A2,1X,I3)
      OPEN(502,FILE=NAST)
      CALL FFNO(IFNO,504,BTLB,LAST,*23)
C
C
C  PRINT OUT HEADER
C
C
13    WRITE(LP,14)LAST
14    FORMAT(1H1,40X,'PROJECT NO. 05-5857-130',//,30X,'CORRECTED',1X,
     1'PETTER ENGINE DATA FOR FUEL BLENDS',//,23X,'FUEL BLEND:',1X,
     225A2,//,22X,60('*'),/,24X,'FUEL',6X,'BHP',7X,'BSFC',6X,'BSVC',
     35X,'SPECIFIC',3X,'THERMAL',/,65X,'RANGE',/,24X,'NO.',15X,
     4'LB/HP-HR',3X,'GAL/HP-HR',3X,'HP-HR/GAL',4X,'EFF.',/,22X,60('*'))
C
C
C  DETERMINE NUMBER OF ENTRIES IN A FUEL FILE
C
C
      N=0
350   READ(502,*,END=400)
      N=N+1
      GO TO 350
400   REWIND 502
C
C
C  READ DATA FROM FUEL FILE. DATA INCLUDES:
C
C     A(I,1) = ATMOSPHERIC PRESSURE
C     A(I,2) = AMBIENT AIR TEMP. OF TEST(F)
C     A(I,3) = WATER VAPOR PRESSURE AT A(I,2)
C     A(I,4) = RELATIVE HUMIDITY
C     A(I,5) = BRAKE HORSEPOWER
C     A(I,6) = BRAKE SPECIFIC FUEL CONSUMPTION
C     A(I,7) = BRAKE SPECIFIC VOLUME CONSUMPTION
C
C
      DO 16 I=1,N
      READ(502,*)(A(I,K),K=1,L)
C
C
C  CALCULATE CORRECTION FACTOR(CF) AND CORRECT
C  ENGINE PERFORMANCE DATA.
C
C
      R=A(I,4)/100.
      PV=R*A(I,3)
      BDT=A(I,1)-PV
      CF=(BD/BDT)*(((A(I,2)+AB)/F)**.7)
C
C
C  OUTPUT CORRECTED VARIABLES
C
C     B(I,1) = CORRECTED BHP
```

```
C        B(I,2) = CORRECTED BSFC
C        B(I,3) = CORRECTED BSVC
C        B(I,4) = CORRECTED SPECIFIC RANGE
C        B(I,5) = CORRECTED % THERMAL EFFICIENCY
C
C
         B(I,1)=A(I,5)*CF
         FUG=A(I,5)/B(I,1)
         B(I,2)=A(I,6)*FUG
         B(I,3)=A(I,7)*FUG
         B(I,4)=1./B(I,3)
         B(I,5)=100.*(1./(BTLB*B(I,2)/2544.433))
         WRITE(LP,15)IFNO,(B(I,M),M=1,J)
   15    FORMAT(24X,I3,2X,'*',2X,F6.2,2X,'*',2X,F6.3,2X,'*',2X,F6.4,
        12X,'*',2X,F6.4,2X,'*',2X,F4.1)
   16    CONTINUE
C
C
         X=FLOAT(N)
         WRITE(LP,17)
   17    FORMAT(1X,//,39X,'95% CONFIDENCE INTERVALS',/,37X,28('*'),/,
        137X,'* LOW  * MEAN * HIGH * DEV%*',/,37X,28('*'))
C
C
C  CALCULATE MEANS, 95% CONFIDENCE INTERVALS, AND DEVIATION
C  OF 95% CONFIDENCE INTERVALS AS A PERCENTAGE OF THE MEAN.
C
C
         DO 21 II=1,J
         J1=II+J
         JK=II+2*J
         K2=II+3*J
         J2=II+4*J
         I2=II+5*J
         DO 18 KK=1,NCJ
   18    C(KK)=0.0
         DO 19 I=1,N
         C(II)=C(II)+B(I,II)
         C(J1)=C(J1)+B(I,II)**2.
   19    CONTINUE
         D(II)=C(II)/X
         SDEV=ABS(((C(J1)-(C(II)**2./X))/(X-1.)))**.5
         C(JK)=SDEV/(X**.5)
         C(K2)=D(II)-2.*C(JK)
         C(J2)=D(II)+2.*C(JK)
         C(I2)=((C(J2)-C(K2))/D(II))*100.
         IF(II.NE.4)GO TO 100
C
C
C  OPEN SPECIFIC RANGE FILE.
C  CHECK IF SPECIFIC RANGE FOR FUEL BLEND
C  IS CONTAINED IN FILE.
C  WRITE TO SPECIFIC RANGE FILE IF NOT.
