P-1954

FR-1954

DECLASSIFIED by NRL Contract
Declassification Team
Date: 8 Jul 2016
Reviewer's n... A. THOMPSON, P. HANNA
Declassification authority: NAVY DECLASS GUIDE, 11 DEC 2012

DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by UNLIMITED only.

DECLASSIFIED

30 October 1942 [redacted] NRL Report No. P-1954

NAVY DEPARTMENT

Report on

Sabotage Agents for Use in Lubricants and Fuels for Internal Combustion Engines Part II

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages:	Text - 8 Tables - 3 Plates - 51
Authorization:	Bureau of Ships Project Order 1642/42
Dates of Tests:	June to October 1942
Data Collected by:	V.G. Fitzsimmons, Contract Employee
	H.R. Baker, Contract Employee
	Charles M. Murphy, Jr. Associate Chemist
Prepared by:	H.R. Baker, Contract Employee
	Charles M. Murphy, Jr. Associate Chemist
Reviewed by:	W.A. Zisman, Physicist
	P. Borgstrom, Head Chemist Superintendent, Chemistry Division
Approved by:	H.G. Bowen, Rear Admiral, USN, Director
Distribution:	BuShips (10) BuAero (4)

dev

TABLE OF CONTENTS

Subject	Page
ABSTRACT	
INTRODUCTION	1
(a) Authorization	1
(b) Statement of Problem	1
(c) Known Facts Bearing on the Problem	1
METHODS	2
(a) Apparatus	2
(b) Materials	2
(c) Experimental	3
DATA OBTAINED	3
(a) Results	3
(b) Discussion of Results	3
I Contaminants for Lubricants	4
II Contaminants for Fuel	6
CONCLUSIONS AND RECOMMENDATIONS	7
(a) Facts Established	7
(b) Recommendations	8

APPENDICES

TABLES

Effect of Contaminants in New Oil	I
Effect of Contaminants in New, Used and Detergent Oils	II
Effect of Contaminants in Gasoline	III

PLATES

Piston Assemblies	1 to 44 incl.
Cylinder Blocks	45, 47, 48 & 49
Valves	46, 50 & 51

ABSTRACT

The search for other effective sabotage agents for lubricants is continued in this report. Of the new additives investigated styrene, an oil soluble agent, although unable to stop the engine within the test period (24 hours) caused scoring of the bearings, excessive consumption of the lubricant and a periodic valve knock. Amyl phosphoric acid, an oil insoluble agent, corroded the bearings and caused the formation of a heavy sludge deposit. If the engine was allowed to cool when the above agent was used, it froze and could not be started. In brief, no agents have been found more effective than those previously reported. The effect of sabotage agents should be investigated in engines operating at higher temperatures. Roughly the speed of an organic reaction doubles for each 10°C rise in temperature, therefore, the effect of the agents may vary in different engines. In addition, the nature of the reaction products may vary with the temperature.

The delaying action of used and detergent oils on sabotage agents for lubricants was investigated. It was found that the delaying action of these oils varied with the nature of the sabotage agent used, being more effective in case of some agents than others.

Sabotage agents for use in fuels were also investigated. Drying oils when present in concentrations of 0.14%, built up a thermoplastic deposit on the intake valve stem which hardens when the engine cools, sticking the valve. To stop the engine, concentrations of 0.7% are necessary. Gasoline soluble resins act in a similar manner but are effective in smaller concentrations, 0.075% being sufficient in most cases, to stick the valves when the engine is allowed to cool. However a nonvolatile contaminant, present in these concentrations, can be detected by any standard gum test. The volatile contaminant ethyl orthosilicate in concentrations of 0.7% and 0.35% stopped the engine in 8-1/4 hours and 15-1/3 hours respectively by fouling the spark plug.

[redacted]

INTRODUCTION

(a) Authorization

1. This project was authorized by the Bureau of Ships under Project Order 1642/42.

(b) Statement of Problem

2. Additives having a deleterious effect upon the operation of internal combustion engines are of concern to the Navy.

A. The results may serve as a guide in determining the nature of the contaminants used in the sabotage of Naval fuels, lubricants and equipment.
B. Any satisfactory additive found could be used when necessary to render useless fuels and lubricants which might fall into enemy hands.
C. Such materials could be employed for the sabotage of enemy fuels and lubricants.

(c) Known Facts Bearing on the Problem

3. The properties of the ideal sabotage agent for lubricants and possible modes of action are discussed in NRL Report No. P-1902. It was found that the sabotage agents investigated were less effective when added to an engine lubricated with a used oil than with a new oil. This property of a used oil is attributed to the oxidation and reaction products formed during use. There are many other materials which may be effective sabotage agents for lubricants. This report is a continuation of the search for effective agents.

4. An internal combustion engine may also be effectively sabotaged by the use of a contaminated fuel. The properties of the ideal sabotage agent for fuels are about the same as for lubricants (NRL Report No. P-1902). There are several possible modes of action for fuel sabotage agents.

A. Failure of Valve System.

5. Gums or resins when present in gasoline tend to deposit out, particularly on the intake valve stems. This is due to the vaporization of the volatile portion of the fuel at the valve stem temperature and the accumulation of a deposit of the nonvolatile gums or resins. This residue can build up to such an extent that the valve springs are not strong enough to seat the valve properly causing a loss of compression and power. Eventually the deposit may reach such proportions that the valve sticks. Some gasolines contain considerable amounts of unsaturated compounds which tend to oxidize and polymerize to form nonvolatile materials or gums. Such gasolines generally contain "inhibitors" to stabilize the unsaturates against gum formation. Any agent which would destroy or neutralize the effect of

[redacted]

the inhibitor and accelerate the formation of gums would be a good sabotage agent. The gum content of any gasoline may be raised to a dangerous amount by the addition of a soluble gum or resin to the fuel.

B. Failure of the Fuel System.

6. The precipitation or deposition of gums in the valves of the carburetor is also possible. Such a deposit would make the engine slow to respond to the throttle, and the deposit might reach such proportions as to cause valve sticking. Also a gum deposit may build up in the intake port causing a constriction which retards the flow of the fuel-air mixture. Any agent causing the clogging of the fuel lines would be an effective sabotage agent. A soluble wax or resin dissolved in the fuel would be precipitated out if the temperature were lowered sufficiently. These agents would be particularly adapted to aircraft sabotage, as at high altitudes very low temperatures are encountered. Compounds causing corrosion might accomplish the same purpose if the products of corrosion were sufficient to clog the lines.

C. Failure of the Ignition System.

7. Any agent which formed a deposit on or corroded the points of the spark plugs would change the gap. This change might be sufficient to cause improper firing of the fuel. Another method of attack would be to damage the porcelain. Certain fluorine compounds may be effective.

D. Abrasive Materials.

8. Organometallic compounds soluble in gasoline may oxidize or react in the combustion chamber to form abrasive products. These would cause excessive wear of the cylinder walls and piston rings.

E. Reduction of the Octane Number.

9. There are a number of compounds which reduce the octane number and cause knocking. A large number of compounds have been investigated by NDRC and the results given in Report Div. B. Serial 13 dated 3/3/41.

METHODS

(a) Apparatus

10. The sabotage agents were studied in the Onan 10-LS test engine which is described in NRL Report No. P-1857.

(b) Materials

11. The lubricants used for the tests were Navy Symbol 2135 (SAE 20) from The Texas Company and Navy Symbol 9250 (SAE 30). Two 9250 oils were used; "R.P.M. Delo" a product of the Standard Oil Co. of Cal. and "Essolube HD" a product of the Standard Oil Co. of N.J. Both are so called

[redacted]

"detergent oils". The gasoline used was 100 octane leaded aviation fuel. Some runs were made using an aromatic fuel, consisting of 60.0% 100 octane leaded aviation gasoline and 40.0% aromatics. The aromatic fraction consisting of 50.0% benzene 37.5% xylene and 12.5% toluene.

12. The contaminants were either definite chemical compounds or naturally occuring products. Several proprietary products were also used. "Kellin" and "Kellsoy", chemically treated varnish oils having linseed and soybean oils as bases, are products of Spencer Kellog and Sons, Inc. "Pentalyn G" a pentaerythrityl abietate resin is a product of the Hercules Powder Co., Inc. "Copene" and "Nypene" are terpene resins products of The Neville Company. "Electrical Insulating Varnish 'G' and 'R'" are oil soluble varnishes, products of Wm. Zinsser & Co. "Super Beckacite 1001" a phenolic resin is a product of Reichhold Chemicals, Inc. The compatibility and superficial detectibility of all the contaminants discussed here are given in Tables I, II and III.

(c) Experimental

13. The test engines were cleaned and prepared for the runs as described in NRL Report No. P-1857. The lubricant was added and the engine was run for a short time to determine its normal operating characteristics. The contaminant was then added to the oil in the sump and the test run started. The 100 octane leaded aviation gasoline was used as the fuel in all tests on sabotage agents for lubricants. The effects of such contaminants were determined on engines lubricated with Texaco 2135, "R.P.M. Delo", and "Essolube H.D." The normal operating characteristics of the engine were determined before using any particular sabotaged gasoline as fuel. Contaminants which were insoluble in regular test gasoline were run in the aromatic fuel already described.

14. Changes from normal operation, and the time required to stop the engine were observed in each run. In case of non-stoppage the test was discontinued after 24 hours of operation. At the end of the test the engine was dismantled and the cause of stoppage and the condition of the engine was determined and recorded.

DATA OBTAINED

(a) Results

15. The agents tested and their effects on engine operation are summarized in Tables I, II and III.

(b) Discussion of Results

16. The additives are divided into two classes, "Contaminants for Lubricants" and "Contaminants for Fuels". For convenience of discussion and comparison of results, these groups are broken down into broad chemical classes.

[redacted]

I Contaminants for Lubricants

A. Resins.

16. The resins had little, if any, effect upon the operation of the test engine nor did they precipitate out contaminating the engine unduly. It was hoped that the normal oxidation product of the lubricant formed would have a "salting out" effect upon the dissolved resins, i.e., that the resins would be less soluble in the used oil than in the new and would be precipitated out with the accompanying deleterious effect. It is possible that if the lubricant was used for a longer period or if the engine operated at a higher temperature the desired results, would be obtained. When either "Pentalyn G" or rosin were modified with "Kellin" the clogging of the oil rings and the accompanying excessive consumption of oil was attributed to the "Kellin" (see NRL Report No. P-1920 for similar effects of drying oils). The oil soluble electrical insulating varnishes (composition unknown) though unable to stop the engine within the test period stuck the oil rings thus causing the consumption during the run of two-thirds of the lubricant. After each of these runs the engine was very dirty.

B. Corrosive Materials.

17. A series of runs were made with additives which might corrode the bearings or breakdown to form corrosive products. The bearings in the test engine are of the following materials:

Crankshaft bearing - Babbit, Steel Backed.
Main bearing - Hi-Lead Bronze, Steel Backed.
Connecting Rod Bearing - Machined aluminum.

