SURVEY OF LOW-SULFUR DIESEL FUELS AND AVIATION KEROSENES FROM U.S. MILITARY INSTALLATIONS

INTERIM REPORT
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By

S. R. Westbrook
U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, TX

And

M.E. LePera
U.S. Army TARDEC
Mobility Technology Center - Belvoir
Fort Belvoir, Virginia

Under Contract to
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13. ABSTRACT (Maximum 200 words)

In support of the Department of Defense goal to streamline procurements, the Army recently decided to discontinue use of VV-F-800D as the purchase specification for diesel fuel being supplied to continental United States military installations. The Army will instead issue a commercial item description for direct fuel deliveries under the Post/Camp/Station (PCS) contract bulletin program. In parallel, the Defense Fuel Supply Center (DFSC) and the U.S. Army Mobility Technology Center-Belvoir (MTCB at Ft. Belvoir, VA) initiated a fuel survey to assess the general quality and lubricity characteristics of low sulfur diesel fuels being supplied to military installations under the PCS system. Under this project, diesel fuel delivery samples were obtained from selected military installations and analyzed according to a predetermined protocol. The results obtained from various tests show that the average, low-sulfur diesel fuel meets military requirements for DF-2 with the exception of lubricity performance. Proposed fuel lubricity requirements for military, ground-vehicle, diesel fuels are presented.

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EXECUTIVE SUMMARY

Problem: The introduction of EPA mandated, low-sulfur diesel fuel in October 1993 increased the Army's potential for fuel-related problems such as increased engine wear and low cetane number.

Objectives:

- To assess the lubricity characteristics of low-sulfur diesel fuels being supplied to military installations under the PCS system, since neither the military nor the commercial specification contain a lubricity requirement;
- To confirm the likelihood that the currently supplied, commercial-quality fuel will meet the military requirements shown in Table 1;
- To provide the information to support development of a commercial item description (CID) for future diesel fuel procurements.

Importance of Project: The results of this project will provide the Army with reliable data concerning the quality of fuel at U.S. military bases and the associated potential for fuel-related problems.

Technical Approach: Low-sulfur diesel fuel samples were obtained from selected CONUS military installations and analyzed according to a pre-determined protocol. Samples were taken during the summer of 1994 and the first three months of 1995.

Accomplishments: A total of 112 fuel samples were received and analyzed.

Military Impact: The study found that the average diesel fuel meets specification requirements. The results also showed that the majority of the fuels had acceptable lubricity characteristics.

FOREWORD/ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

I. BACKGROUND AND OBJECTIVE

Effective October 1, 1993, federal regulations implemented by the Environmental Protection Agency (EPA) limited the maximum fuel sulfur content to a mass fraction of 0.05% from its previous level of 0.5%, according to ASTM D 975[1]. Additionally, the total aromatics content in the fuel was limited to a maximum volume fraction of 35%, or a minimum cetane number of 40 as an alternative limit. The tendency toward more highly refined fuels to meet these federal regulations increased the potential for accelerated wear in some diesel engine fuel system components[2]. The Army is especially vulnerable to fuel related problems for the following reasons:

- The severe operational requirements placed on Army vehicles (long periods of non-use followed by short periods of high use levels, and operation in hostile environments, including all extremes of temperature, humidity, dust, and terrain) increase the likelihood of problems in the field.

- Because non-military users buy fuel from numerous commercial sources, such as filling stations and truck stops, the chance of a non-military vehicle operating on only poor lubricity fuel is comparatively low. Conversely, military vehicles at any given post/camp/station are required to use fuel from a single supplier, as the minimum period for these contracts is twelve months.

- The routine military practice of slow fuel turnover allows fuels purchased in late fall and winter to be used in vehicles during spring and summer. This is a potential lubricity problem since winter fuels tend to be lower in density and viscosity.

- The Army/Department of Defense (DOD) has a high volume of military vehicles/equipment (V/E) with fuel sensitive pumps, such as rotary-type, fuel-injection pumps.

- Non-military users also have the option of additizing their fuels if necessary. This solution is more difficult in the military because of additive non-availability, additive costs, and inadequate additive introduction systems.

- The changes in fuel refining, processing and distribution required by these new federal regulations also raised the question of how some other fuel properties might be affected. These properties include cloud point, freeze point, pour point, stability, and cleanliness.

As part of the overall DOD goal to streamline military procurements, the Army recently decided to discontinue use of VV-F-800D[3] as the purchase specification for diesel fuel supplied to continental United States (CONUS) military installations under the direct delivery Post-Camp-Station (PCS) contract bulletin program. This decision was made in accordance with a DOD-wide effort to reduce the number of government specifications in favor of commercial specifications. This decision was also based on the government's continuing difficulties in finding fuel suppliers willing to submit bids to supply fuel against the more stringent requirements of VV-F-800D. Virtually all of the fuel delivered to the Army under the PCS program is produced to meet the requirements of ASTM D 975 instead of the more restrictive VV-F-800D. Limited testing of the delivered fuel, after receipt by the Army, showed that the majority of the fuel meets the additional requirements of the federal specification. As a result of the Army's decision, future purchases of ground vehicle diesel fuel will be made against the commercial specification, ASTM D 975. However, D 975 currently has no requirements for particulate contamination levels or accelerated stability. Also, the D 975 requirements for cloud point are less stringent than in VV-F-800D. Table 1 is a comparison of the requirements of these two specifications. Neither commercial nor military specifications contain any requirement for diesel fuel lubricity; since the Army is especially vulnerable to fuel lubricity problems, it was deemed very important that reliable information regarding the lubricity of these fuels be obtained.

In response, the Defense Fuel Supply Center (DFSC) and the U.S. Army Mobility Technology Center-Belvoir (MTCB at Ft. Belvoir, VA) initiated a fuel survey. The primary objectives of the survey were:

- to assess the lubricity characteristics of low-sulfur diesel fuels being supplied to military installations under the PCS system, since neither the military nor the commercial specification contain a lubricity requirement;

- to confirm the likelihood that the currently supplied, commercial-quality fuel will meet the military requirements shown in Table 1;

- to provide the information to support development of a commercial item description (CID) for future diesel fuel procurements.

Table 1. Specification Requirements of VV-F-800D and D 975

Property	ASTM Method	VV-F-800D Grade DF-2	D 975 Grade Low-sulfur 2D
Visual Appearance	D 4176	Clean & Bright	Clean & Bright
Density, kg/L	D 1298	Report	NR
Flash Point, °C	D 93	52,min	52, min
Cloud Point, °C	D 2500	Local	Local
Pour Point, °C	D 97	Report	NR
K. Vis, mm/s^2 at 40°C	D 445	1.9 - 4.4	1.9 - 4.1
Distillation, °C	D 86		
50% evap		Report	NR
90% evap		338,max	282 - 338
End Point		370,max	NR
Residue, vol%		3.0,max	NR
Carbon Residue, 10 % Bottoms, mass %	D 524	0.35, max	0.35, max
Sulfur, mass %	D 4294	0.5, max	0.05, max
Copper Strip Corrosion	D 130	3, max	3, max
Ash, mass %	D 482	0.01, max	0.01, max
Accelerated Stability, mg/100 mL	D 2274	1.5, max	NR
TAN, mg KOH/g	D 974	0.10,max*	NR
Particulate Contamination, mg/L	D 2276	10.0, max	NR
Cetane Number	D 613	40, min	40, min
In D 975: One of the following properties must be met:			
(1) Cetane Index	D 976	NR	40, min
(2) Aromaticity, % vol.	D 1319	NR	35, max

II. APPROACH

Under this project, low-sulfur diesel fuel (LSDF) delivery samples were obtained from selected CONUS military installations and analyzed according to a predetermined testing protocol. The first set of samples was obtained during the summer of 1994. The second set of samples was obtained during the first three months of 1995. The fuel samples were representative of fuel deliveries to selected CONUS military facilities and were taken from delivery vehicles at the time of delivery. Each of the fuel samples was analyzed for the properties listed in Table 2.

Table 2. Low-sulfur Diesel Fuel Analyses

Property	Units	Test Method*
Fuel Lubricity, Wear Scar Diameter	mm	High Frequency Reciprocating Rig (proposed ISO and ASTM test method)
Fuel Lubricity, Scuffing Load	kg	U.S. Army Scuffing Load Wear Test (proposed ASTM test method)
Ball-On-Cylinder Lubricity Evaluator, Wear Scar Diameter	mm	D 5001†
Sulfur	mass %	D 4294
Aromatic Hydrocarbons, mono-, di-, tri-, and total	mass %	D 5186
Kinematic Viscosity at 40°C	mm^2/sec	D 445
Cloud Point	°C	Automatic Tester
Freeze Point	°C	Automatic Tester
Pour Point	°C	D 97
Accelerated Stability, Total Insolubles	mg/100 mL	D 2274
Particulate Contamination	mg/L	Modified D 5452
Density at 15°C	g/mL	D 4052

*** A more complete description of the U.S. Army Scuffing Load Wear Test is found elsewhere.[4]**

† Test methods beginning with D refer to ASTM standards found in Volume 5 of the Book of Standards.

III. ANALYTICAL RESULTS AND DISCUSSION

A total of 112 fuel samples were received and analyzed. Table 3 is a complete listing of the test results for these fuels. Table 4 contains descriptive statistics for each of the properties.

Discussions of the results, along with frequency histograms for selected properties, follow.