C
C
```

```
      OPEN(505,FILE=NSRG)
      NF=0
97    READ(505,*,END=98)
      NF=NF+1
      GO TO 97
98    REWIND 505
      DO 225 I=1,NF
      READ(505,60)LFNO,DEE,MAST
      IF(IFNO.EQ.LFNO)GO TO 100
225   CONTINUE
      WRITE(505,60)IFNO,D(II),LAST
60    FORMAT(1X,I3,2X,F5.2,2X,25A2)
100   WRITE(LP,20)C(K2),D(II),C(J2),C(J2)
20    FORMAT(37X,F6.3,1X,'*',F5.3,1X,'*',F5.3,1X,'* ,1X,F3.1)
      CLOSE(505)
21    CONTINUE
C
C
C  DETERMINE IF SPECIFIC RANGE OUTPUT IS DESIRED
C
C
      WRITE(LU,35)
35    FORMAT(1X,'SUPPRESS SPECIFIC RANGE OUTPUT ?  Y  OR  N')
      READ(LU,36)NERF
36    FORMAT(1A1)
      IF(NERF.NE.1HY.AND.NERF.NE.1HN)GO TO 29
      IF(NERF.EQ.1HY)GO TO 25
      WRITE(LU,71)
71    FORMAT(1X,'TYPE LU FOR HARD COPY OF SPECIFIC RANGE DATA---')
      READ(LU,*)L2
      OPEN(505,FILE=NSRG)
      ICHR=0
40    READ(505,*,END=50)
      ICHR=ICHR+1
      GO TO 40
50    REWIND 505
      IF(IFNO.EQ.NBF.AND.LFN.EQ.1HY)GO TO 75
      WRITE(L2,45)
45    FORMAT(1H1,/,4X,75('#'),/,4X,'#',1 ,'FUEL NO.',4X,'SPECIFIC RANGE',
     13X,'% FROM BASELINE',5X,'FUEL DESC PTION',7X,'#',/,4X,75('#'))
C
C
C  OUTPUT SPECIFIC RANGE DATA AND % DEVIATION FROM BASELINE
C  FOR A PARTICULAR FUEL BLEND.
C
C
75    DO 70 I=1,ICHR
      READ(505,60)LFNO,SRAN,LAST
      IF(LFNO.EQ.NBF)GO TO 80
70    CONTINUE
      GO TO 120
80    SPRN=SRAN
      REWIND 505
      IF(LFN.EQ.1HY)GO TO 175
      DO 110 I=1,ICHR
```

```
          READ(505,60)LFNO,SRAN,LAST
          IF(LFNO.EQ.NBF)GO TO 110
          DELT=(SRAN-SPRN)/SPRN*100.
          WRITE(LZ,150)LFNO,SRAN,DELT,LAST
    150   FORMAT(10X,I3,10X,F5.2,10X,F5.1,10X,25A2)
    110   CONTINUE
          GO TO 140
    175   DO 180 I=1,ICHR
          READ(505,60)LFNO,SRAN,LAST
          IF(IFNO.EQ.NBF)GO TO 140
          IF(LFNO.EQ.NBF)GO TO 180
          IF(IFNO.EQ.LFNO)GO TO 190
    180   CONTINUE
          CLOSE(505)
          GO TO 23
    190   DELT=(SRAN-SPRN)/SPRN*100.
          WRITE(LZ,150)IFNO,SRAN,DELT,LAST
C
C
C  CLOSE ALL FILES, EXIT PROGRAM
C
C
          GO TO 140
    120   WRITE(LU,130)
          WRITE(LZ,130)
    130   FORMAT(1X,'NO BASELINES FOR COMPARISONS')
    140   CLOSE(505)
          IF(LP.NE.6)GO TO 25
          WRITE(LU,22)
    22    FORMAT(1X,//,1X,'PROGRAM COMPLETE, DATA OUTPUTS ON LINE PRINTER ')
          GO TO 25
    23    WRITE(LU,24)IFNO
    24    FORMAT(1X,///,'FUEL BLEND NO.',1X,I3,1X,'HAS NOT BEEN TESTED--')
    25    WRITE(LU,115)
    115   FORMAT(1X,'EXAMINE ANOTHER FUEL ? Y OR N ')
          READ(LU,116)NUT
    116   FORMAT(1A1)
          IF(NUT.NE.1HY.AND.NUT.NE.1HN)GO TO 29
          IF(NUT.EQ.1HY)GO TO 450
    29    CLOSE(502)
    30    CLOSE(5   )
          IF(LFN.EQ.1HY)GO TO 26
          CLOSE(503)
    26    CLOSE(504)
          END
```

FTN4X COMPILER: HP92834 REV.2030 (800821)

** NO WARNINGS ** NO ERRORS ** PROGRAM: 5525 COMMON: (NONE)

```
&FFNO  T=00004 IS ON CR00037 USING 00002 BLKS R=0000

FTN4,L
      SUBROUTINE FFNO(I,NIT,B,ND,*)
      INTEGER ND(25)
      N=0
1     READ(NIT,*,END=2)
      N=N+1
      GO TO 1
2     REWIND NIT
      DO 10 IF=1,N
      READ(NIT,5)L,B,ND
5     FORMAT(I3,2X,F5.0,2X,25A2)
      IF(I.EQ.L)GO TO 20
10    CONTINUE
      GO TO 30
20    CONTINUE
      REWIND NIT
      RETURN
30    CONTINUE
      REWIND NIT
      RETURN 1
      END
```

APPENDIX F

BASELINE NO. 1

FUEL NO.	SPECIFIC RANGE	% FROM BASELINE	FUEL DESCRIPTION
116	15.34	3.8	72% JP-10 25% NAPTHALENE 3% AMYL NITRATE
113	14.84	.4	90.99% DF-2 AL-9979-F 9.01% PHENANTHRENE
115	16.16	9.3	75% TETRALIN 24% AL-10115-F 1% AMYL NITRATE
114	16.77	13.5	50% CAT 1-H AL-10115-F 50% RJ5G AL-7159-F
123	13.30	-10.0	85.6% FRF-A 14.4% NAPTHALENE
118	14.81	.2	63% FRF(#102) 37% RJ5G AL-7159-F
112	14.78	0.0	80.58% DF-2 AL-9979-F 19.42% NAPTHALENE
102	13.06	-11.6	84% AL-10115-F 10% DEIONIZED H2O 6% EA78
200	14.36	-2.8	JET-A AL-10112-F
111	15.70	6.2	99% JP-10 AL-9220-F 1% AMYL NITRATE
120	14.70	-.5	50% FRF(#102) 50% JP-10

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: CAT 1-H AL-13115-F

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
100	5.26	.467	.0660	15.160	29.2