None of the additives had any effect upon the operation of the engine, nor did they attack the bearings with the exception of amyl phosphoric acid. Using 3% amyl phosphoric acid as a sabotage agent in oil, the engine ran out of gasoline after 17 hours of operation. The following morning the engine was found frozen and could not be started. When dismantled the connecting rod bearing was stuck and the other bearings and oil pump were tight. The piston rings were fouled and piston was tight in the cylinder. The connecting rod bearing was etched and the main bearing was also attacked. Approximately 1/3 of the lubricant was consumed during the run. Another run was made using 1% of amyl phosphoric acid. The engine was operated for 6 hours, then stopped and allowed to cool to room temperature. Again the engine "froze" and could not be started. On dismantling it the connecting rod bearing was found stuck, the main bearing tight and piston rings fouled. The oil consumption was about the same as in the 3% run. The interior of the engine was covered with sludge and was very difficult to clean. Since amyl phosphoric acid is also an alkylating agent this may account for the sludge formation.

18. If moisture were present in the crankcase, it is possible that some of the other agents investigated would be effective sabotage agents. The hydrolysis of, and subsequent ionization of the hydrolytic products would

[redacted]

greatly accelerate their corrosive action.

C. Polymerizable compounds.

19. Styrene, although unable to stop the engine within the test period, had a very noticeable effect upon the operation of the engine. After an hour's operation with a lubricant containing 3% styrene, the engine had developed a valve knock. This increased in intensity and then diminished periodically. When the engine was dismantled at the end of the run the connecting rod bearing was badly scored and main and cam shaft bearings were scratched. There was no evidence of a deposit on any of these bearings. A deposit was found around the top of the exhaust valve guide. Although there was little evidence of a deposit on, or sticking of the piston rings, about 1/2 of the lubricant was consumed during the run. A check run was made using 3% styrene but containing the inhibitor, hydroquinone, and the same results were obtained. The interior of the engine was covered with a "medium heavy" sludge deposit after both runs. A possible explanation of the periodicity of the valve knock, is that the styrene polymerizes on the exhaust valve stem and guide. As this deposit built up the friction of the moving parts caused an increase in the temperature. The temperature finally reached a point where the polymerized styrene melted or depolymerized, then the temperature fell and the cycle started again. The absence of a deposit on the bearings and rings may be explained by the same mechanism. None of the other polymerizable compounds investigated had any noticeable effect upon the operation of the engine.

D. Miscellaneous contaminants.

20. None of these additives had any appreciable effect upon the operation of the engine. The ethyl orthosilicate decomposed to form an abrasive material but the particles were so fine that they merely had a polishing action on the bearings and cylinder walls. It is believed that it would take too many hours of operation before deleterious results would be obtained with this additive.

The additives, hexone, manganese linoleate, triethyl amine, pinene, and Bunker-C fuel oil caused some sticking of the rings with the accompanying high oil consumption and the formation of varying amounts of sludge as shown in Table I.

21. It should be emphasized that all the above runs were made on an engine of low power output and low operating temperature. It is quite possible that some of the agents investigated would be much more effective in engines operating at higher temperatures. In general, the speed of a reaction doubles with a 10°C temperature rise, therefore, in cases of stoppage due to the decomposition or reaction of the sabotage agent, higher operating temperatures should decrease the time to cause sabotage. Also there is the possibility that the breakdown and reaction products of the sabotage agent may be different for different temperatures; if this is the case, the temperature effect will be specific to the engine involved.

[redacted]

E. Detergent Oils.

22. In Table II is shown a comparison of the effects of sabotage agents in new, used and detergent oils. The runs on new and used oils are described in NRL Report No. P-1902 and are shown here for comparison. A 3% concentration of tung oil in new oil stopped the test engine after 4 hours operation by sticking the piston in the cylinder. When added to a used oil (lubricant previously used in test engine for 20 hours) the time of stoppage was 7-3/4 hours. Both the detergent oils prevented the tung oil additive from stopping the engine within the 24 hour test period. 1% Molasses ("Brer Rabbitt") in new oil stuck the bearings and stopped the engine after two hours' operation but was not effective in either the used or detergent oils. When 3% was used the time of stoppage with new oil was one hour; 6-3/4 hours with used oil; 2-3/4 hours with Essolube HD-30 and 2-1/3 hours with RPM Delo. The difference in time of stoppage of the detergent oils is within the experimental error of such measurements. 2% of molasses in either of the detergent oils gave approximately the same times of stoppage. The used oil delays the action of molasses ("Brer Rabbitt") as a sabotage agent to a greater extent than the detergent oils. The syrup "Karo Red Label" plus quinoline in new oil, stopped the engine in less than an hour,. required 5-3/4 hours in used oil and was unable to stop the engine within 24 hours in the detergent oils. The delaying action of the detergent oils on a 3% mixture of a saturated sucrose solution containing urea or urine was slight, being about the same as for molasses ("Brer Rabbitt").

23. The protective or delaying action of a used oil is probably due to the formation on the parts of the engine of an adsorbed film of polar oxidation or reaction products of the lubricant. This adsorbed film prevents or delays the adherence to, and attack, of the vital parts of the engine by the sabotage agent or its decomposition products. Also the formation of such a film on globules or agglomerates of the sabotage agent will prevent their coalescence, tending to keep them from settling out and adhering to parts of the engine. The detergent oils act similarily. The delaying action of detergent oils is expected to be specific, depending upon the nature of the detergent used in the oil as well as nature of the sabotage agent. Some detergent oils will be more effective than others upon a given type contaminant, and their effectiveness may be reversed when another type contaminant is used. From Table II it is seen that the used oil had a greater delaying effect upon molasses than did the detergent oils. On the other hand the detergent oils were more effective than the used oil where the contaminant was tung oil or Karo and quinoline. It is also possible that on mixing different types of detergent oils the detergents in the oils might react with each other or be precipitated out and their effectiveness lost.

II Contaminants for Fuel

A. Drying Oils.

24. Tung oil when present in gasoline in concentrations of 0.7% which is equivalent to a gum content of 500 mg/100 cc of fuel, stopped the

[redacted]

engine after 2-1/3 hours by sticking the intake valve. A heavy deposit of polymerized tung oil had built up in the intake port. This deposit was so heavy that it interferred with the flow to the engine of the carbureted fuel resulting in a loss of power and a considerable reduction in speed. A concentration of 0.14% tung oil was insufficient to stop the engine. At the end of the test period and after the engine had cooled, it could not be started again due to a stuck intake valve. Another run was made on 0.14% tung oil in fuel. If the engine was allowed to cool after 12 hours of operation it could not be started again due to the sticking of the intake valve. The deposit of polymerized tung oil is evidently thermoplastic, setting to a hard mass on cooling. The action of the other drying oils was similar to that of tung oil. A thermoplastic resin formed on the valve stem and hardened on cooling, thus sticking the intake valve. The smallest effective concentration of all the drying oils was found to be 0.14%. Although not superficially detectable in the fuel the presence of nonvolatile contaminants can be detected by any standard gum test.

B. Resins.

25. Of the resins investigated in a concentration of 0.15% only "Super Beckacite 1001" was able to stop the engine. If allowed to cool after 12 hours of operation, the engine could not be started if a fuel containing 0.075% "Super Beckacite 1001" had been used. Although unable to stop the engine when operated at 1800 r.p.m. on a fuel containing 0.075% "Super Beckacite 1001", it was stopped in 12 hours if the speed employed was 1200 r.p.m. If the concentration was 0.025% again using 1200 r.p.m. it was stopped in 18 hours. The "Nypene" "Pentalyn" and "Pentalyn G" resins, when present in 0.15% concentrations formed deposits which stick the intake valve after the engine was allowed to cool upon completing 3 hours of operation. The time required to build up a sufficient deposit was doubled if this concentration was halved (0.075%). Concentrations less than 0.075% were ineffective. An aromatic fuel was used on gum Damar and on copal resins, since they were insoluble in the regular fuel. However, the presence of such resins can readily be detected by a standard gum test.

C. Miscellaneous Contaminants.

26. Amyl silicate and styrene in gasoline had no effect upon the operation of the engine. Ethyl ortho silicate in 0.70% concentrations stopped the engine in 8-1/4 hours by fouling the spark plug. A concentration of 0.35% was effective in 15-1/3 hours. A silicate deposit was formed between the points of the spark plug. This reached such proportions that the fuel was not fired. There was also a slight abrasive action on the piston rings and cylinder walls, but the particles were so fine as to cause merely a polishing effect. The ethyl orthosilicate cannot be detected by a gum test as it is volatile at the temperature of the test.

CONCLUSIONS AND RECOMMENDATIONS

(a) Facts Established

A. Contaminants for Lubricants

27. The oil soluble resins described here have little, if any

[redacted]

effect upon the operation of the test engine, nor do they seriously contaminate the engine.

28. Of the corrosive materials here discussed amyl phosphoric acid was the most effective.

29. Styrene, although unable to stop the engine within the test period, had a detrimental effect upon the engine and its operation. There is little, if any, difference in the effect of styrene and styrene containing 0.1% hydroquinone as a polymerization inhibitor.

30. Of the miscellaneous compounds described here pinene was the most effective.

31. The protective effect of the detergent oils tested varies with the type of contaminant used. This effect was specific, varying with the type of detergent used in the oil and also with the nature of the contaminant.

B. Contaminants for fuels.

32. The drying oils tested were effective sabotage agents for gasoline. A thermoplastic deposit was formed on the exhaust valve stem which hardened on cooling sufficiently to stick the valve. Concentrations of 0.70% of tung oil or raw linseed oil in the fuel formed a deposit heavy enough to stick the valve and stop the engine.

33. The gasoline soluble resins described here acted in a similar manner to the drying oils but were effective in smaller concentrations. Both of above mentioned types of contaminants can be detected by a gum test.

34. Ethyl orthosilicate when present in concentrations of 0.35 to 0.70% in the fuel stopped the engine by fouling the spark plugs. It also has a polishing effect.

(b) Recommendations

35. The effects of the sabotage agents described here should be studied in engines operating at higher temperatures than the Onan test engine.

36. It is suggested that the most promising agents found here be given full scale engine tests.

[redacted]

