

AD-A012 779

**EVALUATION OF BIOCIDES EFFECTS ON DIESEL FUEL UNDER
PROLONGED STORAGE**

E. A. Frame, et al

Southwest Research Institute

Prepared for:

**Army Mobility Equipment Research and
Development Center**

April 1975

DISTRIBUTED BY:

NTIS

**National Technical Information Service
U. S. DEPARTMENT OF COMMERCE**

EVALUATION OF BIOCIDES EFFECTS ON DIESEL FUEL UNDER PROLONGED STORAGE

AFLRL REPORT NO. 61

by

**E. A. Frame
J. N. Bowden**

Approved for public release;
distribution unlimited.

Prepared by

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

under contract to

**U.S. Army Mobility Equipment Research and Development Center
Petroleum & Materials Department
Fort Belvoir, Virginia**

Reproduced by
**NATIONAL TECHNICAL
INFORMATION SERVICE**
U S Department of Commerce
Springfield VA 22151

Contract No. DAAK02-73-C-0221

April 1975

217058
AD A012779

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFLRL No. 61	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Evaluation of Biocides Effects on Diesel Fuel Under Prolonged Storage		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER AFLRL No. 61
7. AUTHOR(s) E. A. Frame J. N. Bowden		8. CONTRACT OR GRANT NUMBER(s) DAAK02-73-C-0221
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Fuels & Lubricants Research Laboratory Southwest Research Institute San Antonio, Texas 78284		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Mobility Equipment Research and Development Center, Petroleum and Materials Department, Ft. Belvoir, Virginia 22060		12. REPORT DATE April 1975
		13. NUMBER OF PAGES 57
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Diesel Fuel Fuel-Soluble Biocides Fuel Storage Water-Soluble Biocides Biocides		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Five fuel-soluble and two water-soluble materials, recommended by the U.S. Army Natick Laboratories as being effective biocides for controlling growth of bacteria and fungi in fuels, were evaluated at the U.S. Army Fuels and Lubricants Research Laboratory for their effects on other fuel properties, under prolonged storage conditions. Laboratory evaluations indicated that two commercially available fuel-soluble materials and one water-soluble material had minimal effects on fuel properties. Of these, one material was selected for engine evaluation. The results of laboratory and engine evaluations are presented.		

DDC
JUL 29 1975
A

TABLE OF CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS	<i>iv</i>
LIST OF TABLES	<i>iv</i>
INTRODUCTION	1
SUMMARY	1
DISCUSSION	2
CONCLUSIONS	11
APPENDIX A—Report of Comparison of Treated Vs. Untreated Fuel Running Concurrently in a Detroit Diesel 6V-71N Truck Engine	13
APPENDIX B—Test Procedures	57
DISTRIBUTION LIST	

Preceding page blank

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Ambient Temperature Storage	7
2	Ambient Temperature Storage, 10% Water Bottoms	7
3	43°C (110°F) Cycle, No Water Bottom	8
4	43°C (110°F) Cycle, 10% Water Bottom	8

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Fuel-Soluble Biocide Storage Evaluation	4
2	Fuel-Soluble Biocide Storage Evaluation Samples Stored Over 10% Water Bottom	5
3	Storage of Diesel Fuel Over Water-Soluble Biocides	10

INTRODUCTION

Microbiological contamination of fuels has been recognized for several years as a potential problem in storage and use of fuels. Bacteria and fungi that attack hydrocarbons have been identified, and it has been recognized that biological degradation of hydrocarbons occurs at the fuel-water interface. Therefore, the elimination of water contamination is the first step in preventing deterioration due to microbes; however, complete elimination of water from storage and vehicle tanks is not always practical or, in some cases, possible. Ethylene glycol monomethyl ether (EGME), which is added to aircraft turbine fuels primarily as a fuel system icing inhibitor, has been found to be an effective biocide. Military Specification MIL-I-27686E, Inhibitor, Icing, Fuel System, is composed entirely of EGME, and evaluation and experience have shown that it does not affect the performance of fuels in jet engines. A commercially available material known as Biobor* JF is marketed as "biocide for control of micro-organisms in jet aircraft, diesel and other hydrocarbon fuels"; however, this material is not used in military fuels.

A considerable number of reports of field problems concerning microbiological deterioration of military materiel was instrumental in the initiation of a program at the U.S. Army Natick Laboratories to evaluate commercially available and experimental materials for their effectiveness as biocides in fuels. This program resulted in recommendations of five fuel-soluble materials, which included Biobor JF and EGME, and two water-soluble materials, for further evaluation.

The U.S. Army Fuels and Lubricants Research Laboratory was assigned the task of evaluating the effects of these biocides on storage, physical, chemical, and performance properties of diesel fuels treated with these materials.

This report presents the results of this evaluation.

SUMMARY

Five fuel-soluble and two water-soluble materials recommended by the U.S. Army Natick Laboratories as being effective in controlling bacterial and fungi growth were evaluated to determine their effects on the physical, chemical, and ignition properties of a standard reference diesel fuel under prolonged storage. Two of the fuel-soluble biocides, commercially available EGME and Biobor JF, produced very slight fuel deterioration during storage. Two experimental materials, described as quinolinols, had more significant effects on fuel properties than the first two materials. The gasoline antioxidant, known as "phenylene diamine" and used here in much greater concentration than in gasoline to be an

*Biobor is a trademark of United States Borax and Chemical Corporation. Composition:

Active Ingredients

2,2'-oxybis(4,4,6-trimethyl-1,3,2-dioxaborinane) 95%

2,2'-(1-methyltrimethylenedioxy)bis(4-methyl-1,3,2-dioxaborinane)

Inert Ingredients

Petroleum Naphtha [Boiling Range 127°C (260°F) to 135°C (275°F)] 5%

100%

effective biocide, caused emulsification, increased filter plugging and severe potential gum formation before and after storage. One water-soluble biocide caused very slight changes in fuel properties while the other one yielded more severe changes.

An engine evaluation of the fuel containing 270 ppm Biobor JF, which was found by laboratory evaluation to be one of the best fuel-soluble biocide candidates, was conducted in a two-cycle Detroit Diesel 6V-71N engine by the Department of Engines, Fuels, and Lubricants of Southwest Research Institute. This particular engine was selected because the basic design of the engine allows fuel system isolation between the left and right banks of the engine, thus permitting the use of the base fuel through one bank and the additive-treated fuel through the second bank. The report on the engine evaluation, which shows no harmful or beneficial effect of the biocide additive on the performance of the fuel, constitutes Appendix A of this report.

DISCUSSION

Fuel-Soluble Biocides

The five fuel-soluble biocides evaluated and the concentrations used are listed below:

Biocide	Code	Concentration, ppm
Biobor JF	BJF	270
2-methoxyethanol (methyl cellosolve or ethylene glycol monomethyl ether)	EGME	1500
DuPont A022 (N, N', di-sec-butyl para phenylenediamine)	A022	1000
5-diethylaminomethyl-8-quinolinol	EQ	200
5-di-n-butylaminomethyl-8-quinolinol	BQ	100

The BJF, EGME, and A022 are commercially available materials, while the EQ and BQ are available in small laboratory quantities.

One-gallon samples of a reference diesel fuel were stored for 6 months in glass jars with and without each of the biocides present. The samples were stored at ambient temperature, and in a temperature-controlled storage box at 43°C (110°F). Heat to the storage box was turned off each Friday afternoon, allowing the samples to cool from 43°C (110°F) to ambient temperature over the weekend in order to simulate temperature changes which might be encountered during field storage. Each fuel-biocide system was stored with and without a 10-percent volume water bottom present to simulate storage tank conditions. Deionized water of 7.5 pH was used for the water bottoms.

Before storage, the water-partition effect of each biocide in diesel fuel was determined. The procedure used was based on FTM No. 791B, Method 5340.1, "Fuel System Icing Inhibitor in Hydrocarbon Fuels" (Refractometer Method). The method consisted of shaking

800 ml of biocide containing diesel fuel with 50 ml water for 3 min. in a separatory funnel. The refractive index (R.I.) of the water layer was then determined. By comparing the R.I. of the water wash with the R.I.'s of standard biocide water solutions, the concentration of biocide in the water wash was determined. The results should be considered as approximations of partition effects because very small changes in R.I. are representative of relatively large differences in biocide concentration. The results are tabulated below:

Material	R.I. (N_D^{20})	Approximate percentage of biocide extracted from fuel
Distilled water	1.3339	---
Water wash of reference fuel + 270 ppm BJB	1.3342	60
Water wash of reference fuel + 1500 ppm EGME	1.3355	90
Water wash of reference fuel + 1000 ppm A022	1.3340	10
Water wash of reference fuel + 200 ppm EQ	1.3339	0
Water wash of reference fuel + 100 ppm BQ	1.3339	0

The EGME had the greatest extraction from the fuel by water, while EQ and BQ were not extracted by water.

The analyses of the fuel-soluble biocide samples before and after storage are tabulated in Table 1. In Table 2 are the analyses of the fuel-soluble biocide samples before and after storage over 10-percent water bottoms. A general trend observed was that storage over 10-percent water bottoms at 43°C (110°F) with the weekly cycle to ambient resulted in borderline to poor filter plugging tendencies for all samples.

As shown by the cetane numbers in Tables 1 and 2, essentially no loss in ignition quality was observed before or after prolonged storage with the biocides present. While there are some numerical differences evident in the fuel properties before and after storage as shown in Tables 1 and 2, only the most significant, detrimental changes are discussed in this report. Considering the significant changes in fuel properties of biocide-containing fuels before and after storage, the biocides were classified into three groups. The first biocide group included 270 ppm BJB and 1500 ppm EGME. Very slight detrimental effects were observed with BJB or EGME present. BJB significantly increased the fuel rust tendencies before storage as shown below:

Rust Tendencies Before Storage

Reference diesel fuel	0 (no rust)
Reference diesel fuel + 270 ppm BJB	4 (four or more large rust spots)
Reference diesel fuel + 1500 ppm EGME	0

