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ARMY EXPERIENCE AND REQUIREMENTS FOR STABILITY AND CLEANLINESS OF DIESEL FUEL

**INTERIM REPORT
AFLRL No. 128**

by

L. L. Stavinoha and S. R. Westbrook

**U. S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas**

and

M. E. LePera

**Energy and Water Resources Laboratory
U. S. Army Mobility Equipment Research
and Development Command
Fort Belvoir, Virginia**

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anticipating deleterious product formation in current and future fuel formulations composed of diverse petroleum crude and synthetic (shale or coal) crude oils, fuel/equipment interactions, diverse storage conditions, and the increased desire for prolonged storage periods provide the driving factors in defining the Army's fuel stability research programs. While placing these concerns in perspective, the Army's present and future needs for diesel fuel stability and cleanliness control are identified.

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FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, San Antonio, Texas, under Contract DAAK70-80-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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I. INTRODUCTION

Long-term storage stability has been a requirement imposed on military fuels designed for tactical/combat environments. This requirement has been necessary because of a need to ensure that fuels delivered or deployed in strategic locations will be satisfactory for use during combat operations regardless of the time interval between refinery production and ultimate use. This becomes very critical in relation to prepositioning of fuel stocks in which good fuel quality must be maintained. Without guaranteed maintenance of fuel stability, combat fuels could prove to be the weak link during combat operations. Poor fuel could lead to engine malfunctions, increased maintenance problems, equipment vulnerability, decreased mobility, and numerous other problems.

During the North African campaign of World War II, gasoline stored in 5-gallon metal cans caused serious engine problems due to inadequate stability. Consequently, the Ordnance Corps (and later the Army Materiel Command) sponsored research with Stanford Research Institute, the Bureau of Mines, and other organizations designed to investigate the causes or origins or both for fuel instability as related to gasoline. This research led to the development of Military Specification MIL-G-3056, combat automotive gasoline, designed to have a storage capability of 3 to 5 years. This increased stability was the result of the incorporation of an additive package and of the inclusion of restrictive controls and requirements into the specification. Concurrently, the Army has conducted research to define diesel fuel stability and investigate a number of fuel stability-related problems.

In an effort to promote basic research in the area of "Diesel Fuel Stability," the U.S. Army Research Office (ARO) sponsored a seminar at Southwest Research Institute in San Antonio, Texas, in April 1977. A report based on an "overview" presented at the ARO-sponsored meeting provides a review of the general topic of fuel deterioration, with primary emphasis on diesel or distillate fuels used in compression ignition engines which power the majority of Army tactical and combat vehicles. ⁽¹⁾*

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

A considerable amount of work has been performed in developing tests which predict the storage stability of distillate fuels. A large variety of predictive tests, referred to as accelerated aging tests, have been used or are in use for evaluating fuel stability. In a presentation by MacDonald and Jones, 26 different test methods were tabulated.⁽²⁾ Some of the test conditions and evaluating methods employed have been shown to relate directly to fuel in actual storage under certain correlated storage conditions. While time and temperature are accepted variables in accelerated tests, the range in containers, conditions, and, especially in the method of sample evaluation, causes tremendous variation in results.

The Navy-Coordinating Research Council Barge Storage Program⁽³⁾, conducted in the 1950s to determine the scale-down factor from barge to bottle or drum-storage, provided data indicating the usefulness of storage at 43.3°C (110°F) as a predictive variable for long-term storage. With the accumulation of additional data, most researchers have accepted the results of aging fuels at 43.3°C for 13 weeks to be approximately equivalent to either drum or bottle storage at ambient temperatures for one year.⁽⁴⁻⁷⁾ Although the American Society for Testing and Materials (ASTM) has accepted several accelerated tests for evaluating petroleum products, only the "Test for Stability of Distillate Fuel (ASTM D 2274-74)" is directly applicable to distillates.⁽⁸⁾ This test has industry-wide acceptance and has been a requirement in military fuel specifications for several years.

The ASTM D 2274-74 accelerated stability technique is currently specified in VV-F-800b as a prediction of storage stability for bulk fuel deliveries at the time of procurement. Two additional test methods are used specifically as measures of contamination:

1. ASTM Method D 2276 ("Particulate Contaminant in Aviation Turbine Fuels") test modified to use 1.2-micrometer filters to determine particulates; and
2. ASTM Method D 381, "Test for Existent Gum in Fuels by Jet Evaporation."

Methods such as these have proved useful in determining the stability of diesel in storage in a 2-year, 100-barrel, above-ground, steel tank storage program using four diesel fuels meeting Federal Specification VV-F-800a.⁽⁹⁾ The results of the 2-year storage test provided additional correlation to support the D 2274 procedure in defining product stability.

Table 1 lists major thrust areas which have been identified in the Army distillate fuel stability program and provides a basis for discussion of Army needs for diesel fuel stability and cleanliness. Experimental test procedures used for evaluating the cleanliness and stability of distillate fuels in Army programs are provided as an appendix to this paper.

TABLE 1. MAJOR THRUST AREAS IN ARMY DISTILLATE FUEL STABILITY PROGRAM

● Field Test Technique Development	Test quality and predict future quality.
● Survey Quality of Petroleum Fuels	Laboratory methods correlation, specifications, field manuals.
● Conduct Field Problem Surveillance	Identify fuel-related problems and adequacy of fuel procurement and handling practices.
● Evaluate Additives for Depot Use and Prepositioning	Provide fuel additive package for dormant storage of fully fueled vehicles.
● Conduct Basic Research	Define factors leading to deleterious products in both short- and long-term storage.

While not included in Table 1 as a thrust area, support of programs within the Department of Energy's Bartlesville Energy Technology Center and the ASTM technical division E-V on "Fuel Stability and Cleanliness" is considered vital to the Army's stability program. These sources have and will continue to provide fuel stability information and test method development.

II. FIELD TEST TECHNIQUE DEVELOPMENT

A laboratory study was initiated in late 1976 to define the relative stability characteristics of a base set of fourteen test fuels as an input to the definition of a field test capability for measuring quality and predicting stability. Table 2 summarizes particulate data for seven test fuels using five accelerated test procedures described in the appendix.

TABLE 2. DISTILLATE STABILITY DATA BASE FUEL PARTICULATES BY VARIOUS ACCELERATED STORAGE TESTS

Stability Test	Particulates, mg/100 ml						
	Fuel Sample Number						
	1	2	3	4	5	6	7
D 2274	0.23	0.29	0.29	0.66	1.05	1.82	6.33
D 873	0.4	1.6	1.2	0.9	2.8	5.1	19.9
150°C 90 min	1.0	3.4	1.0	1.6	2.0	2.6	4.3
80°C 72 hours	0.8	1.2	0.3	0.4	0.4	1.7	1.4
168 hours	0.6	1.7	0.4	1.0	1.7	3.5	4.1
43°C 16 weeks	0.8	0.6	1.1	0.2	0.2	3.6	0.4
32 weeks	0.8	0.5	1.1	0.5	0.2	5.5	1.4

Based on data correlations of the fuels ranked according to particulates and sediment at 43.3°C (110°F) storage for 32 weeks, the best correlations were with the 80°C (175°F) test data for seven days (168 hr). The D 2274 test data correlation was particularly poor. The test with the greatest potential for field use, based on its simplicity and short test time, was the 150°C (300°F) test tube method requiring 90 minutes of reaction time. Unfortunately, the 150°C (300°F) test data correlated poorly for the ranked fuels. However, this method may offer some potential if a go-no-go value of 3.0 mg/100 ml is used, since this particular value and approach combination has been somewhat reinforced. This reinforcement is the result of the additional data given in Table 3 for a number of field samples, some of which are from

vehicle fuel cells. Note that the particulates in the 150°C, 80°C, and 43.3°C methods are determined using a modified D 2276 method outlined in the appendix.

TABLE 3. COMPARISON OF D 2274 AND 150°C TEST DATA FOR FIVE FUELS

Method	Particulates, mg/100 ml				
	Fuel 1*	Fuel 2*	Fuel 3*	Fuel 4**	Fuel 5**
D 2274	4.9	3.2	3.2	5.7	0.9
150°C 90 min	11.3	8.6	6.0	10.2	2.6

* Vehicle fuel cell samples.

