

JAERI-M
87-141

DATA ON RADIATION RESISTANCE OF
LUBRICATING OIL

September 1987

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編集兼発行 日本原子力研究所
印 刷 日立高速印刷株式会社

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(Received August 14, 1987)

This report presents data of radiation resistance of commercial lubricating oils. Data included are the radiation induced change of properties such as kinematic viscosity, total acid number, flash point, pour point, specific gravity and color, and the results by instrumental analysis such as gas analysis by gas chromatography, ESR spectra, infrared spectra, mass spectra, and molecular weight distribution by liquid chromatography.

Twenty-seven different kinds of commercial lubricating oils including mineral oils, a synthetic hydrocarbon oil, ester lubricants, a polyether, silicone oils, fluorinated oils and aromatic oils were irradiated with ^{60}Co γ -rays at room temperature in a vacuum, in air and under bubbling oxygen. The irradiation was carried out up to 30 MGy at a dose rate of 10 kGy/h.

Keywords: Radiation Resistance, Mineral Oil, Ester, Aromatic Oil, Fluorinated Oil, Viscosity, Total Acid Number, Silicone, Radical, Infrared Spectra, ESR Spectra, Mass Spectra, Molecular Weight

* Matsumura Oil Research Corporation.

潤滑油の耐放射線性に関するデータ集

日本原子力研究所高崎研究所開発部

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(1987年8月14日受理)

この報告書は市販潤滑油の耐放射線性に関するデータ集である。このデータには放射線による動粘度、全酸価、引火点、流動点、比重、色などの性状変化、およびガスクロマトグラフによるガス分析、ESRスペクトル、赤外スペクトル、マススペクトル、液体クロマトグラフによる分子量分布などの機器分析の結果を含んでいる。

鉱油、合成炭化水素油、エステル油、ポリエーテル、シリコーン油、フッ素油、および芳香族油など27種類の市販潤滑油を、真空中、空气中、および酸素バーピング中において、⁶⁰C₀-r線を室温で照射した。照射は10KGy/hの線量率で30MGyまで行った。

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1. Introduction

The number of nuclear power plants is increasing and the output power per unit is becoming larger. The necessity to secure the safety and reliability of the nuclear power plants is increasing, too. Organic materials used in the reactors, such as wire insulating materials, paints, lubricating oils and greases are required to maintain high reliable performance over a long period.

The lubricating oils used in the plants are deteriorated by radiation, heat, oxidation and mechanical degradation. Therefore, the estimation of the radiation resistance of lubricating oils is necessary to avoid a trouble in the operation of nuclear power facilities where they are used.

In case of irradiation in air, the rate of oxygen diffusion into oil and that of oxygen consumption in oil depend on the size and the shape of irradiation vessels. Therefore, it is difficult to compare the results obtained by different experiments.

Though the fact that radiation accelerates the oxidation of lubricants and degrades their physical properties and performance is well known, the effect of the irradiation atmospheres for the degradation of oil is not clear yet. This report describes the effect of radiation on twenty-seven different commercial lubricating oils under three different irradiation conditions such as in a vacuum, in air, and with bubbling oxygen. The data contain the radiation-induced property change of lubricants such as viscosity, total acid number, flash point, specific gravity, pour point, color, and breakdown voltage measurement,

and the results of instrumental analysis such as gas analysis by gas chromatography, ESR spectra, infrared spectra, mass spectra, molecular weight distribution by liquid chromatography.

2. Experimental

2.1 Materials

The lubricating oils tested are all commercial products as shown in Table 1 and are used without any more refinement. The abbreviations, %C_P, %C_N, and %C_A used in Section 3 are the percentage of paraffinic, naphthenic and aromatic carbon to the total carbon of the oil. The percentage %C_A is usually determined by ri-VGC method, but for the synthetic oils it was calculated from the chemical structure of the sample.

Liquid paraffins P-80 and P-350 consist of paraffinic and naphthenic hydrocarbons. In addition to these two types of hydrocarbons, paraffinic neutral oil N-350 and N-500, and naphthenic neutral oil contain aromatic hydrocarbons. Liquid paraffin P-80 is the same grade as Blandol and Ramor (Witco Chemical Co.) and Primol 80 (Esso Standard Oil Co.). Liquid paraffin P-350 is the same grade as Kaydol and Ramor 350 (Witco Chemical Co.) and Marcol 355 (Esso Standard Oil Co.). Poly- α -olefin is a mixture of hydrogenated tetramer of 1-decene.

2.2 Irradiation procedure and condition

The samples were irradiated with ^{60}Co γ -rays under three

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2. Experimental

2.1 Materials

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2.2 Irradiation procedure and condition

The samples were irradiated with ^{60}Co γ -rays under three

different conditions at a dose rate of 10 kGy/h and at room temperature.

For irradiation in a vacuum, about 150 ml of the sample was poured into the 400 ml glass ampule of 4 cm diameter and 40 cm height as shown in Fig.1. The sample was bubbled with nitrogen for one hour at the flow rate of 1.2 l/min to purge air solved in the oil. Then the sample was evacuated to 5.2×10^{-2} Pa for 2 hours at room temperature, sealed off and irradiated with γ -rays. With this treatment before the irradiation, a total acid number which is a good indicator for oxidation was not detectable after irradiation for oils such as liquid paraffin, paraffinic neutral oil, etc.

For irradiation under bubbling oxygen, 750 ml of the sample was poured into gas bubbling bottle of 9 cm diameter and 31 cm height, and then irradiated under oxygen bubbling at various flow rate as shown in Fig.1. As seen in Figs.2 and 3, the total acid number, viscosity change, flash point and specific gravity remain constant above the oxygen flow rate of 250 ml/min. The flow rate of oxygen into the oil is, therefore, determined as 250 ml/min. The irradiation procedure is shown in Fig.1.

For irradiation in air, about 150 ml of sample in a 200 ml beaker of 7 cm diameter and 9 cm height was irradiated stationarily in air.

2.3 Measurement of oil property

Kinematic viscosity, total acid number by color-indicator titration, specific gravity, flash point by Cleveland open cup,

pour point and ASTM color were measured according to ASTM D445 (JIS K2283), ASTM D974 (JIS K2501), ASTM D1298 (JIS K2249), ASTM D92 (JIS K2265), ASTM D97 (JIS K2269) and ASTM D1500, respectively.

2.4 Instrumental analysis

2.4.1 Measurement of molecular weight distribution

Molecular weight distribution of the sample was measured by liquid chromatography (Toyo Soda HLC-802A). The column used was TSK-GEL (7.8 mm ID x 30 cm, 16,000 TP/ft).

2.4.2 Measurement of infrared spectra

The oxidated product was estimated from the increase of absorption at 1720 cm^{-1} measured by the infrared absorption spectrometer (Japan Spectroscopy Co. A-302).

2.4.3 Measurement of ESR

Radicals formed in the irradiated oils at $-196\text{ }^{\circ}\text{C}$ were measured by ESR spectrometer (JEOL type JES-FE 3X). The sample was frozen with liquid nitrogen and evacuated to 10^{-3} Pa and irradiated at $-196\text{ }^{\circ}\text{C}$ with exposure rate of $3.21 \times 10^2\text{ C/kg}$. After irradiation, ESR was measured at the same temperature. Then the irradiated sample was bleached by sun-light keeping the temperature at $-196\text{ }^{\circ}\text{C}$ and ESR was again measured (denote; after photo bleach) at the same temperature. The G values of radical yield were calculated by using the energy absorption coefficients. All ESR spectra were measured at the same gain except the spectra

remarkably reduced by photo bleach.

2.4.4 Measurement of mass spectra

Mass spectra of the sample was measured by a DI (Direct Inlet) method using a gas chromatograph double focussing mass spectrometer (HITACHI Model M-80B). In the DI method a sample is applied to the tip of the probe, which was heated under the control of a computer and directly inserted into the ionization chamber. A molecule of vaporized oil was ionized by electron impact at 70 eV.

2.4.5 Gas analysis by gas chromatograph

Each sample (1 g) was evacuated at 2.6×10^{-3} Pa in a Pyrex glass tube with a break off seal. The samples were irradiated with ^{60}Co γ -rays at a dose rate of 10 kGy/h to the dosage of 1 to 30 MGy. After irradiation the sample tube was connected to a vacuum line as shown in Fig.4 ; the total pressure was measured by the MKS-Baratron 210-capacitance manometer (dynamic range 0.1 to 133 kPa). The gas evolved was analyzed by two gas chromatographs (GCs). The operating conditions were as follows: GC(I) was Hitachi Model 163 equipped with a thermal conductivity detector. Helium was used as the carrier gas at a flow rate of 40.0 ml/min. Molecular sieve 5A (30 to 60 mesh) was packed in stainless steel column (3 m long and 3 mm diameter). The column was kept at 43 °C. The GC(II) was Yanagimoto GCG-550T equipped with a thermal conductivity detector. Helium was used as the carrier gas at a flow rate of 32 ml/min. Porapack S (80

to 100 mesh) was packed into stainless steel column (2.2 m long and 3 mm diameter). The column was kept at 40°C. The GC(I) was used for smaller molecules such as hydrogen, oxygen, methane, and carbon monoxide and the GC(II) for carbon dioxide, ethane, and ethylene. The G values (number of gas molecules liberated per absorbed energy of 100 eV) were calculated by using the gas composition, volume, temperature, and pressure of the gas in the irradiated sample tubes.

2.5 Measurement of electrical property

2.5.1 Dielectric breakdown voltage (ASTM D877, JIS C2101)

The electrodes used were polished brass disks 12.5 mm in diameter and 1.5 mm thick, with square edges. Voltage was applied and increased from zero at the rate of 1 kV/s until breakdown occurs as indicated by operation of the circuit-interrupting equipment, and the value was recorded at 50 Hz. If breakdown does not occur until 45.5 kV, the test would stop after voltage retains 45.5 kV for 5 min. Voltage is calculated as $V = (V_2 + V_3 + V_4 + V_5)/4$.

Table 1 The name of lubricating oils used in this work.

Chemical Name	Commercial Name	Maker
Liquid paraffin P-80	Liquid paraffin P-80	Matsumura Oil Research Corp.
Liquid paraffin P-350	Liquid paraffin P-350	Matsumura Oil Research Corp.
Paraffinic neutral Oil N-350	Paraffinic neutral Oil N-350	Cosmo Oil Co.
Paraffinic neutral Oil N-500	Paraffinic neutral Oil N-500	Cosmo Oil Co.
Naphthenic neutral Oil	SUN 500N	Sun Oil Co.
Poly- α -olefin	PAOL-40	Bray Oil Co.
Di-2-ethylhexyl sebacate	Sansosizer DOS	New Japan Chemical Co.
Di-2-ethylhexyl adipate	Sansosizer DOA	New Japan Chemical Co.
Pentaerythritol ester		Nippon Fine Chemical Co.
Tricresyl phosphate	Tricrexyl phosphate	Daihachi Chemical Co.
Trioctyl phosphate	Triocetyl phosphate	Daihachi Chemical Co.
Poly propylene glycol	Newpol LB625	Sanyo Chemical Industries
Di-methyl silicone	KF-96	Shin-Etsu Chemical Co.
Pentaphenyl trimethyl trisiloxane	Hivac F-5	Shin-Etsu Chemical Co.

Table 1 (continuation)

Chemical Name	Commercial Name		Maker
Polychlorotrifluoroethylene	Daifluoil #10		Daikin Industries
Trifluoropropyl methyl polysiloxane	FS 1265		Toray Silicone Co.
Perfluoropolyether	Fomblin Y-25		Nippon Montedison K.K.
Dialkyl benzene	Neovac DB-12		Matsumura Oil Research Corp.
Mono-alkyl diphenyl ether C-14	Moresco Hirad RA-18		Matsumura Oil Research Corp.
Mono-alkyl diphenyl ether C-16	Moresco Hirad RA-20		Matsumura Oil Research Corp.
Mono-alkyl diphenyl ether C-18	Moresco Hirad RA-26		Matsumura Oil Research Corp.
Di-alkyl diphenyl ether C-16	Moresco Hirad RA-84		Matsumura Oil Research Corp.
m-(m-Phenoxyphenoxy) diphenyl	Moresco Hirad RP-42		Matsumura Oil Research Corp.
Pentaphenyl ether	Santovac 5, OS-124		Monsanto Co.
mix-Alkyl diphenyl ether	Moresco Hirad RA-56		Matsumura Oil Research Corp.
mix-Phenoxyphenoxy diphenyl	Moresco Hirad RP-42*		Matsumura Oil Research Corp.
mix-Poly(phenyl ether)	Moresco Hirad RP-42S		Matsumura Oil Research Corp.

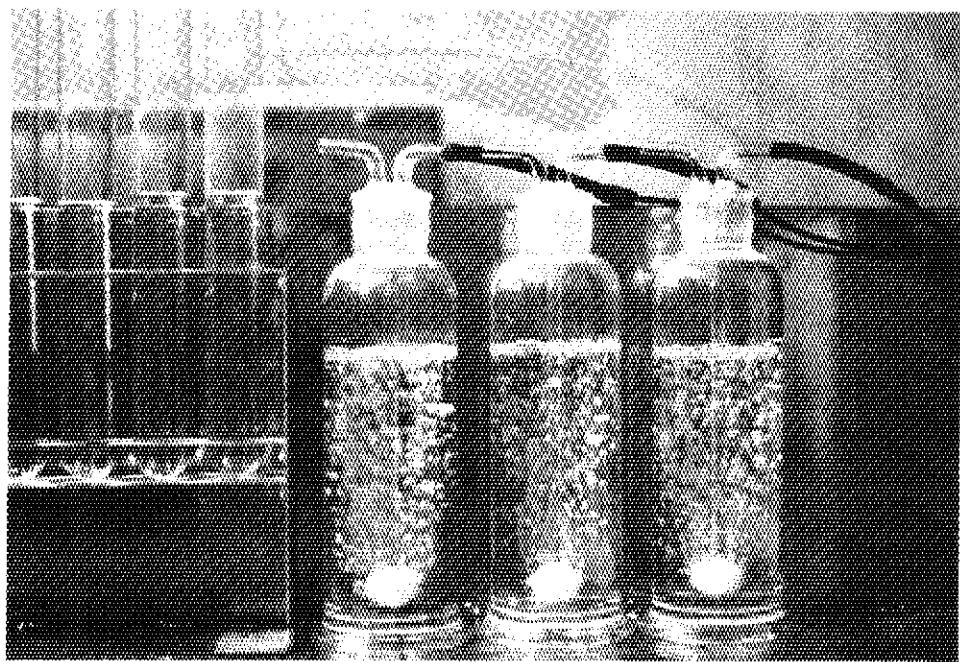


Fig.1 Photograph for irradiation procedure.

OIL NAME: Liquid paraffin P-350

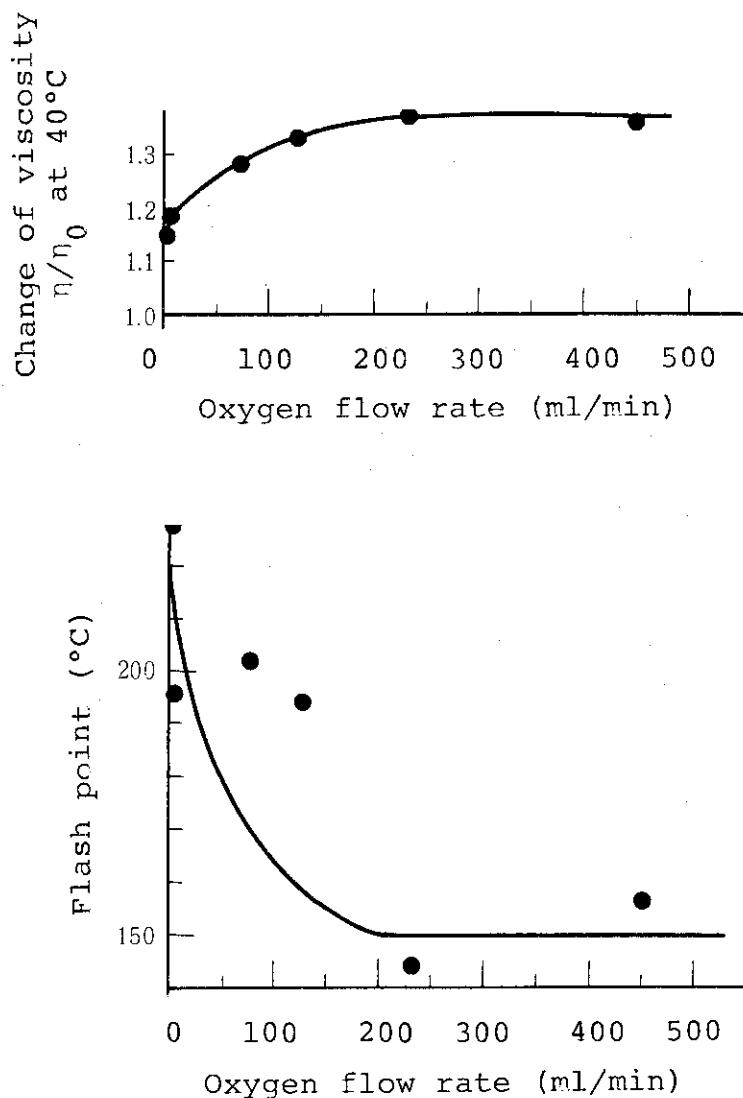


Fig.2 Effect of bubbling oxygen flow rate
on the change of properties for
Liquid paraffin P-350.
(total dose 1 MGy, dose rate 10 kGy/h)

OIL NAME: Liquid paraffin P-350

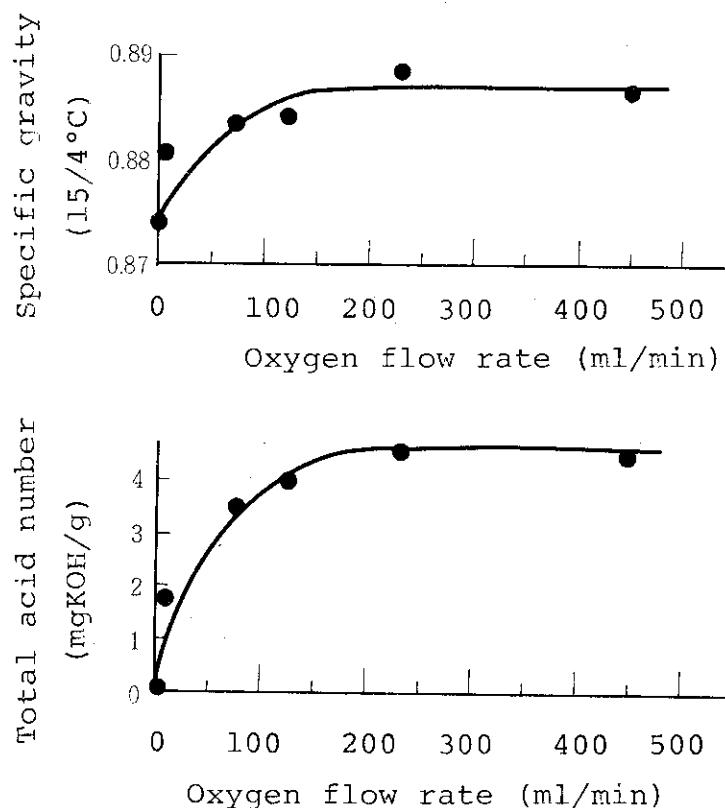


Fig.3 Effect of bubbling oxygen flow rate
on the change of properties for
Liquid paraffin P-350.
(total dose 1 MGy, dose rate 10 kGy/h)

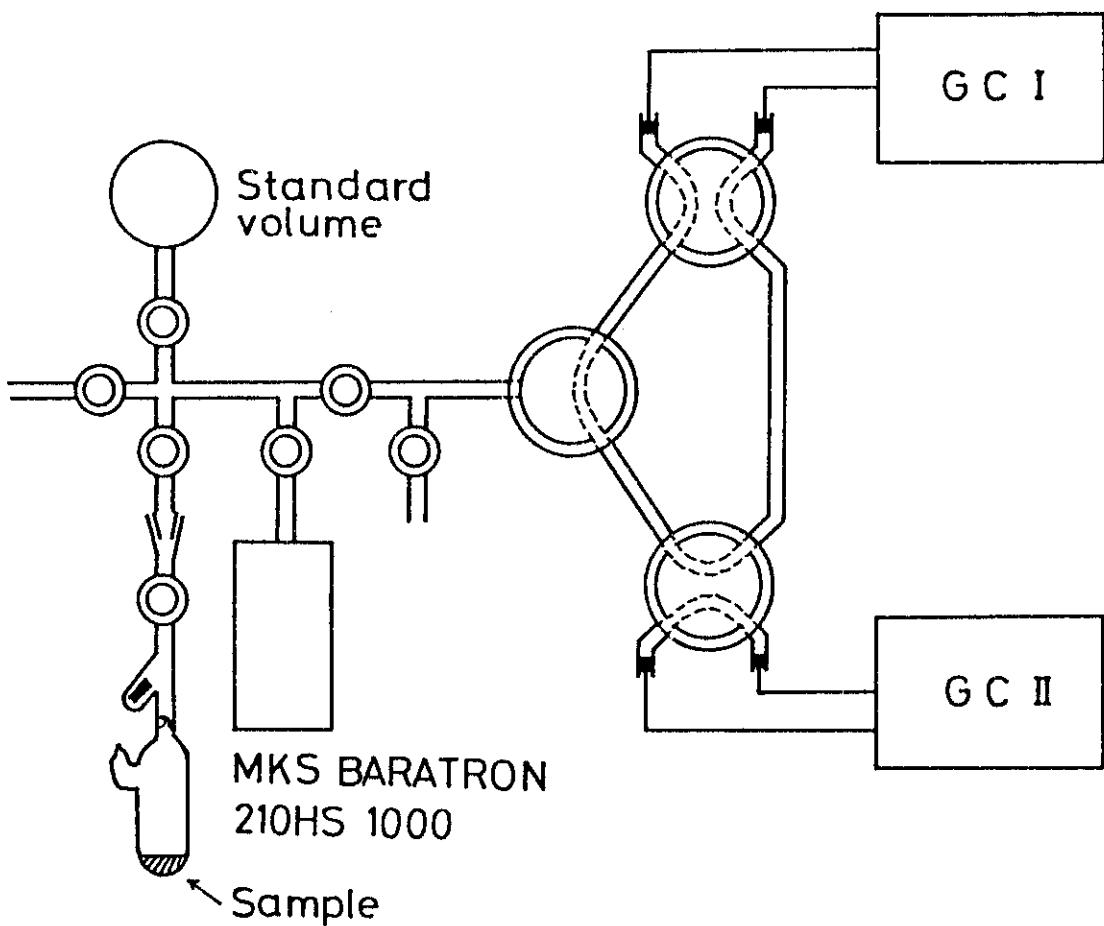


Fig. 4 Schematic diagram for gas analysis.

3. RESULTS

- 3.1 Mineral oils
- 3.2 Synthetic hydrocarbon
- 3.3 Esters
- 3.4 Polyether
- 3.5 Silicone oils
- 3.6 Fluorinated oils
- 3.7 Aromatic oils

3.1 Mineral oils

- 3.1.1 Liquid paraffin P-80
- 3.1.2 Liquid paraffin P-350
- 3.1.3 Paraffinic neutral oil N-350
- 3.1.4 Paraffinic neutral oil N-500
- 3.1.5 Naphthenic neutral oil

OIL NAME: Liquid paraffin P-80

STRUCTURE OR FEATURE: Refined mineral oil

MOLECULAR WEIGHT: 330 (Average molecular weight)

VISCOSITY at 40°C: 14.8×10^{-6} m²/s (3.45x10⁻⁶ m²/s at 100°C)

VISCOSITY INDEX: 108 SPECIFIC GRAVITY(15/4°C): 0.849

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 204

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
in vacuum	1.0	0.848	16.09	3.658	1.09	1.06
	3.0	0.848	21.12	4.385	1.43	1.27
in oxygen bubbling	0.05	0.843	14.75	3.436	1.00	1.00
	0.21	0.845	15.12	3.474	1.02	1.01
	0.5	0.847	15.92	3.556	1.07	1.03
	0.98	0.852	17.51	3.739	1.18	1.08
	3.2	0.873	26.85	4.559	1.81	1.32
	5.4	0.892	41.12	5.986	2.78	1.74
in air	0.05	0.843	14.60	3.434	0.99	1.00
	0.5	0.844	15.24	3.516	1.03	1.02
	1.0	0.846	16.42	3.704	1.11	1.07
	1.6	0.847	17.62	3.960	1.19	1.15
	2.3	0.849	19.61	4.155	1.32	1.20
	3.0	0.851	21.80	4.249	1.47	1.23
	5.0	0.853	28.30	5.361	1.91	1.55
	10.5	0.864	50.56	7.912	3.41	2.29

COMMENTIRRADIATION CONDITION

Dose rate; 10 kGy/h

OIL NAME : Liquid paraffin P-80

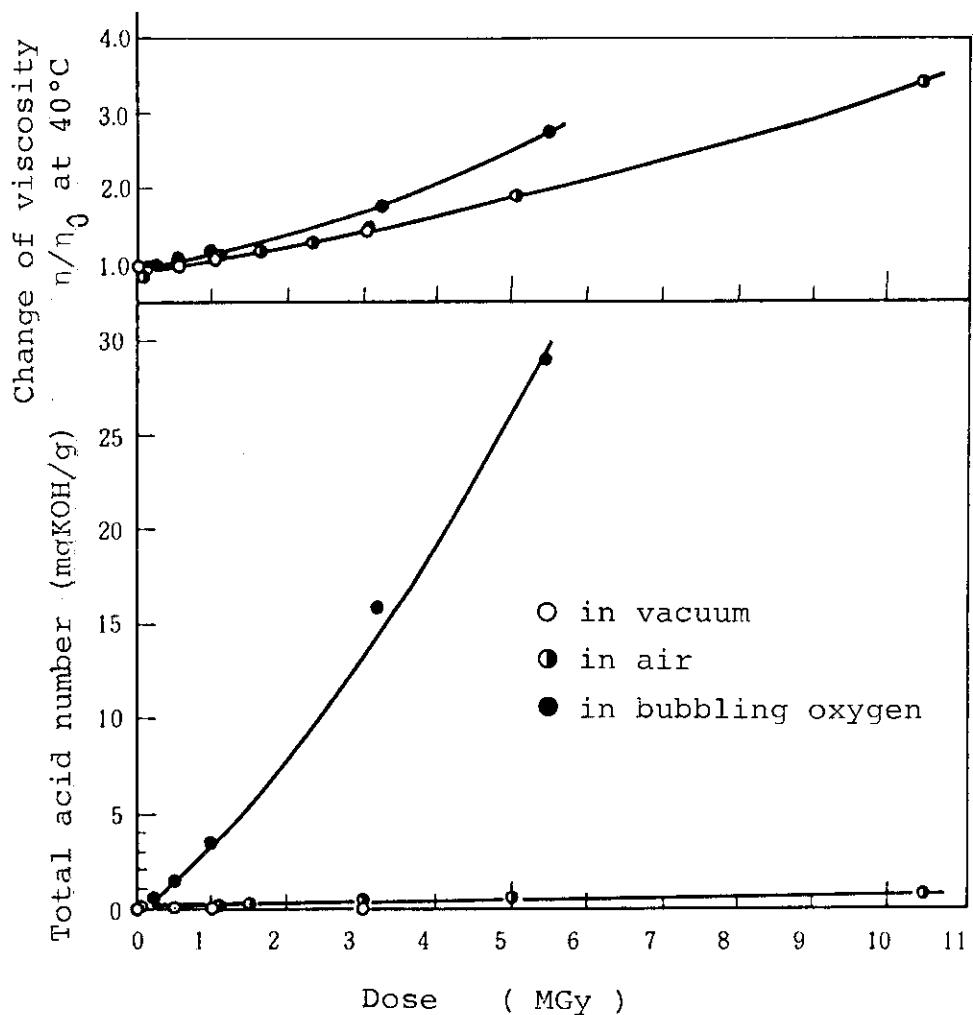
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color uion	ASTM
in vacuum	1.0	112	0.00	204	1(-)	L0.5
	3.0	118	0.00	184	1/2(-)	L0.5
in oxygen bubbling	0.05	108	0.10	196	1(-)	L0.5
	0.21	106	0.49	190	1(-)	L0.5
	0.5	103	1.49	168	1(-)	L0.5
	0.98	100	3.44	190	1(-)	L0.5
	3.2	71	16.1	148	1(-)	L0.5
	5.4	85	29.0	150	1(-)	L0.5
in air	0.05	110	0.01	200	1(-)	L0.5
	0.5	110	0.04	194	1(-)	L0.5
	1.0	112	0.07	202	1(-)	L0.5
	1.6	102	0.31	188	1(-)	L0.5
	2.3	115	0.35	188	1(-)	L0.5
	3.0	97	0.53	184	1/2(-)	L0.5
	5.0	126	0.58	182	2(-)	L1.5
	10.5	125	0.75	178	3(-)	L2.5

COMMENTIRRADIATION CONDITION

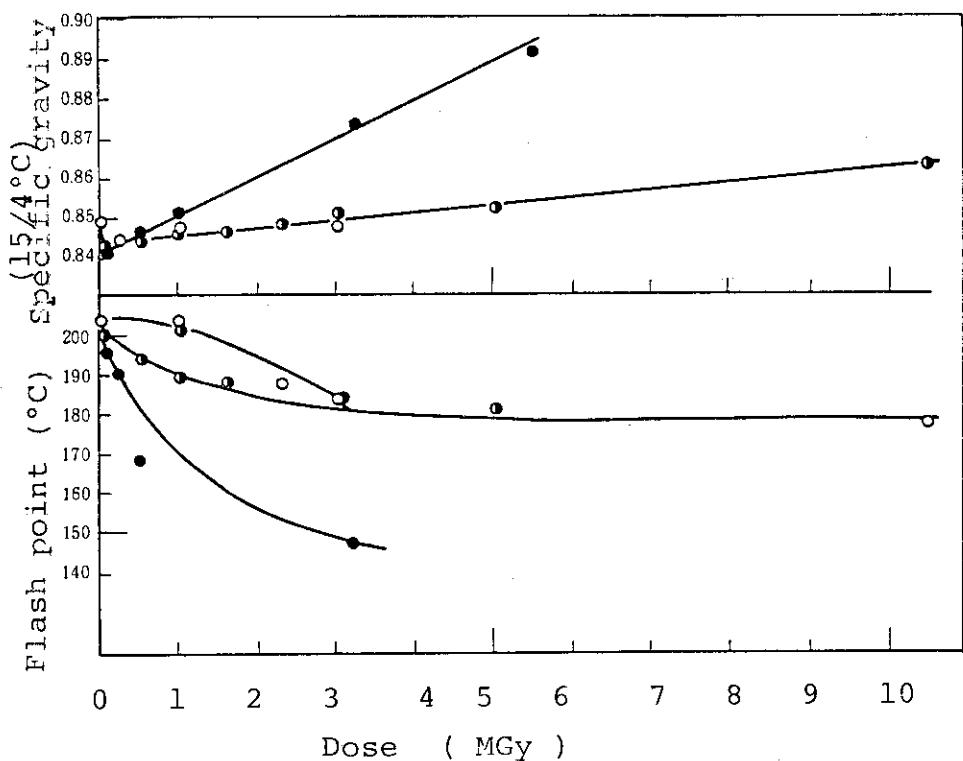
Dose rate; 10 kGy/h

OIL NAME : Liquid paraffin P-80

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENTIRRADIATION CONDITION

Dose rate: 10 kGy/h

OIL NAME : Liquid paraffin P-80

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

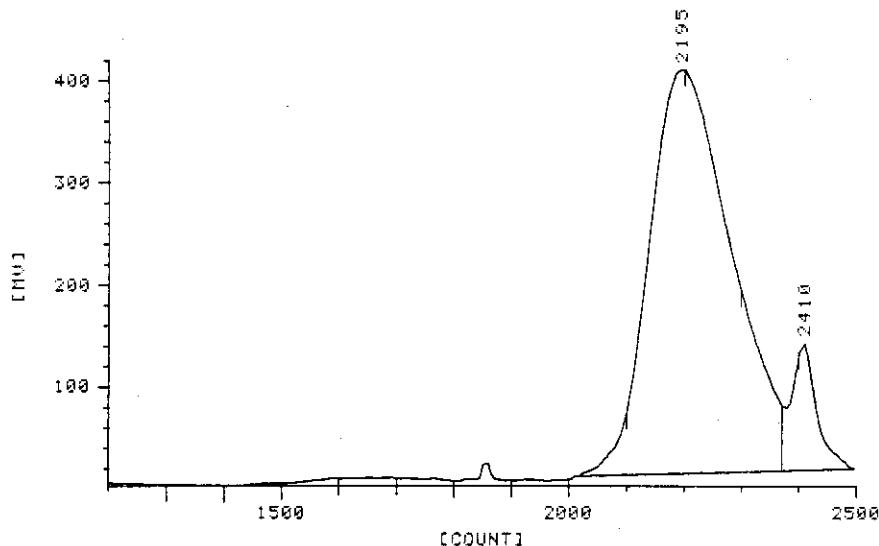
Symbol:

- in vacuum
- in air
- in bubbling oxygen

COMMENTIRRADIATION CONDITION

Dose rate: 10 kGy/h

OIL NAME: Liquid paraffin P-80

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/03 14:33 JOB FILE 1

SAMPLE NO. 0 NAME: 1-1

SERIAL NO. 0041

CH.NO 1

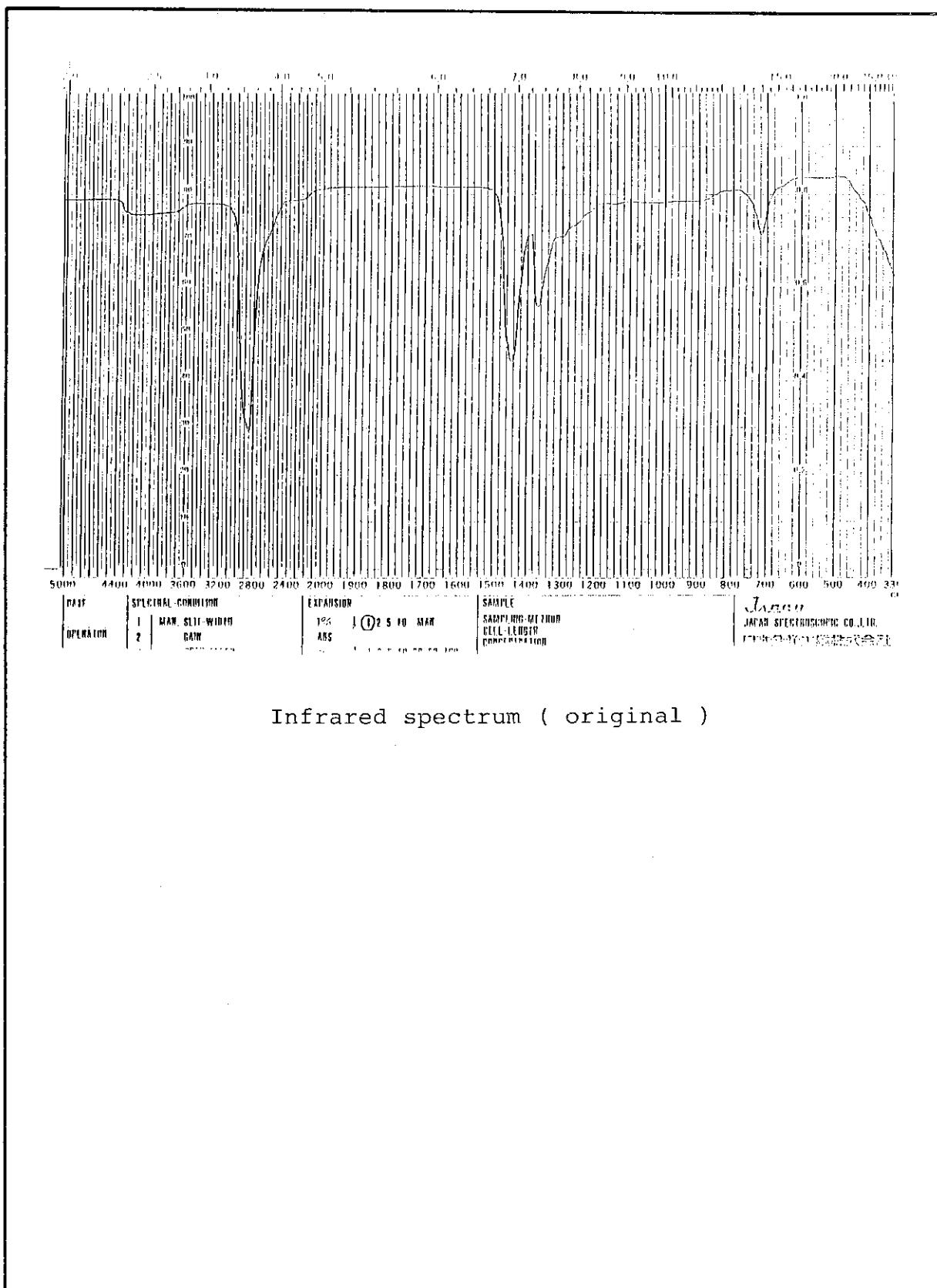
METHOD 2

PEAK NO. 1 BASE		START	TOP	END	MN	MW	MZ	MU
C	2010	2195	2370	5.17358E+02	5.24163E+02	5.31067E+02	5.24161E+02	
U	11.4	411.3	81.1	MW/MN	MZ/MW	AREA	AREAN%	
M	833	539	397	1.01	4.01	6.56328E+04	90.79	

PEAK NO. 2 VALLEY		START	TOP	END	MN	MW	MZ	MU
C	2370	2410	2495	3.64927E+02	3.65978E+02	3.66988E+02	3.65977E+02	
U	81.1	142.4	19.3	MW/MN	MZ/MW	AREA	AREAN%	
M	397	365	296	1.00	1.00	6.66093E+03	9.21	

TOTAL		START	TOP	END	MN	MW	MZ	MU
C	2010	2195	2495	4.98185E+02	5.09588E+02	5.20210E+02	5.09587E+02	
U	11.4	411.3	19.3	MW/MN	MZ/MW	AREA	AREAN%	
M	833	539	296	1.02	1.02	7.22937E+04	100.00	

OIL NAME: Liquid paraffin P-80



OIL NAME : Liquid paraffin P-80

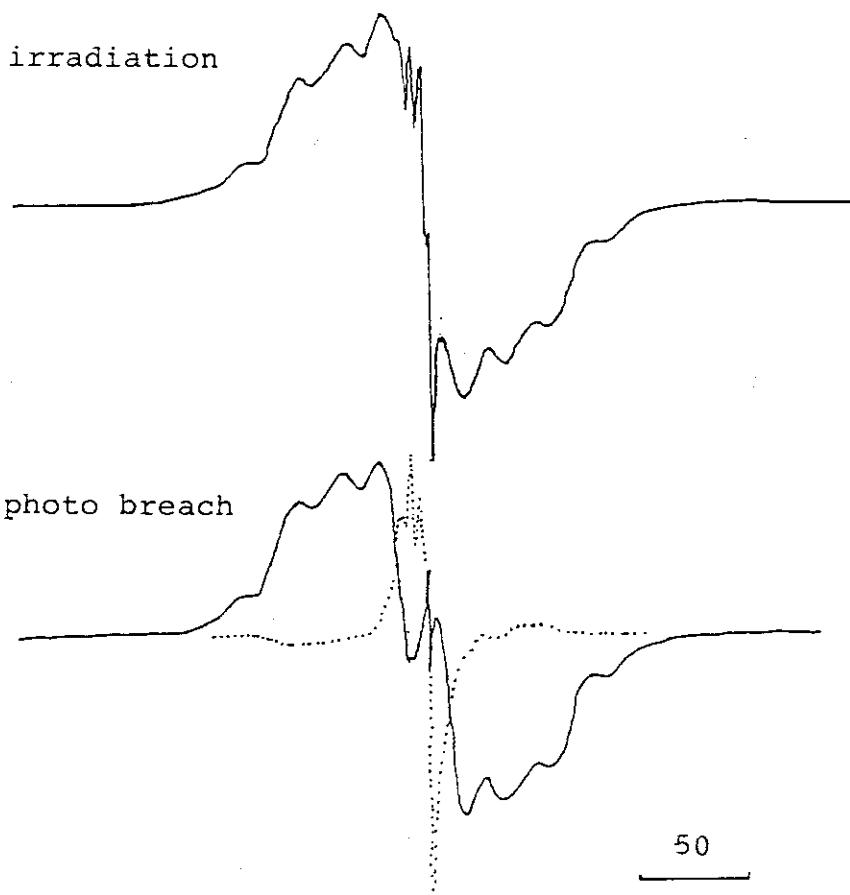
IRRADIATION CONDITION

Temp.: -196°C

Dose 11 kGy

in Vacuum

after irradiation



after photo breach

50

ESR CONDITION

Sweep range(Gauss): ± 250 Power(μW): 1

Modulation width(100kHz,Gauss): 2 at -196°C

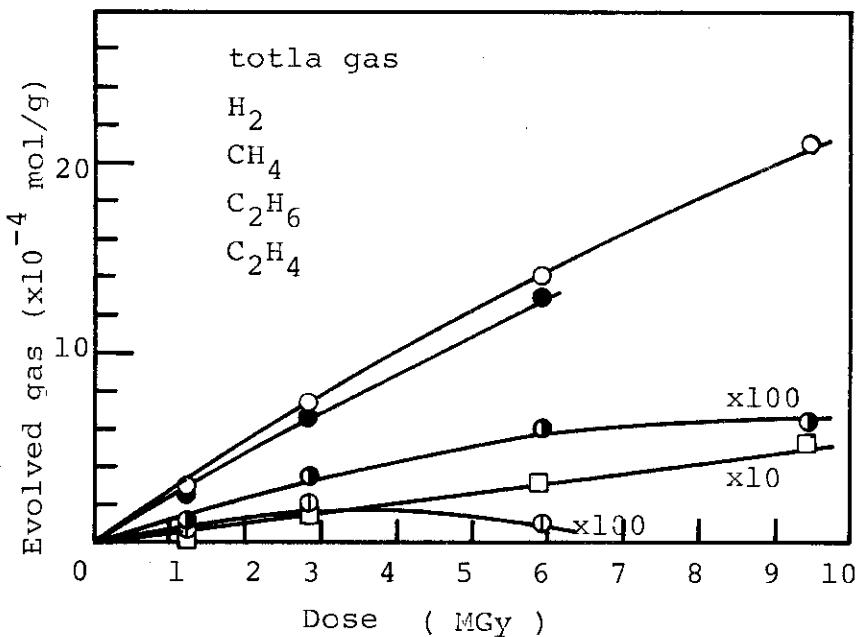
G[R.]after irradiation

3.9

after Photo breach

3.8

OIL NAME : Liquid paraffin P-80

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	2.8
$G(H_2)$	2.6
$G(CH_4)$	4.3×10^{-2}
$G(C_2H_6)$	1.4×10^{-2}
$G(C_2H_4)$	1.7×10^{-2}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	2.6
5 MGy	12.4
10 MGy	22.0

COMMENTIRRADIATION CONDITION

in vacuum, dose rate; 10 kGy/h

OIL NAME: Liquid paraffin P-350

STRUCTURE OR FEATURE: Refined mineral oil

MOLECULAR WEIGHT: 400 (Average molecular weight)

VISCOSITY at 40°C: 66.29×10^{-6} m²/s (7.853x10⁻⁶ m²/s at 100°C)

VISCOSITY INDEX: 78 SPECIFIC GRAVITY(15/4°C): 0.883

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 224

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6}$ m ² /s (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	n/n_0 (40°C)	n/n_0 (100°C)
in vacuum	1.0	0.885	75.59	8.637	1.14	1.10	
	3.0	0.887	105.6	10.80	1.59	1.38	
	5.6	0.888	165.5	14.85	2.50	1.89	
	9.2	0.894	526.3	33.31	7.94	4.24	
in oxygen bubbling	0.05	0.877	67.46	8.820	1.02	1.10	
	0.21	0.879	68.22	8.648	1.03	1.10	
	0.50	0.880	74.95	8.877	1.13	1.13	
	0.98	0.883	86.32	9.469	1.30	1.21	
	2.9	0.920	212.1	14.38	3.20	1.83	
	5.3	0.951	587.1	22.74	8.86	2.90	
	9.1	0.998	2897	49.33	43.7	6.28	
in air	0.05	0.872	67.40	8.532	1.02	1.09	
	0.2	0.873	68.65	8.733	1.04	1.11	
	0.5	0.873	70.42	8.618	1.06	1.10	
	1.0	0.874	75.41	9.236	1.14	1.18	
	2.3	0.876	85.06	10.31	1.28	1.31	
	3.0	0.889	105.2	10.60	1.59	1.35	
	5.0	0.883	153.7	14.88	2.32	1.89	
	7.5	0.887	275.3	22.42	4.15	2.85	
	10	0.902	531.8	30.71	8.02	3.91	

IRRADIATION CONDITION Dose rate; 10kGy/h

OIL NAME : Liquid paraffin P-350

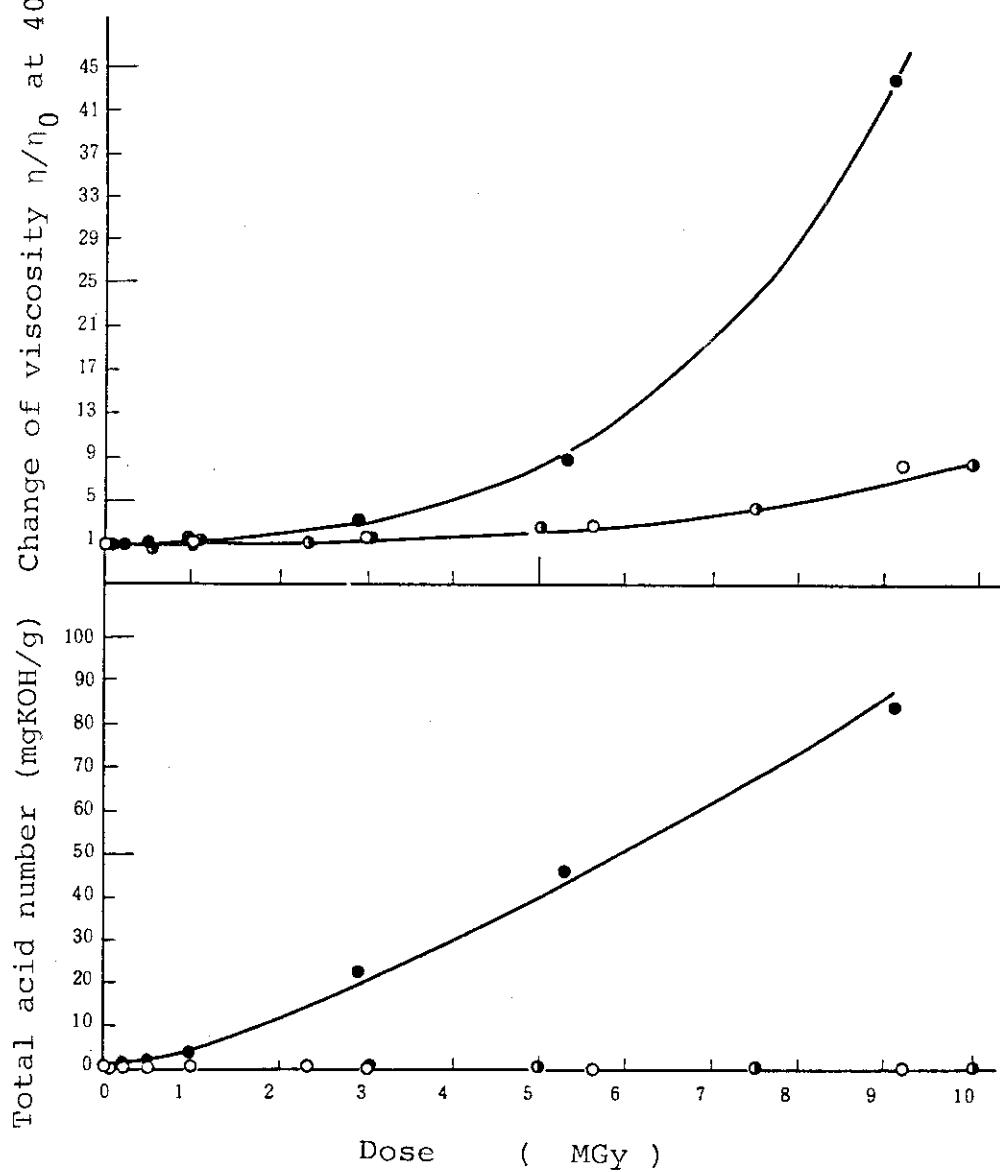
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	82	0.00	214	1(-)	L0.5
	3.0	83	0.00	210	1(1/2)	L0.5
	5.6	88	0.00	212	1(1/2)	1.0
	9.2	96	0.00	194	2	2.0
in oxygen bubbling	0.05	99	0.11	232	1(-)	L0.5
	0.21	98	0.52	232	1(-)	L0.5
	0.5	90	1.52	230	1(-)	L0.5
	0.98	83	3.64	194	1(-)	L0.5
	2.9	47	22.2	150	1(-)	L0.5
	5.3	10	45.9	150	1(1/2)	0.5
	9.1	21	84.1	140	1(1/2)	0.5
in air	0.05	96	0.00	234	1(-)	L0.5
	0.2	99	0.01	234	1(-)	L0.5
	0.5	92	0.02	244	1(-)	L0.5
	1.0	97	0.06	228	2(-)	L1.5
	2.3	103	0.28	216	2(-)	L1.5
	3.0	80	0.31	206	2(-)	1.0
	5.0	96	0.35	212	2(1/2)	2.0
	7.5	99	0.36	214	3(1/2)	L3.0
	10	85	0.76	202	4(-)	3.5