TABLE 1. FUEL-SOLUBLE BIOCIDES STORAGE EVALUATION

Fuel	Neat Fuel		270 ppm S.I.		1500 ppm EGME		1000 ppm A022		200 ppm EO		Ref. 10 *	
	NS	RT	NS	RT	NS	RT	NS	RT	NS	RT	NS	RT
Storage Temperature °C(°F)	43(110)	43(110)	43(110)	43(110)	43(110)	43(110)	43(110)	43(110)	43(110)	43(110)	43(110)	43(110)
Analyses												
Cetane Number	51	50	51	50	50	50	49	50	49	49	50	50
Existent Gum mg/100 ml	7.4	5.2	6.2	6.6	6.4	8.0	10.6	17.4	6.4	5.8	5.0	5.2
Accelerated Stability mg/100 ml	5.6	2.1	6.5	2.9	6.8	6.3	33.0	35.3	0.5	0.9	0.3	0.4
Rambottom Carbon Residue on 10% heptans %	0.79	0.17	0.92	0.14	0.19	0.67	0.13	0.16	0.76	0.14	0.75	0.13
Filterability Index ^a	12 ^a	69 ^b	22 ^a	54 ^b	5 ^a	50 ^b	29 ^b	10 ^a	59 ^b	88 ^a	20 ^b	76 ^a
Interfacial Tension dynes/cm	28.1	28.3	28.2	28.8	25.7	22.6	25.3	24.4	16.0	14.9	16.8	27.5
Cu Strip Corrosion	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A
Total Acid Number	0.13	0.21	0.05	0.11	0.19	0.11	0.21	0.17	0.08	0.13	0.24	0.21
Ras. Tendencies ^b	0	5	4	4	3	0	2	3	0	1	0	0
Cloud Point, °C(°F)	-5	-7	-3	-7	-7	-3	-7	-7	-2	-7	-7	-7
Pour Point, °C(°F)	(25)	(20)	(26)	(20)	(20)	(26)	(20)	(20)	(28)	(20)	(20)	(20)
Viscosity @ 37.8°C(100°F), cs	(11)	(15)	(13)	(15)	(15)	(15)	(15)	(15)	(17)	(15)	(15)	(15)
	3-21	ND	3-22	ND	3-20	3-20	3-17	3-20	ND	ND	3-19	3-22
Emulsion Tendencies												
FTM 550 Cycle 1	5	3	3	3	3	3	3	3	4	4	4	4
Cycle 2	5	2	3	4	4	3	3	3	5	4	3	4
Cycle 3	5	3	3	4	4	3	3	3	5	4	3	4
Cycle 4	4	3	3	4	4	3	3	3	4	3	4	4
Cycle 5	5	3	5	4	4	4	4	4	5	4	4	5
Cycle 6	5	3	4	4	4	4	4	4	5	4	4	5
Cycle 7	5	4	5	4	5	4	4	4	4	4	4	5
Cycle 8	4	4	5	4	5	4	4	4	5	4	4	5
Cycle 9	4	4	5	4	5	4	4	4	5	4	4	5
Cycle 10	5	4	5	4	5	4	4	4	5	4	4	5

a - DuPont Filterability Index: 0°-35° = Good; 36°-80° = Fair/Borderline; 81°-91° = Poor
 b - By method in MIL-1-25017C: 0 = No rust; 1 = <6 sm. spots (6mm); 2 = 6-20 sm. spots; 3 = 21-40 sm. spots or 1-3 lg. spots; 4 = 4+ lg. spots; 5 = light red rust; 6 = hy. rust
 p - Precipitate present
 NS - Not stored, samples before storage RT - Room temperature ND - Not determined

TABLE 2. FUEL-SOLUBLE BIOCIDE STORAGE EVALUATION SAMPLES STORED OVER 10% WATER BOTTOM

Fuel	Acet Fuel		Ref. 10*		Ref. 10*		Ref. 10*		Ref. 10*	
	Ref. 10*	Ref. 10*	Ref. 10*	Ref. 10*	Ref. 10*	Ref. 10*	Ref. 10*	Ref. 10*	Ref. 10*	Ref. 10*
Storage Temperature (°C)	NS	RT	NS	RT	NS	RT	NS	RT	NS	RT
Analyses										
Cetane Number	51	51	51	51	51	51	51	51	51	51
Residual Gum mg/100 ml	7.4	3.4	5.1	5.8	5.0	3.2	3.2	6.8	7.6	10.8
Accelerated Stability mg/100 ml	5.9	3.5	5.6	5.0	5.1	1.5	1.5	1.2	1.3	2.4
Bottom Carbon Residue on 10 bottoms	0.08	0.21	0.67	1.8	1.8	0.20	0.20	0.78	0.78	2.4
Waterability Index ^a	12*	47*	50*	72*	87*	86*	86*	81*	88*	89*
Interfacial Tension dynes/cm	28.1	28.9	28.2	29.5	27.8	14.8	14.8	27.5	32.4	37.8
Oil Strip Corrosion	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A
Total Acid Number	0.15	0.15	0.05	0.11	0.21	0.15	0.15	0.02	0.11	0.14
Rust Tendencies ^b	0	0	4	0	0	0	0	0	0	0
Cloud Point, °C(°F)	-5	-7	-3	-7	-7	-2	-7	-1	-7	-7
Four Point, °C(°F)	(23)	(20)	(26)	(20)	(20)	(20)	(20)	(20)	(20)	(20)
Viscosity @ 37.8°C(100°F), cs	(11)	(15)	(15)	(15)	(15)	(15)	(15)	(15)	(15)	(15)
	NS	ND	NS	ND	ND	NS	ND	NS	ND	NS
Emulsion Tendencies										
FIN 550 Cycle 1	3	2	3	3	2	4	4*	2	2	2
Cycle 2	5	2	3	3	2	5	5	4p	2	3
Cycle 3	5	2	3	3	3	4	4	3p	3	3
Cycle 4	4	2*	3	3	3	4	4	4p	3	3
Cycle 5	5	3	3	3	3	5	5	4p	3	3
Cycle 6	5	3	3	3	3	4	4	4p	3	3
Cycle 7	5	3	3	3	3	5	5	4p	3	3
Cycle 8	4*	3	3	3	3	4	4	4p	3	3
Cycle 9	4	3	3	3	3	5	5	4p	3	3
Cycle 10	5	3	3	3	3	7	10	4+p	3	3

a - Four Filterability Index 0° 45° = Good, 46°-80° = Fair/Borderline, 81°-90° = Poor
 b - By method in MIL-12501V. C = No rust, 1 = 16 sm. spots (1mm); 2 = 6-20 sm. spots; 3 = 21-40 sm. spots; 4 = 41-80 sm. spots; 5 = 81-160 sm. spots; 6 = hy. rust

p = Precipitate present
 NS = Not stored, samples before storage RT = Room temperature ND = Not determined

After storage, without water bottoms present, the reference and EGME fuels had slightly increased rust tendencies, while the BJF fuels remained about the same as shown above. Fuels of the same composition stored over 10-percent water bottoms had excellent rust test performance. It is postulated that the decrease in rust tendency of BJF-containing fuels stored over water bottoms reflects the water extraction of BJF from the fuel. This explanation is consistent with the water-partition effects discussed earlier, which showed BJF to be readily extracted by water. The second biocide group included 200 ppm EQ and 100 ppm BQ. Greater detrimental effects on fuel properties were observed when these biocides were present. Fuels containing EQ had consistently poor filter plugging tendencies. Before storage, the rating was 81° (poor), and after storage the average of the four EQ-containing samples was 82° (poor). Several fuels containing EQ showed weakness in the emulsion tendencies test as a precipitate formed both before and after storage. Slight copper strip corrosion (1B rating) was observed after storage for two EQ fuels and one BQ fuel. One fuel with BQ present had very poor emulsion tendencies (a 9+ rating) after storage. Fuels containing EQ or BQ had significantly lower 16-hr accelerated gum stability values when compared to the base fuel and thus appear to have antioxidant functionality as shown below. The after-storage values are the average of all samples stored, with and without a water bottom, at ambient and at 43°C (110°F).

16-Hr Accelerated Stability Gum, mg/100 ml

	<u>Before storage</u>	<u>After storage (Avg of all samples)</u>
Reference diesel fuel	5.6	3.9
Reference diesel fuel + 200 ppm EQ	0.2	0.7
Reference diesel fuel + 100 ppm BQ	0.2	0.5

The third biocide group included only 1000 ppm A022. Severe detrimental effects on fuel properties were observed before and after storage. Potential problem areas included emulsion tendencies, filter plugging tendencies, and increased gum formation. The potential gum formation is illustrated below:

16-Hr Accelerated Stability Gum, mg/1000 ml

	<u>Before storage</u>	<u>After storage (Avg of all samples)</u>
Reference diesel fuel	5.6	3.9
Reference diesel fuel + 1000 ppm A022	24.4	27.0

Figures 1 through 4 are photographs illustrating the deterioration of the fuels containing 1000 ppm A022. For comparison, the fuels are labeled as to biocide content, and each photograph represents a different storage condition as follows:

- Figure 1 Ambient, no water bottom
- Figure 2 Ambient, 10-percent water bottom
- Figure 3 43°C (110°F) cycle, no water bottom
- Figure 4 43°C (110°F) cycle, 10-percent water bottom