** Bulk underground storage samples.

Quick, simple, and, most importantly, reliable methods of detecting excess fuel contamination in the field have long been sought. Field laboratories offer a solution to this problem, but are usually large (requiring a vehicle to transport them), as well as being expensive to operate and maintain. A more practical solution is a small, self-contained portable kit, which would be used to furnish a go-no-go type answer with regards to any given supply of fuel. Kits of this type are available commercially. One such device is the Fuel Contamination Detector manufactured by Gulton Industries (NSN 56630-706-2302). This kit has a self-contained vacuum pump to filter the fuel and uses a photovoltaic cell to determine the amount of light that passes through the filter as a measure of the amount of contamination. Although the unit has not been evaluated for diesel fuel, the Navy has evaluated it for use with Marine Diesel fuel and has concluded that the device could be used to give a go-no-go answer. The major drawback of the kit is that it requires an a-c power source.

The Army has developed a Fuel Contamination Test Kit. The kit, designed primarily for field use, is used to determine both the free (undissolved) water content and sediment (solid particulate) content of liquid aviation and automotive fuels. It is also used to identify liquid fuel types based on gravity. In order to determine sediment, a known volume of fuel is filtered through matched-weight membrane filters (test and control) contained in a plastic monitor. The filters are then removed, dried, and weighed on a

torsion balance. Sediment content is determined by comparing the increase in weight of the test membrane over the control membrane.

This kit has not as yet been fielded for use by the Army. One drawback is that care must be taken to level and calibrate the kit's balance, and, after leveling and calibration, it should be moved as little as possible. Also, as mentioned above, the kit requires the use of matched weight filters, which are costly relative to unmatched filters; this latter issue is currently under review.

Another test used in the past for determining fuel cleanliness is the Filterability Ratio Test (see appendix--based on Ref. 10). In this test, the time it takes to filter a given amount of contaminated fuel is compared to the filtering time for an equal portion of the same fuel that has been pre-filtered. A value of 1.0 for the test indicates a clean fuel. However, this test requires that the vacuum source be constant, which is sometimes difficult in a field situation. This procedure has been used with considerable success in the laboratory in predicting potential fuel deterioration/cleanliness problems.

In addition to testing for cleanliness, it is desirable to rate a fuel's approximate storage stability. The Army Fuels and Lubricants Research Laboratory (AFLFL) has an ongoing program devoted to development and evaluation of an in-the-field fuel cleanliness/stability testing device.

There are basically four functions envisioned for an in-the-field fuel cleanliness/stability testing device:

- (1) sample the fuel from its storage container;
- (2) rate the fuel for cleanliness;
- (3) age the fuel in some manner; and
- (4) rate the aged fuel for stability.

To accomplish item (1) above, a small hand pump or d-c powered pump may be used to siphon the fuel from its storage container. This fuel is then filtered by an apparatus similar to that used in ASTM Method D 2276. A prototype Contaminated Filter Measuring Device (described in Figure 1) is used for rating filters for particulate levels.

LEGEND

- ① RANGE SELECTOR SWITCH
- ② LAMP INTENSITY CONTROL KNOB
- ③ FILTER TESTING COMPARTMENT
- ④ FUSE
- ⑤ ON/OFF SWITCH
- ⑥ CALCULATOR
- ⑦ STORAGE COMPARTMENT
- ⑧ DIGITAL READOUT

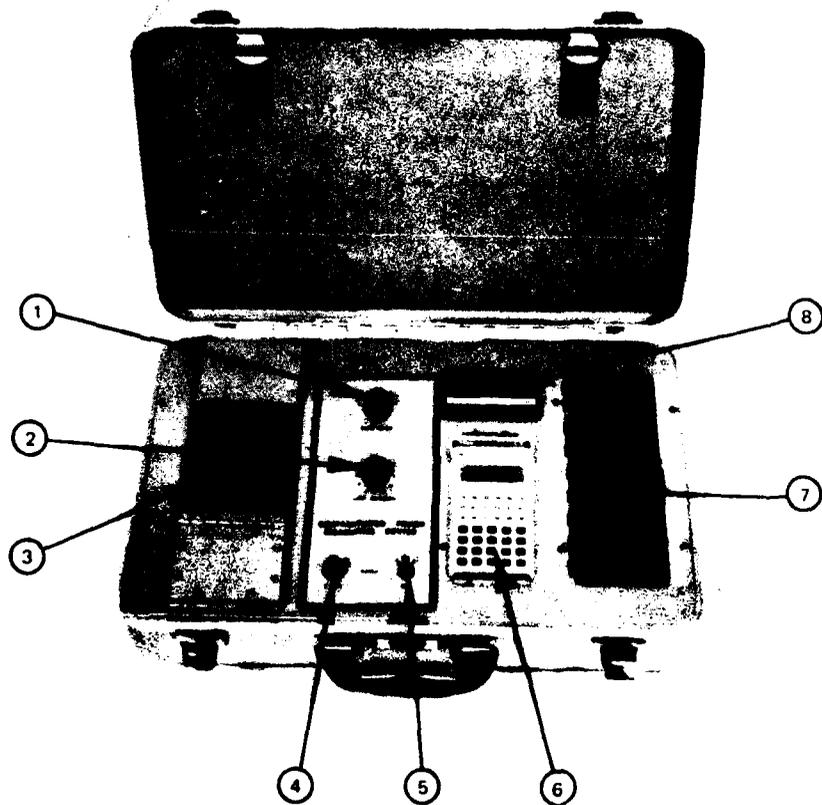


FIGURE 1 CONTAMINATED FILTER MEASURING DEVICE

Components 1 and 2 in Figure 1 are the output range selector switch and the lamp intensity control, respectively. Component 3, when placed in the upright position, is where the contaminated filter is placed for testing. Components 4, 5, and 6 are the fuse, on/off switch, and calculator, respectively. Component 7 is a storage compartment for power cords, spare parts, etc. Component 8 is a digital display that reads out d-c volts.

In operating this device, a contaminated filter is placed into the testing compartment, and a beam of light is passed through it. The amount of light that passes through the filter is measured by a photosensitive cell. This light is converted to d-c voltage, and the amount of voltage is displayed on the digital readout. By comparing this value with the output value for a clean reference filter and employing a calibration process currently being developed, one can approximate the amount of contamination present on the filter.

To predict the future quality of the fuel, 50 milliliters of fuel are aged at 150°C (300°F) for 1.5 hours. This aged fuel is then filtered, and the filter membranes are rated for contamination using the device in Figure 1. A program is currently underway at AFLRL to evaluate and correlate this approach with actual field and fleet test programs.

III. SURVEY PETROLEUM FUELS

Diesel fuels meeting the requirements of Federal Specification VV-F-800b Fuel Oil, Diesel must not exceed a particulate contamination limit of 8.0 mg/liter using a 1.2-micrometer membrane filter. This maximum value is a procurement limit imposed at the time of purchase and is intended to ensure a minimal degree of cleanliness in terms of contaminants such as insoluble oxidation products, dirt, lint, fibers, dust particles, rust, etc. Aviation turbine fuels, however, have more stringent limits for particulate contamination, as is noted by the maximum limit of 1.0 mg/liter in MIL-T-5624 (JP-4 and JP-5, Aviation Turbine Fuel). Diesel fuels are somewhat "less clean," because of the less stringent product quality requirements being imposed during refinement (e.g., thermal stability, smoke volatility index, etc.), as well as the heavier blending stocks being used (i.e., naphtha and kerosene versus diesel, distillate, gas oil, etc.)

Based on a survey of ten Army bulk diesel fuel storage facilities in 1976, particulates ranged from a low of 0.3 mg/liter to a high of 4.5 mg/liter. D 2276 stability values ranged from 0.2 to 0.7 mg/100 ml. A 1977-1978 sample survey of ten diesel fuel (VV-F-800b) samples, as delivered to Army Depot facilities, reveals the average level of particulate contamination to be 2.5 mg/liter, with values ranging from 0.3 to 5.9 mg/liter. The D 2274 stability values ranged from a low of 0.3 to a high of 1.4 mg/100 ml. As the fuel is moved from bulk storage to intermediate tankage and, ultimately to the final dispensing point, it will pick up additional contaminants, thereby increasing the level of particulate contamination.