TABLE I

EFFECT OF CONTAMINANTS IN NEW OIL ON THE OPERATION OF THE TEST ENGINES

Plate No.	Run No.	Contaminants	Volume Conc.	Compatibility	Odor	Cylinder Walls	Rings: Oil	Rings: Compression	Piston Skirt	Conn. Rod Oil Passage	Bearings: Conn. Rod	Bearings: Main	Bearings: Cam Shaft	Oil Pump	Oil Pump Screen	Deposit: Crankcase	Deposit: Crankshaft	Deposit: Cam Shaft	Condition of Oil	Oil Consumption	Time of Stoppage	Cause of Stoppage
1	7	Control Run	—	—	No	B-B	F-L	F-L	B	C	C-P	C-P	C-P	F	C	Slight	Slight	Slight	L	Slight	24hr	Disc.
		RESINS																				
2	87	Rosin in Benzene	3%	Sol.	Sl	P-D	F-1/3Cl	F-L	B-L	C	F-G	N	N	F	N	L	L	L	L	N	24hr	Disc.
3	90	Rosin in Benzene + "Kellin"	3%	Sol.	Sl	P-D	F-1/3Cl	F-L	B-L	C	F-G	N	N	F	N	L	L	L	L	N	24hr	Disc.
4	91	Pentalyn G in Benzene + "Kellin"	3%	Sol.	Sl	P-D	St-9/10Cl	1/3T-L	B-M	C	N	N	N	P	1/2Cl	M	L	L	M	1/3	24hr	Disc.
—	92	Hypene	3%	Sol.	No	P-W	F-L	F-L	B-L	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
5	122	Super Beccacite 1001 in Benzene	3%	Sol.	Sl	P-D	T-1/2Cl	F-L	B-L	C	N	N	N	P	N	L	L	L	L	N	24hr	Disc.
6	163	Electrical Insulating Varnish G	3%	Sol.	No	P-W	St-H	F-L	B-M	C	N	N	N	F	3/4Cl	M	L	L	M	2/3	24hr	Disc.
7	168	Electrical Insulating Varnish R	3%	Sol.	No	P-W	St-H	F-L	B-W	C	N	N	N	F	9/10Cl	M	L	L	M	2/3	24hr	Disc.
		CORROSIVE MATERIALS																				
8	102	Isoamyl nitrite	3%	Insol.	Dist.	P-D	F-L	F-L	B-W	C	N	N	N	P	N	M	L	L	M	N	24hr	Disc.
9	103	Bromobenzene	3%	Sol.	Dist.	P-D	F-L	F-L	B-M	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
—	106	Glyceroldichlorhydrin	3%	Insol.	Sl	P-D	F-1/3Cl	F-L	B-L	C	N	N	N	F	N	L	L	L	L	1/3	24hr	Disc.
10	124	Amyl phosphoric acid	1%	Insol.	Dist.	B-D	F-L	F-L	B-L	C	St	T	N	F	N	M	L	L	M	1/3	6	St-Br.
11	112	Amyl phosphoric acid	3%	Insol.	Dist.	G-W	T-1/2Cl	2/3T-W	G-M	M	St	T	T	T	1/3Cl	M	L	L	M	1/3	17hr	St-Br.
12	134	Paraffin Wax Sulfonyl chloride	3%	Sol.	Dist.	P-W	F-L	F-L	B-L	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
13	135	Nitrobenzene	3%	Sol.	Dist.	P-W	F-L	F-L	B-L	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
14	138	O-dichlorobenzene	3%	Sol.	Dist.	P-W	F-L	F-L	B-L	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
15	165	Butane Sulfonyl chloride	2%	Sol.	Dist.	P-W	F-L	F-L	B-L	C	N	N	N	F	N	L	L	L	L	1/2	24hr	Disc.
16	166	Dichloronitropropane	3%	Sol.	Sl	P-W	F-L	F-L	B-M	C	N	N	N	F	1/2Cl	L	L	L	L	2/3	24hr	Disc.
		POLYMERIZABLE COMPOUNDS																				
17	70	α Methyl Styrene	3%	Sol.	Sl	P-W	F-L	F-L	V-M	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
18	88	Indene	3%	Sol.	Sl	P-W	F-L	F-L	B-M	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
19	89	Vinyl acetate	3%	Sol.	Dist.	P-D	F-L	F-L	B-L	C	N	N	N	F	N	M	L	L	M	N	24hr	Disc.
20	156	Vinyl acetate + inhibitor	3%	Sol.	Dist.	P-W	F-L	F-L	B-L	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
21	104	Ethyl acetoacetate	3%	Insol.	Sl	P-D	F-L	F-L	B-L	C	N	N	N	P	N	M	L	L	M	1/3	24hr	Disc.
22	113	Hexaldehyde	3%	Insol.	Dist.	P-W	F-1/3Cl	F-L	B-L	C	N	N	N	F	N	L	L	L	L	1/3	24hr	Disc.
23	201	Styrene	3%	Sol.	Sl	P-D	F-W	F-L	B-L	C	Sc	Sct	Sct	F	1/2Cl	M	L	L	M	2/3	24hr	Disc.
24	196	Styrene + inhibitor	3%	Sol.	Sl	P-D	F-L	F-L	B-L	C	Sc	Sct	Sct	F	1/3Cl	M	L	L	M	1/2	24hr	Disc.
		MISCELLANEOUS																				
25	71	Ethylorthosilicate	3%	Sol.	No	P-W	F-L	F-L	B-L	C	N	N	N	F	N	M	L	L	L	N	24hr	Disc.
26	76	Triamyl borate	3%	Sol.	No	P-W	F-L	F-L	B-L	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
27	83	Rosin Oil	3%	Sol.	Sl	P-W	F-L	F-L	B-L	C	N	N	N	P	N	L	L	L	L	N	24hr	Disc.
28	84	Pine Oil	3%	Sol.	Dist.	P-W	F-L	F-L	B-L	C	N	N	N	P	N	L	L	L	L	1/5	24hr	Disc.
29	85	Pine Tar Oil	3%	Sol.	Dist.	P-W	F-L	F-L	V-M	C	N	N	N	P	N	L	L	L	L	N	24hr	Disc.
30	101	Pinene	3%	Sol.	Dist.	P-D	F-1/3Cl	F-L	B-M	C	N	N	N	F	N	M	L	L	M	2/3	24hr	Disc.
31	105	Hexone	3%	Insol.	Dist.	P-D	F-L	F-L	B-M	C	N	N	N	P	N	M	L	L	M	1/6	24hr	Disc.
—	132	Triethylamine	3%	Sol.	Dist.	P-W	T-L	F-L	B-L	C	N	N	N	F	N	L	L	L	L	N	24hr	Disc.
—	136	Manganese Linoleate	1%	Sol.	No	P-D	T-1/3Cl	F-L	B-M	C	N	N	N	P	N	L	L	L	L	N	24hr	Disc.
32	137	Bunker C Fuel Oil	3%	Sol.	No	P-W	F-1/3Cl	F-L	B-M	C	N	N	N	F	1/3Cl	L	L	L	L	N	24hr	Disc.

LEGEND

B	Burnished	F	Free	M	Medium Deposit	Sc	Scored
Br	Bearing	G	Gummy	N	Normal	Sl	Slight
C	Clean	Gr	Gritty	No	None	Sol	Soluble
Cl	Clogged	H	Heavy Deposit	P	Polished	St	Stuck
D	Dry	Hr	Hour	Pn	Piston	T	Tight
Disc.	Discontinued	Insol.	Insoluble	S	Sludge	V	Varnish
Dist.	Distinctive	L	Light Deposit	Sct	Scratched	W	Moist

[redacted]

TABLE II

COMPARISON OF EFFECT OF CONTAMINANTS IN NEW, USED AND DETERGENT OILS

Plate No.	Run No.	Contaminants	Volume Conc.	Compatibility	Odor	Cylinder Walls	Rings: Oil	Rings: Compression	Piston Skirt	Conn. Rod Oil Passage	Bearings: Conn. Rod	Bearings: Main	Bearings: Cam Shaft	Oil Pump	Oil Pump Screen	Deposit: Crankcase	Deposit: Crankshaft	Deposit: Cam Shaft	Condition of Oil	Oil Consumption	Time of Stoppage	Cause of Stoppage
		NEW OIL																				
—	11	Tung Oil	3%	Sol.	No	D-Sct	St-Cl	St-H	Sct-H	C	V-F	N	N	T	Cl	H	H	H	N-S	1/3	4hr	St-Pn
—	15	Molasses "Brer Rabbitt"	1%	Insol.	No	D-Sct	T-1/2Cl	T-L	Sct-H	Cl	St-Sct	St	T	St	1/2Cl	H	L	M	N-G	N	2hr	St-Br
—	10	Molasses "Brer Rabbitt"	3%	Insol.	No	D-Sct	T-3/4Cl	T-H	Sct-H	Cl	St	St	T	St	1/2Cl	H	H	M	N-G	N	1hr	St-Br
—	30	Karo + Quinoline	1%	Insol.	No	D-Sc	P-1/2Cl	P-H	N	Cl	St	T	N	P	1/5Cl	M	L	L	L-G	N	2/3hr	St-Br
—	28	Sucrose + Urea	1%	Insol.	No	D-Sct	T-3/4Cl	P-L	N	Cl	St	H	H	P	1/2Cl	M	L	L	N-G	N	3hr	St-Br
—	40	Sucrose in Urine	1%	Insol.	No	D-Sct	P-1/2Cl	P-L	N	9/10 Cl	St	N	N	P	1/2Cl	M	L	L	N-G	N	2-3/4hr	St-Br
		USED OILS																				
—	66	Tung Oil	3%	Sol.	No	D-Sct	St-Cl	T-H	N	1/4Cl	N	N	N	P	Cl	H	M	N	N-S	1/3	7-3/4hr	St-Pn
—	61	Molasses "Brer Rabbitt"	1%	Insol.	No	D-P	P-3/4Cl	P-L	N	9/10 Cl	P-Sct	N	N	P	1/3Cl	M	L	L	N-S	1/5	24hr	Disc.
—	64	Molasses "Brer Rabbitt"	3%	Insol.	No	D-Sct	T-1/2Cl	P-L	B-H	Cl	St	St	T	St	2/3Cl	M	L	L	N-Gr	1/5	6-3/4hr	St-Br
—	47	Karo + Quinoline	1%	Insol.	No	D-P	P-L	P-L	N	Cl	St	N	N	P	1/3Cl	M	L	L	N-Gr	N	5-3/4hr	St-Br
		DETERGENT OILS Essolube HD-30																				
33-	94	Tung Oil	3%	Sol.	No	P-D	T-1/2Cl	P-L	B-L	C	N	N	N	P	1/2Cl	M	L	L	N	N	24hr	Disc.
34	219	Molasses "Brer Rabbitt"	1%	Insol.	No	W-G	P-N	P-L	G-H	C	N	N	N	P	1/2Cl	M	L	L	N	N	24hr	Disc.
35	99	Molasses "Brer Rabbitt"	2%	Insol.	No	W-G	St-1/2Cl	T-H	H-G	Cl	St	St	T	St	N	M	L	L	N	N	2-1/4hr	St-Br
36	97	Molasses "Brer Rabbitt"	3%	Insol.	No	D-G	St-Cl	T-H	D-H-G	Cl	St	St	St	St	N	M	M	M	M	N	2-3/4hr	St-Br
37	93	Karo + Quinoline	1%	Insol.	No	P-W	P-Cl	P-L	G-H	C	N	N	N	P	N	M	L	L	N	N	24hr	Disc.
38	215	Sucrose + Urea	3%	Insol.	No	P-D	T-1/2Cl	P-H	H-G-Sct	Cl	St	T	T	P	1/2Cl	M	L	L	M	N	3hr	St-Br
		NEW DELO SAE-30																				
39	176	Tung Oil	3%	Sol.	No	P-D	P-N	P-L	B-L	C	N	N	N	P	1/2Cl	M	M	N	N	1/2	24hr	Disc.
40	218	Molasses "Brer Rabbitt"	1%	Insol.	No	W-G	P-N	P-L	G-H	C	N	N	N	P	4/5Cl	M	M	N	N	1/2	24hr	Disc.
41	177	Molasses "Brer Rabbitt"	2%	Insol.	No	P-D	T-1/2Cl	P-L	Sc-H	Cl	St	P-G	P	P	1/2Cl	M	M	M	M	N	2-1/2hr	St-Br
—	177A	Molasses "Brer Rabbitt"	3%	Insol.	No	P-D	T-2/3Cl	P-L	Sc-H	Cl	St	St	St	St	1/2Cl	M	M	M	M	N	2-1/2hr	St-Br
42	175	Karo + Quinoline	1%	Insol.	No	P-D	P-N	P-N	B-H	C	N	N	N	P	N	M	M	M	M	1/2	24hr	Disc.
43	212	Sucrose + Urea	3%	Insol.	No	P-D	P-N	P-L	Sc-H	Cl	St	St	St	St	3/4Cl	M	M	M	M	N	2-1/4hr	St-Br
44	191	Sucrose in Urine	3%	Insol.	No	Sct-D	P-1/2Cl	P-H	Sc-H	Cl	St	T	T	St	3/4Cl	M	M	M	M	N	2-1/2hr	St-Br

