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RADIATION EFFECTS ON MATERIALS

UNITED STATES ATOMIC ENERGY COMMISSION

**DEVELOPMENT OF RADIATION
RESISTANT OILS**

Report No. 11

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June 16, 1958

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Richmond, California**

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CALIFORNIA RESEARCH CORPORATION
RICHMOND, CALIFORNIA

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California Research-AEC Report No. 11
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SUMMARY

The objective of this work was to develop oils of maximum radiation stability from readily available ingredients. Lubricants in three viscosity grades were made from an alkylbenzene containing select polymers and inhibitors. Each new oil was subjected to standard tests to determine if it met the specifications for presently used mineral oils. The special oils complied with most requirements, and shortcomings were generally correctable.

Both the special and conventional oils were irradiated in the Canal Gamma Source at the Materials Test Reactor (MTR). Most conventional oils were damaged beyond usefulness at 10×10^8 roentgens (r). The alkylbenzene fluids retained lubricating qualities after 50 to 70×10^8 r. These results prove the feasibility of making radiation resistant lubricants by this approach.

Introduction

The objectives of the developments described herein include:

- a. Formulation of lubricating oils of maximum radiation resistance.
- b. Evaluation of their performance and limitations.
- c. Comparison of their performance and radiation stability with selected general purpose lubricants.
- d. A specification for a general purpose radiation resistant oil.

During the reactor development program of the early 1950's, there was much interest in lubricants with high radiation stability. Reactor designers wanted to know the radiation threshold or limits of use of lubricants. With such information, savings in shielding weight might be made. Accordingly, California Research Corporation undertook the development of special lubricants. They were to be general purpose in nature; i. e., emphasis was to be placed on radiation resistance even though fluid range, low temperature viscosity, and other properties were less than optimum. Also, samples were to be made available to people concerned with lubrication problems in nuclear applications. The status report of this development was made previously⁽¹⁾. The present report discusses later developments and final formulations and test work.

Earlier work⁽¹⁾ established that organic fluids vary by a large factor in their resistance to nuclear radiation. Aromatic structures were shown to be the most stable. Therefore, the initial lubricants were based on a commercially available mixed alkylbenzenes. The poor viscosity index (V.I.) was improved and the low viscosity was

(1) "Radiation Resistant Lubricants - Their Development and Status," California Research-AEC Report No. 7, TID 5186, June 30, 1954.

raised to suitable levels by the addition of high molecular weight polymers. This practice is common in making lubricants for non-nuclear applications⁽²⁾. Further stability was imparted to the formulations by adding a dialkyl selenide. The organic selenides are particularly effective as oxidation inhibitors⁽³⁾ and also as agents which retard radiation damage in these base oils⁽¹⁾. The new lubricants were made up in several viscosity grades and exposed to gamma radiation for about 10^{10} r. Although severely damaged, they remained fluid after this extremely high radiation dosage⁽¹⁾.

The results from the above approach were so encouraging that additional work was done and is reported here. Three special oils were made up as before, using the mixed alkylbenzenes, polymers, and the dialkyl selenide. Each of the three oils represented a grade defined by viscosity limits. Within each grade, three or more conventional mineral oils were chosen as references. Each special oil was tested against the requirements which were common to the reference oils within the respective grade. The special and the conventional oils (20 in all) were then irradiated with gamma dosage up to about 70×10^8 r. Postirradiation tests were conducted so that results could be compared with data on the original oils.

All irradiations were made in the Canal Gamma Source at the Materials Testing Reactor (MTR). This source comprises spent fuel elements placed in a frame under 20 feet of water for shielding. Gamma dosages are expressed here in terms of the roentgen (r). The

- (1) "Radiation Resistant Lubricants - Their Development and Status," California Research-AEC Report No. 7, TID 5186, June 30, 1954.
- (2) V. A. Kalichesky, "Lubricating Oil Additives," Petrol. Refiner 28, No. 7, July 1949, p. 125.
- (3) G. H. Denison and P. C. Condit, "Oxidation of Lubricating Oils - Dialkyl Selenides as Inhibitors," Ind. and Eng. Chem. 41, May 1949, p. 44.

value of r in more familiar units of energy may be expressed as:
 $10^8 r \approx 362$ Btu per pound. Measurements in the MTR source are both determined⁽¹⁾ (by replacing a sample with a monitor) and reported in terms of r . Thus, the unit is familiar and meaningful even though it is properly applied only to the strength of the radiation field rather than to energy absorbed by the sample. The prevailing dose rate varied ten-fold to a maximum of about 2×10^7 r/hour. The values of dosage are accurate to $\pm 10\%$. A few irradiations were conducted in the California Research-AEC cobalt-60 source⁽³⁾ in which the dose rate was about 3.2×10^5 r/hour; dosages are accurate to $\pm 5\%$. The gamma dosages shown were not corrected for attenuation by the container walls. Calculations showed that this error was less than 5% for the containers used.

In most exposures in the MTR source, about 150 ml of the oil was placed in a sample container open to the air, as described previously⁽²⁾. Samples exposed in the cobalt-60 source were held in glass vials to which air had access.

The physical and chemical properties of the oils and their performances in bench tests were measured by recognized procedures as set forth in the Federal Test Method Standard⁽⁴⁾ and ASTM Standards⁽⁵⁾.

- (1) C. H. Hogg, "Gamma Ray Dosage Rate Measurements," U.S. AEC Document IDO-16205, November 22, 1955.
- (2) J. G. Carroll and S. R. Calish, "Some Effects of Gamma Radiation on Commercial Lubricants," Lube Eng., 13, No. 7, July 1957.
- (3) B. Manowitz, "Use of Kilocurie Radiation Sources," Nucleonics 9, No. 2, August 1951, p. 10.
- (4) Federal Test Method Standard No. 791, December 15, 1955.
- (5) ASTM Standards on Petroleum Products and Lubricants, ASTM Committee D-2, November 1955.

SELECTION OF LUBRICANTS

For base stocks, the commercially available alkylbenzenes* were used as in the work previously described. These are made by the HF alkylation of benzene with polypropene. Certain physical properties are noted in Table I.

Table I
Properties of Mixed Alkylbenzenes

	Alkylbenzene 250	Alkylbenzene 350
Average Mole Weight	~ 250	~ 350
Alkyl Carbon Atoms	~ 12	~ 20
Viscosity at 210°F, cs	1.78	3.99
Viscosity at 100°F, cs	6.51	29.6
Viscosity Index	(23)	-40
Pour Point, °F	-80	-40
Flash Point, °F	260	355
Initial Boiling Point, °F	662	786

Polymers were used to raise the viscosity and improve the V.I. of the alkylbenzene. The poly(α -methylstyrene) raised the viscosity level. The styrene-alkene improved V.I. and raised viscosity. As this polymer was an experimental product, an alternate formulation in each grade was made using commercially available polybutene. A dialkyl selenide was included in all formulations as an oxidation and radiation damage inhibitor. In Fluid 0-4C, a sulfur additive was included to impart film strength. The composition and properties of the special oils are shown in Table II.