A recent industry survey conducted in conjunction with an ASTM cooperative program addressed the quality of diesel fuel at the point of use. The study revealed the particulate contamination level as ranging from 0.7 mg/liter to 39 mg/liter, with the average being 8.5 mg/liter.

Aviation turbine fuel contamination obviously has greater impact than diesel fuel contamination because of the safety aspects (i.e., regarding flight malfunction, etc.). For this reason, a contaminant package has been developed and is in use for test fuels used in aviation gas turbine engine components and systems qualification testing under AV-E-8593B. This package is comprised of the following:

Iron Oxide	=	30 g/1000 gal
Quartz Dust	=	4 g/1000 gal
Arizona Road Dust	=	8 g/1000 gal
Cotton Liners	=	0.1 g/1000 gal
Naphthenic Acid	=	0.03 vol%
Salt Water	=	0.01 vol%

A recent validation of these contaminants was conducted and reported in AFLRL Report No. 90, "Definition of Aviation Turbine Fuel Contamination Under Simulated Combat Conditions."⁽¹¹⁾ This requirement is used by the United States Aviation Research and Development Command (AVRADCOM) and in United States Air Force (USAF) and United States Navy (USN) engine/component development programs.

MIL-HDBK-200E provides a guide for petroleum and lubricant (POL) product quality surveillance. For all POL, specification requirements or limits or both are given, as well as "deterioration limits." "The Allowable Deterioration Limit (use limit)" is defined as the extent that properties of a product may deteriorate without requiring downgrading or rendering the product unusable for its intended use. The deterioration limit given for diesel fuel (VV-F-800b), 10 mg/liter, represents an acceptable deviation to the product specification requirement while still permitting use of the product in fuel consuming equipment.

Because of the unique characteristics of the different types of fuel contamination, as well as the complex processes involved in fuel filter/fuel system malfunctions, no single set of limits differentiating a fuel-related problem from an equipment-related problem has been developed for ground-vehicle fuels. Additionally, unacceptably high filterability ratios have been observed for some fuels having low particulate contaminant levels. In one case, a filterability ratio value of 2.6 (1.0 being clean and 1.5 being go-no-go limit) was observed for a fuel having particulate contamination of only 2.5 mg/liter. These and other similar anomalies further add to the difficulties in attempting to establish a critical maximum limit for particulate contamination.

IV. FIELD PROBLEM SURVEILLANCE

A selected group of field-identified, fuel-related problems has been summarized in Table 4 to illustrate the extent of fuel-related problems peculiar to military fuel use situations. While the information in Table 4 with respect to date, location, problems, and primary cause or causes identified is self-explanatory, items numbers 2, 4, 5, 6, 8, 9, 10 and 12 of the table are of particular interest. These events emphasize that while bulk storage conditions and time can result in fuel stability-related problems, as was the case with the Whiteman AFB Missile Site stored fuel (Item No. 2, Table 4), bulk storage is not a single controlling factor under field use conditions. Fuel deterioration, filter plugging, and tank corrosion occur in vehicle fuel tank systems, as observed at several Army depots in 1973 (Item No. 4, Table 4).

TABLE 4. FUEL STABILITY RELATED FIELD PROBLEMS

Item Number	Year	Location	Problem	Primary Cause or Causes Identified
1	1965	Camp Pendleton	M60 and M48 Vehicle Fuel Injection Pump Seizures	<ol style="list-style-type: none"> (1) Metallurgical errors and improper plunger tolerances in overhaul of fuel injection pumps. (2) Particulate debris due to degradation of fuel improperly maintained in fuel cells aggravated problem (1) above.
2	1968	Whiteman AFB	Malfunction of Engine-Generator Sets	Organic fuel deterioration products from VV-F-800 fuel (DF-2) which had been in storage approximately 4 years.
3	1971	Red River Army Depot	M561 Gamma Goat Fuel Filler Pipe Corrosion and Filter Plugging	The lead coating on some military fuel tank filler pipes is susceptible to extensive and rapid corrosive action through a chemical process involving diesel fuel vapors and air under certain storage/use conditions. The primary cause is thought to be insufficient fuel system maintenance.
4	1973	Several Army Depots	Fuel Deterioration, Filter Plugging, and Corrosion in Vehicle Fuel Tanks	The combined effects of fuel storage instability and thermal instability on the particular diesel fuels would create (1) acidic impurities leading to corrosion and water emulsification problems, (2) oxygenated precursors participating in oxidation-condensation polymerization reactions which degrade the quality of the fuel, and (3) combinations of contaminants which further complicate fuel quality by entrainment of rust and extraneous materials, and emulsification of water which provides a continuous source for microbiological deterioration. In addition, the introducing of preservative-type lubricants (which contain zinc organic complexes) into vehicle fuel systems provides soluble zinc contaminants which degrade fuel thermal stability.
5	1975	Letterkenny Army Depot	Manufacturer Stored M60A2 Tank Fuel Deterioration-Filter Plugging	<ol style="list-style-type: none"> (1) Deterioration of the residual fuel in the vehicle fuel cells, during long-term storage resulting in insoluble oxidation products and corrosion of metal parts in vehicle fuel systems, caused a build-up of residue on the filters. (2) The "in house" diesel fuel used at Chrysler Detroit Tank Plant appears to be contaminated with particulate matter which could contribute to the filter plugging. (3) The preservative oil VV-L-800 contains a carboxylic acid which could react with certain metals present in the fuel system forming soaps which would contribute to the filter plugging.
6	1976	Camp Guernsey, Wyoming	M110 Self Propelled Howitzer Vehicle Fuel Filter Plugging	While diesel fuel storage and thermal stability in the fuel cell over a prolonged period of time is partially causing the filter plugging problem, the lack of tank water bottom removal and open air storage without routine preventive maintenance is also responsible.
7	1976	Yuma Proving Ground	M107 Self Propelled Howitzer Vehicle Fuel Deterioration, Tank Corrosion, and Filter Plugging	Filter plugging due to fuel deterioration and corrosion debris both of which occur in the fuel tank due to nature of random operation, heat sink use of fuel tank, and fuel's sensitivity and lack of corrosion inhibitor.
8	1976	Combat Equipment Battalion East, Europe	Vehicle Diesel Fuel Tank Rust and Corrosion	Cause not clearly defined but probably due to lack of adequate preservation.
9	1977	Fort Riley, Kansas	M60A1 Tank Engine Starvation due to Filter Plugging	Diesel fuel in use at the time was of marginal to poor stability; primary cause of filter plugging was due to microbiological debris and fuel deterioration products.
10	1977	California National Guard Unit	Gamma Goat Fuel Tank Filter Pipe and Cap Corrosion	Corrosion of fuel filler pipe and cap of similar vehicles are thought to be due to a combination of lack of sufficient corrosion inhibitors in a fuel tank system breathing moisture and carbon dioxide containing air and exposed to daily temperature extremes (including direct sun exposure) over extended periods of time without adequate preventive maintenance.
11	1977	Fort Hood, Texas	M60A1 Tank Engine Fuel Filter Plugging	Presence of microbiological debris and fuel deterioration products identified. Lack of fuel system maintenance and fuel treatment identified as probable cause.
12	1977	Fort Lewis, Washington	M551 Sheridan Tank Fuel Filter Plugging	Fuel deterioration products and microbial contamination present, but cause not yet defined. However, equipment improvement request to facilitate complete draining of fuel tank water bottoms was recommended.