LEGEND

B	Burnished	F	Free	M	Medium Deposit	Sc	Scoured
Br	Bearing	G	Gummy	N	Normal	Sl	Slight
C	Clean	Gr	Gritty	No	None	Sol	Soluble
Cl	Clogged	H	Heavy Deposit	P	Polished	St	Stuck
D	Dry	Hr	Hour	Pn	Piston	T	Tight
Disc	Discontinued	Insol	Insoluble	S	Sludge	V	Varnish
Dist	Distinctive	L	Light Deposit	Sct	Scratched	W	Moist

CONFIDENTIAL

EFFECT OF CONTAMINANTS IN GASOLINE ON THE OPERATION OF THE TEST ENGINE

Plate No.	Run No.	Contaminants	Weight Conc. Percent	Odor	Color	Approximate Gum Content	Carburetor	Intake Port	Intake Valve	Exhaust Valve	Combustion Chamber	Piston Rings	Time of Stoppage	Cause of Stoppage
		Control Run		N	Blue	1 mg.	C	C	F-C	F-So	So	M-P-F	—	—
	DRYING OILS													
46-A	117	Tung Oil	0.14	N	N	100 mg.	C	Pl-G-H	St-G	F	M	F-M	12 hr.	St-I-V (1)
——	117-A	Tung Oil	0.14	N	N	100 mg.	C	Pl-G-H	St-G	F	M	F-M	24 hr.	St-I-V (1)
45	114	Tung Oil	0.70	N	N	500 mg.	C	Pl-G-M	St-G	F	M	F-D	2-1/3 hr.	St-I-V
46-D	112	Kellin	0.14	N	N	100 mg.	C	Pl-G-M	St-G	F	M	F-M	12 hr.	St-I-V (1)
46-C	118-A	Kellin	0.14	N	N	100 mg.	C	Pl-G-M	St-G	F	M	F-M	24 hr.	St-I-V (1)
48	116	Kellin	0.70	N	N	500 mg.	C	Pl-G-M	St-G	F	M	F-M	1-1/2 hr.	St-I-V
——	111	Kellsoy	0.70	N	N	500 mg.	C	Pl-G-M	P-G	F	M	F-M	24 hr.	Disc.
46-B	120	Raw Linseed Oil	0.14	N	N	100 mg.	C	Pl-G-M	P-G	F	M	F-M	24 hr.	Disc.
47	115	Raw Linseed Oil	0.70	N	N	500 mg.	C	Pl-G-M	St-G	F	M	F-M	3-1/3 hr.	St-I-V
——	121-A	Soya Bean Oil	0.14	N	N	100 mg.	C	Pl-G-M	St-G	F	M	F-M	24 hr.	St-I-V (1)
——	121	Soya Bean Oil	0.14	N	N	100 mg.	C	Pl-G-M	St-G	F	M	F-M	15 hr.	St-I-V (1)
	RESINS													
51-L	144	Super Beckacite (1001)	0.032	N	N	25 mg.	G-M-St	G-H-Ha	St	F	M	F-M	18 hr.	St-I-V (2)
51-K	141	Super Beckacite (1001)	0.075	N	N	50 mg.	G-M-St	G-H-Ha	St	F	M	F-M	12 hr.	St-I-V (2)
51-J	129	Super Beckacite (1001)	0.075	N	N	50 mg.	C	G-H-Ha	St	F	M	F-M	12 hr.	St-I-V (2)
51-I	129-A	Super Beckacite (1001)	0.075	N	N	50 mg.	C	G-H-Ha	St-G	F	M	F-M	24 hr.	St-I-V (1)
49	125	Super Beckacite (1001)	0.15	N	N	100 mg.	C	G-H-Ha	St	F	M	F-M	5-1/2 hr.	St-I-V
50-E	139	Gum Damar *	0.075	N	N	50 mg.	C	G-H-Ha	St	F	M	F-M	6 hr.	St-I-V (1)
——	139-A	Gum Damar *	0.075	N	N	50 mg.	C	G-H-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
——	145	Gum Damar	0.075	N	Wh-ppt	50 mg.	C	G-M-Pl	T	F	M	F-M	24 hr.	Disc.
——	142	Gum Damar	0.15	N	Wh-ppt	100 mg.	C	G-M-Pl	T	F	M	F-M	24 hr.	Disc.
——	146-A	Copal Resin *	0.15	N	N	100 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
50-F	146	Copal Resin *	0.15	N	N	100 mg.	C	G-M-Ha	St	F	M	F-M	6 hr.	St-I-V (1)
——	173-A	Nypene Resin	0.075	N	Sl.ppt	50 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
——	173	Nypene Resin	0.075	N	Sl.ppt	50 mg.	C	G-M-Ha	St	F	M	F-M	6 hr.	St-I-V (1)
——	170-A	Nypene Resin	0.15	N	Sl.ppt	100 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
50-G	170	Nypene Resin	0.15	N	Sl.ppt	100 mg.	C	G-M-Ha	St	F	M	F-M	3 hr.	St-I-V (1)
——	174-A	Copene Resin	0.075	N	Sl.ppt	50 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
——	174	Copene Resin	0.075	N	Sl.ppt	50 mg.	C	G-M-Ha	St	F	M	F-M	6 hr.	St-I-V (1)
——	172-A	Copene Resin	0.15	N	Sl.ppt	100 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
50-H	172	Copene Resin	0.15	N	Sl.ppt	100 mg.	C	G-M-Ha	St	F	M	F-M	3 hr.	St-I-V (1)
——	194	Paraffin Wax	0.15	N	Sl.ppt	100 mg.	C	N	N	N	N	N	24 hr.	Disc.
——	213-A	Pentalyn	0.075	N	Sl.ppt	50 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
——	213	Pentalyn	0.075	N	Sl.ppt	50 mg.	C	G-M-Ha	St	F	M	F-M	6 hr.	St-I-V (1)
——	193-A	Pentalyn	0.15	N	Sl.ppt	100 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
——	193	Pentalyn	0.15	N	Sl.ppt	100 mg.	C	G-M-Ha	St	F	M	F-M	3 hr.	St-I-V (1)
——	214-A	Pentalyn G	0.075	N	Sl.ppt	50 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
——	214	Pentalyn G	0.075	N	Sl.ppt	50 mg.	C	G-M-Ha	St	F	M	F-M	6 hr.	St-I-V (1)
——	195-A	Pentalyn G	0.15	N	Sl.ppt	100 mg.	C	G-M-Ha	St	F	M	F-M	24 hr.	St-I-V (1)
——	195	Pentalyn G	0.15	N	Sl.ppt	100 mg.	C	G-M-Ha	St	F	M	F-M	3 hr.	St-I-V (1)
——	164	Electrical Insulating Varnish	0.15	N	N	100 mg.	C	G-M-Pl	P-G	F	M	F-M	24 hr.	Disc.
——	169	Electrical Insulating Varnish	0.15	N	N	100 mg.	C	G-M-Pl	P-G	F	M	F-M	24 hr.	Disc.
	MISCELLANEOUS													
——	98	Ethyl orthosilicate	0.35	N	N	——	C	So	F	F	Si-L	D-F	15-1/3 hr.	S.P. Fo.
——	86	Ethyl orthosilicate	0.70	N	N	——	C	So	F	F	Si-M	D-P-F	8-1/4 hr.	S.P. Fo.
——	171	Amyl Silicate	0.35	N	N	——	C	So	F	F	Si-L	D-F	24 hr.	Disc.
——	206	Styrene	0.14	N	N	——	C	N	N	N	N	N	24 hr.	Disc.

(1) Engine stopped and allowed to cool
(2) Engine operated at idling speed - 1200 RPM
* Aromatic gasoline used

LEGEND

C	Clean	Hr	Hour	Si	Silica
D	Dry	I	Intake	Sl	Slight
Disc	Discontinued	L	Light Deposit	So	Sooty
F	Free	M	Medium Deposit	S.P.	Spark Plug
Fo	Fouled	N	Normal	St	Stuck
G	Gummy	P	Polished	T	Tight
H	Heavy Deposit	Pl	Pliable	V	Valve
Ha	Hard	ppt	Precipitate	W	Moist
				Wh	White