*Alkylbenzene 250 is a distilled product, mostly monoalkylbenzene;
Alkylbenzene 350 is a bottoms product, mostly dialkylbenzene.

TABLE II

COMPOSITION AND PROPERTIES OF SPECIAL OILS

Grade Number	Light		Medium		Heavy		
	0-1.5	0-1.5A	0-2.5	0-2.5A	0-3.5	0-3.5A	0-4C
<u>Composition, Wt. %</u>							
Alkylbenzene 250 ^a	67.2	66.20	-	-	-	-	-
Alkylbenzene 350 ^b	-	-	71.95	68.95	45.95	43.95	42.95
Poly(α -methylstyrene) ^c	21.8	21.8	18.0	18.0	40.0	40.0	35.0
Styrene-Alkene Copolymer ^d	5.98	-	5.0	-	9.0	-	-
Polybutene 128 ^e	-	7.0	-	8.0	-	11.0	12.0
Didodecyl Selenide ^f	4.97	4.95	5.0	5.0	5.0	5.0	5.0
Pinene P ₂ S ₅ ^g	-	-	-	-	-	-	5.0
Quinizarin ^h	0.05	0.05	0.05	0.05	0.05	0.05	0.05
<u>Viscosity</u> at 210°F, cs	4.80	4.42	9.48	9.35	18.3	16.9	17.3
100°F, cs	26.4	25.8	105	108.4	312	367	332
210°F, SSU	42.4	40.77	57.5	57.07	90.8	85.4	87.2
100°F, SSU	125	122.9	499	502	1449	1701	1542
<u>Viscosity Index</u>	114	82	65	57	61	19	42

- a. Oronite Alkane 56
b. Oronite Aromatics ABH
c. Dow V-9 Resin
d. Monsanto Santodex

- e. Oronite Polybutene 128
f. Oronite OLOA 250
g. Monsanto Santolube 395X
h. Eastman T-3054

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The radiation resistance of polybutene is similar to that of the styrene-alkene copolymer. (See Appendix I.) Further comparisons of several polybutenes with the copolymer were made in solutions of the alkylbenzene base stock. Table III shows results of exposures in a Co-60 gamma source. Figure 1 shows graphically the variation of viscosity with gamma dosage. Of the polybutenes, the low molecular weight material was preferable. This compound was also slightly better than the copolymer in thermal stability tests at 400° F as shown in Table IV and in Figure 2.

TABLE III

RADIATION STABILITY OF POLYMER SOLUTIONS

Composition, Wt. %	Blend 1		Blend 2		Blend 3		Blend 4	
Alkylbenzene	60.45		55.45		55.95		54.45	
Poly(α -methylstyrene)	32		32		32		32	
Styrene-Alkene Copolymer	-		-		-		8.50 ^a	
Polybutene	2.50		7		7		-	
Didodecyl Selenide	5.00		5		5		5	
Quinizarin	0.05		0.05		0.05		0.05	
Viscosity of Polybutene								
SSU at 210° F	560,000		20,000		18,270		-	
Radiation Resistance								
Dosage, 10 ⁸ r ^b	Viscosity, SSU							
	100° F	210° F	100° F	210° F	100° F	210° F	100° F	210° F
0	888	74.7	770	62.3	778	62.5	1079	81.3
0.026	814	70.4	766	62.2	776	62.5	1077	81.1
0.077	733	65.4	760	62.1	768	62.2	1074	80.6
0.15	663	61.6	753	61.5	764	61.8	1064	79.8
0.31	598	57.6	739	60.8	749	60.2	1041	78.0
0.69	532	54.0	704	59.4	711	59.2	991	75.9
1.10	500	52.4	679	58.2	681	58.1	953	73.3
1.54	484	51.6	656	57.2	648	57.2	897	71.3
1.92	476	51.2	642	56.6	634	56.5	881	69.7
2.30	476	51.0	637	56.4	642	56.4	883	69.4
3.15	475	50.7	625	55.7	633	55.9	882	67.8

FIGURE I

RESISTANCE OF POLYMER SOLUTIONS TO GAMMA RAYS

CO⁶⁰ SOURCE, ALKYL BENZENE 350 BASE OIL (SEE TABLE III)

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TABLE IV

THERMAL STABILITY OF SPECIAL OILS

Composition, % by Wt.	Blend 1 0-3		Blend 2 0-3A	
Alkylbenzene 350	54.45		55.95	
Poly(α -methylstyrene)	32.00		32.00	
Styrene-Alkene Copolymer	8.00		-	
Polybutene	-		7.00	
Didodecyl Selenide	5.00		5.00	
Quinizarin	0.05		0.05	
Viscosity, SSU at	100° F		210° F	
400° F in 410 stainless				
steel capsules for - 0 weeks	787		73.1	
(sealed under helium) 1	375		51.4	
2	348		49.4	
3	294		47.8	
4	264		46.0	
5	298		46.8	
			780	
			507	
			544	
			460	
			554	
			487	
			62.4	
			55.6	
			56.0	
			54.3	
			56.6	
			54.8	

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PERFORMANCE OF SPECIAL OILS IN SPECIFICATION TESTS WITHOUT RADIATION

The new oils were tested against the requirements common to conventional oils in each of the three viscosity grades listed in Table V. Results are in Tables VI, VII, and VIII, respectively, for light, medium, and heavy grade oils. The performance of the special oils is summarized as follows:

1. Outstanding: Oxidation-corrosion at 250° F (light and heavy grades), turbine oil oxidation at 200° F (medium grade).
2. Satisfactory: Flash point (except heavy grade), color neutralization number, copper corrosion, ash, saponification number, carbon residue, sulfur, and precipitation number.
3. Marginal: Foaming, emulsion, film strength, and pour point.

In general, the new formulations are acceptable lubricants as indicated by the specification tests. Viscosity can be adjusted by varying the ratio of base oil to polymer. The marginal properties are those which normally can be controlled or improved by additives.

TABLE V

TYPICAL LUBRICATING OILS

I. Light Grade - Viscosity Range - 70 - 120 SSU at 130°F

a. MIL-L-15016A; Grade 2075	Lubricating Oil,	General Purpose
b. MIL-L-15017; Grade 2110H	Lubricating Oil,	Hydraulic
c. MIL-L-644A;	Lubricating Oil,	Preservative, Special
d. MIL-O-5606	Lubricating Oil,	Hydraulic, Aircraft

II. Medium Grade - Viscosity Range - 55 - 70 SSU at 210°F

a. MIL-L-15016A; Grade 2190	Lubricating Oil,	General Purpose
b. MIL-L-17331(Ships); Grade 2190T	Lubricating Oil,	Turbine (Noncorrosive)
c. MIL-L-2104A; Grade 30	Lubricating Oil,	Internal Combustion Engine Heavy Duty
d. MIL-L-9000A(Ships); Grade 9030	Lubricating Oil,	Diesel Engine
e. MIL-L-6086A(ASG); Grade M	Lubricating Oil,	Gear, Petroleum Base