TABLE 4. FUEL STABILITY RELATED FIELD PROBLEMS (CONT'D)

Item Number	Year	Location	Problem	Primary Cause or Causes Identified
13	1977	Boatwright Fort Knox, KY	M60A1 Fuel Tank Sludge	Data indicated sludge to be water/oil mixture containing a profusion of fungal and bacterial contamination.
14	1978	White Sands Missile Range, New Mexico	Patriot Missile Turbine Generator 600 gallon Fuel Storage Tank Filter Plugging	While contamination and deterioration during storage and transfer of fuel was identified, a more adequate filtration and water separator system was recommended for adaptation to the generator fuel storage tank.
15	1979	Fort Polk, LA	M60A1 and M60A2 and MSS1 tank engine starvation and plugged fuel filter	Microbial debris minor cause; primary cause identified as fuel deterioration and inorganic debris. Lack of routine water bottom removal and low vehicle utilization level probably contributed to fuel deterioration and microbial contamination.
16	1979	Fort Bliss, TX	M60A1 tank engine fuel starvation and plugged fuel filters	Problem was determined to be a result of poor fuel stability and improper use of procedures to minimize water accumulation and debris in fuel cells.
17	1980	Fort Hood, TX	M60 Tank Fuel Filter Plugging	Problem under investigation; fuel system decontamination procedures requested.
18	1980	Fort Irwin, CA	Fuel Filter Plugging in Tracked vehicles	Problem under investigation.

Diesel fuel systems circulate the fuel as an injector coolant during operation, breathe air containing oxygen, water vapor, etc., and are reaction vessels of undefined composition and dimension. Under these conditions, the combined effects of thermal and storage instability of the particular fuels would create: (1) acidic impurities leading to corrosion and water emulsification problems; (2) oxygenated precursors participating in oxidation-condensation polymerization reactions which degrade the quality of the fuel; and (3) combinations of contaminants which further complicate fuel quality by entrainment of rust and extraneous materials and emulsification of water, which provides a continuous source of microbiological activity and deterioration of the fuel. Additionally, the use of some zinc organic-complex-containing lubricants (preservative-type) in the fuel during extended vehicle storage is a source of soluble zinc contaminants, which degrade fuel thermal stability.⁽¹²⁾ The amount of fuel left in the stored vehicles is usually small compared to the fuel tank size and results in maximum environmental effects on the residual fuel, as in the case of the Letterkenny Army Depot fuel (Item No. 5, Table 4). Also, in this case the bulk dispensing fuel at the manufacturing plant was of questionable quality, and the preservative oil contained an acid which could react with the aluminum fuel tank to form metallic soaps. Both of these factors would cause filter plugging when the vehicle was placed in use if the tank was not thoroughly cleaned prior to field fueling and operation.

Generally, the storage of a vehicle fuel system is assumed to be acceptable for short periods of time if the system is first drained of most fuel and if a "preservative" is added prior to storage. Fuel tank design usually prohibits complete fuel tank drainage, which means that water bottoms cannot be completely drained. Microbiological activity at the fuel-water interface (particularly during dormant periods of fully fueled vehicle storage) can result in filter plugging by microbiological debris and fuel oxidation products, as was the case at Fort Riley, Kansas, and probably at Fort Lewis, Washington (Item Nos. 9 and 12, respectively, Table 4). Figures 2 and 3 are photographic reproductions of microbiological debris found in fuel systems at Fort Riley, Kansas (Item No. 9, Table 4). Evaluation of the Fort Riley fuel system debris by the U.S. Army Natick Research and Development Command (NARA-DCOM) has indicated the presence of a yeast, tentatively identified as Candida humicola, and of a gram negative bacterium. Table 5 summarizes those microorganisms isolated and identified from contaminated fuel or filter samples.

TABLE 5. IDENTIFICATION* OF MICROORGANISMS ISOLATED FROM CONTAMINATED FUEL/FILTER SAMPLES

<u>Location</u>	<u>Sample No.</u>	<u>Identification Status</u>
Ft. Riley, KS	AL-6818-X	unidentified fungal organism
Ft. Riley, KS	AL-6839-X	1) Yeast - <u>Candida humicola</u>
		2) <u>Pseudomonas Aspergillus</u>
Ft. Riley, KS	AL-6840-F	slow growing yeast?
Ft. Riley, KS	AL-6843-F	
Ft. Knox, KY	AL-6854-X	<u>Aspergillus flavus</u>
Ft. Hood, TX	AL-6963-X	no microbial growth
Ft. Hood, TX	AL-6964-X	no microbial growth
Ft. Hood, TX	AL-6965-X	no microbial growth
Ft. Hood, TX	AL-6977-F	no microbial growth
Ft. Hood, TX	AL-6978-F	growth?
Ft. Lewis, WA	AL-6979-X	<u>Cladosporium resinae</u>
Ft. Lewis, WA	AL-6980-X	<u>Cladosporium resinae</u>
Ft. Lewis, WA	AL-6981-X	<u>Cladosporium resinae</u>
		plus unidentified yeast?
Ft. Lewis, WA	AL-6982-X	<u>Cladosporium residae</u>
		plus unidentified yeast?
Ft. Lewis, WA	AL-6986-X	<u>Cladosporium resinae</u>
Ft. Lewis, WA	AL-7011-F	undergoing identification

* All fungal organisms were identified by Miss Bonnie Wiley, DRDNA-YPB, FSL, U.S.A. Research and Development Laboratory, Natick, MA 01760.

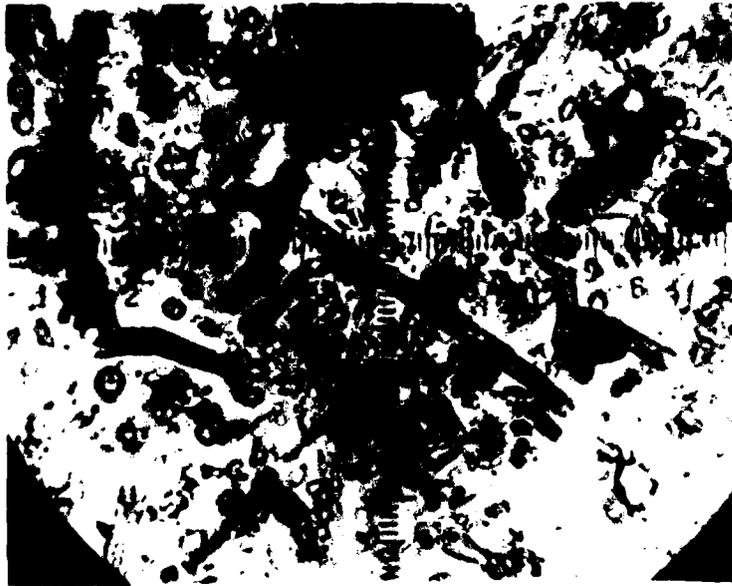


FIGURE 2 PHOTOGRAPH OF DEBRIS ON PRIMARY FUEL FILTER FROM ONE FORT RILEY M60A1 TANK

(1.4 μm /scale division, wet sample, oil wetted lens, 970X, M60A1 Tank USA #09A05772)

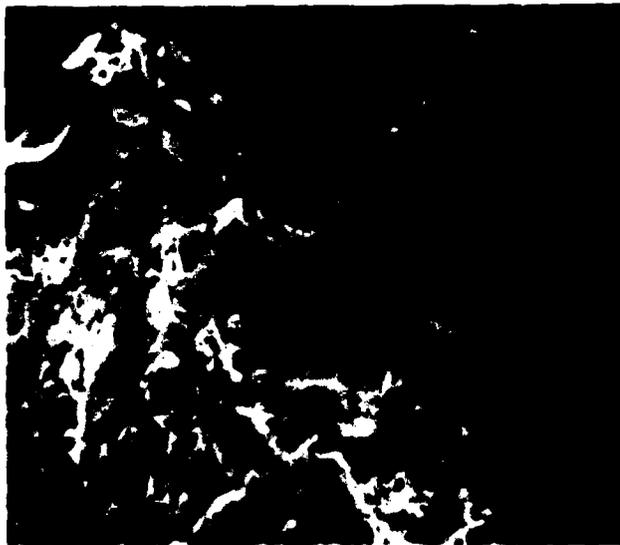


FIGURE 3 SEM OF M60A1 ENGINE SERIAL NO. 15554 SECONDARY FUEL FILTER RESERVOIR PARTICULATE SAMPLE

(Magnification, 1000X; sample was gold fluxed)
(SEM preparation courtesy of Mr. Bill Doebbler, Yuma Proving Grounds, Yuma, Arizona)

A report prepared by NARADCOM indicated that the typical fuel-utilizing organisms isolated from the scraping of the surface coating on the filters and from fuel samples (as indicated in Table 5) do not necessarily indicate that the microorganisms were the major cause of the filter plugging.⁽¹³⁾ Microorganisms can be isolated from the surface of filters or from the fuel even when filter plugging is not a problem, since they are normal residents in most fuel systems. Usually, when microorganisms cause the problem, the filter will reveal a heavy membranous coating that can be pulled away. The filter samples received from the Fort Riley fuel systems revealed only a dark gel or wax-like coating. In some instances, the gel or coating was so small that extensive scraping with a sterile spatula was required to remove enough material for culturing.