COMMENTIRRADIATION CONDITION

Dose rate ; 10 kGy/h

OIL NAME : Liquid paraffin P-350

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENT

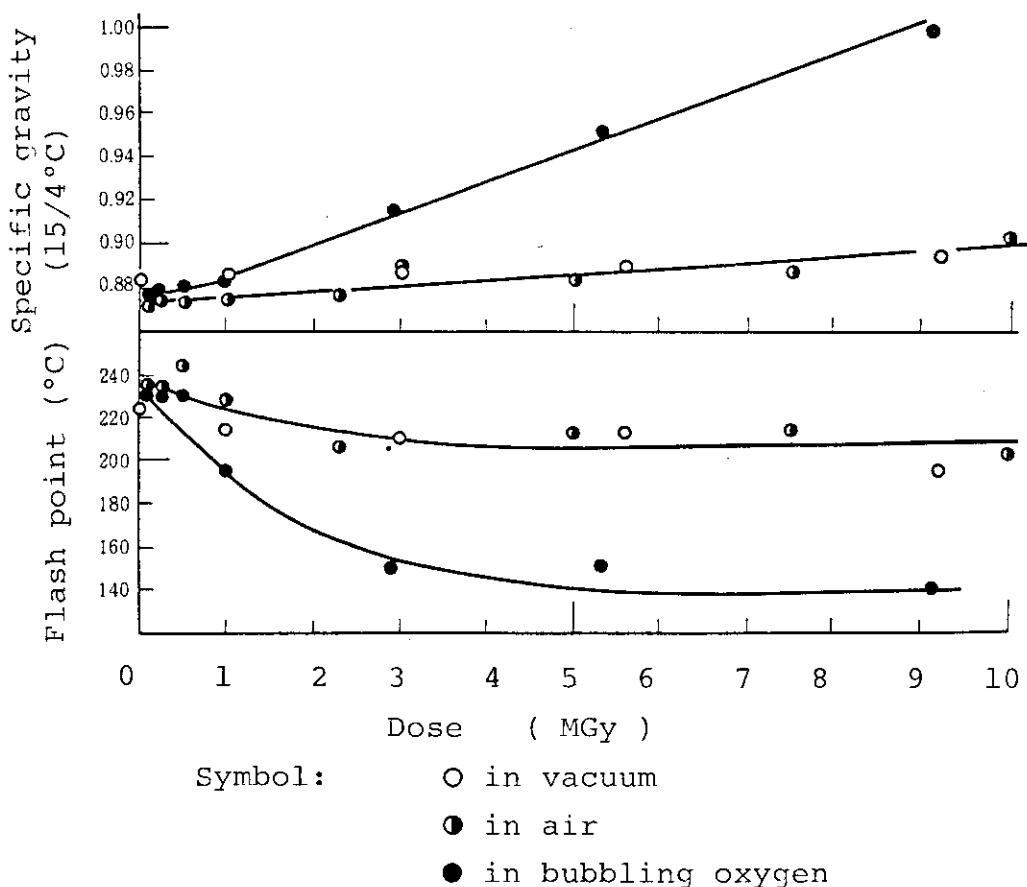
Symbol: ○ in vacuum

● in air

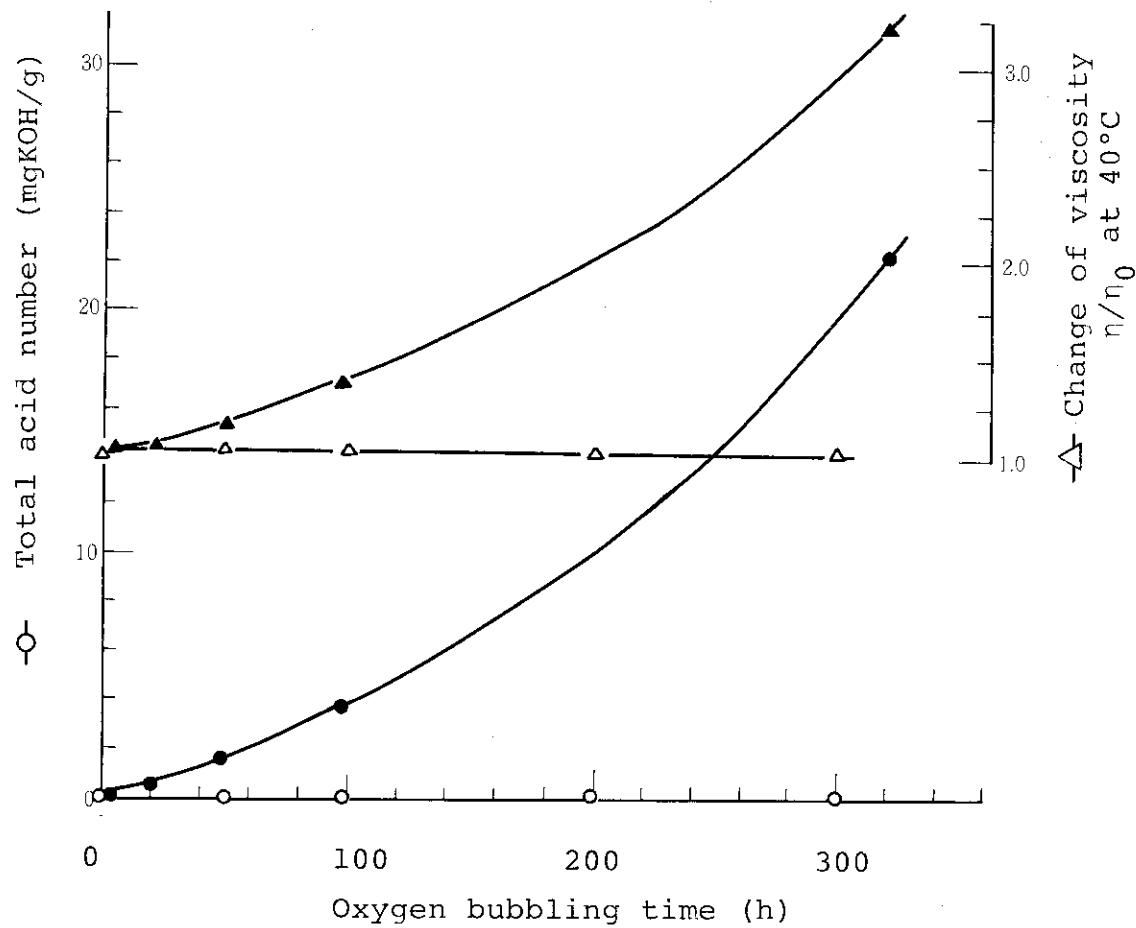
● in bubbling oxygen

IRRADIATION CONDITION

OIL NAME : Liquid paraffin P-350

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENTIRRADIATION CONDITION

OIL NAME : Liquid paraffin P-350

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Effect of bubbling oxygen in Liquid paraffin P-350.

○ △ unirradiated

● ▲ irradiated (dose rate 10 kGy/h)

COMMENTIRRADIATION CONDITION

OIL NAME: Liquid paraffin P-350

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	Viscosity (40°C)	Viscosity (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
<u>in air</u>							
20	1.0	0.884	74.46	8.626	1.12	1.10	
10	1.0	0.874	75.41	9.236	1.14	1.18	
3.0	1.0	0.885	74.47	8.512	1.12	1.08	
1.0	1.0	0.885	76.97	8.666	1.16	1.10	
0.7	1.0	0.875	74.51	9.098	1.12	1.16	
0.5	1.0	0.886	75.29	8.502	1.14	1.08	
<u>in bubbling oxygen</u>							
3.0	0.05	0.881	68.03	8.147	1.03	1.04	
3.0	0.2	0.881	70.43	8.233	1.06	1.05	
3.0	0.41		75.13	8.410	1.13	1.07	
3.0	1.0	0.893	98.50	9.537	1.49	1.21	
1.0	0.054	0.882	67.27	8.011	1.01	1.02	
1.0	0.19	0.885	71.60	8.167	1.08	1.04	
1.0	0.5	0.889	83.10	8.863	1.25	1.13	
1.0	1.01	0.898	108.7	9.855	1.64	1.25	

OIL NAME: Liquid paraffin P-350

DOSE RATE EFFECT

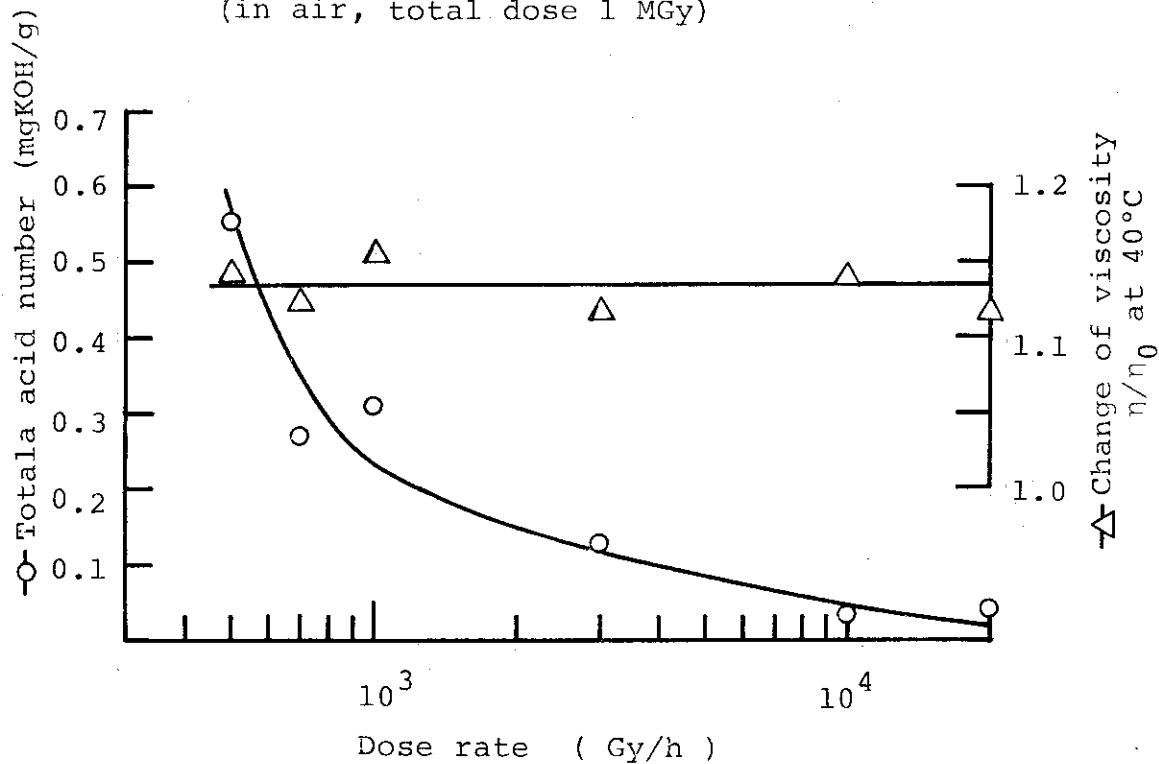
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
<u>in air</u>						
20	1.0	84	0.07	218	1(-)	L0.5
10	1.0	97	0.06	228	1(-)	L0.5
3.0	1.0	81	0.13	226	1(-)	L0.5
1.0	1.0	85	0.31	224	1(-)	L0.5
0.7	1.0	96	0.26	232	1(-)	L0.5
0.5	1.0	78	0.55	230	1(-)	L0.5
<u>in bubbling oxygen</u>						
3.0	0.05	64	0.47	220	1(-)	L0.5
3.0	0.2	81	1.10	214	1(-)	L0.5
3.0	0.41	76		206	1(-)	L0.5
3.0	1.0	64	6.25	196	1(-)	L0.5
1.0	0.054	81	0.14	218	1(-)	L0.5
1.0	0.19	76	0.98	218	1(-)	L0.5
1.0	0.5	73	4.44	212	1(-)	L0.5
1.0	1.01	56	11.4	180	1(-)	L0.5

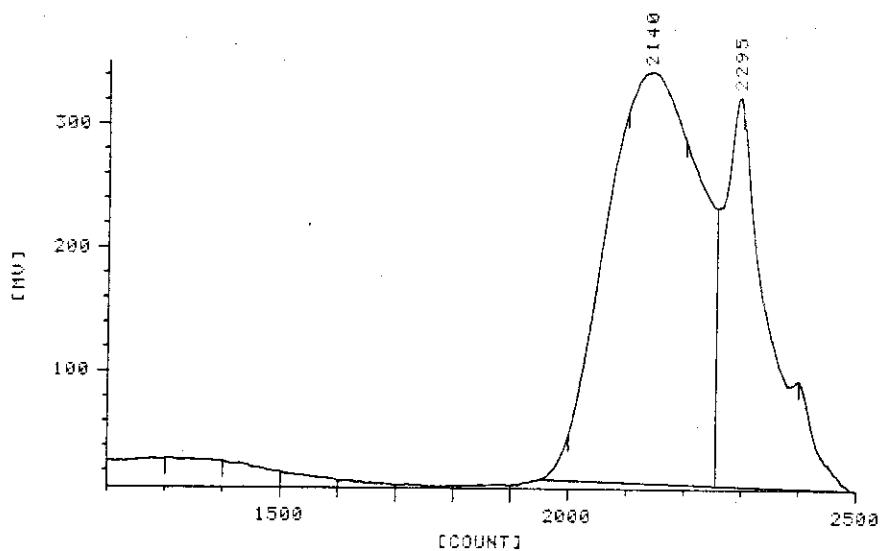
OIL NAME: Liquid paraffin P-350

DOSE RATE EFFECT

(in air, total dose 1 MGy)

COMMENTIRRADIATION CONDITION

OIL NAME: Liquid paraffin P-350

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/07 17:01 JOB FILE 1

SAMPLE NO. 8 NAME: 1-2

SERIAL NO. 0037

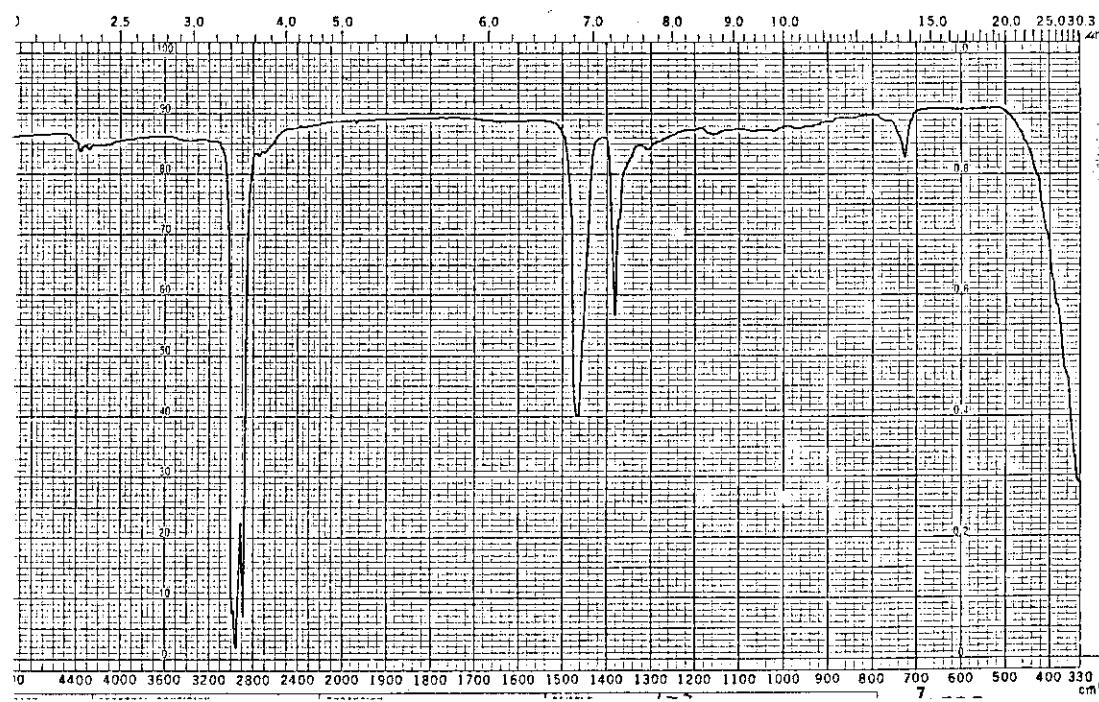
CH.NO 1 METHOD 2

PEAK NO. 1 BASE		START	TOP	END	MN	MW	MZ	MU
C	1950	2148	2255	5.90240E+02	6.09198E+02	6.21257E+02	6.09196E+02	
U	13.1	343.6	233.2	MW/MN	MZ/MW	AREA	AREAN%	
M	1059	596	487	1.02	1.02	6.23761E+04	67.70	

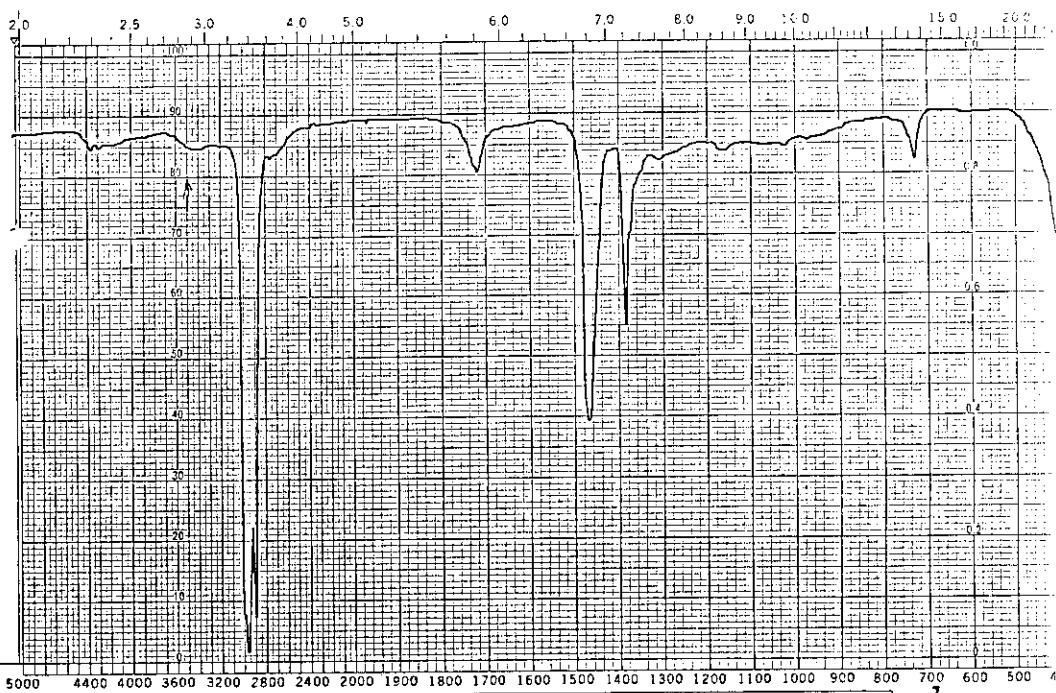
PEAK NO. 2 VALLEY		START	TOP	END	MN	MW	MZ	MU
C	2255	2295	2495	4.31579E+02	4.35246E+02	4.38595E+02	4.35245E+02	
U	233.2	323.8	4.8	MW/MN	MZ/MW	AREA	AREAN%	
M	487	455	296	1.01	1.01	2.97584E+04	32.30	

TOTAL		START	TOP	END	MN	MW	MZ	MU
C	1950	2148	2495	5.31898E+02	5.53014E+02	5.74823E+02	5.53012E+02	
U	13.1	343.6	4.8	MW/MN	MZ/MW	AREA	AREAN%	
M	1059	596	296	1.04	1.04	9.21346E+04	100.00	

OIL NAME: Liquid paraffin P-350

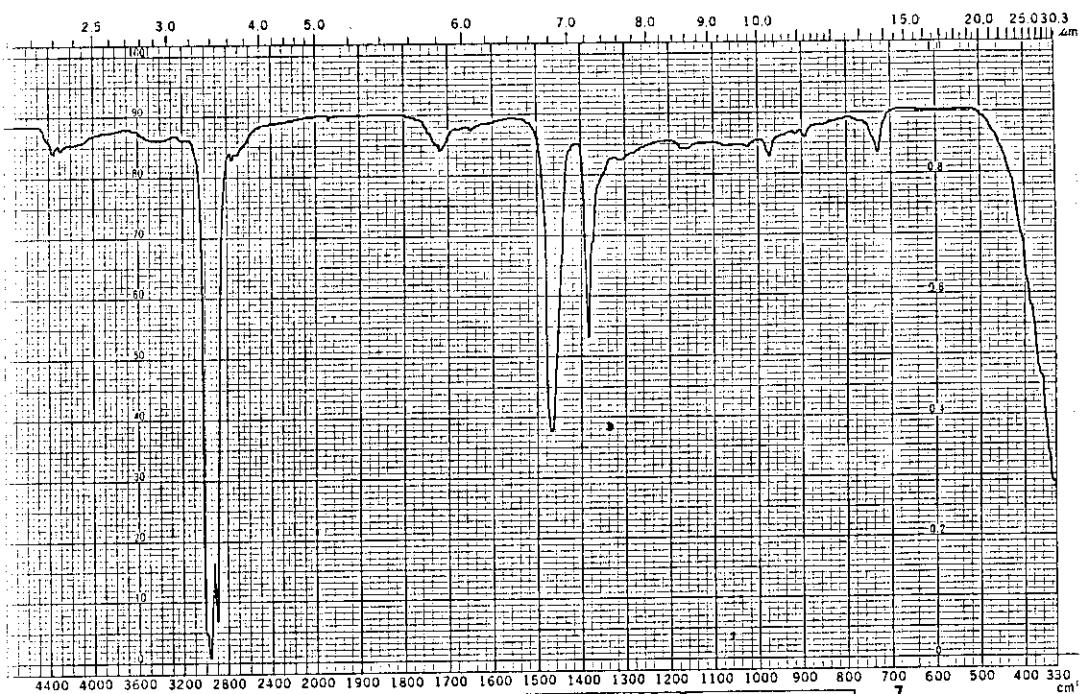


Infrared spectrum (original)



Infrared spectrum (0.98 MGy in bubbling oxygen)

OIL NAME: Liquid paraffin P-350

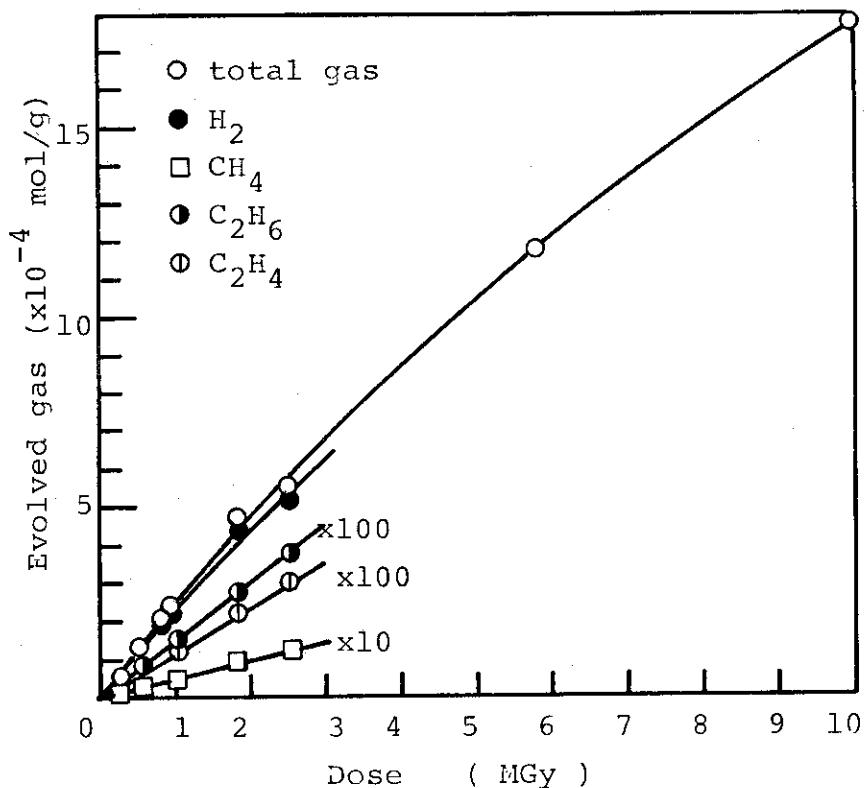


Infrared spectrum (10 MGy in air)

COMMENT

IRRADIATION CONDITION

OIL NAME : Liquid paraffin P-350

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	2.8
$G(H_2)$	2.7
$G(CH_4)$	5.1×10^{-2}
$G(C_2H_6)$	1.7×10^{-2}
$G(C_2H_4)$	1.4×10^{-2}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	2.7
5 MGy	10.7
10 MGy	17.8

COMMENTIRRADIATION CONDITION

in vacuum, dose rate; 10 kGy/h

OIL NAME: Paraffinic neutral oil N-350

STRUCTURE OR FEATURE: Mineral oil

MOLECULAR WEIGHT: 400 (Average molecular weight)

VISCOSITY at 40°C: 72.99×10^{-6} m²/s (8.665x10⁻⁶ m²/s at 100°C)

VISCOSITY INDEX: 89 SPECIFIC GRAVITY(15/4°C): 0.882

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 244

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6}$ m ² /s (15/4°C) (40°C) (100°C)	η/η_0 (40°C) (100°C)
in vacuum	1.0		78.93	9.596 1.08 1.11
	3.0	0.885	94.87	10.98 1.30 1.27
	5.6	0.884	140.3	15.47 1.92 1.79
	9.0	0.889	233.4	21.07 3.20 2.43
in oxygen bubbling	0.05	0.884	74.08	9.169 1.01 1.06
	0.21	0.885	78.84	9.460 1.08 1.09
	0.50	0.889	87.78	9.932 1.20 1.15
	0.98	0.894	100.3	10.56 1.37 1.22
	1.1	0.892	99.79	10.59 1.37 1.22
	2.9	0.895	117.2	11.78 1.61 1.36
	3.2	0.906	153.0	13.38 2.10 1.54
	4.4	0.900	137.3	13.06 1.91 1.48
	6.1	0.925	272.5	18.41 3.73 2.12
	9.0	0.935	402.9	22.23 5.52 2.57
in air	10.6	0.952	902.9	33.86 12.4 3.91
	0.05	0.885	89.72	10.48 1.22 1.21
	0.2	0.880	78.07	9.462 1.07 1.09
	0.5	0.880	78.97	9.693 1.08 1.12
	1.0	0.883	80.17	9.693 1.10 1.12

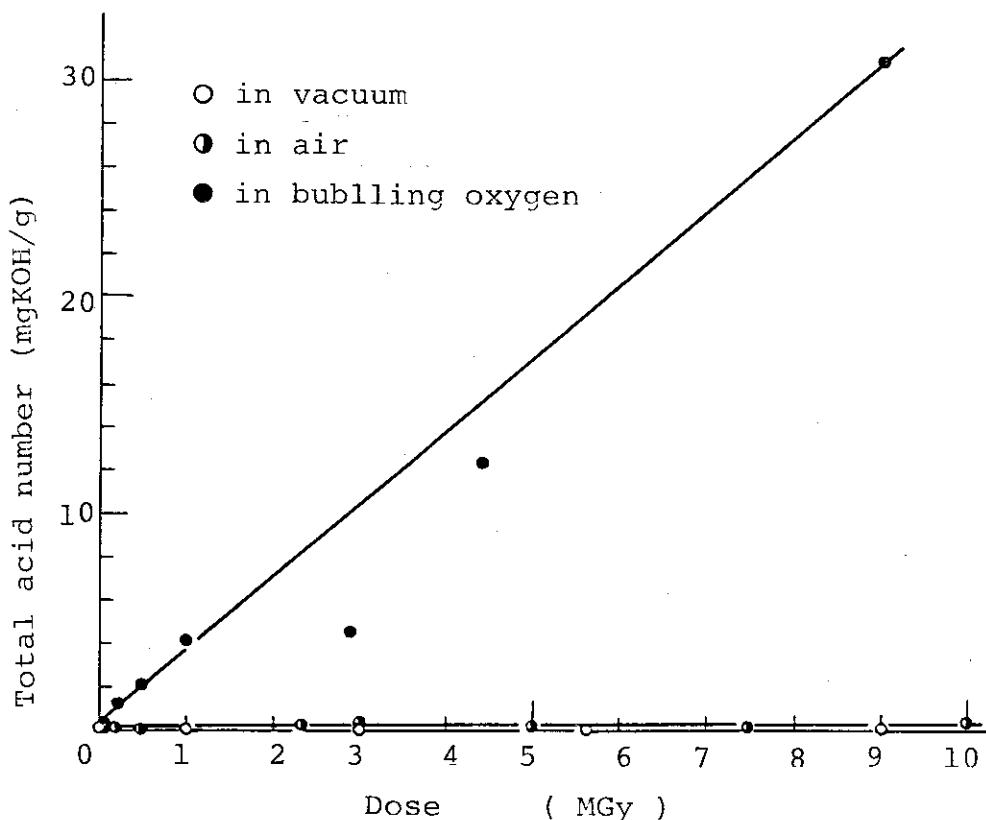
IRRADIATION CONDITION

Dose rate; 10 kGy/h

OIL NAME : Paraffinic neutral oil N-350

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (40°C) (100°C)	η/η_0 (40°C) (100°C)
in air	2.3	0.884	95.17	1.30 1.25
	3.0	0.887	106.7	1.46 1.28
	5.0	0.891	134.5	1.84 1.60
	7.5	0.889	198.1	2.71 2.08
	10	0.895	213.1	2.92 2.20

COMMENTIRRADIATION CONDITION

Dose rate; 10 kGy/h

OIL NAME : Paraffinic neutral oil N-350

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	98	0.00	252	2 (1/2)	L2.5
	3.0	97	0.00	234	4	L4.5
	5.6	114	0.00	208	6 (-)	6.0
	9.0	106	0.00	196	7	8.0
in oxygen bubbling	0.05	98	0.16	248	2 (1/2)	L2.0
	0.21	96	0.79	246	4 (-)	L3.5
	0.5	91	1.94	246	4 (1/2)	L5.0
	0.98	85	4.18	240	6	L5.5
	1.1	87	4.32	190	8 (-)	L7.5
	2.9	87	4.47	226	8	8.0
	3.2	78	14.8	210	8	8.0
	4.4	87	12.4	116	8	8.0
	6.1	69	24.1	170	8	8+
	9.0	59	30.8	170	8	8+
	10.6	48	53.9	170	8	8+
in air	0.05	89	0.02	244	1 (-)	L0.5
	0.2	97	0.03	244	2 (-)	L1.5
	0.5	100	0.03	242	2 (-)	L1.5
	1.0	101	0.02	240	4 (-)	L3.5
	2.3	98	0.16	246	5 (-)	L5.0
	3.0	87	0.38	244	5	5.5
	5.0	99	0.20	228	6 (-)	6.0
	7.5	100	0.12	222	7 (-)	7.0
	10	100	0.26	238	8	7.5

COMMENT:

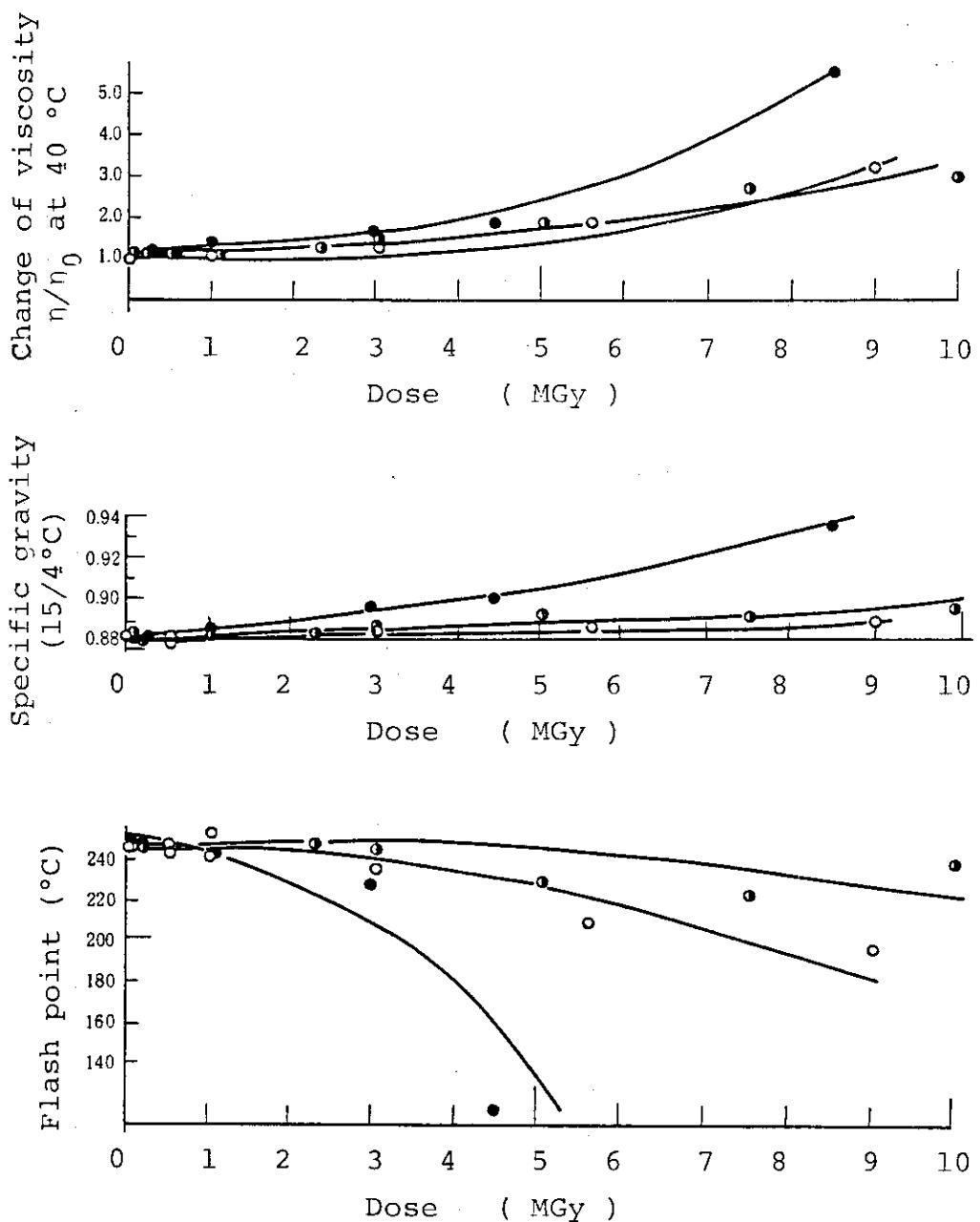
$$\%C_P = 64, \%C_N = 31, \%C_A = 5.$$

$\%C_P$ = fraction of carbon atoms in paraffinic chain,

$\%C_N$ = fraction of carbon atoms in naphthenic ring,

$\%C_A$ = fraction of carbon atoms in aromatic ring.

OIL NAME : Paraffinic neutral oil N-350

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Symbol:

- in vacuum
- in air
- in bubbling oxygen

OIL NAME: Paraffinic neutral oil N-350

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	(40°C)	(100°C)	η/η_0 (40°C)	(100°C)
<u>in air</u>							
20	1.0	0.883	126.7	9.645	1.74	1.11	
10	1.0	0.883	80.17	9.698	1.10	1.12	
3.0	1.0	0.881	84.79	9.907	1.16	1.14	
1.0	1.0	0.881	83.94	9.900	1.15	1.14	
0.5	1.0	0.882	85.20	10.03	1.17	1.16	

OIL NAME: Paraffinic neutral oil N-350

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

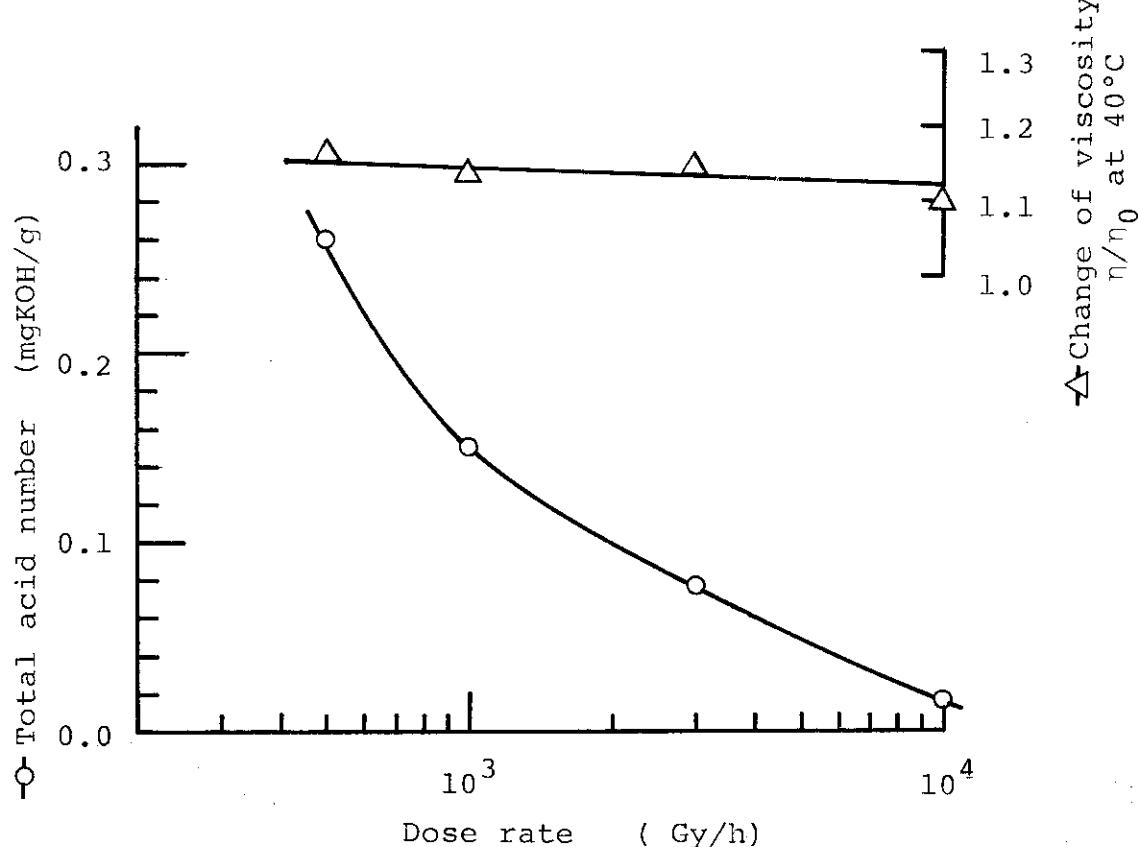
Dose rate [kGy/h]	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
<u>in air</u>						
20	1.0	20	2.89	254	3(1/2)	L3.0
10	1.0	101	0.02	240	4(-)	L3.5
3.0	1.0	95	0.08	248	4(-)	L4.0
1.0	1.0	96	0.16	250	4(-)	L3.5
0.5	1.0	97	0.27	246	4(-)	L4.0

OIL NAME : Paraffinic neutral oil N-350

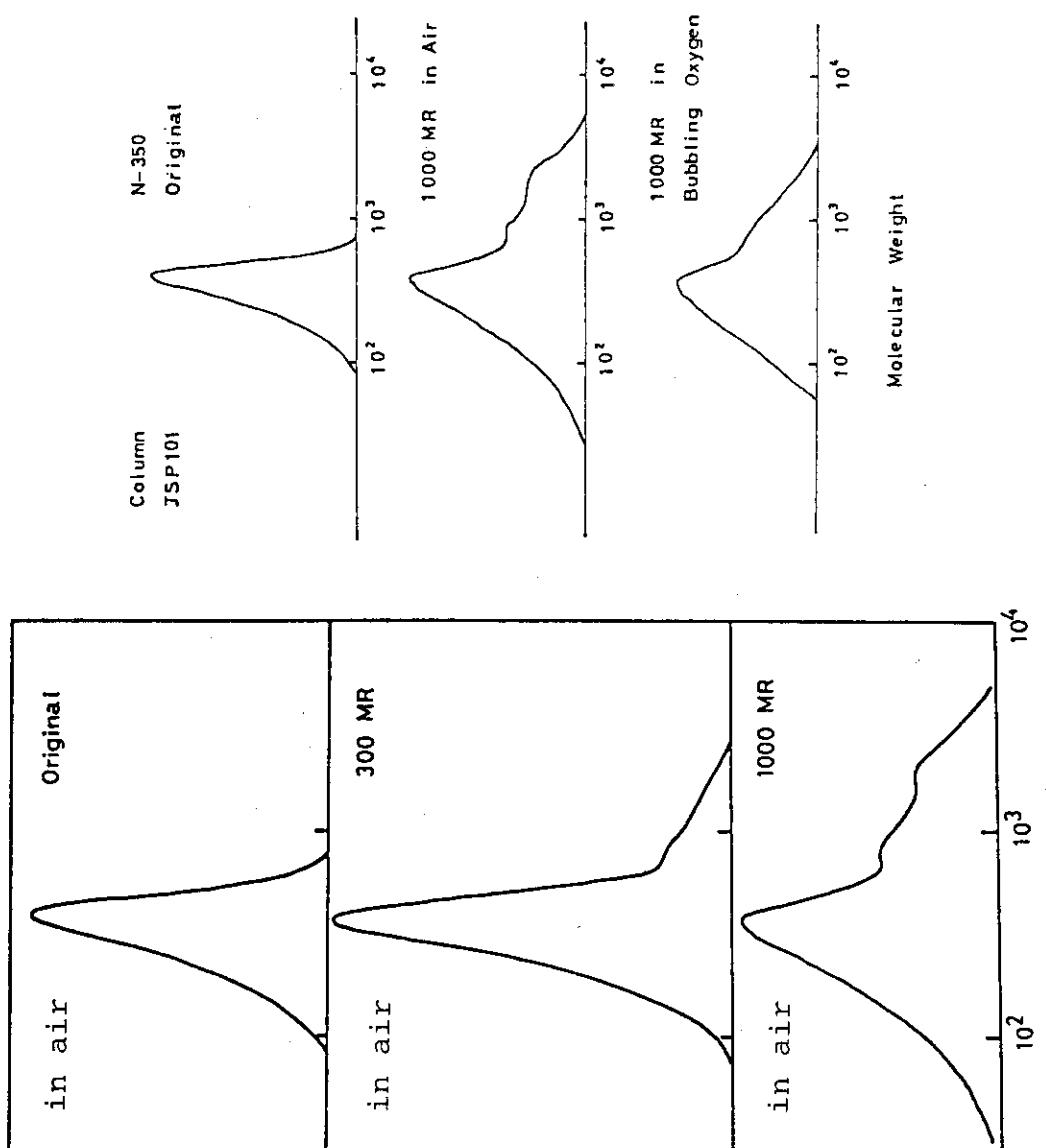
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

DOSE RATE EFFECT

(in air, total dose 1 MGy)

COMMENTIRRADIATION CONDITION

OIL NAME: Paraffinic neutral oil N-350

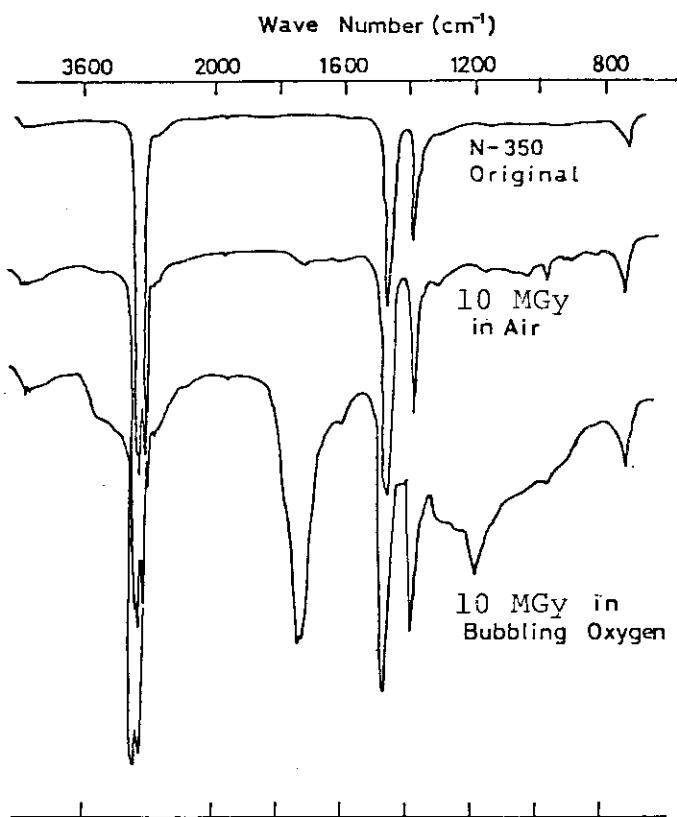


Change of molecular weight distribution of N-350 using liquid chromatogram.