III. Heavy Grade - Viscosity Range - 85 - 200 SSU at 210°F

a. VV-L-765; Grades 90, 140	Lubricant,	Enclosed Gear, Straight Mineral
b. MIL-L-6082A; Grades 1065, 1100	Lubricating Oil,	Aircraft Engine
c. MIL-L-2105; Grade 90	Lubricant,	Gear, Universal

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TABLE VI

PROPERTIES OF LIGHT GRADE LUBRICATING OILS

F.S. a Method No.	Specification Description Date of Specification Custodian General	MIL-L-15016A	MIL-L-15017		MIL-L-644A	MIL-O-5606 ^b	Oil No. 0-1.5
		Grade 2075	Grade 2075H	Grade 2110H			
		October 18, 1950 Navy Bureau Ships	Am. No. 1 October 1, 1950 Navy Bureau Ships		Am. No. 2 February 15, 1950 Army - Ordnance	Am. No. 1 August 22, 1950 Air Force	
		For General Purpose Use	For General Use in Hydraulic Systems: General Purpose		Lubrication and Protection of Small Arms: General Purpose Squirt Can	For Use in Hydraulic Systems, Autopilots, Absorbers, Brakes	
	<u>Test or Property</u>						
40.1	Specific Gravity, 60/60°F	Report	Report		-	-	0.9106
	°API	Report	Report		-	-	4.8
30.5	Viscosity, cs at 210°F	(13.07-18.15)	(13.07-18.16) (18.16-25.20)		12	10	13.9
	130°F				7200 at -40°F	500 at -40°F	26.4
	100°F						1000 ^c
	0°F Max						42
910.1	Viscosity, SSU at 210°F	70-90	70-90				73
	130°F		90-120				125
	100°F						
	0°F Max						
911.1	Viscosity Index	Report	Report				114
20.1	Pour Point, °F Max	-10	-10		-70	-75	15
110.3	Flash Point, °F Min	315	315		275	200	380
345.1	Work Factor, Min	0.80	0.90		-	-	Not tested
10.2	Color	Report	Report		Lighter than No. 7	red	4-1/2
510.1	Neutrality, qualitative	Neutral	Neutral		-	-	Neutral
510.5	Neutralization No., Max	0.10	0.20		-	0.20	N11
530.3	Corrosion, Copper at 212°F	No Discoloration	No Discoloration		No Discoloration	No Discoloration	SL tarnish
300.1	Water, % Max	None	None		-	-	N11
542.1	Ash, % Max	0.003	Report		-	-	0.00
540.1	Saponification No., Max	0.5	0.5		-	-	0.35
500.1	Carbon Residue, % Max	0.10	0.10		-	-	0.11
	Nature of Carbon	Loose and Flaky	Loose and Flaky		-	-	L and F
520.2	Total Sulfur, % Max	0.50	0.50		-	-	0.41
310.1	Precipitation No., Max	0.01	0.01		0	0	Trace
401.1B	Rust Prevention, sea water	-	pass		-	-	Not tested
321.1	Foaming after Sequence No.1	-	300 ml		-	-	Pass
	10 min of collapse Sequence No.2	-	25 ml		-	-	Pass
		-	300 ml		-	-	Pass
320.1	Emulsion at 130°F	-	Stable in 30 Minutes		-	-	Not pass
	<u>Oxidation Corrosion</u>						
	168 hrs at 250°F Evaporation Loss	-			-	-	1.3%
	Change in 100°F Viscosity				-5% to +20%	-5% to +20%	-0.4
	Increase in Neutralization No.				<0.20	<0.20	+0.03
	Weight Change, Copper				+0.2	+0.6	0.10
	mg/cm ² Steel				+0.2	+0.2	0.00
	Aluminum				+0.2	+0.2	+0.01
	Magnesium				+0.2	+0.2	-0.01
	Cadmium				+0.2	+0.2	+0.01
	<u>Corrosion Protection</u>						
	200 hrs at 100% R.H. and 120°F				No corrosion on one panel; removable	-	Not tested
	Gumminess at 210°F				No gumminess	-	Not tested
	<u>Machine Gun Performance</u>						
	Caliber .50 M ₂				Satisfactory at -70°F	-	Not tested
	Stability at -65°F				Compare	Stable	Not tested
	<u>Shear Stability</u>					Compare to Reference fluid	Not tested
	5000 cycles in pump				-	20-31	54
	Swell of Synthetic Rubber L, %				-	Not hard or tacky	Not tested
	Evaporation - 4 hrs at 150°F				-		

- a. Federal Test Method Standard No. 791
- b. Properties of base oil and additives also specified
- c. Extrapolated

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TABLE VII

PROPERTIES OF MEDIUM GRADE LUBRICATING OILS

Method No.			Specification	MIL-L-15016A, Am. 1 Grade 2190 October 18, 1950 Navy-Bureau of Ships	MIL-L-17331 (Ships), Am. 1 Grade 2190T March 9, 1953 Navy-Bureau of Ships	MIL-L-2104A, Am. 1 Grade 30 May 6, 1954 Army-Ordnance	MIL-L-9000A (Ships) Grade 9030 January 2, 1952 Navy-Bureau of Ships	MIL-L-6086A, Am. 1 (ASG) Grade M January 3, 1955 Air Force-WADC	Oil No. 0-2.5
a	b	Army Ordnance	Date of Specification Custodian General	For General Purpose Use	Turbines, Reduction Gears, General Purpose	Heavy Duty Internal Combustion Engines	Heavy Duty Diesel Engine	Aircraft Gears	
F.S.	ASTM		Test or Property						
40.1	D287	-	Specific Gravity, 60°/60°F	Report	-	-	-	-	0.911
40.1	D287	-	API Gravity	Report	Report	-	-	-	23.8
30.5	D445	-	Viscosity, cs at 210°F	-	8.2 min.	9.65 - 12.98	9.7 - 13.0	-	9.48
			130°F	39.75 - 44.28	-	-	-	-	40.7
			100°F	-	82 - 110	-	-	60 - 82	105.
			0°F	-	-	43,570 max. c	-	-	25,000 c
910.1	D446	-	Viscosity, SSU at 210°F	-	-	58 - 70	58 - 70	-	57.5
			130°F	185 - 205	-	-	-	-	190
			100°F	-	-	-	-	-	489
			0°F	-	-	200,000 max. c	-	-	115,000 c
911.1	D567	-	Viscosity Index	Report	-	-	Report	80 min.	65
110.3	D92	-	Flash Point, °F	350 min.	350 min.	390 min.	390 min.	310 min.	340
20.1	D97	-	Pour Point, °F	35 max.	20 max.	0 max.	10 max.	-20 max.	+20
345.1	-	-	Work Factor	0.80 min.	-	-	-	-	not tested
10.2	D155	-	Color	Report	Report	-	-	8 dil. max.	4.5
510.1	-	-	Neutrality, Qualitative	Neutral	Neutral	-	-	-	neutral
510.5	-	-	Neutralization No.	0.10 max.	-	-	Report	1.0 max.	nil
531.3	D130	-	Copper Corrosion at 212°F	Pass	Slight Tarnish	-	-	no blackening or pitting	Slight Tarnish
300.1	D95	-	Water, %	None	None	-	-	-	none
542.1	D482	-	Ash, %	0.003 max.	-	-	-	-	0
540.1	-	-	Saponification No.	0.5 max.	-	-	-	-	0.38
500.1	D189	-	Carbon Residue, %	0.40 max.	Report	-	Report	-	0.07
			Nature of Carbon	L & F	-	-	-	-	L & F
520.2	D129	-	Sulfur, %	0.50 max.	-	-	Report	-	0.44
310.1	D91	-	Precipitation No.	0.01 max.	-	-	0.03 max.	0.10 max.	0
-	D974	-	Neutralization No.	-	0.20 max.	-	-	-	0
401.1-B	D665	-	Corrosion in Salt Water	-	None	-	-	-	not tested
542.2	D874	-	Ash, Sulfated, %	-	Report	-	Report	-	0
320.1	-	-	Emulsion, Min.	-	30 max.	-	-	-	pass
-	D943	-	Oxidation Test, Hrs.	-	1000 min.	-	-	-	3800+
321.1	D892	-	Foaming	-	Pass	Pass	-	-	Borderline
-	-	AXS1554	Oxidation Test	-	-	Pass	-	-	Not tested
-	-	AXS1551	Engine Test	-	-	Pass	-	-	Not tested
6503	-	-	Mean Hertz Load	-	-	-	-	40 min.	13.5