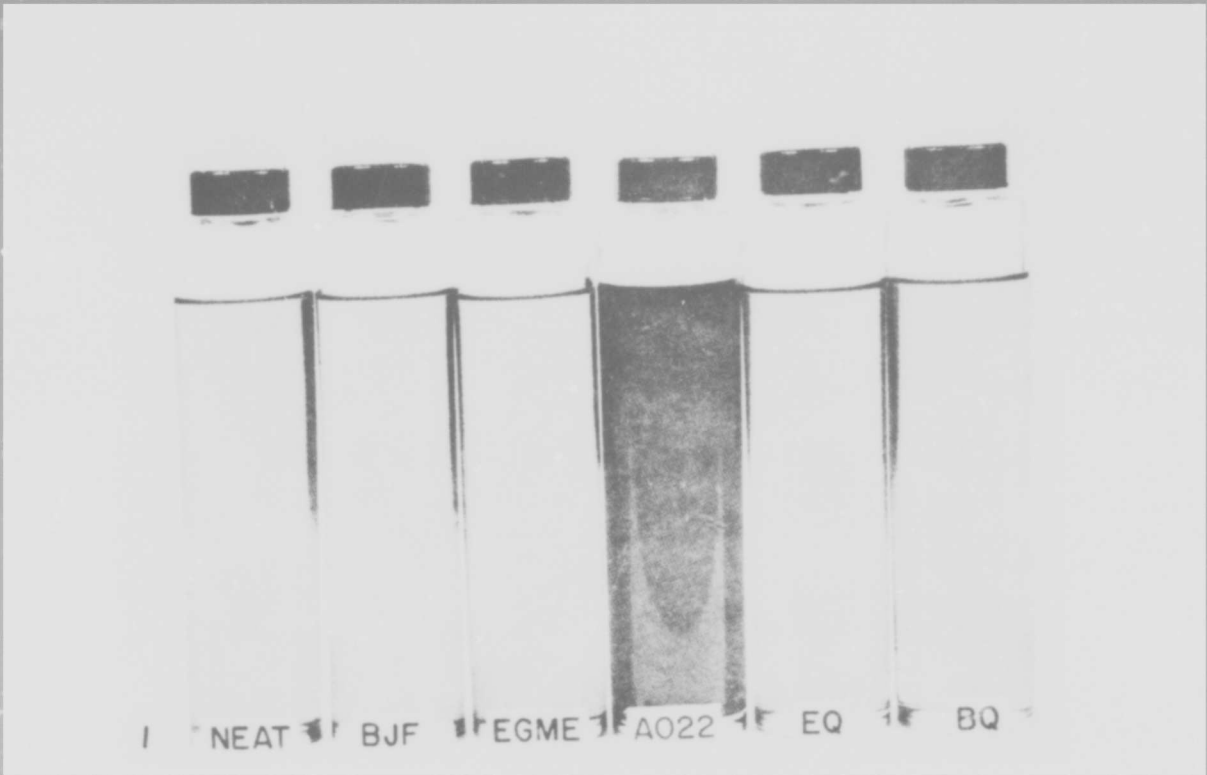


FIGURE 1. AMBIENT TEMPERATURE STORAGE

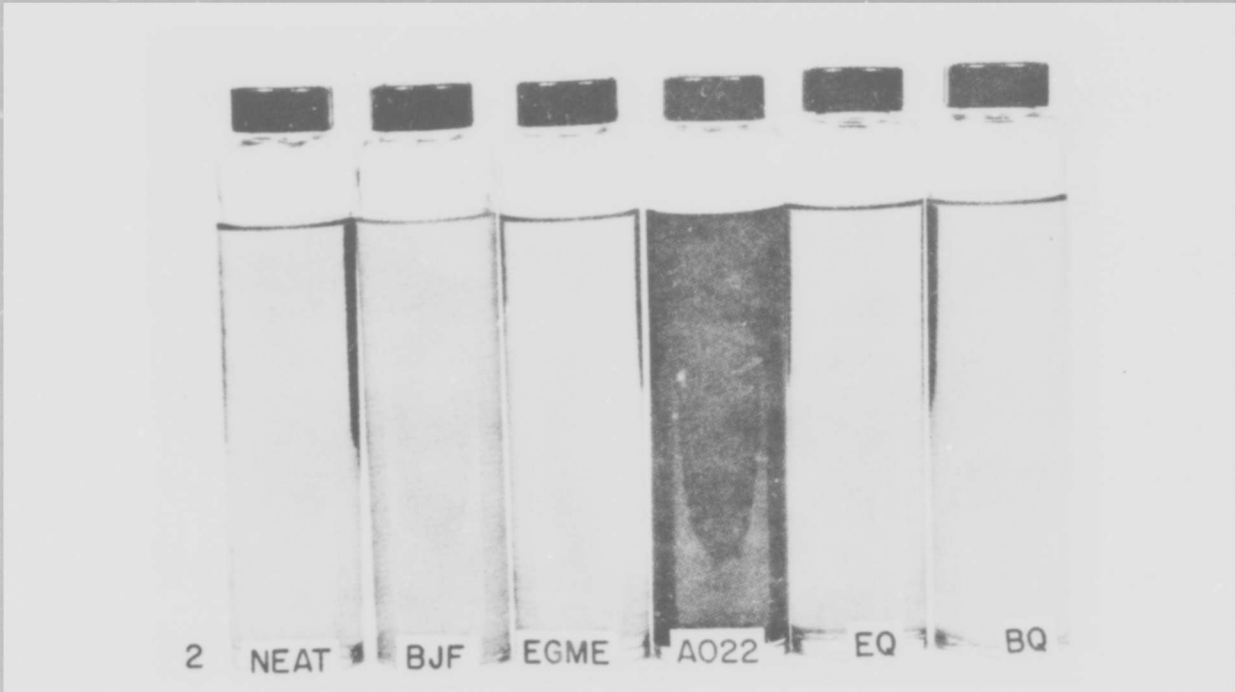


FIGURE 2. AMBIENT TEMPERATURE STORAGE, 10% WATER BOTTOMS

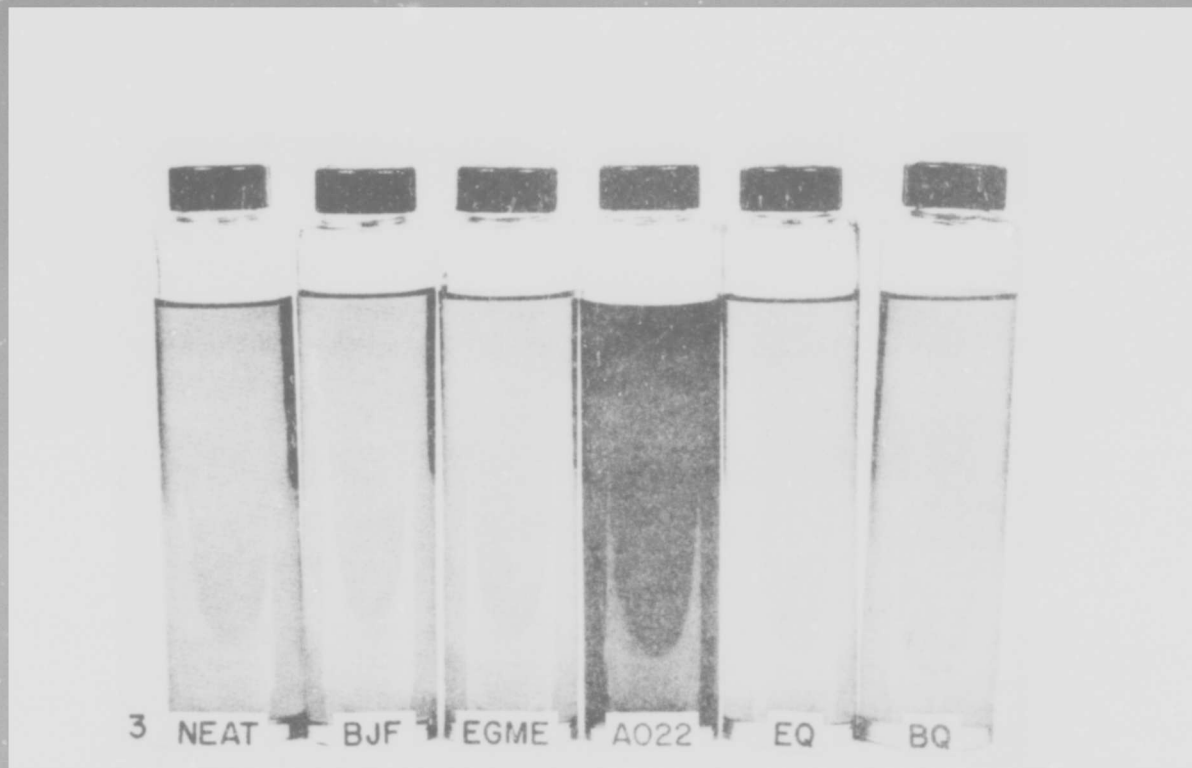


FIGURE 3. 43°C (110°F) CYCLE, NO WATER BOTTOM

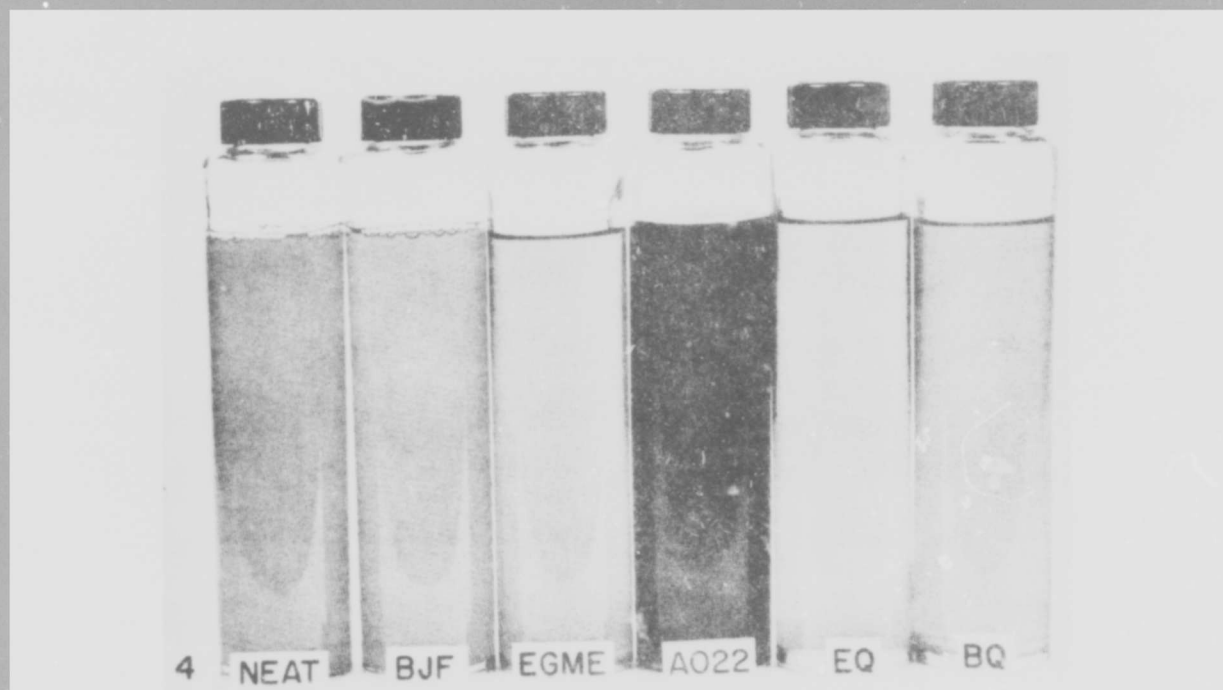


FIGURE 4. 43°C (110°F) CYCLE, 10% WATER BOTTOM

To summarize the evaluation of the fuel-soluble biocides, EGME and BJF were judged to be the only acceptable materials since they had a minimal effect on fuel properties during storage. Fuels containing biocides EQ and BQ exhibited some undesirable characteristics, and fuels with A022 had severe problems in emulsion tendencies, filter plugging, and gum formation.

Water-Soluble Biocides

The two water-soluble biocides evaluated, and the concentrations used are listed below:

<u>Biocide</u>	<u>Code</u>	<u>Concentration, ppm</u>
Lauryl isoquinolinium sacharinate (Onyxide 4300)	LIQS	10
Dodecylguanadine-HCl (Cytos 2013)	DGH	50

One-gallon samples of reference diesel fuel were stored for 6 weeks ... glass jars over neat and biocide-containing 10-percent volume water bottoms. The water bottoms had buffered pH levels of 5.8, 7.0, and 8.0. Storage was at ambient temperature and at 43°C (110°F) with a weekly cycle to ambient using the same cycle procedure as in the fuel-soluble biocide evaluation. The Onyxide 4300 (LIQS) was not readily soluble in water. With heat applied, the solubility was improved, but was still difficult.

In Table 3 are the analyses of reference diesel fuel before storage, and after storage over 10-percent water bottoms. In general, the fuel properties showed insignificant change after storage, and the water bottom pH's remained unchanged. Initially, a cetane number reduction had been reported for about half the samples stored over these biocides. Because of the wide range of cetane numbers determined and lack of correlation between cetane numbers and storage conditions, storage samples were prepared again, and the storage procedure repeated. Cetane numbers of fuels from the second storage test showed essentially no loss in ignition quality.