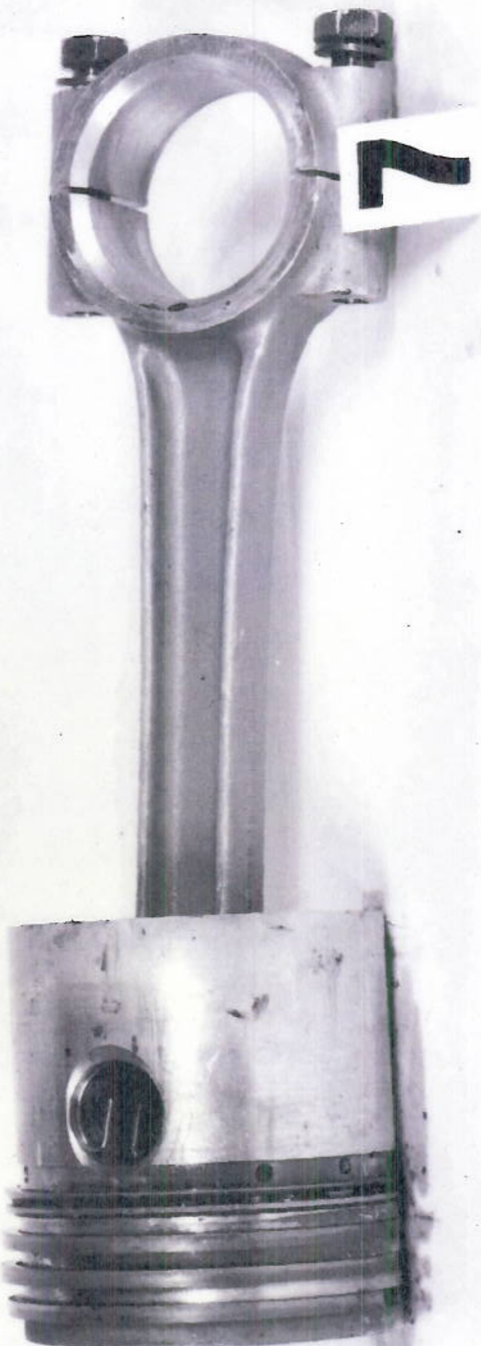

PLATE I

PLATE 2

DECLASSIFIED

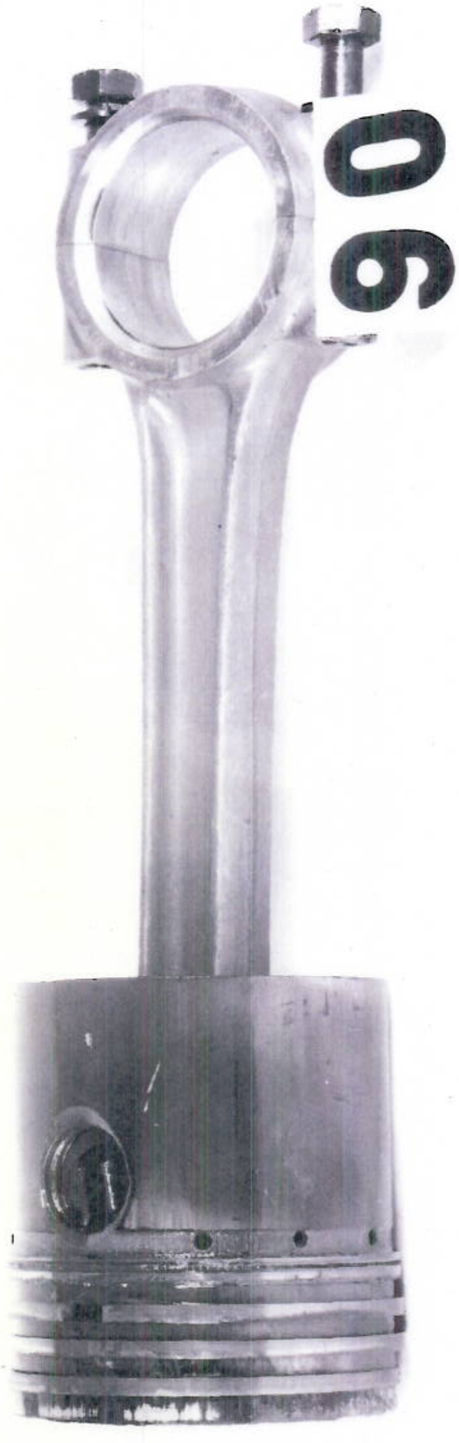

PLATE 3

PLATE 5

PLATE 6

PLATE 7

PLATE 8

DECLASSIFIED

PLATE 9

PLATE 10

PLATE 11

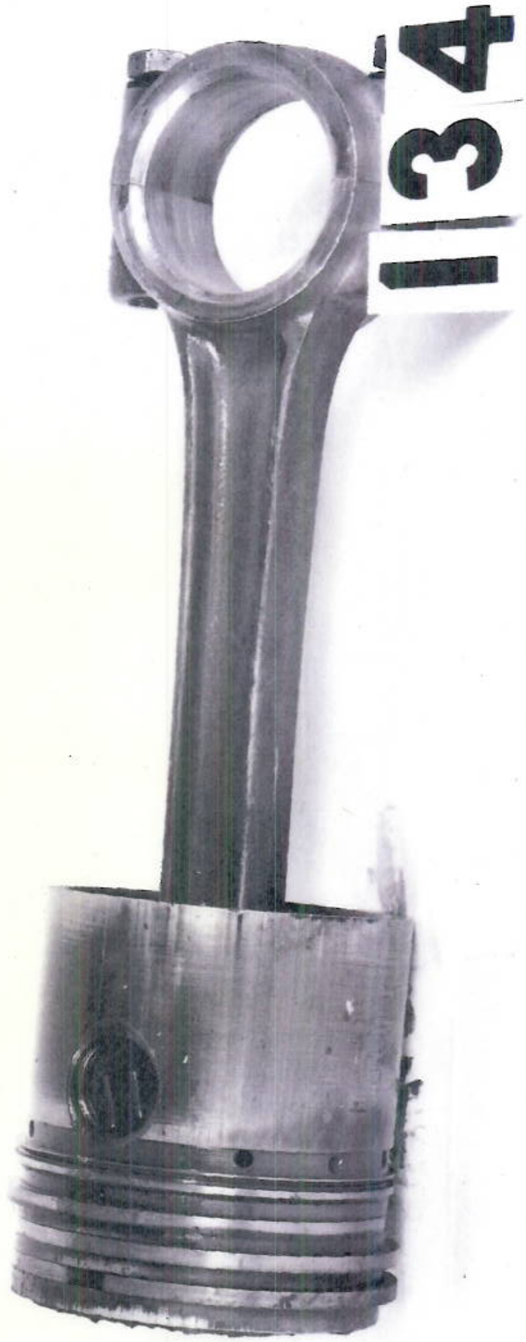

PLATE 12

DECLASSIFIED

PLATE 13

PLATE 14

PLATE 15

PLATE 16

PLATE 17