a. Federal Test Method Standard No. 791

b. American Society for Testing Materials, Standards on Petroleum Products and Lubricants

c. Extrapolated

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TABLE VIII

PROPERTIES OF HEAVY GRADE LUBRICATING OILS

Method No.				Specification Description Date of Specification Custodian	VV-L-765		MIL-L-6082A		MIL-L-2105	Oil No. 0-3.5
					Grade 90	Grade 140	Grade 1065	Grade 1100	Grade 90	
				General	July 18, 1950		October 9, 1951		April 7, 1950	
					General Services Administration		Navy Bureau Aero.		Army Ordnance	
a	b	Army	CRC	General	Mineral Oil For Use In Auto and Industrial Gears Below 250°F, Nonextreme Pressure		Oil Shall Be Suitable For Use In Aircraft Engines		For Use In Automotive Gears	
F. S.	ASTM	Ordnance								
30.4	D 88			Test or Property						
				Viscosity, cs. at 210°F						18.3
				100°F						312
				0°F						130,000 ^d
				Viscosity, SSU at 210°F		120-200	62-68	93-103	80-90	91
				100°F	800-1500					1449
				0°F						
911.1	D 567			Viscosity Index, Min.	50	50	100	95	85	61
20.1	D 97			Pour Point, °F, Max.	0	35	0	10	-	20
110.3	D 92			Flash Point, °F, Min.	375	400	420	470	325	340
542.1	D 482			Ash, % Max.	0.02	0.05	0.5 mg per 20 gm		-	0.00
510.1	-			Neutrality		Neutral	Neutral		-	Neutral
510.3				Neutralization No., Max.	-	-	0.10		-	Nil
310.1	D 91			Precipitation No.	Trace	0.1	0		-	Trace
530.3	-			Corrosion to Copper		Negative	Negative		-	Sl. tarnish
345.1				Work Factor, Min.	-	-	0.85		-	Not tested
540.1				Saponification No., Min.	-	-	0.5		-	0.41
520.2				Total Sulfur, %, Max.	-	-	0.5		-	0.44
				Contamination	-	-	<15 mg per gal		-	Not tested
500.1				Carbon Residue, %, Max.	-	-	0.6	1.2	-	0.10
		AXS-1565	L-15-445	Channel Point, °F	-	-	-	-	0	
		AXS-1566	L-16-445	Copper Corrosion	-	-	-	-	No Blackening	
		AXS-1563	L-13-445	Rusting	-	-	-	-	Pass	
		AXS-1569	L-19-645	High Speed Axle Test	-	-	-	-	Pass	Not Tested
		AXS-1570	L-20-445	High Torque Axle Test	-	-	-	-	Pass	
		AXS-1571	L-21-445	Moisture Corrosion Test	-	-	-	-	Pass	
		AXS-1572	L-22-445	Storage Solubility	-	-	-	-	Pass	
321.1		AXS-1562	L-12-445	Foaming	-	-	-	-	Pass	Marginal
520.2	D 129			Sulfur	-	-	-	-	To Be Determined By Procuring Agency	Not Tested
561.1	D 810			Lead	-	-	-	-		
566.1	D 809			Phosphorous	-	-	-	-		
565.1	D 808			Chlorine	-	-	-	-		
(MIL-O-5606)				Oxidation Corrosion						
				168 Hours at 250°F						0.6%
				Evaporation Loss						0.00
				Change in 100°F Visc.						+0.01
				Change in Neutr. No.						+0.08
				Weight Change: Copper						+0.02
				Steel						0.00
				mg/cm ² Aluminum						+0.02
				Magnesium						+0.01
				Cadmium						

- a. Federal Test Method Standard No. 791
b. American Society for Testing Materials, Standards on Petroleum Products and Lubricants
c. Coordinating Research Council
d. Extrapolated

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RESULTS OF IRRADIATIONS

Both the special and conventional oils were irradiated in the MTR Canal Source for approximate dosages of 5, 10, and 50×10^8 r. Post-irradiation tests were conducted on the limited size samples. Results are shown in Tables IX, X, and XI, respectively, for light, medium, and heavy grade oils. No mineral oils survived the 50×10^8 r exposure. All were reduced to brittle, glassy solids. Figure 3 illustrates their typical appearance. By contrast, all the special oils were still fluid and only slightly darkened by this level of irradiation.

Viscosity change is a good over-all index of radiation damage and is easily measured. Figures 4, 5, and 6 illustrate radiation-induced viscosity change for light, medium, and heavy oils, respectively. Not all oils are shown, but the curves include the best and the worst of those tested. The slopes are indicative of the rates of viscosity change. The heavy oils increase in viscosity at a faster rate than the lighter oils. For all grades, aromatic base lubricants were clearly superior.

The effect of radiation on the V.I. of thickened^(1, 2) and of unthickened⁽²⁾ lubricants was reported previously and was confirmed by these results. The possibility of making a "constant viscosity" fluid for a given radiation dosage range, i. e., an oil which would have the same or only slightly different viscosity after exposure to a selected dosage relative to its original value, was also mentioned before⁽¹⁾. Figure 7 illustrates the loss and recovery of viscosity with gamma radiation for the type of polymer-in-oil system discussed here. A proper choice of polymers (see Appendix I) would minimize the initial viscosity decrease shown in Figure 7 and allow a lubricant to be designed to recover its original viscosity after a given dosage.