All fuels, whether stored over neat or biocide-containing water bottoms showed slightly increased rust tendencies compared to the reference fuel before storage. Most of the fuels stored over DGH had slightly greater filter plugging and emulsion tendencies than fuels stored over neat or LIQS-containing water bottoms. Both conditions indicate a trend towards very slight deterioration of fuel properties. In summary, storage of diesel fuel over either LIQS or DGH was acceptable, with LIQS being preferred, despite its reluctant water solubility, because it resulted in the least fuel property changes.

Engine Evaluation

The prolonged storage evaluation of the candidate biocides indicated that two fuel-soluble and one water-soluble additives had minimal effects on diesel fuel characteristics. Both fuel-soluble materials are commercially available and one, EGME, has been used extensively in aircraft turbine fuels with no detrimental effects on performance. JP-5 aircraft turbine fuel, which requires the addition of a minimum of 0.1 v percent EGME, has been

used as the alternate fuel for compression ignition engines, and frequently in Alaska, Jet A-1 containing EGME is the primary fuel for diesel-powered equipment. Therefore, on recommendation of the Petroleum and Materials Department of MERDC, BJB was selected for an engine evaluation, which was conducted by the Department of Engines, Fuels and Lubricants of Southwest Research Institute. A two-cycle Detroit Diesel 6V-71N engine was utilized which permits fuel system isolation between the left and right banks of the engine. Thus, the engine fuel evaluation was conducted by supplying a base diesel fuel to the left bank and the fuel treated with BJB to the right bank. A report on engine test results appears as Appendix A, and indicates that exhaust emissions, smoke engine wear, and deposit formation were not significantly affected by the presence of the additive.

Since the water-soluble biocide theoretically would perform its function in a fuel storage tank, and would not be solubilized into the fuel prior to combustion in an engine, the evaluation of the LIQS water-soluble material in an engine test was not deemed necessary.

CONCLUSIONS

Two fuel-soluble biocides, BJB and EGME, and one water-soluble biocide, LIQS, had very minimal effects on diesel fuel properties under prolonged storage. Fuel-soluble EQ and BQ, and water-soluble DGH showed greater potential fuel deterioration during storage. Fuel-soluble A022 was not satisfactory for use at 1000 ppm because of the detrimental effects on fuel properties observed before and after prolonged storage.

Analysis of the engine performance data and inspection indicated that the fuel treated with BJB had neither a helpful nor a detrimental effect.

APPENDIX A

**REPORT OF COMPARISON OF TREATED VS. UNTREATED
FUEL RUNNING CONCURRENTLY IN A
DETROIT DIESEL 6V-71N TRUCK ENGINE**

Preceding page blank

TABLE OF CONTENTS

	Page
INTRODUCTION	17
DISCUSSION	18
OPERATING DATA.	21
ENGINE PERFORMANCE DATA.	23
SMOKE AND EMISSIONS DATA	29
ENGINE WEAR DATA	33
ENGINE DEPOSITS.	49
BASE FUEL INSPECTION.	55

Preceding page blank

INTRODUCTION

This engine evaluation was programmed to provide data on diesel engine performance and internal cleanliness when operated on a fuel containing a chemical supplied and blended by the U.S. Army Fuels and Lubricants Research Laboratory.

A 2 cycle Detroit Diesel 6V-71N engine was used for this program. The basic design of this engine permits fuel system isolation between the left and right banks of the engine. For this work the base (untreated) fuel was run in the left bank and base fuel plus chemical (treated) was run in the right bank.

The operational mode was a 531 hour Detroit Diesel Allison truck cycle.

Preceding page blank

DISCUSSION

A Detroit Diesel 6V-71N diesel engine was rebuilt to new engine tolerances and specifications. The engine fuel system was modified to permit normal operation with left and right banks of the engine completely isolated from each other.

During the initial engine buildup each injector was evaluated using a liquid-injection bench apparatus. This procedure permits clear observation of the spray pattern, to include penetration, cone angle and detection of erratic sprays from individual tip holes. Comparison of all injectors and between individual injectors before and after the engine test were made. No spray pattern changes were noted which would indicate additive-injector system incompatibility. A typical spray pattern display is shown on page 4.

The engine was mounted on a test stand and connected to a 400 horsepower eddy current dynamometer for power absorption and control. Pressure gauges and thermocouples were utilized for monitoring engine performance and condition. Pressures and temperatures were maintained with preset automatic controls. Operational command is accomplished by programmed timer.

Engine performance data was obtained initially, during and at the conclusion of the test. Performance data obtained included brake horsepower, brake specific fuel consumption, exhaust smoke, and exhaust gas analysis.

A Caterpillar 1-11 reference diesel fuel was used as the test fuel to which 270 ppm Biobor JF, a commercial biocide product, was added. This fuel blend had been evaluated* for fuel-additive compatibility, under accelerated laboratory conditions prior to the engine test reported herein. The storage studies showed no detrimental additive effects on the base fuel's chemical, physical or ignition properties. During the engine evaluation phase, fuel degradation was monitored using ASTM D381 Existent Gum procedure. The following data were obtained:

<u>Sampling</u>	<u>Existent Gum mg/100 ml</u>
Initial fuel blend (12-10-73)	4.3
Fuel remaining in tank (12-28-73)	7.8
After addition of 1000 gallons new fuel batch (12-28-73)	3.9

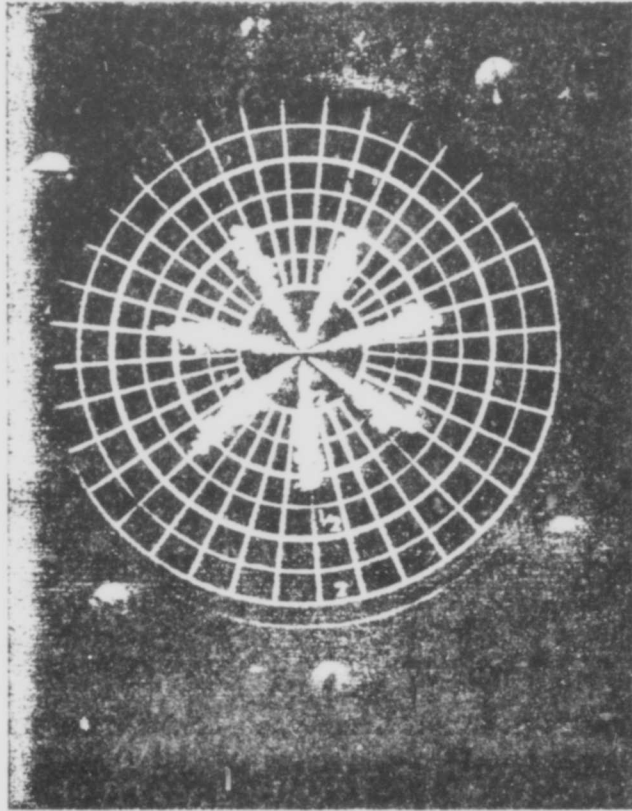
These results indicate that some fuel deterioration occurred due to heating-recycling of the fuel during engine operation, however the degradation was within acceptable limits and compared favorably with past storage data.

At the conclusion of the 531 hour procedure the engine was disassembled, inspected for engine condition and deposit formation.

Analysis of performance data and engine inspection indicates that the treated fuel has neither a helpful nor a detrimental effect.

* Evaluation of Biocide Effects on Diesel Fuel Under Prolonged Storage, AFLRL, 11 March 74.

A TYPICAL SPRAY PATTERN



!

OPERATING DATA

DETROIT DIESEL 6V-71N
FUEL TEST

Lubricant: Mobil Delvac 1130 SAE 30 Date January 9, 1974

Fuel Code Right Bank - Treated DF-126 Duration of test, hrs. 531

Left Bank - Untreated RDF-6

OPERATING CONDITIONS
TRUCK CYCLE

PHASE 1

	<u>Max.</u>	<u>Min.</u>	<u>Avg.</u>
Speed, rpm	508	491	500
Load, bhp	2.0	2.0	2.0
Crankcase Oil Temperature, °F	130	118	123
Water Out Temperature, °F	126	112	119
Exhaust Back Pressure, in. hg. L.B.	2.4	0.1	0.8
Exhaust Back Pressure, in. hg. R.B.	2.4	0.1	0.9
Oil Pressure, psi	25.0	15.5	19.9

PHASE 2

Speed, rpm	2310	2297	2301
Load, bhp	228.6	223.2	224.7
Crankcase Oil Temperature, °F	260	248	254
Water Out Temperature, °F	200	190	194
Exhaust Back Pressure, in. hg. L.B.	4.2	3.8	4.0
Exhaust Back Pressure, in. hg. R.B.	4.3	3.9	4.0
Oil Pressure, psi	51.5	48.5	49.6
Blowby rate, cfh	338	249	284
Fuel Flow, lbs/hr L.B.	45.6	40.3	43.3
Fuel Flow, lbs/hr R.B.	45.3	40.3	43.3

PHASE 3

Speed, rpm	2413	2392	2404
Load, bhp	230.8	226.0	230.0
Crankcase Oil Temperature, °F	259	250	255
Water Out Temperature, °F	197	190	195
Exhaust Back Pressure, in. hg. L.B.	4.1	4.0	4.0
Exhaust Back Pressure, in. hg. R.B.	4.2	4.0	4.0
Oil Pressure, psi	50.5	49.0	49.8
Blowby rate, cfh	321	249	297
Fuel Flow, lbs/hr L.B.	47.1	42.7	44.6
Fuel Flow, lbs/hr R.B.	47.0	42.3	44.4

Oil Consumption 0 - 531 Hours 0.1526 lbs/hr

ENGINE PERFORMANCE DATA

ENGINE PERFORMANCE DATA
(Before Test)

Fuel: Untreated (RDF -6)

Condition	Test Condition	2200 RPM Full Throttle	2000 RPM Full Throttle	1800 RPM Full Throttle	1600 RPM Full Throttle
Beam Load, Lbs.	293	346	363	366	368
BHP	224.6	253.7	242.0	219.6	196.3
Fuel Flow, Lbs./Hr.					
Left	42.65	52.48	48.26	45.45	40.63
Right	42.55	51.14	47.75	44.67	40.27
Total	85.20	103.62	96.01	90.12	81.00
BSFC, Left	0.3798	0.4137	0.3988	0.4139	0.4140
BSFC, Right	0.3789	0.4032	0.3946	0.4068	0.4103
BSFC, Average	0.3793	0.4084	0.3967	0.4104	0.4126