Table 3. Fuel Analysis Data

Fuel I.D.	Cetane Number	HFRR, mm	Scuff Load, g	BOCLE, mm	Sulfur, mass %	Mono-Arom	Di-Arom	Tri-Arom	Total Arom	Vis. 40C cSt.	Cloud Pt,C	Freeze Pt., C	Pour Pt., C	Acc. Stab., mg/100mL	Part. mg/L	Density D-4052
22059	50.5	0.22	2500	0.67	0.03	23.6	6.2	1.6	31.4	3.46	-8.4	-4.3	-12	0.17	9.0	0.8592
22132	56.1	0.22	3800	0.56	0.01	11.1	1.5	0.4	13.0	2.96	-13.2	-8.9	-12	0.21	4.7	0.8387
22239	58.7	0.25	4600	0.57	0.02	15.9	3.0	0.9	19.8	4.05	-2.6	-1.0	-6	0.38	1.6	0.8401
22410	50.1	0.20	4300	0.54	0.03	24.5	6.8	1.3	32.6	2.56	-12.4	-9.6	-15	0.28	1.5	0.8474
22413	42.8	0.23	3800	0.60	0.04	29.0	11.4	2.4	42.8	2.65	-19.8	-17.3	-21	1.39	1.1	0.8660
22419	57.0	0.29	3900	0.57	0.05	11.7	3.3	0.7	15.7	3.13	-4.6	1.4	-6	0.40	2.4	0.8280
22439	47.5	0.17	4000	0.60	0.04	27.6	8.2	2.2	38.0	3.16	-9.0	-5.4	-15	0.74	2.8	0.8666
22440	54.0	0.27	4300	0.54	0.02	16.5	2.8	0.9	20.2	2.55	-22.5	-19.3	-39	0.08	6.0	0.8310
22441	52.4	0.21	4600	0.52	0.03	24.6	7.2	1.3	33.1	2.60	-13.4	-9.8	-18	0.16	3.1	0.8484
22460	54.5	0.24	3000	0.66	0.03	21.6	3.9	0.7	26.2	2.34	-14.3	-9.7	-21	0.80	2.6	0.8321
22461	54.2	0.25	3500	0.56	0.04	22.5	9.0	1.5	33.0	2.51	-12.8	-10.0	-18	0.90	15.4	0.8448
22462	53.7	0.23	3100	0.60	0.03	26.2	7.6	1.2	35.0	2.81	-11.6	-7.9	-15	4.30	1.3	0.8542
22475	50.3	0.24	3600	0.59	0.04	26.8	6.2	1.7	34.7	3.19	-10.8	-7.8	-12	0.60	1.9	0.8605
22478	58.2	0.23	3600	0.56	0.01	18.4	3.3	0.9	22.6	3.15	-8.9	-3.3	-9	2.00	1.0	0.8459
22488	50.5	0.21	3200	0.57	0.04	25.4	11.1	1.7	38.2	3.00	-11.3	-10.0	-15	0.50	9.6	0.8588
22492	45.6	0.16	2800	0.64	0.03	25.0	5.2	1.2	31.4	2.86	-8.2	-4.8	-12	0.70	2.1	0.8522
22502	55.4	0.22	3200	0.48	0.02	15.0	3.0	0.8	18.8	2.47	-15.2	-11.5	-18	1.20	1.7	0.8401
22503	55.5	0.23	2500	0.53	0.02	18.6	3.6	0.8	23.0	2.57	-9.6	-7.0	-12	0.30	4.2	0.8423
22639	54.5	0.23	2400	0.58	0.02	16.1	3.2	0.9	20.2	4.02	-2.8	1.5	-6	1.10	5.7	0.8401
22641	53.3	0.15	4500	0.61	0.03	24.6	5.6	1.4	31.6	3.38	-12.3	-6.1	-12	0.30	2.6	0.8602
22698	55.0	0.25	3100	0.61	0.02	23.6	6.7	1.2	31.5	2.73	-13.7	-9.9	-17	<0.10	1.0	0.8447
22709	53.5	0.20	2500	0.60	0.03	26.3	8.5	1.8	36.6	2.95	-11.3	-6.8	-13	<0.10	1.8	0.8553
22710	49.5	0.50	1900	0.62	0.03	30.5	4.0	0.9	35.4	2.06	-18.4	-17.0	-23	0.20	2.4	0.8400
22721	50.6	0.53	3000	0.57	0.04	24.9	8.3	1.1	34.3	2.37	-15.7	-14.2	-21	0.20	2.0	0.8465
22748	54.5	0.21	2200	0.60	0.04	26.2	9.4	1.9	37.5	3.05	-11.0	-6.0	-12	0.10	1.1	0.8573
22751	46.6	0.30	2000	0.54	0.09	14.9	3.9	0.2	19.0	1.34	-52.3	-46.7	-48	<0.10	0.8	0.8115
22752	52.7	0.21	3700	0.55	0.03	23.2	5.2	1.0	29.4	2.38	-15.5	-13.0	-20	0.50	1.3	0.8417
22894	51.2	0.21	2800	0.59	0.03	25.7	11.3	2.0	39.0	3.13	-11.4	-9.9	-17	0.10	0.9	0.8613

Table 3. Fuel Analysis Data

Fuel I.D.	Cetane Number	HFRR, mm	Scuff Load, g	BOCLE, mm	Sulfur, mass %	Mono-Arom	Di-Arom	Tri-Arom	Total Arom	Vis. 40C cSt.	Cloud Pt,C	Freeze Pt., C	Pour Pt., C	Acc. Stab., mg/100mL	Part. mg/L	Density D-4052
22895	57.0	0.23	2800	0.51	0.02	15.2	2.2	0.5	17.9	2.52	-9.2	-6.6	-19	0.20	1.7	0.8380
22896	49.5	0.20	3500	0.59	0.04	26.8	8.9	1.6	37.3	2.70	-14.5	-9.7	-15	0.30	0.7	0.8552
22921	47.6	0.20	2100	0.61	0.03	30.0	6.6	1.3	37.9	3.13	-9.9	-6.9	-13	0.20	0.7	0.8652
22940	48.9	0.26	3100	0.60	0.03	27.2	8.1	1.2	36.5	2.59	-19.5	-15.5	-15	0.30	0.8	0.8516
22946	49.4	0.59	2600	0.59	0.02	18.1	2.5	0.4	21.0	1.49	-43.2	-43.4	-41	0.10	0.8	0.8118
22971	51.2	0.23	3200	0.58	0.02	23.4	4.8	1.0	29.2	3.17	-11.1	-7.4	-22	0.20	1.1	0.8536
22982	41.2	0.35	2400	0.49	0.08	19.9	3.4	0.5	23.8	1.23	-58.6	-51.7	-53	0.10	0.8	0.8125
22983	58.2	0.27	2600	0.52	0.04	12.9	4.6	0.8	18.3	2.50	1.3	6.6	-5	0.30	1.7	0.8278
23000	---	0.20	3600	0.58	0.03	25.9	8.2	2.4	36.5	2.81	-13.3	-10.1	-19	<0.10	1.2	0.8571
23009	44.7	0.71	1300	0.80	0.01	21.6	1.5	0.3	23.4	1.49	-48.6	-44.5	-43	<0.10	0.4	0.8150
23338	49.7	0.39	3800	0.62	0.04	25.6	6.9	1.4	33.9	3.41	-9.5	-5.9	-24	0.10	0.8	0.8639
23390	47.9	0.37	3600	0.61	0.04	25.5	7.9	1.3	34.7	2.66	-13.4	-10.4	-30	0.10	0.8	0.8527
23392	53.2	0.18	4200	0.54	0.05	12.7	5.0	0.4	18.1	2.60	-7.3	-3.2	-15	0.20	12.4	0.8323
23396	42.9	0.42	1800	0.55	0.10	15.7	4.0	0.1	19.8	1.32	-52.8	-46.5	-60	0.30	0.4	0.8114
23402	45.7	0.65	1700	0.65	0.03	18.4	2.5	0.1	21.0	1.53	-48.2	-43.8	-66	<0.10	0.5	0.8178
23411	42.7	0.70	1200	0.94	<0.01	18.0	0.6	<0.1	18.6	1.28	< -75	< -76	-87	<0.10	0.4	0.8069
23415	42.4	0.42	2100	0.53	0.08	20.1	3.5	0.1	23.7	1.22	-53.8	-52.0	-75	<0.10	0.5	0.8125
23437	48.7	0.46	4600	0.61	0.03	27.6	8.5	1.6	37.7	2.89	-13.3	-9.6	-24	<0.10	0.4	0.8583
23442	47.8	0.39	4600	0.61	0.03	26.5	5.0	0.8	32.3	3.02	-13.6	-10.6	-24	0.10	2.3	0.8612
23496	48.3	0.45	4300	0.61	0.03	27.1	7.9	1.4	36.4	2.86	-13.1	-9.9	-27	0.10	0.4	0.8560
23507	47.4	0.61	2400	0.56	0.02	18.1	2.3	0.1	20.5	1.51	-47.5	-43.6	-60	0.10	1.7	0.8138
23508	54.4	0.25	3600	0.46	0.03	13.4	3.9	0.5	17.8	2.06	-20.2	-15.8	-39	<0.10	3.6	0.8151
23509	48.5	0.40	3900	0.60	0.03	26.5	7.8	1.0	35.3	2.64	-14.5	-12.1	-24	<0.10	1.2	0.8500
23516	48.3	0.30	4400	0.61	0.03	27.1	8.7	1.7	37.5	3.09	-13.4	-10.0	-24	<0.10	0.6	0.8647
23521	51.9	0.36	2700	0.54	0.02	17.8	2.2	0.2	20.2	2.27	-8.2	-3.6	-18	0.10	1.1	0.8378
23526	53.7	0.49	2200	0.65	<0.01	17.2	3.8	0.7	21.7	3.64	-9.9	-7.3	-21	0.20	0.7	0.8428
23529	49.6	0.49	3800	0.61	0.04	25.7	10.7	1.3	37.7	3.04	-11.2	-8.3	-21	0.20	0.7	0.8577
23539	49.3	0.37	2200	0.55	0.02	15.4	3.5	<0.1	18.9	1.43	-47.9	-45.6	-60	0.10	0.4	0.8098