COMMENT

IRRADIATION CONDITION

OIL NAME: Paraffinic neutral oil N-350



The infrared spectrum of paraffinic neutral oil
N-350

COMMENT

IRRADIATION CONDITION

OIL NAME : Parafinic neutral oil N-350

IRRADIATION CONDITION

Temp.: -196°C

Dose

11kGy

in Vacuum

after irradiation

after photo breach

50

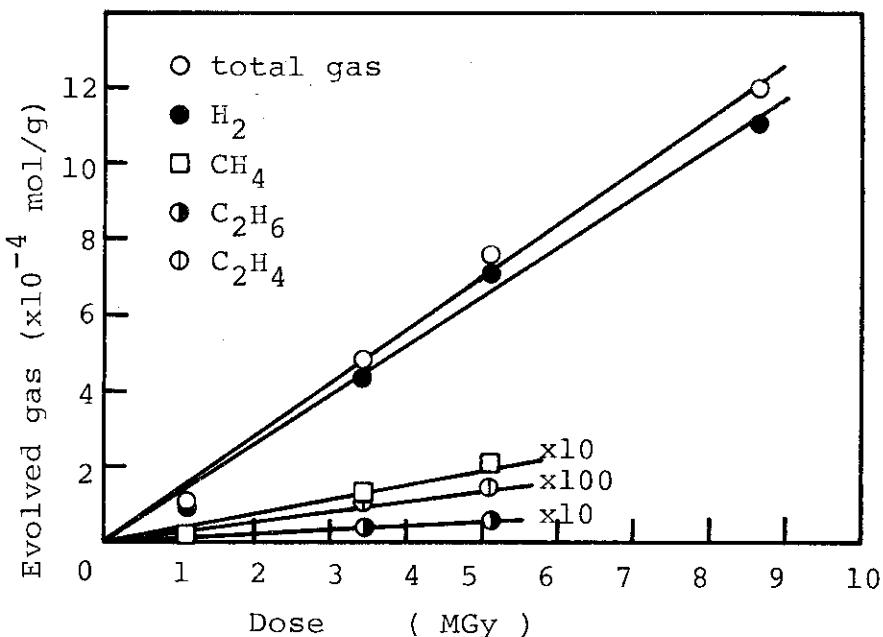
ESR CONDITION Sweep range(Gauss): ± 250 Power(μW): 1
 Modulation width(100kHz, Gauss): 2 at -196°C

G[R.]after irradiationafter Photo breach

2.9

2.0₅

OIL NAME : Paraffinic neutral oil N-350

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	1.4
$G(H_2)$	1.3
$G(CH_4)$	3.9×10^{-2}
$G(C_2H_6)$	9.7×10^{-3}
$G(C_2H_4)$	2.4×10^{-3}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	1.4
5 MGy	7.4
10 MGy	14.1

COMMENTIRRADIATION CONDITION

in vacuum, dose rate; 10 kGy/h

OIL NAME: Paraffinic neutral oil N-350

BREAKDOWN VOLTAGE

Measurement times	Breakdown voltage (kV)			
	original	1 MGy	5 MGy	10 MGy
1 (V_1)	45.5	34.4	23.8	4.0
2 (V_2)	45.5	26.5	38.7	5.9
3 (V_3)	32.4	27.5	42.0	9.0
4 (V_4)	37.5	28.7	36.4	9.3
5 (V_5)	33.2	29.9	35.3	16.3
average (V)	37.2	28.2	38.1	10.1

COMMENTIRRADIATION CONDITION

OIL NAME: Paraffinic neutral oil N-500

STRUCTURE OR FEATURE: Mineral oil

MOLECULAR WEIGHT: 450 (average molecular weight)

VISCOSITY at 40°C: 93.54×10^{-6} m²/s (10.76×10^{-6} m²/s at 100°C)

VISCOSITY INDEX: 98 SPECIFIC GRAVITY(15/4°C): 0.888

TOTAL ACID NUMBER: 0.01 mgKOH/g, FLASH POINT(°C): 260

COLOR: UNION 1x1/2 (-), ASTM L1.0 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6}$ m ² /s (15/4°C) (40°C) (100°C)	η/η_0 (40°C) (100°C)	
in vacuum	1.0	0.881	101.1	11.45	1.08
	3.0	0.886	115.9	12.48	1.24
in bubbling oxygen	0.05	0.887	100.1	10.96	1.07
	0.21	0.891	104.2	11.34	1.11
	0.5	0.892	115.9	11.95	1.24
	0.98	0.894	134.3	12.78	1.44
	1.1	0.897	132.3	12.40	1.41
	2.5	0.907	175.5	14.91	1.88
	3.3	0.912	207.5	16.29	2.22
in air	0.65	0.886	96.11	10.91	1.03
	1.0	0.886	102.3	11.48	1.09
	1.4	0.886	102.4	11.38	1.09
	2.3	0.889	112.8	12.29	1.21
	3.0	0.887	125.9	13.17	1.35
	5.0	0.892	153.8	15.03	1.64
	7.5	0.897	212.4	19.05	2.27
	10	0.897	263.9	22.34	2.82
					2.08

COMMENT: next page

IRRADIATION CONDITION

Dose rate; 10 kGy/h

OIL NAME : Paraffinic neutral oil N-500

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in vacuum	1.0	100	0.01	258	3(1/3)	L3.5
	3.0	99	0.01	240	5	5.5
in bubbling oxygen	0.05	93	0.12	262	2(1/2)	L2.0
	0.21	94	0.62	262	4(1/2)	L4.5
	0.5	91	1.78	260	5	L6.0
	0.98	83	3.43	210	6	L6.5
	1.1	81	3.90	252		L7.0
	2.5	81	44.6	124		8.0
	3.3	78	14.47	242		8.0
in air	1.0	98	0.02	260	3	L3.0
	2.3	99	0.16	248	4(1/2)	L4.5
	3.0	98	0.17	264	5(-)	5.5
	5.0	98	0.18	234	6(-)	6.0
	7.5	101	0.24	224	7(-)	7.5
	10	103	0.45	204	8(-)	7.5

COMMENT

$$\%C_P = 65, \%C_N = 28, \%C_A = 7.$$

$\%C_P$ = fraction of carbon atoms in paraffinic chain,

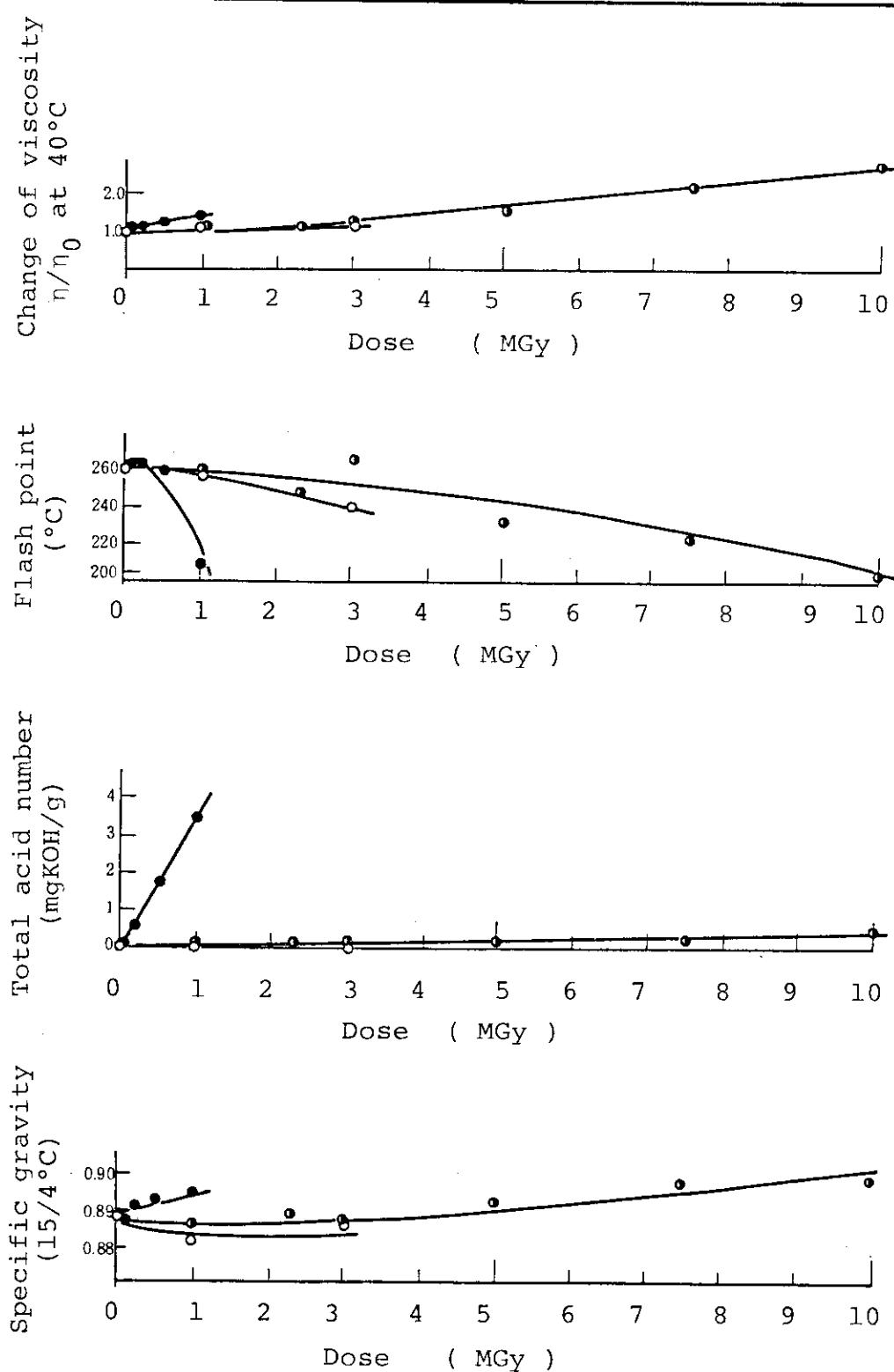
$\%C_N$ = fraction of carbon atoms in naphthenic ring,

$\%C_A$ = fraction of carbon atoms in aromatic ring.

IRRADIATION CONDITION

Dose rate; 10 kGy/h

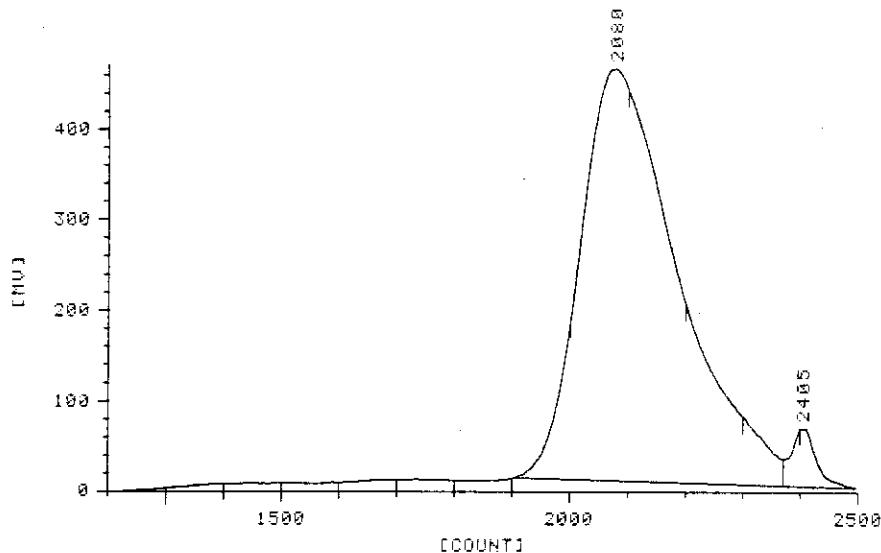
OIL NAME: Paraffinic neutral oil N-500



Symbol:

○ in vacuum, ● in bubbling oxygen, ◉ in air.

OIL NAME: Paraffinic neutral oil N-500

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/07 18:47 JOB FILE 1

SAMPLE NO. 0 NAME: 2-2

SERIAL NO. 0039

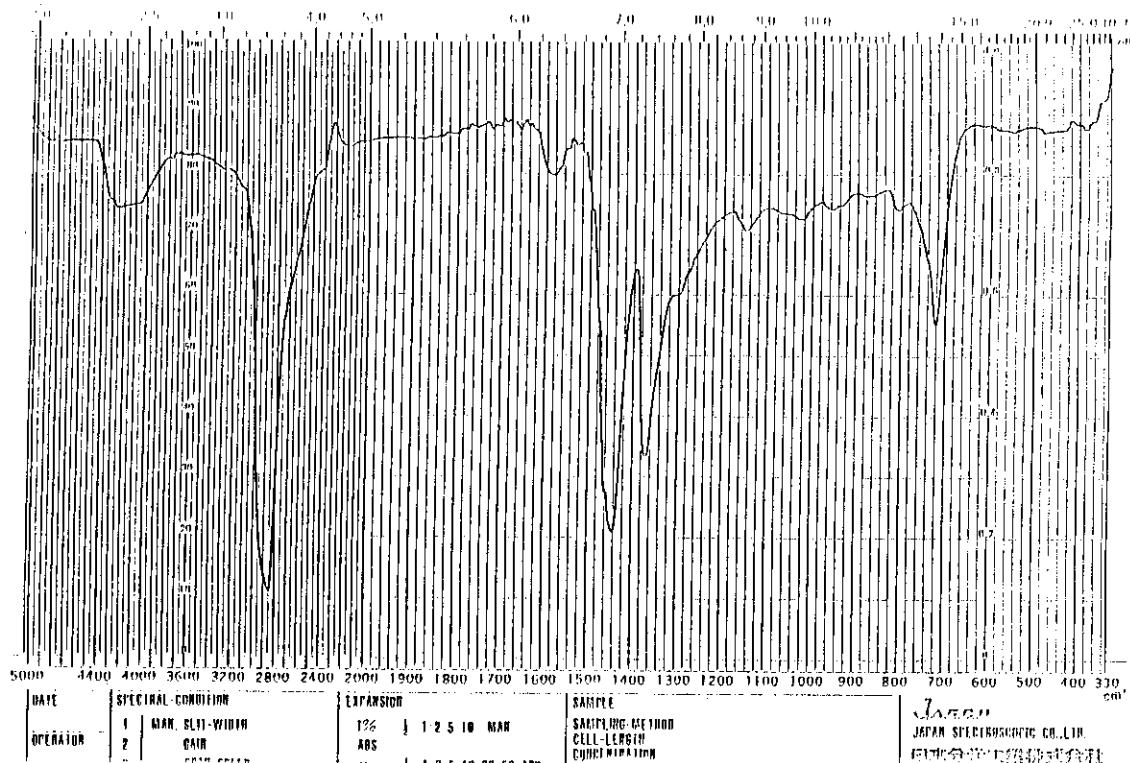
CH.NO 1 METHOD 2

PEAK NO. 1		BASE	START	TOP	END	MN	MW	MZ	MU
C	1905	2088	2378	6.26823E+02	6.49457E+02	6.73112E+02	6.49455E+02		
U	14.7	467.9	34.9	MW/MN	MZ/MW	AREA	AREP%		
M	1342	680	397	1.04	1.04	9.00290E+04	96.48		

PEAK NO. 2		VALLEY	START	TOP	END	MN	MW	MZ	MU
C	2378	2485	2495	3.66758E+02	3.67665E+02	3.69536E+02	3.67664E+02		
U	34.9	68.4	3.4	MW/MN	MZ/MW	AREA	AREP%		
M	397	369	296	1.00	1.00	3.28176E+03	3.52		

TOTAL		START	TOP	END	MN	MW	MZ	MU
C	1905	2088	2495	6.11571E+02	6.39547E+02	6.66954E+02	6.39545E+02	
U	14.7	467.9	3.4	MW/MN	MZ/MW	AREA	AREP%	
M	1342	680	296	1.05	1.04	9.33108E+04	100.00	

OIL NAME: Paraffinic neutral oil N-500



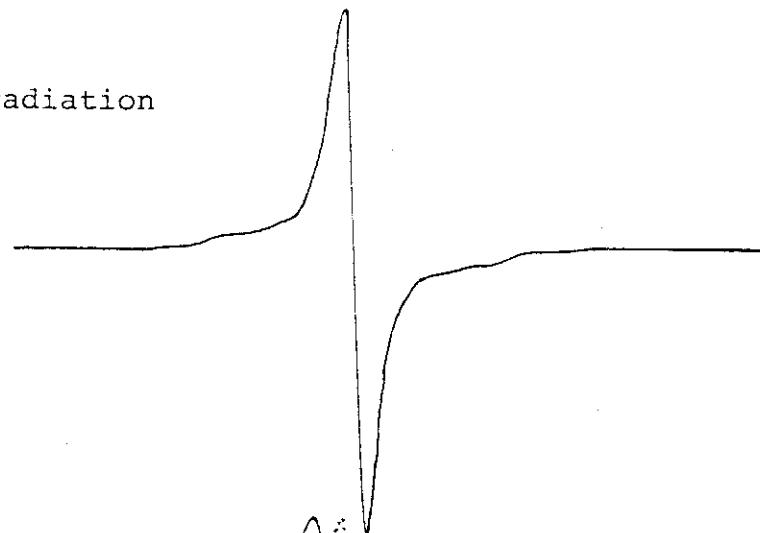
Infrared spectrum (original)

OIL NAME : Parafinic neutral oil N-500

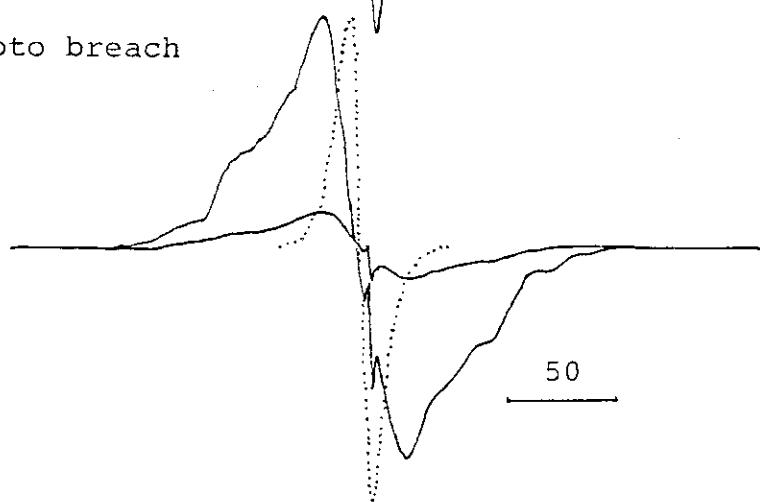
IRRADIATION CONDITION

Temp.: -196°C Dose 11kGy in Vacuum

after irradiation



after photo breach

ESR CONDITIONSweep range(Gauss): \pm 250 Power(μ W): 1

Modulation width(100kHz, Gauss): 2 at -196°C

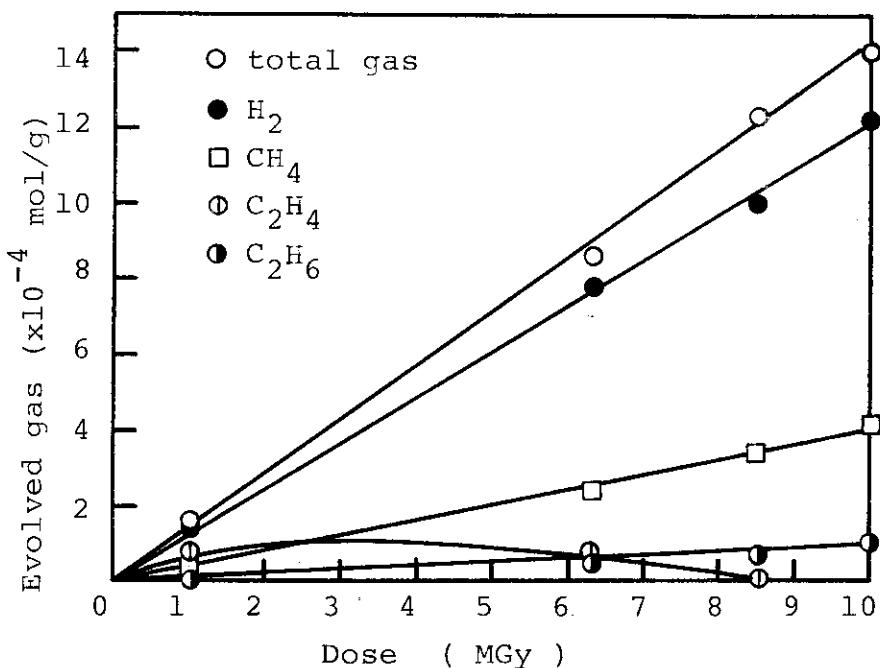
G[R.I.]after irradiation

3.1

after Photo breach

2.0

OIL NAME : Paraffinic neutral oil N-500

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	1.4
$G(H_2)$	1.3
$G(CH_4)$	4.0×10^{-2}
$G(C_2H_6)$	9.7×10^{-3}
$G(C_2H_4)$	7.7×10^{-3}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	1.4
5 MGy	7.0
10 MGy	14

COMMENTIRRADIATION CONDITION

in vacuum, dose rate; 10 kGy/h

OIL NAME: Naphthenic neutral oil

STRUCTURE OR FEATURE: Mineral oil

MOLECULAR WEIGHT: 400 (Average molecular weight)

VISCOSITY at 40°C: 95.45×10^{-6} m²/s (7.949 $\times 10^{-6}$ m²/s at 100°C)

VISCOSITY INDEX: 9 SPECIFIC GRAVITY(15/4°C): 0.932

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 192

COLOR: UNION 2x1/2 , ASTM L2.0 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6}$ m ² /s (15/4°C) (40°C) (100°C)	η/η_0 (40°C) (100°C)
in vacuum	1.0	0.932	105.4 8.446	1.10 1.06
	3.0	0.933	124.8 9.289	1.31 1.17
	5.6	0.936	169.2 11.03	1.77 1.39
in bubbling oxygen	0.06	0.931	98.03 8.281	1.03 1.04
	0.25	0.936	116.4 8.658	1.22 1.09
	0.5	0.942	164.0 9.934	1.72 1.25
	1.0	0.950	240.4 11.92	2.52 1.50
in air	1.0	0.933	105.7 8.432	1.11 1.06
	3.0	0.934	116.4 9.360	1.22 1.18
	10	0.941	344.8 16.76	3.61 2.11

COMMENT $\%C_p$; 43, $\%C_N$; 40, $\%C_A$ 17. $\%C_p$ = fraction of carbon atoms in paraffinic chain, $\%C_N$ = fraction of carbon atoms in naphthenic ring, $\%C_A$ = fraction of carbon atoms in aromatic ring.

Commercial name; SUN 500N (Sun Oil Co.)

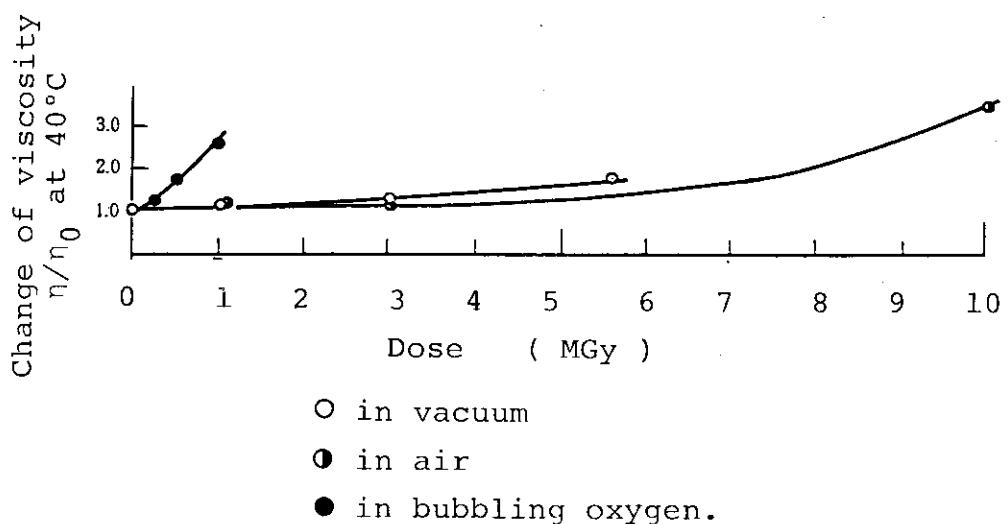
IRRADIATION CONDITION

Dose rate; 10 kGy/h

OIL NAME : Naphthenic neutral oil

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

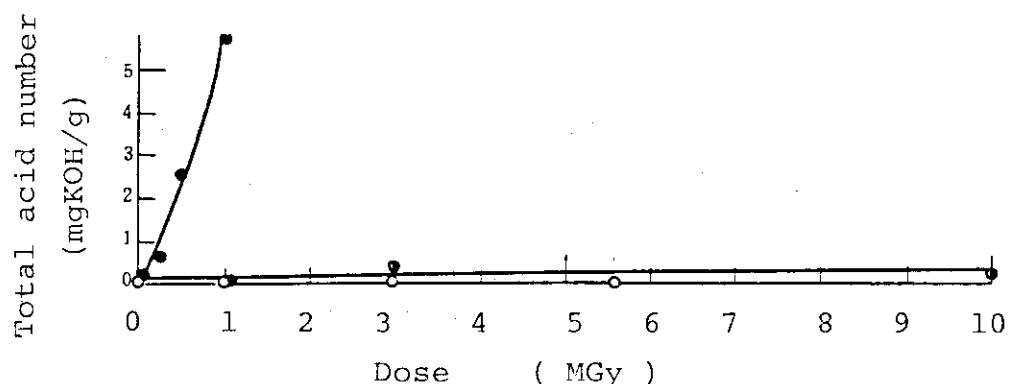
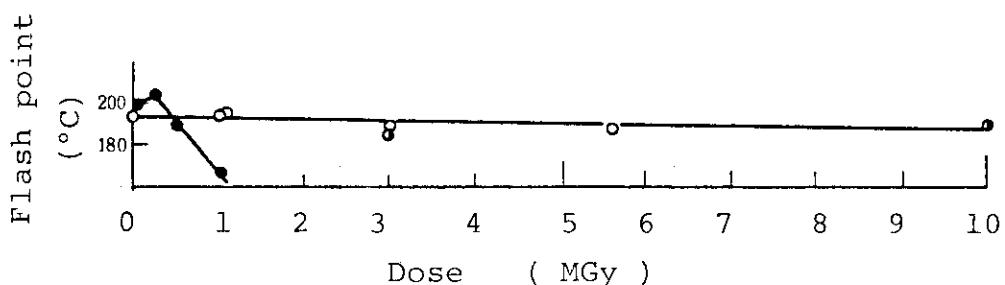
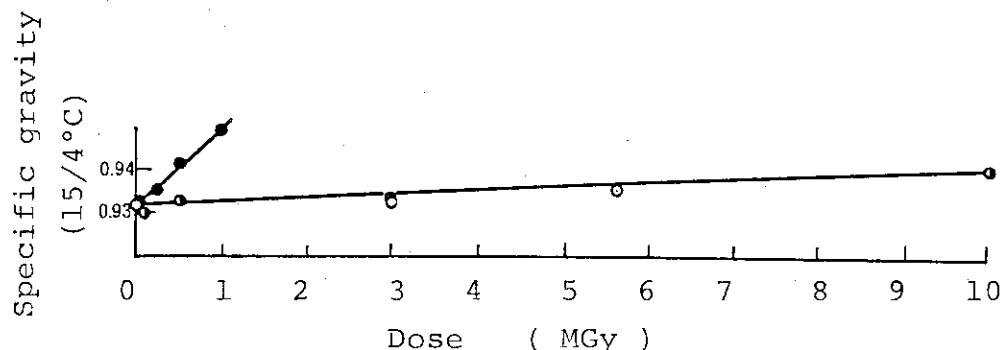
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	11	0.00	194		L1.5
	3.0	10	0.00	188		1.5
	5.6	7	0.00	188		2.5
in bubbling oxygen	0.06	19	0.14	198		L3.0
	0.25	-2	0.59	202		4.5
	0.5	-28	2.55	188		L6.5
	1.0	-44	5.73	166		8.0
in air	1.0	9	0.00	194		L2.5
	3.0	27	0.38	184		3.0
	10	8	0.19	190		L4.5

IRRADIATION CONDITION

Dose rate; 10 kGy/h

OIL NAME : Naphthenic neutral oil

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

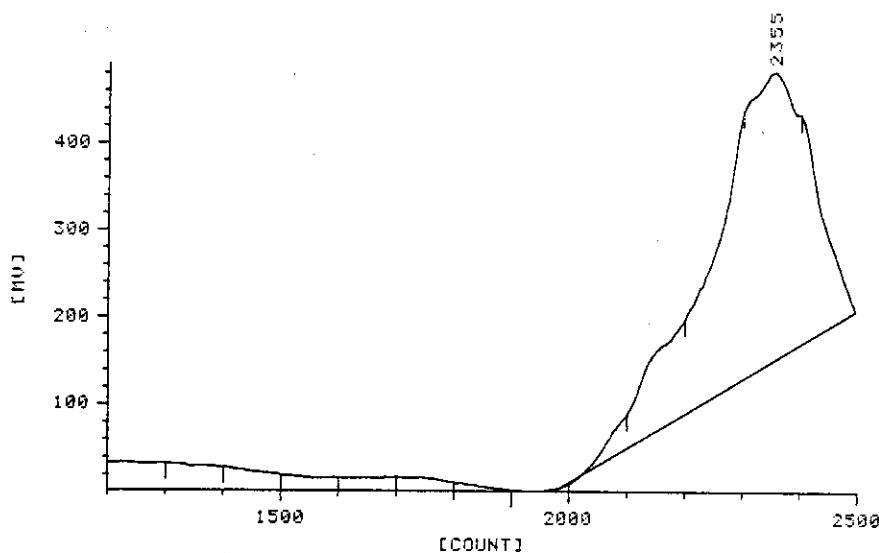


Symbol:

- in vacuum
- ◐ in air
- in bubbling oxygen

IRRADIATION CONDITION

OIL NAME: Naphthenic neutral oil

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/08 15:11 JOB FILE 1

SAMPLE NO. 0 NAME: 3 - O

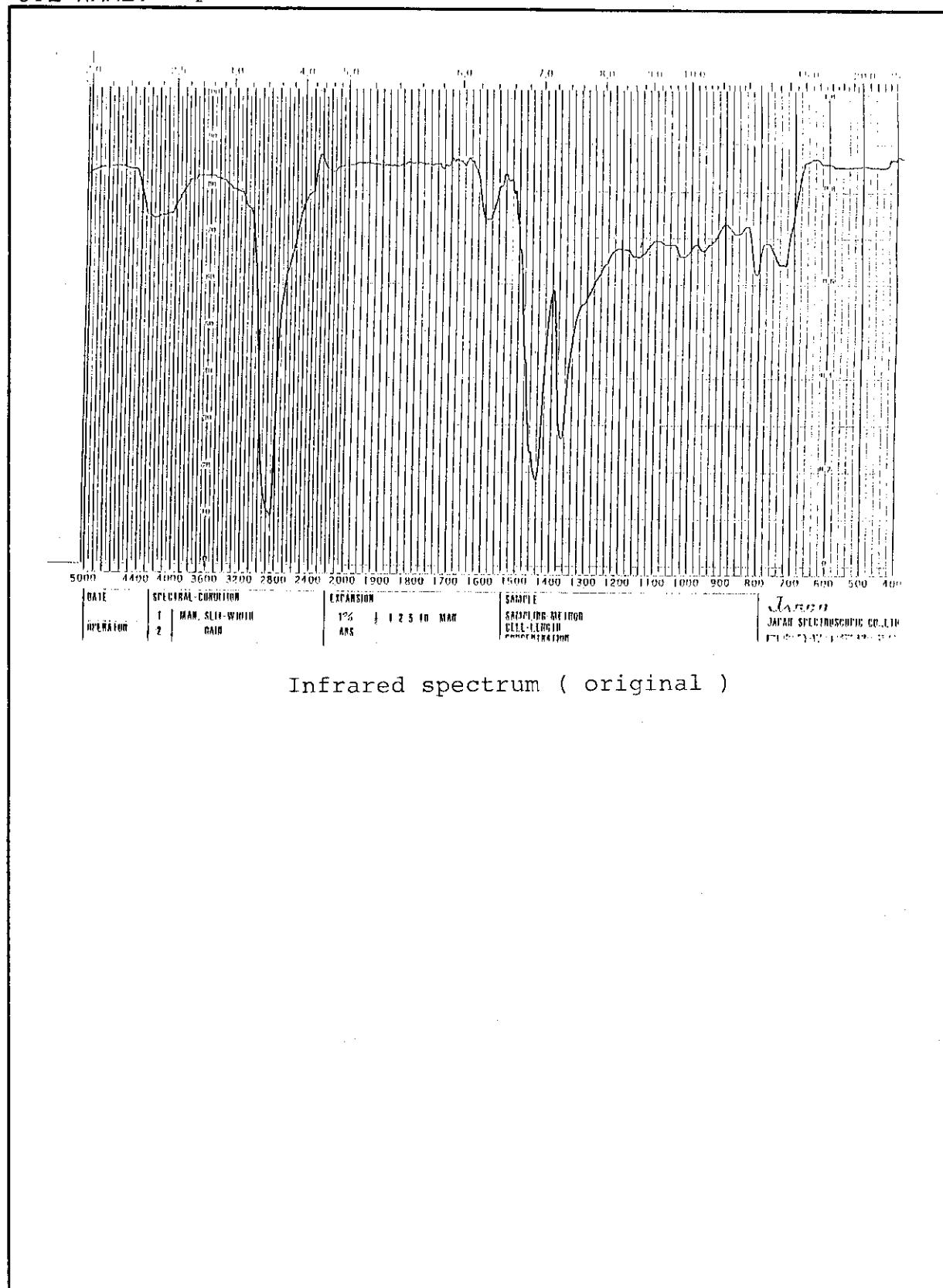
SERIAL NO. 0042

CH.NO 1

METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	1985	2355	2495	4.34371E+02	4.46767E+02	4.60561E+02	4.46765E+02	
V	4.6	483.6	298.4	MW/MN	MZ/MW	AREA	AREA%	
M	912	409	296	1.03	1.03	6.95818E+04	100.00	

OIL NAME: Naphthenic neutral oil

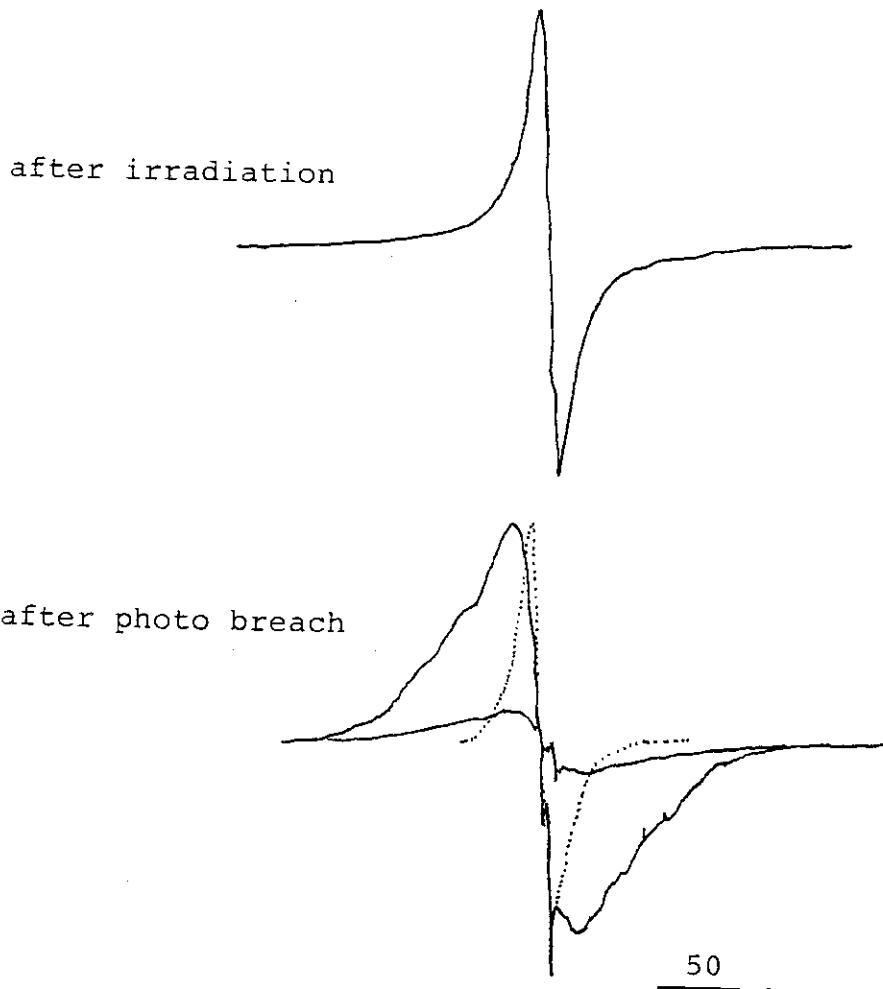


Infrared spectrum (original)

OIL NAME : Naphthenic neutral oil

IRRADIATION CONDITION

Temp.: -196°C Dose 11kGy in Vacuum

ESR CONDITION

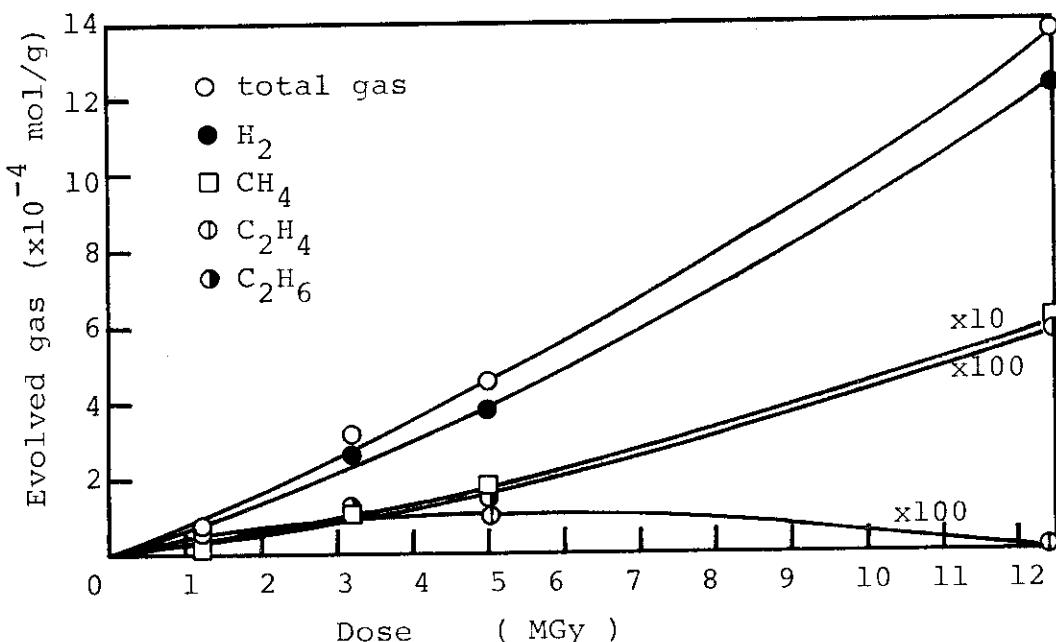
Sweep range(Gauss): ± 250 Power(μW): 1
 Modulation width(100kHz, Gauss): 2 at -196°C

G[R.]after irradiationafter Photo breach

3.1

1.9

OIL NAME : Naphthenic neutral oil

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	9.4×10^{-1}
$G(H_2)$	8.5×10^{-1}
$G(CH_4)$	3.5×10^{-2}
$G(C_2H_6)$	3.0×10^{-3}
$G(C_2H_4)$	2.1×10^{-3}

AMOUNT OF TOTAL EVOLVED GASES: ($\times 10^{-4}$ mol/g)

1 MGy	0.9
5 MGy	4.9
10 MGy	9.8

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h

3.2 Synthetic hydrocarbon

3.2.1 Poly- α -olefin

OIL NAME: Poly- α -olefin

STRUCTURE OR FEATURE: Synthetic lubricant

MOLECULAR WEIGHT: 560 (Average molecular weight)

VISCOSITY at 40°C: 17.26×10^{-6} m²/s (3.947×10^{-6} m²/s at 100°C)

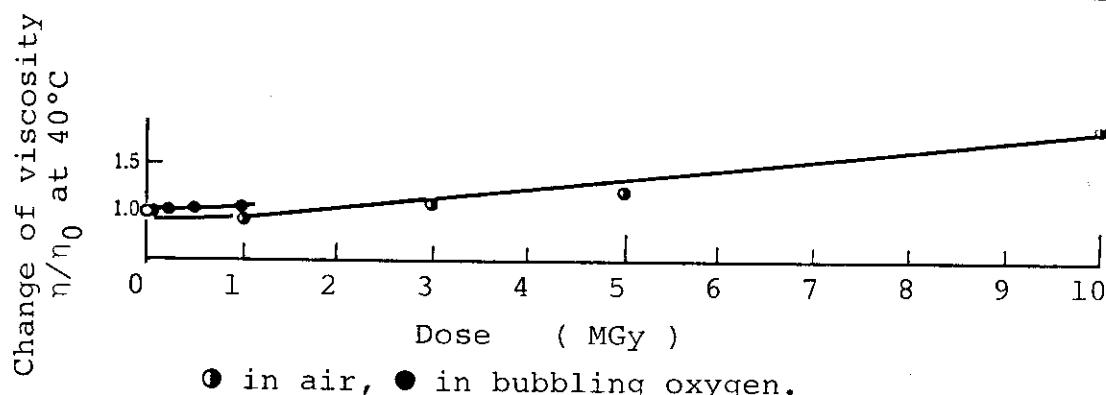
VISCOSITY INDEX: SPECIFIC GRAVITY(15/4°C): 0.820

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 230

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
in	0.06	0.821	17.31	3.909	1.00	0.99
bubbling	0.22	0.821	17.40	3.834	1.01	0.97
oxygen	0.48	0.825	17.72	3.866	1.03	0.98
	1.0	0.831	18.43	3.941	1.07	1.00
in air	1.0	0.819	17.16	3.925	0.99	0.99
	3.0	0.825	18.60	4.131	1.08	1.05
	5.0	0.827	21.36	4.627	1.24	1.17
	10	0.835	32.88	6.372	1.90	1.61



COMMENT:

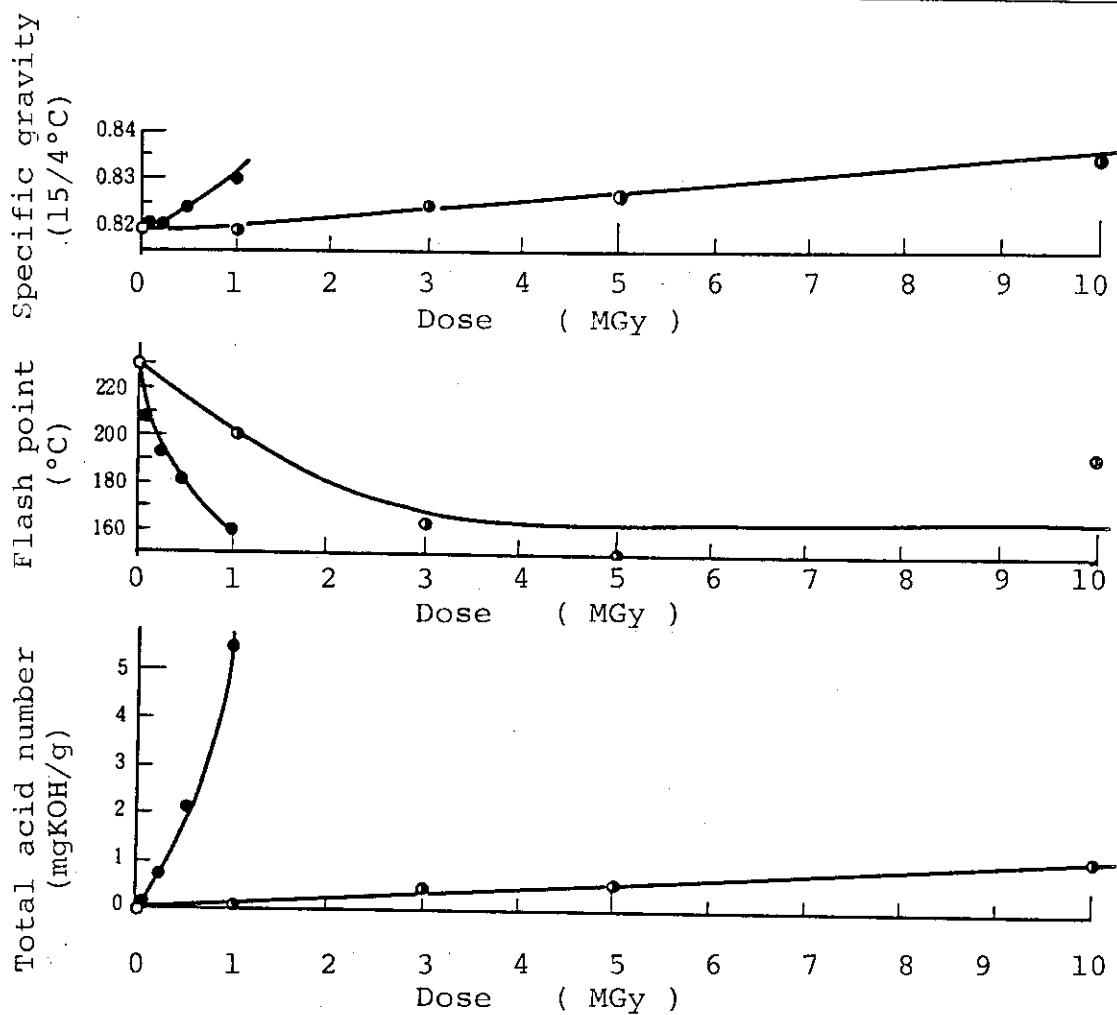
Commercial name; PAOL-40 (Bray Oil Co.)