Preceding page blank

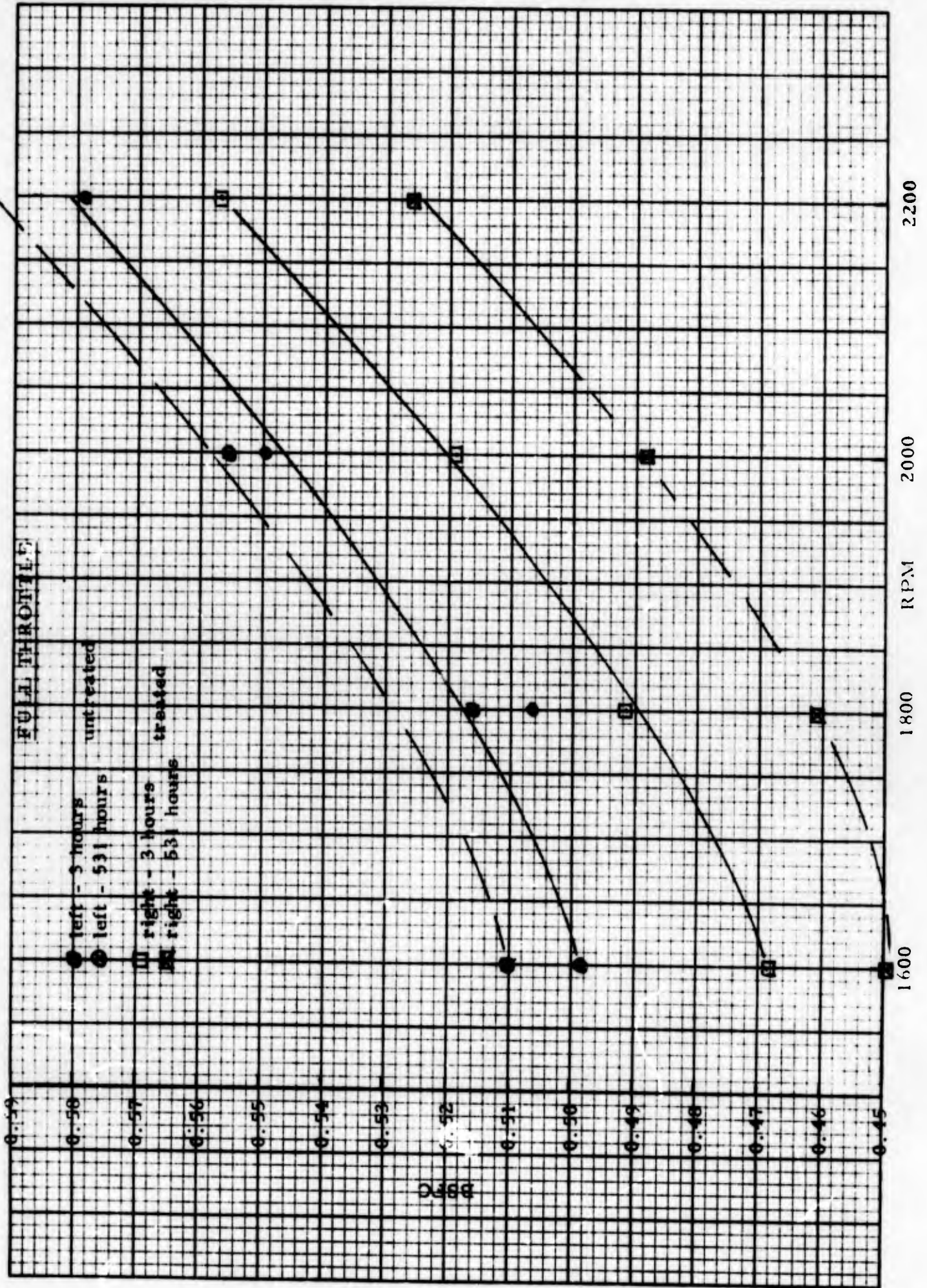
ENGINE PERFORMANCE DATA

(Left Bank) Fuel: Untreated (RDF -6)

Condition	1600 RPM		1800 RPM		2000 RPM		2200 RPM	
	Full Throttle	531	Full Throttle	531	Full Throttle	531	Full Throttle	531
Interval, Hours	3	531	3	531	3	531	3	531
Beam Load, Lbs.	146	152	147	145	134	132	124	120
BHP	83.2	81.1	88.2	87.0	89.3	88.0	90.9	88.0
Fuel Flow, Lbs./Hr.	41.47	41.38	44.67	44.89	49.11	48.91	52.63	52.79
BSFC	0.4984	0.5102	0.5065	0.5160	0.5499	0.5558	0.5790	0.5998

(Right Bank) Fuel: Treated (DF -126)

Condition	1600 RPM		1800 RPM		2000 RPM		2200 RPM	
	Full Throttle	531	Full Throttle	531	Full Throttle	531	Full Throttle	531
Interval, Hours	3	531	3	531	3	531	3	531
Beam Load, Lbs.	159	165	151	158	139	147	127	133
BHP	84.8	88.0	90.6	94.8	92.7	98.0	93.1	97.5
Fuel Flow, Lbs./Hr.	39.74	39.56	44.55	43.69	48.13	47.87	51.87	51.28
BSFC	0.4686	0.4496	0.4917	0.4609	0.5192	0.4885	0.5571	0.5260



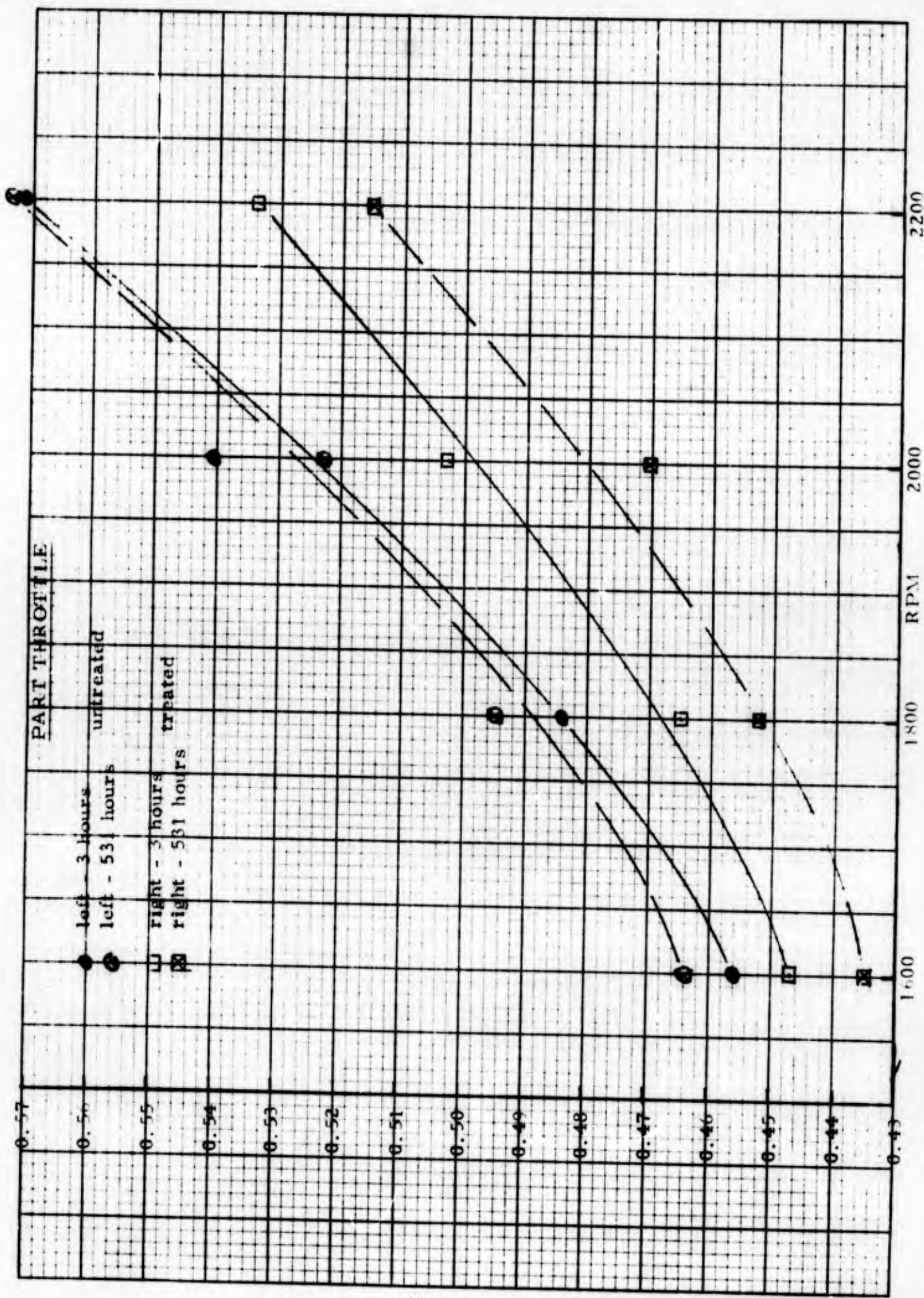
ENGINE PERFORMANCE DATA

(Left Bank) Fuel: Untreated (RDF-6)

Condition	1600 RPM		1800 RPM		2000 RPM		2200 RPM	
	Part	Throttle	Part	Throttle	Part	Throttle	Part	Throttle
Interval, Hours	3	531	3	531	3	531	3	531
Beam Load, Lbs.	149	146	142	140	130	126	117	115
BHP	79.5	77.9	85.2	84.0	86.7	84.0	85.8	84.3
Fuel Flow, Lbs./Hr.	36.25	36.14	41.24	41.28	46.88	43.90	49.05	48.26
BSFC	0.4560	0.4640	0.4840	0.4915	0.5407	0.5226	0.5717	0.5724

(Right Bank) Fuel: Treated (DF-126)

Condition	1600 RPM		1800 RPM		2000 RPM		2200 RPM	
	Part	Throttle	Part	Throttle	Part	Throttle	Part	Throttle
Interval, Hours	3	531	3	531	3	531	3	531
Beam Load, Lbs.	153	160	145	152	135	141	123	126
BHP	81.6	85.3	87.0	91.2	90.0	94.0	90.2	92.4
Fuel Flow, Lbs./Hr.	36.44	37.11	40.45	41.28	45.23	44.23	48.13	47.62
BSFC	0.4466	0.4351	0.4649	0.4527	0.5026	0.4705	0.5336	0.5154



SMOKE AND EMISSIONS DATA

EXHAUST SMOKE RATINGS

<u>Interval, Hours</u>	<u>Right Bank (Treated)</u>	<u>Left Bank (Untreated)</u>
24	1.40	1.96
387	0.83	1.76
503	1.06	2.56

EXHAUST GAS EMISSION DATA

RIGHT SIDE (TREATED)

<u>Interval, Hours</u>	<u>CO, %</u>	<u>CO₂, %</u>	<u>O₂ %</u>	<u>HC, ppm</u>	<u>NO, ppm</u>	<u>NO_x, ppm</u>
24	0.003	6.40	12.41	67	720	750
503	0.002	6.20	12.41	37	597	647

LEFT SIDE (UNTREATED)

<u>Interval, Hours</u>	<u>CO, %</u>	<u>CO₂, %</u>	<u>O₂ %</u>	<u>HC, ppm</u>	<u>NO, ppm</u>	<u>NO_x, ppm</u>
24	0.022	6.47	12.16	60	616	650
503	0.027	6.40	12.00	40	530	564

ENGINE WEAR DATA

Preceding page blank

CONNECTING ROD BEARING CLEARANCE
INCHES, (PLASTIGAGE)