A filter provides an ideal surface for microbial activity. Nutrients, including oxygen, water, minerals, and organic matter, are carried into the filter by circulating fuel. Waste products which would normally accumulate and eventually inhibit growth are carried away as the fuel passes through the filters. Thus, an ideal dynamic culture system is set up for the production of large masses of protoplasm. However, in no instance was there any massive or visual build-up of microbial material on any of the Fort Riley filters examined, although microscopic examination showed the presence of fungal mycelia, bacterial cells, and other debris. A probable explanation for this phenomenon is that the circulation of hot fuel inhibited growth in this area. However, during nonoperating periods, spores not destroyed by the hot fuel can begin to grow and, thus, could account for the microscopic growth observed. Also, new microbial inocula can be introduced via tank breathing and refueling and, therefore, could account for the isolation of viable cells from the filters and fuel samples.

In the laboratory, usually about two weeks or more of ideal conditions (shaking flasks at 30°C) are required for Cladosporium resinae to develop any volume of mycelia. In the field, extensive studies would be required to determine conclusively that the intermittent filter plugging is caused by poor fuel-handling practices and unstable diesel fuel, rather than microbiological contamination.

Short storage periods may not be feasible in the case of Army depot vehicle overhauls; in such instances, more stringent fuel tank condition controls are required. Although the total standard time required for shipment of a vehicle from an operating unit to a depot, for awaiting overhaul at the depot, and for overhaul has been noted as ranging from 7.1 to 10.1 months for the M113A1 and M-88 tanks, respectively, a recent Comptroller General's report⁽¹⁴⁾ estimated actual overhaul time for the same vehicles at 68.9 and 69.7 months, respectively.

In some cases, such as the ones at Camp Guernsey, Wyoming and at Ft. Bliss, Texas (Items Nos. 6 and 16, respectively, Table 4), combined effects of poor fuel stability, continued intermittent operation, contamination, and lack of preventative maintenance (such as annual draining and cleaning of fuel tanks) have led to severe fuel filter plugging, as shown in the photograph in Figure 4. Difficulty in cleaning this type of fuel tank and fuel conservation requirements both contribute to reduced mandatory draining and cleaning of fuel tanks as routine maintenance requirements.

As shown by fuel tank problems in European Prepositioned Overseas Materiel Configured in Unit Sets (POMCUS) (Item No. 8, Table 4), long storage periods of 1 to 4 years, even under controlled humidity conditions, can result in fuel storage-related problems unless preventative measures such as the use of stability additives now under development and of fuel condition monitoring are taken. The extent to which a fuel tank is drained, the quality of the residual fuel, the presence of water, the effectiveness of preservative-oil applications, etc. combine to determine the future residual fuel quality and fuel tank condition. In the case of storing fully fueled equipment, an impending requirement for POMCUS equipment, even more stringent preventative measures will be required to avoid fuel and fuel tank deterioration related problems. A constant humidity environment does not eliminate the fuel tank breathing associated with daily high-low temperature variation. Such breathing causes cycling of the tank fuel and vapor temperatures, resulting in vapor escape at high temperature and subsequent air entrance into the tank during fuel and vapor cooling. Corrosion of fuel filler pipe and cap as shown in Figure 5 (and Item No. 10, Table 4) is thought to be due to a combination of factors: lack of sufficient corrosion inhibitors in a fuel tank system which

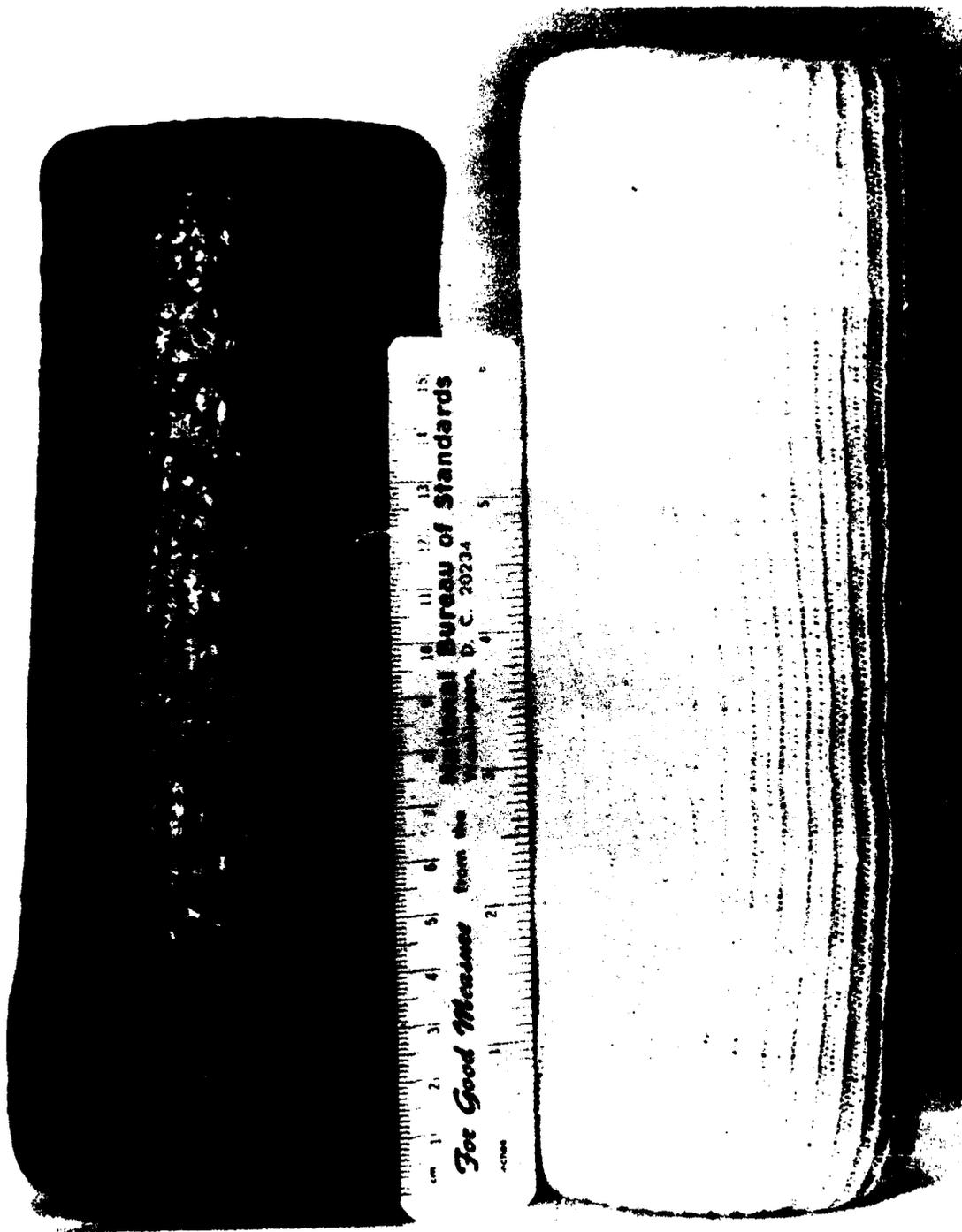


FIGURE 4 COMPARISON OF A SEVERELY PLUGGED PRIMARY FUEL FILTER FROM AN M110 SP VEHICLE (#12FH64) WITH A CLEAN FILTER



Severely Corroded



Non-Corroded

FIGURE 5 COMPARISON OF CORRODED FUEL/TANK FILLER PIPE AND CAP OF IMPROPERLY STORED M561 GAMMA GOAT WITH A NONCORRODED FILLER PIPE AND CAP

breathes moisture, oxygen, and carbon dioxide-containing air; and exposure to daily temperature extremes (including direct sun exposure) over extended periods of time without adequate preventative maintenance such as tank draining and cleaning.