- (1) R. O. Bolt and J. G. Carroll, "Radiolysis and Radiolytic Oxidation of Lubricants," Ind. and Eng. Chem. 50, No. 1, January 1958, p. 221.
- (2) J. G. Carroll and S. R. Calish, "Some Effects of Gamma Radiation on Commercial Lubricants," Lube Eng. 13, No. 7, July 1957, p. 388.

TABLE IX

TEST RESULTS ON IRRADIATED LIGHT GRADE LUBRICATING OILS

	MIL-L-15016A, Grade 2075					MIL-L-15017, Grade 2110H					MIL-L-644A				
Gamma Dosage, 10 ⁶ r	-	3.75	7.12	7.85	43.0	-	6.75	13.2	13.6	81.0	-	7.45	14.9	15.0	89.0
Appearance of Oil	-	-	hazy	hazy	tacky	-	-	althaze	clear	hard	-	-	alt haze	clear	hard
Color, ASTM	2	-	4	4	dark	2	-	4-1/2	5-	-	3-1/2	-	3-1/2	3-1/2	-
Appearance of Can	-	-	OK	OK	OK	-	-	OK	OK	-	-	-	OK	OK	-
Viscosity, cs at 210°F	4.85	6.57	7.75	8.02	ROBERTY	5.58	10.9	18.3	19.4	GLASS-LIKE	2.78	4.96	9.89	10.3	GLASS-LIKE
100°F	34.6	57.0	71.0	77.7		39.0	110	231	240		11.9	32.7	86.4	91.1	
SSU at 210°F	42.1	47.7	51.6	53.2		44.5	62.5	91.1	96.1		35.6	42.5	58.9	60.4	
100°F	162	265	329	360		182	512	1069	1113		65.7	154	400	422	
Viscosity Index	46	62	76	77	-	85	90	95	100		77	75	102	103	
Copper Corrosion, 3 hr at 212°F	1a	1a	1a	1a		1a	1a	1a	1a		1b	1a	1a	1a	
Insolubles, wt per cent	-	-	0.02	0.03	-	-	-	-	-	-	-	-	0	0.04	-
Neutralization Number, mg KOH/g (Micro)	0.07	0.06	0.04	0.07	-	0.07	0.05	0.05	0.04	-	0.54	0.01	0.05	0.01	
Four-Ball Wear Test Scar diameter in mm 10 kg load, 30 min at 1200 rpm; st/st	0.384 0.400 0.384 0.404														
Four Point, °F	-10	-15	-35	-25	-	-10	-30	-10	-5	-	-70	-60	-50	-55	-
Evaporation, per cent 22 hr at 210°F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	MIL-O-5606					Oil No. 0-1.5					Oil No. 0-1.5A				
Gamma Dosage, 10 ⁶ r	0	7.20	14.7	14.9	88.0	0	6.20	12.9	13.4	77.0	0	4.67	10.4	10.7	57.0
Appearance of Oil	-	-	clear	clear	hard	-	-	sludge	sludge	sludge	-	-	alt haze	alt cloudy	-
Color, ASTM	5-6	-	4-1/2	4	-	4	-	opaque	opaque	8-	4-	-	4-	4-	4-1/2
Appearance of Can	-	-	rough	rough	OK	-	-	black	black	-	-	-	OK	OK	-
Viscosity, cs at 210°F	5.07	2.94	4.91	4.80	GLASS-LIKE	4.94	3.86	3.69	3.74	15.1	4.43	3.51	3.80	3.71	7.10
100°F	13.1	12.0	26.6	25.5		26.1	21.3	20.1	20.2	264	25.7	20.3	22.2	21.5	72.2
SSU at 210°F	42.9	36.1	42.4	38.8		42.4	40.0	38.5	38.6	78.3	40.8	37.9	38.8	38.5	49.5
100°F	70.1	66.5	126	122		124	103	98.3	98.6	1224	122	99.2	107	104	335
Viscosity Index	232	107	122	122		129	68	60	67	42	85	22	41	40	43
Copper Corrosion, 3 hr at 212°F	1a	1a	1a	1a		1b	2c	3b	3b	2c	1b	2c	2c	2c	2c
Insolubles, wt per cent	-	-	-	-		-	0.07	0.04	0.03	-	-	0	-	0	-
Neutralization Number, mg KOH/g (Micro)	n11	0.35	0.43	0.32		0.03	-	0.08	0.05	0.05	n11	0.10	0.06	0.03	0.02
Four-Ball Wear Test Scar diameter in mm; 10 kg load, 30 min at 1200 rpm; st/st											0.505 0.507	-	0.503 0.571	-	
Four Point, °F	-75	-70	-75	-65		+15	-20	-45	-50	-25	+15	-20	-65	-70	-40
Evaporation, per cent 22 hr at 210°F	-	-	-	-	-	-	-	-	-	-	31.1	-	-	30.3	-

TABLE X

TEST RESULTS ON IRRADIATED MEDIUM GRADE LUBRICATING OILS

	MIL-L-15016A, Grade 2190					MIL-L-17331 (Ships) Grade 2190T					MIL-L-2104A, Grade 30					MIL-L-9000A (Ships) Grade 9030				
Gamma Dosage, 10 ⁶ r	-	4.15	4.55	9.40	43.0	-	5.45	6.15	12.8	62.3	-	6.40	7.42	14.0	81.0	-	6.72	7.90	13.9	89.0
Appearance	-	hazy	hazy	-	GLASS-LIKE	-	clear	hazy	-	-	-	clear	hazy	-	-	-	clear	clear	-	-
Color, ASTM	2	8+	8-	-		1-1/2	4-	5	-	SOLID	7-	8+	8+	-	SOLID	5	7	7	-	SOLID
Appearance of Can	-	OK	OK	-		-	OK	OK	-		-	OK	OK	med stain		-	1t stain	med stain	-	
Viscosity, cs at 210°F	9.04	12.3	12.5	24.0		9.12	15.8	16.7	67.3		11.8	21.3	boils	94.2		10.7	17.8	19.7	45.6	
SSU at 210°F	93.6	146	150	412		84.2	184	200	1366		127	293	314	2210		133	305	332	1420	
100°F	56.0	67.4	68.3	116		56.5	81.0	84.5	314		65.7	104	boils	439		61.8	89.4	97.3	214	
100°F	433	677	695	1909		390	853	916	6331		587	1357	1457	10,243		618	1415	1537	6581	
Viscosity Index	72	77	77	81		91	95	95	107		87	90	-	67		60	60	70	67	
Copper Corrosion, 3 hr at 212°F	1a	1a	-	1a		1a	1a	-	1a		1a	2c	-	1a		1a	1a	-	1a	
Insolubles, wt per cent	-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-	
Neutralization Number, mg KOH/g (Micro)	0.01	0.09	-	0.11		0.09	0.05	-	0.08		0.03	0.06	-	0.11		0.23	0.04	-	0.14	
Four-Ball Wear Test Scar diameter in mm; 10 kg load, 30 min at 1200 rpm; st/st	0.34 0.37			0.31 0.34																
Pour Point, °F	0	-5	-5	0		0	0	-5	0		0	-10	-5	0		0	-10	-10	-15	
Evaporation, per cent 22 hr at 210°F	-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-	