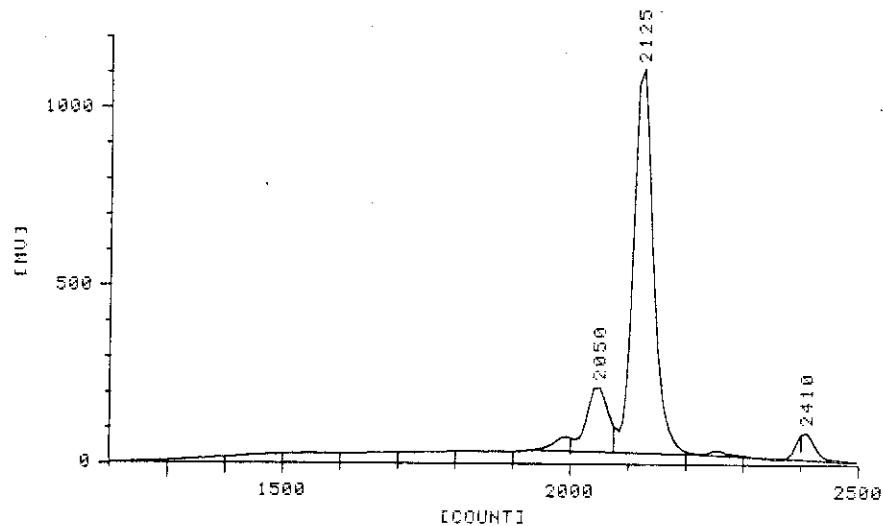
IRRADIATION CONDITION

Dose rate 10 kGy/h

OIL NAME : Poly- α -olefinPROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in bubbling oxygen	0.06	122	0.12	208	1(-)	L0.5
	0.22	111	0.75	194	1(-)	L0.5
	0.48	111	2.13	182	1(-)	L0.5
	1.0	108	5.51	160	1(-)	L0.5
in air	1.0	126	0.07	200	1(-)	L0.5
	3.0	126	0.44	164	1(-)	L0.5
	5.0	137	0.55	150	1(-)	L0.5
	10	149	1.09	192	1	1.0



OIL NAME: Poly- α -olefinMOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/08 17:09 JOB FILE 1

SAMPLE NO. 0 NAME: 1-3

SERIAL NO. 0045

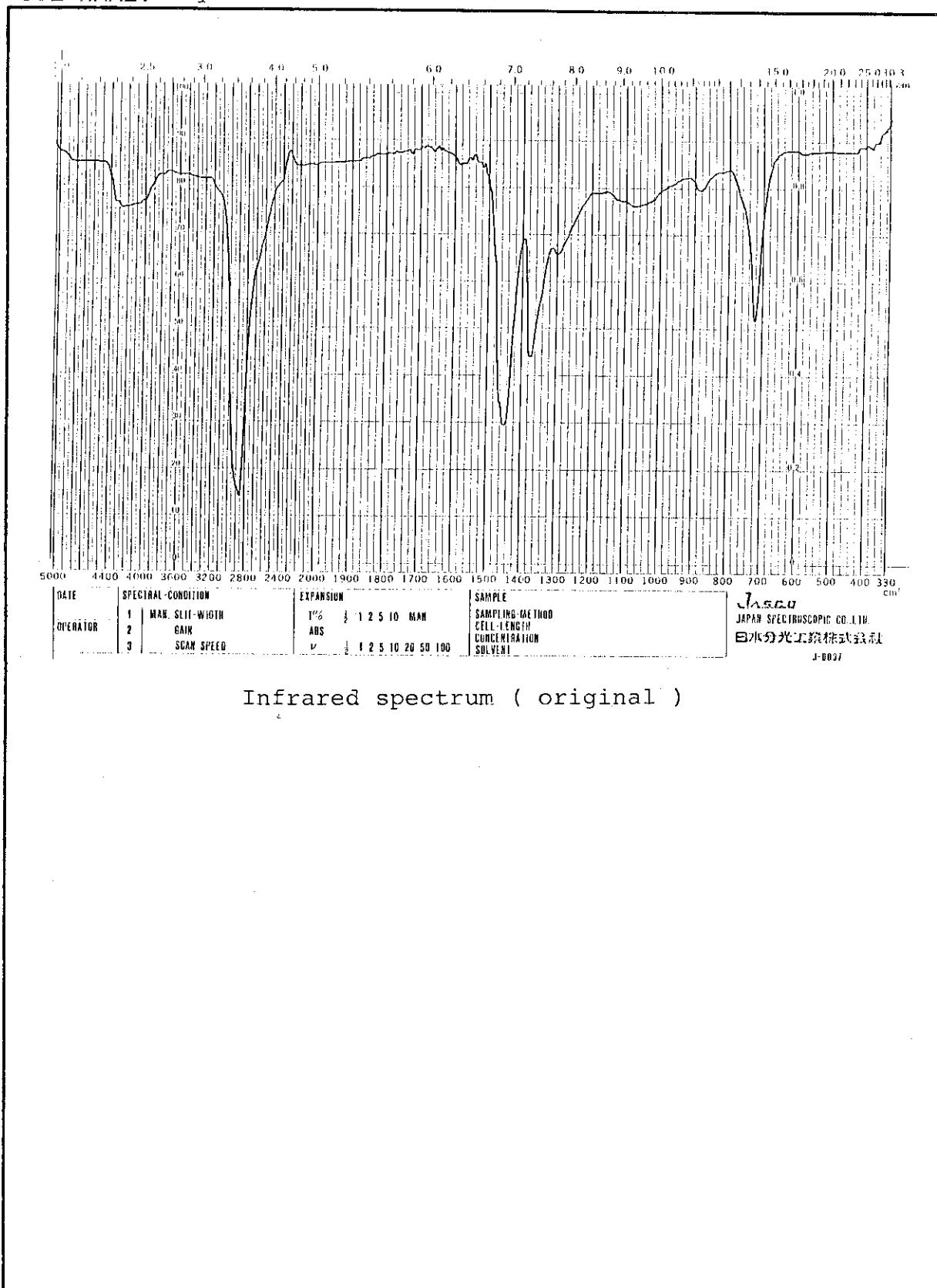
CH.NO 1 METHOD 2

PEAK NO. 1 BASE		START	TOP	END	MN	MW	MZ	MU
C	1930	2050	2075	7.71917E+02	7.78382E+02	7.85778E+02	7.78379E+02	
V	38.0	217.9	104.8	MW/MN	MZ/MW	AREA	AREAN%	
M	1168	736	689	1.01	1.01	9.25564E+03	16.12	

PEAK NO. 2 VALLEY		START	TOP	END	MN	MW	MZ	MU
C	2075	2125	2220	6.14842E+02	6.15752E+02	6.16657E+02	6.15749E+02	
V	104.8	1114.1	27.5	MW/MN	MZ/MW	AREA	AREAN%	
M	689	614	516	1.00	1.00	4.49147E+04	78.24	

PEAK NO. 3 BASE		START	TOP	END	MN	MW	MZ	MU
C	2220	2410	2495	3.76900E+02	3.80842E+02	3.85499E+02	3.80841E+02	
V	27.5	88.8	7.5	MW/MN	MZ/MW	AREA	AREAN%	
M	516	365	296	1.01	1.01	3.23363E+03	5.63	

TOTAL		START	TOP	END	MN	MW	MZ	MU
C	1930	2125	2495	6.13154E+02	6.28741E+02	6.42528E+02	6.29739E+02	
V	38.0	1114.1	7.5	MW/MN	MZ/MW	AREA	AREAN%	
M	1168	614	296	1.03	1.02	5.74840E+04	100.00	

OIL NAME: Poly- α -olefin

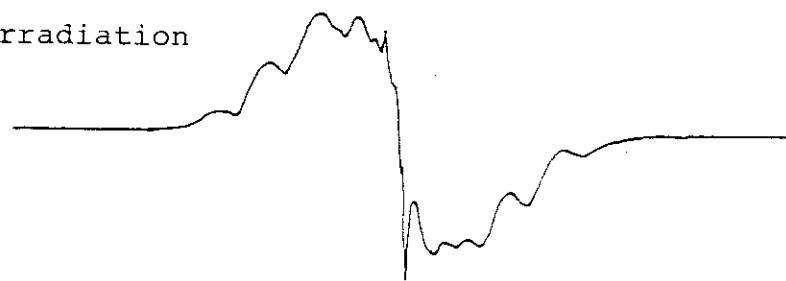
OIL NAME : Poly- α -olefinIRRADIATION CONDITION

Temp.: -196°C

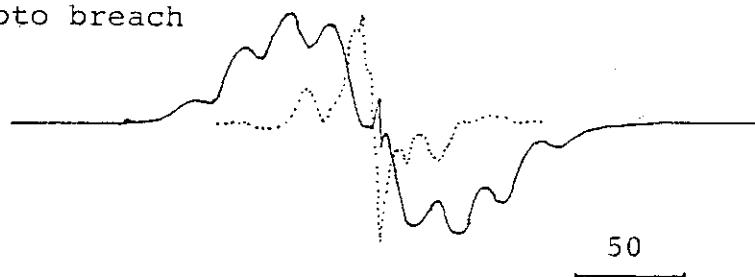
Dose 11kGy

in Vacuum

after irradiation



after photo breach

ESR CONDITIONSweep range(Gauss): ± 250 Power(μ W): 1

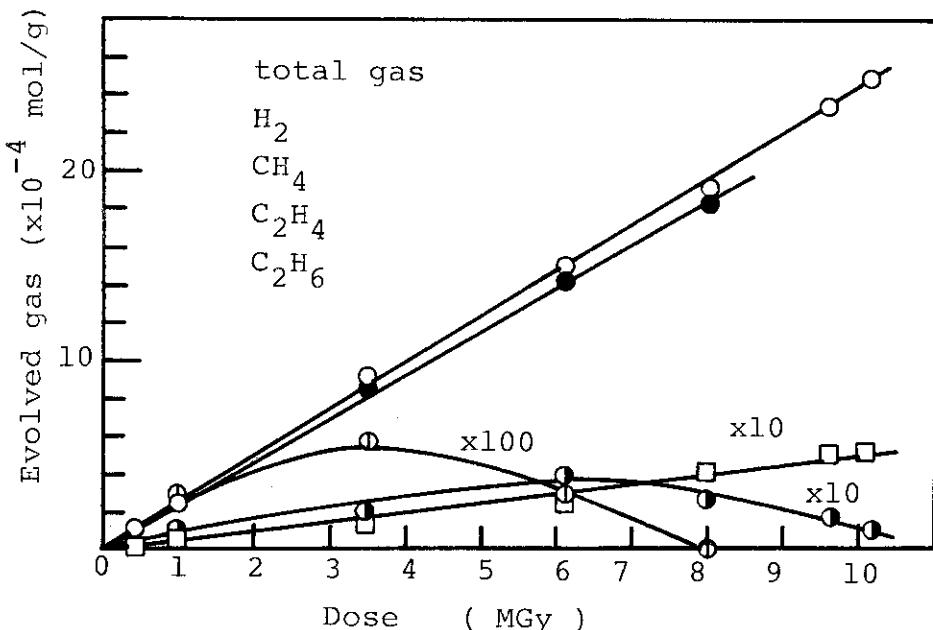
Modulation width(100kHz, Gauss): 2 at -196°C

G[R.]after irradiation

4.4

after Photo breach

4.2

OIL NAME : Poly- α -olefinRADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	2.4
$G(H_2)$	2.3
$G(CH_4)$	4.8×10^{-2}
$G(C_2H_6)$	2.8×10^{-2}
$G(C_2H_4)$	1.5×10^{-2}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	2.4
5 MGy	12.2
10 MGy	24.4

COMMENT

in vacuum, dose rate 10 kGy/h

IRRADIATION CONDITION

3.3 Ester

3.3.1 Di-2-ethylhexyl sebacate

3.3.2 Di-2-ethylhexyl adipate

3.3.3 Pentaerythritol ester

3.3.4 Tricresyl phosphate

3.3.5 Trioctyl phosphate

OIL NAME: Di-2-ethylhexyl sebacate

STRUCTURE OR FEATURE: ROOC(CH₂)₈COOR, R:C₄H₉(C₂H₅)CHCH₂-
MOLECULAR WEIGHT: 426

VISCOSITY at 40°C: 11.43x10⁻⁶ m²/s (3.211x10⁻⁶ m²/s at 100°C)

VISCOSITY INDEX: 137 SPECIFIC GRAVITY(15/4°C): 0.918

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 234

COLOR: UNION 1(-), ASTM L0.5.

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity nx10 ⁻⁶ m ² /s (15/4°C)	Viscosity nx10 ⁻⁶ m ² /s (40°C)	Viscosity nx10 ⁻⁶ m ² /s (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
in vacuum	1.0	0.920	14.18	3.684	1.24	1.24	1.15
	3.0	0.928	21.43	4.869	1.87	1.87	1.52
	5.5	1.01	41.28	7.809	3.61	3.61	2.43
	9.0	1.01	114.4	16.94	10.0	10.0	5.28
in bubbling oxygen	0.05	0.921	11.57	3.200	1.01	1.01	0.997
	0.23	0.922	11.57	3.223	1.01	1.01	1.00
	0.5	0.923	12.24	3.298	1.07	1.07	1.03
	0.99	0.927	13.11	3.423	1.15	1.15	1.07
	1.08	0.929	13.51	3.438	1.18	1.18	1.07
	1.7	0.934	15.13	3.694	1.32	1.32	1.15
in air	0.05	0.918	11.66	3.250	1.02	1.02	1.03
	0.2	0.919	11.96	3.322	1.05	1.05	1.03
	0.5	0.920	12.54	3.392	1.10	1.10	1.06
	1.0	0.923	14.11	3.707	1.23	1.23	1.15
	3.0	0.932	22.76	5.017	1.99	1.99	1.56
	5.0	0.940	43.11	7.767	3.77	3.77	2.42
	7.5	0.943	80.68	12.19	7.06	7.06	3.80
	10	0.968	160.7	20.23	14.1	14.1	6.30

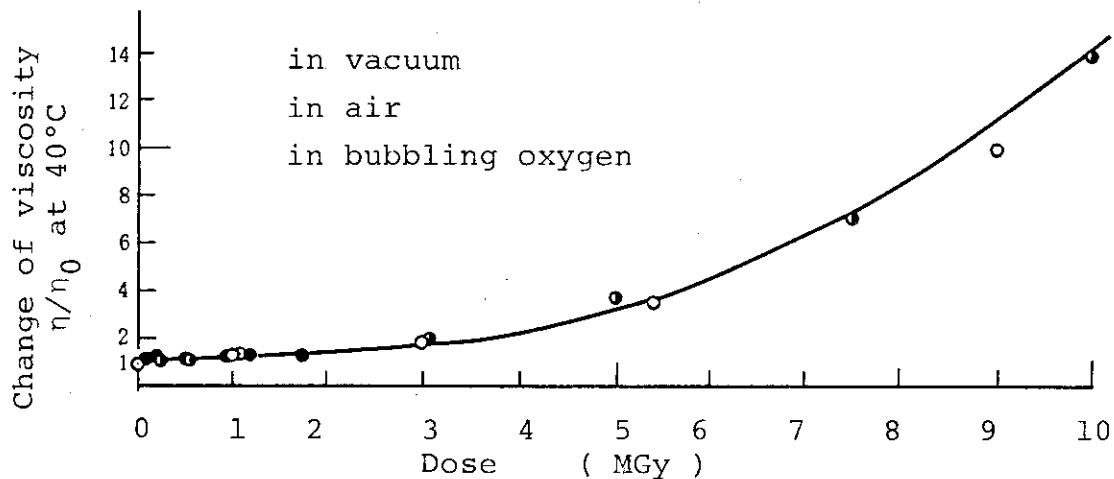
IRRADIATION CONDITION

Dose rate 10 kGy/h

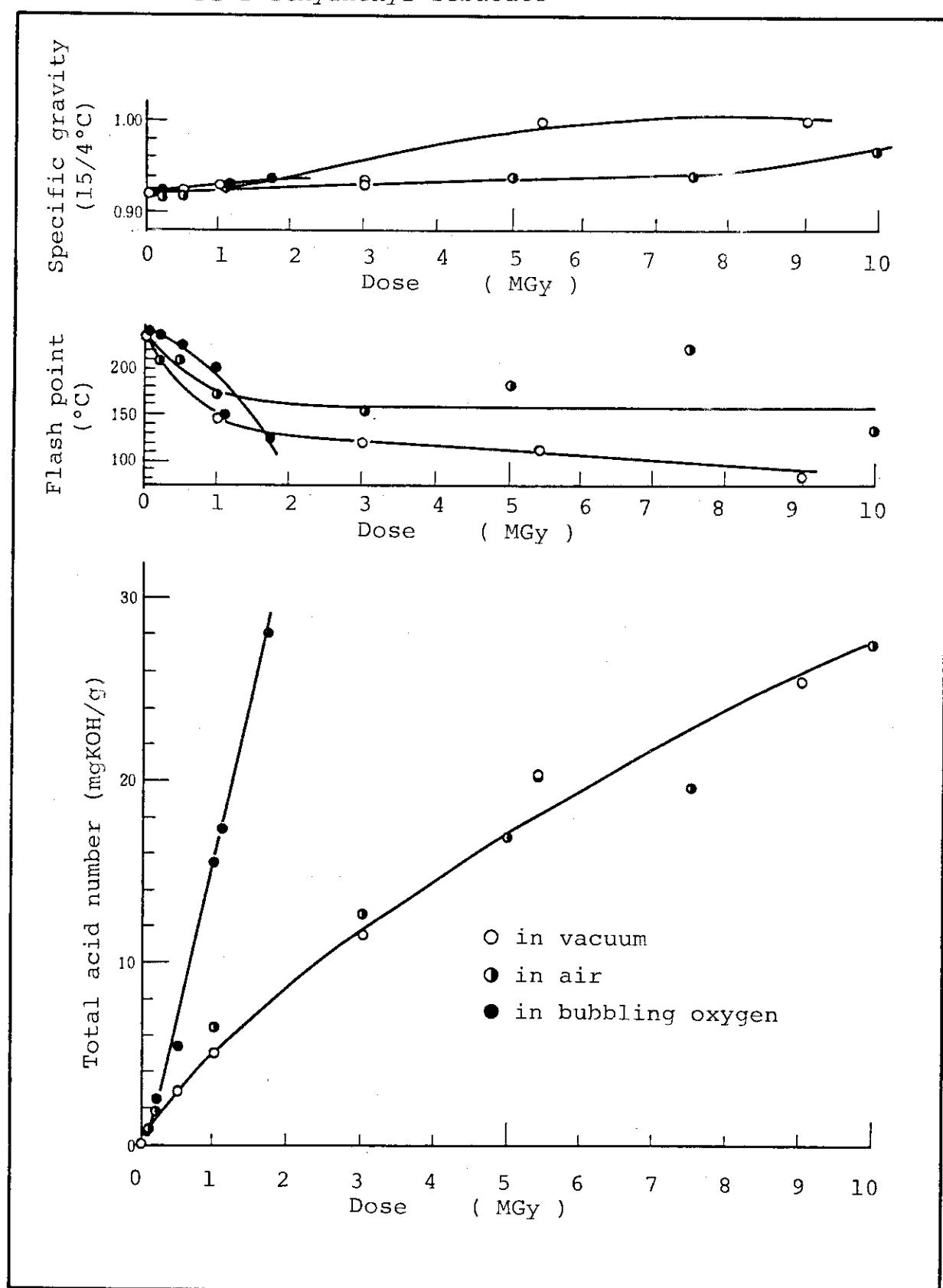
OIL NAME : Di-2-ethylhexyl sebacate

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

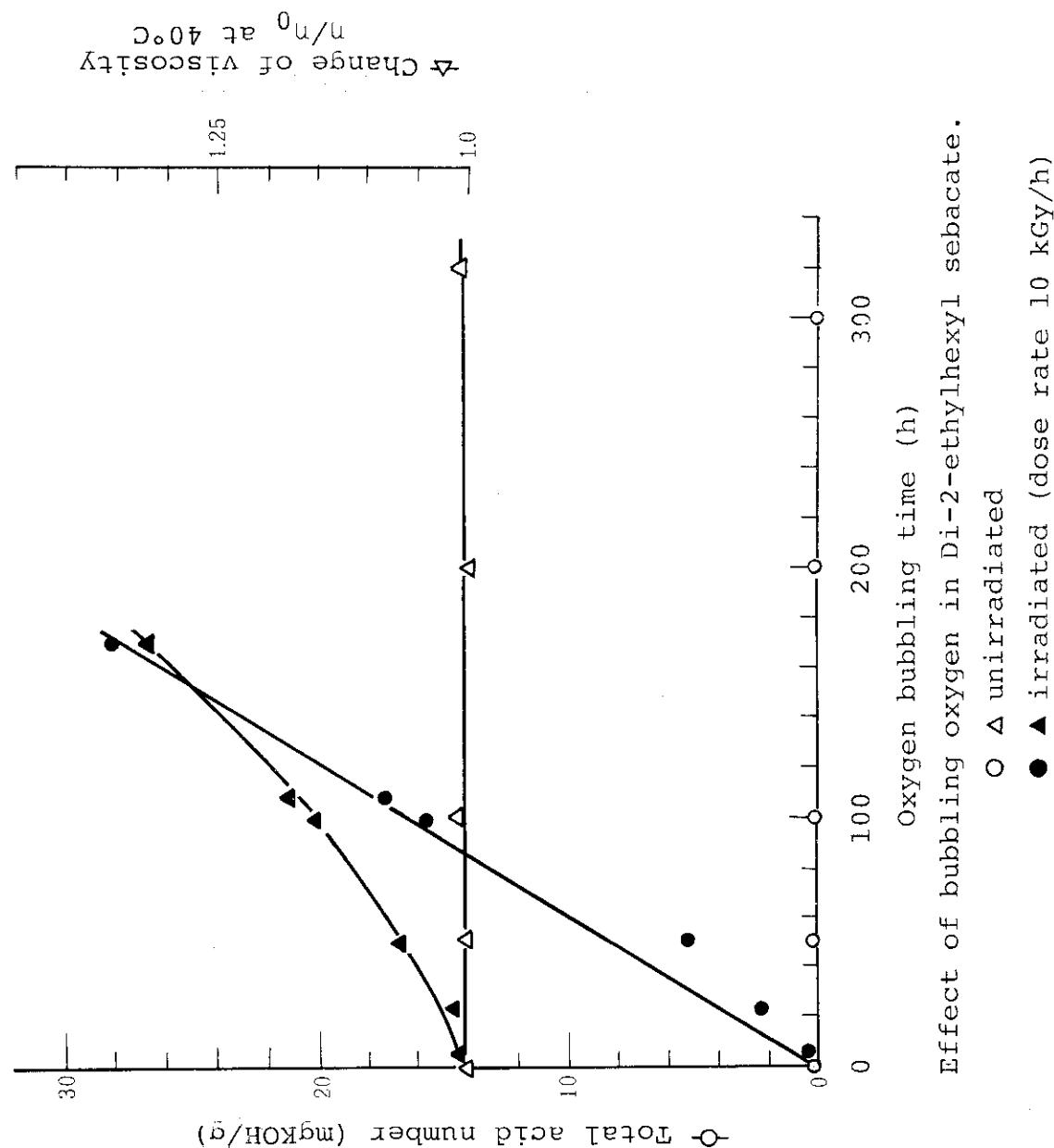
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in vacuum	1.0	154	5.04	144	1 (-)	L0.5
	3.0	158	11.5	118	1 (-)	L0.5
	5.4	163	20.4	110	1	L0.5
	9.0	162	25.4	78	1 (1/2)	L0.5
in bubbling oxygen	0.05	150	0.62	240	1 (-)	L0.5
	0.23	153	2.49	236	1 (-)	L0.5
	0.5	147	5.40	224	1 (-)	L0.5
	0.99	142	15.6	200	1 (-)	L0.5
	1.08	135	17.4	148	1 (-)	L0.5
	1.7	135	28.1	124	1 (-)	L0.5
in air	0.05	156	0.67	234	1 (-)	L0.5
	0.2	159	1.78	208	1 (-)	L0.5
	0.5	153	2.99	208	1 (-)	L0.5
	1.0	160	6.49	170	1 (-)	L0.5
	3.0	155	12.7	154	1 (-)	L0.5
	5.0	151	16.9	180	1 (-)	L0.5
	7.5	147	19.6	224	1 (1/2)	0.5
	10	146	27.5	130	1 (1/2)	L0.0



OIL NAME: Di-2-ethylhexyl sebacate



OIL NAME : Di-2-ethylhexyl sebacate

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENTIRRADIATION CONDITION

OIL NAME : Di-2-ethylhexyl sebacate

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	Viscosity (40°C)	Viscosity (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
<u>in air</u>							
20	1.0	0.920	13.82	3.584	1.21	1.12	
10	1.0	0.923	14.11	3.707	1.23	1.15	
3.0	1.0	0.923	14.26	3.663	1.25	1.14	
1.0	1.0	0.923	14.16	3.656	1.24	1.14	
0.5	1.0	0.923	13.61	3.617	1.19	1.13	
<u>in bubbling oxygen</u>							
10	0.05	0.921	11.57	3.200	1.01	1.00	
10	0.23	0.922	11.57	3.223	1.01	1.00	
10	0.5	0.923	12.24	3.298	1.07	1.03	
10	0.99	0.927	13.11	3.423	1.15	1.07	
3.0	0.05	0.917	11.54	3.190	1.01	0.99	
3.0	0.26	0.920	12.20	3.190	1.07	0.99	
3.0	0.53	0.922	12.33	3.340	1.08	1.04	
3.0	1.0	0.927	13.46	3.514	1.18	1.09	
1.0	0.05	0.919	11.34	3.197	0.99	1.00	
1.0	0.23	0.920	11.76	3.275	1.03	1.02	
1.0	0.5		12.39	3.320	1.08	1.03	
1.0	1.1	0.929	14.09	3.509	1.23	1.09	

OIL NAME: Di-2-ethylhexyl sebacate

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

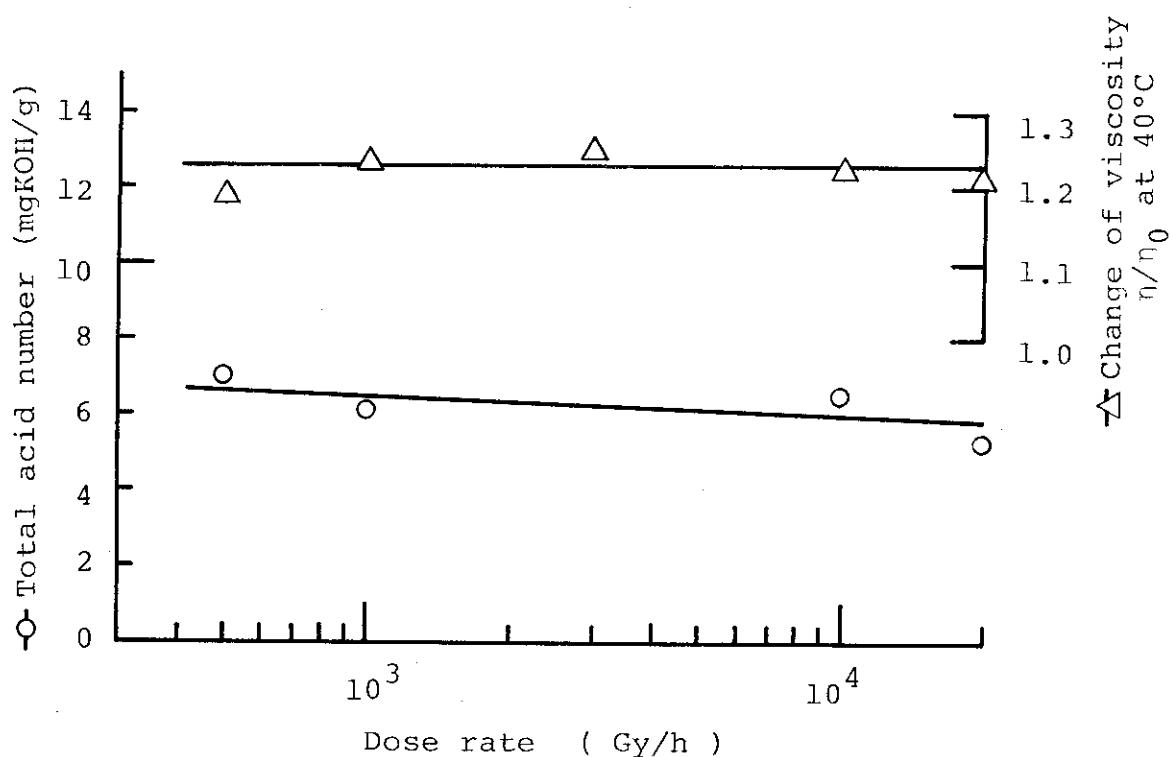
Dose rate [kGy/h]	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
<u>in air</u>						
20	1.0	148	5.23	176	1(-)	L0.5
10	1.0	160	6.49	170	1(-)	L0.5
3.0	1.0	149	15.3	176	1(-)	L0.5
1.0	1.0	151	6.27	182	1(-)	L0.5
0.5	1.0	159	6.96	182	1(-)	L0.5
<u>in bubbling oxygen</u>						
10	0.05	150	0.62	240	1(-)	L0.5
10	0.23	153	2.49	236	1(-)	L0.5
10	0.5	147	5.40	224	1(-)	L0.5
10	0.99	142	15.6	200	1(-)	L0.5
3.0	0.05	149	0.01	212	1(-)	L0.5
3.0	0.26	130	3.47	208	1(-)	L0.5
3.0	0.53	151	7.69	186	1(-)	L0.5
3.0	1.0	147	15.4	170	1(-)	L0.5
1.0	0.05	157	0.97	210	1(-)	L0.5
1.0	0.23	157	3.82	208	1(-)	L0.5
1.0	0.5	146	8.00	178	1(-)	L0.5
1.0	1.1	131	17.4	158	1(-)	L0.5

OIL NAME : Di-2-ethylhexyl sebacate

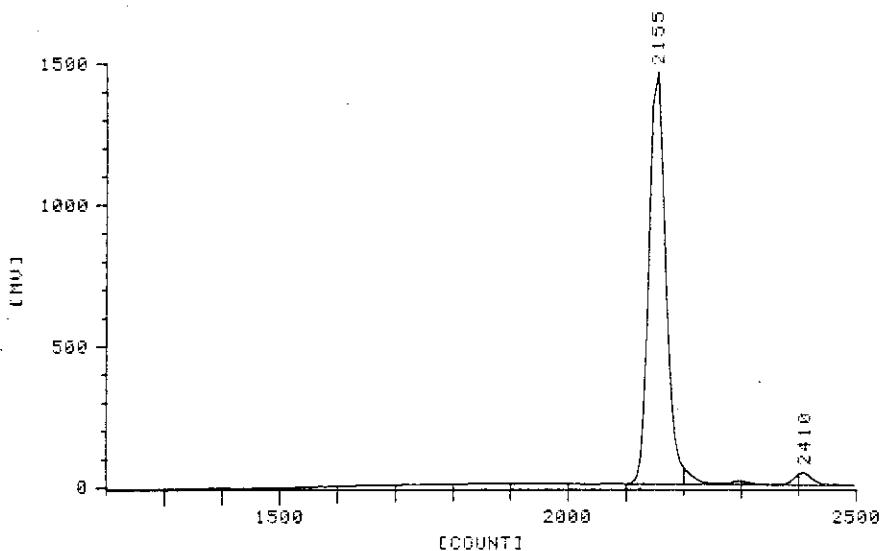
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

DOSE RATE EFFECT

(in air, total dose 1 MGy)

COMMENTIRRADIATION CONDITION

OIL NAME: Di-2-ethylhexyl sebacate

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/08 13:39 JOB FILE 1

SAMPLE NO. 0 NAME: 4-1 SERIAL NO. 0040

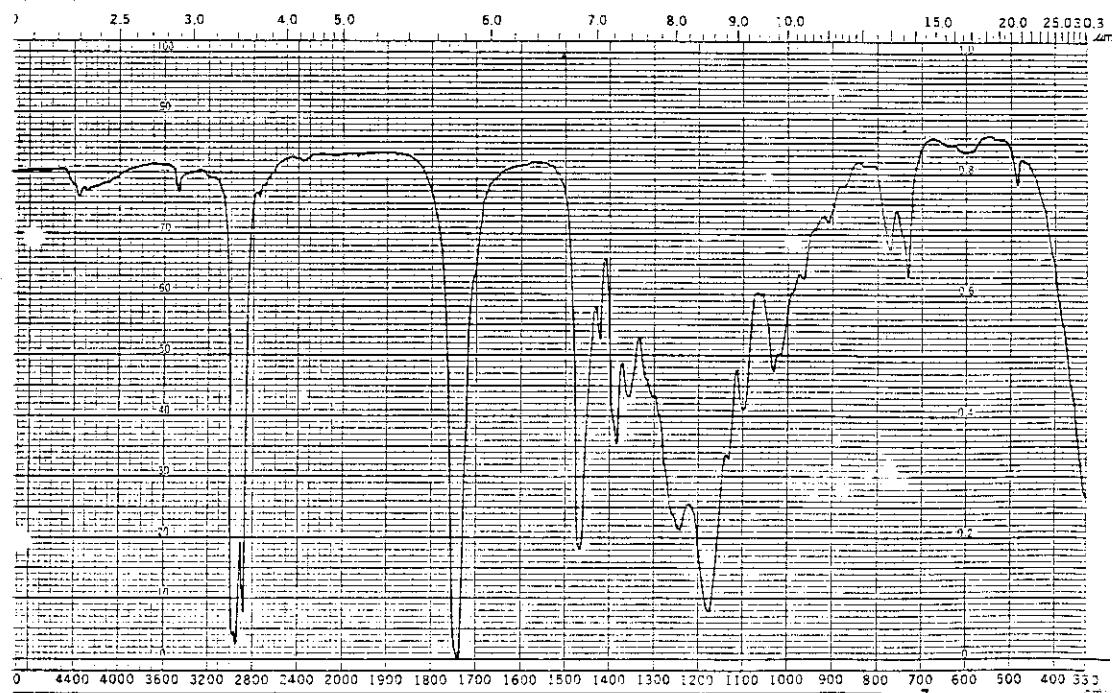
CH.NO 1 METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2095	2155	2260	5.78138E+02	5.78665E+02	5.79179E+02	5.78663E+02	
V	9.4	1472.9	7.8	MW/MN	MZ/MW	AREA	AREAX	
M	656	579	483	1.00	1.00	5.11252E+04	96.19	

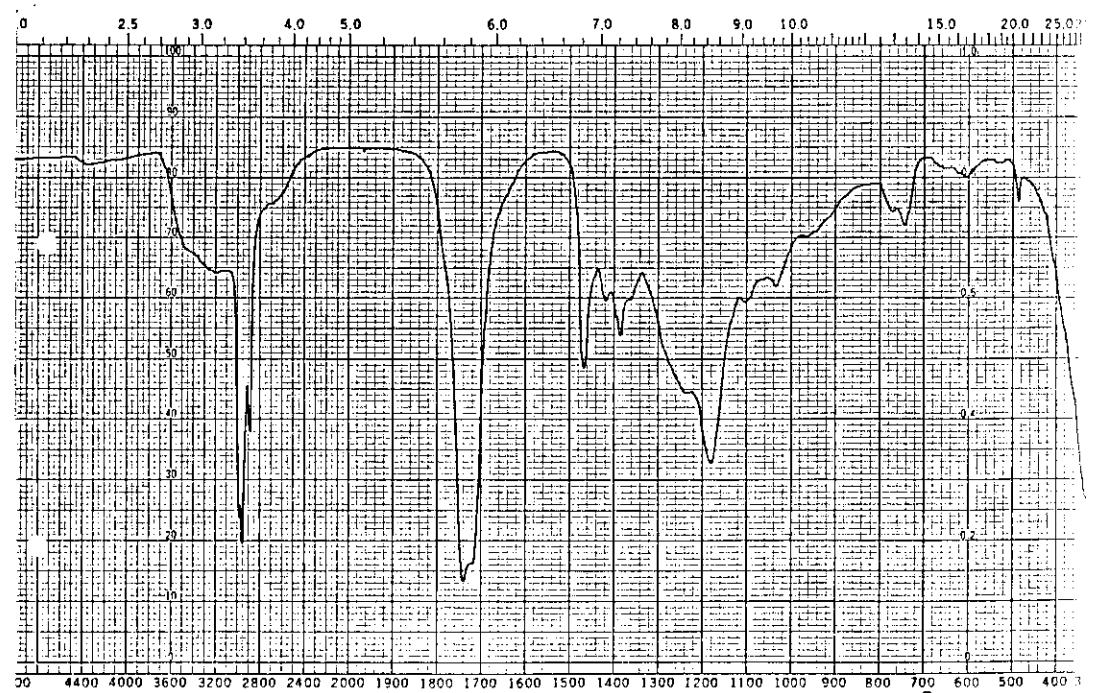
PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2260	2410	2495	3.76214E+02	3.81532E+02	3.85167E+02	3.81531E+02	
V	7.8	49.8	3.6	MW/MN	MZ/MW	AREA	AREAX	
M	483	365	296	1.01	1.01	2.02367E+03	3.81	

TOTAL	START	TOP	END	MN	MW	MZ	MU
C	2095	2155	2495	5.66731E+02	5.71159E+02	5.74244E+02	5.71157E+02
V	9.4	1472.9	3.6	MW/MN	MZ/MW	AREA	AREAX
M	656	579	296	1.01	1.01	5.31489E+04	100.00

OIL NAME: Di-2-ethylhexyl sebacate

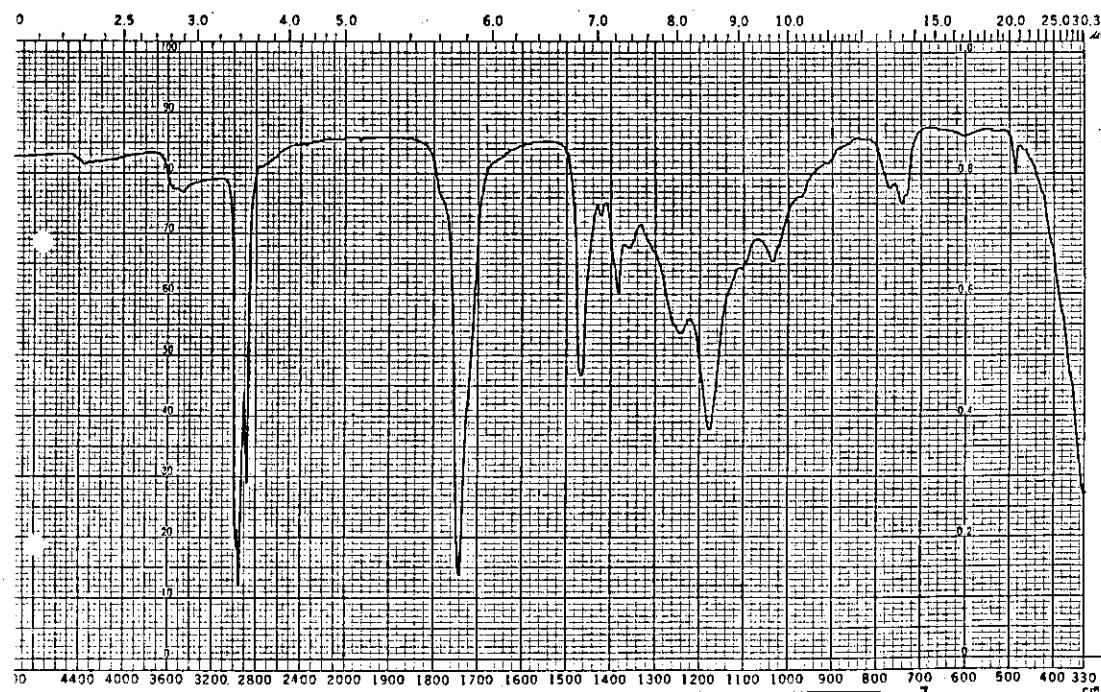


The infrared spectrum of Di-2-ethylhexyl sebacate
(original)



Infrared apectrum (10 MGy in bubbling oxygen)

OIL NAME: Di-2-ethylhexyl sebacate



The infrared spectrum (in vacuum, 10 MGy)

OIL NAME : Di-2-ethylhexyl sebacate

IRRADIATION CONDITION

Temp.: -196°C Dose 10.8 kGy in Vacuum

after irradiation

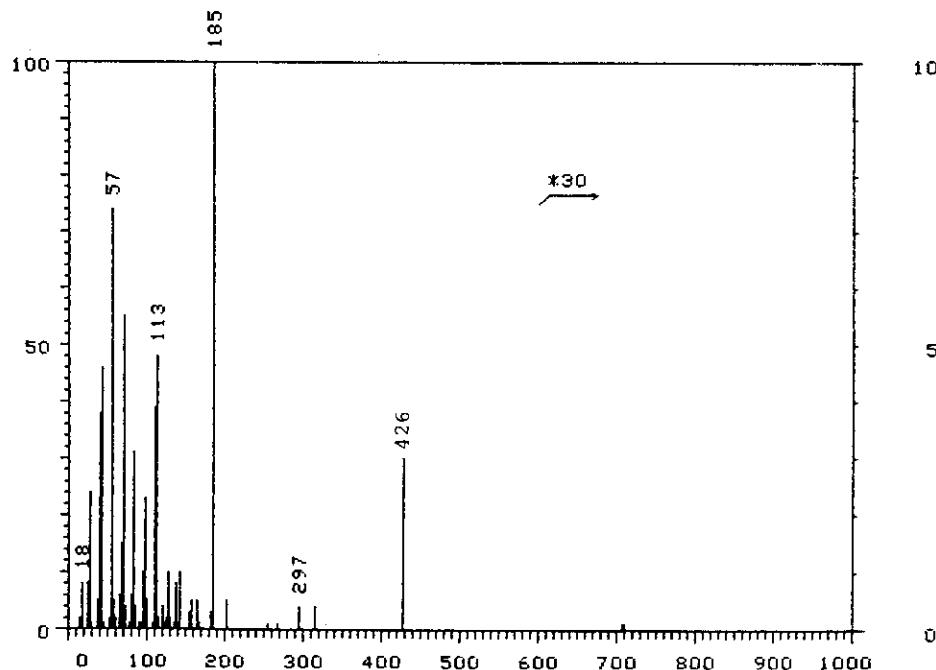
after photo breach

— 50 —

ESR CONDITION Sweep range(Gauss): \pm 250 Power(μ W): 1
 Modulation width(100kHz, Gauss): 2 at -196°C

<u>G[R.]</u>	<u>after irradiation</u>	<u>after Photo breach</u>
	4.0	2.15

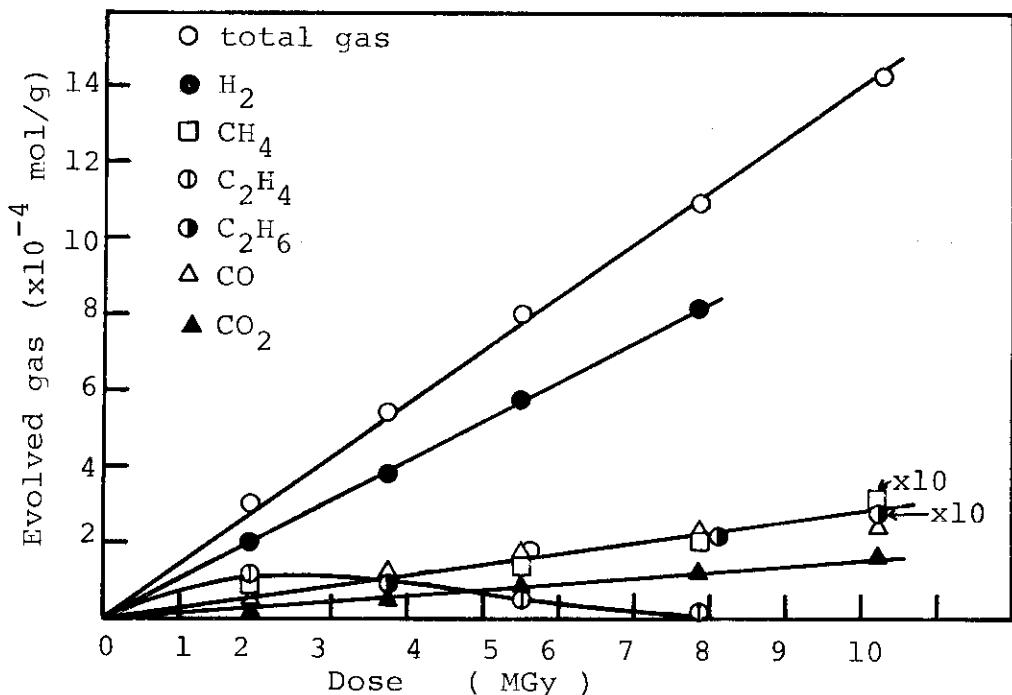
OU NAME: Di-2-ethylhexyl sebacate



(original)

The mass spectrum of Di-2-ethylhexyl sebacate.

OIL NAME : Di-2-ethylhexyl sebacate

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	1.5	$G(C_2H_6)$	2.7×10^{-2}
$G(H_2)$	9.9×10^{-1}	$G(C_2H_4)$	5.7×10^{-3}
$G(CH_4)$	2.6×10^{-2}		
$G(CO)$	3.4×10^{-1}		
$G(CO_2)$	1.5×10^{-1}		

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	1.5
5 MGy	7.3
10 MGy	14.0

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h

OIL NAME: Di-2-ethylhexyl adipate

STRUCTURE OR FEATURE: ROOC(CH₂)₄COOR, R:C₄H₉(C₂H₅)CHCH₂-

MOLECULAR WEIGHT: 370

VISCOSITY at 40°C: 7.616x10⁻⁶ m²/s (2.328x10⁻⁶ m²/s at 100°C)

VISCOSITY INDEX: 126 SPECIFIC GRAVITY(15/4°C): 0.930

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 214

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

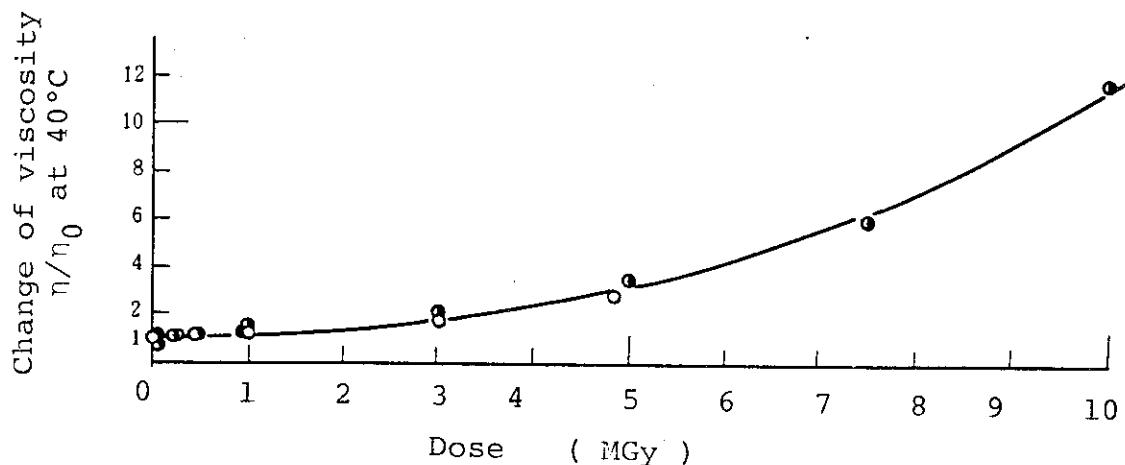
Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity ηx10 ⁻⁶ m ² /s (40°C)	Viscosity ηx10 ⁻⁶ m ² /s (100°C)	n/n ₀ (40°C)	n/n ₀ (100°C)
in vacuum	1.0	0.932	9.093	2.595	1.19	1.11
	3.0	0.937	13.25	3.290	1.74	1.41
	4.8	0.941	20.05	4.320	2.63	1.86
in bubbling oxygen	0.05	0.931	7.779	2.324	1.02	1.00
	0.23	0.933	7.783	2.350	1.02	1.01
	0.5	0.935	8.337	2.439	1.09	1.05
	0.99	0.940	8.931	2.465	1.17	1.06
in air	0.05	0.929	7.504	2.414	0.99	1.04
	0.2	0.931	7.940	2.389	1.04	1.03
	0.5	0.931	8.284	2.397	1.09	1.03
	1.0	0.934	9.301	2.627	1.22	1.13
	3.0	0.944	15.13	3.625	1.99	1.56
	5.0	0.953	26.94	5.197	3.54	2.23
	7.5	0.959	45.36	7.456	5.96	3.20
	10	0.959	88.75	11.58	11.7	4.97

IRRADIATION CONDITION

OIL NAME : Di-2-ethylhexyl adipate

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

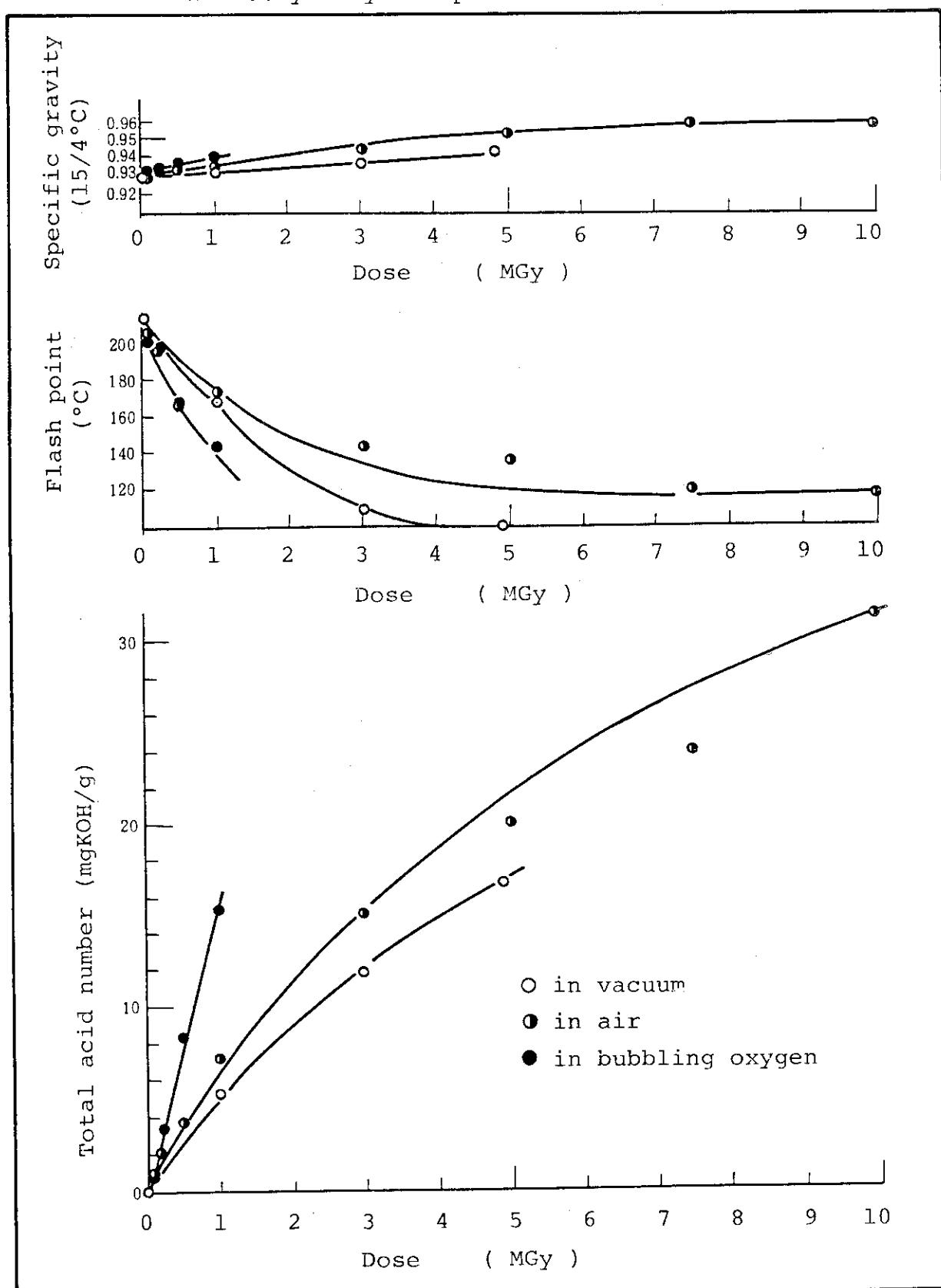
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	121	5.31	108	1(-)	L0.5
	3.0	119	11.80	108	1(-)	L0.5
	4.8	125	16.48	100	1(-)	L0.5
in bubbling oxygen	0.05	114	0.69	200	1(-)	L0.5
	0.23	122	3.34	198	1(-)	L0.5
	0.5	107	8.26	168	1(-)	L0.5
	0.99	98	15.4	144	1(-)	L0.5
in air	0.05	157	0.88	206	1(-)	L0.5
	0.2	125	2.14	196	1(-)	L0.5
	0.5	110	3.70	166	1(-)	L0.5
	1.0	120	7.22	174	1(-)	L0.5
	3.0	126	15.1	144	1(-)	L0.5
	5.0	126	20.0	136	1(-)	L0.5
	7.5	129	23.9	118	1(1/2)	L1.0
	10	120	31.2	116	1(1/2)	L1.0



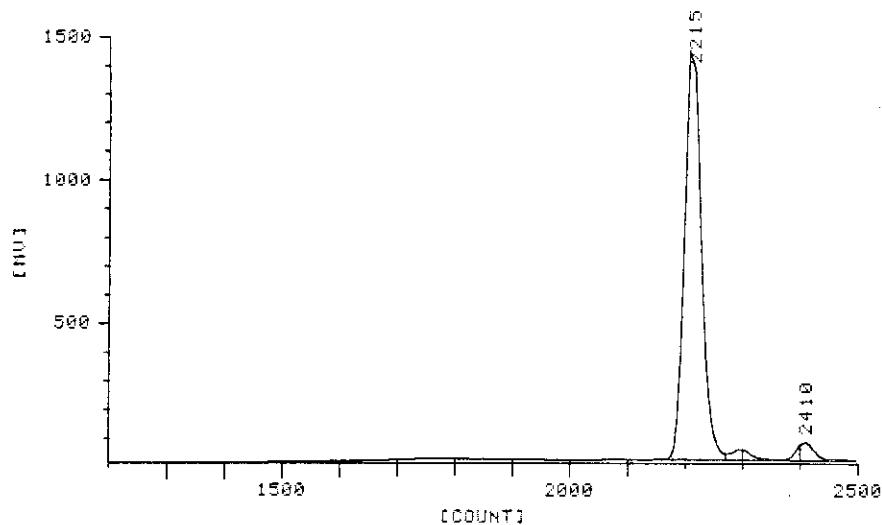
Symbol:

○ in vacuum, ● in air, • in bubbling oxygen.