V. ADDITIVES FOR DEPOT USE

The U.S. Army Mobility Equipment Research and Development Command (MERADCOM) at Fort Belvoir, Virginia, has over the past several years, coordinated and worked closely with the U.S. Army Natick Research and Development Command (NARADCOM) in defining the origin of fuel system/contamination problems occurring in the field. MERADCOM involvement has been in the area of fuel deterioration and quality, whereas NARADCOM has addressed the issue of microbiological deterioration, since this is associated with their lead function in the Department of the Army. To date, collective efforts have revealed that most instances of fuel system malfunctioning and contamination are due to improper fuel use, fuel with marginal stability, excessive water contamination, poor fuel system housekeeping, and improper attention to quality surveillance procedures.

As an insurance measure, it was desired to make available a biocide that would be effective and at the same time not cause any adverse side effects. To achieve this objective, NARADCOM undertook a comprehensive evaluation of commercial and experimental biocides to ascertain their relative effectiveness in controlling bacterial and fungal growth. These efforts resulted in the selection of BIOBOR* JF as a biocide.

A project concurrently completed by the U.S. Army Fuels and Lubricants Research Laboratory involved evaluation of the effects of biocides on the storage and performance characteristics of treated fuels. The project report, entitled "Evaluation of Biocides' Effects on Diesel Fuels Under Prolonged Storage," was issued in 1975.⁽¹⁵⁾ Since the completion of this report, a candidate additive stabilizer package consisting of a trifunctional, multipurpose additive and the biocide BIOBOR JF has been selected. The multipur-

* Registered trademark of United States Borax and Chemical Corporation.

pose additive is a commercial product which incorporates a dispersant and antioxidant, a metal deactivator, and a rust inhibitor. This additive stabilizer is being field tested in Europe to define its feasibility in storing fully fueled combat equipment. Also, the additive stabilizer package is being tested at the Chrysler Tank plant facility for new M60 tanks. The two-package stabilizer system provides a treatment per tank full of fuel of 270 ppm of BIOBOR JF and 25 pounds of the multifunctional additive per 1000 barrels of fuel. An additional field test limited to several tracked, self-propelled guns, is underway at Yuma Proving Grounds; a proposed test, possibly at Letterkenny Army Depot, is planned.

A purchase specification for general use of the additive stabilizer package for special-purpose fuel storage is not being considered.

Table 6 provides an example of the effectiveness of the additive package in reducing particulate formation on the European fuel, using three accelerated test methods.

TABLE 6. EFFECTIVENESS OF ADDITIVE PACKAGE IN EUROPEAN TEST FUEL

<u>Test Method</u>	<u>Particulates, mg/100 ml</u>	
	<u>Base Fuel</u>	<u>Base Fuel Plus Additive</u>
D 2274	1.4	0.3
D 873 Modified	20.2	6.3
150°C 90 min	3.3	0.8

Based on average D 2274 storage data (0.7 versus 1.3 mg/100 ml for additive-treated fuel versus nonadditive-treated fuel, respectively) for samples taken during the first 18 months of storage of fully fueled vehicles in Europe, the additive has been deemed effective. However, a few vehicle fuel samples show high D 2274 results for treated fuel. Because of this random occurrence, concern has been expressed that the fuel cells were not initially cleaned. The program is currently being reviewed, and, therefore, conclusions regarding the effectiveness of additive-treated fuel cannot yet be made.

It should be noted that the fuel stabilizer package currently in use for storage of fuel in vehicles does not provide for corrosion inhibition of the tank ullage. It is desirable to place a source of volatile corrosion inhibitor in the filler pipe area of fuel tanks to provide corrosion inhibition which would be compatible with the fuel in vehicle fuel cells. A plan to study viable approaches to providing volatile corrosion inhibition for fuel tanks containing fuel has been developed, but has not, as yet, been implemented.

VI. BASIC RESEARCH

Accelerated test results can be related to long-term storage results and can indicate the less stable fuels. However, absolute test methods for predicting fuel quality at specific time intervals, under all types of storage conditions, have yet to be developed. Basic research into the mechanism of diesel fuel deterioration has been investigated at AFLRL in an effort to better define the chemical composition parameters and their interrelation in the formation of deleterious degradation products. Strict compositional relationships have not yet been developed successfully; consequently, more emphasis is being placed on the development of empirical relationships.

Fuel filter plugging, visible vehicle fuel cell and filler pipe corrosion, and the appearance of gums, gels, and matted material during visual inspections of filters, containers, tank bottoms, etc., are thought to involve not only fuel deterioration (virtual or induced), but a combination of fuel container instability, contamination directly or indirectly from the fuel container environment, and application (or misapplication) of maintenance practices. Fuels handling and fuel supply maintenance are extremely critical to problem-free Army operations. Fuel stability related problems will likely increase in view of current projections for growing dependence on off-shore/foreign crude and alternate "synthetic crudes," in addition to the escalation of the practice of strategically storing fuels and fully fueled vehicles.

Means of testing fuel quality, predicting fuel stability, and preventing fuel-related material problems in the field continue to be improved. Basic research to better define the mechanisms involved in diesel fuel stability will contribute to this effort. The energy crisis and manpower cuts, with their

resultant effects on maintenance practices, mandate better field methods for detecting and preventing fuel and fuel-related material defects that develop in the field. Future fuel stability mechanism research should be approached in its broadest framework, so as to include quantity (both large and small), term (short and long), container (bulk and vehicle), and environment (external and internal components). This viewpoint will best serve both short- and long-term material readiness as affected by fuel and fuel storage stability.

The Army Research Office has recently (June 1980) funded a "Basic Study of Fuel Storage Stability" at Stanford Research Institute International. Funding of basic research (as opposed to on-going applied research) in diesel and turbine fuel deterioration is planned for initiation at MERADCOM in fiscal year 1982.

VII. SUMMARY

This report has attempted to summarize the Army's experience and requirements for stability and cleanliness of diesel fuel by reviewing major program thrust areas. The major thrust areas in the Army distillate fuel stability program have been identified as:

- (1) Field Test Technique Development,
- (2) Survey Quality of Petroleum Fuels,
- (3) Conduct Field Problem Surveillance,
- (4) Evaluate Additives for Depot Use and Prepositioning, and
- (5) Conduct Basic Research.

It is anticipated that the desire to preposition fuel and fueled vehicles and the need to reduce fuel stability-related problems coupled with the potential increased use of synthetic derived fuels and increased use of nonhydrotreated cracked stocks will continue to be driving forces influencing research and development regarding diesel fuel stability and cleanliness.

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APPENDIX
EXPERIMENTAL TEST PROCEDURE FOR DISTILLATE FUELS

The following experimental methods are used to test distillate fuels:

1. Color: ASTM D 1500-64
2. Steam Jet Gum: ASTM D 381-70 (Modified)

Modification: The residue is dried an extra 0.5 hour in the gum block if it still appears wet after the first 0.5 hour.

3. Particulate Contamination: ASTM D 2276-73 (Modified)

Modifications:

- 47-mm diameter filters are used instead of 37-mm diameter filters.
 - 1.2-micrometer pore size filters are used instead of 0.8-micrometer pore size filters.
 - n-heptane is used as the solvent.
 - The sample size may range from 100 to 1000 ml.
4. Accelerated Stability: ASTM D 2274-74.
 5. NACE Standard TM-01-72 Steel Corrosion: Antirust properties of petroleum products pipeline cargoes test method.
 6. 43°C Storage Test: This test method is used for studying the storage stability of distillate fuels under vented 43°C storage conditions.

The bottles used were made of Pyrex Brand glass [Curtis Matheson Scientific, Inc., Catalog No. 037-598 (1977)], are rectangular (the cross section is 6.35 cm x 9.53 cm), and are 27.31 cm in overall height. The volume of each bottle is 1 liter. The bottles have a tool-finished neck for increased strength, with an opening that takes a No. 6 rubber stop-

per. A 10.2-cm square, thin sheet of Teflon was wired securely around the neck to cover the opening. A 0.64-cm diameter hole was punched into the sheet for insertion of a bent piece of glass tubing to act as a vent.