	MIL-L-6086, Grade M					Oil No. 0-2.5					Oil No. 0-2.5A				
Gamma Dosage, 10 ⁶ r	-	6.30	7.45	12.6	88.0	-	5.20	6.25	9.5	77.0	-	3.65	4.65	6.5	57.0
Appearance	-	clear	cloudy	-	-	-	cloudy	cloudy	-	-	-	hazy	hazy	-	-
Color, ASTM	8+	black	black	-	-	4-1/2	4-1/2	opaque	-	8+	4	3-1/2	3-1/2	-	8+
Appearance of Can	-	black	black	heavy stain	-	-	black	black	-	heavy stain	-	black	black	-	heavy stain
Viscosity, cs at 210°F	8.00	12.8	15.4	25.5	SOLID	9.44	7.83	-	8.49	117	9.29	6.96	-	7.58	26.7
SSU at 210°F	70.7	141	162	414		106	88.8	94.6	108	1034	108	75.5	76.2	84.9	765
100°F	52.5	69.4	79.4	122		57.4	51.9	boils	54.1	542	56.9	49.0	boils	51.1	127
100°F	328	655	751	1917		489	415	439	500	4840	499	350	353	893	3550
Viscosity Index	85	89	104	89		54	37	-	27	-	56	24	-	35	31
Copper Corrosion, 3 hr at 212°F	1b	4a	-	3b		1b	2c	-	2c	1a	1a	1a	-	2b	1b
Insolubles, wt per cent	-	-	-	-		-	-	-	-	-	-	-	-	-	-
Neutralization Number, mg KOH/g (Micro)	0.05	0.91	-	0.48		nil	0.11	-	0.09	0.03	nil	0.07	-	0.09	0.03
Four-Ball Wear Test Scar diameter in mm; 10 kg load, 30 min at 1200 rpm; st/st											0.33 0.34			0.36 0.37	
Pour Point, °F	-25	-30	-36	-20		+20	-15	-	-25	+10	+20	-10	-20	-50	0
Evaporation, per cent 22 hr at 210°F	-	-	-	-		-	-	-	-	-	13.0	-	-	7.3	-

TABLE XI

TEST RESULTS ON IRRADIATED HEAVY GRADE LUBRICATING OILS

	VV-L-765, Grade 90					VV-L-765, Grade 140					MIL-L-6082A, Grade 1100					MIL-L-2105, Grade 90				
Gamma Dosage, 10 ⁸ r	-	5.65	9.05	7.5	34.5	-	7.50	12.2	10.6	49.5	-	9.00	13.8	13.6	63.2	-	9.8	14.0	15.0	70.5
Appearance of Oil	-	clear	-	hazy	-	-	clear	-	hazy	-	-	clear	-	cloudy	-	-	clear	-	cloudy	-
Color, ASTM	8+	8	-	8+	-	8+	8+	-	8+	-	7	6	-	6	-	8+	black	-	black	-
Appearance of Can	-	OK	-	OK	OK	-	OK	-	OK	OK	-	OK	-	OK	OK	-	black	-	corr.	corr.
Viscosity, cs at 210°F	18.8	28.6	70.2	42.0	SOLID	38.8	53.9	556	169	SOLID	20.3	27.4	-	236	SOLID	17.1	30.5	39.3	60.2	SOLID
SSU at 210°F	268	482	1650	796		843	1050	-	6290		272	580	-	6325		214	496	524	1221	
100°F	93.2	136	328	195		182	252	-	787		99.9	131	-	1102		86.1	145	183	281	
100°F	1240	2234	7647	3692		3904	4866	-	29,152		1258	2686	-	29,314		992	2301	2410	5659	
Viscosity Index	84	92	102	98		87	105	-	-		95	70	-	-		92	97	(-40)	105	
Copper Corrosion, 3 hr at 212°F	1a	1a	1a	1a		1a	1a	1a	1a		1a	1a	-	1a		3b	2d	3b	3a	
Insolubles, wt per cent	-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-	
Neutralization Number, mg KOH/g (Micro)	0.03	0.03	0.08	0.03		0.03	0.04	0.12	0.07		0.01	0.07	-	0.02		0.14	0.33	0.29	0.14	
Four-Ball Wear Test																				
Scar diameter in mm;	0.30	-	0.29	-																
10 kg load; 30 min at	0.33	-	0.30	-																
1200 rpm; st/st																				
Pour Point, °F	-5	-5	0	-		+30	-5	+30	0		0	0	-	-10		+10	+5	-5	+5	
Evaporation, per cent 22 hr at 210°F	-	-	-	-		-	-	-	-		-	-	-	-		-	-	-	-	

	Oil No. 0-3.5					Oil No. 0-3.5A					Oil No. 0-4C				
Gamma Dosage, 10 ⁸ r	-	9.34	13.0	14.8	69.0	-	8.00	10.3	13.3	59.0	-	5.90	7.2	10.8	45.5
Appearance of Oil	-	cloudy	-	sludgy	hazy	-	clear	-	cloudy	-	-	clear	-	hazy	-
Color, ASTM	4-1/2	5	-	opaque	8+	4-	3-1/2	-	5	8	4-1/2	7	-	opaque	8+
Appearance of Can	-	black	-	black	black	-	OK	-	black	black	-	OK	-	OK	med stain
Viscosity, cs at 210°F	18.2	12.8	13.4	13.4	69.7	17.2	10.9	10.2	11.0	31.1	17.4	11.4	11.0	11.0	16.4
SSU at 210°F	315	223	270	245	982	366	202	213	198	1155	328	189	193	181	392
100°F	90.7	69.4	71.7	71.3	323	86.6	62.6	60.2	62.9	146	87.4	64.4	62.7	62.9	82.9
100°F	1460	1035	1252	1136	4600	1698	934	985	917	5370	1520	877	895	837	1830
Viscosity Index	60	22	2	(20)	-	24	-13	-55	(1)	11	44	17	(-3)	14	-3
Copper Corrosion, 3 hr at 212°F	1b	2e	3a	2e	1a	1b	2a	2b	2a	1b	3b	4c	4c	4b	2c
Insolubles, wt per cent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Neutralization Number, mg KOH/g (Micro)	nil	0.11	0.09	0.06	0.02	0.01	0.09	0.08	0.06	0.01	-	0.26	0.29	0.96	0.66
Four-Ball Wear Test															
Scar diameter in mm;											0.31	-	0.36	-	-
10 kg load; 30 min at											0.33	-	0.36	-	-
1200 rpm; st/st															
Pour Point, °F	+20	-15	-10	-10	+10	+20	-20	-10	-5	0	+20	-20	-15	-20	0
Evaporation, per cent 22 hr at 210°F	-	-	-	-	-	-	-	-	-	-	4.6	-	7.6	-	-