100	5.22	.474	.0670	14.933	28.8
100	5.21	.482	.0681	14.682	28.3
100	5.21	.482	.0681	14.682	28.3
100	5.24	.459	.0649	15.413	29.7
100	5.24	.466	.0659	15.180	29.2
100	5.15	.472	.0673	14.865	28.9
100	5.13	.497	.0693	14.434	27.4
100	5.11	.490	.0693	14.440	27.8
100	5.06	.497	.0703	14.232	27.4
100	5.15	.472	.0667	15.002	28.9
100	5.18	.468	.0656	15.232	29.2
100	5.15	.481	.0682	14.671	28.3
100	5.14	.479	.0671	14.909	28.5
100	5.02	.484	.0686	14.574	28.1
100	5.04	.486	.0686	14.574	28.1
100	5.07	.479	.0675	14.818	28.5
100	5.04	.480	.0675	14.818	28.4
100	5.13	.466	.0659	15.178	29.2
100	5.13	.473	.0669	14.948	28.8
100	5.11	.461	.0652	15.342	29.5
100	5.11	.468	.0662	15.106	29.1
100	5.10	.469	.0663	15.085	29.1
100	5.10	.469	.0663	15.085	29.1
100	5.13	.487	.0689	14.512	28.0
100	5.13	.487	.0689	14.512	28.0
100	5.15	.493	.0697	14.347	27.7
100	5.15	.486	.0687	14.558	28.1
100	5.18	.476	.0673	14.867	28.6
100	5.18	.483	.0683	14.649	28.2
100	5.15	.485	.0687	14.556	28.1
100	5.15	.479	.0677	14.773	28.5
100	5.20	.480	.0680	14.703	28.4
100	5.30	.480	.0680	14.703	28.4
100	5.20	.488	.0690	14.490	27.9
100	5.20	.488	.0690	14.490	27.9
100	5.18	.482	.0683	14.652	28.3
100	5.15	.485	.0687	14.557	28.1

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.130	5.151	5.171	.8
.476	.479	.482	1.3
.067	.068	.068	1.3
14.688	14.78	14.88	1.3
28.291	28.47	28.66	1.3

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 84% AL-10115-F 10% DEIONIZED H2O 6% EA78

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
102	5.15	.560	.0768	13.026	28.5
102	5.15	.563	.0778	12.861	28.3
102	5.15	.560	.0767	13.030	28.4
102	5.15	.560	.0768	13.026	28.5
102	5.15	.561	.0768	13.026	28.4
102	5.15	.561	.0768	13.026	28.4
102	5.18	.556	.0763	13.114	28.7
102	5.18	.555	.0763	13.114	28.7
102	5.18	.554	.0763	13.114	28.8
102	5.18	.553	.0763	13.114	28.8
102	5.18	.555	.0763	13.110	28.7
102	5.18	.535	.0763	13.110	28.7

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.155	5.165	5.175	.4
.556	.558	.560	.7
.076	.077	.077	.7
13.013	13.06	13.10	.7
28.480	28.58	28.68	.7

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 99% JP-10 AL-9220-F 1% AMYL NITRATE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
111	5.09	.501	.0644	15.525	27.5
111	5.13	.495	.0631	15.836	27.9
111	5.13	.496	.0631	15.837	27.8
111	5.11	.499	.0642	15.586	27.7
111	5.13	.497	.0631	15.837	27.8
111	5.13	.502	.0642	15.586	27.5

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.102	5.116	5.129	.5
.496	.498	.501	.9
.063	.064	.064	1.6
15.579	15.70	15.82	1.6
27.565	27.69	27.82	.9

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 90.99% DF-2 AL-9979-F 9.01% PHENANTHRENE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
113	5.27	.492	.0679	14.718	28.2
113	5.25	.492	.0679	14.718	28.2
113	5.26	.483	.0670	14.915	28.7
113	5.26	.484	.0672	14.892	28.6
113	5.24	.487	.0672	14.892	28.5
113	5.25	.481	.0672	14.892	28.8

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.245	5.255	5.265	.4
.483	.486	.490	1.5
.067	.067	.068	1.0
14.762	14.84	14.91	1.0
28.285	28.50	28.71	1.5

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 80.58% DF-2 AL-9979-F 19.42% NAPTHALENE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
112	5.10	.511	.0703	14.219	27.4
112	5.11	.489	.0671	14.895	28.6
112	5.18	.483	.0660	15.150	29.0
112	5.21	.535	.0736	13.578	26.2
112	5.21	.479	.0656	15.250	29.2
112	5.22	.487	.0667	14.997	28.8
112	5.09	.490	.0675	14.823	28.6
112	5.09	.482	.0664	15.051	29.1
112	5.10	.483	.0662	15.101	29.0

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.108	5.146	5.185	1.5
.481	.493	.505	4.9
.066	.068	.069	5.2
14.423	14.78	15.15	4.9
27.789	28.45	29.11	4.6

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 50% CAT 1-H AL-10115-F 50% RJ5G AL-7159-F

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
114	5.26	.491	.0609	16.433	28.2
114	5.27	.485	.0598	16.713	28.5
114	5.27	.485	.0598	16.713	28.5
114	5.27	.484	.0598	16.713	28.6
114	5.29	.477	.0587	17.028	29.0
114	5.28	.477	.0587	17.028	29.0

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.269	5.278	5.286	.3
.479	.483	.487	1.8
.059	.060	.060	2.2