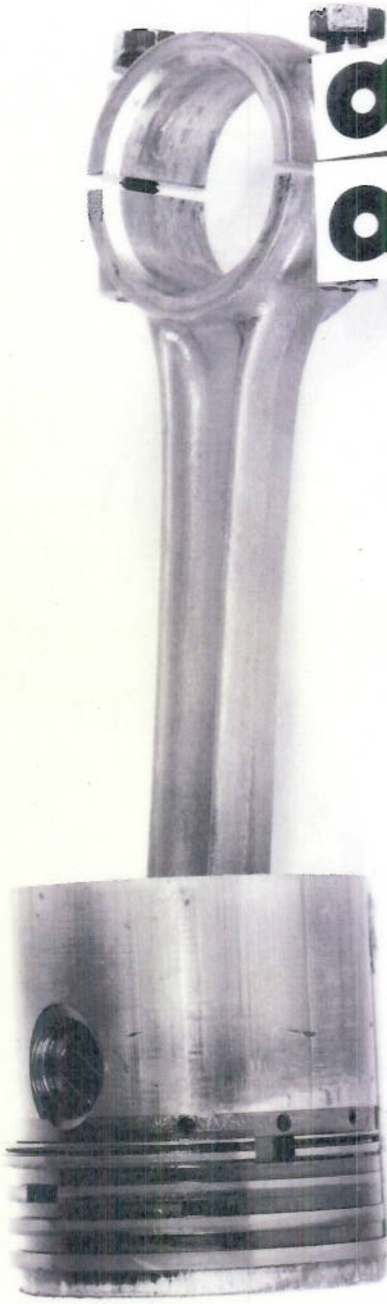

PLATE 18

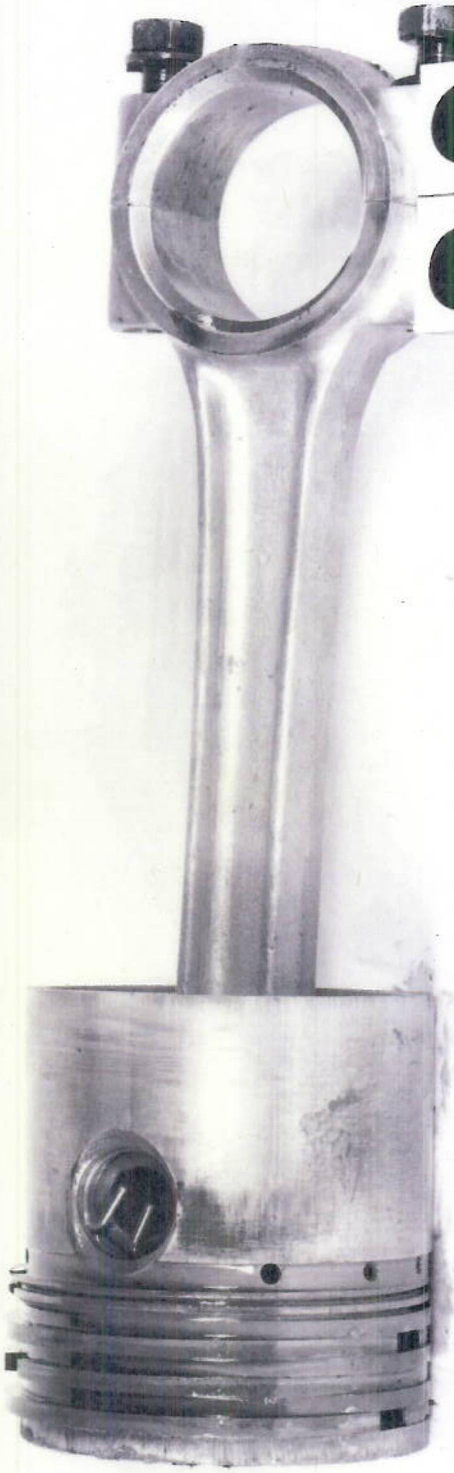

PLATE 19

PLATE 20

PLATE 21

DECLASSIFIED

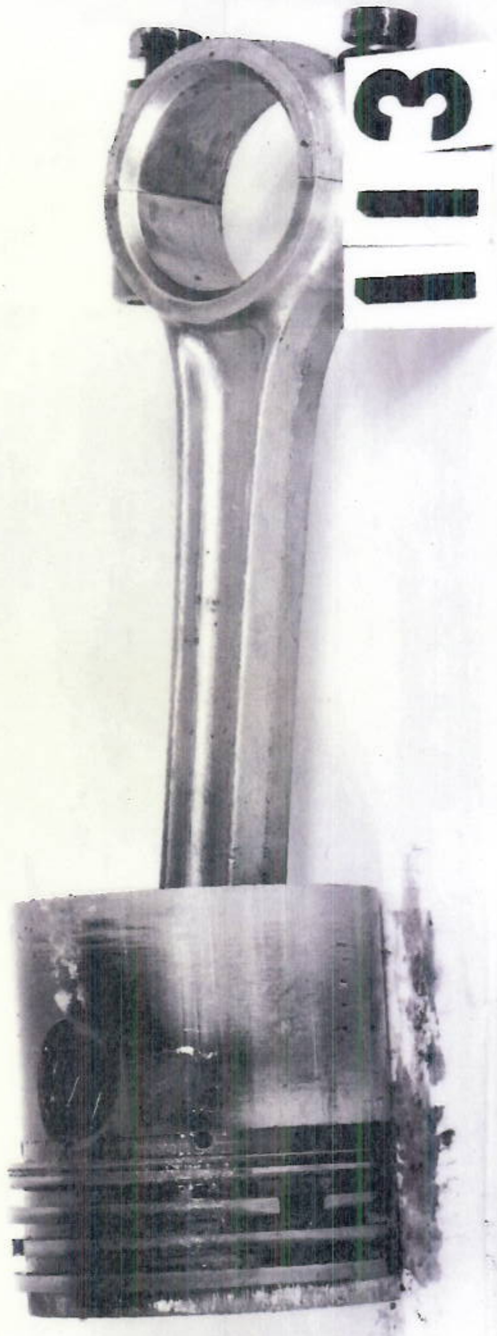

PLATE 22

PLATE 23

PLATE 24

DECLASSIFIED

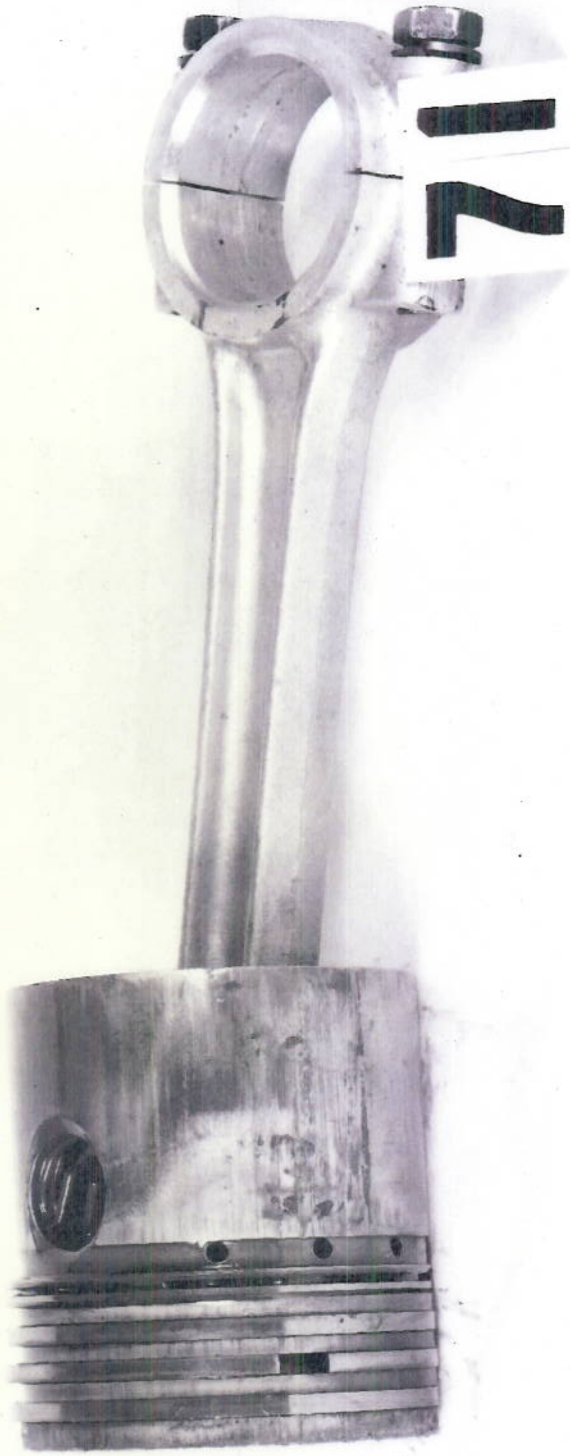

PLATE 25

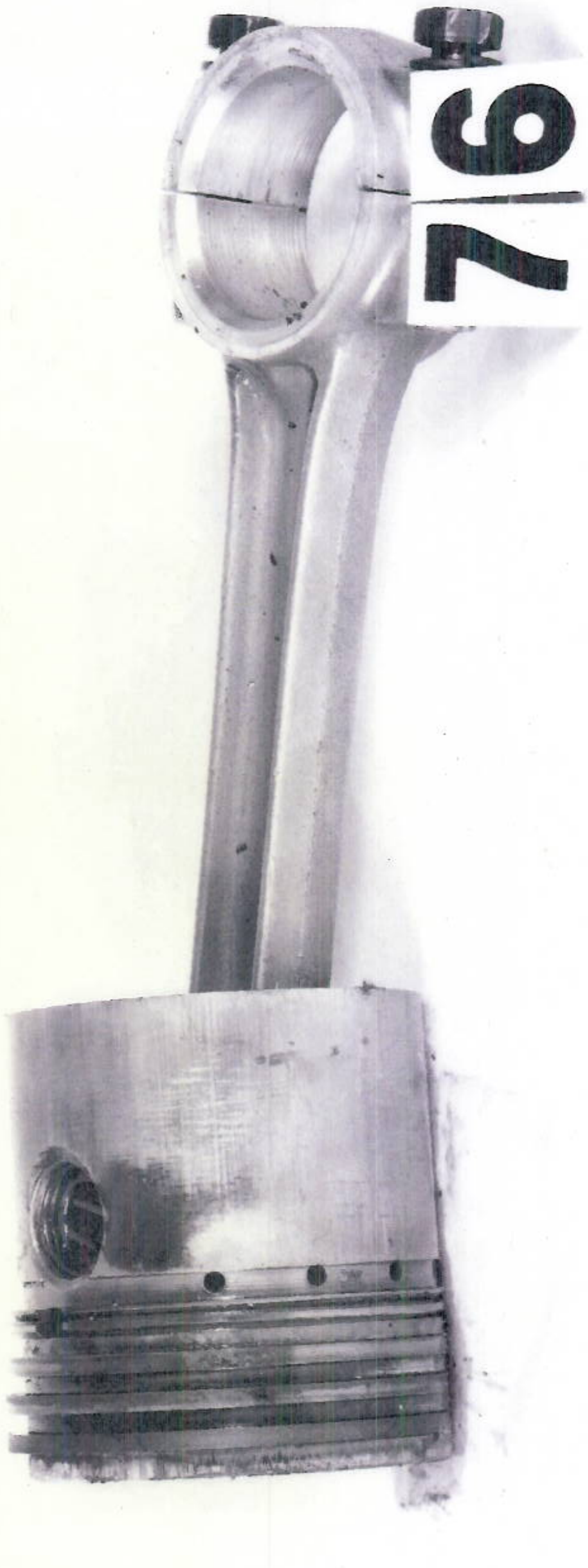

PLATE 26

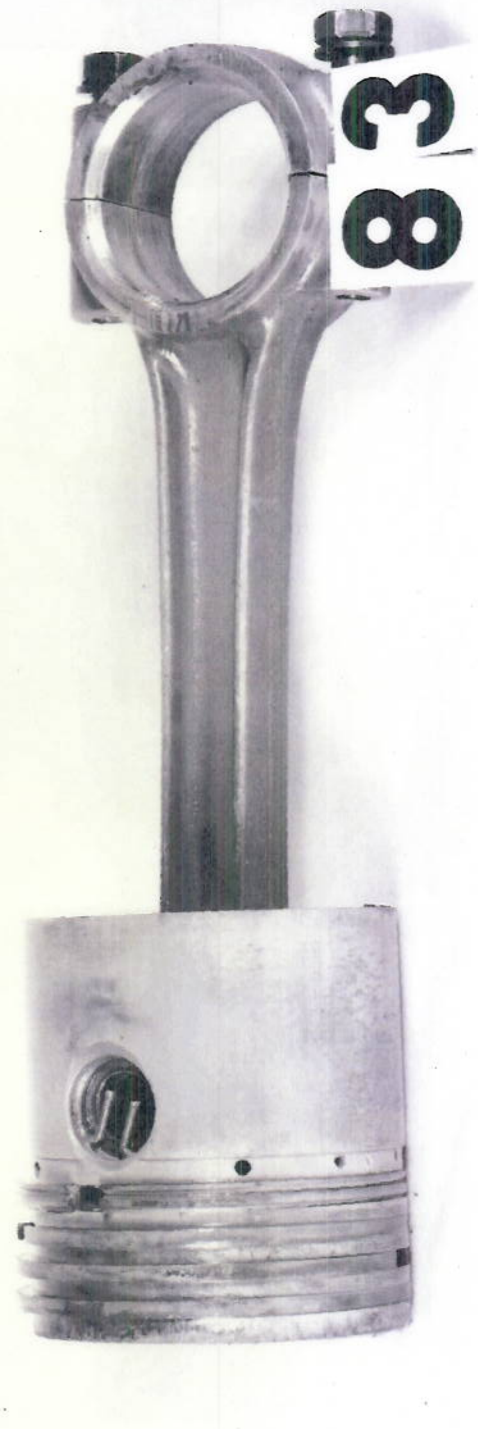