Table 3. Fuel Analysis Data

Fuel I.D.	Cetane Number	HFRR, mm	Scuff Load, g	BOCLE, mm	Sulfur, mass %	Mono-Arom	Di-Arom	Tri-Arom	Total Arom	Vis. 40C cSt.	Cloud Pt,C	Freeze Pt., C	Pour Pt., C	Acc. Stab., mg/100mL	Part. mg/L	Density D-4052
23540	46.0	0.49	2950	0.62	0.04	30.0	6.6	0.6	37.2	2.09	-15.8	-12.5	-27	<0.10	0.8	0.8422
23556	48.5	0.49	4250	0.63	0.03	27.7	8.6	1.4	37.7	2.76	-13.7	-10.4	-27	<0.10	1.0	0.8554
23557	53.1	0.29	2800	0.56	0.03	15.5	4.7	0.8	21.0	3.59	-20.4	-17.4	-27	0.10	0.6	0.8455
23571	50.3	0.42	4200	0.56	0.03	26.7	8.7	1.5	36.9	2.74	-12.4	-9.5	-24	<0.10	1.0	0.8550
23759	50.4	0.37	5400	0.60	0.03	25.1	4.5	0.6	30.2	3.25	-14.7	-10.0	-18	0.20	1.8	0.8578
23843	49.4	0.38	4300	0.62	0.03	24.8	5.9	0.8	31.5	3.19	-10.5	-7.6	-18	0.20	1.5	0.8553
23851	47.5	0.68	2300	0.59	0.02	19.0	2.0	<0.1	21.0	1.48	-49.3	-45.0	-63	0.10	0.5	0.8141
23984	46.4	0.72	1400	0.63	0.04	17.4	1.2	0.1	18.7	1.20	-57.5	-53.1	-75	0.10	0.6	0.7943
23988	49.6	0.74	1500	0.63	0.08	17.3	1.1	0.1	18.5	1.15	-55.4	-51.3	-72	<0.10	1.0	0.7888
23989	51.2	0.71	1600	0.60	0.04	17.3	1.1	0.1	18.5	1.20	-53.3	-53.2	-66	<0.10	0.8	0.7958
24051	50.9	0.71	1800	0.59	0.05	15.2	2.0	0.0	17.2	1.26	-46.6	-47.0	-60	0.30	0.7	0.8003
24053	46.6	0.73	1700	0.62	< 0.01	18.7	1.2	0.0	19.9	1.26	-66.5	-66.1	< -78	0.10	0.8	0.8185
24093	51.5	0.68	1700	0.59	0.04	15.2	2.4	0.3	17.9	1.24	-53.3	-47.5	-69	0.30	0.8	0.7998
24095	53.6	0.34	3300	0.49	0.03	14.8	3.6	0.2	18.6	1.73	-27.7	-26.3	-42	0.20	0.5	0.8129
24103	50.9	0.71	1400	0.78	0.03	21.2	1.8	0.1	23.1	1.42	-52.8	-49.2	-60	0.20	0.4	0.8102
24134	50.6	0.71	2000	0.57	0.06	18.7	1.8	0.1	20.6	1.18	-55.9	-55.7	-72	0.20	1.5	0.7969
24143	50.1	0.47	2400	0.54	0.02	16.2	3.3	0.1	19.6	1.38	-55.3	-51.0	-66	0.10	0.7	0.8102
24147	45.7	0.48	3900	0.57	0.03	24.9	9.0	1.4	35.3	2.72	-14.8	-11.1	-24	0.10	0.9	0.8512
24253	52.6	0.28	4150	0.57	0.03	16.5	5.4	1.0	22.9	3.21	-20.3	-16.4	-30	0.20	2.0	0.8433
24260	43.9	0.26	3700	0.61	0.04	23.0	8.1	1.4	32.5	2.52	-13.7	-11.1	-24	0.20	1.1	0.8478
24282	41.3	0.19	4400	0.55	0.04	24.9	9.2	1.8	35.9	2.93	-14.5	-10.6	-24	0.20	0.3	0.8580
24284	44.6	0.71	1200	0.80	0.01	22.2	0.9	< 0.1	23.2	1.29	-52.4	-54.8	-66	0.10	0.9	0.8047
24293	46.0	0.20	4400	0.55	0.04	25.2	9.1	1.8	36.1	2.93	-13.7	-9.5	-21	0.30	2.8	0.8576
24310	47.0	0.67	1900	0.57	0.04	19.8	2.5	0.1	22.4	1.37	-45.8	-37.3	-63	0.20	0.8	0.8098
24317	44.6	0.63	2600	0.51	0.03	26.5	8.9	0.9	36.3	2.80	-12.8	-11.7	-24	0.30	1.8	0.8100
24323	45.7	0.43	4550	0.57	0.03	26.1	8.8	1.5	36.4	2.74	-15.2	-27.0	-12	0.20	1.7	0.8529
24326	43.3	0.67	1950	0.57	0.05	19.7	2.5	0.1	22.3	1.37	-42.6	-30.7	-63	0.20	0.8	0.8096
24329	40.4	0.60	2050	0.70	0.03	19.6	2.9	0.1	22.6	1.58	-48.2	-57.0	-43	0.10	0.6	0.8179

Table 3. Fuel Analysis Data

Fuel I.D.	Cetane Number	HFRR, mm	Scuff Load, g	BOCLE, mm	Sulfur, mass %	Mono-Arom	Di-Arom	Tri-Arom	Total Arom	Vis. 40C cSt.	Cloud Pt,C	Freeze Pt., C	Pour Pt., C	Acc. Stab., mg/100mL	Part. mg/L	Density D-4052
24330	42.9	0.22	4250	0.51	0.04	25.1	8.3	1.8	35.2	2.95	-13.1	-9.5	-21	0.20	0.8	0.8546
24331	39.2	0.40	2700	0.54	0.09	20.4	3.8	0.1	24.3	1.22	-51.2	-51.5	-69	0.10	0.8	0.8121
24353	48.8	0.27	3500	0.57	0.04	14.4	4.8	0.7	19.9	2.72	-20.2	-15.8	-27	0.20	0.6	0.8318
24361	40.6	0.71	2200	0.55	<0.01	22.2	1.4	0.1	23.7	1.24	-44.1	-31.8	-69	0.20	0.8	0.8040
24364	43.3	0.39	3350	0.62	0.04	26.2	4.6	0.7	31.5	3.32	-13.3	-8.4	-21	0.20	1.2	0.8579
24365	44.5	0.28	3850	0.58	0.04	25.4	7.3	1.3	34.0	2.66	-13.9	-10.5	-21	0.20	1.3	0.8475
24366	---	0.21	3400	0.52	0.04	15.9	4.4	0.2	20.5	1.77	-33.7	-29.5	-42	0.20	8.9	0.8135
24367	46.5	0.67	1700	0.55	0.05	19.7	2.5	0.1	22.3	1.37	-46.0	-39.4	-63	0.20	1.0	0.8097
24368	40.6	0.23	2100	0.51	0.03	22.7	1.3	0.1	24.1	1.40	-50.2	-45.9	-60	0.20	1.2	0.8111
24369	40.6	0.36	1200	0.81	0.03	22.9	1.2	0.1	24.2	1.40	-47.9	-45.2	-57	0.20	0.6	0.8106
24371	46.5	0.59	2600	0.57	0.02	18.6	2.4	0.1	21.1	1.53	-47.7	-43.7	-57	0.20	0.7	0.8169
24373	39.3	0.43	2200	0.53	0.1	20.1	4.0	0.1	24.2	1.23	-49.0	-50.9	-66	0.10	0.2	0.8132
24375	42.9	0.66	1900	0.67	0.03	19.5	3.0	0.1	22.6	1.56	-47.4	-41.6	-54	0.10	0.0	0.8179
24376	44.0	0.64	1750	0.58	0.06	19.1	2.4	0.1	21.6	1.36	-40.5	-32.4	-63	0.20	0.8	0.8091
24378	45.2	0.32	4450	0.59	0.04	25.6	8.9	1.8	36.3	2.59	-12.0	-9.1	-27	0.20	1.0	0.8513
23244	50.3	0.65	2300	0.58	0.09	19.0	2.2	0.2	21.4	1.39	-53.0	-49.0	-63	---	---	---
24379	43.7	0.28	4500	0.58	0.04	25.8	8.2	1.7	25.7	2.77	-13.4	-10.3	-21	0.20	2.5	0.8546
24380	44.5	0.28	4250	0.56	0.03	25.2	8.5	2.1	35.8	3.05	-14.7	-10.9	-24	0.30	0.8	0.8621
24383	---	0.20	4000	0.57	0.03	16.4	5.6	1.0	23.0	3.66	-24.7	-20.4	-30	0.10	0.9	0.8496
24385	45.8	0.38	4200	0.58	0.04	26.2	12.1	1.8	40.1	2.92	-9.4	-6.7	-21	0.10	0.6	0.8579
24386	44.7	0.72	1800	0.63	0.01	21.0	2.4	0.1	23.5	1.33	-49.6	-42.3	-63	0.10	<0.1	0.8086
24387	43.4	0.31	4350	0.55	0.04	27.5	9.2	1.8	38.5	2.66	-13.3	-9.8	-24	0.10	2.0	0.8555
24388	46.6	0.67	1600	0.56	0.07	18.8	2.6	0.1	21.5	1.37	-43.5	-38.4	-60	0.10	0.9	0.8094
24391	42.5	0.45	4500	0.57	0.04	28.3	8.9	1.6	38.8	2.70	-11.8	-9.2	-21	0.10	0.7	0.8553
24393	45.7	0.60	2050	0.60	0.04	20.8	6.1	0.7	27.6	1.80	-24.0	-20.6	-42	0.10	0.3	0.8298
24405	44.9	0.68	1900	0.70	0.02	18.3	1.8	0.1	20.2	1.36	-38.5	-25.0	-60	0.20	0.8	0.8060
24431	44.8	0.39	3650	0.58	0.04	25.1	8.8	1.5	35.4	2.70	-13.4	-9.8	-21	0.10	0.7	0.8520
24459	52.8	0.21	5450	0.57	0.04	24.9	7.9	1.5	34.3	2.82	-13.2	-9.1	-21	0.20	1.3	0.8553