16.586	16.77	16.96	2.2
28.369	28.63	28.89	1.8

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 75% TETRALIN 24% AL-10115-F 1% AMYL NITRATE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
115	5.23	.486	.0618	16.173	29.4
115	5.23	.485	.0618	16.173	29.5
115	5.23	.484	.0619	16.163	29.5
115	5.23	.484	.0619	16.163	29.5
115	5.23	.484	.0619	16.163	29.5
115	5.22	.485	.0620	16.136	29.5

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.221	5.225	5.229	.2
.484	.484	.485	.2
.062	.062	.062	.1
16.150	16.16	16.17	.1
29.459	29.49	29.52	.2

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 72% JP-10 25% NAPTHALENE 3% AMYL NITRATE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
116	5.12	.514	.0640	15.617	28.2
116	5.12	.494	.0620	16.129	29.4
116	5.12	.528	.0661	15.136	27.5
116	5.12	.525	.0661	15.136	27.6
116	5.12	.528	.0661	15.136	27.5
116	5.11	.532	.0671	14.894	27.3

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.115	5.115	5.115	0.0
.509	.520	.532	4.4
.064	.065	.067	4.7
14.972	15.34	15.71	4.8
27.292	27.93	28.57	4.6

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 63% FRF(#102) 37% RJ5G AL-7159-F

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
118	5.29	.542	.0681	14.674	27.8
118	5.29	.537	.0671	14.893	28.1
118	5.29	.542	.0681	14.674	27.8
118	5.28	.538	.0672	14.883	28.1
118	5.28	.533	.0672	14.883	28.4
118	5.28	.538	.0672	14.883	28.1

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.287	5.287	5.287	0.0
.535	.538	.541	1.1
.067	.068	.068	1.2
14.726	14.81	14.90	1.2
27.899	28.05	28.21	1.1

PROJECT NO. 05-5057-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 50% FRF(#102) 50% JP-10

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
120	5.30	.513	.0680	14.703	28.8
120	5.20	.523	.0680	14.703	28.2
120	5.30	.513	.0680	14.703	28.8
120	5.30	.513	.0680	14.703	28.8
120	5.30	.513	.0680	14.703	28.8
120	5.20	.523	.0680	14.703	28.2

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.223	5.266	5.308	1.6
.512	.516	.521	1.6
.068	.068	.068	.1
14.703	14.70	14.70	0.0
28.374	28.61	28.84	1.6

PROJECT NO. 05-5057-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 85.6% FRF-A 14.4% NAPTHALENE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
123	5.15	.560	.0757	13.202	28.4
123	5.15	.558	.0747	13.380	28.5
123	5.17	.558	.0755	13.249	28.5
123	5.15	.554	.0747	13.380	28.6
123	5.15	.554	.0747	13.380	28.6
123	5.15	.560	.0757	13.202	28.4

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.146	5.152	5.157	.2
.555	.557	.559	.7
.075	.075	.076	1.1
13.225	13.30	13.37	1.1
28.407	28.50	28.60	.7

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: JET-A AL-10112-F

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
200	5.21	.465	.0699	14.307	29.0
200	5.21	.466	.0699	14.307	28.9
200	5.21	.467	.0699	14.312	28.9
200	5.21	.465	.0689	14.520	29.0
200	5.21	.464	.0689	14.524	29.1
200	5.21	.464	.0689	14.524	29.1
200	5.17	.467	.0694	14.406	28.9
200	5.15	.468	.0697	14.357	28.8
200	5.17	.467	.0694	14.406	28.9
200	5.15	.468	.0697	14.357	28.8
200	5.15	.468	.0697	14.357	28.8
200	5.15	.477	.0717	13.953	28.2

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.167	5.183	5.200	.6
.465	.467	.469	.9
.069	.070	.070	1.2
14.273	14.36	14.45	1.2
28.724	28.85	28.97	.9

APPENDIX G

BASELINE NO. 2

FUEL NO.	SPECIFIC RANGE	% FROM BASELINE	FUEL DESCRIPTION
144	13.67	-10.8	79% DF-2 6% EA-78 5% RJ-5 10% WATER
176	15.36	.3	15% NAPHTHALENE 85% CAT-1H
175	15.97	4.2	80% TETRALEN 19% CAT-1H 1% AMYL NITRATE
150	14.67	-4.2	81% DF-2 3.5% EA-78 10% RJ-5 5% WATER
167	15.41	.6	80% #5 BURNER OIL 20% JP-10
169	16.05	4.8	79% #6 BURNER OIL 20% JP-10 1% AMYL NITRATE
170	16.15	5.4	89% #6 BURNER OIL 10% CAT-1H 1% AMYL NITRATE
168	15.67	2.3	90% #5 BURNER OIL 10% CAT-1H
182	17.15	11.9	RJ-6M
117	16.50	7.7	97% TETRALIN AL-9762-A 3% AMYL NITRATE
102	13.41	-12.5	84% AL-10115-F 10% DEIONIZED H2O 6% EA78
156	15.00	-2.1	84% AL-10115-F 6% EA-78 5% RJ-5 5% H2O(DI)
164	16.41	7.1	80% JP-10 20% NAPTHALENE
149	15.72	2.6	86.5% CAT-1H 3.5% EA-8 5% RJ5 5% (DI)H2O

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: CAT 1-H AL-10115-F