PLATE 27

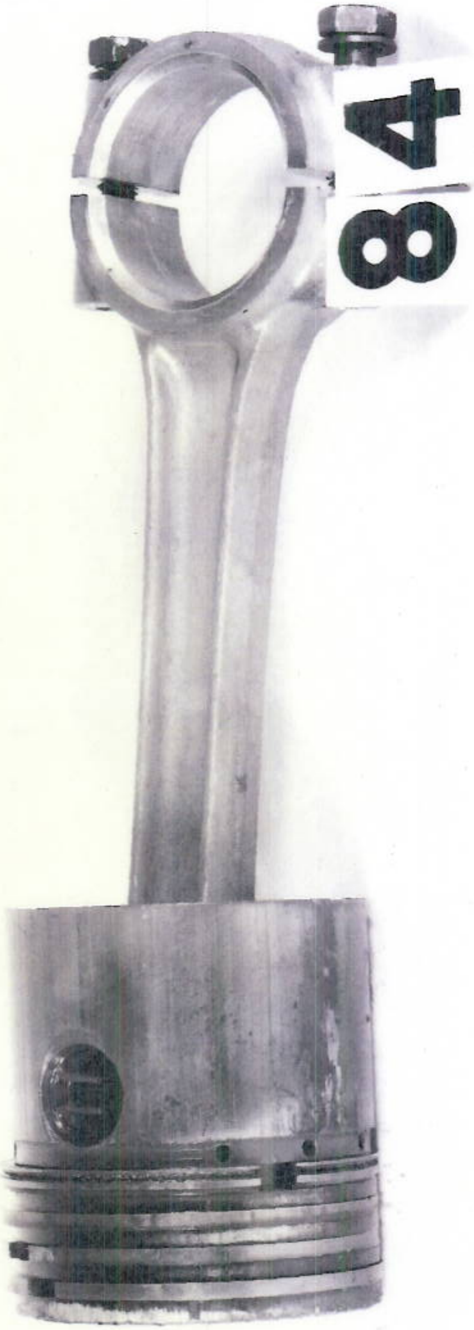

PLATE 28

DECLASSIFIED

PLATE 29

PLATE 30

PLATE 31

PLATE 32

DECLASSIFIED

PLATE 33

PLATE 34

PLATE 35

PLATE 36

PLATE 37

PLATE 38

PLATE 39

PLATE 40

DECLASSIFIED

PLATE 41

PLATE 42

DECLASSIFIED

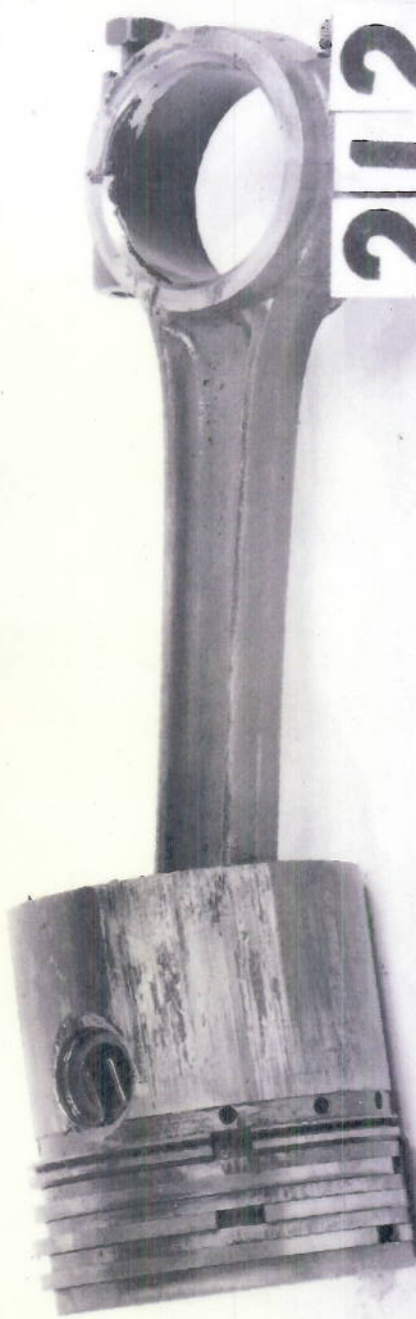

PLATE 43

PLATE 44