The storage bottles were cleaned with alkaline laboratory cleaner and then rinsed with water. Each bottle was filled approximately half full with chromic acid cleaning solution and rolled in such a way that all of the inner surface came in contact with the acid solution. The bottle was allowed to stand for at least 1 hr before it was rinsed four times with deionized water. The bottles were allowed to drain and then dry overnight in an oven at 150°C.

The fuels to be tested were prefiltered through a 1.2-micrometer filter membrane (Millipore Corp., Bedford, Mass., Catalog No. RA-WP-047-00). Then four samples (650 ml per sample) of each fuel under study were placed in the bottles and properly labeled. The perforated caps previously described were placed on the bottles. One bottle from each series was retained for analysis at "zero weeks storage." The control samples were stored in the dark under nitrogen at -1° to 4°C until analyzed. The remaining bottles were placed in the 43°C oven.

One bottle of each fuel was removed after 12, 16, and 32 weeks of storage. The samples were carefully inspected for the appearance of visual sediment and were analyzed for color by ASTM Method D 1500. Filterability ratio (modified) and steam jet gum were also determined. Then 100 ml of each sample were filtered through a 1.2-micrometer filter membrane (as described above). The filter membrane was dried and weighed. The resulting particulates were reported as mg/100 ml.

7. 80°C Storage Test: In this test, ten 120-ml volume sample bottles were used for each fuel. The caps of these bottles were fitted with a Teflon liner, and each liner was pierced with a 0.64 cm diameter hole. A bent glass tube was placed in the hole to act as a vent. Each bottle contained 105 ml of sample.

One control sample of each fuel tested was set aside under nitrogen and in the dark. The other nine samples of each fuel were placed in a force-draft oven at 80°C. Of these samples, three of each fuel were removed from the oven after 24 hr, another three samples after 72 hr, and the final sample of fuel after 168 hr. The samples were tested for color (ASTM D 1500), light absorbance, steam jet gum (D 381), visual sediment, and particulates (D 2276).

8. 150°C Accelerated Fuel Oil Stability Test: In this test, three 55-ml samples of a fuel were measured into 2.5 cm x 20.0 cm culture tubes with screw caps. These tubes were Kimax Brand glass [Curtis Matheson Scientific, Inc., Catalog No. 225-870 (1977)]. The tubes containing the samples were submerged to the necks in a 150°±1°C oil bath. The caps on the tubes were loosened slightly to allow for air expansion in the tube. The samples remained in the batch for 90 minutes.

Two of the samples were combined and analyzed for color (D 1500), light absorbance, and particulates (D 2276), while the third was analyzed for jet gum (D 381).

9. ASTM D 873-74 Oxidation Stability of Aviation Fuels (modified), often referred to as the potential residue method, measures the tendency of fuels to form gum and deposits under accelerated aging conditions. The modifications made to this test and used in these studies are as follows:

- The gum solvent was replaced with n-heptane.
- The sintered glass crucible was replaced with a 1.2-micrometer filter using double filter tare procedure as in ASTM D 2276.
- Items A (particulate), B (insoluble gum), and C (soluble gum) were all reported as milligrams per 100 ml of sample (mg/100 ml).
- The color (D 1500) was reported for the treated sample.
- The visible sediment was reported.
- The treated sample was examined for "sour" or "oxidized linseed oil" odor and reported.

10. Light Absorbance; Spectrophotometric Analysis of Fuels: Light absorbance was measured on a UV-Visible Spectrophotometer.

The light absorbance was recorded over the wavelength scanning range of 650 to 400 nanometers (nm) at a scanning speed setting of 2 nm per second, and the light absorbance values were reported at 650, 575, 540, and 500 nm.

The instrument was "zeroed" without cells in the light path. Deionized water was placed in both cells and scanned over the 650- to 400-nm range to determine the cleanliness of the cells and any possible deviation of the baseline. The cells used were 1-cm corex cells which had been cleaned with solvents, detergents and/or cleaning solution as required to maintain a zero baseline (± 0.005 absorbance units). The deionized water was removed from the sample cell, and the cell was rinsed with acetone and dried with clean air. The fuel to be examined was placed in the sample cell, and the scan was repeated. For each fuel examined, the cell was cleaned as noted previously. Periodically, the zero and baseline scan were checked with deionized water.

11. Method for Testing Fuel Filterability

● Discussion: In this method, 500-ml samples of clean and test fuel were filtered through a 1.2-micrometer filter disc. Fuel filterability was evaluated by the ratio of the filtering time for the test fuel to the filtering time for the clean fuel.

Equipment:	<u>Suggested Supplier</u>
a. 1-092-10V1, Air Pump	Fisher Scientific
b. 1000-ml Filter Flask	Fisher Scientific
c. 500-ml graduate cylinder	Fisher Scientific
d. Stop watch	Fisher Scientific
e. XX10-047-00 Pyrex Filter Holder	Millipore Corporation
f. 1.2 micrometer Filter Disc No. RAWP-047-00	Millipore Corporation
g. Petri-Dishes PD-10-047-00	Millipore Corporation

● Procedure:

- Install a 1.2-micrometer filter disc in holder.
- Pour approximately 510 ml of fuel to be tested in a 500-ml graduate cylinder. Heat or cool the sample to $27^{\circ}\pm 1^{\circ}\text{C}$.
- Turn on vacuum (allow to run 10 or 15 sec to assure full vacuum), then pour the fuel into the filter at such a rate that the fuel filter bowl is full and remains full until all fuel has been poured from graduate.
- When all the fuel has been pulled through the filter and the filter sucked dry, remove disc and save for visual rating. Pour exactly 500 ml of filtrate into the 500-ml graduate.
- Install a clean 1.2-micrometer disc in the filter holder. Then pour 500 ml of filtered fuel into the filter exactly as before, but start the stop watch when the fuel hits the filter disc, and stop it when all the fuel has been pulled through. (Starting and stopping the watch at the exact time is very important). For tests to be conducted at less than $27^{\circ}\pm 1^{\circ}\text{C}$, the sample is to be cooled to and maintained within $\pm 1^{\circ}\text{C}$ of the test temperature for 4 hr prior to completing this step.
- Do not remove the filter disc, but pour out the fuel in the flask. Then filter and time 500 ml of test fuel through the same filter disc that was used in step 5. For tests to be conducted at less than $27^{\circ}\text{C}\pm 1^{\circ}\text{C}$, the sample is to be cooled to and maintained within $\pm 1^{\circ}\text{C}$ of the test temperature for 4 hours prior to completing this step.
- Divide time obtained in step 6 by time obtained in step 5; the results should be 1.0 or more. If the result is 1.0, the fuel was perfectly filterable. Values greater than 1.0 denote a potential problem. The higher the ratio value, the greater the problem in filterability.

- Notes: It is very important to make all filtrations of any one sample at the same temperature. It is also important to keep the filter base clean. Clean it with petroleum solvents, only. This should be done by pouring solvent into the outlet of the filter base and then forcing it through the base with air; then, suck all the solvent from the base before using it to filter fuel.