Table 4. Descriptive Statistics						
Column	Size	Missing	Mean	Range	Max	Min
Cetane Number	112	3	48.484	19.500	58.700	39.200
HFRR,mm	112	0	0.400	0.590	0.740	0.150
Scuff Load,g	112	0	3055.357	4250.000	5450.000	1200.000
BOCLE,mm	112	0	0.590	0.480	0.940	0.460
Sulfur,mass%	112	0	0.0359	0.0900	0.1000	0.01000
Mono-Arom	112	0	21.640	19.400	30.500	11.100
Di-Arom	112	0	5.244	11.500	12.100	0.600
Tri-Arom	112	0	0.859	2.400	2.400	0.000
Total-Arom	112	0	27.651	29.800	42.800	13.000
Vis. 40°C,cSt	112	0	2.339	2.900	4.050	1.150
Cloud Pt,C	112	0	-25.716	76.300	1.300	-75.000
Freeze Pt,C	112	0	-22.271	82.600	6.600	-76.000
Pour Pt,C	112	0	-34.423	82.000	-5.000	-87.000
Acc.Stab.,mg/100mL	112	1	0.279	4.400	4.300	-0.1000
Part., mg/L	112	1	1.717	15.400	15.400	0.000
Density D 4052	112	1	0.836	0.0778	0.867	0.789

Total Sulfur – Figure 1 is a frequency histogram of the total sulfur data. Nine of the samples exceeded the 0.05 mass% sulfur, maximum specification limit. The samples that failed the sulfur requirement were from installations in Alaska.

Accelerated Stability – Figure 2 is a frequency histogram of the accelerated stability data. Only two samples failed to meet the specification requirements for accelerated stability. This is not unexpected since the great majority of these fuels are refinery fresh, or very nearly so.

Particulates – Figure 3 is a frequency histogram of the particulates data. Two of the samples failed to meet the 10 mg/L particulates requirement. Like the stability results, this very low failure rate is expected since these are refinery fresh fuels. These data also indicate that the delivery systems used for these fuels are generally kept clean.

Cetane Number – Figure 4 is a frequency histogram of the cetane number data. Only two samples had cetane numbers below 40 (both 39). The high value was 59; the average was 49.

Other Properties – For several of the fuel properties, the analytical results are divided into two groups of data. These two groups of data correspond to the two fuel grades, 1 and 2, of the samples. Properties of this type include total aromatics, kinematic viscosity, cloud point, freeze point, pour point, and density.

Lubricity – HFRR and Scuffing Load Wear Test – Figure 5 is a frequency histogram of the High Frequency Reciprocating Rig (HFRR) data. Figure 6 is a frequency histogram of the U.S. Army Scuffing Load Wear Test (SLWT) results.

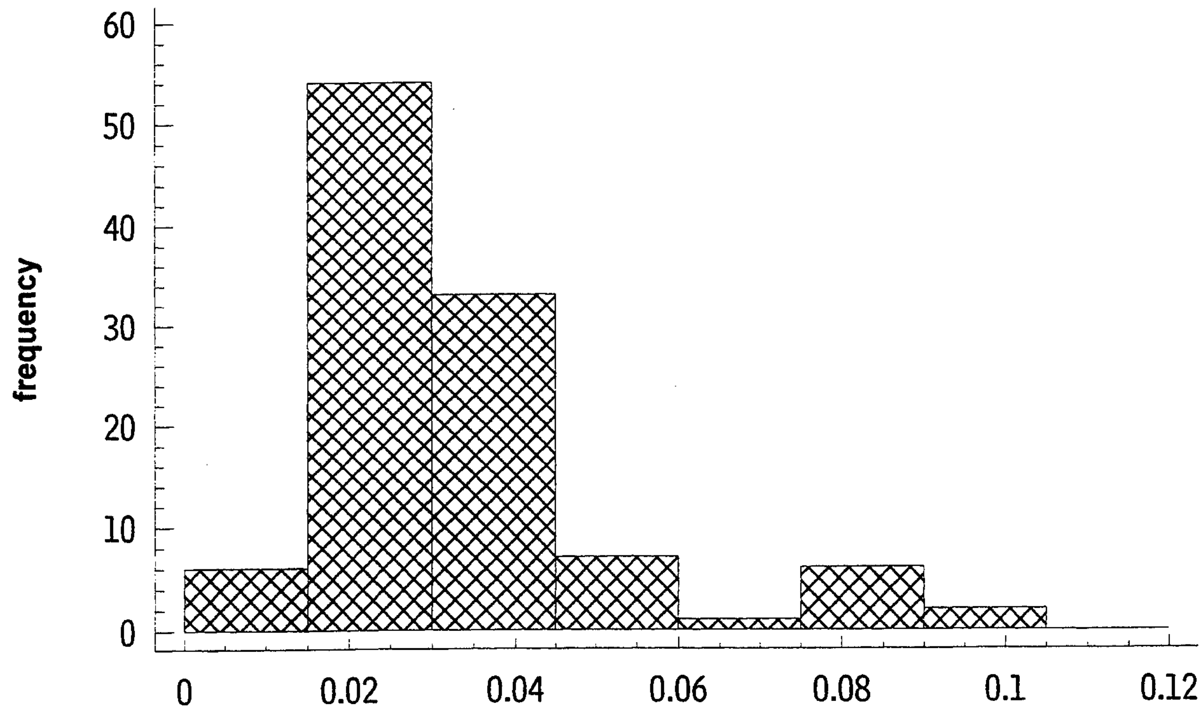

Figure 1. Frequency Histogram of Total Sulfur Data (mass %)

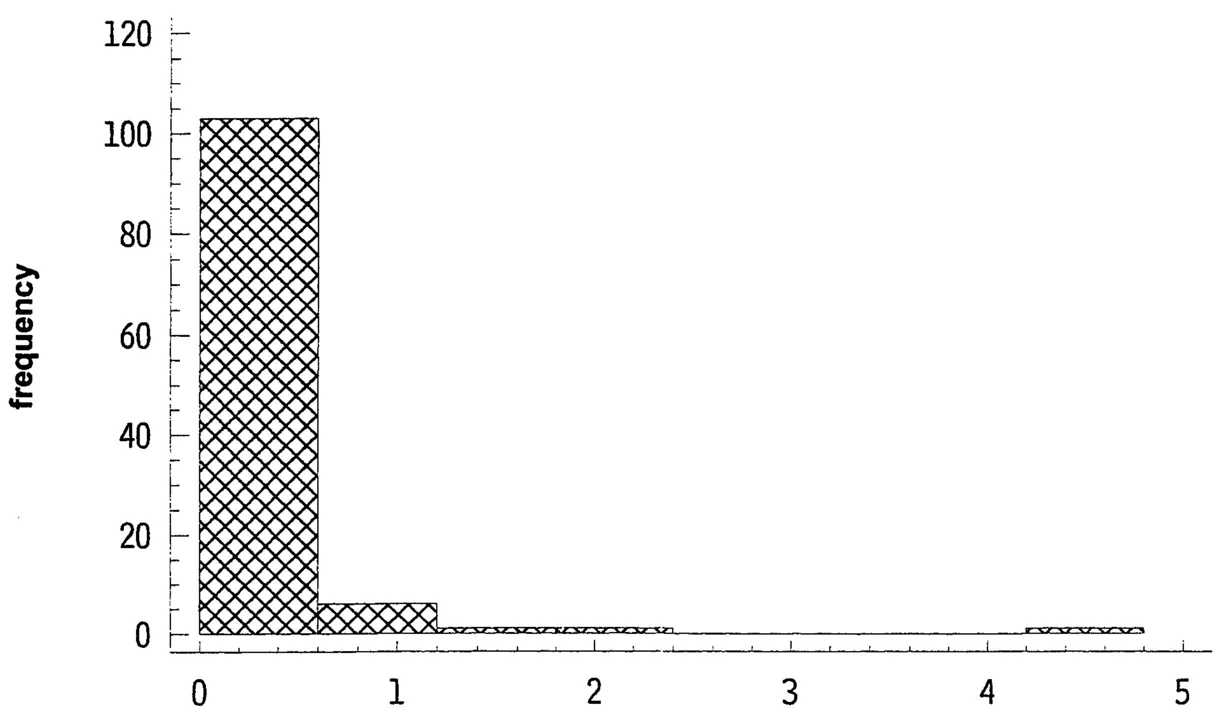

Figure 2. Frequency Histogram of Accelerated Stability Data (total insolubles, mg/100 mL)