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
100	5.30	.448	.0634	15.779	30.4
100	5.30	.452	.0640	15.633	30.1
100	5.31	.452	.0639	15.657	30.1
100	5.31	.451	.0639	15.657	30.2
100	5.31	.452	.0639	15.657	30.1
100	5.30	.450	.0637	15.706	30.3
100	5.22	.469	.0661	15.125	29.1
100	5.21	.465	.0657	15.217	29.3
100	5.21	.469	.0662	15.102	29.1
100	5.21	.470	.0663	15.080	29.0
100	5.25	.439	.0620	16.134	31.1
100	5.22	.477	.0674	14.829	28.6
100	5.22	.463	.0654	15.283	29.4
100	5.22	.455	.0644	15.522	29.9
100	5.21	.456	.0645	15.498	29.9
100	5.24	.450	.0635	15.740	30.3
100	5.25	.453	.0640	15.619	30.1
100	5.22	.477	.0673	14.862	28.6
100	5.21	.467	.0659	15.178	29.2
100	5.25	.462	.0652	15.326	29.5
100	5.26	.456	.0645	15.515	29.9
100	5.33	.448	.0633	15.796	30.4
100	5.32	.448	.0633	15.796	30.4
100	5.23	.463	.0654	15.281	29.5
100	5.23	.459	.0647	15.446	29.7
100	5.25	.462	.0652	15.334	29.5
100	5.24	.464	.0655	15.264	29.4
100	5.22	.480	.0678	14.750	28.4
100	5.23	.471	.0666	15.015	28.9
100	5.20	.472	.0668	14.980	28.9
100	5.21	.471	.0667	15.002	28.9
100	5.17	.475	.0671	14.900	28.7
100	5.17	.470	.0665	15.035	29.0
100	5.13	.460	.0650	15.383	29.6
100	5.19	.457	.0645	15.499	29.8
100	5.21	.458	.0647	15.451	29.8
100	5.23	.457	.0646	15.483	29.8
100	5.23	.457	.0645	15.507	29.8
100	5.17	.469	.0662	15.104	29.0
100	5.14	.459	.0648	15.431	29.7
100	5.17	.467	.0659	15.182	29.2
100	5.19	.457	.0646	15.489	29.9
100	5.12	.475	.0671	14.898	28.7
100	5.12	.469	.0662	15.105	29.1
100	5.10	.469	.0661	15.119	29.1
100	5.11	.466	.0659	15.166	29.2
100	5.12	.475	.0671	14.898	28.7
100	5.12	.469	.0662	15.105	29.1
100	5.10	.469	.0661	15.119	29.1

100	5.11	.466	.0659	15.166	29.2

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.194	5.211	5.228	.7
.460	.462	.465	1.1
.065	.065	.066	1.1
15.229	15.32	15.40	1.1
29.326	29.49	29.66	1.1

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 84% AL-10115-F 10% DEIONIZED H2O 6% EA78

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
102	5.19	.534	.0732	13.665	29.9
102	5.19	.548	.0751	13.321	29.1
102	5.23	.551	.0756	13.233	28.9

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.179	5.206	5.233	1.0
.534	.544	.554	3.8
.073	.075	.076	3.9
13.143	13.41	13.67	3.9
28.739	29.31	29.87	3.9

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 97% TETRALIN AL-9762-A 3% AMYL NITRATE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
117	5.26	.494	.0608	16.446	29.7
117	5.26	.492	.0605	16.527	29.8
117	5.26	.487	.0599	16.692	30.1
117	5.25	.496	.0610	16.392	29.6
117	5.24	.497	.0611	16.365	29.5
117	5.26	.491	.0604	16.554	29.9

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.244	5.250	5.257	.3
.489	.492	.495	1.2
.060	.061	.061	1.2
16.397	16.50	16.59	1.2
29.569	29.75	29.93	1.2

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 79% DF-2 6% EA-78 5% RJ-5 10% WATER

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
144	5.26	.543	.0732	13.670	29.0
144	5.23	.547	.0736	13.578	28.8
144	5.25	.542	.0730	13.708	29.1
144	5.24	.541	.0729	13.726	29.1

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.234	5.247	5.260	.5
.540	.543	.546	1.0
.073	.073	.074	1.0
13.605	13.67	13.74	1.0
28.861	29.00	29.14	1.0

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 86.5% CAT-1H 3.5% EA-8 5% RJ5 5% (DI)H20

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
149	5.24	.471	.0643	15.554	31.1
149	5.24	.466	.0635	15.749	31.5
149	5.23	.466	.0636	15.724	31.5
149	5.24	.466	.0635	15.749	31.5
149	5.24	.464	.0633	15.799	31.7
149	5.24	.465	.0634	15.774	31.6

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.231	5.235	5.240	.2
.464	.466	.468	1.0
.063	.064	.064	.9
15.653	15.72	15.80	.9
31.334	31.49	31.64	1.0

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 81% DF-2 3.5% EA-78 10% RJ-5 5% WATER

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
150	5.20	.506	.0680	14.702	29.0
150	5.20	.507	.0682	14.658	29.0
150	5.19	.508	.0683	14.637	28.9

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.186	5.192	5.199	.2
.506	.507	.509	.4
.068	.068	.068	.5
14.627	14.67	14.70	.5
28.919	28.98	29.05	.4