RIGHT SIDE

No. 1 Right

0.002

No. 2 Right

0.002

No. 3 Right

0.002

LEFT SIDE

No. 1 Left

0.002

No. 2 Left

0.002

No. 3 Left

0.002

CONNECTING ROD BEARING WEIGHTS, GRAMS

RIGHT SIDE

<u>Upper Half</u>	<u>No. 1 Right</u>	<u>No. 2 Right</u>	<u>No. 3 Right</u>
Start	83.3124	83.2872	83.3326
Finish	83.2432	83.2270	83.2735
Loss	00.0692	00.0602	00.0591
<u>Lower Half</u>			
Start	69.6142	69.8515	69.6973
Finish	69.6030	69.8330	69.6874
Loss	00.0112	00.0185	00.0099
 Total Loss	 00.0804	 00.0787	 00.0690

LEFT SIDE

<u>Upper Half</u>	<u>No. 1 Left</u>	<u>No. 2 Left</u>	<u>No. 3 Left</u>
Start	83.7512	83.7776	83.6444
Finish	83.6720	83.6995	83.5780
Loss	00.0792	00.0781	00.0664
<u>Lower Half</u>			
Start	72.5041	69.7002	72.0407
Finish	72.4917	69.6896	72.0244
Loss	00.0124	00.0106	00.0153
 Total Loss	 00.0916	 00.0887	 00.0817

RING GAP MEASUREMENTS, INCHES

	<u>Ring Position</u>	<u>Cylinder No. 1 Right</u>	<u>Cylinder No. 2 Right</u>	<u>Cylinder No. 3 Right</u>	<u>Average</u>
1.	(Top) Finish	0.043	0.044	0.042	
	Start	0.036	0.032	0.035	
	Increase	0.009	0.012	0.007	0.009
2.	Finish	0.032	0.032	0.035	
	Start	0.030	0.031	0.034	
	Increase	0.002	0.001	0.001	0.001
3.	Finish	0.032	0.031	0.033	
	Start	0.030	0.031	0.032	
	Increase	0.002	0.000	0.001	0.001
4.	Finish	0.028	0.032	0.034	
	Start	0.028	0.032	0.034	
	Increase	0.000	0.000	0.000	0.000
5.	(Top) Finish	0.026	0.020	0.024	
	Start	0.024	0.020	0.024	
	Increase	0.002	0.000	0.000	0.001
5.	(Bot.) Finish	0.025	0.024	0.024	
	Start	0.022	0.023	0.022	
	Increase	0.003	0.001	0.002	0.002
6.	(Top) Finish	0.026	0.025	0.022	
	Start	0.021	0.024	0.020	
	Increase	0.005	0.001	0.002	0.003
6.	(Bot.) Finish	0.025	0.025	0.025	
	Start	0.021	0.025	0.022	
	Increase	0.004	0.000	0.003	0.002

RING GAP MEASUREMENTS, INCHES

	<u>Ring Position</u>	<u>Cylinder No. 1 Left</u>	<u>Cylinder No. 2 Left</u>	<u>Cylinder No. 3 Left</u>	<u>Average</u>
1.	(Top) Finish	0.044	0.040	0.042	0.009
	Start	0.035	0.031	0.032	
	Increase	0.009	0.009	0.010	
2.	Finish	0.031	0.031	0.031	0.001
	Start	0.030	0.030	0.030	
	Increase	0.001	0.001	0.001	
3.	Finish	0.033	0.031	0.028	0.001
	Start	0.031	0.030	0.028	
	Increase	0.002	0.001	0.000	
4.	Finish	0.033	0.031	0.031	0.001
	Start	0.031	0.031	0.030	
	Increase	0.002	0.000	0.001	
5.	(Top) Finish	0.022	0.026	0.024	0.000
	Start	0.022	0.025	0.024	
	Increase	0.000	0.001	0.000	
5.	(Bot.) Finish	0.027	0.026	0.029	0.004
	Start	0.024	0.023	0.024	
	Increase	0.003	0.003	0.005	
6.	(Top) Finish	0.027	0.027	0.022	0.002
	Start	0.024	0.025	0.020	
	Increase	0.003	0.002	0.002	
6.	(Bot.) Finish	0.025	0.026	0.022	0.001
	Start	0.024	0.024	0.022	
	Increase	0.001	0.002	0.000	

PISTON RING SIDE CLEARANCE, INCHES

PISTON NO. 1 (RIGHT)

	<u>Ring No. 1</u>		<u>Ring No. 2</u>		<u>Ring No. 3</u>		<u>Ring No. 4</u>		<u>Ring No. 5</u>		<u>Ring No. 6</u>	
	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>
Finish	0.0055	0.0050	0.0110	0.0100	0.0055	0.0050	0.0055	0.0050	0.0045	0.0040	0.0040	0.0040
Start	0.0045	0.0040	0.0115	0.0110	0.0055	0.0050	0.0055	0.0050	0.0040	0.0035	0.0035	0.0030
Difference	0.0010	0.0010	-0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0005	0.0005	0.0010

PISTON NO. 2 (RIGHT)

Finish	0.0060	0.0050	0.0110	0.0090	0.0050	0.0040	0.0050	0.0040	0.0040	0.0035	0.0050	0.0040
Start	0.0060	0.0060	0.0115	0.0110	0.0055	0.0050	0.0055	0.0050	0.0035	0.0030	0.0035	0.0030
Difference	0.0000	-0.0010	-0.0005	-0.0020	-0.0005	-0.0010	-0.0005	-0.0010	0.0005	0.0005	0.0015	0.0010

PISTON NO. 3 (RIGHT)

Finish	0.0050	0.0050	0.0115	0.0110	0.0060	0.0050	0.0060	0.0055	0.0050	0.0050	0.0045	0.0045
Start	0.0045	0.0040	0.0110	0.0105	0.0055	0.0050	0.0055	0.0050	0.0035	0.0030	0.0040	0.0035
Difference	0.0005	0.0010	0.0005	0.0005	0.0005	0.0000	0.0005	0.0005	0.0015	0.0020	0.0005	0.0010

PISTON RING SIDE CLEARANCE, INCHES

PISTON NO. 1 (LEFT)

	<u>Ring No. 1</u>		<u>Ring No. 2</u>		<u>Ring No. 3</u>		<u>Ring No. 4</u>		<u>Ring No. 5</u>		<u>Ring No. 6</u>	
	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>
Finish	0.0050	0.0030	0.0110	0.0070	0.0055	0.0050	0.0055	0.0050	0.0045	0.0040	0.0040	0.0040
Start	0.0045	0.0040	0.0110	0.0105	0.0055	0.0050	0.0055	0.0050	0.0040	0.0035	0.0035	0.0030
Difference	0.0005	-0.0010	0.0000	-0.0035	0.0000	0.0000	0.0000	0.0000	0.0005	0.0005	0.0005	0.0010

PISTON NO. 2 (LEFT)

Finish	0.0040	0.0040	0.0110	0.0095	0.0045	0.0040	0.0050	0.0040	0.0040	0.0040	0.0040	0.0040
Start	0.0050	0.0050	0.0115	0.0110	0.0050	0.0050	0.0050	0.0050	0.0035	0.0030	0.0040	0.0035
Difference	-0.0010	-0.0010	-0.0005	-0.0010	-0.0005	-0.0010	-0.0000	-0.0010	0.0005	0.0010	0.0000	0.0005

PISTON NO. 3 (LEFT)

Finish	0.0060	0.0070	0.0120	0.0110	0.0055	0.0050	0.0055	0.0050	0.0050	0.0050	0.0040	0.0040
Start	0.0055	0.0060	0.0115	0.0115	0.0055	0.0050	0.0055	0.0055	0.0040	0.0040	0.0040	0.0035
Difference	0.0005	0.0010	0.0005	-0.0005	0.0000	0.0000	0.0000	-0.0005	0.0010	0.0010	0.0000	0.0005

RING WEIGHT MEASUREMENTS, GRAMS

	<u>Ring Position</u>	<u>Cylinder No. 1 Right</u>	<u>Cylinder No. 2 Right</u>	<u>Cylinder No. 3 Right</u>	<u>Average</u>
1.	(Top) Start	20.1052	20.2187	20.1485	
	Finish	20.0202	20.0598	20.0368	
	Loss	00.0850	00.1589	00.1117	00.1185
2.	Start	20.4802	20.4389	20.6480	
	Finish	20.4499	20.4049	20.6192	
	Loss	00.0303	00.0340	00.0288	00.0310
3.	Start	20.6923	20.4623	20.6726	
	Finish	20.6779	20.4475	20.6621	
	Loss	00.0144	00.0148	00.0105	00.0132
4.	Start	20.6028	20.6281	20.6430	
	Finish	20.5960	20.6216	20.6363	
	Loss	00.0068	00.0065	00.0067	00.0067
5.	(Top) Start	13.8660	13.7742	13.7565	
	Finish	13.8491	13.7584	13.7396	
	Loss	00.0169	00.0158	00.0169	00.0165
5.	(Bot.) Start	13.4136	13.4615	13.2772	
	Finish	13.3903	13.4411	13.2559	
	Loss	00.0233	00.0204	00.0213	00.0217
6.	(Top) Start	13.4181	13.7080	13.4043	
	Finish	13.3989	13.6910	13.3844	
	Loss	00.0192	00.0170	00.0199	00.0187
6.	(Bot.) Start	13.4033	13.4652	13.6236	
	Finish	13.3866	13.4497	13.6034	
	Loss	00.0167	00.0155	00.0202	00.0175

RING WEIGHT MEASUREMENTS, GRAMS

	<u>Ring Position</u>	<u>Cylinder No. 1 Left</u>	<u>Cylinder No. 2 Left</u>	<u>Cylinder No. 3 Left</u>	<u>Average</u>
1.	(Top) Start	20.3408	20.0658	20.0655	
	Finish	20.2122	19.9635	19.9596	
	Loss	00.1326	00.1023	00.1059	00.1136
2.	Start	20.4026	20.4281	20.4619	
	Finish	20.3563	20.3988	20.4372	
	Loss	00.0463	00.0293	00.0247	00.0334
3.	Start	20.6294	20.6574	20.3680	
	Finish	20.5955	20.6450	20.3581	
	Loss	00.0339	00.0124	00.0099	00.0187
4.	Start	20.4314	20.4257	20.5745	
	Finish	20.4088	20.4171	20.5657	
	Loss	00.0226	00.0086	00.0088	00.0133
5.	(Top) Start	13.5781	14.0293	13.4890	
	Finish	13.5567	14.0136	13.4647	
	Loss	00.0214	00.0157	00.0243	00.0205
5.	(Bot.) Start	13.4849	13.3529	13.6173	
	Finish	13.4593	13.3286	13.5832	
	Loss	00.0256	00.0243	00.0341	00.0280
6.	(Top) Start	13.5095	13.1412	13.2763	
	Finish	13.4870	13.1196	13.2516	
	Loss	00.0225	00.0216	00.0247	00.0229
6.	(Bot.) Start	13.6195	13.7458	13.6745	
	Finish	13.5992	13.7244	13.6511	
	Loss	00.0203	00.0214	00.0234	00.0217