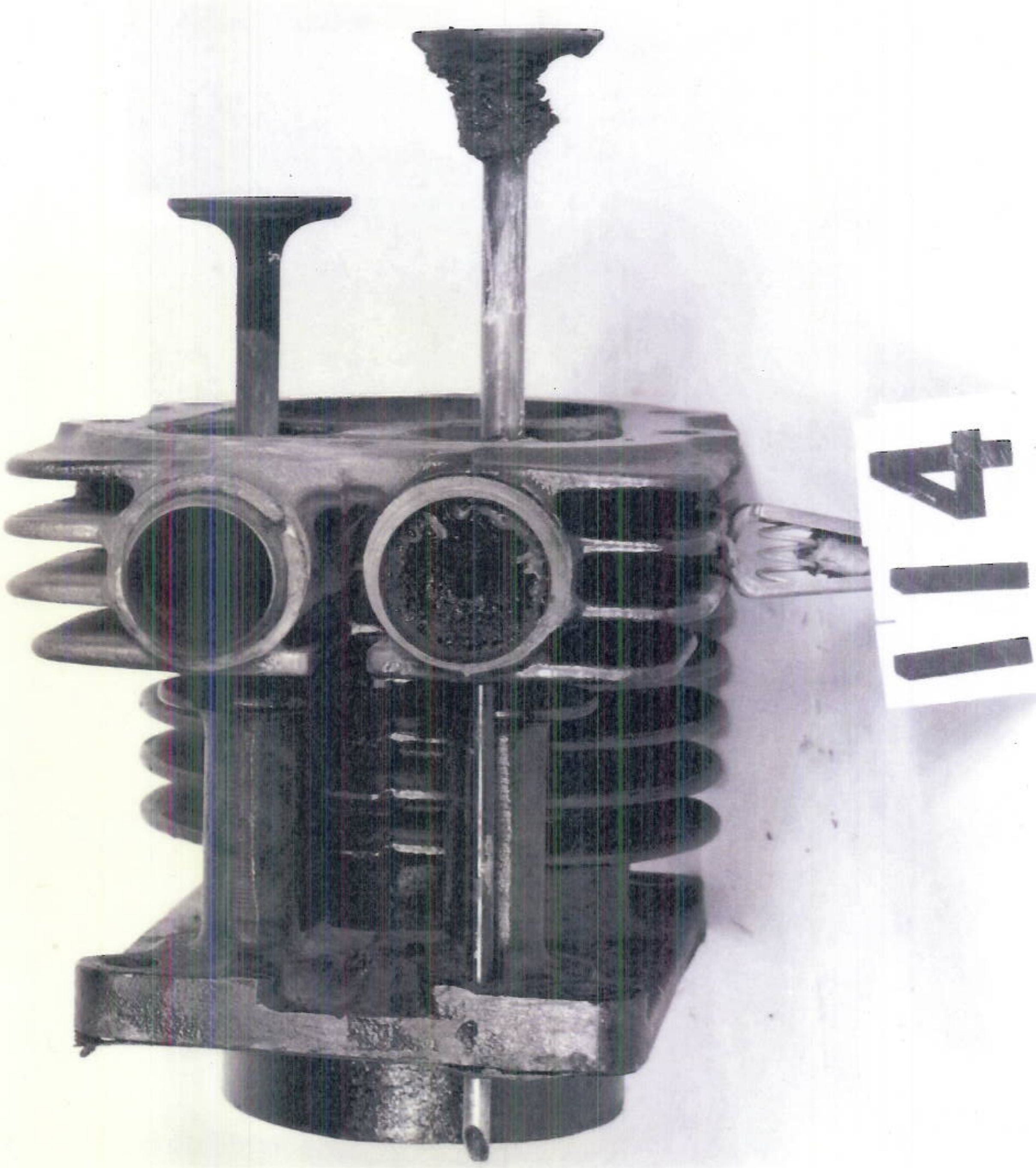

PLATE 45

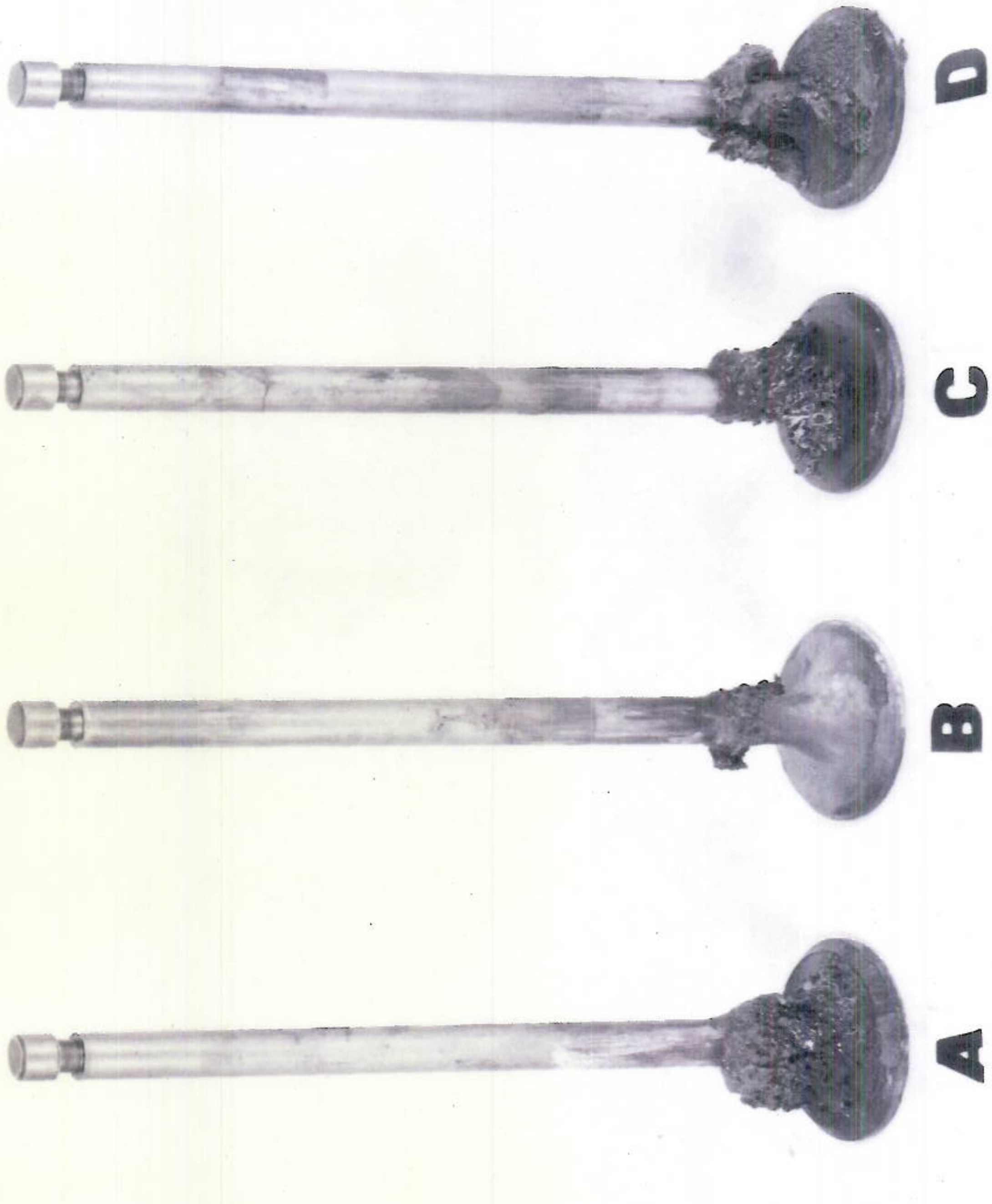

PLATE 46

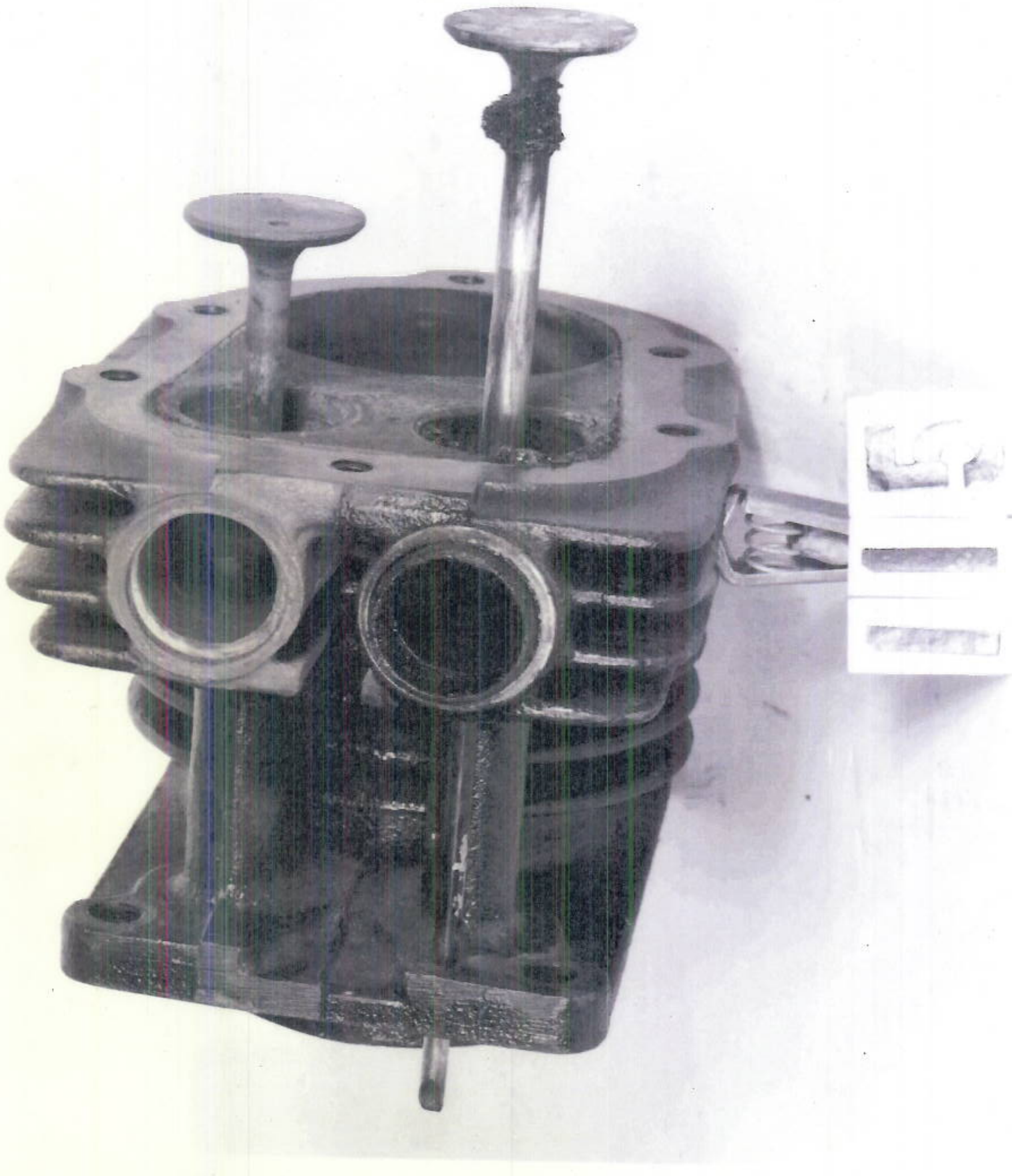

PLATE 47

DECLASSIFIED

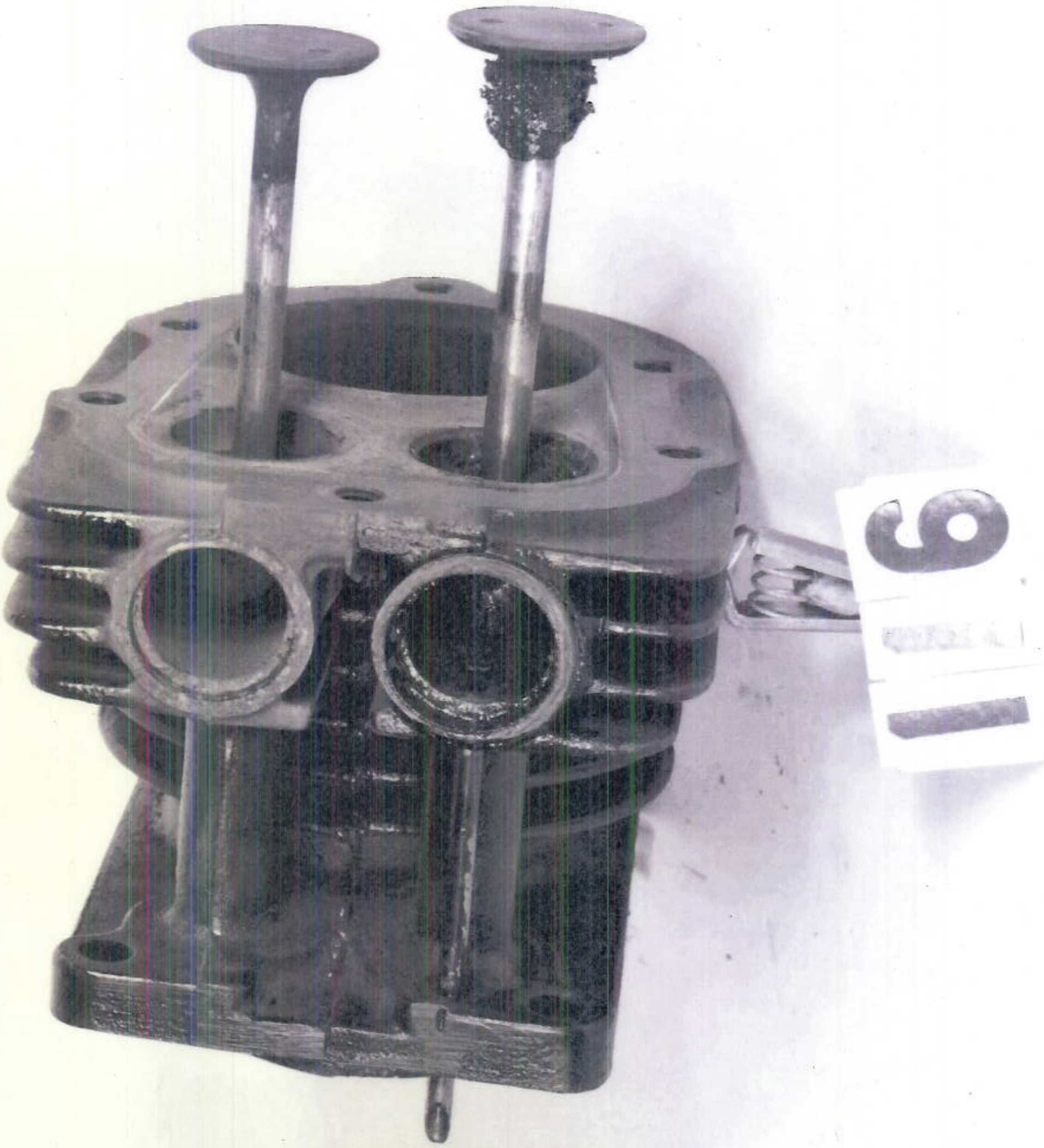

PLATE 48

PLATE 49

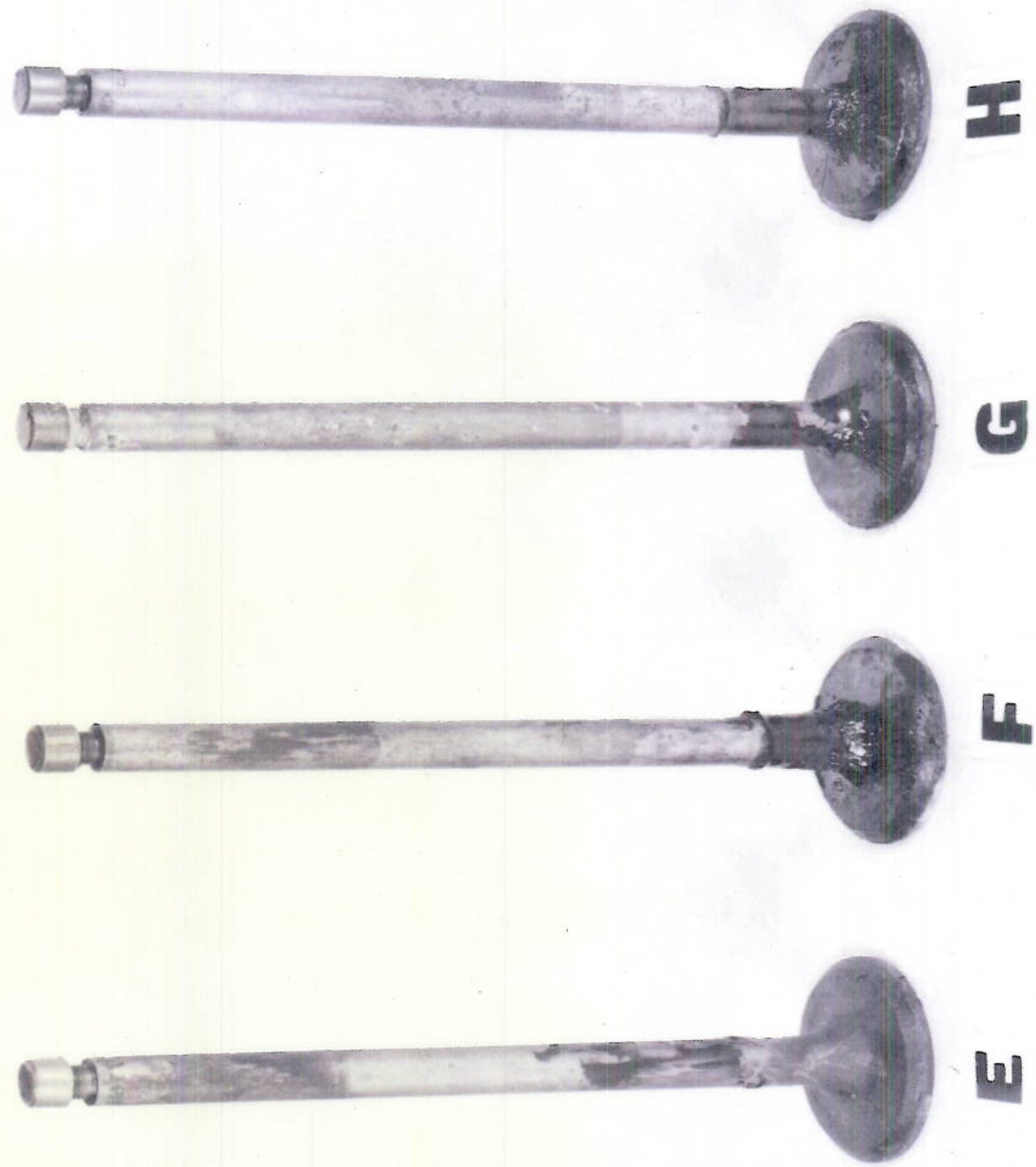

PLATE 50

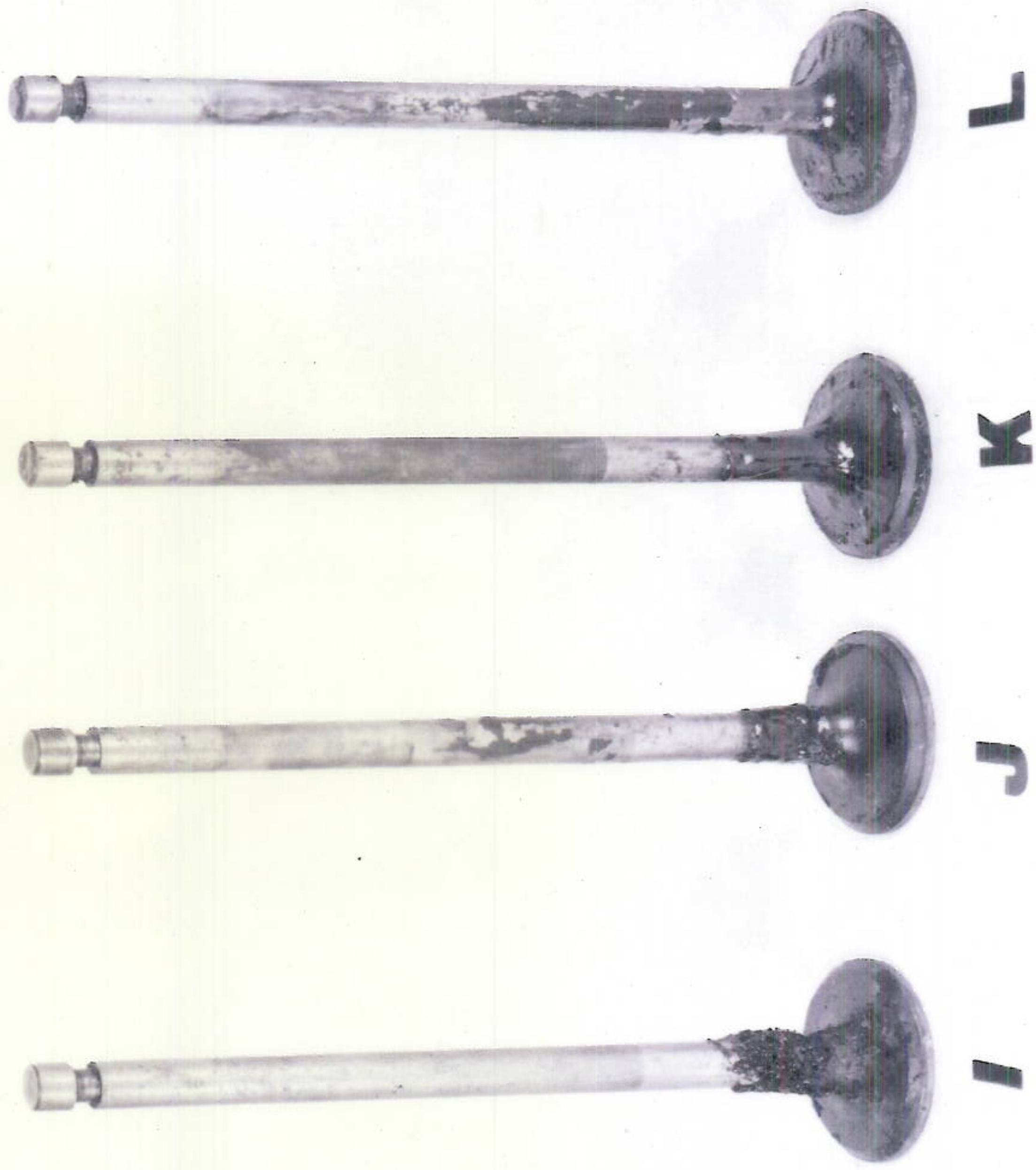

PLATE 51

DECLASSIFIED