OIL NAME: Di-2-ethylhexyl adipate



OIL NAME: Di-2-ethylhexyl adipate

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/03 15:43 JOB FILE 1

SAMPLE NO. 0 NAME: 4-2 SERIAL NO. 8843

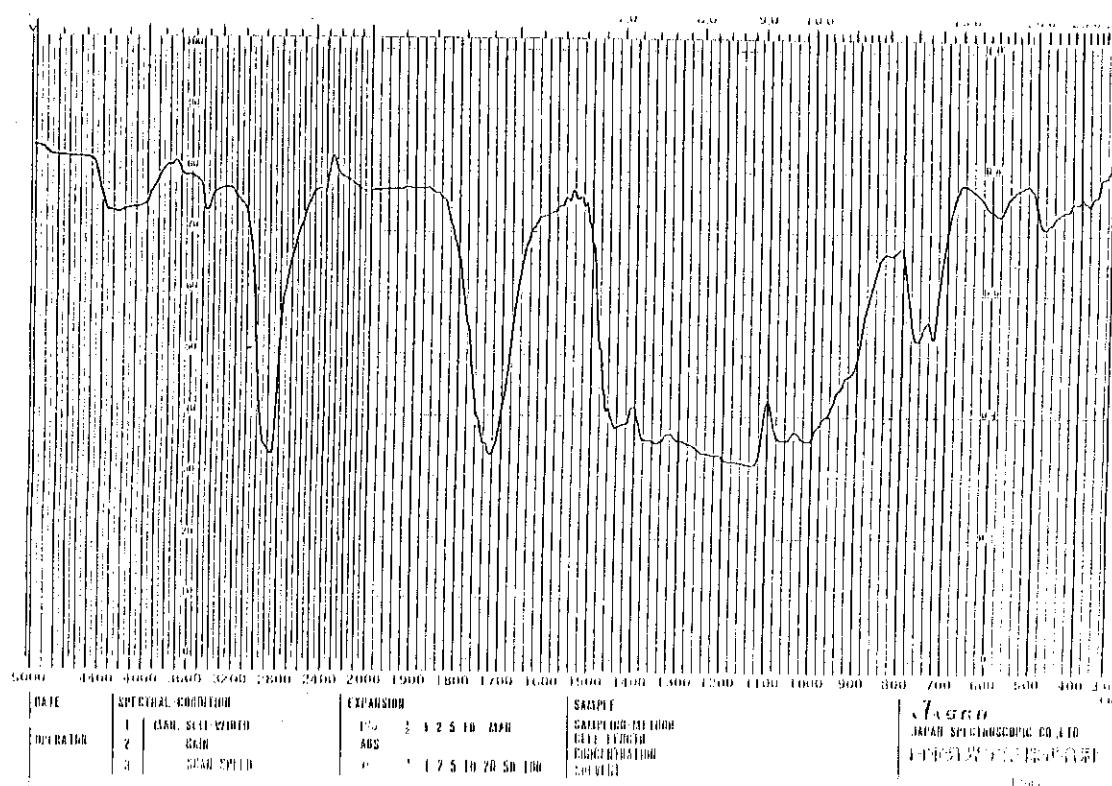
CH.NO 1 METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2155	2215	2270	5.22370E+02	5.22675E+02	5.22977E+02	5.22673E+02	
V	26.7	1387.9	43.8	MW/MN	MZ/MW	AREA	AREAN	
M	579	520	475	1.00	1.00	4.94941E+04	93.13	

PEAK NO.	VALLEY	START	TOP	END	MN	MW	MZ	MU
C	2270	2410	2495	3.94482E+02	3.99531E+02	4.04741E+02	3.99530E+02	
V	43.8	87.1	23.2	MW/MN	MZ/MW	AREA	AREAN	
M	475	365	296	1.01	1.01	3.64925E+03	6.87	

TOTAL	START	TOP	END	MN	MW	MZ	MU
C	2155	2215	2495	5.10995E+02	5.14219E+02	5.16668E+02	5.14217E+02
V	26.7	1387.9	23.2	MW/MN	MZ/MW	AREA	AREAN
M	579	520	296	1.01	1.00	5.31434E+04	100.00

OIL NAME: Di-2-ethylhexyl adipate



Infrared spectrum (original)

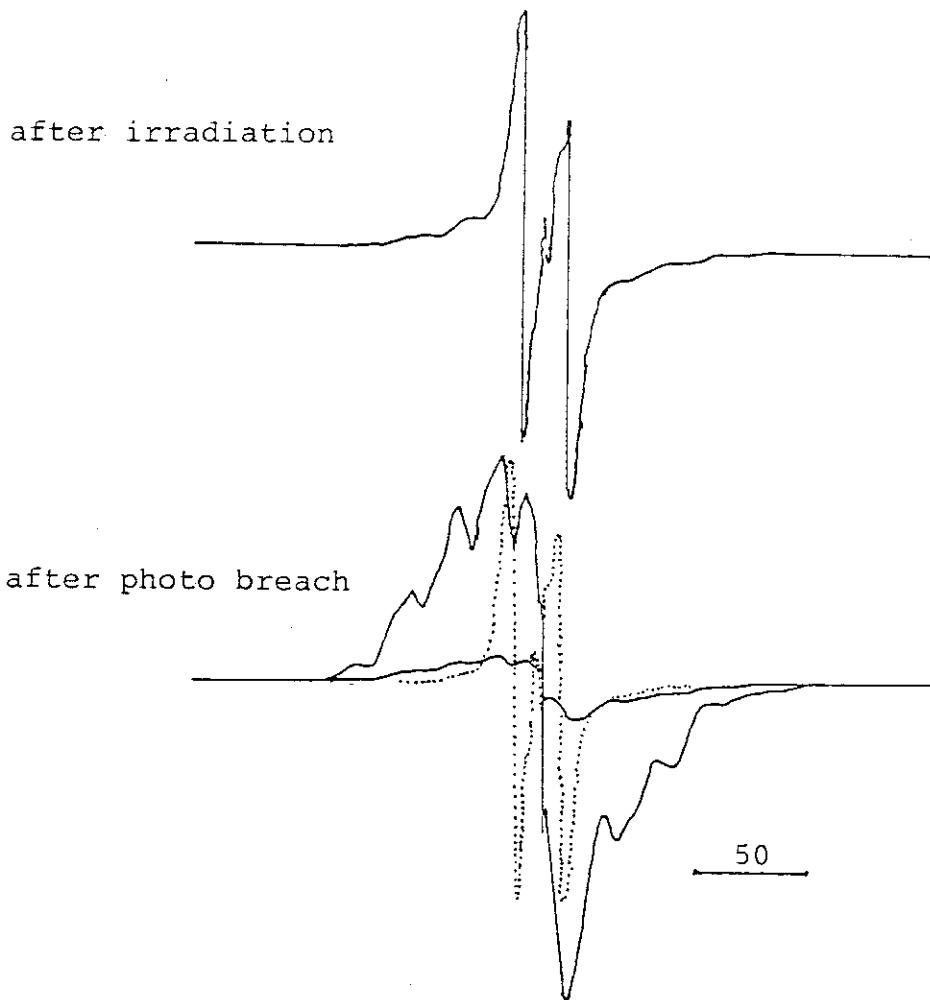
OIL NAME : Di-2-ethylhexyl adipate

IRRADIATION CONDITION

Temp.: -196°C

Dose 10.8kGy

in Vacuum

ESR CONDITIONSweep range(Gauss): \pm 250 Power(μ W): 1

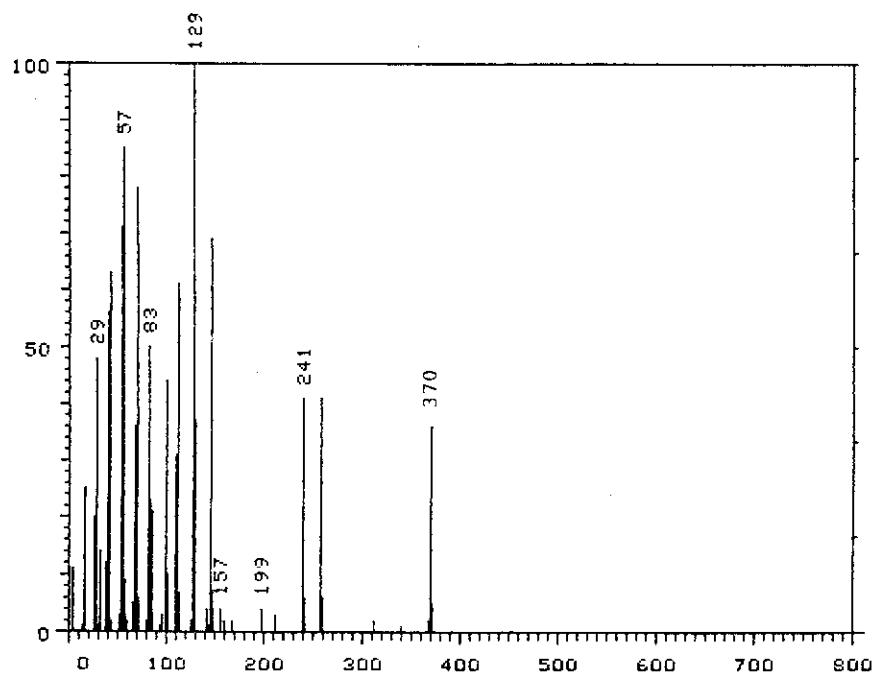
Modulation width(100kHz, Gauss): 2 at -196°C

G[R.]after irradiationafter Photo breach

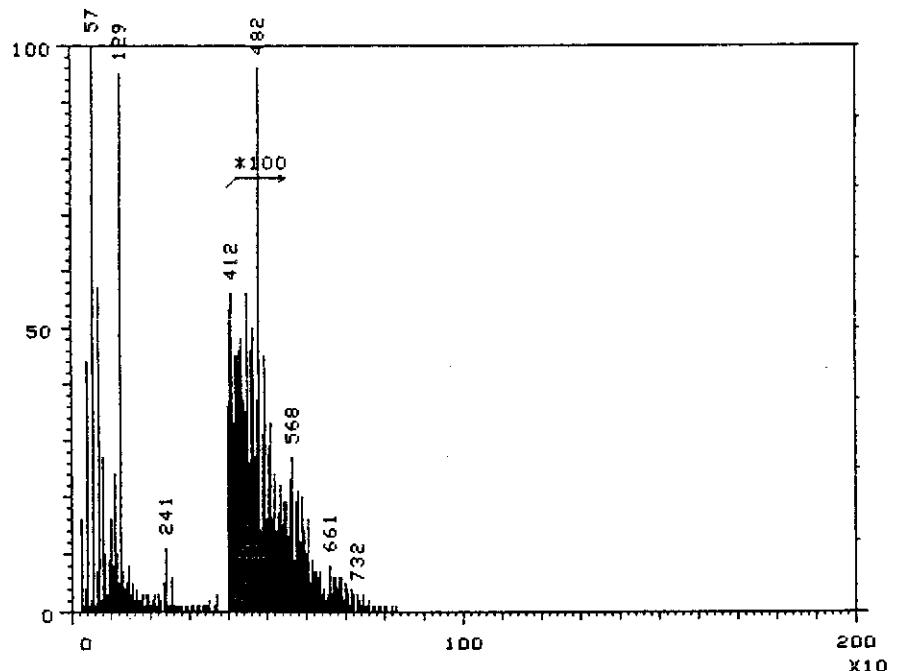
3.5

2.0

OIL NAME: Di-2-ethylhexyl adipate



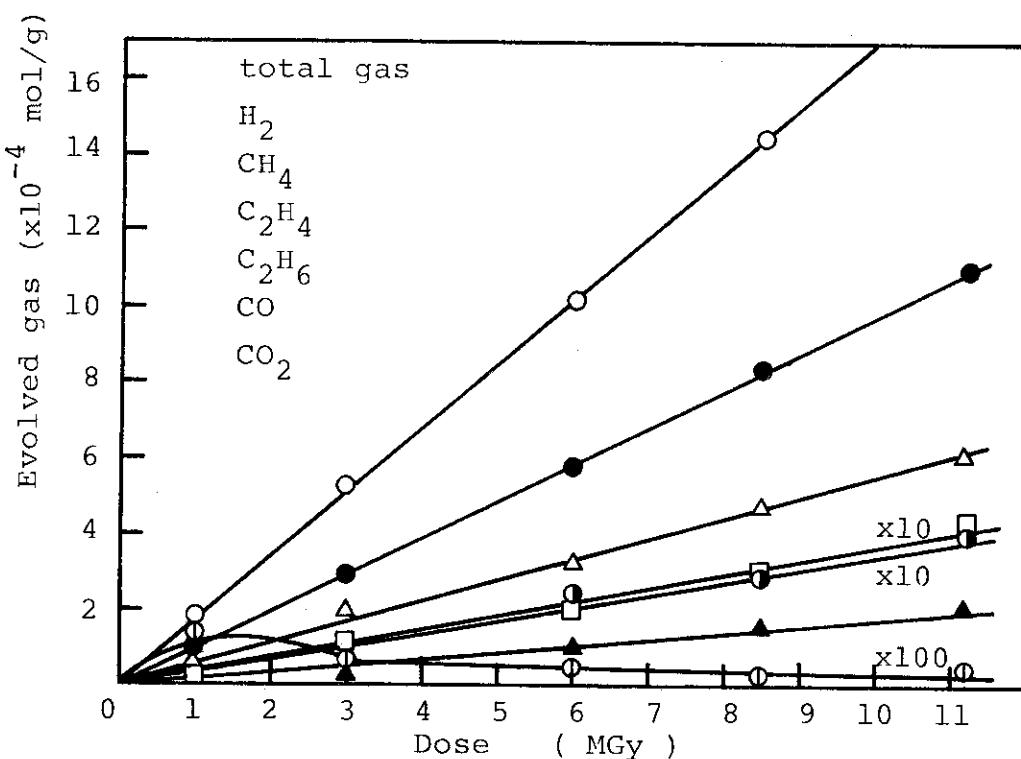
(original)



(10 MGy in vacuum)

The mass spectrum of Di-2-ethylhexyl adipate.

OIL NAME : Di-2-ethylhexyl adipate

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	1.7	$G(C_2H_6)$	3.7×10^{-2}
$G(H_2)$	9.3×10^{-1}	$G(C_2H_4)$	9.7×10^{-4}
$G(CH_4)$	3.7×10^{-2}		
$G(CO)$	5.4×10^{-1}		
$G(CO_2)$	1.8×10^{-1}		

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	1.8
5 MGy	8.6
10 MGy	17.4

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h

OIL NAME: Pentaerythritol ester

STRUCTURE OR FEATURE: $C(CH_2OOCR)_4$, R: $C_4H_9(C_2H_5)CH-$

MOLECULAR WEIGHT: 640

VISCOSITY at 40°C: $42.97 \times 10^{-6} \text{ m}^2/\text{s}$ ($6.162 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: 85 SPECIFIC GRAVITY(15/4°C): 0.964

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 240

COLOR: UNION 1(-), ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

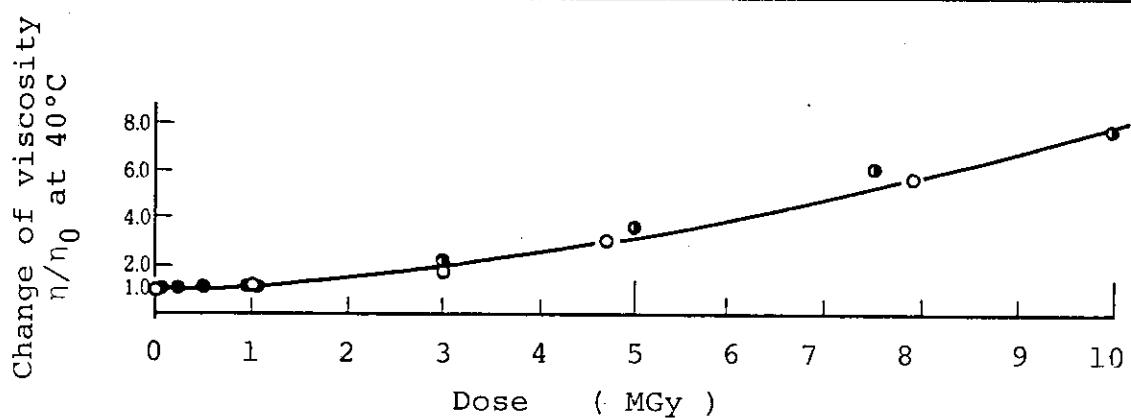
Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$	η/η_0	
		(15/4°C)	(40°C)	(100°C)	(40°C)
in vacuum	1.0	0.980	51.05	6.951	1.19 1.13
	3.0	0.978	74.22	8.846	1.73 1.44
	4.7	0.980	129.9	13.17	3.02 2.14
	7.9	0.985	241.0	21.05	5.61 3.42
in bubbling oxygen	0.05	0.967	43.99	6.244	1.02 1.01
	0.23	0.973	45.53	6.271	1.06 1.02
	0.5	0.972	47.72	6.452	1.11 1.05
	0.99	0.977	52.04	6.599	1.21 1.07
in air	0.05	0.967	43.43	6.107	1.01 0.99
	0.20	0.967	44.50	6.353	1.04 1.03
	0.5	0.968	47.34	6.560	1.10 1.06
	1.0	0.972	53.05	7.047	1.23 1.14
	3.0	0.983	90.10	9.882	2.10 1.60
	5.0	0.987	156.4	14.17	3.64 2.30
	7.5	0.988	258.6	19.32	6.02 3.14
	10	1.001	326.8	28.65	7.61 4.65

IRRADIATION CONDITION

OIL NAME : Pentaerythritol ester

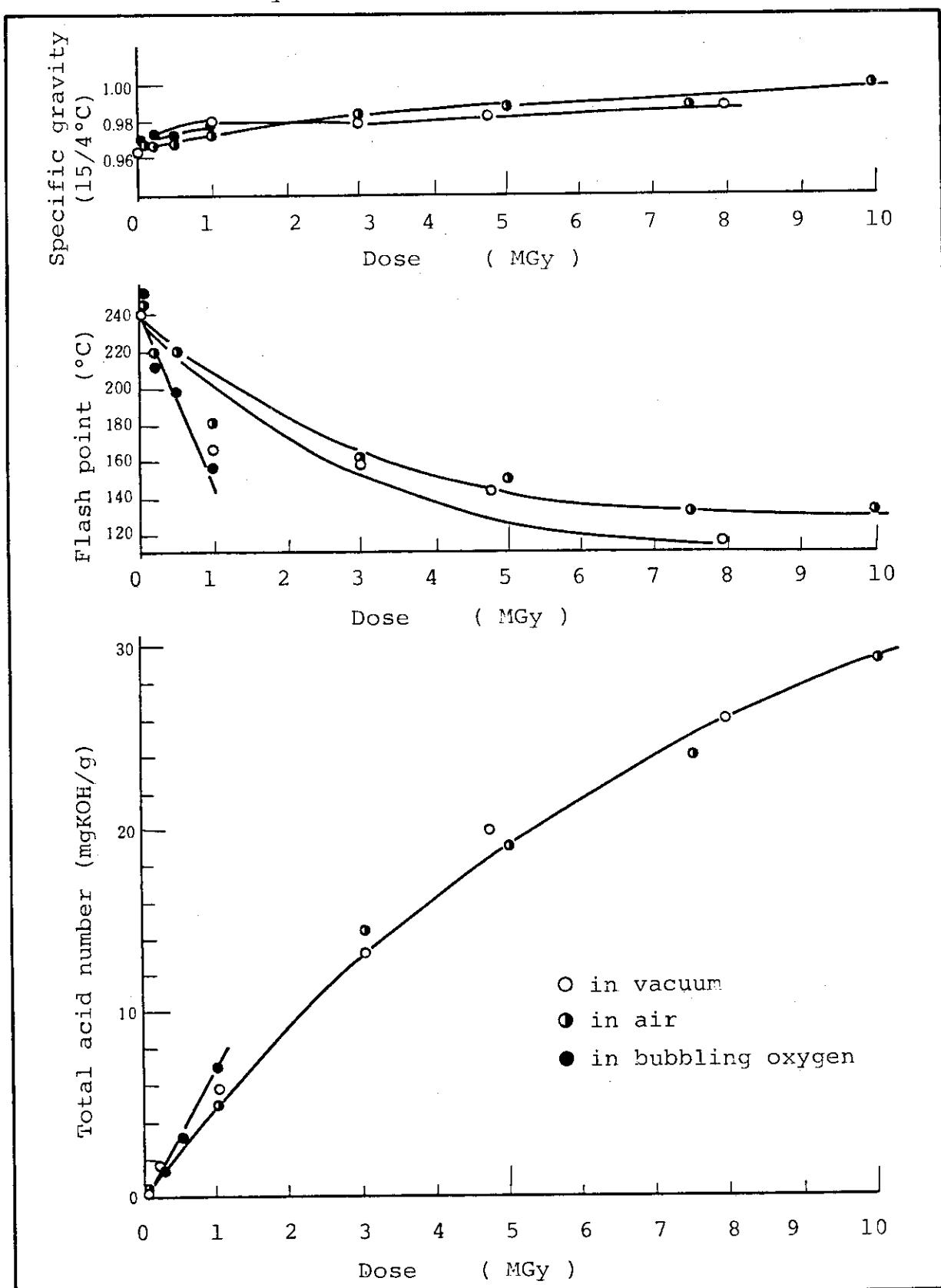
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	90	5.89	166	1 (-)	L0.5
	3.0	90	13.2	158	1 (-)	L0.5
	4.7	95	19.9	142	1 (1/2)	0.5
	7.9	103	25.9	116	2 (-)	1.5
in bubbling oxygen	0.05	84	0.34	252	1 (-)	L0.5
	0.23	79	1.39	212	1 (-)	L0.5
	0.5	79	3.14	198	1 (-)	L0.5
	0.99	69	6.97	156	1 (-)	L0.5
in air	0.05	80	0.49	246	1 (-)	L0.5
	0.2	87	1.65	220	1 (-)	L0.5
	0.5	86	3.19	220	1 (-)	L0.5
	1.0	86	4.91	182	1 (-)	L0.5
	3.0	86	14.5	162	1 (-)	L0.5
	5.0	86	19.0	150	1 (-)	L0.5
	7.5	83	24.0	132	1 (1/2)	0.5
	10	119	29.1	132	1 (1/2)	L1.0

IRRADIATION CONDITION

Dose rate 10 kGy/h

OIL NAME: Pentaerytheitol ester



OIL NAME: Pentaerythritol ester

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	(40°C)	(100°C)	η/η_0 (40°C)	(100°C)
<u>in air</u>							
20	1.0	0.970	51.95	7.046	1.21	1.14	
10	1.0	0.972	53.05	7.047	1.23	1.14	
5.0	1.0	0.971	53.84	7.133	1.25	1.16	
1.0	1.0	0.971	52.61	7.105	1.22	1.15	
0.5	1.0	0.971	51.71	6.950	1.20	1.13	

OIL NAME: Pentaerythritol ester

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

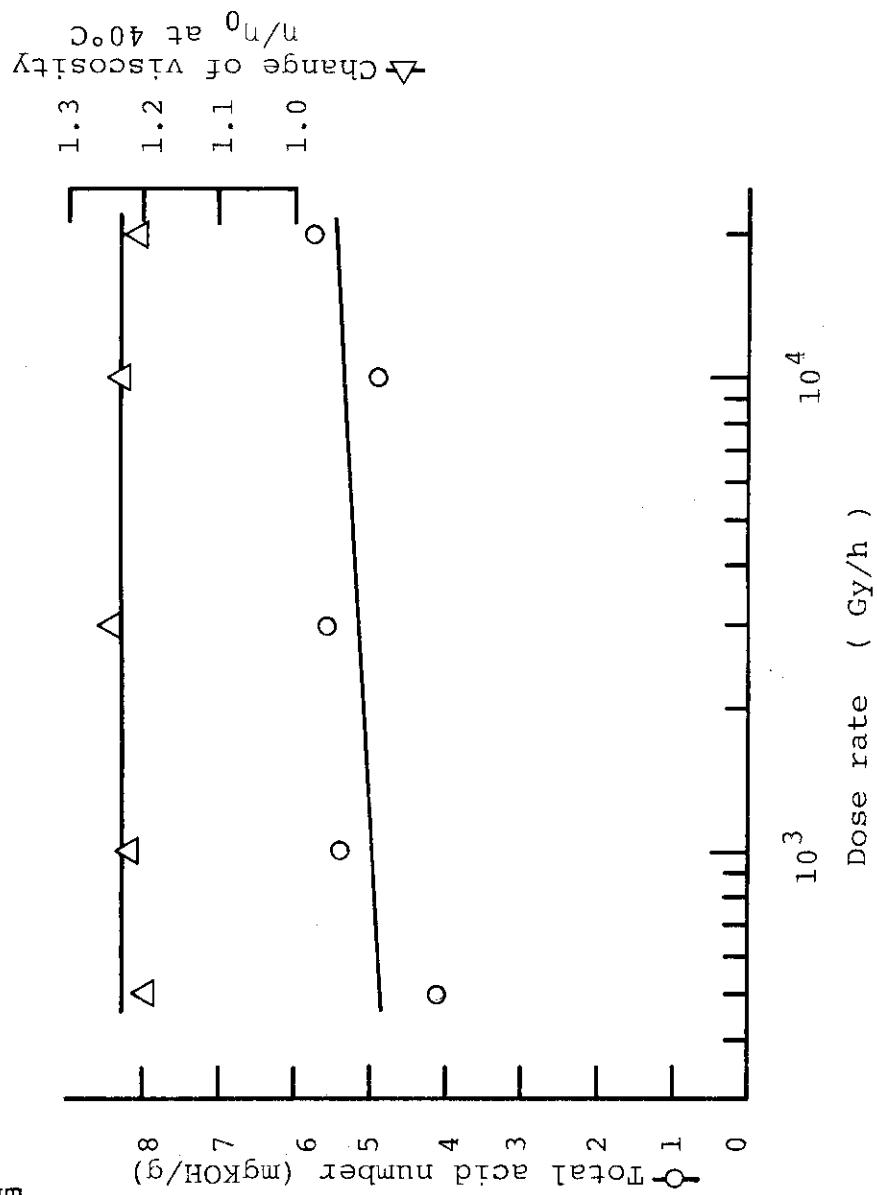
Dose rate [kGy/h]	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
<u>in air</u>						
20	1.0	91	5.75	196	1(-)	L0.5
10	1.0	87	4.91	182	1(-)	L0.5
5.0	1.0	87	5.55	194	1(-)	L0.5
1.0	1.0	91	5.43	196	1(-)	L0.5
0.5	1.0	87	4.11	226	1(-)	L0.5

OIL NAME :Pentaerythritol ester

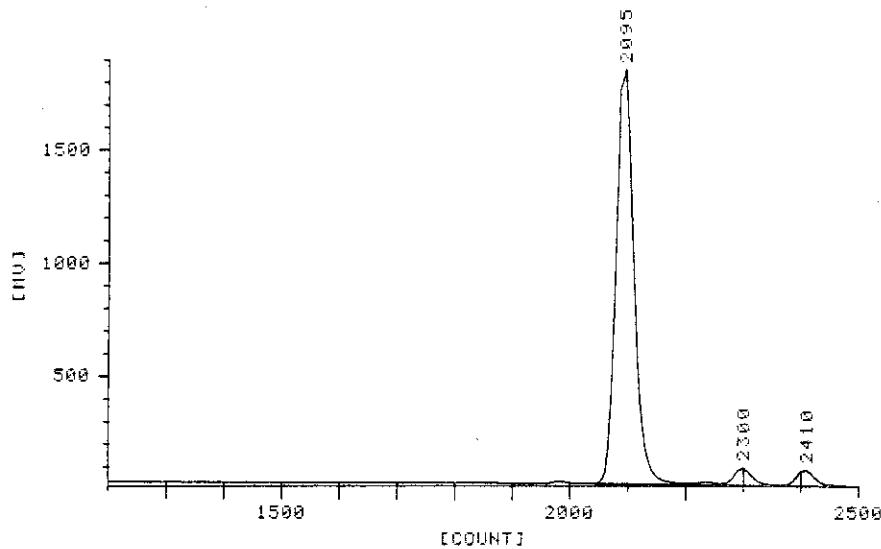
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

DOSE RATE EFFECT

(in air, total dose 1 MGy)

COMMENTIRRADIATION CONDITION

OIL NAME: Pentaerythritol ester

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/06 16:31 JOB FILE 1

SAMPLE NO. 0 NAME: 5-O SERIAL NO. 0044

CH.NO 1 METHOD 2

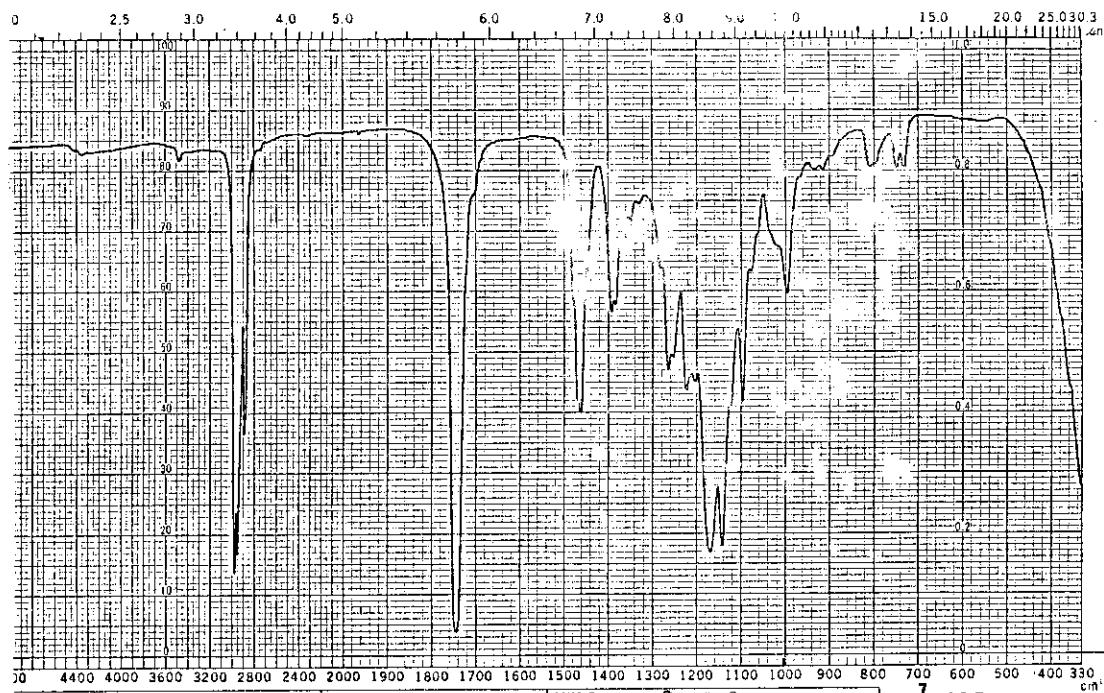
PEAK NO. 1 BASE		START	TOP	END	MN	MW	MZ	MU
C	2040	2095	2205	6.56172E+02	6.57034E+02	6.57877E+02	6.57032E+02	
V	24.0	1856.7	22.6	MW/MN	MZ/MW	AREA	AREAN%	
M	757	656	529	1.00	1.00	6.62744E+04	92.27	

PEAK NO. 2 VALLEY		START	TOP	END	MN	MW	MZ	MU
C	2295	2300	2360	4.56247E+02	4.57134E+02	4.58068E+02	4.57133E+02	
V	22.6	92.9	17.4	MW/MN	MZ/MW	AREA	AREAN%	
M	529	451	405	1.00	1.00	2.98319E+03	4.15	

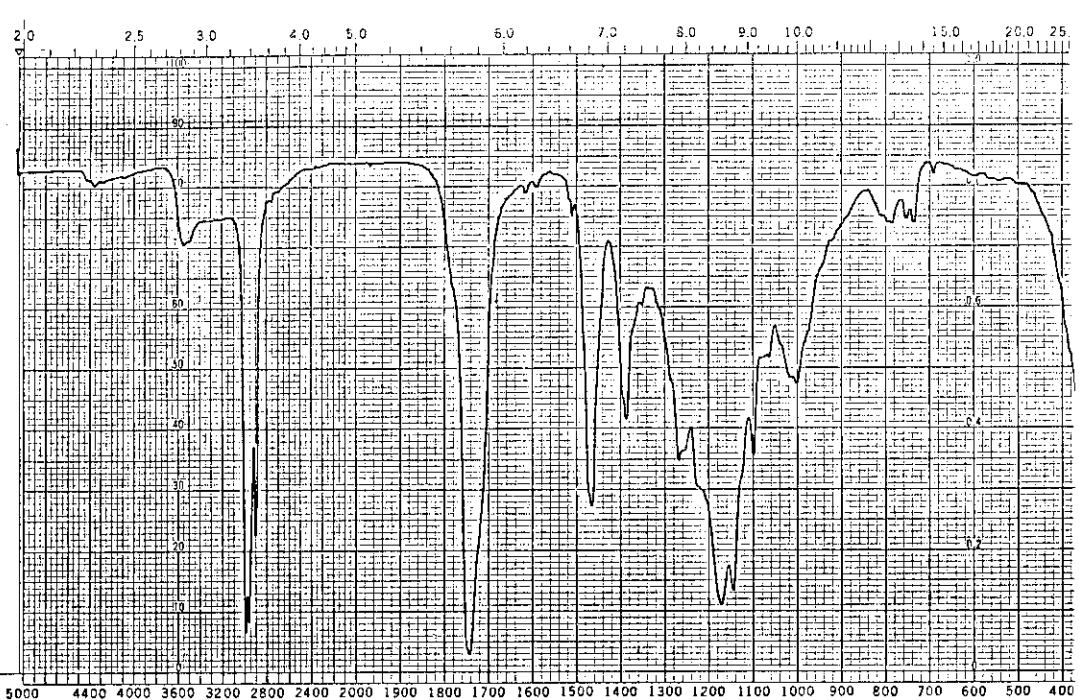
PEAK NO. 3 BASE		START	TOP	END	MN	MW	MZ	MU
C	2360	2410	2495	3.64350E+02	3.64906E+02	3.65439E+02	3.64906E+02	
V	17.4	84.6	12.4	MW/MN	MZ/MW	AREA	AREAN%	
M	405	365	296	1.00	1.00	2.56849E+03	3.58	

TOTAL		START	TOP	END	MN	MW	MZ	MU
C	2040	2095	2495	6.26811E+02	6.38285E+02	6.45955E+02	6.38283E+02	
V	24.0	1856.7	12.4	MW/MN	MZ/MW	AREA	AREAN%	
M	757	656	296	1.02	1.01	7.18261E+04	100.00	

OIL NAME: Pentaerythritol ester

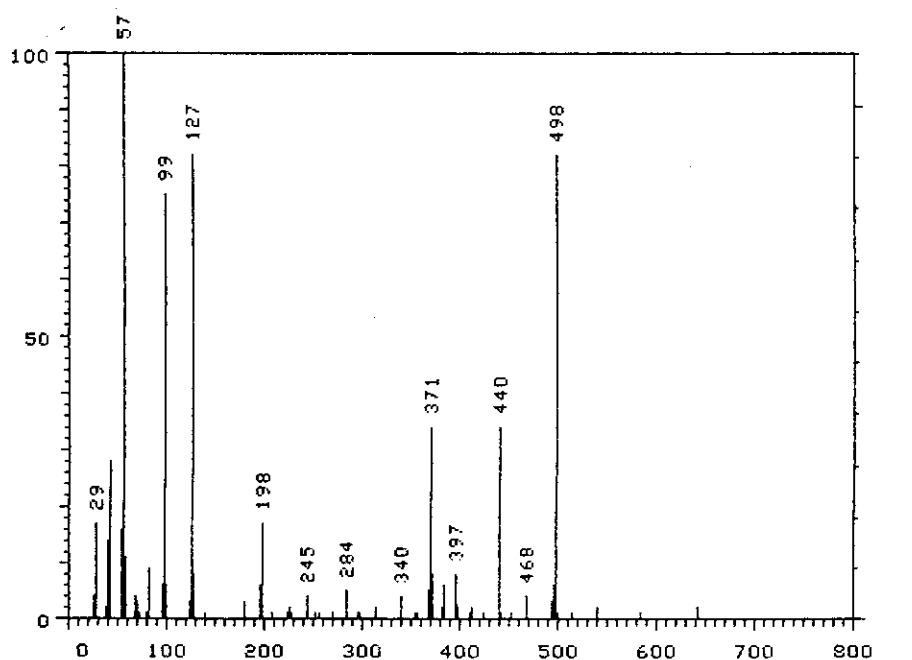


Infrared spectrum (original)

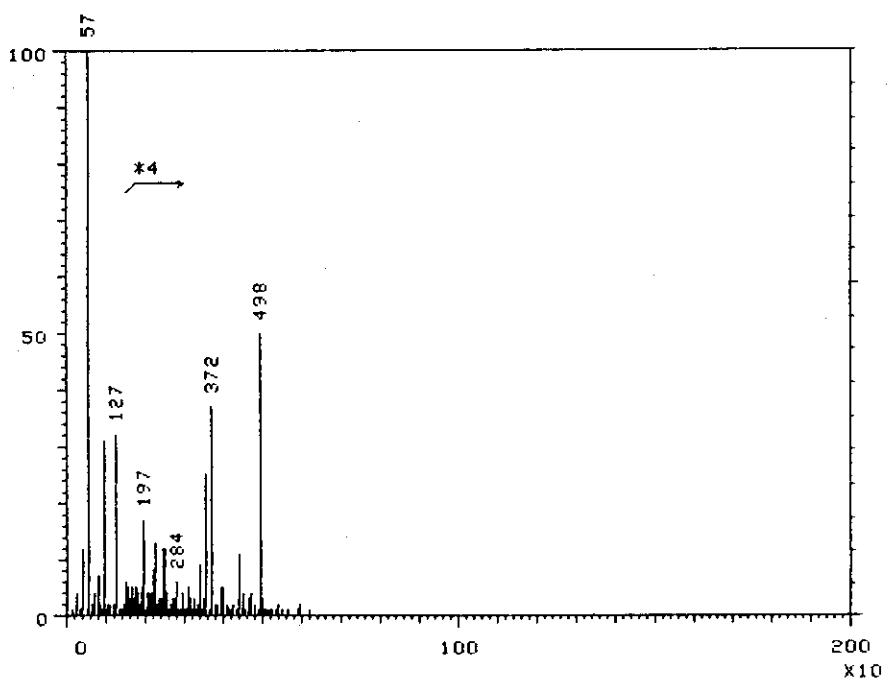


Infrared spectrum (10 MGy in air)

OIL NAME: Pentaerythritol ester



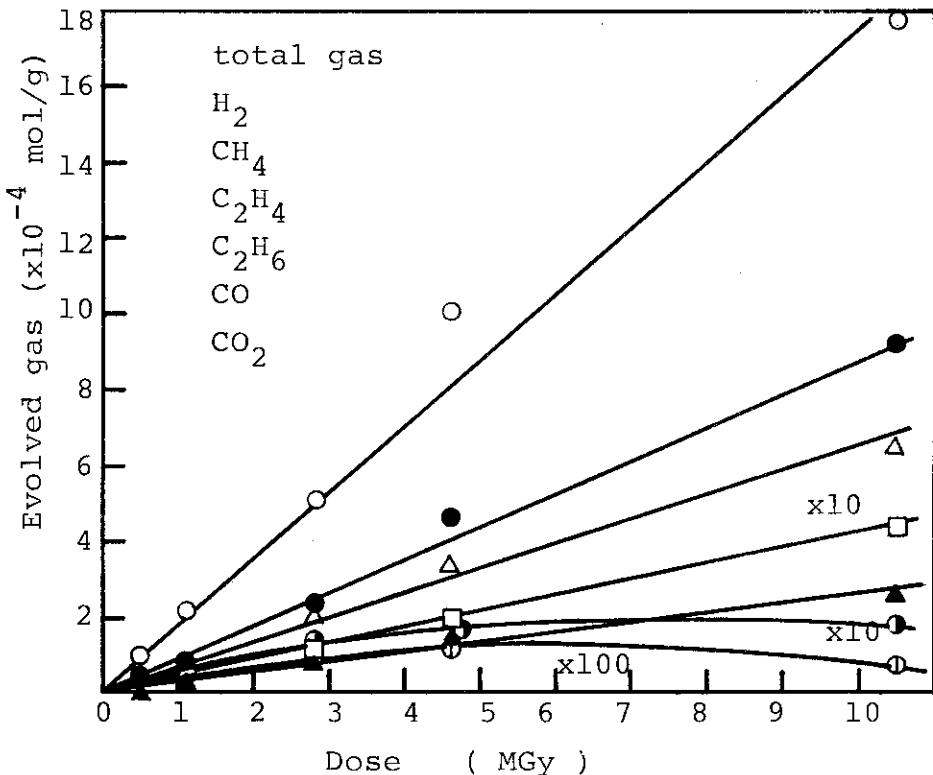
(original)



(10 MGy in vacuum)

The mass spectrum of Pentaerythritol ester.

OIL NAME : Pentaerythritol ester

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	1.9	$G(C_2H_6)$	2.2×10^{-2}
$G(H_2)$	8.0×10^{-1}	$G(C_2H_4)$	3.2×10^{-3}
$G(CH_4)$	2.9×10^{-1}		
$G(CO)$	7.5×10^{-1}		
$G(CO_2)$	2.7×10^{-1}		

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	2.0
5 MGy	9.8
10 MGy	17.7

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h

OIL NAME: Tricresyl phosphate

STRUCTURE OR FEATURE: $O=P(O\phi-CH_3)_3$, ϕ :benzene ring

MOLECULAR WEIGHT: 368

VISCOSITY at 40°C: $21.73 \times 10^{-6} \text{ m}^2/\text{s}$ ($3.689 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: 5 SPECIFIC GRAVITY(15/4°C): 1.178

TOTAL ACID NUMBER: 0.01 mgKOH/g, FLASH POINT(°C): 252

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

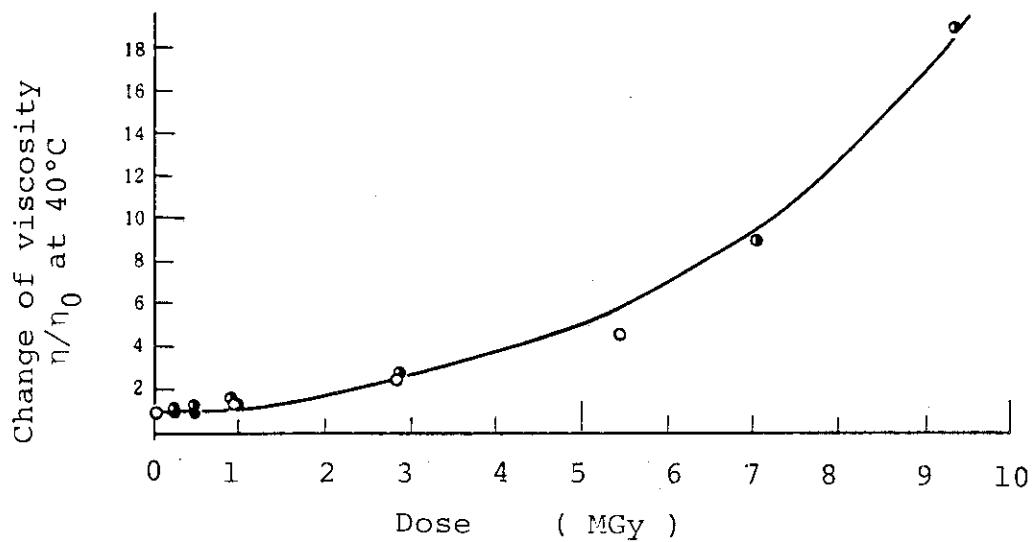
Irradiation condition	Dose [MGy]	Specific gravity	Viscosity	η/η_0	
		(15/4°C)	$\eta \times 10^{-6} \text{ m}^2/\text{s}$ (40°C)	(100°C)	(40°C)
in vacuum	0.93	1.186	30.15	4.591	1.39
	2.8	1.184	53.68	6.300	2.47
	5.4	1.192	101.4	9.880	4.67
in bubbling oxygen	0.05	1.178	21.98		1.01
	0.21	1.178	23.50	3.811	1.01
	0.46	1.184	25.44	4.082	1.08
in air	0.91	1.188	29.51	4.388	1.35
	0.05	1.182	22.09	3.751	1.02
	0.2	1.182	23.26	3.805	1.07
	0.45	1.182	26.17	4.154	1.20
	0.9	1.184	31.06	4.510	1.43
	2.8	1.192	60.15	6.544	2.77
	7.0	1.259	198.2	13.16	9.12
	9.3	1.236	412.3	19.56	19.0
					5.30

IRRADIATION CONDITION

OIL NAME : Tricresyl phosphate

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

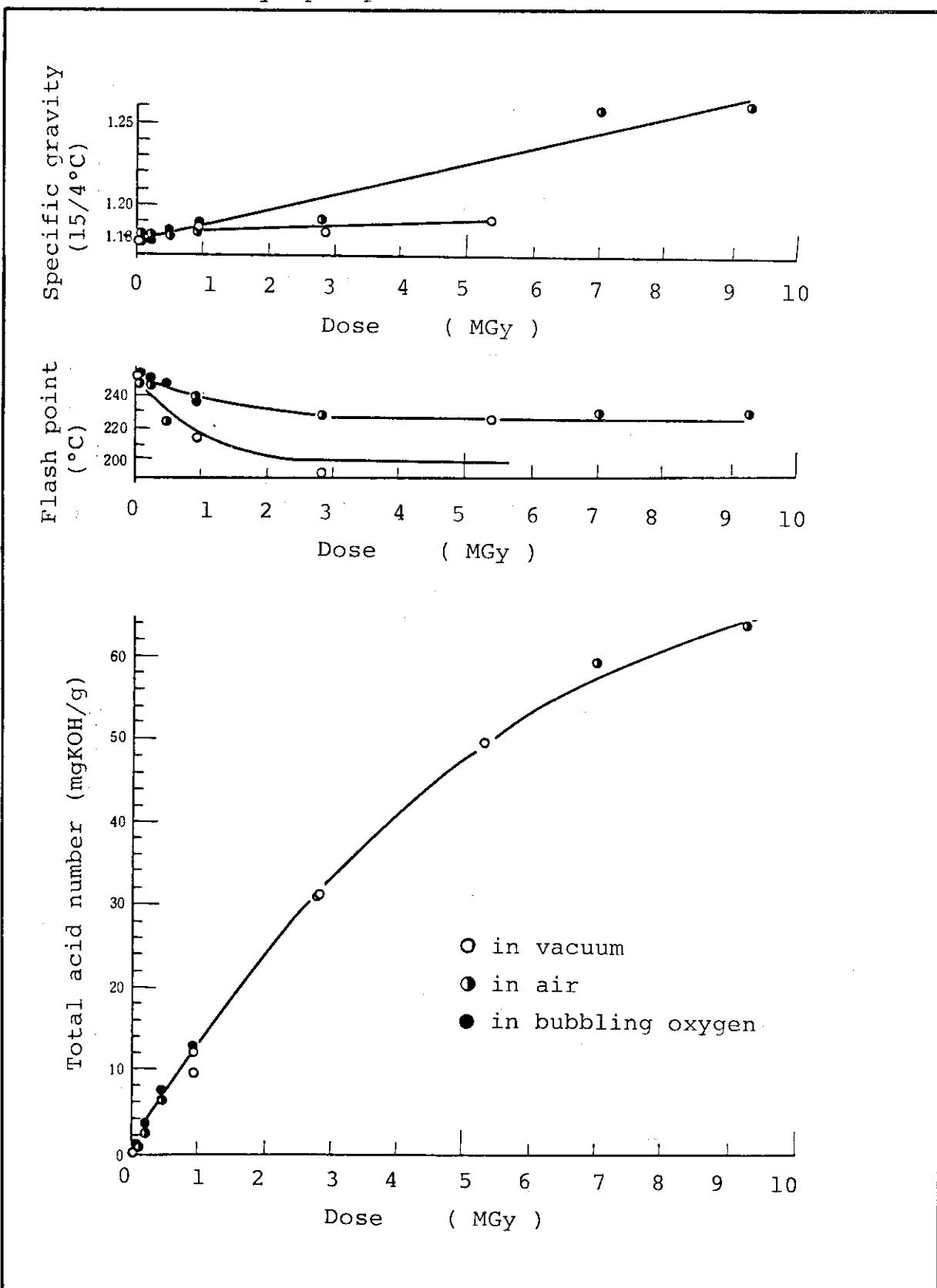
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	0.93	37	9.69	214	4	L4.0
	2.8	43	31.4	192	8	L8.0
	5.4	68	49.8	226	8	8.0
in bubbling oxygen	0.05		0.86	250	2(1/2)	L2.0
	0.21	5	3.73	250	3(-)	L2.5
	0.46	14	7.07	248	3(1/2)	L3.5
	0.91	11	12.9	236	4(1/2)	L4.5
in air	0.05	10	0.69	246	1(-)	L0.5
	0.2	0	2.49	246	1(-)	L0.5
	0.45	15	6.44	224	2(-)	L1.5
	0.9	13	12.4	238	2(-)	L1.5
	2.8	32	31.0	238	4(-)	3.5
	7.0	34	59.4	228	8(-)	7.0
	9.3	24	63.8	228	8(-)	8.0



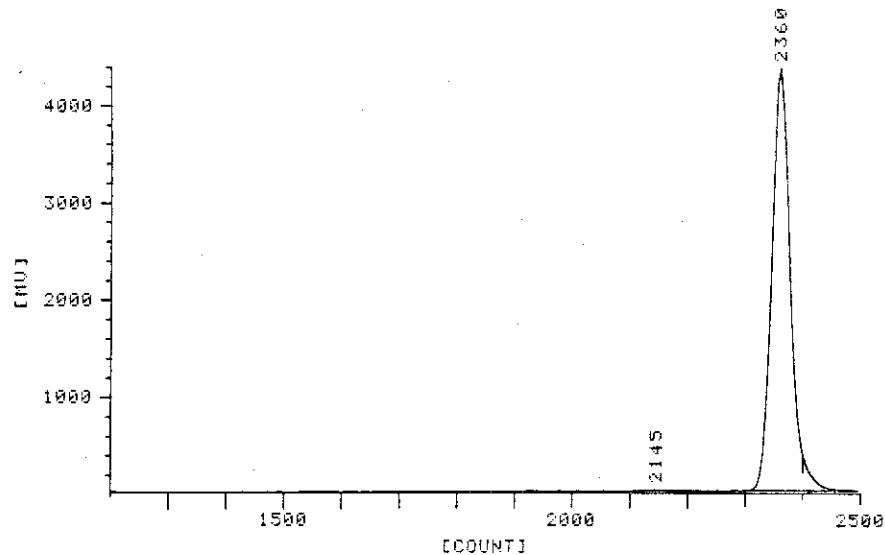
Symbol:

○ in vacuum, ◉ in air, ● in bubbling oxygen.