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CDR US ARMY ABERDEEN PROVING GROUND ATTN STEAP-MT	1	CDR THEATER ARMY MATERIAL MGMT CENTER (200TH)	
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MICHIGAN ARMY MISSILE PLANT PROG MGR, FIGHTING VEHICLE SYS ATTN DRCPM-FVS-SE	1	P O BOX 12211	
WARREN MI 48090		RSCH TRIANGLE PARK NC 27709	
PROJ MGR, M60 TANK DEVELOPMENT ATTN DRCPM-M60-E	1	DIR US ARMY R&T LAB ADVANCED SYSTEMS RSCH OFC	
WARREN MI 48090		ATTN MR D WILSTED	1
PROG MGR, M113/M113A1 FAMILY OF VEHICLES ATTN DRCPM-M113	1	AMES RSCH CTR	
WARREN MI 48090		MOFFITT FIELD CA 94035	
PROJ MGR, MOBILE ELECTRIC POWER ATTN DRCPM-MEP-TM	1	CDR TOBYHANNA ARMY DEPOT ATTN SDSTO-TP-S	1
7500 BACKLICK ROAD		TOBYHANNA PA 18466	
SPRINGFIELD VA 22150		DIR US ARMY MATERIALS & MECHANICS RSCH CTR	
OFC OF PROJ MGR, IMPROVED TOW VEHICLE US ARMY TANK-AUTOMOTIVE R&D CMD ATTN DRCPM-ITV-T	1	ATTN DRXMR	1
WARREN MI 48090		WATERTOWN MA 02172	
CDR US ARMY EUROPE & SEVENTH ARMY ATTN AEAGC-FMD	1	CDR US ARMY DEPOT SYSTEMS CMD ATTN DRSDS	1
APO NY 09403		CHAMBERSBURG PA 17201	
		CDR US ARMY WATERVLIET ARSENAL ATTN SARWY-RDD	1
		WATERVLIET NY 12189	
		CDR US ARMY LEA ATTN DALO-LEP	1
		NEW CUMBERLAND ARMY DEPOT	
		NEW CUMBERLAND PA 17070	

CDR US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY ATTN STSGP-PW (MR PRICE) 1 SHARPE ARMY DEPOT LATHROP CA 95330	CDR US ARMY NATICK RES & DEV CMD ATTN DRDNA-YEP (DR KAPLAN) 1 NATICK MA 01760
CDR US ARMY FOREIGN SCIENCE & TECH CENTER ATTN DRXST-MT1 1 FEDERAL BLDG CHARLOTTESVILLE VA 22901	CDR US ARMY TRANSPORTATION SCHOOL ATTN ATSP-CD-MS 1 FORT EUSTIS VA 23604
CDR DARCOM MATERIAL READINESS SUPPORT ACTIVITY (MRSA) ATTN DRXMD-MS 1 LEXINGTON KY 40511	CDR US ARMY QUARTERMASTER SCHOOL ATTN ATSM-CD-M 1 ATSM-CTD-MS 1 ATSM-TNG-PT (COL VOLPE) 1 FORT LEE VA 23801
HQ, US ARMY T&E COMMAND ATTN DRSTE-TO-O 1 ABERDEEN PROVING GROUND, MD 21005	HQ, US ARMY ARMOR SCHOOL ATTN ATSB-TD 1 FORT KNOX KY 40121
HQ, US ARMY ARMAMENT R&D CMD ATTN DRDAR-SCM-OO (MR MUFFLEY) 1 DRDAR-TST-S 1 DOVER NJ 07801	CDR US ARMY LOGISTICS CTR ATTN ATCL-MS (MR A MARSHALL) 1 FORT LEE VA 23801
HQ, US ARMY TROOP SUPPORT & AVIATION MATERIAL READINESS COMMAND ATTN DRSTS-MFG (2) 1 DRCPO-PDE (LTC FOSTER) 1 4300 GOODFELLOW BLVD ST LOUIS MO 63120	CDR US ARMY FIELD ARTILLERY SCHOOL ATTN ATSF-CD 1 FORT SILL OK 73503
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HQ US ARMY TRAINING & DOCTRINE CMD ATTN ATCD-SL (MAJ HARVEY) 1 FORT MONROE VA 23651	CDR US ARMY ENGINEER SCHOOL ATTN ATSE-CDM 1 FORT BELVOIR VA 22060
DIRECTOR US ARMY RSCH & TECH LAB (AVRADCOM) PROPULSION LABORATORY ATTN DAVDL-PL-D (MR ACURIO) 1 21000 BROOKPARK ROAD CLEVELAND OH 44135	CDR US ARMY INFANTRY SCHOOL ATTN ATSH-CD-MS-M 1 FORT BENNING GA 31905
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DEPARTMENT OF THE NAVY

CDR
 NAVAL AIR PROPULSION CENTER
 ATTN PE-71 (MR MAGETTI) 1
 PE-72 (MR D'ORAZIO) 1
 P O BOX 7176
 TRENTON NJ 06828

CDR
 NAVAL SHIP ENGINEERING CTR
 CODE 6101F (MR R LAYNE) 1
 WASHINGTON DC 20362

CDR
 DAVID TAYLOR NAVAL SHIP R&D CTR
 CODE 2830 (MR G BOSMAJIAN) 1
 CODE 2831 1
 ANNAPOLIS MD 21402

JOINT OIL ANALYSIS PROGRAM -
 TECHNICAL SUPPORT CTR
 BLDG 780
 NAVAL AIR STATION
 PENSACOLA FL 32508

DEPARTMENT OF THE NAVY
 HQ, US MARINE CORPS
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 LMM (MAJ GRIGGS) 1
 WASHINGTON DC 20380

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 WASHINGTON DC 20361

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 WARMINSTER PA 18974

CDR
 NAVAL RESEARCH LABORATORY
 ATTN CODE 6170 (MR H RAVNER) 1
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 CODE 6110 (DR HARVEY) 1
 WASHINGTON DC 20375

CDR
 NAVAL FACILITIES ENGR CTR
 ATTN CODE 1202B (MR R BURRIS) 1
 CODE 120B (MR BUSCHELMAN) 1
 200 STONEWALL ST
 ALEXANDRIA VA 22322

CHIEF OF NAVAL RESEARCH
 ATTN CODE 473 (DR R MILLER) 1
 ARLINGTON VA 22217

CDR
 NAVAL AIR ENGR CENTER
 ATTN CODE 92727 1
 LAKEHURST NJ 08733

CDR
 NAVY FACILITIES ENGRG CMD
 CIVIL ENGR SUPPORT OFC
 CODE 15312A (ATTN EOC COOK) 1
 NAVAL CONSTRUCTION BATTALION CTR
 PORT HUENEME CA 93043

CDR, NAVAL MATERIAL COMMAND
 ATTN MAT-08T3 (DR A ROBERTS) 1
 CP6, RM 606
 WASHINGTON DC 20360

CDR
 NAVY PETROLEUM OFC
 ATTN CODE 40 1
 CAMERON STATION
 ALEXANDRIA VA 22314

CDR
 MARINE CORPS LOGISTICS SUPPORT
 BASE ATLANTIC
 ATTN CODE P841 1
 ALBANY GA 31704

DEPARTMENT OF THE AIR FORCE

HQ, USAF
 ATTN RDPT (MR EAFFY) 1
 WASHINGTON DC 20330

CDR
 US AIR FORCE WRIGHT AERONAUTICAL
 LAB
 ATTN AFWAL/POSF (MR CHURCHILL) 1
 AFWAL/POSL (MR JONES) 1
 WRIGHT-PATTERSON AFB OH 45433

CDR
USAF SAN ANTONIO AIR LOGISTICS
CTR
ATTN SAALC/SFQ (MR MAKRIS) 1
SAALC/MMPRR (MR ELLIOT) 1
KELLY AIR FORCE BASE, TX 78241

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US AIR FORCE WRIGHT AERONAUTICAL
LAB
ATTN AFWAL/MLSE (MR MORRIS) 1
AFWAL/MLBT 1
WRIGHT-PATTERSON AFB OH 45433

CDR
USAF WARNER ROBINS AIR LOGISTIC
CTR
ATTN WR-ALC/MMIRAB-1 (MR GRAHAM) 1
ROBINS AFB GA 31098

OTHER GOVERNMENT AGENCIES

US DEPARTMENT OF TRANSPORTATION
ATTN AIRCRAFT DESIGN CRITERIA
BRANCH 2
FEDERAL AVIATION ADMIN
2100 2ND ST SW
WASHINGTON DC 20590

US DEPARTMENT OF ENERGY
DIV OF TRANS ENERGY CONSERV 2
ALTERNATIVE FUELS UTILIZATION
BRANCH
20 MASSACHUSETTS AVENUE
WASHINGTON DC 20545

DIRECTOR
NATL MAINTENANCE TECH SUPPORT
CTR 2
US POSTAL SERVICE
NORMAN OK 73069

US DEPARTMENT OF ENERGY
BARTLESVILLE ENERGY RSCH CTR
DIV OF PROCESSING & THERMO RES 1
DIV OF UTILIZATION RES 1
BOX 1398
BARTLESVILLE OK 74003

SCI & TECH INFO FACILITY
ATTN NASA REP (SAK/DL) 1
P O BOX 8757
BALTIMORE/WASH INT AIRPORT MD 21240