CYLINDER LINER WEAR, INCHES

<u>Distance From Top Of Liner</u>	<u>No. 1 Right</u>	<u>No. 2 Right</u>	<u>No. 3 Right</u>	<u>No. 1 Left</u>	<u>No. 2 Left</u>	<u>No. 3 Left</u>
5/16"	0.0013	0.0016	0.0005	-0.0004	-0.0012	-0.0006
7/8"	0.0017	0.0011	0.0005	-0.0002	-0.0004	-0.0002
1 9/16"	0.0010	0.0010	0.0003	-0.0004	-0.0006	-0.0002
2 1/4"	0.0003	0.0006	0.0000	-0.0002	-0.0009	-0.0002
3"	0.0006	0.0007	0.0001	-0.0002	-0.0004	0.0006
3 9/16"	0.0007	0.0008	0.0003	-0.0001	-0.0002	0.0005
5 9/16"	0.0010	0.0007	0.0001	0.0000	0.0001	0.0004
7 1/2"	0.0001	0.0002	0.0001	-0.0001	-0.0008	-0.0007
10"	0.0001	0.0000	0.0002	0.0001	-0.0003	-0.0006

CYLINDER MEASUREMENTS, INCHES

NO. 1 RIGHT

Distance From Top of Liner	ABOVE PORTS					BELOW PORTS			
	5/16"	7/8"	1 9/16"	2 1/4"	3"	3 9/16"	5 9/16"	7 1/2"	10"
(Before) XZ	4.2487	4.2486	4.2486	4.2489	4.2495	4.2496	4.2501	4.2490	4.2499
Cyl. No. XW	4.2495	4.2492	4.2491	4.2495	4.2499	4.2502	4.2510	4.2498	4.2489
I Right WY	4.2493	4.2488	4.2483	4.2488	4.2492	4.2496	4.2495	4.2487	4.2493
WZ	4.2485	4.2483	4.2483	4.2482	4.2487	4.2488	4.2484	4.2485	4.2500
Avg. Diameter	4.2490	4.2487	4.2486	4.2489	4.2493	4.2496	4.2498	4.2492	4.2495
(After) XZ	4.2504	4.2500	4.2496	4.2495	4.2499	4.2506	4.2506	4.2492	4.2496
Cyl. No. XW	4.2504	4.2503	4.2501	4.2491	4.2506	4.2507	4.2511	4.2495	4.2499
I Right WY	4.2509	4.2502	4.2497	4.2495	4.2499	4.2501	4.2509	4.2494	4.2496
WZ	4.2494	4.2507	4.2491	4.2488	4.2493	4.2497	4.2507	4.2492	4.2493
Avg. Diameter	4.2503	4.2504	4.2496	4.2492	4.2499	4.2503	4.2508	4.2493	4.2496
After	4.2503	4.2504	4.2496	4.2492	4.2499	4.2503	4.2508	4.2493	4.2496
Before	4.2490	4.2487	4.2486	4.2489	4.2493	4.2496	4.2498	4.2492	4.2495
Wear	0.0013	0.0017	0.0010	0.0003	0.0006	0.0007	0.0010	0.0001	0.0001

XZ - Transverse Axis
 XW
 WY - Longitudinal Axis
 WZ

CYLINDER MEASUREMENTS, INCHES

NO. 2 RIGHT

Distance From Top of Liner	ABOVE PORTS					BELOW PORTS			
	5/16"	7/8"	1 9/16"	2 1/4"	3"	3 9/16"	5 9/16"	7 1/2"	10"
(Before) XZ	4.2486	4.2485	4.2481	4.2485	4.2488	4.2489	4.2493	4.2487	4.2483
Cyl. No. XW	4.2490	4.2486	4.2484	4.2486	4.2489	4.2492	4.2496	4.2490	4.2487
2 Right WY	4.2483	4.2481	4.2479	4.2481	4.2486	4.2490	4.2489	4.2488	4.2492
WZ	4.2481	4.2481	4.2478	4.2481	4.2485	4.2489	4.2487	4.2485	4.2493
Avg. Diameter	4.2485	4.2483	4.2481	4.2483	4.2487	4.2490	4.2491	4.2488	4.2489
(After) XZ	4.2506	4.2498	4.2495	4.2492	4.2500	4.2503	4.2500	4.2495	4.2496
Cyl. No. XW	4.2496	4.2491	4.2490	4.2492	4.2496	4.2498	4.2505	4.2497	4.2496
2 Right WY	4.2497	4.2490	4.2490	4.2487	4.2490	4.2493	4.2498	4.2485	4.2481
WZ	4.2506	4.2496	4.2489	4.2486	4.2489	4.2498	4.2490	4.2481	4.2483
Avg. Diameter	4.2501	4.2494	4.2491	4.2489	4.2494	4.2498	4.2498	4.2490	4.2489
After	4.2501	4.2494	4.2491	4.2489	4.2494	4.2498	4.2498	4.2490	4.2489
Before	4.2485	4.2483	4.2481	4.2483	4.2487	4.2490	4.2491	4.2488	4.2489
Wear	0.0016	0.0011	0.0010	0.0006	0.0007	0.0008	0.0007	0.0002	0.0000

XZ - Transverse Axis
 XW
 WY - Longitudinal Axis
 WZ

CYLINDER MEASUREMENTS, INCHES

NO. 3 RIGHT

Distance From Top of Liner	ABOVE PORTS						BELOW PORTS			
	5/16"	7/8"	1 9/16"	2 1/4"	3"	3 9/16"	5 9/16"	7 1/2"	10"	
(Before) XZ	4.2487	4.2481	4.2481	4.2480	4.2484	4.2488	4.2496	4.2495	4.2496	
Cyl. No. XW	4.2501	4.2498	4.2495	4.2499	4.2502	4.2504	4.2508	4.2503	4.2492	
3 Right WY	4.2505	4.2496	4.2496	4.2498	4.2502	4.2503	4.2505	4.2495	4.2491	
WZ	4.2493	4.2486	4.2488	4.2489	4.2494	4.2494	4.2493	4.2487	4.2492	
Avg. Diameter	4.2497	4.2490	4.2490	4.2492	4.2496	4.2497	4.2501	4.2495	4.2493	
(After) XZ	4.2496	4.2496	4.2492	4.2491	4.2498	4.2501	4.2496	4.2494	4.2498	
Cyl. No. XW	4.2502	4.2495	4.2495	4.2495	4.2502	4.2503	4.2500	4.2492	4.2494	
3 Right WY	4.2503	4.2496	4.2494	4.2495	4.2497	4.2500	4.2507	4.2498	4.2493	
WZ	4.2507	4.2492	4.2489	4.2488	4.2491	4.2494	4.2505	4.2498	4.2495	
Avg. Diameter	4.2502	4.2495	4.2493	4.2492	4.2497	4.2500	4.2502	4.2496	4.2495	
After	4.2502	4.2495	4.2493	4.2492	4.2497	4.2500	4.2502	4.2496	4.2495	
Before	4.2497	4.2490	4.2490	4.2492	4.2496	4.2497	4.2501	4.2495	4.2493	
Wear	0.0005	0.0005	0.0003	0.0000	0.0001	0.0003	0.0001	0.0001	0.0002	

XZ - Transverse Axis
 XW
 WY - Longitudinal Axis
 WZ

CYLINDER MEASUREMENTS, INCHES

NO. 1 LEFT

Distance From Top of Liner	ABOVE PORTS					BELOW PORTS				
	5/16"	7/8"	1 9/16"	2 1/4"	3"	3 9/16"	5 9/16"	7 1/2"	10"	
(Before)	4.2495	4.2491	4.2488	4.2491	4.2492	4.2495	4.2498	4.2493	4.2491	
Cyl. No.	4.2501	4.2496	4.2495	4.2497	4.2500	4.2504	4.2499	4.2493	4.2495	
1 Left	4.2496	4.2492	4.2492	4.2496	4.2499	4.2502	4.2499	4.2495	4.2498	
	4.2490	4.2489	4.2487	4.2487	4.2493	4.2495	4.2498	4.2494	4.2494	
Avg. Diameter	4.2496	4.2492	4.2491	4.2493	4.2496	4.2499	4.2499	4.2494	4.2495	
(After)	4.2494	4.2490	4.2490	4.2496	4.2500	4.2507	4.2512	4.2500	4.2500	
Cyl. No.	4.2494	4.2493	4.2489	4.2498	4.2496	4.2500	4.2507	4.2497	4.2488	
1 Left	4.2494	4.2492	4.2486	4.2487	4.2489	4.2493	4.2491	4.2487	4.2494	
	4.2487	4.2486	4.2483	4.2483	4.2490	4.2491	4.2486	4.2487	4.2501	
Avg. Diameter	4.2492	4.2490	4.2487	4.2491	4.2494	4.2498	4.2499	4.2493	4.2496	
After	4.2492	4.2490	4.2487	4.2491	4.2494	4.2498	4.2499	4.2493	4.2496	
Before	4.2496	4.2492	4.2491	4.2493	4.2496	4.2499	4.2499	4.2494	4.2495	
Wear	-0.0004	-0.0002	-0.0004	-0.0002	-0.0002	-0.0001	0.0000	-0.0001	0.0001	

XZ - Transverse Axis
 XW
 WY - Longitudinal Axis
 WZ

CYLINDER MEASUREMENTS, INCHES

NO. 2 LEFT

Distance From <u>Top of Liner</u>	<u>ABOVE PORTS</u>						<u>BELOW PORTS</u>		
	<u>5/16"</u>	<u>7/8"</u>	<u>1 9/16"</u>	<u>2 1/4"</u>	<u>3"</u>	<u>3 9/16"</u>	<u>5 9/16"</u>	<u>7 1/2"</u>	<u>10"</u>
(Before)	XZ	4.2502	4.2491	4.2491	4.2492	4.2495	4.2498	4.2492	4.2492
Cyl. No.	XW	4.2493	4.2487	4.2487	4.2490	4.2493	4.2502	4.2497	4.2495
2 Left	WY	4.2492	4.2487	4.2487	4.2490	4.2492	4.2496	4.2487	4.2484
	WZ	4.2498	4.2491	4.2486	4.2487	4.2489	4.2488	4.2484	4.2482
Avg. Diameter		4.2496	4.2489	4.2488	4.2489	4.2493	4.2496	4.2490	4.2488
(After)	XZ	4.2492	4.2491	4.2487	4.2483	4.2490	4.2497	4.2483	4.2484
Cyl. No.	XW	4.2486	4.2486	4.2483	4.2481	4.2489	4.2500	4.2484	4.2484
2 Left	WY	4.2479	4.2480	4.2477	4.2475	4.2483	4.2490	4.2482	4.2485
	WZ	4.2479	4.2482	4.2479	4.2481	4.2484	4.2488	4.2480	4.2485
Avg. Diameter		4.2484	4.2485	4.2482	4.2480	4.2487	4.2491	4.2482	4.2485
After		4.2484	4.2485	4.2482	4.2480	4.2487	4.2491	4.2482	4.2485
Before		4.2496	4.2489	4.2488	4.2489	4.2491	4.2493	4.2490	4.2488
Wear		-0.0012	-0.0004	-0.0006	-0.0009	-0.0004	0.0001	-0.0008	-0.0003