FIGURE 3

PERFORMANCE OF RADIATION RESISTANT OIL

**BASED ON
ALKYL AROMATIC**

**BASED ON
MINERAL OIL**

0 $10^9 r$ $5 \times 10^9 r$

GAMMA DOSAGE

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PM 562296 -1

FIGURE 4
VARIATION OF VISCOSITY
OF LIGHT GRADE OILS WITH IRRADIATION
MTR CANAL SOURCE, OPEN TO AIR

FIGURE 5
EFFECT OF IRRADIATION
ON VISCOSITY OF MEDIUM GRADE OILS
MTR CANAL SOURCE, OPEN TO AIR

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RE 582837-4

FIGURE 6
 CHANGE OF VISCOSITY
 OF HEAVY GRADE OILS WITH IRRADIATION
 MTR CANAL SOURCE, OPEN TO AIR

FIGURE 7
RADIATION-INDUCED
VISCOSITY CHANGE OF A THICKENED OIL
MTR CANAL SOURCE, OPEN TO AIR

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RE 582839-1

SIGNIFICANCE OF RESULTS

The new formulations have outstanding radiation stability. They are still fluid after 50×10^8 r and, for noncritical uses, are probably usable to above 100×10^8 r total dosage. This approaches the limits of radiation tolerance for fluid hydrocarbon lubricants. To gain further radiation stability, the next step would be the use of completely aromatic compounds. However, these compounds, e. g., biphenyl, have high melting points.

The special lubricants meet most of the requirements for conventional oils. Most of the deficiencies of the new oils can be corrected by additives. The low temperature viscosity and pour point are impaired by the particular selenide used.* As the aromatic base fluids are thermally very stable, it is probable that the polybutene V.I. improvers are the ingredients which would limit thermal stability in these formulations. Inhibitors can also be used to impart rust protection, antifoaming, film strength, etc. For each new ingredient, of course, radiation stability would have to be retested.

In the presence of radiation, the behavior of a solution containing polybutene and poly(α -methylstyrene) is complex. The first polymer undergoes a rapid cleavage, causing loss in viscosity and viscosity index. Meanwhile, the second polymer begins to cross-link, thus tending to increase the viscosity. The base oil also begins to polymerize. After an initial decrease in viscosity, there is a gradual increase in both viscosity and viscosity index of the solution. Eventually, solidification occurs.

*Related work has shown that lower pour points result from use of a branched chain tridecyl selenide.

Conclusions

Within the limits of the test work performed, the following conclusions can be made:

1. a. Combinations of aromatic oils, selected polymers, and selenide inhibitors represent a promising approach for radiation resistant oils. Their inherent properties compare favorably with those of presently used mineral oils.

b. The upper limit of usability was not defined in this work. However, such special oils will probably retain residual lubricating properties up to about 100×10^8 r.

2. a. Conventional specification oils are changed to a major extent by radiation.

b. Special oils are affected to a lesser degree.

3. Gamma radiation altered the appearance, color, pour point, viscosity, and viscosity index of lubricants. Gamma radiation did not alter acidity or wear properties.

ACKNOWLEDGMENTS

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A P P E N D I X I

STABILITY OF POLYMER THICKENERS TO GAMMA RAYS

Earlier work involved a study of the stability of several polymers contained in a selenide-inhibited alkylbenzene oil. Viscosity change was the main criterion of damage. Results were reported in "Radiation Resistant Lubricants, Development and Status," Cal Research-AEC Report No. 7 (TID 5186) June 30, 1954. Page 58 of that report is reproduced here as Figure 8. The ordinate of the curve is " η_{10} ," which is defined as: "the viscosity in centistokes of an irradiated fluid at the temperature in degrees Fahrenheit at which the initial viscosity was 10 centistokes." This means that viscosity was taken (by interpolation) at slightly different temperatures so that the initial viscosity in all cases was 10 centistokes.

Items to note in Figure 8 include; (1) The relative positions of the curves, e. g., the polyester degrades the fastest. (2) Most polymers decrease in viscosity except the poly(α -methylstyrene), which increases. (3) The result of mixing fluids to obtain a "constant viscosity" oil is illustrated in the mixture of the poly(propene oxide) with the alkylbenzene.

FIGURE 8

STABILITY OF POLYMER THICKENERS TO GAMMA RAYS
 SERIES G-4 AND G-10 IRRADIATED IN CALIFORNIA RESEARCH CORPORATION SOURCE*

A P P E N D I X I I

DIGEST OF SPECIFICATIONS

I. MIL-L-15016A - Lubricating Oil, General Purpose

This specification calls for a high grade lubricating oil for uses other than special purposes. There is required 100% mineral oil excepting that approved pour point depressants and antifoam agents may be used. Twelve grades are called for in two series of six each. The 2000 series is to be used where normal variations in the ambient and operating temperatures prevail. The 3000 series is to be used where wide variations in the ambient and operating temperatures exist.

II. MIL-L-15017 - Lubricating Oil Hydraulic

This specification covers mineral oils containing approved anticorrosion additives for hydraulic systems. The oils are for general use where special nonmineral oil fluids are not required, such as plane lifts and waterbury speed reducers. The oil may also be used in other applications where a general lubricating oil having anticorrosion characteristics is required. The specification covers three grades which have an over-all temperature range from -20°F to 250°F.

III. MIL-L-644A - Lubricating Oil Preservative Special

This specification calls for one grade of a preservative lubricating oil suitable for use in the lubrication and protection of small arms. Intended uses also include the lubrication of fuse mechanisms and squirt-can use in general aircraft applications. Expected temperature range is from -65°F to 200°F.

IV. MIL-O-5606 - Oil Hydraulic Aircraft Petroleum Base

This lubricant meets the requirements for a petroleum base hydraulic oil for aircraft use from -65°F to 250°F. Intended usages include autopilots, shock absorbers, brakes, and flat control mechanisms.

V. MIL-L-17331 (Ships) - Lubricating Oil Turbine (Noncorrosive)

This specification calls for a single grade of a non-corrosive lubricant for use aboard ship as follows:

- a. Main turbines and gears.
- b. Auxiliary turbine installations.
- c. Certain hydraulic equipment.
- d. General mechanical lubrication.
- e. Air compressors.

The noncorrosive aspect is important. Projected temperature range is from +20°F to about 250°F.

VI. MIL-L-2104A - Lubricating Oil, Internal Combustion Engine, Heavy Duty

This specification calls for one type of heavy duty engine oil suitable for the lubrication of reciprocating engines under all conditions of service where the ambient temperature is above -20°F. Refined petroleum products and the necessary additives are permitted. The three grades of 10, 30, and 50 correspond to the equivalent SAE designations.

VII. MIL-L-9000A (Ships) - Lubricating Oil, Diesel Engine

This specification is the Navy counterpart of MIL-L-2104A. It calls for a heavy duty lubricating oil suitable for all types of marine diesel engines and also for diesels in shore establishments. Refined petroleum products and additives are permitted. The oil is procured in five viscosity grades.

VIII. MIL-L-6086A (ASG) - Lubricating Oil, Gear, Petroleum Base

This lubricant is for use in aircraft gears exclusive of engine gearing at low temperature. Grade L is for use at low temperature (-40°F), while Grade M is for use to about -20°F. Formulations comprise mineral oil and load carrying additives.