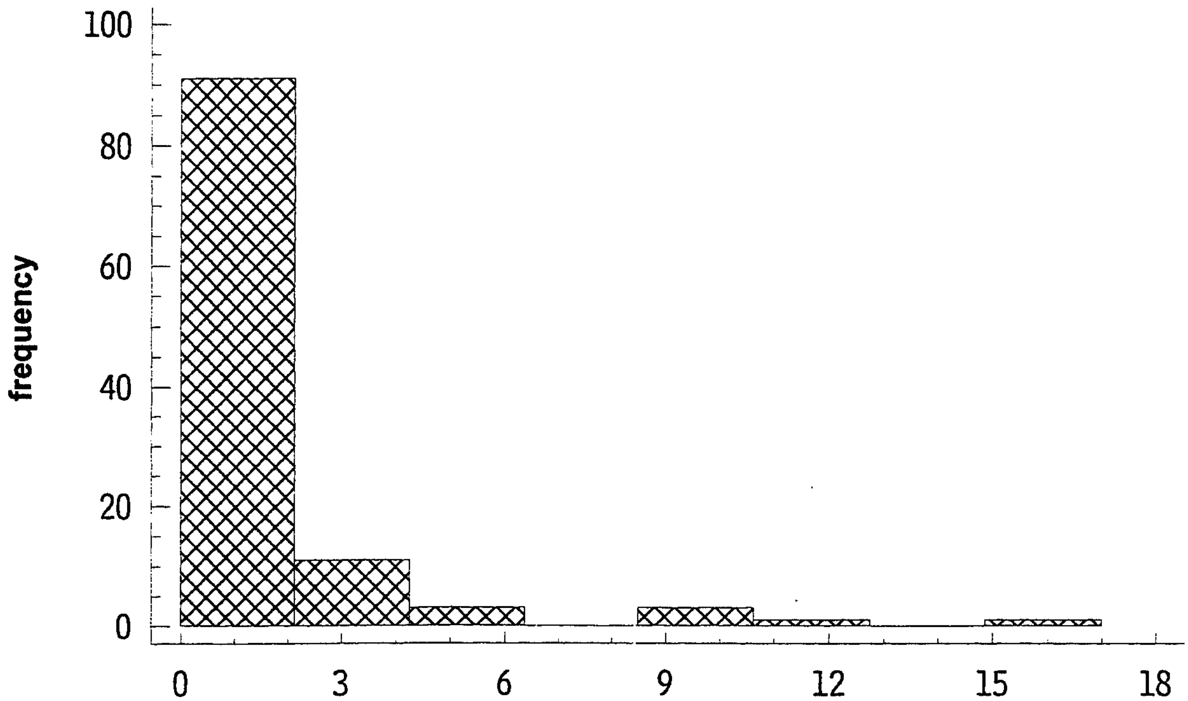

Figure 3. Frequency Histogram of Particulates Data (mg/L)

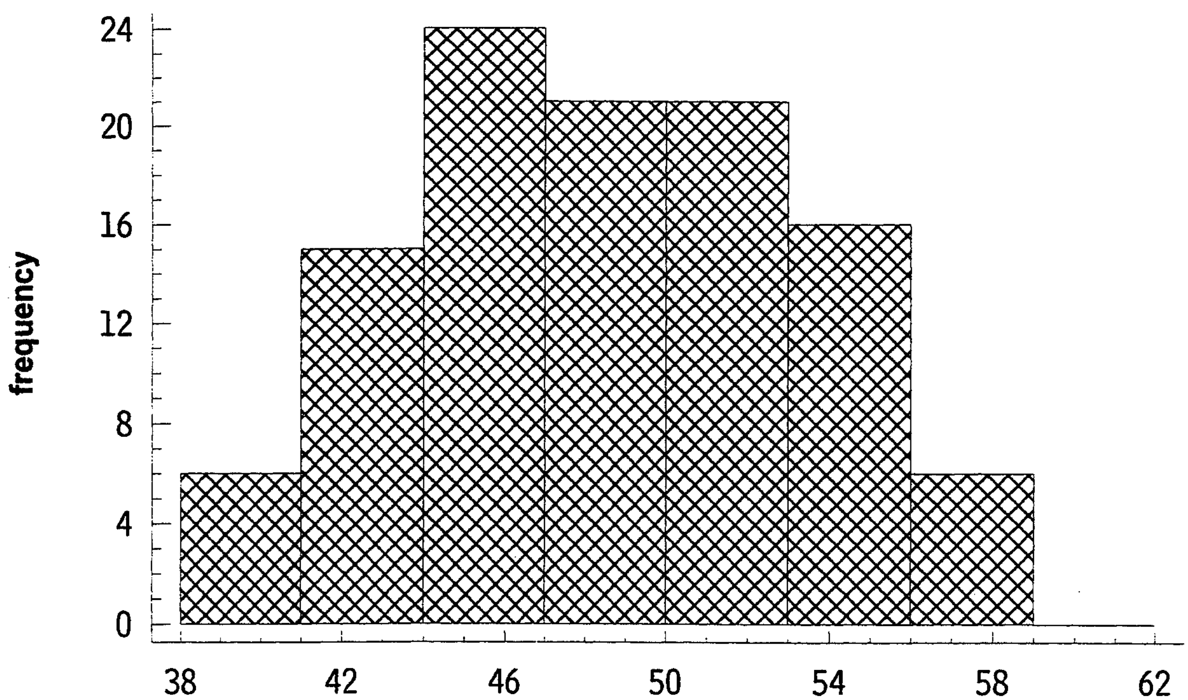

Figure 4. Frequency Histogram of Cetane Number Data

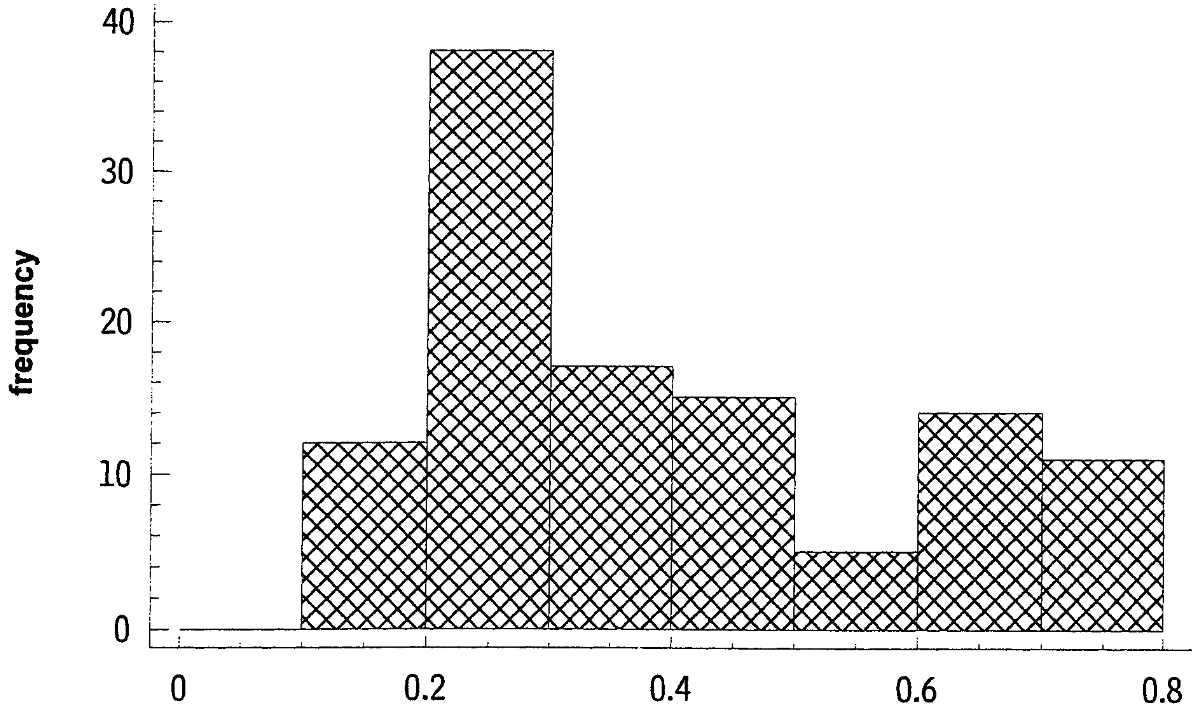

Figure 5. Frequency Histogram of HFRR Wear Scar Diameter Data (mm)