XZ - Transverse Axis
 XW
 WY - Longitudinal Axis
 WZ

CYLINDER MEASUREMENTS, INCHES

NO. 3 LEFT

Distance From Top of Liner	ABOVE PORTS					BELOW PORTS			
	5/16"	7/8"	1 9/16"	2 1/4"	3"	3 9/16"	5 9/16"	7 1/2"	10"
(Before)									
Cyl. No.	XZ	4.2491	4.2487	4.2488	4.2491	4.2491	4.2498	4.2495	4.2498
3 Left	XW	4.2498	4.2494	4.2494	4.2496	4.2496	4.2492	4.2489	4.2493
	WY	4.2495	4.2490	4.2493	4.2496	4.2496	4.2499	4.2495	4.2494
	WZ	4.2493	4.2488	4.2486	4.2487	4.2490	4.2507	4.2501	4.2496
Avg. Diameter		4.2496	4.2489	4.2491	4.2493	4.2497	4.2499	4.2495	4.2495
(After)									
Cyl. No.	XZ	4.2483	4.2478	4.2479	4.2493	4.2501	4.2505	4.2483	4.2493
3 Left	XW	4.2491	4.2496	4.2502	4.2510	4.2511	4.2513	4.2500	4.2490
	WY	4.2500	4.2490	4.2488	4.2500	4.2500	4.2504	4.2486	4.2486
	WZ	4.2487	4.2483	4.2486	4.2491	4.2495	4.2491	4.2484	4.2487
Avg. Diameter		4.2490	4.2487	4.2489	4.2499	4.2502	4.2503	4.2488	4.2489
After		4.2490	4.2487	4.2489	4.2499	4.2502	4.2503	4.2488	4.2489
Before		4.2496	4.2491	4.2489	4.2493	4.2497	4.2499	4.2495	4.2495
Wear		-0.0006	-0.0002	-0.0002	0.0006	0.0005	0.0004	-0.0007	-0.0006

XZ - Transverse Axis
 XW
 WY - Longitudinal Axis
 WZ

ENGINE DEPOSITS

EXHAUST VALVE DEPOSITS, GRAMS

RIGHT HEAD

	<u>Cylinder #1</u>		<u>Cylinder #2</u>		<u>Cylinder #3</u>		<u>Average Deposit</u>
	<u>1C</u>	<u>2C</u>	<u>3C</u>	<u>4C</u>	<u>5C</u>	<u>6C</u>	
Position							
Finish	74.5160	74.7160	74.9703	75.2519	74.6170	74.8710	
Start	74.3961	74.6021	74.8635	75.1246	74.3686	74.6277	
Dep. Wt.	0.1199	0.1139	0.1068	0.1273	0.2484	0.2433	0.1599
Position							
Finish	74.3755	74.2884	74.2135	74.8399	74.6951	74.3377	
Start	74.2810	74.1975	74.1185	74.7428	74.5200	74.2198	
Dep. Wt.	0.0945	0.0909	0.0950	0.0971	0.1751	0.1179	0.1118

LEFT HEAD

	<u>Cylinder #1</u>		<u>Cylinder #2</u>		<u>Cylinder #3</u>		<u>Average Deposit</u>
	<u>1C</u>	<u>2C</u>	<u>3C</u>	<u>4C</u>	<u>5C</u>	<u>6C</u>	
Position							
Finish	74.3380	74.3496	74.5341	74.5800	74.3587	74.7440	
Start	74.2456	74.2831	74.4551	74.5074	74.2731	74.6864	
Dep. Wt.	0.0924	0.0665	0.0790	0.0726	0.0856	0.0586	0.0758
Position							
Finish	75.0877	74.6288	74.1612	74.4111	74.5809	74.4023	
Start	75.0037	74.5744	74.0602	74.3452	74.5042	74.3528	
Dep. Wt.	0.0840	0.0544	0.1010	0.0659	0.0767	0.0495	0.0719

PISTON TOP

<u>Piston No.</u>	<u>Description, CRC Thickness Scale</u>
1 Right	2 percent "C", 98 percent "A" all hard carbon
2 Right	5 percent "C", 95 percent "A" all hard carbon
3 Right	10 percent "C", 90 percent "A" all hard carbon
1 Left	1 percent "C", 99 percent "A" all hard carbon
2 Left	1 percent "C", 99 percent "A" all hard carbon
3 Left	1 percent "C", 99 percent "A" all hard carbon

EXHAUST VALVE TOPS

<u>Cylinder No.</u>	<u>Description, CRC Thickness Scale</u>
1 Right	5 percent "C", 95 percent "A" all hard carbon
2 Right	5 percent "C", 95 percent "A" all hard carbon
3 Right	10 percent "C", 90 percent "A" all hard carbon
1 Left	100 percent "A", hard carbon
2 Left	5 percent "C", 95 percent "A" all hard carbon
3 Left	100 percent "A", hard carbon

EXHAUST VALVE TULIPS

All Valves: 0.5 demerits

RING GROOVE CARBON

PERCENT FILLING

<u>Cylinder</u>	<u>Fire</u>	<u>No. 1</u>	<u>No. 2</u>	<u>No. 3</u>
1 Right	7	65	12	3
2 Right	15	45	25	3
3 Right	20	85	20	5
Average (Right)	14.5	65	19	3.7
1 Left	15	90	40	2
2 Left	15	90	35	4
3 Left	15	95	15	8
Average (Left)	15	91.7	30	4.7

INTAKE PORT PLUGGING, PERCENT

<u>Cylinder</u>	<u>Percent Restriction</u>
1 Right	5
2 Right	11
3 Right	6
Average (Right)	7.3
1 Left	27
2 Left	16
3 Left	21
Average (Left)	21.3

OIL CONTROL RING GROOVES

<u>Piston No.</u>	<u>Groove Demerits</u>	<u>Oil Holes Percent Plug</u>
1 Right	2.0	0.0
2 Right	2.0	0.0
3 Right	2.0	0.0
1 Left	2.0	0.0
2 Left	2.0	0.0
3 Left	2.0	0.0

Ring Condition

All rings: Free

Land Deposits

All lands: Normal

Exhaust Ports

All parts: Normal with CRC "C" scale soft carbon

Oil Screen

0.0 percent plugging

Additional

Oil Pan: 0.4 demerits

Valve Deck: 0.4 demerits

Valve Cover: 0.4 demerits

CYLINDER LINER CONDITION

<u>Cylinder No.</u>	<u>Percent Scuffed</u>			<u>Percent Glazed</u>	<u>Percent Lacquer</u>
	<u>Thrust</u>	<u>Anti-Thrust</u>	<u>Total Area</u>		
1 Right	1	2	1.5	40	12
2 Right	2	10	6.0	60	15
3 Right	1	2	1.5	55	9
Average (Right)	1.3	6.5	3.0	51.7	12.0
1 Left	7	10	8.5	75	6
2 Left	6	11	8.5	65	7
3 Left	9	4	6.5	60	3
Average (Left)	7.3	8.3	7.8	66.7	5.3

PISTON SKIRT CONDITION

<u>Piston No.</u>	<u>Lacquer Demerits</u>	<u>Description</u>
1 Right	3.7	12 percent light scuffing - moderate carbon cutting
2 Right	4.5	14 percent light scuffing - moderate carbon cutting
3 Right	3.7	8 percent light scuffing - moderate carbon cutting
1 Left	4.5	6 percent light scuffing - heavy carbon cutting
2 Left	4.3	19 percent light scuffing - moderate carbon cutting
3 Left	4.0	13 percent light scuffing - moderate carbon cutting

ANALYSIS OF BASE FUEL

<u>Property</u>	<u>Cat 1-H/1-G</u>	
	<u>Test Fuel</u>	<u>Specification*</u>
API Gravity	33.2	Record
Viscosity at 100°F, Cs	3.20	1.6 - 4.5
Flash Point, °F	185	100 min.
Cloud Point, °F	+23	Record
Pour Point, °F	+18	20 max.
Water and Sediment	0.0	0.05 max.
Carbon Residue, %	0.10	Record
Lamp Sulfur, %	0.415	0.35 - 0.45
Acid No.	0.11	Record
Aniline No., °F	145	Record
Copper Corrosion	1A	Pass
Distillation, °F		
IBP	410	Record
10%	468	Record
50%	519	500 min.
90%	603	600 - 640
EP	689	650 - 690
Cetane Number	47 ⁽¹⁾	40 - 45
Higher Heating Value, Btu/lb	19,550 ⁽²⁾	Record
Accelerated Stability, total insolubles, mg/100 ml (max)	---	---

(1) Calculated Cetane Index.

(2) Calculated higher value from gravity, viscosity, and distillation properties.

* Section 4.1, method 341, FTM Std. 791B.

Preceding page blank

APPENDIX B
TEST PROCEDURES

- Cetane Number** ASTM D 613 Test for Ignition Quality of Diesel Fuels by the Cetane Method.
- Existent Gum** ASTM D 381 Test for Existent Gum in Fuels by Jet Evaporation.
- Accelerated Stability** ASTM D 2274 Test for Stability of Distillate Fuel Oil (Accelerated Method).
- Ramsbottom Carbon Residue on 10% Bottoms** ASTM D 524 Test for Ramsbottom Carbon Residue of Petroleum Products.
- Filterability Index** Method described by W.D. Berdolette and H.D. Marvel, "Survey of Roadside Diesel Fuel Filterability," Diesel Fuel Oils, ASTM STP 413, Am. Soc. Testing Mats., 1967, p. 51.
- Cu Strip Corrosion** ASTM D 130 Test for Detection of Copper Corrosion from Petroleum Products.
- Total Acid Number** ASTM D 664 Test for Neutralization Number by Potentiometric Titration.
- Rust Tendencies** ASTM D 665 Test for Rust-Preventing Characteristics of Steam Turbine Oil in the Presence of Water Procedure B modified for fuel testing as described in MIL-I-25017C.
- Cloud Point** ASTM D 2500 Test for Cloud Point of Petroleum Oils.
- Pour Point** ASTM D 97 Test for Pour Point of Petroleum Oils.
- Viscosity** ASTM D 445 Determination of Kinematic Viscosity of Transparent and Opaque Liquids.
- Emulsion Tendencies** Federal Test Method Standard No. 791 B, Method 550 Emulsification Tendencies of Petroleum Fuels by Multiple Contact Extractions.
- Interfacial Tension** ASTM D 971 Test for Interfacial Tension of Oil Against Water by the Ring Method.

Preceding page blank