OIL NAME: Tricresyl phosphate



OIL NAME: Tricresyl phosphate

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/08 18:39 JOB FILE 1

SAMPLE NO. 0 NAME: 7-1 SERIAL NO. 0047

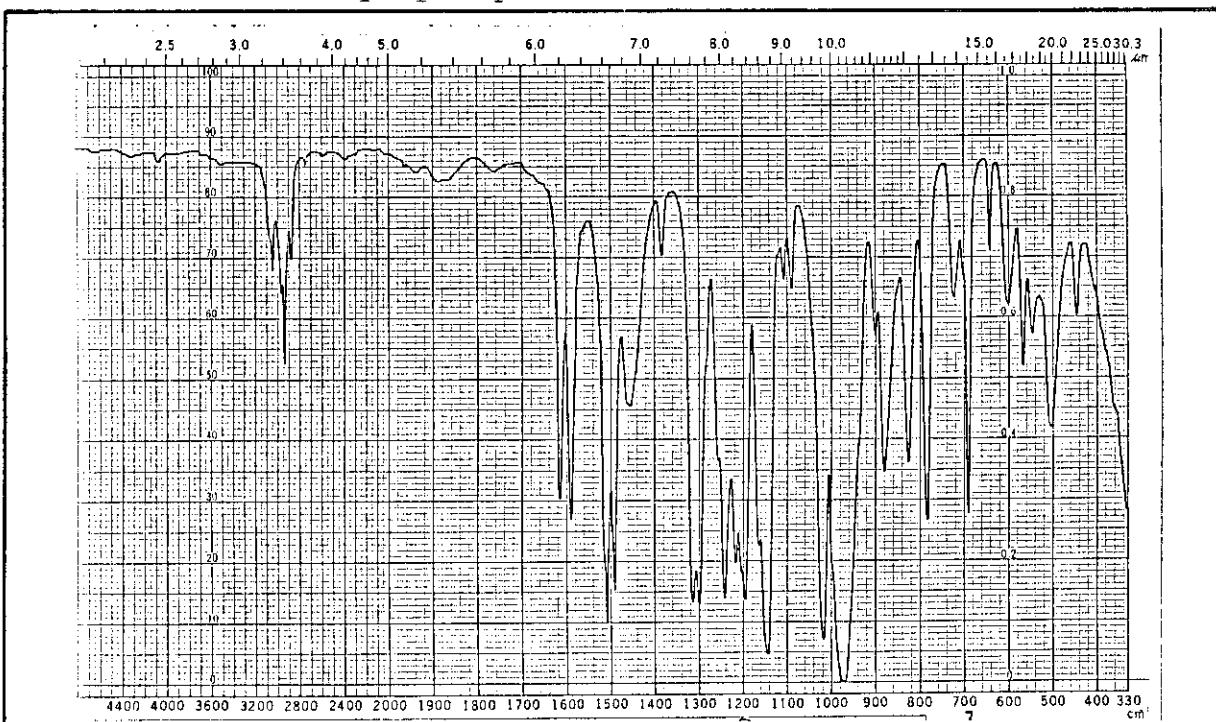
CH.NO 1 METHOD 2

PERK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2105	2145		2200	5.89927E+02	5.90496E+02	5.91063E+02	5.90494E+02
V	32.4	46.9		33.5	MW/MN	MZ/MW	AREA	AREAX
M	641	598		534	1.00	1.00	5.84088E+02	8.35

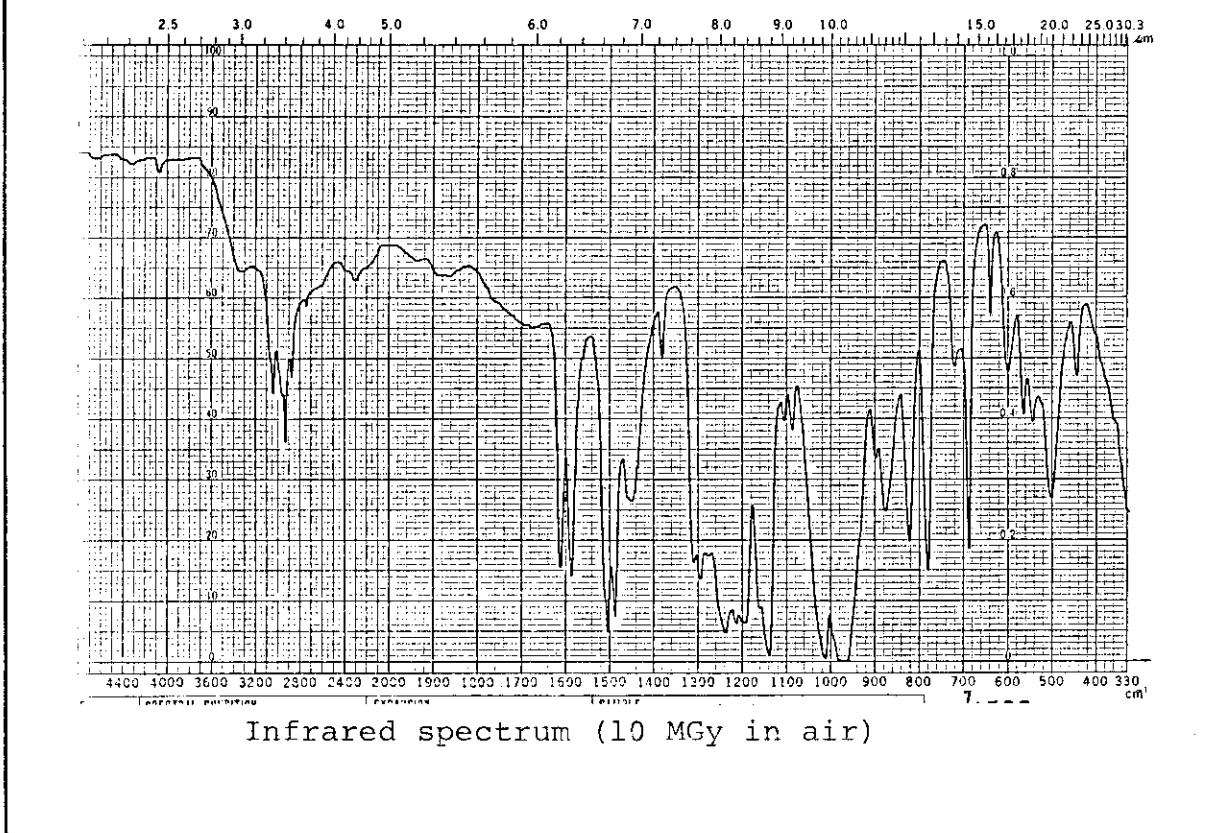
PERK NO.	VALLEY	START	TOP	END	MN	MW	MZ	MU
C		2200	2360	2495	4.01978E+02	4.02492E+02	4.02987E+02	4.02490E+02
V		33.5	4399.0	40.1	MW/MN	MZ/MW	AREA	AREAX
M		534	405	296	1.00	1.00	1.67052E+05	99.65

TOTAL	START	TOP	END	MN	MW	MZ	MU
C	2105	2360	2495	4.02424E+02	4.03147E+02	4.03947E+02	4.03146E+02
V	32.4	4399.0	40.1	MW/MN	MZ/MW	AREA	AREAX
M	641	405	296	1.00	1.00	1.67636E+05	100.00

OIL NAME: Tricresyl phosphate



Infrared spectrum (original)



Infrared spectrum (10 MGy in air)

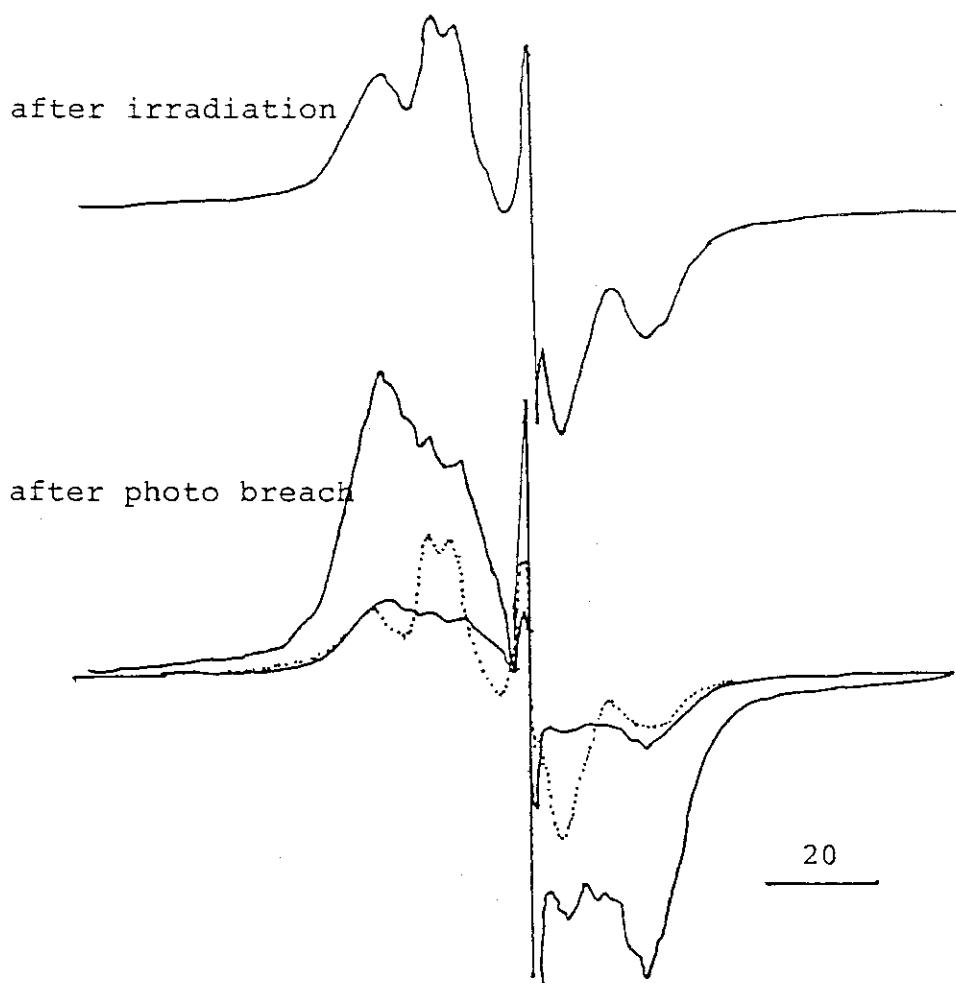
OIL NAME : Tricresyl phosphate

IRRADIATION CONDITION

Temp.: -196°C

Dose 107.1kGy

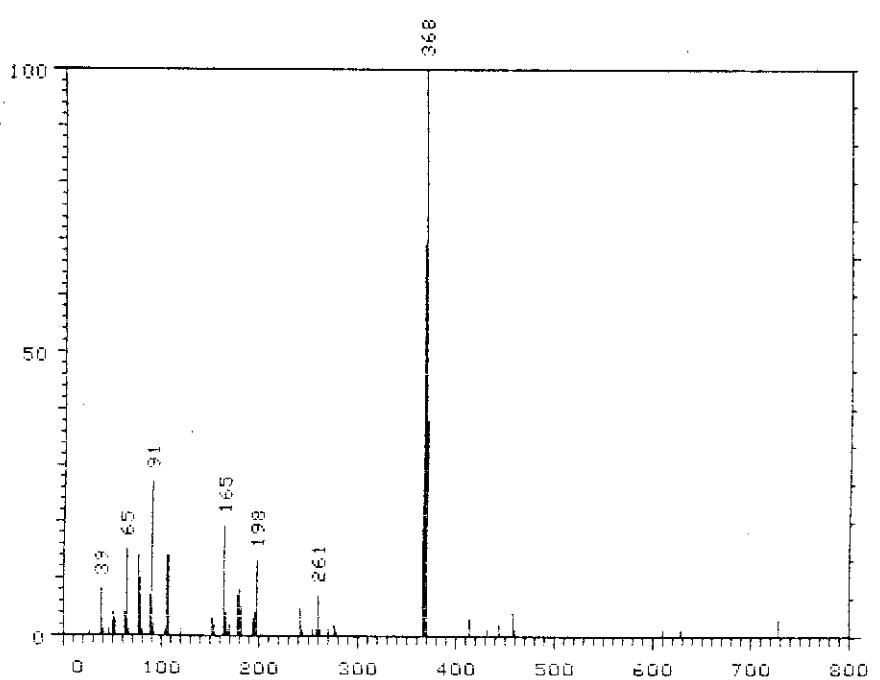
in Vacuum



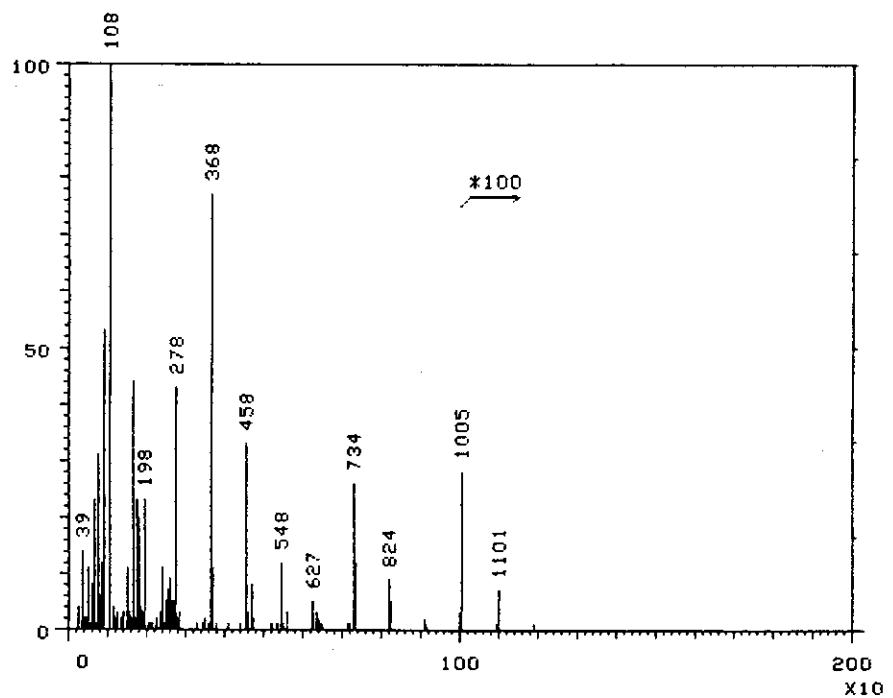
<u>ESR CONDITION</u>	Sweep range(Gauss): ± 100	Power(μW): 1
	Modulation width(100kHz,Gauss): 2	at -196°C

<u>G[R.]</u>	<u>after irradiation</u>	<u>after Photo breach</u>
	0.54	0.24

OIL NAME: Tricresyl phosphate



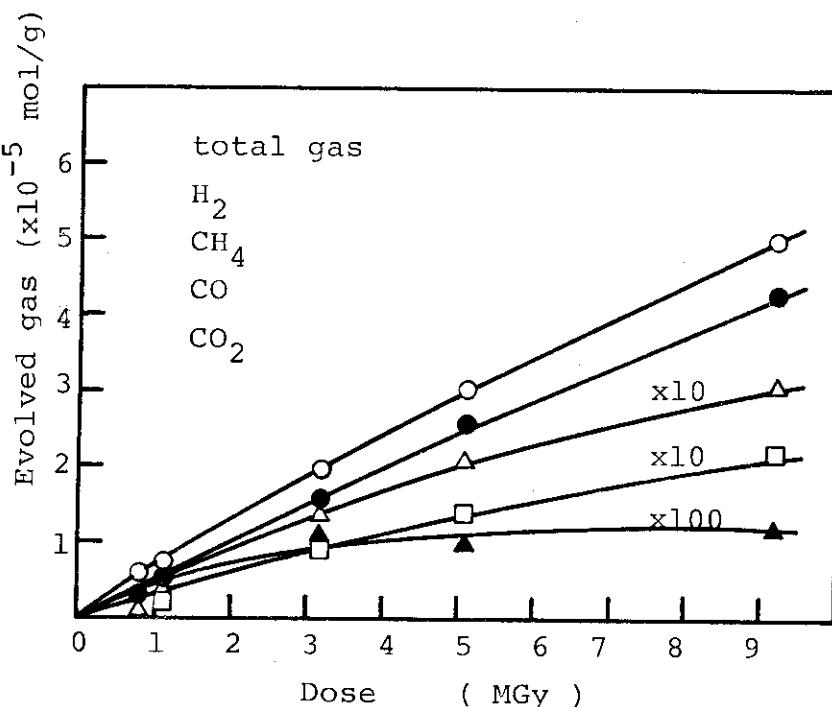
(original)



(6 MGy in vacuum)

The mass spectrum of Tricresyl phosphate.

OIL NAME : Tricresyl phosphate

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	6.1×10^{-2}
$G(H_2)$	4.9×10^{-2}
$G(CH_4)$	2.9×10^{-3}
$G(CO)$	4.1×10^{-3}
$G(CO_2)$	3.9×10^{-4}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-6}$ mol/g)

1 MGy	6.5
5 MGy	31
10 MGy	53

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h

OIL NAME: Trioctyl phosphate

STRUCTURE OR FEATURE: $O=P(O)R_3$, R: $(CH_3)_2CH-(CH_2)_5-$

MOLECULAR WEIGHT: 434

VISCOSITY at 40°C: $7.664 \times 10^{-6} \text{ m}^2/\text{s}$ ($2.209 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: 90 SPECIFIC GRAVITY(15/4°C): 0.928

TOTAL ACID NUMBER: 0.01 mgKOH/g, FLASH POINT(°C): 200°C

COLOR: UNION 1(-), ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

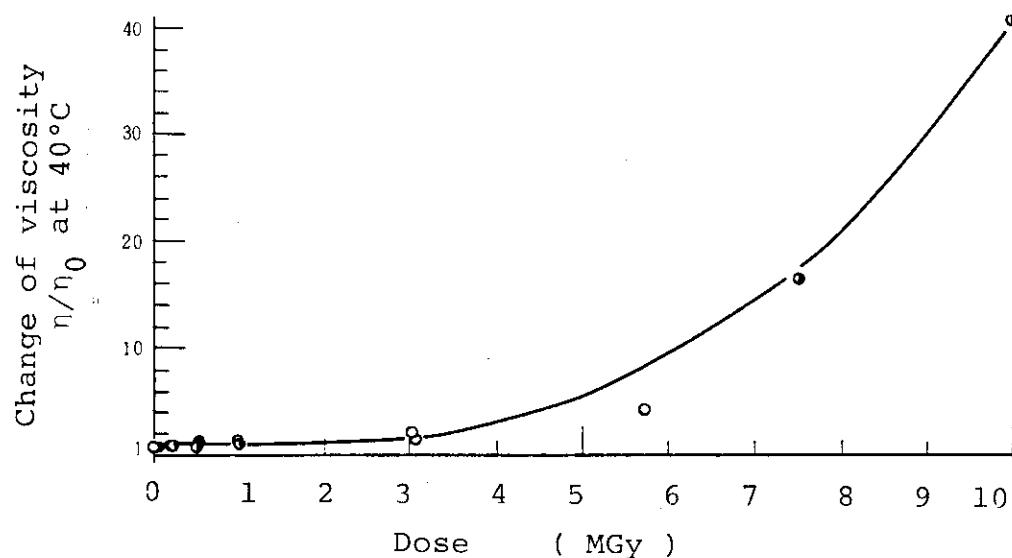
Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	Viscosity $\eta \text{ m}^2/\text{s}$ (40°C)	Viscosity $\eta \text{ m}^2/\text{s}$ (100°C)	n/n_0 (40°C)	n/n_0 (100°C)
in vacuum	1.0	0.931	9.618	2.615	1.25	1.18	
	3.0	0.945	17.34	3.970	2.26	1.80	
	5.7	0.945	33.81	6.780	4.41	3.07	
in bubbling oxygen	0.05	0.930	7.841	2.261	1.02	1.02	
	0.23	0.933	8.183	2.342	1.07	1.06	
	0.5	0.936	9.120	2.524	1.19	1.14	
	0.98	0.941	10.38	2.729	1.35	1.24	
in air	0.05	0.928	7.759	2.238	1.01	1.01	
	0.2	0.929	8.187	2.294	1.07	1.04	
	0.5	0.930	8.518	2.409	1.11	1.09	
	1.0	0.934	9.929	2.624	1.30	1.19	
	3.0	0.946	17.77	3.970	2.32	1.80	
	7.5	0.971	127.2	16.16	16.6	7.32	
	10	0.980	313.1	30.12	40.8	13.6	

IRRADIATION CONDITION

OIL NAME : Trioctyl phosphate

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

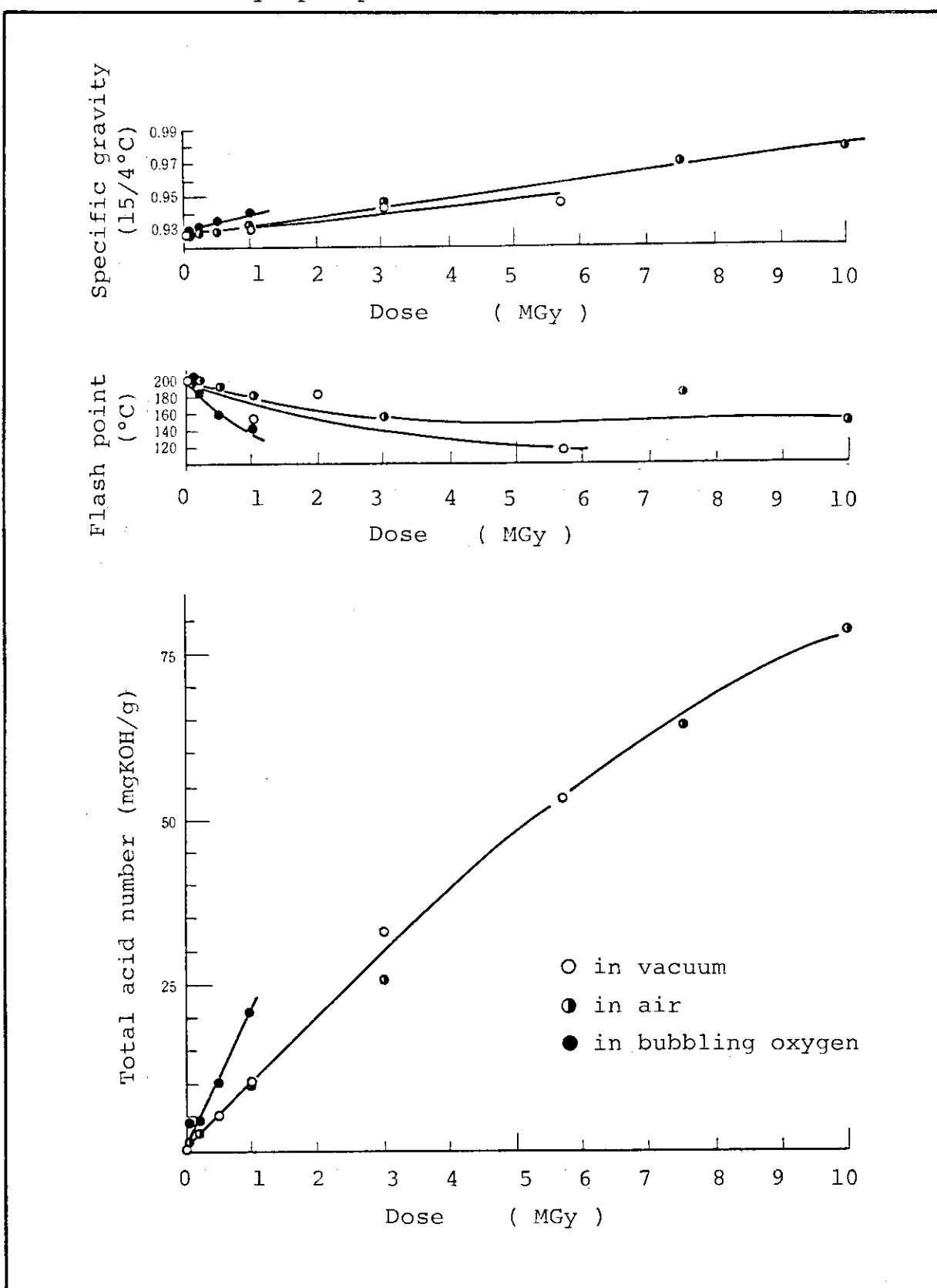
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	105	10.6	154	1(-)	L0.5
	3.0	128	33.1	184	1(-)	L0.5
	5.7	164	53.1	116	1(-)	L0.5
in bubbling oxygen	0.05	94	4.62	206	1(-)	L0.5
	0.23	99	4.82	188	1(-)	L0.5
	0.5	102	10.6	160	1(-)	L0.5
	0.98	102	21.1	144	1(-)	L0.5
in air	0.05	93	0.92	200	1(-)	L0.5
	0.2	85	2.58	202	1(-)	L0.5
	0.5	101	5.38	194	1(-)	L0.5
	1.0	94	10.1	184	1(-)	L0.5
	3.0	121	26.2	156	1(-)	L0.5
	7.5	135	64.5	186	1	L1.5
	10	179	78.8	150	2(-)	L1.5



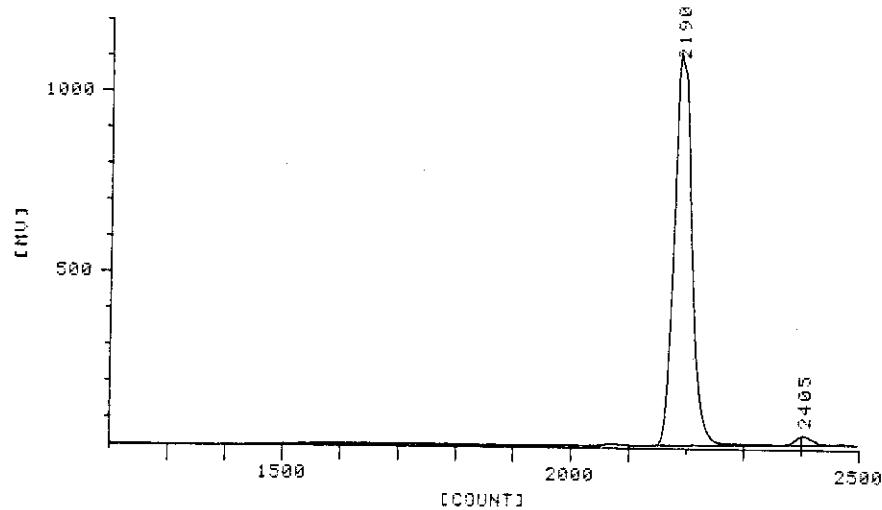
Symbol:

○ in vacuum, ● in air, • in bubbling oxygen.

QIL NAME: Trioctyl phosphate



OIL NAME: Trioctyl phosphate

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/87/09 12:28 JOB FILE 1

SAMPLE NO. 0 NAME: 7 - 2 SERIAL NO. 0049

CH.NO 1 METHOD 2

PEAK NO. 1 BASE

	START	TOP	END	MN	MW	MZ	MU
C	2135	2198	2355	5.41401E+02	5.41880E+02	5.42335E+02	5.41878E+02
V	27.8	1082.6	32.5	MW/MN	MZ/MW	AREA	AREAN%
M	602	543	409	1.00	1.00	3.96468E+04	97.64

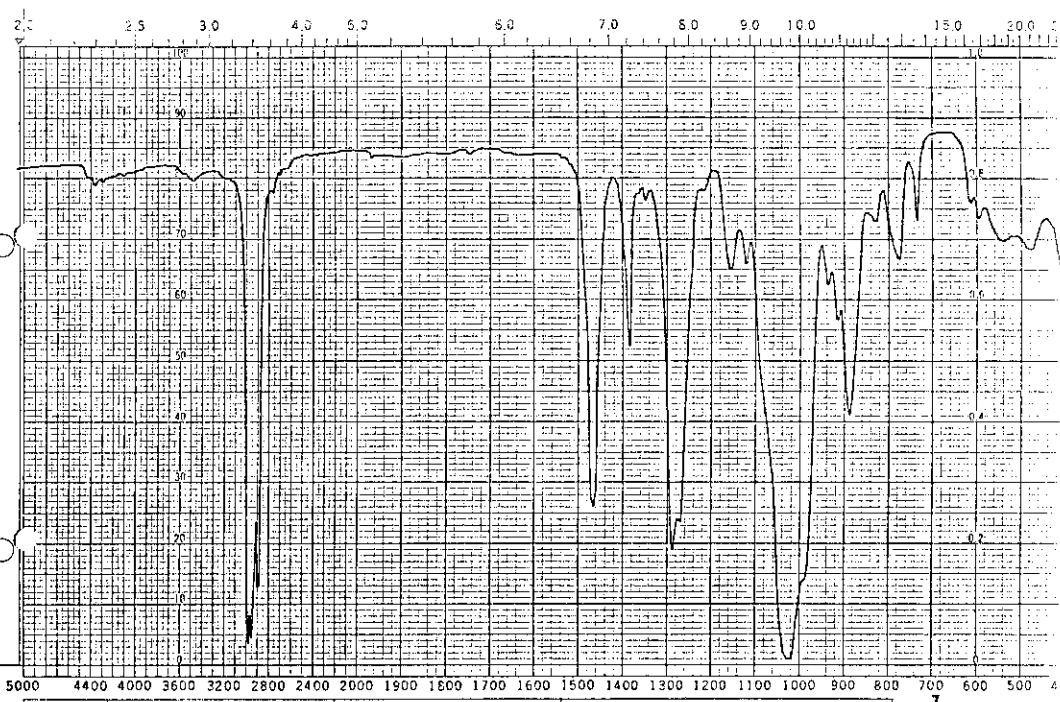
PEAK NO. 2 VALLEY

	START	TOP	END	MN	MW	MZ	MU
C	2355	2405	2495	3.64055E+02	3.64983E+02	3.65848E+02	3.64982E+02
V	32.5	58.5	34.6	MW/MN	MZ/MW	AREA	AREAN%
M	409	369	296	1.00	1.00	9.57614E+02	2.36

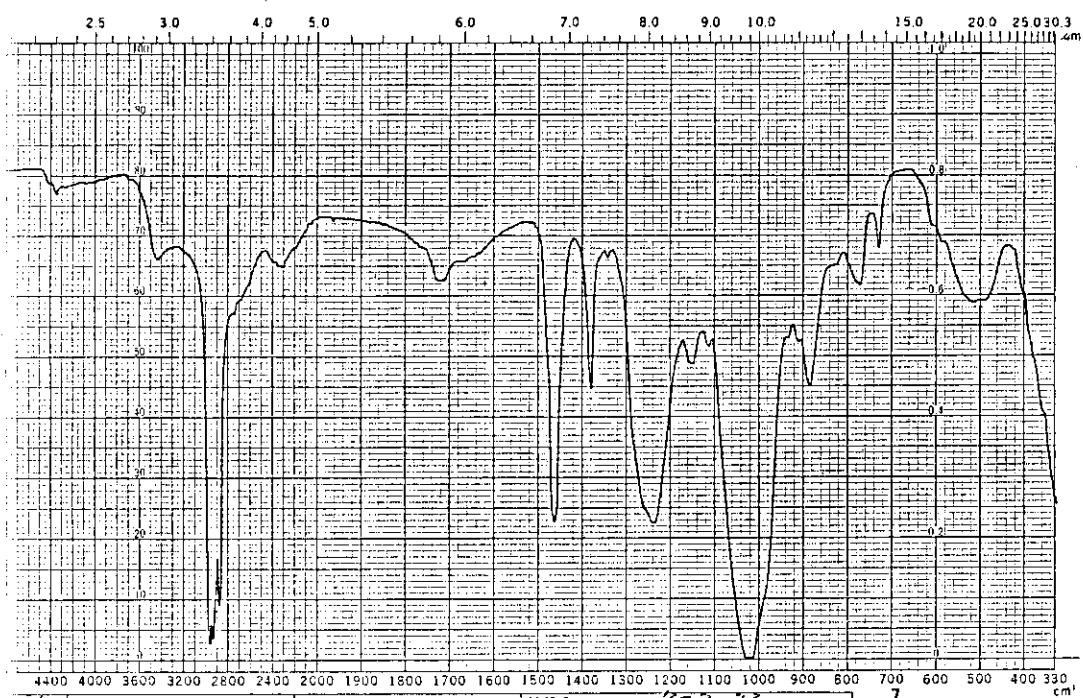
TOTAL

	START	TOP	END	MN	MW	MZ	MU
C	2135	2198	2495	5.35251E+02	5.37708E+02	5.39510E+02	5.37706E+02
V	27.8	1082.6	34.6	MW/MN	MZ/MW	AREA	AREAN%
M	602	543	296	1.00	1.00	4.06044E+04	100.00

OIL NAME: Trioctyl phosphate



Infrared spectrum (original)



Infrared spectrum (10 MGy in air)

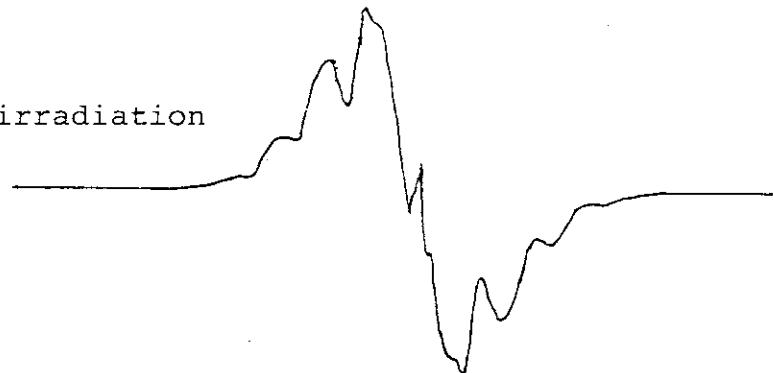
OIL NAME : Trioctyl phosphateIRRADIATION CONDITION

Temp.: -196°C

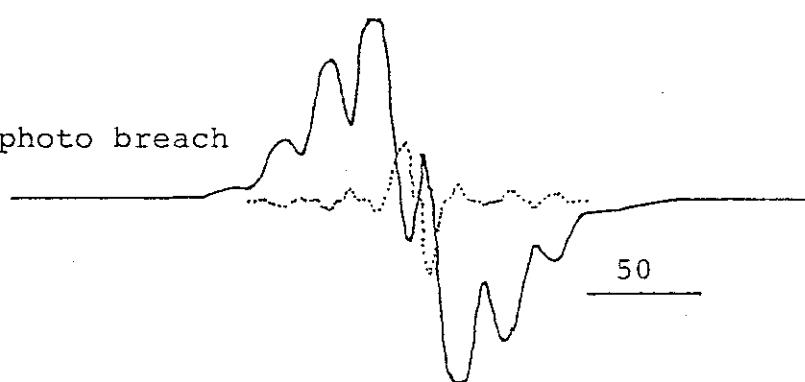
Dose 10.8kGy

in Vacuum

after irradiation



after photo breach

ESR CONDITION

Sweep range(Gauss) : ± 250 Power(μW) : 1

Modulation width(100kHz, Gauss) : 2 at -196°C

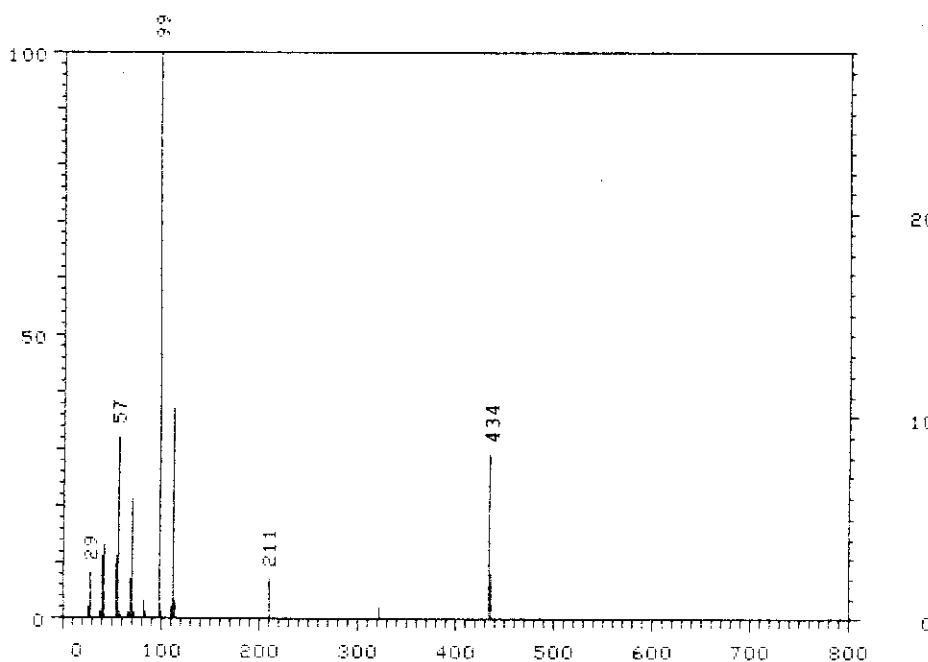
G[R.]after irradiation

4.8

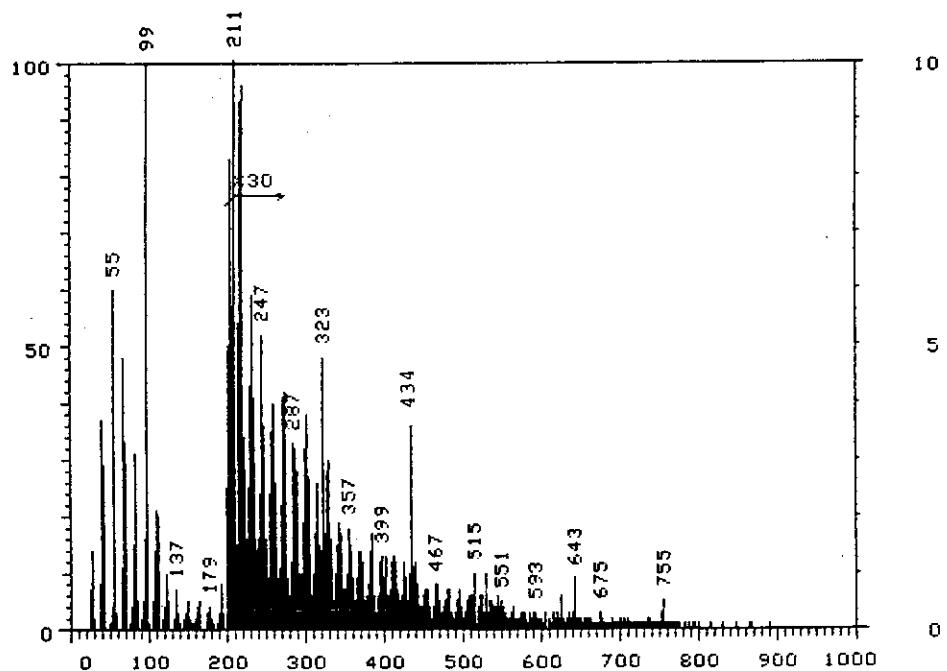
after Photo breach

4.9

OIL NAME: Trioctyl phosphate



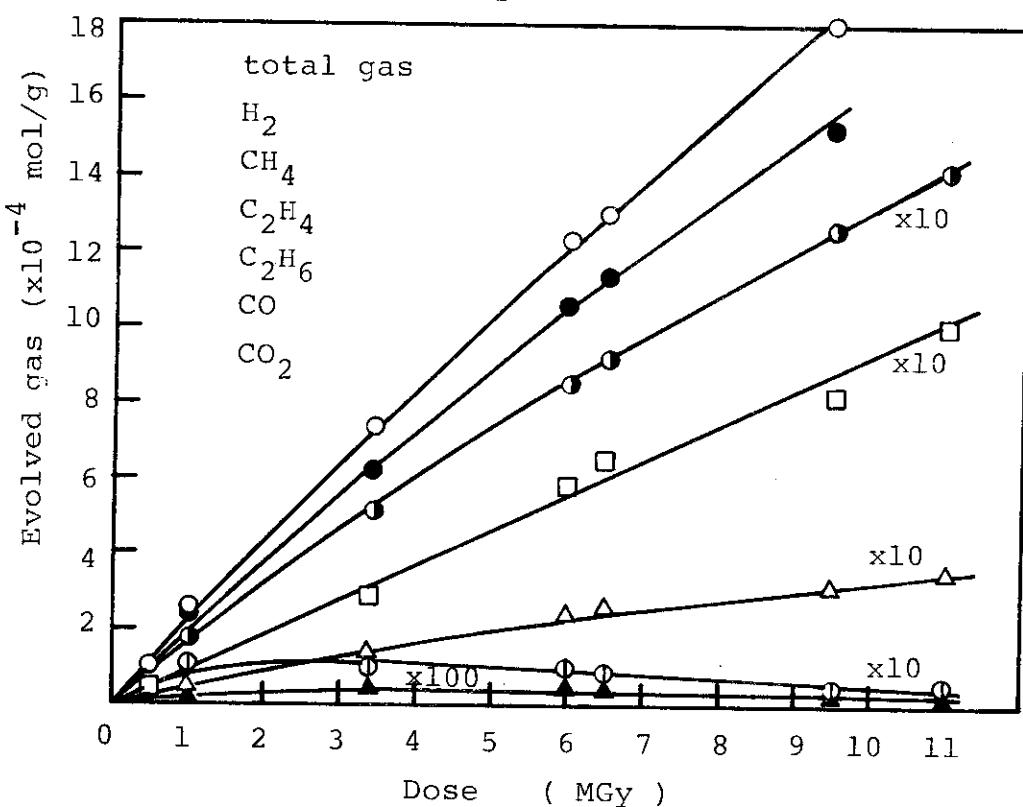
(original)



(10 MGY in vacuum)

The mass spectrum of Trioctyl phosphate.