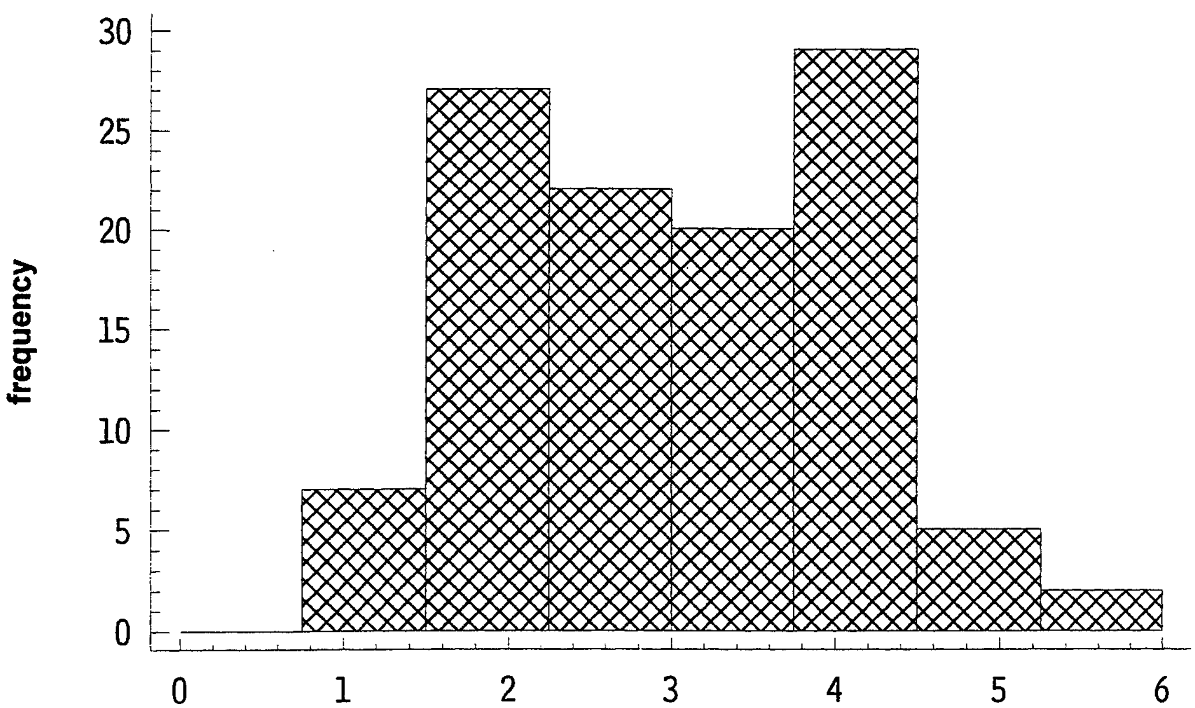

Figure 6. Frequency Histogram of Scuffing Load, kg

Currently, the HFRR and the SLWT are the two most accepted bench tests for diesel fuel lubricity. The factors that influence the lubricity and associated fuel system component wear are numerous, and the interactions are complex. These factors include temperature, vehicle use rates, metallurgy of fuel system components, additives, age and condition of engine, environmental conditions, and composition and properties of the fuel. Of these factors, the one that is probably least understood is fuel composition. Ongoing research has recently addressed this issue.[5,6,7] It has been suggested that reductions in the levels of sulfur or aromatics have contributed in some way to the decreased lubricity often associated with low-sulfur diesel fuel. Fuel viscosity has also been suggested as having a correlation with lubricity. Figures 7 through 12 are plots of the HFRR and SLWT data versus total sulfur, total aromatics, and viscosity. It is obvious from these plots that only the viscosity data have a correlation with the lubricity tests, and this is only slight.

Figure 13 is a plot of the HFRR data versus the SLWT data. The least squares regression fit is also plotted. The correlation of these two sets of data is also low. The correlation coefficient is −0.62.