IX. VV-L-765 - Lubricant, Enclosed Gear, Straight Mineral Oil

This lubricant is for use in all automotive and industrial gears not requiring extreme pressure and operating below 250°F. The material is procured in grades 80, 90, 140, and 250. No additives are permitted in the mineral oil except pour point depressants and antifoam agents.

X. MIL-L-6082A - Lubricating Oil, Aircraft Engine

This specification calls for a straight mineral oil for internal use in aircraft engines. The specification calls for two grades which are denoted 1065 and 1100.

XI. MIL-L-2105 - Lubricant, Gear, Universal

This specification calls for a compounded gear oil made from refined petroleum products and suitable additives. It shall be satisfactory for the lubrication of automotive gear units, heavy duty, industrial type, enclosed gear units, steering gears, and fluid lubricated universal joints. Three grades are called for which are termed 75, 80, and 90.

A P P E N D I X I I I

TECHNICAL ASPECTS OF PROPOSED SPECIFICATION FOR LUBRICATING OIL, RADIATION RESISTANT, GENERAL PURPOSE

1.0 Scope

- 1.1 This specification covers three viscosity grades of lubricating oil for general use in accessory equipment associated with the operation of nuclear power plants. The lowest grade will permit operation of equipment at +15°F. All grades are usable for continuous operation at temperatures as high as 300°F and for short periods at 350°F in the presence of nuclear radiation.

1.2 Classification

General purpose radiation resistant lubricating oils shall be of the following grades:

Light (Typified by oil 0-1.5A)

Medium (Typified by oil 0-2.5A)

Heavy (Typified by oil 0-3.5A)

2.0 Applicable Specifications and Other Publications

Federal Test Method Standard No. 791, ASTM Standards on Petroleum Products and Lubricants.

3.0 Requirements

3.1 Qualification

The oils shall be products which have been tested and have successfully passed the qualification tests specified in Section 3.4.

3.2 Radiation Exposure Conditions

All qualification tests shall be conducted on samples of the oils as manufactured and also on samples which have been exposed with 10^9 roentgens (r) of gamma photons of energies between 0.7 mev and 1.3 mev at a temperature between 50°F and 100°F. A flux of between 10^5 r and 10^8 r per hour shall be employed.

3.3 Materials

The oils are not restricted as to composition. However, special materials and additives will be required to withstand nuclear radiation and, at the same time, meet the performance requirements of this specification. The right is reserved to subject new or unusual compositions to such additional tests as are considered necessary to assure the serviceability of the materials with the equipment to be lubricated.

3.4 Chemical and Physical Requirements

The oils shall conform to the requirements as specified in Table XII.

TABLE XII

REQUIREMENTS OF RADIATION RESISTANT OILS

FS Method No.	ASTM Method No.	Test	Light		Medium		Heavy	
			Before	After 10 ⁹ r	Before	After 10 ⁹ r	Before	After 10 ⁹ r
5412.2	D 97-47	Gravity	Report	-	Report	-	Report	-
305.3		Viscosity (kinematic)						
		cs at 100°F	25-27	20-30	100-110	90-120	300-325	250-350
		cs at 210°F	4-6	3-7	8-12	6-14	16-20	12-24
9111.2		Viscosity Index	Report	-	Report	-	Report	-
		Pour Point, °F, max	+15	+15	+20	+20	+20	+20
1103.5		Flash Point, °F, min	325	Report	325	Report	325	Report
5308.4		Oxidation-Corrosion						
		Evaporation Loss, % max	5	-	5	-	5	-
		Change in Neut No.	< 0.20	-	< 0.20	-	< 0.20	-
		Change in Vis at 100°F	-5% to +20%	-	-5% to +20%	-	-5% to +20%	-
		Wt Change, Mg/Cu ²						
		Copper	+0.6	-	+0.6	-	+0.6	-
		Steel	±0.2	-	±0.2	-	±0.2	-
		Aluminum	±0.2	-	±0.2	-	±0.2	-
		Magnesium	±0.2	-	±0.2	-	±0.2	-
		Cadmium	±0.2	-	±0.2	-	±0.2	-
5309.2		Corrosiveness of Greases (Used for Oils)						
		Copper Strip, 212°F for 3 Hours	Pass	Pass	Pass	Pass	Pass	Pass

3.5 General

3.5.1 The oil shall be free from foreign matter and undissolved solids.

3.5.2 Additives shall remain uniformly distributed throughout the oil at all temperatures above the pour point to 300°F. When the oil is cooled below the pour point, it shall regain homogeneity on standing at temperatures of 10°F above the pour point.

4.0 Sampling, Inspection, and Test Procedures

4.1 Classification of Tests

The testing of an oil under this specification shall be classified as follows:

- a. Qualification tests - Qualification tests are made on samples submitted for qualification as satisfactory products.
- b. Inspection tests - Inspection tests are made on samples manufactured and submitted for acceptance under contract.

4.2 Qualification Tests

The qualification tests of the oil shall consist of all of the tests of Section 3.4, including those before and after 10^9 r irradiation.

4.2.1 Qualification test sample - Qualification samples shall consist of one gallon of fresh oil and one pint of irradiated oil. Samples shall be forwarded to _____, for tests. Containers should be labeled to show oil identity, name of manufacturer, name of submitting agency, and date.

4.3 Inspection Tests

The inspection tests of the oil shall consist of all the tests on the fresh oils only except the oxidation-corrosion test.

4.3.1 The supplier shall be responsible for conducting all inspection tests and supplying samples. All tests shall be conducted under the supervision of a Government inspector at a suitable facility acceptable to him. Tests conducted during manufacture shall in no way be construed as a guarantee of acceptance of the finished product.

4.3.2 Samples - The inspector shall select at random one-quart samples of oil from each batch manufactured and conduct tests according to Section 4.3.

4.3.2.1 Filling containers at the place of manufacture - The inspector shall draw at least two one-quart samples from the discharge line where it enters the containers.

4.3.2.1 Filled containers - Drums; when the oil is filled in drums, at least two drums shall be sampled. Five-gallon cans; where the oil is filled in five-gallon cans, at least five cans shall be sampled.

4.3.3 Rejection of lots - When any sample fails any of the tests, the entire lot of oil shall be rejected.

5.0 Preparation for Delivery

This section to be added; covers packaging, packing, and labeling.

6.0 Notes

6.1 Intended Use

These oils are intended for use in the lubrication of journal, ball, and roller bearings and sliding surfaces; cams, and gears of accessory equipment associated with the operation of nuclear power plants.

Light Grade - High Rotating Speeds, Low Temperatures, Hydraulic Applicators.

Medium Grade - Journal Bearings, Moderate Speeds, Normal Temperatures.

Heavy Grade - Gears, Cams, Slow Speeds, High Temperatures.

The oils are designed for use in the temperature range of +15° F to 300° F, with occasional use at 350° F permissible.

6.2 Other notes to be added as required.