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 84% AL-10115-F 6% EA-78 5% RJ-5 5% H2O(DI)

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
156	5.31	.489	.0670	14.931	30.4
156	5.30	.488	.0668	14.975	30.5
156	5.32	.485	.0664	15.064	30.7
156	5.31	.486	.0666	15.019	30.6
156	5.31	.486	.0666	15.019	30.6
156	5.30	.487	.0667	14.997	30.5

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.306	5.311	5.317	.2
.486	.487	.488	.5
.067	.067	.067	.5
14.964	15.00	15.04	.5
30.472	30.55	30.62	.5

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 80% JP-10 20% NAPTHALENE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
164	5.20	.485	.0610	16.390	29.4
164	5.21	.482	.0607	16.471	29.6
164	3.19	.482	.0607	16.471	29.6
164	3.19	.482	.0607	16.471	29.6
164	5.17	.478	.0602	16.609	29.9
164	5.16	.496	.0624	16.020	28.8

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.175	5.190	5.205	.6
.480	.484	.489	2.0
.060	.061	.062	2.0
16.241	16.41	16.57	2.0
29.200	29.49	29.78	1.9

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 80% #5 BURNER OIL 20% JP-10

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
167	5.16	.503	.0654	15.286	28.4
167	5.23	.500	.0650	15.380	28.5
167	5.23	.499	.0649	15.403	28.6
167	5.20	.498	.0647	15.451	28.6
167	5.21	.497	.0646	15.475	28.7
167	5.19	.497	.0646	15.475	28.7

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.186	5.208	5.229	.8
.497	.499	.500	.7
.065	.065	.065	.8
15.352	15.41	15.47	.8
28.482	28.59	28.69	.7

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 90% #5 BURNER OIL 10% CAT-1H

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
168	5.17	.495	.0645	15.515	28.4
168	5.18	.491	.0638	15.662	28.7
168	5.18	.488	.0635	15.736	28.9
168	5.18	.488	.0634	15.761	28.9
168	5.18	.492	.0641	15.613	28.6
168	5.17	.487	.0634	15.761	28.9

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.172	5.176	5.180	.2
.488	.490	.493	1.0
.063	.064	.064	1.0
15.595	15.67	15.75	1.0
28.584	28.73	28.88	1.0

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 79% #6 BURNER OIL 20% JP-10 1% AMYL NITRATE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
169	5.23	.504	.0623	16.047	29.0
169	5.24	.507	.0627	15.945	28.8
169	5.23	.504	.0623	16.047	29.0
169	5.23	.504	.0622	16.073	29.0
169	5.23	.502	.0621	16.098	29.1
169	5.23	.504	.0622	16.073	29.0

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.225	5.227	5.229	.1
.502	.504	.505	.5
.062	.062	.062	.5
16.004	16.05	16.09	.5
28.928	29.00	29.08	.5

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 89% #6 BURNER OIL 10% CAT-1H 1% AMYL NITRATE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
170	5.23	.494	.0615	16.268	29.3
170	5.24	.497	.0618	16.190	29.1
170	5.23	.502	.0624	16.035	28.8
170	5.25	.497	.0618	16.190	29.1
170	5.24	.498	.0619	16.164	29.1
170	5.22	.501	.0624	16.035	28.9

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.225	5.233	5.241	.3
.496	.498	.501	1.0
.062	.062	.062	.9
16.071	16.15	16.22	.9
28.914	29.05	29.19	1.0

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 80% TETRALEN 19% CAT-1H 1% AMYL NITRATE

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
175	5.21	.498	.0629	15.895	28.8
175	5.22	.500	.0631	15.845	28.7
175	5.23	.501	.0633	15.794	28.7
175	5.21	.501	.0632	15.819	28.7
175	5.20	.488	.0616	16.230	29.4
175	5.21	.488	.0616	16.230	29.4

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.204	5.212	5.220	.3
.491	.496	.501	2.1
.062	.063	.063	2.1
15.802	15.97	16.14	2.1
28.654	28.96	29.26	2.1

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: 15% NAPHTHALENE 85% CAT-1H

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
176	5.17	.479	.0656	15.243	28.8
176	5.18	.476	.0652	15.338	28.9
176	5.17	.473	.0648	15.433	29.1
176	5.17	.475	.0651	15.362	29.0
176	5.18	.474	.0650	15.386	29.1
176	5.17	.475	.0650	15.385	29.0

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.172	5.175	5.179	.1
.474	.476	.477	.7
.065	.065	.065	.7
15.305	15.36	15.41	.7
28.871	28.98	29.08	.7

PROJECT NO. 05-5857-130

CORRECTED PETTER ENGINE DATA FOR FUEL BLENDS

FUEL BLEND: RJ-6M

FUEL NO.	BHP	BSFC LB/HP-HR	BSVC GAL/HP-HR	SPECIFIC RANGE HP-HR/GAL	THERMAL EFF.