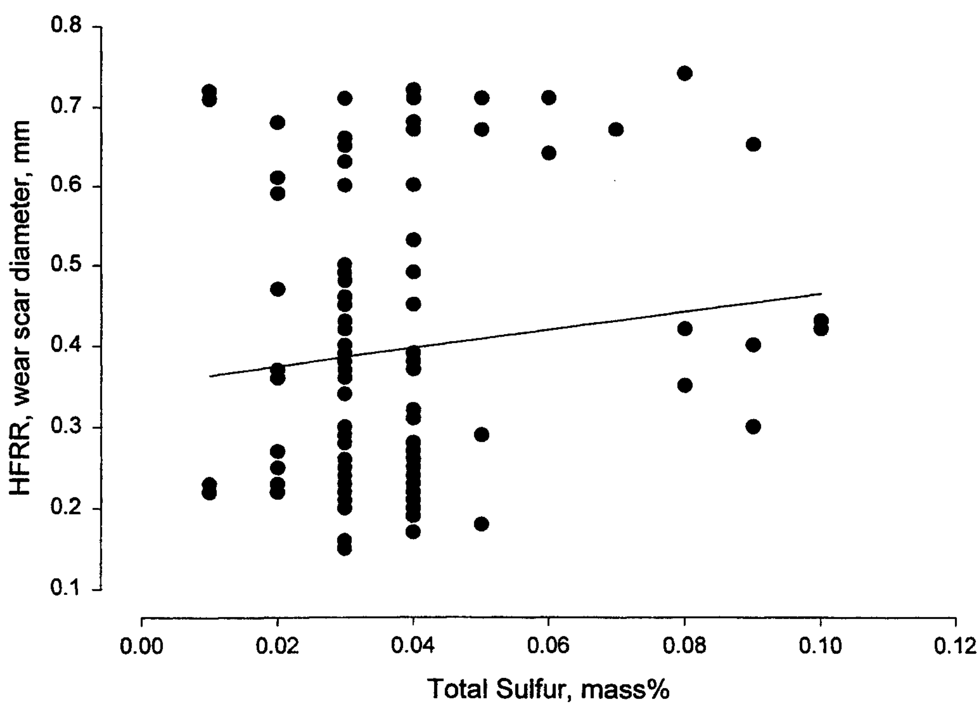

Figure 7. Plot of HFRR Results vs. Total Sulfur Content

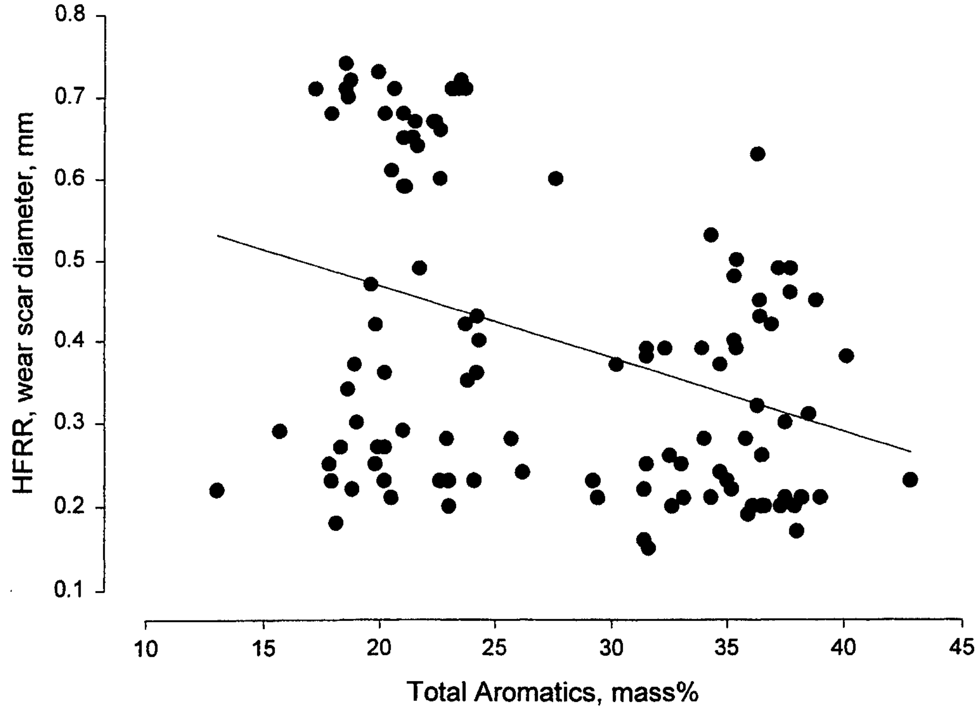

Figure 8. Plot of HFRR Results vs. Total Aromatics

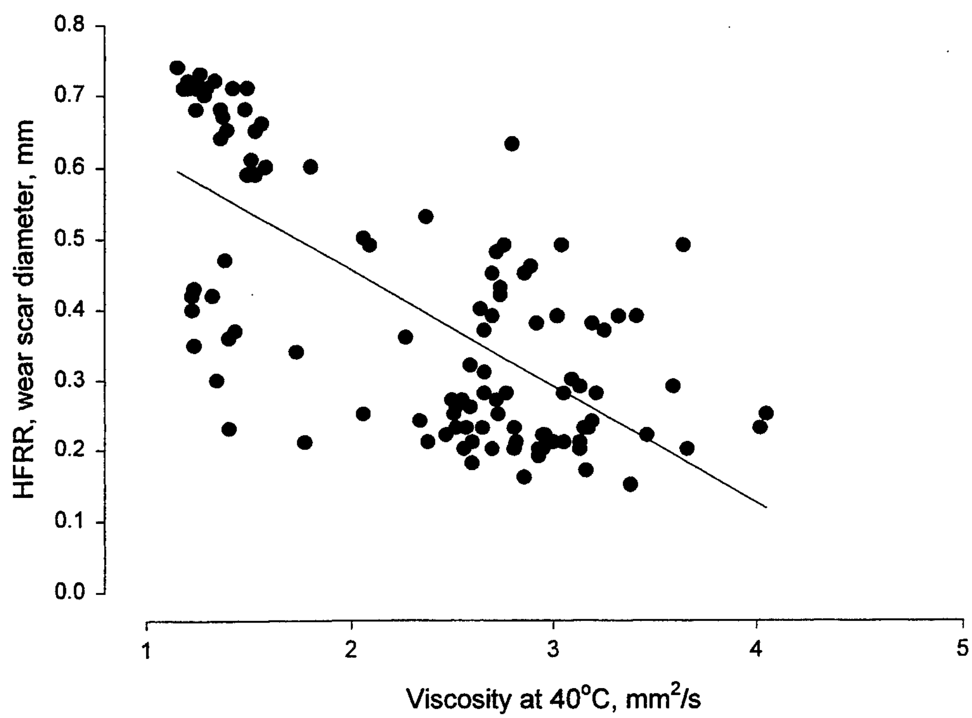

Figure 9. Plot of HFRR Results vs. Kinematic Viscosity at 40°C

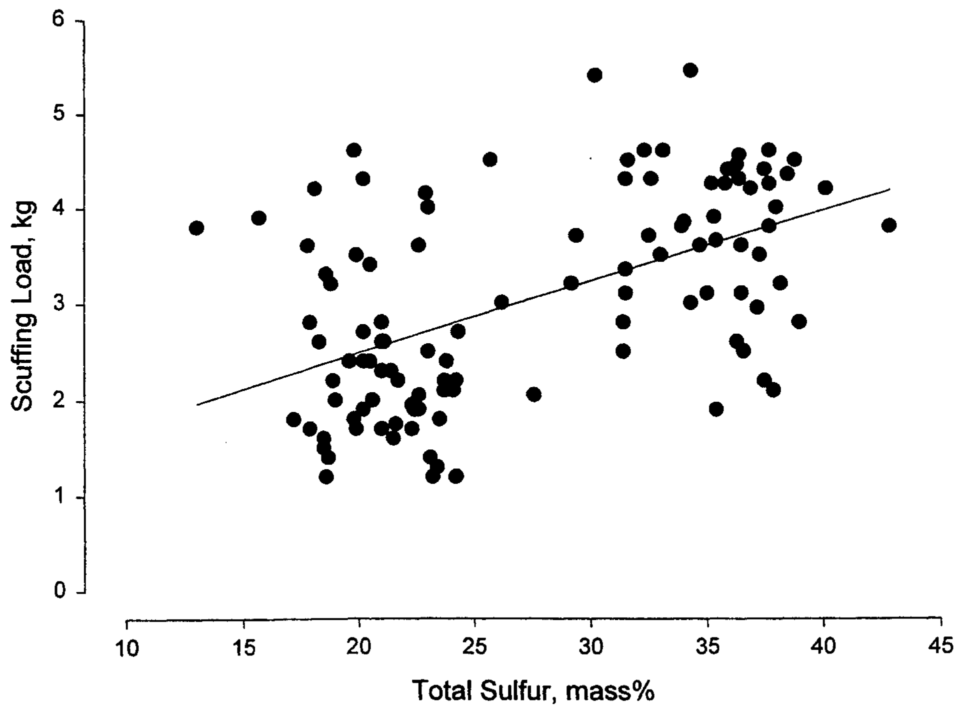

Figure 10. **Plot of Scuffing Load vs.Total Sulfur, mass%**

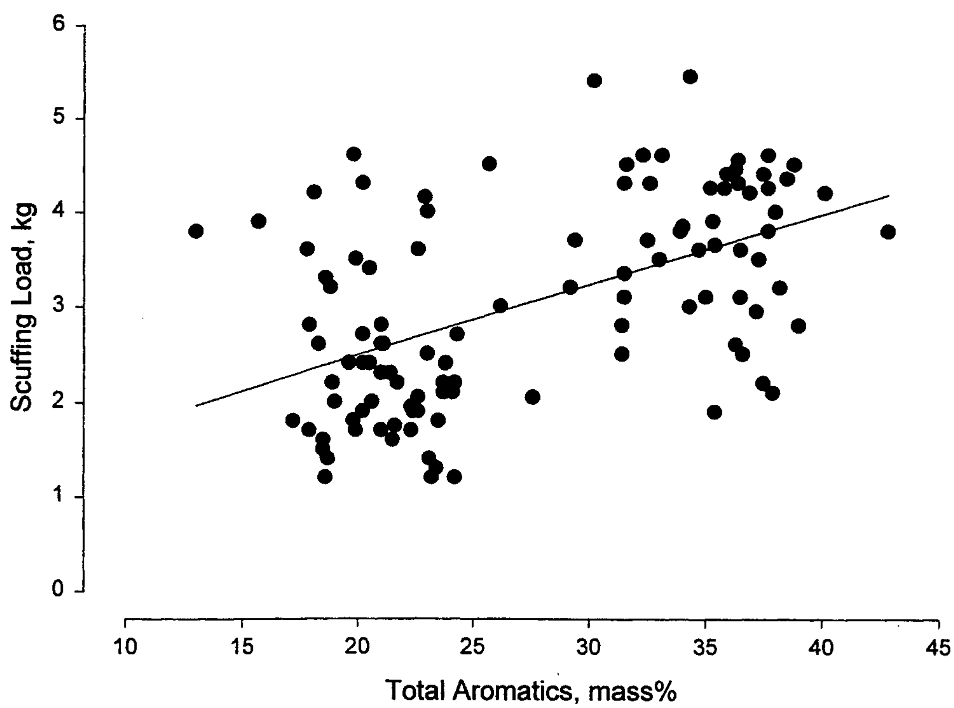

Figure 11. **Plot of Scuffing Load vs. Total Aromatics, mass%**

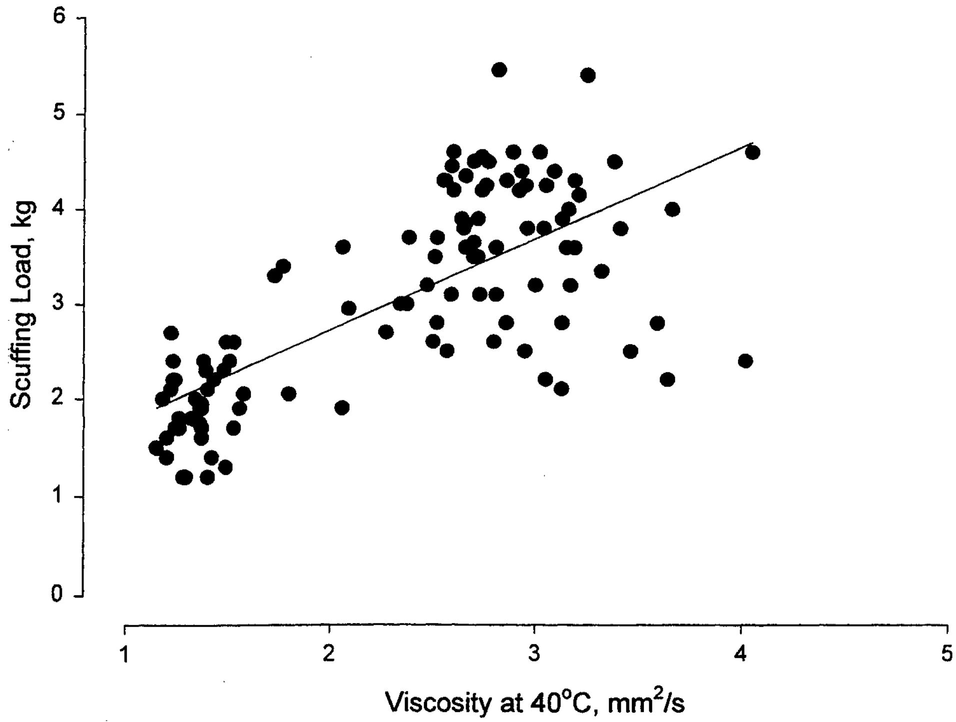

Figure 12. **Plot of Scuffing Load vs. Viscosity at 40◦C**

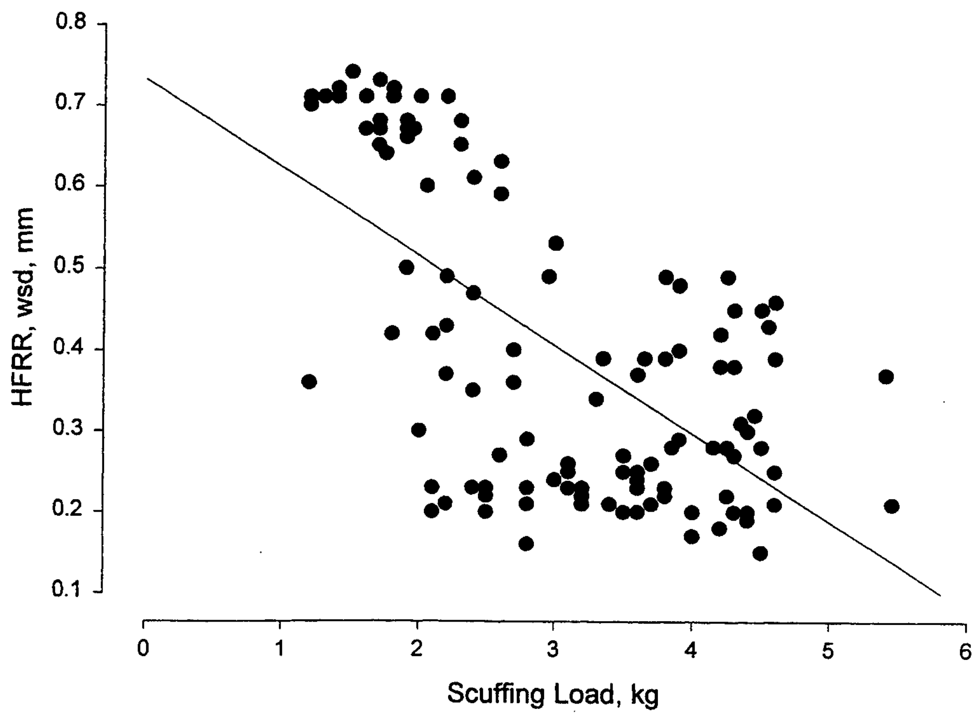

Figure 13. **Plot of HFRR vs. Scuffing Load**

Specific statistics concerning how many of the samples failed to meet the proposed Army lubricity requirements are difficult to obtain because some of the samples were received without fuel grade information. If one makes an assumption that viscosity is a reliable indicator of fuel grade, then some general statistics are possible. There are six fuels that fall at 2.0 kg or below in the SLWT, and six fall at 0.54 mm or above on the HFRR. These six fuels would be considered failed regardless of the fuel grade and would require additive treatment. The fuels that are at or above 2.8 kg (at or below 0.34 mm for the HFRR), regardless of grade, are considered unconditional pass and can be used without concern. It is the fuels that fall between these two lines, 2.0 and 2.8 for the SLWT (0.84 and 0.38 for the HFRR), that must be evaluated according to their fuel grade. The fuels that have viscosities of less than 1.6 and scuffing loads of greater than 2.0 (less than 0.54 for the HFRR) would be considered light kerosene fuels with potentially acceptable lubricity. Fuels with viscosities of greater than 2.9 and scuffing loads of less than 2.8 (greater than 0.34 for HFRR) would be considered grade number 2 fuels with potentially unacceptable lubricity. It is recommended that the users of any fuel with a SLWT result of less than 2.8 more closely monitor their vehicles for signs of accelerated fuel system component wear.

Approximately 10% of the fuels are considered unconditional fails. These fuels require treatment with an approved additive and vehicle monitoring for signs of abnormal wear. Approximately 66% of the fuels are considered unconditional passes. The remaining approximately 25% would have to be considered on the basis of their fuel grade; vehicles operating on these fuels should be monitored more closely for startability, idle roughness, driveability and other symptoms related to fuel injection system/component wear.