OIL NAME : Trioctyl phosphate

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	2.6	$G(C_2H_6)$	1.7×10^{-1}
$G(H_2)$	2.3	$G(C_2H_4)$	8.3×10^{-2}
$G(CH_4)$	8.2×10^{-2}		
$G(CO)$	3.9×10^{-2}		
$G(CO_2)$	1.9×10^{-4}		

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

1 MGy	2.6
5 MGy	10.4
10 MGy	19.1

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

3.4 Polyether

3.4.1 Poly propylene glycol

OIL NAME: Poly propylene glycol

STRUCTURE OR FEATURE: $n\text{-Bu}\text{fOCH}_2\text{-CH}(\text{CH}_3)\text{+}_n\text{OH}$

MOLECULAR WEIGHT: 3000

VISCOSITY at 40°C: $123.3 \times 10^{-6} \text{ m}^2/\text{s}$ ($21.90 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: 206 SPECIFIC GRAVITY(15/4°C): 1.002

TOTAL ACID NUMBER: 0.04 mgKOH/g, FLASH POINT(°C): 236

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity	n/n_0	
		(15/4°C)	$\eta \times 10^{-6} \text{ m}^2/\text{s}$ (40°C)	(100°C)	(40°C)
in vacuum	1.0	1.007	228.1	36.49	1.85
	3.0	1.013	873.8	112.8	7.09
	3.2	caked			5.15
in bubbling oxygen	0.05	1.003	120.2	20.61	0.98
	0.23	1.011	102.9	17.06	0.84
	0.5	1.020	73.46		0.60
	0.99	1.036	44.77		0.36
	3.0	1.051	19.92	3.814	0.16
	4.8	1.070	12.32	3.514	0.10
	9.0	1.089	6.915	2.750	0.06
in air	0.05	1.006	135.0	23.19	1.09
	0.2	1.006	157.5	26.22	1.28
	0.5	1.008	177.3	28.57	1.44
	1.0	1.010	215.6	32.70	1.75
	3.0	1.018	162.5	57.23	1.32
	5.2	1.028	2295	180.6	18.6
	7.5	1.034	3557	267.1	28.8
	10.5	caked			12.2

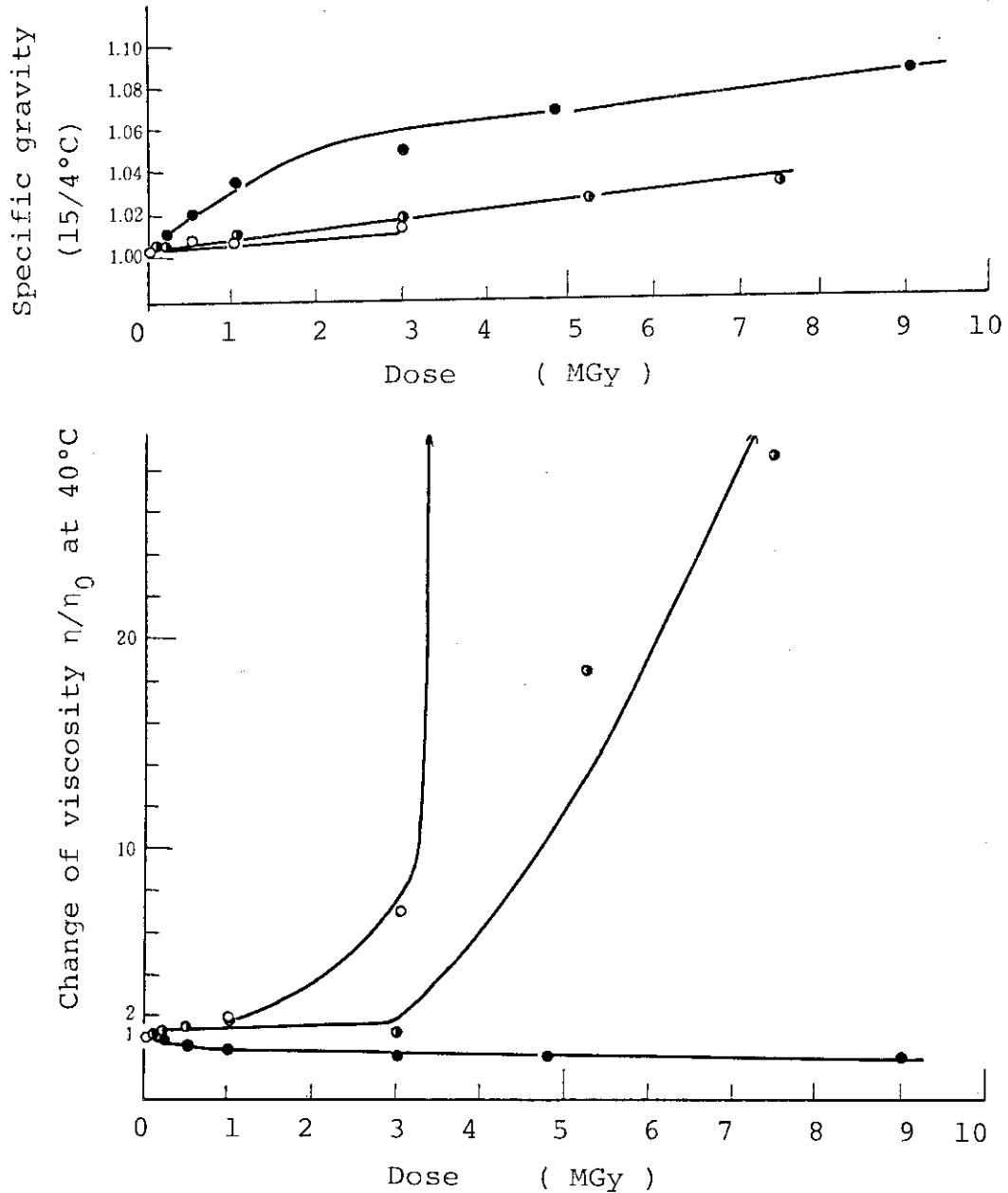
OIL NAME : Poly propylene glycol

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	211	0.08	228	1(-)	L0.5
	3.0	231	0.15	228	1(-)	L0.5
	3.2	caked				
in bubbling oxygen	0.05	197	1.24	216	1(-)	L0.5
	0.23	181	5.65	154	1(-)	L0.5
	0.5		17.5	112	1(-)	L0.5
	0.99		28.2	88	1(-)	L0.5
	3.0	64	68.8	108	1(-)	L0.5
	4.8	179	111	76	1(-)	L0.5
	9.0	327	139	96	1(-)	L0.5
in air	0.05	203	0.07	222	1(-)	L0.5
	0.2	203	0.08	222	1(-)	L0.5
	0.5	201	0.15	212	1(-)	L0.5
	1.0	197	0.32	220	1(-)	L0.5
	3.0	167	1.18	198	1(-)	L0.5
	5.2	197	1.98	312	1(-)	L0.5
	7.5	214	3.18	388	1(-)	L0.5
	10.5	caked				

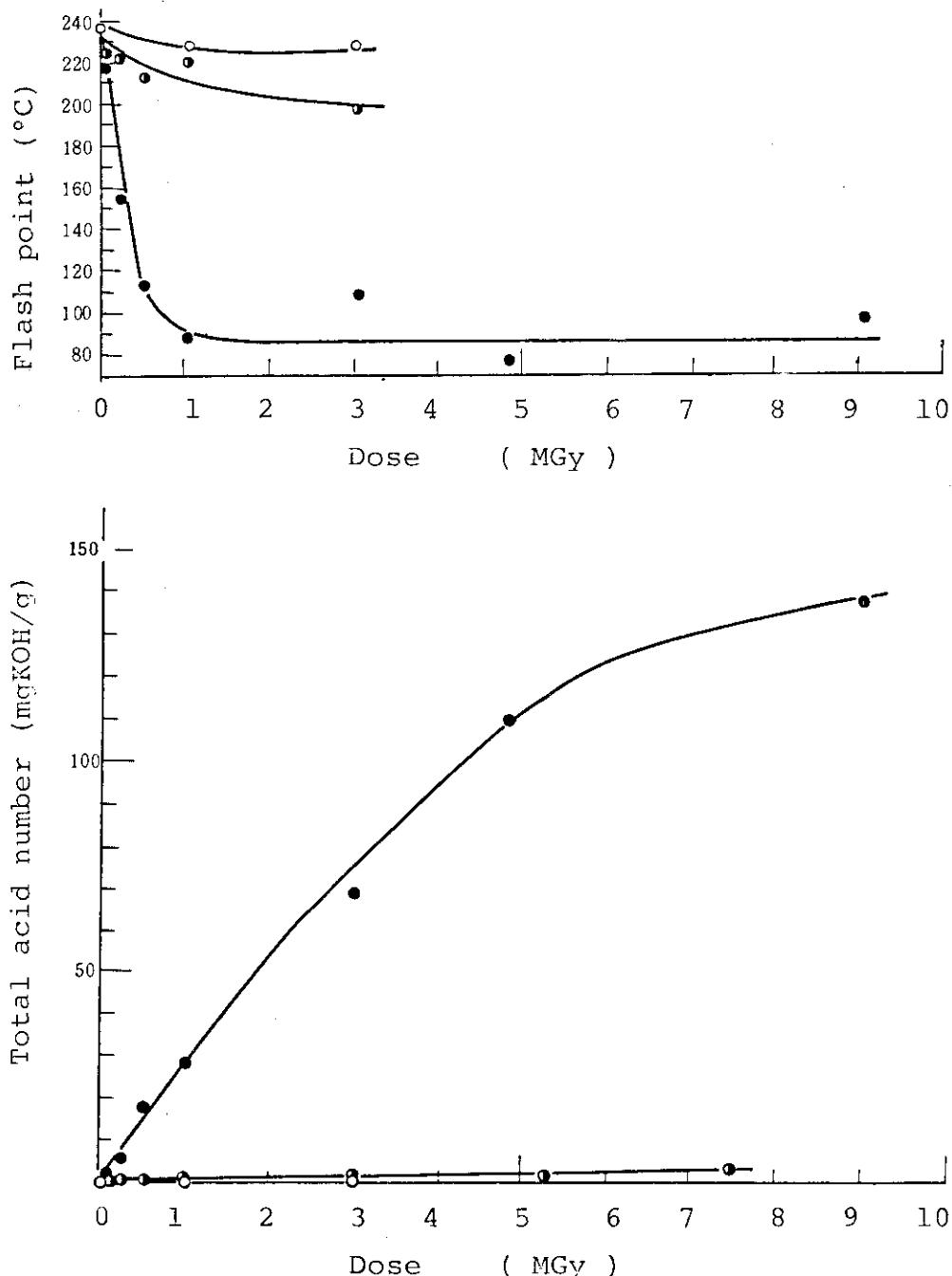
COMMENTIRRADIATION CONDITION

OIL NAME: Poly propylene glycol



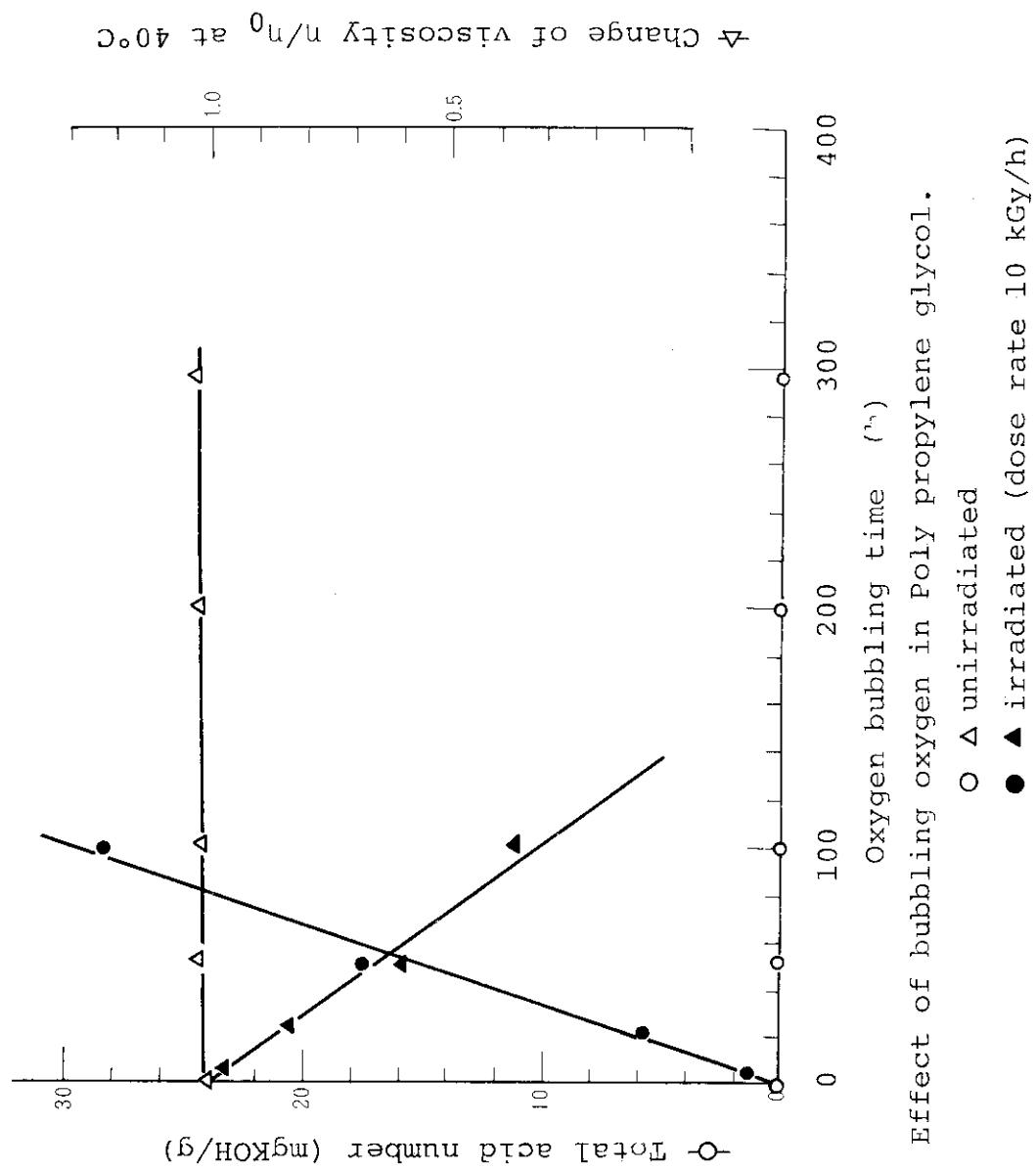
Symbol: ○ in vacuum, ● in air, • in bubbling oxygen.

OIL NAME: Poly propylene glycol



Symbol: ○ in vacuum, ● in air, • in bubbling oxygen.

OIL NAME : Poly propylene glycol

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENTIRRADIATION CONDITION

OIL NAME: Poly propylene glycol

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	(40°C)	(100°C)	n/n_0 (40°C)	(100°C)
<u>in air</u>							
20	1.0	1.007	208.6	31.93	1.69	1.46	
10	1.0	1.010	215.6	32.70	1.75	1.49	
3.0	1.0	1.014	198.1	30.14	1.61	1.38	
1.0	1.0	1.009	184.7	27.69	1.50	1.26	
0.5	1.0	1.011	167.5	25.33	1.36	1.16	
<u>in bubbling oxygen</u>							
10	0.05	1.003	120.2	20.61	0.98	0.94	
10	0.23	1.011	102.9	17.06	0.84	0.78	
10	0.5	1.020	73.46		0.60		
10	0.99	1.036	44.77		0.36		
3.0	0.048	1.002	109.2	19.18	0.89	0.88	
3.0	0.19	1.010	81.10	14.00	0.66	0.64	
3.0	0.48	1.026	42.73	8.137	0.35	0.37	
3.0	1.09	1.053	22.01	5.001	0.18	0.23	
1.0	0.048	1.005	107.6	12.92	0.87	0.59	
1.0	0.21	1.020	70.55	11.54	0.57	0.53	
1.0	0.49	1.036	30.49	6.672	0.25	0.30	
1.0	1.0	1.079	26.31	4.248	0.21	0.19	

OIL NAME: Poly propylene glycol

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

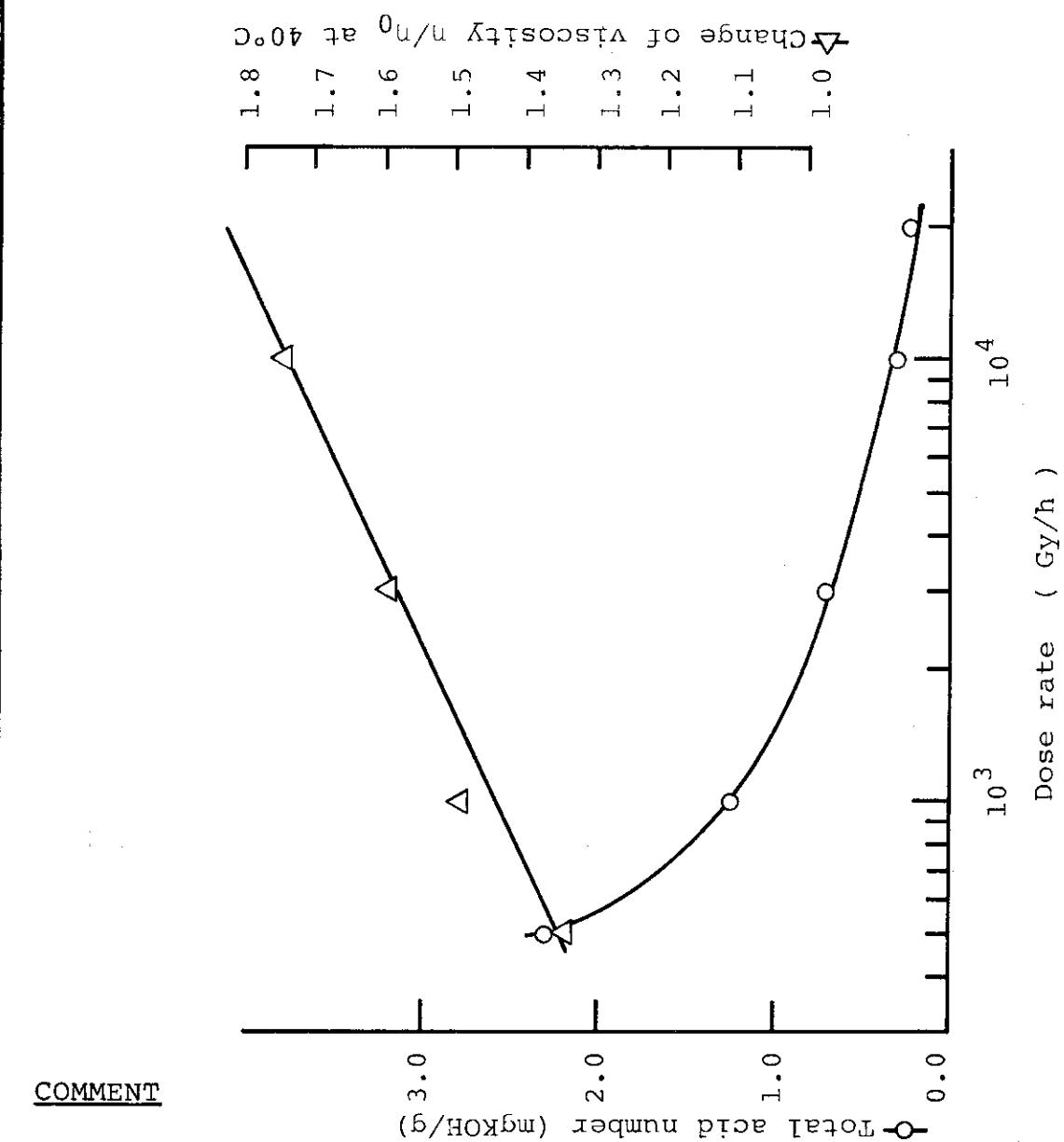
Dose rate [kGy/h]	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
<u>in air</u>						
20	1.0	198	0.25	216	1(-)	L0.5
10	1.0	197	0.32	220	1(-)	L0.5
3.0	1.0	194	0.70	208	1(-)	L0.5
1.0	1.0	188	1.25	202	1(-)	L0.5
0.5	1.0	185	2.32	208	1(-)	L0.5
<u>in bubbling oxygen</u>						
10	0.05	197	1.24	216	1(-)	L0.5
10	0.23	181	5.65	154	1(-)	L0.5
10	0.5		17.5	112	1(-)	L0.5
10	0.99		28.2	88	1(-)	L0.5
3.0	0.048	198	2.82	218	1(-)	L0.5
3.0	0.19	143	13.3	128	1(-)	L0.5
3.0	0.48	168	38.1	114	1(-)	L0.5
3.0	1.09	162	91.4	96	1(-)	L0.5
1.0	0.048	115	3.14	208	1(-)	L0.5
1.0	0.21	158	23.2	146	1(-)	L0.5
1.0	0.49	185	80.9	94	1(-)	L0.5
1.0	1.0	50	114.5	74	1(-)	L0.5

OIL NAME : Poly propylene glycol

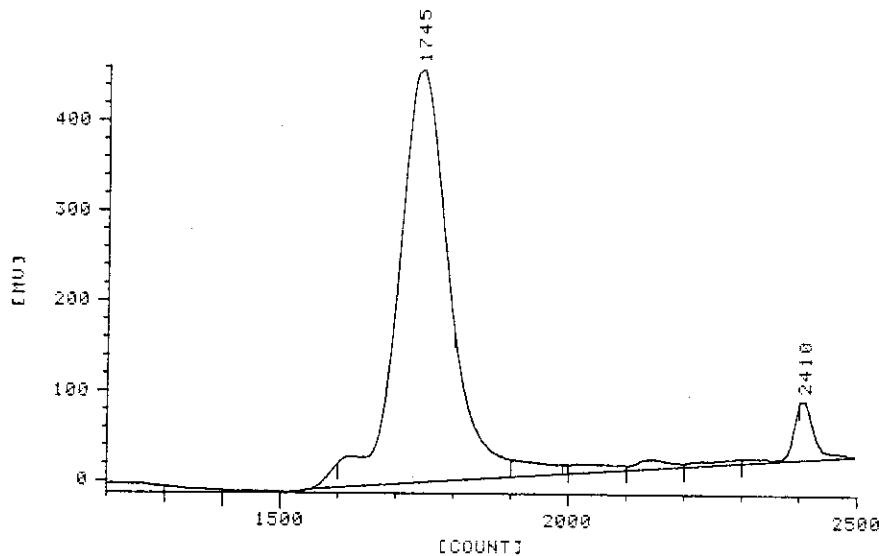
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

DOSE RATE EFFECT

(in air, total dose 1 MGy)

IRRADIATION CONDITION

OIL NAME: Poly propylene glycol

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/08 17:48 JOB FILE 1

SAMPLE NO. 0 NAME: 6-0

SERIAL NO. 0046

CH.NO 1

METHOD 2

PEAK NO. 1 BASE

	START	TOP	END	MN	MW	MZ	MU
C	1555	1745	1990	4.86675E+03	1.20507E+04	9.39580E+04	1.20506E+04
V	-10.0	457.6	17.9	MW/MN	MZ/MW	AREA	AREA%
M	790507	6076	895	2.48	7.30	4.88372E+04	91.07

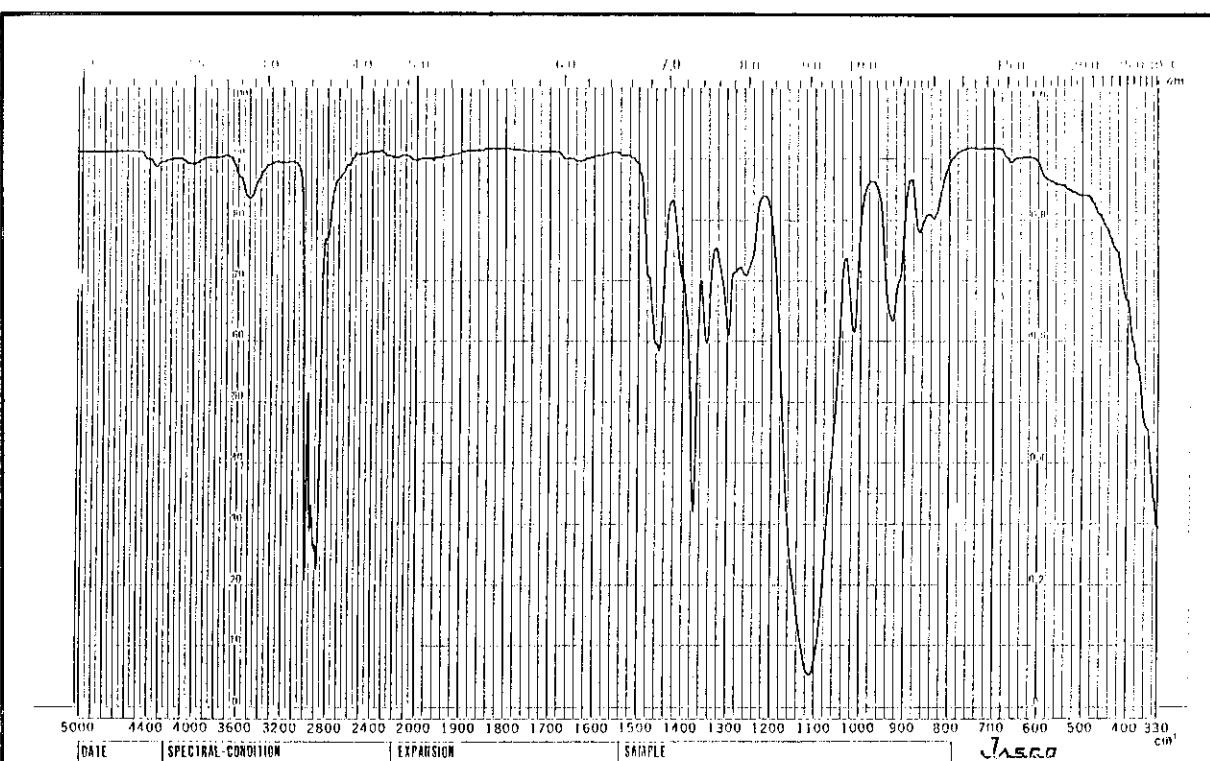
PEAK NO. 2 VALLEY

	START	TOP	END	MN	MW	MZ	MU
C	1990	2410	2495	4.44697E+02	4.86031E+02	5.38790E+02	4.86030E+02
V	17.9	91.4	29.5	MW/MN	MZ/MW	AREA	AREA%
M	895	365	296	1.09	1.11	4.78710E+03	8.93

TOTAL

	START	TOP	END	MN	MW	MZ	MU
C	1555	1745	2495	2.57812E+03	1.10183E+04	9.35901E+04	1.10182E+04
V	-10.0	457.6	29.5	MW/MN	MZ/MW	AREA	AREA%
M	790507	6076	296	4.27	8.49	5.36244E+04	100.00

OIL NAME: Poly propylene glycol



(original)



Infrared spectrum (3 MGy in bubbling oxygen)

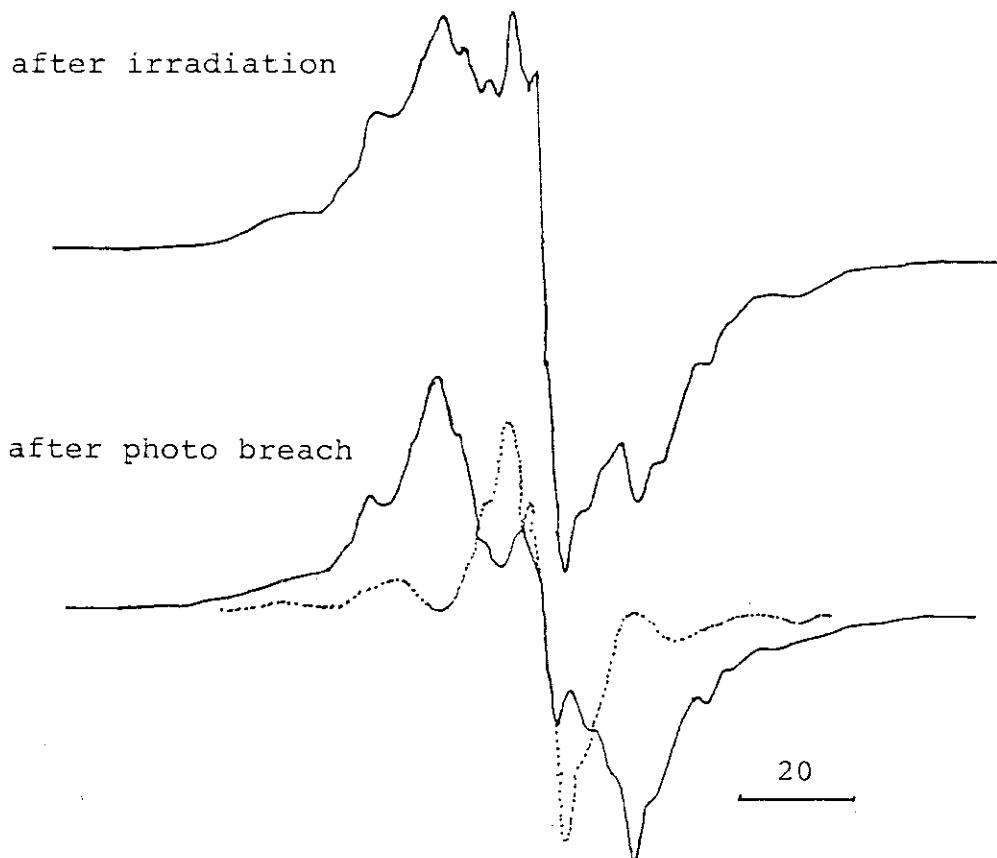
OIL NAME : Poly propylen glycol

IRRADIATION CONDITION

Temp.: -196°C

Dose 10.7kGy

in Vacuum

ESR CONDITIONSweep range(Gauss): ± 100 Power(μW): 1

Modulation width(100kHz, Gauss): 2 at -196°C

G[R.]

after irradiation

3.6

after Photo breach

2.75

3.5 Silicon oils

3.5.1 Di-methyl silicone

3.5.2 Pentaphenyl trimethyl trisiloxane

OIL NAME: Di-methyl silicone

STRUCTURE OR FEATURE: $(\text{CH}_3)_3\text{Si}[\text{OSi}(\text{CH}_3)_2]_n\text{OSi}(\text{CH}_3)_3$

MOLECULAR WEIGHT: 1400

VISCOSITY at 40°C: 232.5×10^{-6} m²/s (96.01 $\times 10^{-6}$ m²/s at 100°C)

VISCOSITY INDEX: 432 SPECIFIC GRAVITY(15/4°C): 0.978

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 326

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

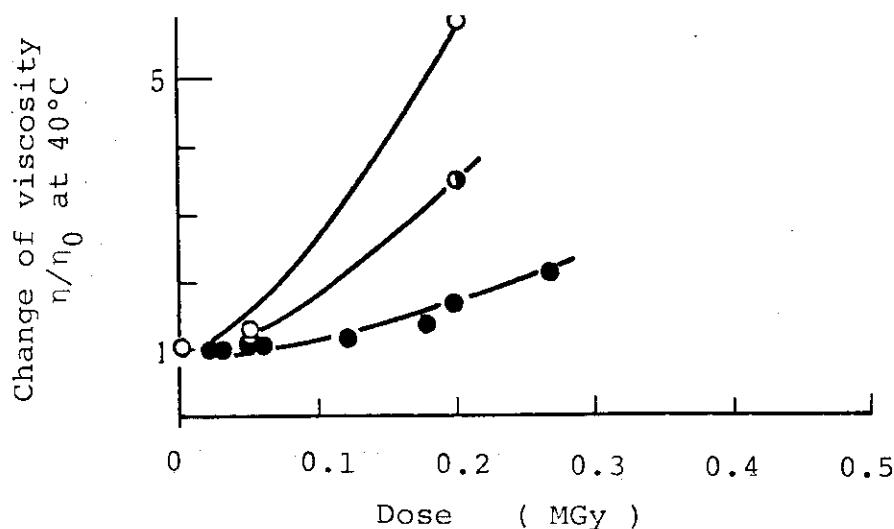
Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	n/n_0 (40°C)	n/n_0 (100°C)
in aacuum	0.05	0.985	297.5	123.8	1.28	1.29
	0.2	1.075	1345	534.9	5.78	5.57
	0.5	gelation				
in bubbling oxygen	0.005	0.971	234.4	97.06	1.01	1.01
	0.02	0.974	237.1	99.41	1.02	1.04
	0.03	0.973	243.3	100.9	1.05	1.05
	0.05		249.7	103.4	1.07	1.08
	0.06	0.979	247.3	100.9	1.06	1.05
	0.12	0.980	277.4	114.0	1.19	1.19
	0.18	0.982	313.7	128.0	1.35	1.33
	0.2		391.6	162.3	1.68	1.69
	0.27	0.980	491.0	198.4	2.11	2.07
	0.5	gelation				
in air	0.05	0.978	274.2	115.0	1.18	1.20
	0.2	0.979	810.0	332.7	3.48	3.47
	0.5	gelation				

IRRADIATION CONDITION

OIL NAME : Di-methyl silicone

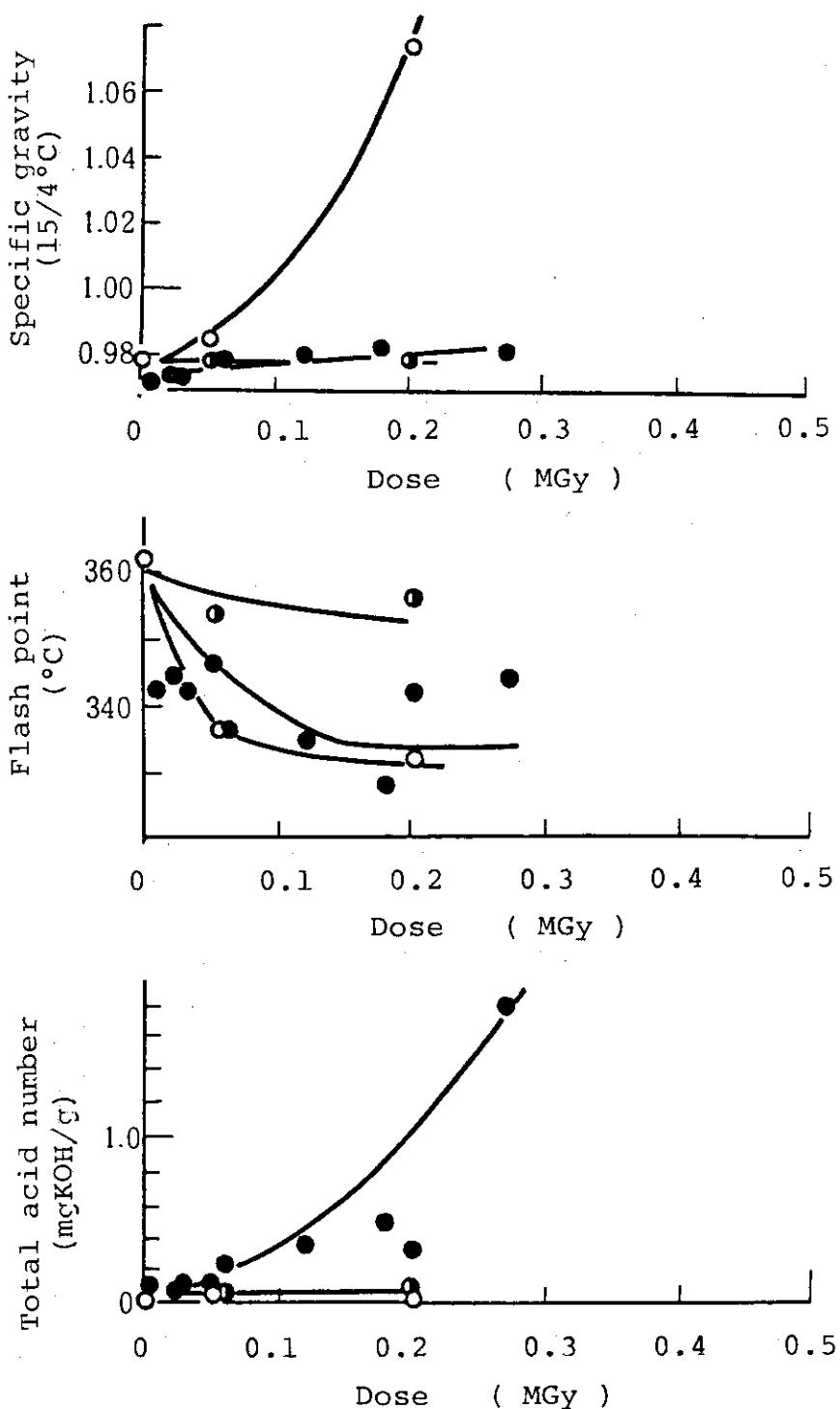
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in vacuum	0.05	441	0.02	336	1(-)	L0.5
	0.2	503	0.02	332	1(-)	L0.5
	0.5	gelation				
in bubbling oxygen	0.005	433	0.11	342	1(-)	L0.5
	0.02	437	0.06	344	1(-)	L0.5
	0.03	435	0.10	342	1(-)	L0.5
	0.05	435	0.11	346	1(-)	L0.5
	0.06	431	0.22	336	1(-)	L0.5
	0.12	436	0.36	334	1(-)	L0.5
	0.18	438	0.48	328	1(-)	L0.5
	0.2	450	0.32	341	1(-)	L0.5
	0.27	453	0.18	344	1(-)	L0.5
	0.5	gelation				
in air	0.05	441	0.03	354	1(-)	L0.5
	0.2	483	0.06	356	1(-)	L0.5
	0.5	gelation				



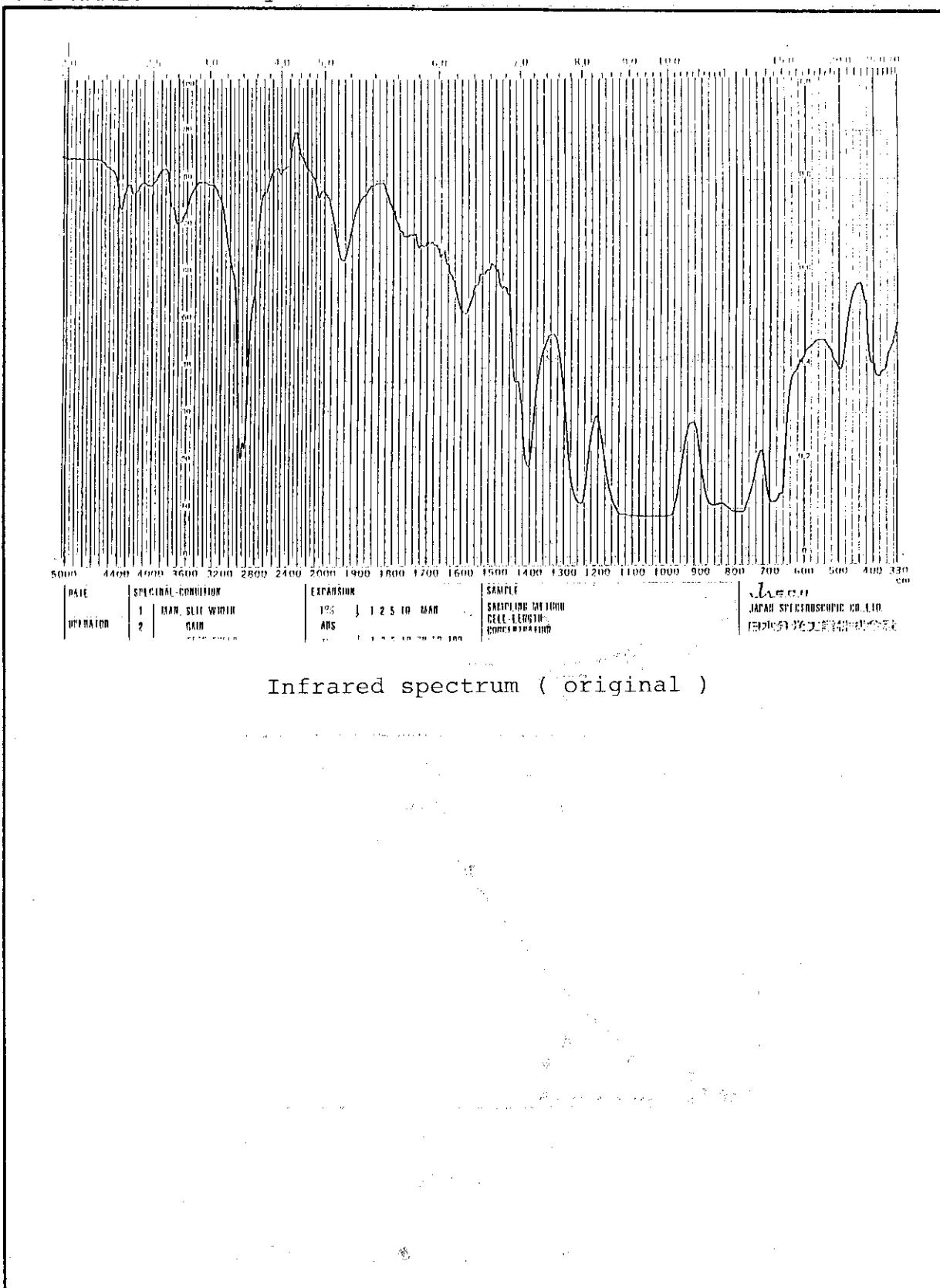
Symbol; ○ in vacuum, ● in air, ● in bubbling oxygen.

OIL NAME: Di-methyl silicone



Symbol; O in vacuum, ● in air, • in bubbling oxygen.

OIL NAME: Di-methyl silicone



OIL NAME : Di-methyl silicone

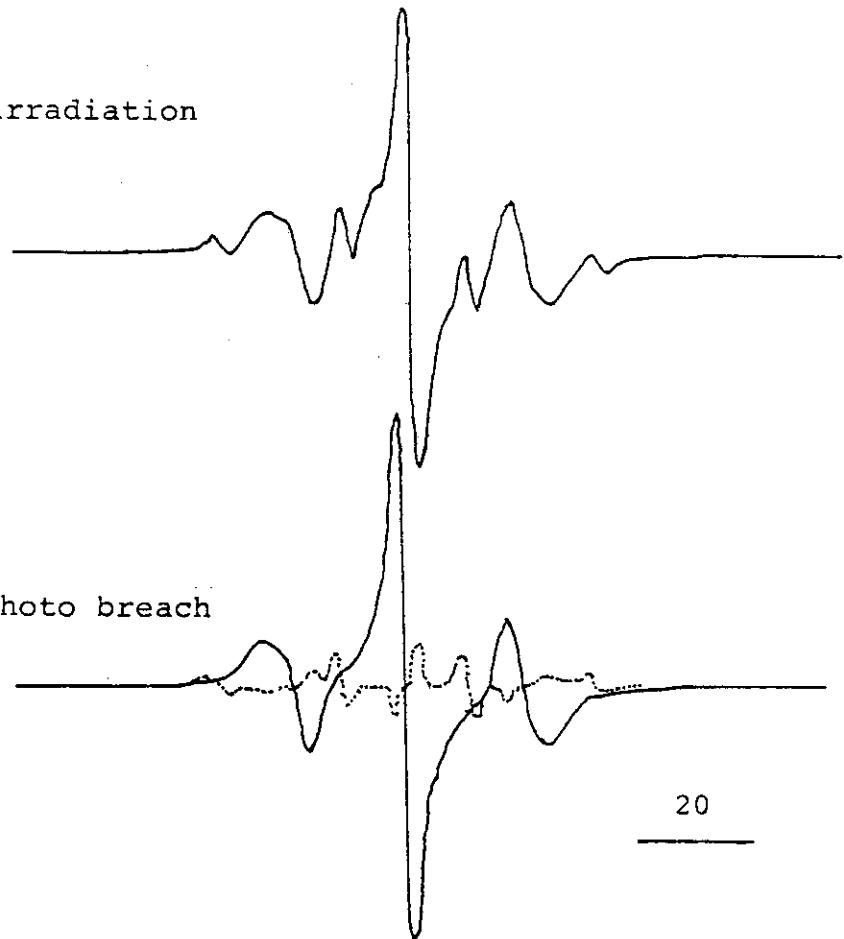
IRRADIATION CONDITION

Temp.: -196°C

Dose 10.45kGy

in Vacuum

after irradiation



after photo breach

20

ESR CONDITION Sweep range(Gauss): \pm 100 Power(μ W): 1
 Modulation width(100kHz,Gauss): 2 at -196°C

G[R.]

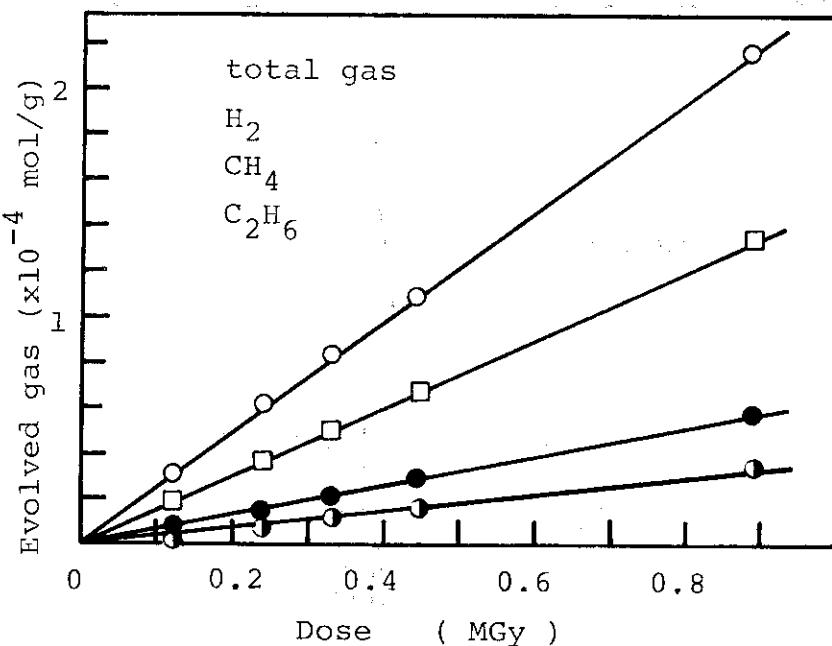
after irradiation

1.2

after Photo breach

1.15

OIL NAME : Di-methyl silicone

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	2.3
$G(H_2)$	6.3×10^{-1}
$G(CH_4)$	1.4
$G(C_2H_6)$	3.0×10^{-1}

AMOUNT OF TOTAL EVOLVED GASES

$$1 \text{ MGy} \quad 2.3 \times 10^{-4} \text{ mol/g}$$

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: Pentaphenyl trimethyl trisiloxane

STRUCTURE OR FEATURE: $\text{CH}_3\text{Si}(\emptyset)_2-\text{OSi}(\emptyset)(\text{CH}_3)-\text{OSi}(\emptyset)_2\text{CH}_3$ MOLECULAR WEIGHT: 546 \emptyset :benzene ringVISCOSITY at 40°C: 59.45×10^{-6} m²/s (7.229 $\times 10^{-6}$ m²/s at 100°C)

VISCOSITY INDEX: 74 SPECIFIC GRAVITY(15/4°C): 1.090

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 244

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

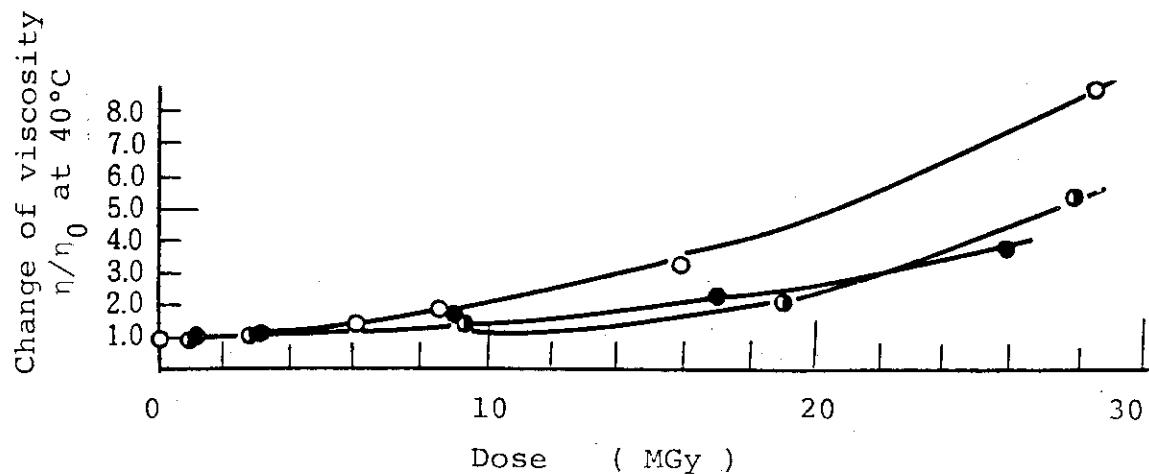
Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6}$ m ² /s (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	n/n_0 (40°C)	n/n_0 (100°C)
in vacuum	2.7	1.094	70.90	8.610	1.19	1.19	
	6.0	1.094	83.90	9.420	1.41	1.30	
	8.6	1.095	97.18	10.39	1.63	1.44	
	15.9	1.140	193.6	15.69	3.26	2.17	
	28.6	1.108	509.3	27.95	8.57	3.87	
in bubbling oxygen	1.0	1.093	61.82	7.736	1.04	1.07	
	3.0	1.094	67.20	8.157	1.13	1.13	
	9.0	1.107	96.16	9.902	1.62	1.37	
	17		138.4	12.07	2.33	1.67	
	26	1.126	220.5	14.90	3.71	2.06	
in air	1.0	1.098	60.99	7.769	1.03	1.07	
	3.0	1.094	65.87	8.228	1.11	1.14	
	9.3	1.095	84.72	9.530	1.43	1.32	
	19	1.108	128.6	12.28	2.16	1.70	
	28	1.106	318.9	23.23	5.36	3.21	

IRRADIATION CONDITION

OIL NAME : Pentaphenyl trimethyl trisloxane

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

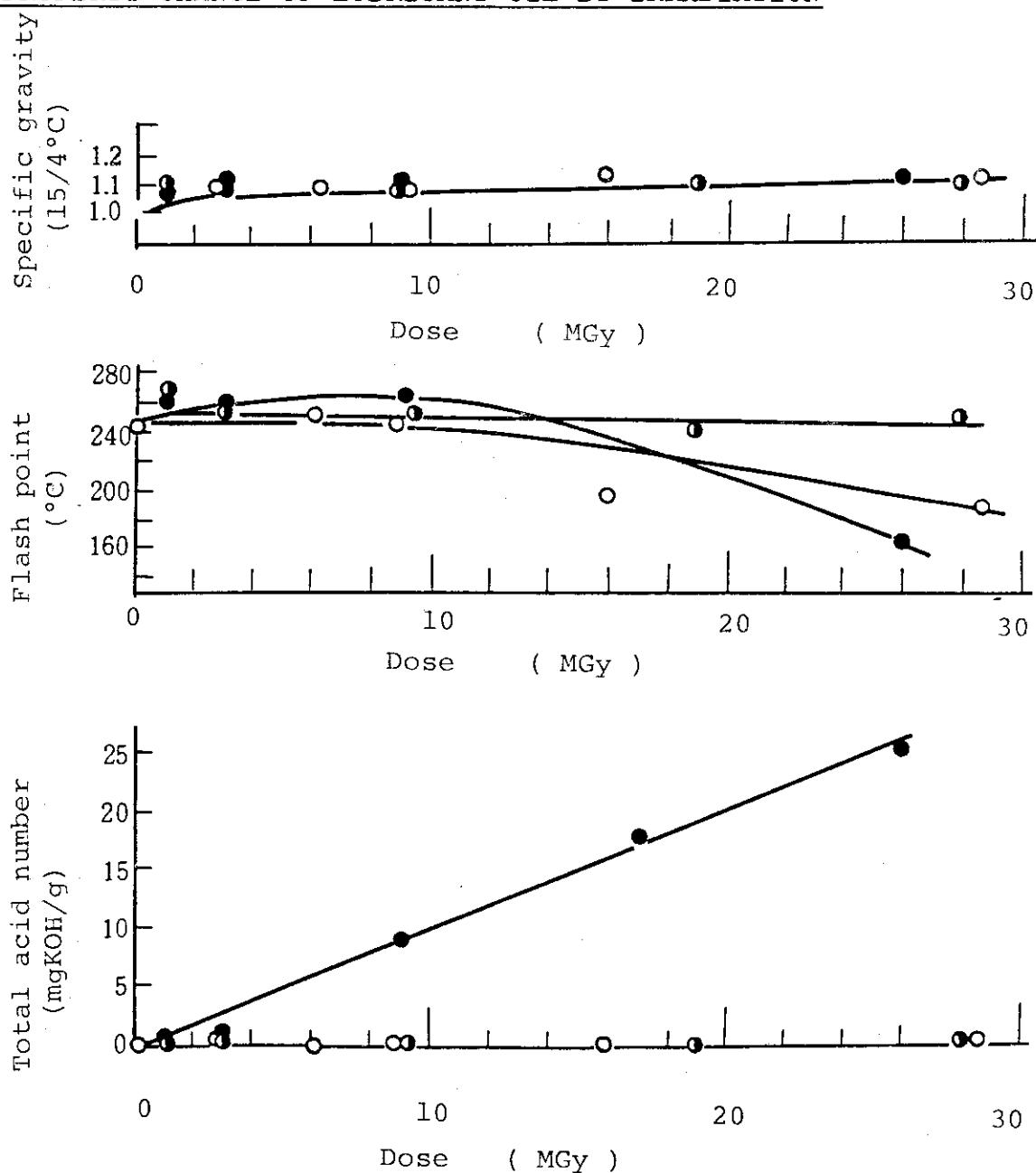
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in vacuum	2.7	91	0.00	258	1	0.5
	6.0	86	0.00	262	1(1/2)	1.0
	8.6	86	0.00	250	1(1/2)	1.0
	15.9	79	0.00	198	3	2.5
	28.6	75	0.00	190	4 (-)	4.0
in bubbling oxygen	1.0	86	0.56	262	2 (-)	L2.0
	3.0	86	1.07	258	3(1/2)	3.0
	9.0	77	8.80	266	6 (-)	L6.5
	17	69	17.9			
	26	50	25.4	168	7 (-)	7.0
in air	1.0	89	0.25	268	1 (-)	L0.5
	3.0	92	0.23	254	1(1/2)	L1.0
	9.3	87	0.20	252	2(1/2)	2.0
	19	83	0.25	244	3	3.0
	28	91	0.42	252	4(1/2)	L4.5



Symbol: ○ in vacuum, ● in air, • in bubbling oxygen.