182	5.11	.488	.0584	17.111	29.0
182	5.15	.485	.0581	17.203	29.2
182	5.13	.487	.0583	17.141	29.1
182	5.14	.486	.0582	17.171	29.1
182	5.15	.487	.0583	17.143	29.0

95% CONFIDENCE INTERVALS

LOW	MEAN	HIGH	DEV%
5.120	5.134	5.149	.6
.486	.487	.488	.4
.058	.058	.058	.4
17.123	17.15	17.18	.4
29.016	29.08	29.14	.4

APPENDIX H

NO. 1 CARBON BLACK (RAVEN 1170)

NO. 2 CARBON BLACK (SL-90)

NO. 3 CARBON BLACK (MOGUL L)

APPENDIX H

NO.1

Properties of Raven 1170[a]
(Cities Service Co.)

Blackness Index	160
Particle Diameter, m (arithmetic mean)	24
Surface Area, sq. meters per gram (by nitrogen adsorption (B.E.T.)	102
Absorption, Oil (Venuto Method) Fluid Paste, cc/gram	7.2
gal./100 lb	86.
Absorption, Oil Stiff Paste Endpoint, cc/gram	.89
gal./100 lb	8.3
Absorption, BDP, cc/100 grams	58
Tinting Strength Index	102
Adsorption Index	6.0
PH	7.0
Fixed Carbon, %	99.0
Volatile matter, %	1.0
Apparent Density, lbs/cu.ft.	
Powder	17
Beads	30
Net Hc[b] Btu/lb	13,875
Ash,[b] wt%	0.5

(a) As supplied by manufacturer

(b) Experimentally determined at AFLRL

APPENDIX H

NO. 2

PROPERTIES [a] OF SL-90 CARBON BLACK

(ASHLAND CHEMICAL CO.)

Heat loss (D 1509-75[b], %	0.3
U.S. #35 Sieve Residue (D 1514-74),%	Nil
U.S. #325 Sieve Residue (D 1514-74,%	0.0111
Ash (D 1506-75),%	0.39
Toluene Discoloration (D 1618)-75) %T	93
Iodine Adsorption (D 1510-76),mg/gm	24.8
DBP Absorption (D 2414-76), cc/100gm	57.5
Tint (D 3265-80),%	42.8
Pour Density (D 1513-74),lbs/cu.ft.	32.3
5' Fines (D 1508-74),%	6.4
20' Fines (D 1508-74),%	8.2
Pellet Hardness (D 3313-74), grams	
High	33
Avg	22
Low	4
Tint (D 3265-76)	39.0

(a) As supplied by manufacturer

(b) D Numbers in parentheses are ASTM Test Methods

APPENDIX H

NO. 3

PROPERTIES[a] OF MOGUL CARBON BLACK

(CABOT CORPORATION)

Nigrometer Index		83
Surface Area (N.S.A.), sg. meters per gram		138
Particle Size, milli microns		24
Oil Absorption (DBS), cc/100 grams		
	Fluffy	60
	Pellets	55
Tinting Strength Index		112
Volatile Content, %		5.0
Fixed Carbon, %		95.0
PH		3.4
Toulene extract, %		0.10
Electrical Resistivity (dry)		H
Density, lbs/cu.ft.		