During this survey, the individual installations were asked to report instances of unusually high wear rates in fuel-lubricated, fuel-system components or other fuel-related problems. The only reports received were of apparent fuel-lubricity problems. Eight installations reported this type of fuel-related problem. Unfortunately, fuel samples were not available from all of these sites. Efforts were made to confirm the cause of the wear with mixed results. Based on the correlation to pump stand tests, which resulted from the early work of the ISO/SAE task force to develop a lubricity test, it is believed that vehicles operating on less-than-acceptable lubricity fuel will have reduced life from fuel-lubricated components. The degree and rate of wear will depend on several factors. And, even though the Army is more likely to operate any given vehicle on the same fuel for extended periods of time, Army overall use rates are relatively low. This is why it is difficult to obtain direct evidence of abnormal wear caused by low-lubricity fuel, except in the cases of extremely poor lubricity fuel. It has been the Army's experience that fuel-system component wear rates are usually noticeably high only when the fuel's lubricity is below 2.0 kg (primarily below 1.6 kg).[8,9]

IV. CONCLUSIONS

- The average fuel falls within the D 975 specification limits for ASTM Grade Low-sulfur D-2.

- The samples that had sulfur levels above the EPA limit of 0.05 mass % had properties consistent with those of aviation kerosene. While it could not be confirmed, these samples may have been JP-8, since these samples were from Alaska (Ft. Richardson and Ft. Wainwright) where kerosene fuels are used year-round.

- Ft. Richardson, Ft. Wainwright, Dobbins AFB, and Malmstrom AFB appear to be receiving kerosene-type fuel, even during the warmest months of the year, which is when these samples were taken.

- The samples from Ft. Bragg and Ft. Irwin show poor accelerated stability characteristics, and would not meet the military requirements.

- Only two samples were outside the fuel particulate content limits for military use.

- It is difficult to draw specific conclusions regarding the cloud point results. Cloud point specifications are both regional and monthly; therefore, we cannot be certain of the actual month the fuels were purchased. However, throughout this survey we received no reports of waxing problems. It is concluded that, in general, the fuel being delivered to U.S. military installations meets the military cloud point requirements.

- There is no apparent correlation of scuffing load from either SLWT or HFRR data with BOCLE, sulfur, aromatics, or viscosity at 40°C. This means that none of these properties can be used to estimate the scuffing load (lubricity) of a given fuel. Also, there appears to be only a minimal relationship between the SLWT and HFRR results.

- Regarding the lubricity results, approximately 10% of the fuels are in the category of unconditional fail. These fuels require treatment with an approved additive and vehicle monitoring for signs of abnormal wear. Approximately 66% of the fuels are considered unconditional passes. The remaining approximately 25% would have to be considered on the basis of their fuel grade, and vehicles operating on these fuels should be monitored more closely for startability, idle roughness, and driveability.

- None of the JP-8 fuels met the proposed minimum scuffing load requirement of 2.8 kg for grade 2-DLS, and only 3 of the fuels met the minimum SLWT of 2.0 recommended for JP-8.

- The sulfur values for the JP-8 fuels tended to be higher than those for the LSDF.

- Approximately 85% of the JP-8 fuel met the MIL-T-83133 specification requirement of 0.65 mm maximum wear scar on the standard BOCLE, D 5001.

- All of the JP-8 fuel samples met the MIL-T-83133 specification requirement for aromatics, 25 mass % maximum.

V. REFERENCES

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[4] Lacey, P.I., "Development of a Lubricity Test Based on the Transition From Boundary Lubrication to Severe Adhesive Wear in Fuels," Lubrication Engineering, 50, No. 10, October 1994.

[5] Lacey, P.I., and Lestz, S. J., "Fuel Lubricity Requirements for Diesel Injection Systems," Interim Report BLRF No. 270, Southwest Research Institute, San Antonio, Texas, February 1991.

[6] Lacey, P.I., "Wear Mechanism Evaluation and Measurment in Fuel-Lubricated Components, "Interim Report BFLRF No. 286, Southwest Research Institute, San Antonio, Texas, September 1994.

[7] Lacey, Westbrook, S.R., "Diesel Fuel Lubricity," SAE Technical Paper No. 950248, February 27-March 2, 1995.

[8] Lacey, P.I. and Lestz, S.J., "Effect of Low-Lubricity Fuels on Diesel Injection Pumps-Part I; Field Performance," SAE Technical Paper No. 920823, February 24-28, 1992.

[9] Lacey, P.I. and Lestz, S.J., "Effect of Low-Lubricity Fuels on Diesel Injection Pumps-Part II; Laboratory Evaluation," SAE Technical Paper No. 920824, February 24-28, 1992.

Fuels Distribution List

Department of Defense

DEFENSE TECH INFO CTR 12
ATTN: DTIC OCC
8725 JOHN J KINGMAN RD
STE 0944
FT BELVOIR VA 22060-6218

ODUSD
ATTN: (L) MRM 1
PETROLEUM STAFF ANALYST
PENTAGON
WASHINGTON DC 20301-8000

US CINCPAC
ATTN: J422 BOX 64020 1
CAMP H M SMITH
HI 96861-4020

JOAP TSC 1
BLDG 780
NAVAL AIR STA
PENSACOLA FL 32508-5300

DIR DLA
ATTN: DLA MMSLP 1
8725 JOHN J KINGMAN RD
STE 2533
FT BELVOIR VA 22060-6221

CDR
DEFENSE FUEL SUPPLY CTR
ATTN: DFSC I (C MARTIN) 1
DFSC IT (R GRAY) 1
DFSC IQ (L OPPENHEIM) 1
8725 JOHN J KINGMAN RD
STE 2941
FT BELVOIR VA 22060-6222

DIR
DEFENSE ADV RSCH PROJ AGENCY
ATTN: ARPA/ASTO 1
3701 N FAIRFAX DR
ARLINGTON VA 22203-1714

Department of the Army

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DALO SM 1
500 PENTAGON
WASHINGTON DC 20310-0500

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WASHINGTON DC 20310-0103

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AMCRD E 1
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INGALLS RD BLDG 163
FT MONROE VA 23651-5194

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ATSB TSM T 1
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FT EUSTIS VA 23604-5000

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ATSH AT 1
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FT LEONARD WOOD
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P O BOX 9005
CHAMPAIGN IL 61826-9005

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FT BELVOIR VA 22060-5818

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FT LEWIS WA 98433-5000

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RED RIVER ARMY DEPOT
ATTN: SDSRR M 1
SDSRR Q 1
TEXARKANA TX 75501-5000

PS MAGAZINE DIV
ATTN: AMXLS PS 1
DIR LOGSA
REDSTONE ARSENAL AL 35898-7466

Department of the Navy

OFC CHIEF NAVAL OPER
ATTN: DR A ROBERTS (N420) 1
2000 NAVY PENTAGON
WASHINGTON DC 20350-2000

CDR
NAVAL SEA SYSTEMS CMD
ATTN: SEA 03M3 1
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

CDR

CDR
NAVAL AIR WARFARE CTR
ATTN: CODE PE33 AJD 1
P O BOX 7176
TRENTON NJ 08628-0176

CDR 1
NAVAL PETROLEUM OFFICE
8725 JOHN J KINGMAN RD
STE 3719
FT BELVOIR VA 22060-6224

CDR

NAVAL SURFACE WARFARE CTR
ATTN: CODE 63 1
CODE 632 1
CODE 859 1
3A LEGGETT CIRCLE
ANNAPOLIS MD 21402-5067

NAVAL RSCH LABORATORY
ATTN: CODE 6181 1
WASHINGTON DC 20375-5342

Department of the Navy/U.S. Marine Corps

HQ USMC
ATTN: LPP 1
WASHINGTON DC 20380-0001

PROG MGR COMBAT SER SPT 1
MARINE CORPS SYS CMD
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

PROG MGR GROUND WEAPONS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080
PROG MGR ENGR SYS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

CDR
MARINE CORPS SYS CMD
ATTN: SSE 1
2030 BARNETT AVE STE 315
QUANTICO VA 22134-5010

CDR
BLOUNT ISLAND CMD
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5880 CHANNEL VIEW BLVD
JACKSONVILLE FL 32226-3404

CDR
ATTN: CODE 837 1
814 RADFORD BLVD
ALBANY GA 31704-1128

CDR 1
2ND MARINE DIV
PSC BOX 20090
CAMP LEJEUNNE
NC 28542-0090

CDR 1
FMFPAC G4
BOX 64118
CAMP H M SMITH
HI 96861-4118

Department of the Air Force

HQ USAF/LGSF
ATTN: FUELS POLICY 1
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

HQ USAF/LGTV
ATTN: VEH EQUIP/FACILITY 1
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

AIR FORCE WRIGHT LAB
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WL/POSF 1
1790 LOOP RD N
WRIGHT PATTERSON AFB
OH 45433-7103

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BLDG 613 STE 2
ENGLIN AFB FL 32542-5303

SA ALC/SFT 1
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KELLY AFB TX 78241-5603

SA ALC/LDPG
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580 PERRIN BLDG 329
KELLY AFB TX 78241-6439

WR ALC/LVRS 1
225 OCMULGEE CT
ROBINS AFB
GA 31098-1647

Other Federal Agencies

NASA LEWIS RESEARCH CENTER CLEVELAND OH 44135	1	EPA AIR POLLUTION CONTROL 2565 PLYMOUTH RD ANN ARBOR MI 48105	1
RAYMOND P. ANDERSON, PH.D., MANAGER FUELS & ENGINE TESTING BDM-OKLAHOMA, INC. 220 N. VIRGINIA BARTLESVILLE OK 74003	1	DOT FAA AWS 110 800 INDEPENDENCE AVE SW WASHINGTON DC 20590	1