	Fluffy	15
	Pellets	33
Net Hc[b], Btu/lb		13,240

(a) As supplied by manufacturer

(b) Experimentally determined at AFLRL

DEPARTMENT OF DEFENSE

DEFENSE DOCUMENTATION CTR CAMERON STATION ALEXANDRIA VA 22314	12
DEPT OF DEFENSE ATTN: DASD(MRAL)-LM(MR DYCKMAN) WASHINGTON DC 20301	1
COMMANDER DEFENSE LOGISTICS AGY ATTN DLA-SME (MRS P MCLAIN) CAMERON STATION ALEXANDRIA VA 22314	1
COMMANDER DEFENSE FUEL SUPPLY CTR ATTN: DFSC-T (MR. MARTIN) CAMERON STA ALEXANDRIA VA 22314	1
COMMANDER DEFENSE GENERAL SUPPLY CTR ATTN: DGSC-SSA RICHMOND VA 23297	1
DOD OFC OF SEC OF DEF ATTN USD (R&E) WASHINGTON, DC 20301	1
DOD ATTN OASD (MRA&L)-TD PENTAGON, 3C841 WASHINGTON DC 20301	1
DEFENSE ADVANCED RES PROJ AGENCY DEFENSE SCIENCES OFC 1400 WILSON BLVD ARLINGTON VA 22209	1

DEPARTMENT OF THE ARMY

HQ, DEPT OF ARMY ATTN: DALO-TSE (COL ARNAUD)	1
DALO-AV	1
DALO-SMZ-E	1
DAMA-CSS-P (DR BRYANT)	1
DAMA-ARZ (DR CHURCH)	1
DAMA-SMZ WASHINGTON DC 20310	1
CDR U.S. ARMY MOBILITY EQUIPMENT R&D COMMAND Attn: DRDME-GL FORT BELVOIR VA 22060	10
CDR US ARMY MATERIEL DEVEL&READINESS COMMAND ATTN: DRCLD (MR BENDER)	1
DRCDMR (MR GREINER)	1
DRCDMD-ST (DR HALEY)	1
DRCQA-E	1
DRCDE-SS	1
DRCIS-[illegible] (LTC CROW) 5001 EISENHOWER AVE ALEXANDRIA VA 22333	1
CDR US ARMY TANK-AUTOMOTIVE CMD ATTN DRSTA-NW (TWVMO)	1
DRSTA-RG (MR HAMPARIAN)	1
DRSTA-NS (DR PETRICK)	1
DRSTA-G	1
DRSTA-M	1
DRSTA-GBP (MR MCCARTNEY) WARREN MI 48090	1
DIRECTOR US ARMY MATERIEL SYSTEMS ANALYSIS AGENCY ATTN DRXSY-CM	1
DRXSY-S	1
DRXSY-L ABERDEEN PROVING GROUND MD 21005	1
DIRECTOR APPLIED TECHNOLOGY LAB U.S. ARMY R&T LAB (AVRADCOM) ATTN DAVDL-ATL-ATP (MR MORROW)	1
DAVDL-ATL-ASV (MR CARPER) FORT EUSTIS VA 23604	1
HQ, 172D INFANTRY BRIGADE (ALASKA) ATTN APZT-DI-L	1
APZT-DI-M DIRECTORATE OF INDUSTRIAL OPERATIONS FT RICHARDSON AK 99505	1

CDR
US ARMY GENERAL MATERIAL &
PETROLEUM ACTIVITY
ATTN STSGP-F (MR SPRIGGS) 1
STSGP-PE (MR MCKNIGHT),
BLDG 85-3 1
STSGP (COL CLIFTON) 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

CDR
US ARMY MATERIEL ARMAMEMT
READINESS CMD
ATTN DRSAR-LEM (MR MENKE) 1
ROCK ISLAND ARSENAL IL 61299

CDR
US ARMY COLD REGION TEST CENTER
ATTN STECR-TA 1
APO SEATTLE 98733

HQ, DEPT. OF ARMY
ATTN: DAEN-RDZ-B 1
WASHINGTON, DC 20310

CDR
US ARMY RES & STDZN GROUP
(EUROPE)
ATTN DRXSN-UK-RA 1
BOX 65
FPO NEW YORK 09510

HQ, US ARMY AVIATION R&D CMD
ATTN DRDAV-GT (MR R LEWIS) 1
DRDAV-D (MR CRAWFORD) 1
DRDAV-N (MR BORGMAN) 1
DRDAV-E (MR LONG) 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120

CDR
US ARMY FORCES COMMAND
ATTN AFLC-REG 1
AFLC-POP 1
FORT MCPHERSON GA 30330

CDR
US ARMY ABERDEEN PROVING GROUND
ATTN: STEAP-MT-U (MR DEAVER) 1
ABERDEEN PROVING GROUND MD 21005

CDR
US ARMY YUMA PROVING GROUND
ATTN STEYP-MT (MR DOEBBLER) 1
YUMA AZ 85364

MICHIGAN ARMY MISSILE PLANT
OFC OF PROJ MGR, ABRAMS TANK SYS
ATTN DRCPM-GCM-S 1
WARREN MI 48090

MICHIGAN ARMY MISSILE PLANT
PROG MGR, FIGHTING VEHICLE SYS
ATTN DRCPM-FVS-SE 1
WARREN MI 48090

PROJ MGR, M60 TANK DEVELOPMENT
USMC-LNO, MAJ. VARELLA 1
US ARMY TANK-AUTOMOTIVE CMD (TACOM)
WARREN MI 48090

PROG MGR, M113/M113A1 FAMILY
OF VEHICLES
ATTN DRCPM-M113 1
WARREN MI 48090

PROJ MGR, MOBILE ELECTRIC POWER
ATTN DRCPM-MEP-TM 1
7500 BACKLICK ROAD
SPRINGFIELD VA 22150

OFC OF PROJ MGR, IMPROVED TOW
VEHICLE
US ARMY TANK-AUTOMOTIVE R&D CMD
ATTN DRCPM-ITV-T 1
WARREN MI 48090

CDR
US ARMY EUROPE & SEVENTH ARMY
ATTN AEAGC-FMD 1
APO NY 09403

PROJ MGR, PATRIOT PROJ OFC
ATTN DRCPM-MD-T-G 1
US ARMY DARCOM
REDSTONE ARSENAL AL 35809

CDR
THEATER ARMY MATERIAL MGMT
CENTER (200TH)
DIRECTORATE FOR PETROL MGMT
ATTN AEAGD-MM-PT-Q (MR PINZOLA) 1
ZWEIBRUCKEN
APO NY 09052

CDR
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