IRRADIATION CONDITION

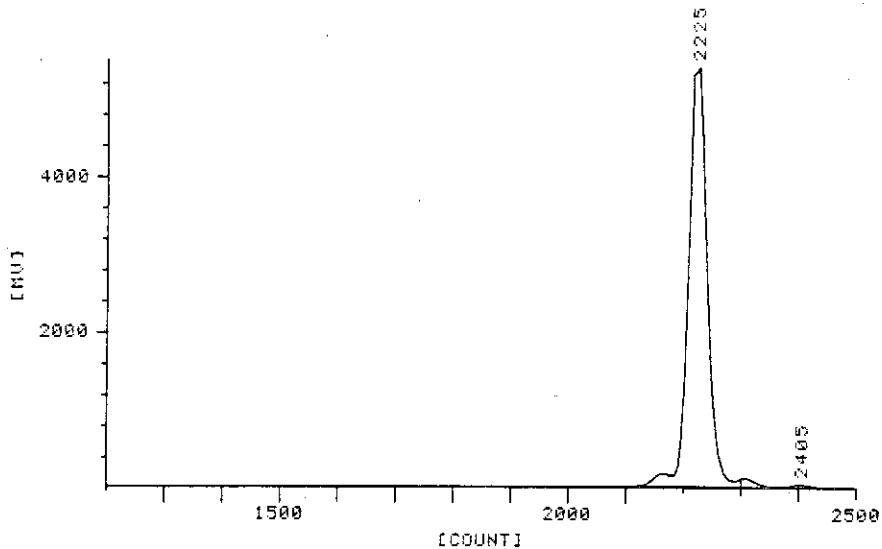
OIL NAME : Pentaphenyl trimethyl trisiloxane

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Symbol: ○ in vacuum, ● in air, ● in bubbling oxygen.

IRRADIATION CONDITION

OIL NAME: Pentaphenyl trimethyl trisiloxane

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/09 19:04 JOB FILE 1

SAMPLE NO. 0 NAME: 8 - 2 SERIAL NO. 0056

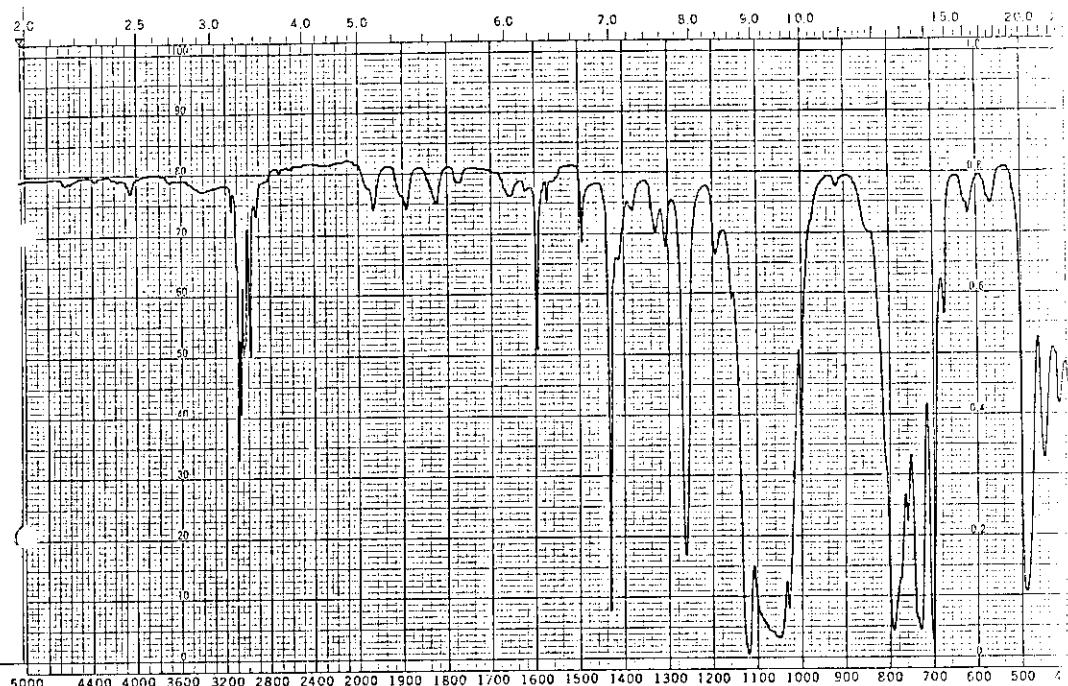
CH.NO 1 METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2110	2225		2365	$5.12495E+02$	$5.13220E+02$	$5.13932E+02$	$5.13219E+02$
V	41.9	5434.3		33.6	MW/MN	MZ/MW	AREA	AREAX%
M	634	512		481	1.00	1.00	$2.10545E+05$	99.52

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2365	2405		2495	$3.68651E+02$	$3.68979E+02$	$3.69300E+02$	$3.68978E+02$
V	33.6	62.6		27.8	MW/MN	MZ/MW	AREA	AREAX%
M	481	369		296	1.00	1.00	$1.01139E+03$	0.48

TOTAL	START	TOP	END	MN	MW	MZ	MU	
C	2110	2225		2495	$5.11541E+02$	$5.12530E+02$	$5.13434E+02$	$5.12529E+02$
V	41.9	5434.3		27.8	MW/MN	MZ/MW	AREA	AREAX%
M	634	512		296	1.00	1.00	$2.11557E+05$	100.00

OIL NAME: Pentaphenyl trimethyl trisiloxane



Infrared spectrum (original)



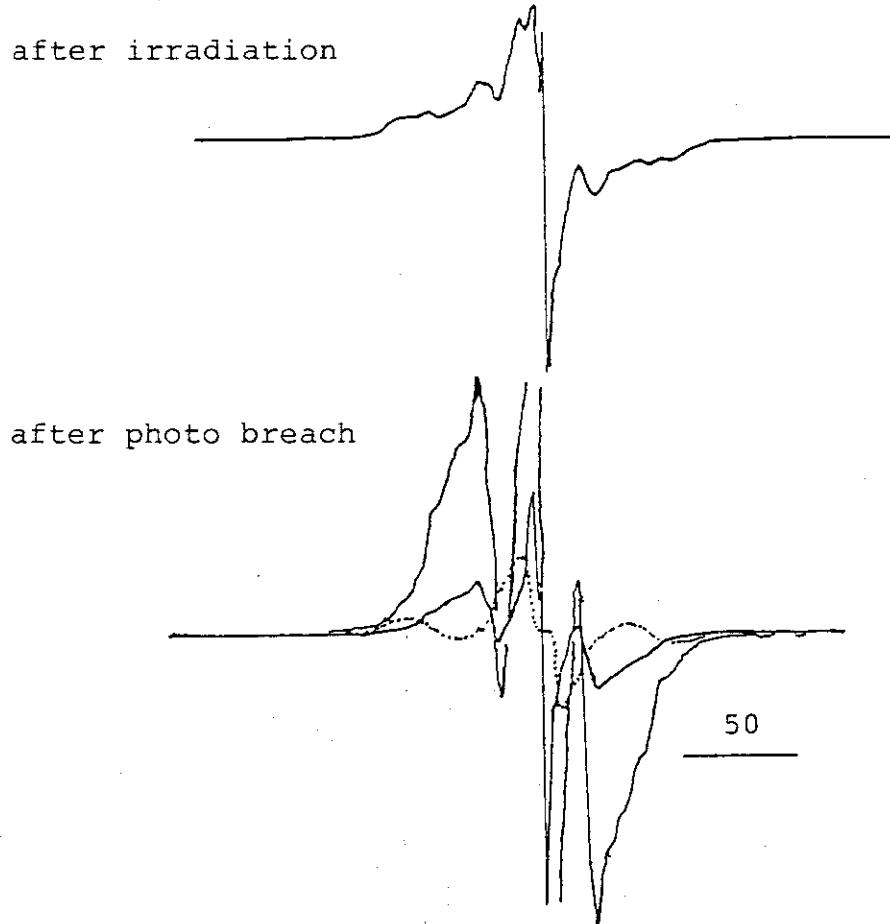
Infrared spectrum (30 MGy in bubbling oxygen)

OIL NAME : Pentaphenyl trimethyl trisiloxaneIRRADIATION CONDITION

Temp.: -196°C

Dose 107.8kGy

in Vacuum

ESR CONDITIONSweep range(Gauss) : \pm 250 Power(μ W) : 1

Modulation width(100kHz, Gauss) : 2 at -196°C

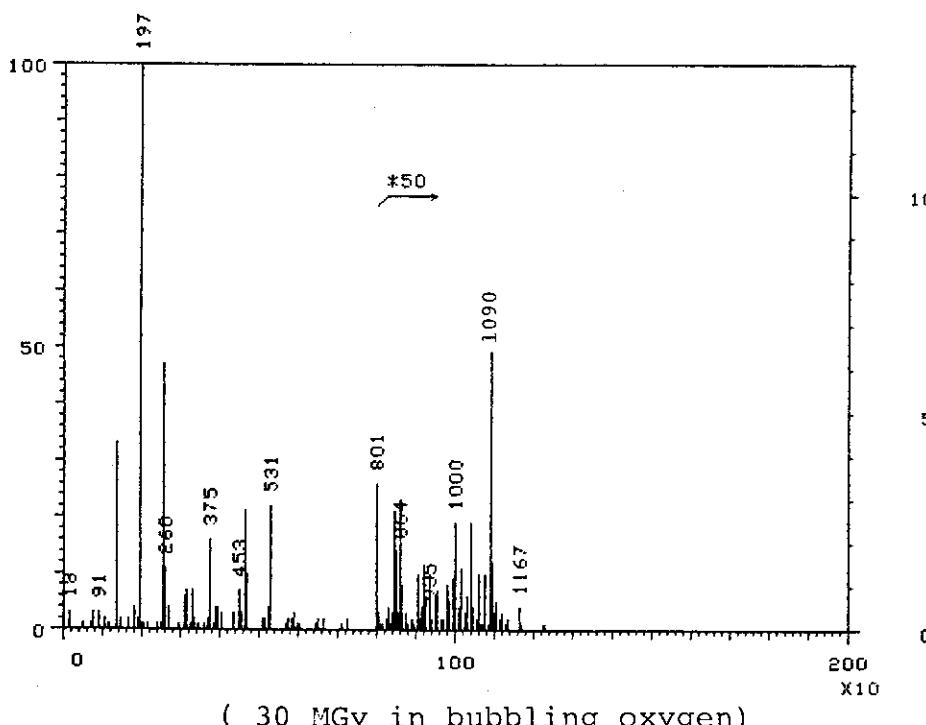
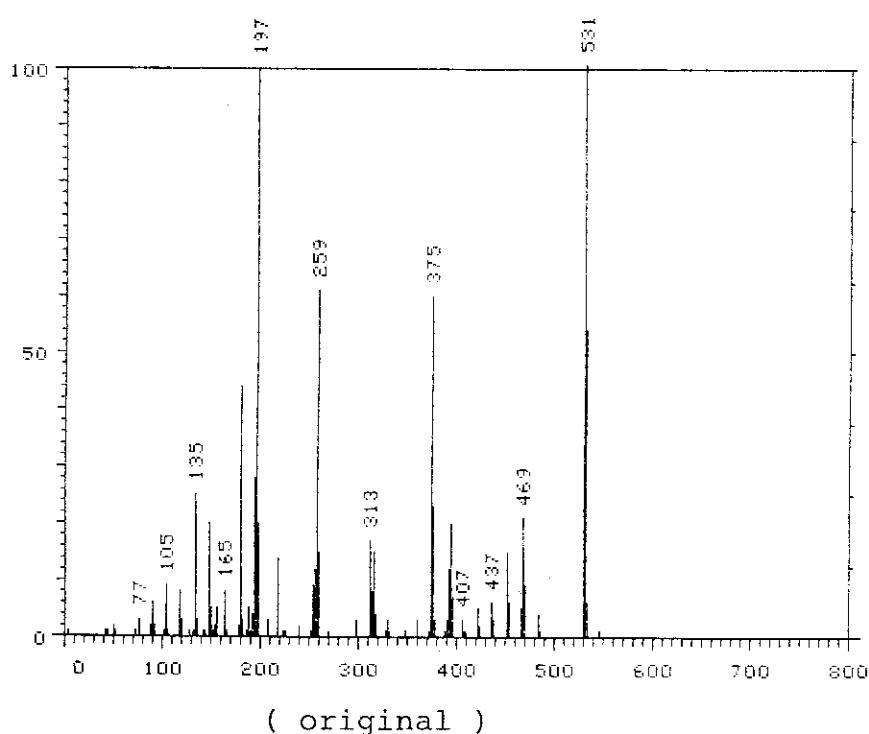
G[R.]after irradiation

0.22

after Photo breach

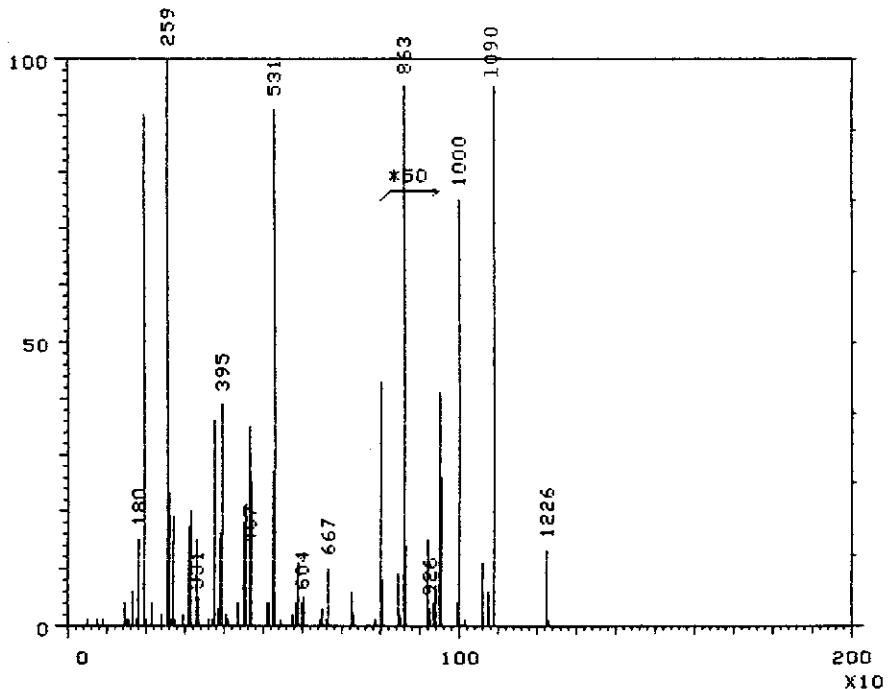
0.14

OIL NAME: Pentaphenyl trimethyl trisiloxane



The mass spectrum of pentaphenyl trimethyl trisiloxane.

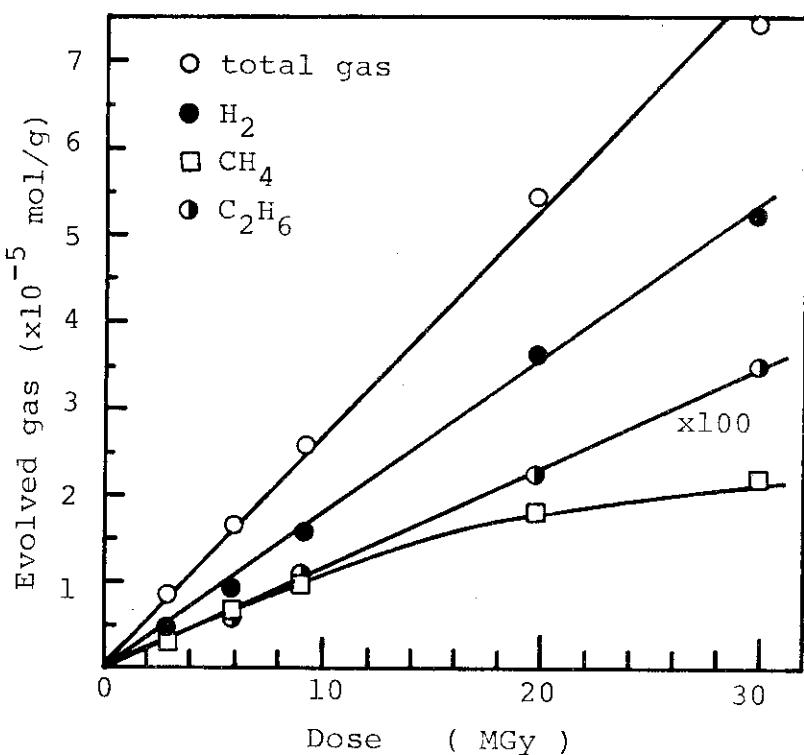
OIL NAME: Pentaphenyl trimethyl trisiloxane



(30 MGy in vacuum)

The mass spectrum of Pentaphenyl trimethyl trisiloxane.

OIL NAME : Pentaphenyl trimethyl trisiloxane

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	2.7×10^{-2}
$G(H_2)$	1.6×10^{-2}
$G(CH_4)$	1.1×10^{-2}
$G(C_2H_6)$	1.2×10^{-4}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-6}$ mol/g)

1 MGy	3.0
10 MGy	27
30 MGy	74

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: Pentaphenyl trimethyl trisiloxane

BREAKDOWN VOLTAGE

Measurement		Breakdown voltage (kV)		
times		original	1 MGy	5 MGy
1	(V ₁)	45.5	45.5	45.5
2	(V ₂)	45.5	40.8	45.5
3	(V ₃)	36.9	45.5	45.5
4	(V ₄)	45.5	45.5	45.5
5	(V ₅)	45.5	45.5	44.3
average (V)		43.4	44.3	45.5
				39.2

COMMENTIRRADIATION CONDITION

3.6 Florinated oil

3.6.1 Polychlorotrifluoroethylene

3.6.2 Trifluoropropyl methyl polysiloxane

3.6.3 Perfluoropolyether

OIL NAME: Polychlorotrifluoroethylene

STRUCTURE OR FEATURE: $\text{CClF-CF}_2\text{n}$

MOLECULAR WEIGHT: 900

VISCOSITY at 40°C: $49.66 \times 10^{-6} \text{ m}^2/\text{s}$ ($4.536 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: -203 SPECIFIC GRAVITY(15/4°C): 1.928

TOTAL ACID NUMBER: 0.02 mgKOH/g, FLASH POINT(°C):

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity	η/η_0	
		(15/4°C)	(40°C)	(100°C)	(40°C)
in vacuum	0.85	1.930	63.87	5.187	1.29
in bubbling oxygen	0.04	1.945	55.89	4.758	1.13
	0.2	1.940	51.60	4.588	1.04
	0.42	1.937	46.27	4.274	0.93
	0.85	1.937	40.88	4.078	0.82
in air	0.04	1.956	51.36	4.637	1.03
	0.17	1.953	54.76	4.698	1.10
	0.42	1.953	58.94	4.968	1.19
	0.85	1.937	68.16	5.343	1.37
					1.18

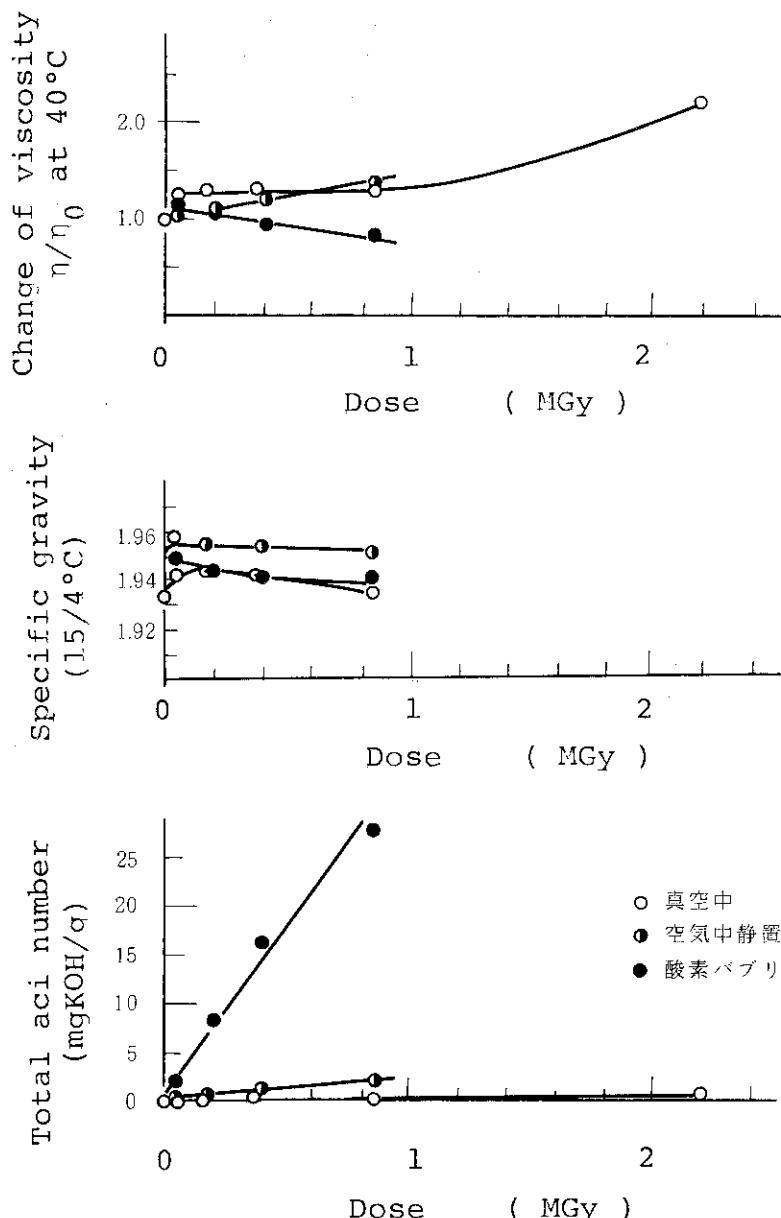
OIL NAME : Polychlorotrifluoroethylene

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	0.85	-153	0.34		1(-)	L0.5
in bubbling oxygen	0.04	-199	2.26		1(-)	L0.5
	0.2	-209	8.42		1(-)	L0.5
	0.42	-256	16.4		1(-)	L0.5
	0.85	-241	28.1		1(-)	L0.5
in air	0.04	-189	0.36		1(-)	L0.5
	0.17	-207	0.77		1(-)	L0.5
	0.42	-167	1.26		1(-)	L0.5
	0.85	-152	2.18		1(-)	L0.5

COMMENTIRRADIATION CONDITION

OIL NAME : Polychlorotrifluoroethylene

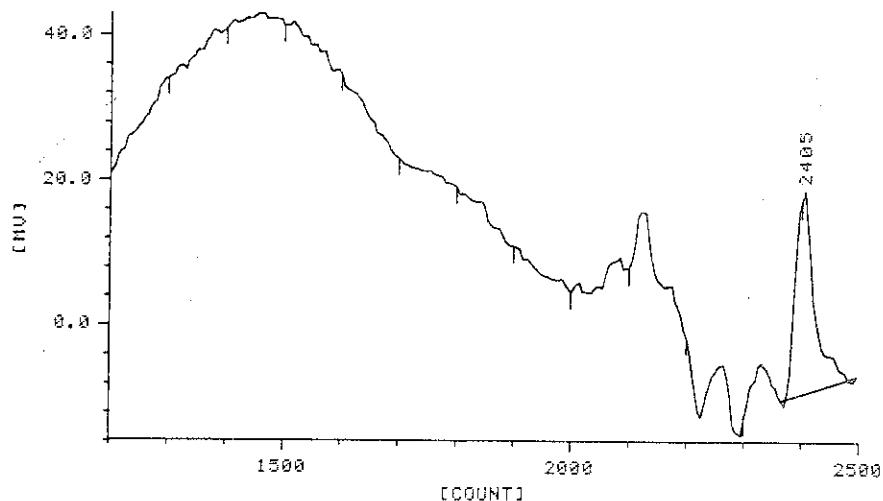
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENT

Symbol: ○ in vacuum, ● in air, • in bubbling oxygen.

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Polychlorotrifluoroethylene

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/09 18:07 JOB FILE 1

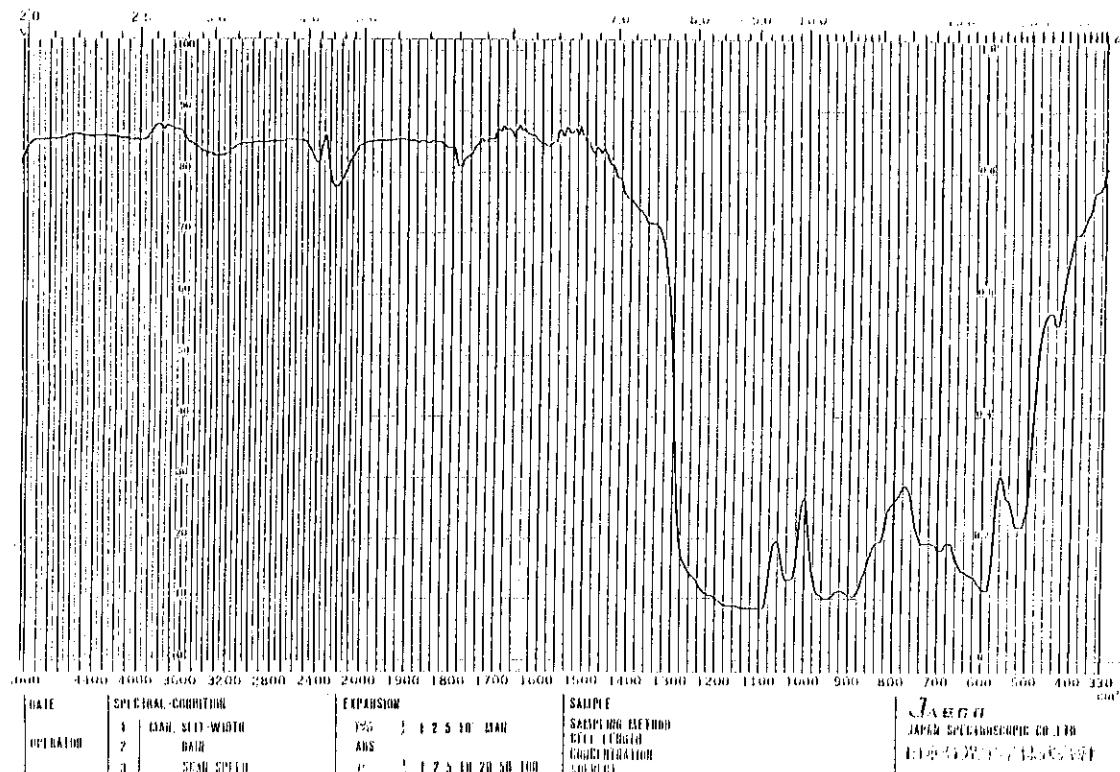
SAMPLE NO. 0 NAME: 12-1

SERIAL NO. 0055

CH.NO 1 METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2365	2405	2495	3.64547E+02	3.65251E+02	3.65921E+02	3.65250E+02	
V	-10.3	18.3	-6.9	MW/MN	MZ/MW	AREA	AREAN%	
M	401	369	296	1.00	1.00	1.06914E+03	100.00	

OIL NAME: Polychlorotrifluoroethylene



Infrared spectrum (original)

OIL NAME : Polychlorotrifluoroethylene

IRRADIATION CONDITION

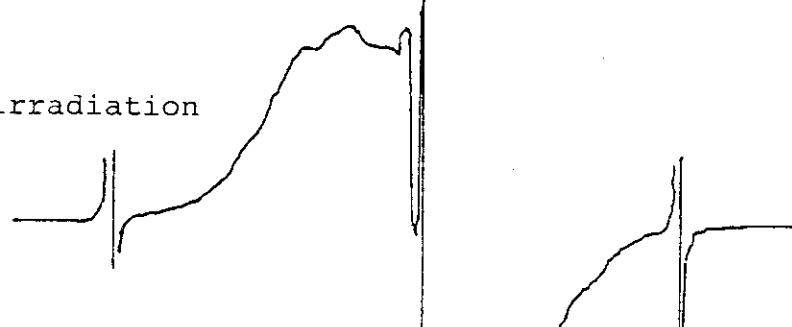
Temp.: -196°C

Dose

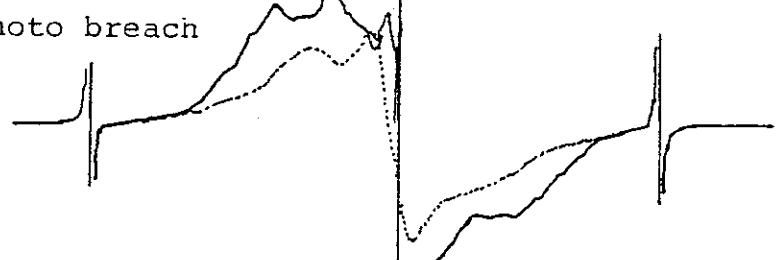
97.6kGy

in Vacuum

after irradiation



after photo breach



100

ESR CONDITIONSweep range(Gauss) : ± 500 Power(μW) : 1

Modulation width(100kHz, Gauss) : 2 at -196°C

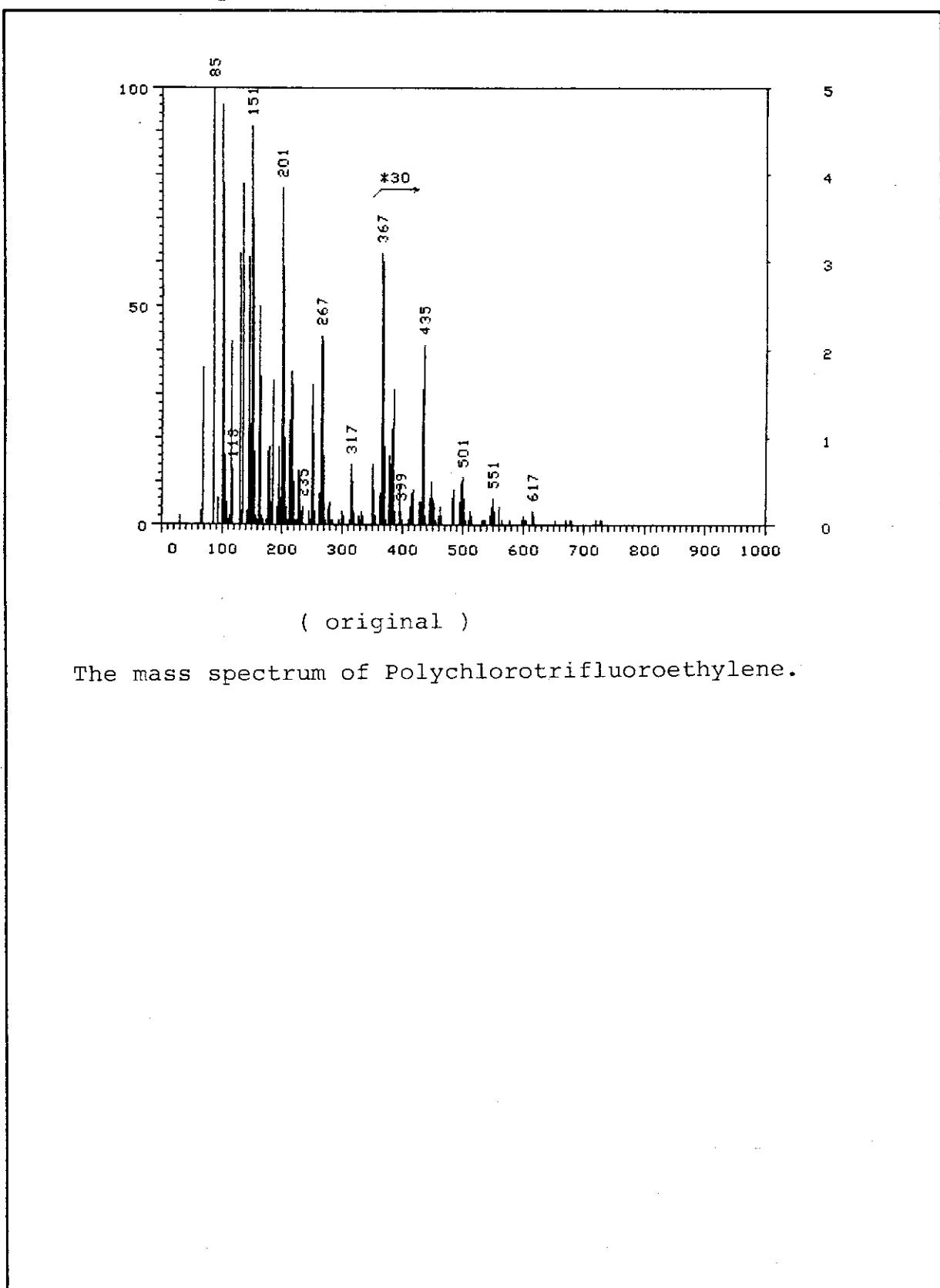
G[R.]

after irradiation after Photo breach

1.5

0.92

OIL NAME: Polychlorotrifluoroethylene



(original)

The mass spectrum of Polychlorotrifluoroethylene.

OIL NAME: Trifluoropropyl methyl polysiloxane

STRUCTURE OR FEATURE: $(\text{CH}_3)_3\text{Si-O-Si}(\text{CH}_3)(\text{C}_2\text{H}_4\text{CF}_3)\text{O}_n\text{Si}(\text{CH}_3)_3$

MOLECULAR WEIGHT:

VISCOSITY at 40°C: $150.4 \times 10^{-6} \text{ m}^2/\text{s}$ ($27.07 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: 218 SPECIFIC GRAVITY(15/4°C): 1.251

TOTAL ACID NUMBER: 0.02 mgKOH/g, FLASH POINT(°C):

COLOR: UNION 1(-) , ASTM L0.5.

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (40°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (100°C)	n/n_0 (40°C)	n/n_0 (100°C)
in vacuum	0.05	1.245	156.62	27.92	1.04	1.03	
	0.2	1.245	169.3	30.21	1.13	1.12	
	0.4	1.245	185.3	33.06	1.23	1.22	
	0.9	1.245	266.3	46.40	1.77	1.71	
	2.3	gelation					
in	0.05	1.240	149.8	27.00	1.00	1.00	
bubbling	0.1	1.242	148.5	27.05	0.99	1.00	
oxygen	0.28	1.241	146.9	26.45	0.98	0.98	
	0.45	1.248	148.3	26.57	0.99	0.98	
in air	0.06	1.248	155.1	27.80	1.03	1.03	
	0.20	1.246	166.4	29.61	1.11	1.09	
	0.46	1.248	194.4	33.74	1.29	1.25	
	0.9	1.258	278.5	45.70	1.85	1.69	

OIL NAME : Trifluoropropyl methyl polysiloxane

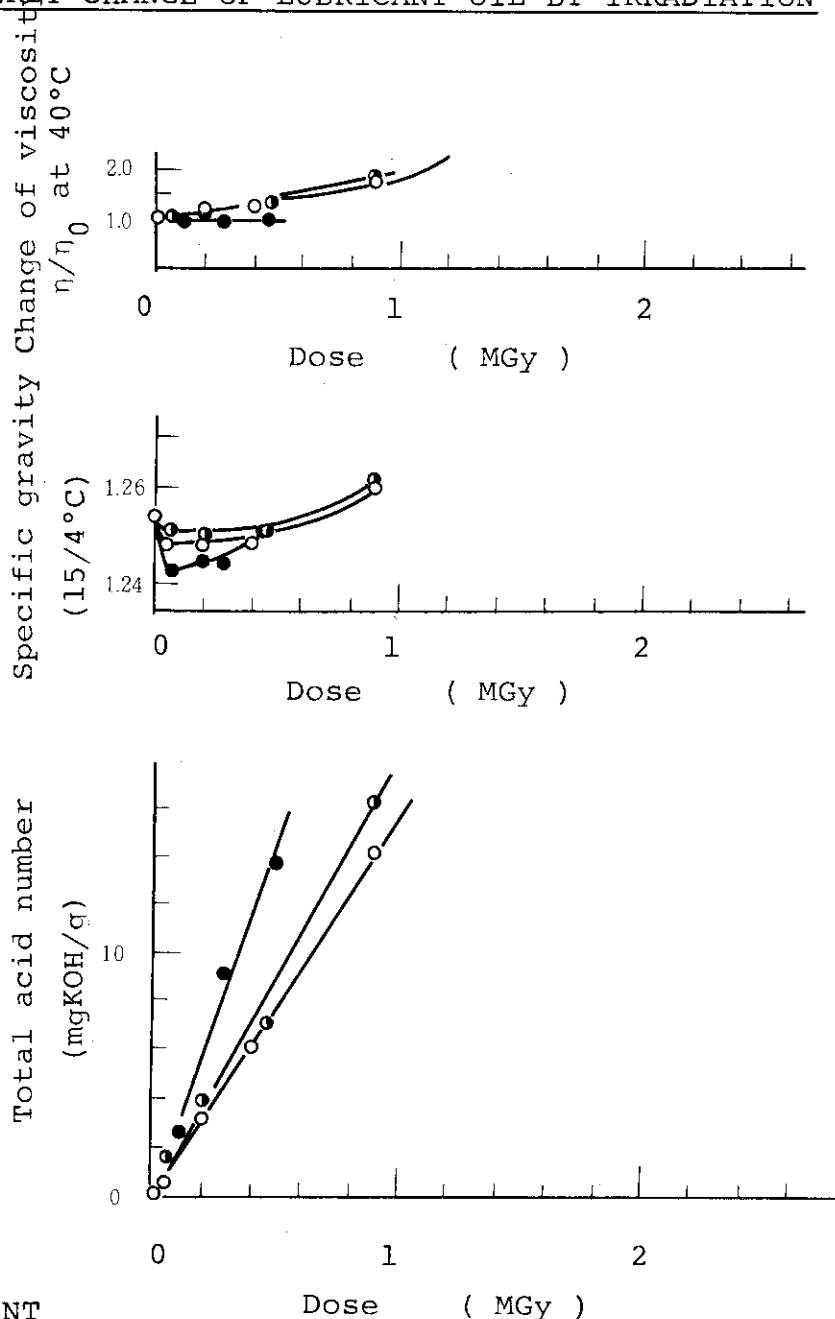
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in vacuum	0.05	218	0.52		1 (-)	L0.5
	0.2	221	3.05		1 (-)	L0.5
	0.4	225	6.14		1 (-)	L0.5
	0.9	235	14.1		1 (-)	L0.5
	2.3	gelation				
in bubbling oxygen	0.05	218	1.58		1 (-)	L0.5
	0.1	220	2.56		1 (-)	L0.5
	0.28	217	9.04		1 (-)	L0.5
	0.45	217	13.7		1 (-)	L0.5
in air	0.06	219	1.62		1 (-)	L0.5
	0.2	220	3.91		1 (-)	L0.5
	0.46	221	7.12		1 (-)	L0.5
	0.9	224	16.2		1 (-)	L0.5

COMMENTIRRADIATION CONDITION

OIL NAME : Trifluoropropyl methyl polysiloxane

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION



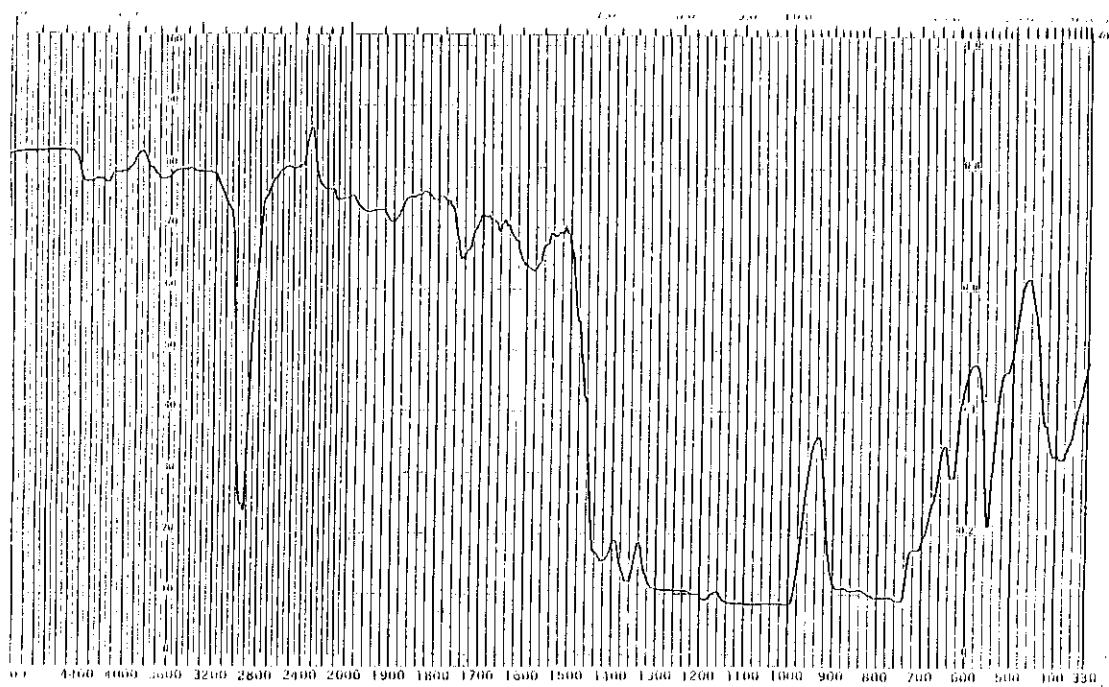
COMMENT

Symbol: \circ in vacuum, \bullet in air, \blacksquare in bubbling oxygen.

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Trifluoropropyl methyl polysiloxane



DATE	SPECTRAL CONDITION	EXPANSION	SAMPLE	JASCO
RETRATOR	1. LIQUID, SLIT WIDTH	15x 1 2 5 10 MAN	SAMPLING-METHOD	JAPAN SPECTROSCOPIC CO., LTD.
2.	REIN	AUS	CELL 112610	FIRBOSYUKEI SEISAKUSHO
3.	STAR SPEED	P 1 2 5 10 20 50 100	CORR-BUTTON	
			SAMPLE	1001

Infrared spectrum (original)

OIL NAME : Trifluoropropyl methyl polysiloxane

IRRADIATION CONDITION

Temp.: -196°C

Dose

9.9kGy

in Vacuum

after irradiation

after photo breach

50

ESR CONDITIONSweep range(Gauss): ± 250 Power(μW): 1

Modulation width(100kHz, Gauss): 2 at -196°C

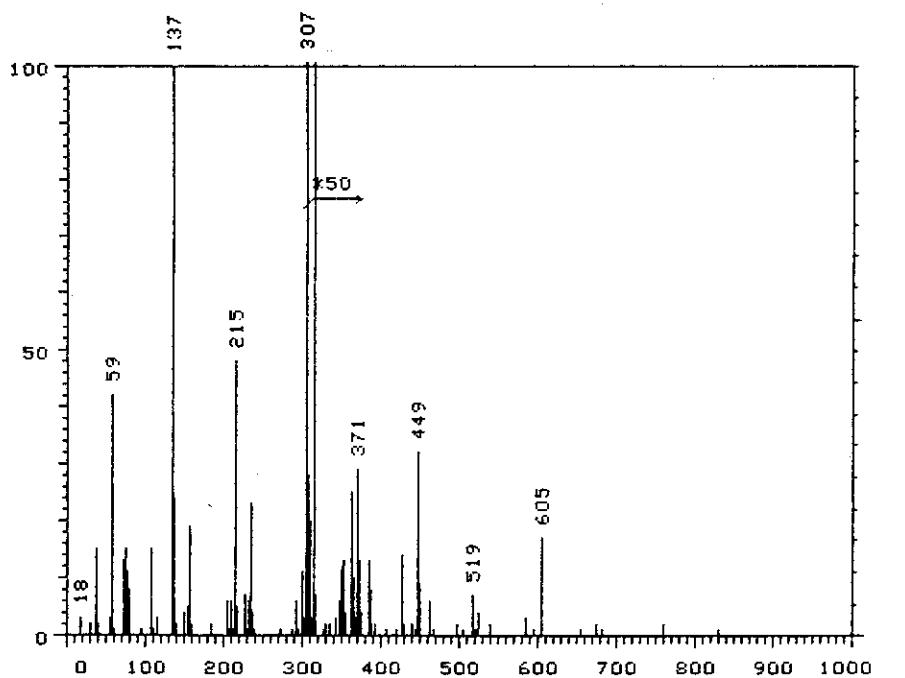
G[R.]

after irradiationafter Photo breach

3.4

3.1

OIL NAME: Trifluoropropyl methyl polysiloxane



(Original)

The mass spectrum of Trifluoropropyl methyl polysiloxane.

OIL NAME: Perfluoropolyether

STRUCTURE OR FEATURE: $\text{CF}_3\text{O}+\text{CF}(\text{CF}_3)-\text{CF}_2-\text{O}+\text{x}+\text{CF}_2\text{O}+\text{y}\text{CF}_3$

MOLECULAR WEIGHT: 3000

 $x:y = 10:1$ VISCOSITY at 40°C: $82.16 \times 10^{-6} \text{ m}^2/\text{s}$ ($10.63 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: 114 SPECIFIC GRAVITY(15/4°C): 1.893

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C):

COLOR: UNION 1(-), ASTM L0.5.

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (40°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (100°C)	n/n_0 (40°C)	n/n_0 (100°C)
in vacuum	0.05	1.887	79.61	10.35	0.97	0.97	
	0.2	1.882	73.90	10.05	0.90	0.95	
	0.42	1.880	67.64	9.690	0.82	0.91	
	0.85	1.893	79.25	9.824	0.96	0.92	
in bubbling oxygen	0.05	1.883	80.18	10.54	0.98	0.99	
	0.1	1.879	77.17	10.66	0.94	1.00	
	0.25	1.883	68.64	9.456	0.84	0.89	
	0.42	1.878	61.69	8.654	0.75	0.81	
in air	0.05	1.892	81.54	10.58	0.99	1.00	
	0.2	1.894	81.12	10.75	0.99	1.01	
	0.42	1.894	80.28	10.28	0.98	0.97	
	0.85	1.885	64.30	9.167	0.78	0.86	

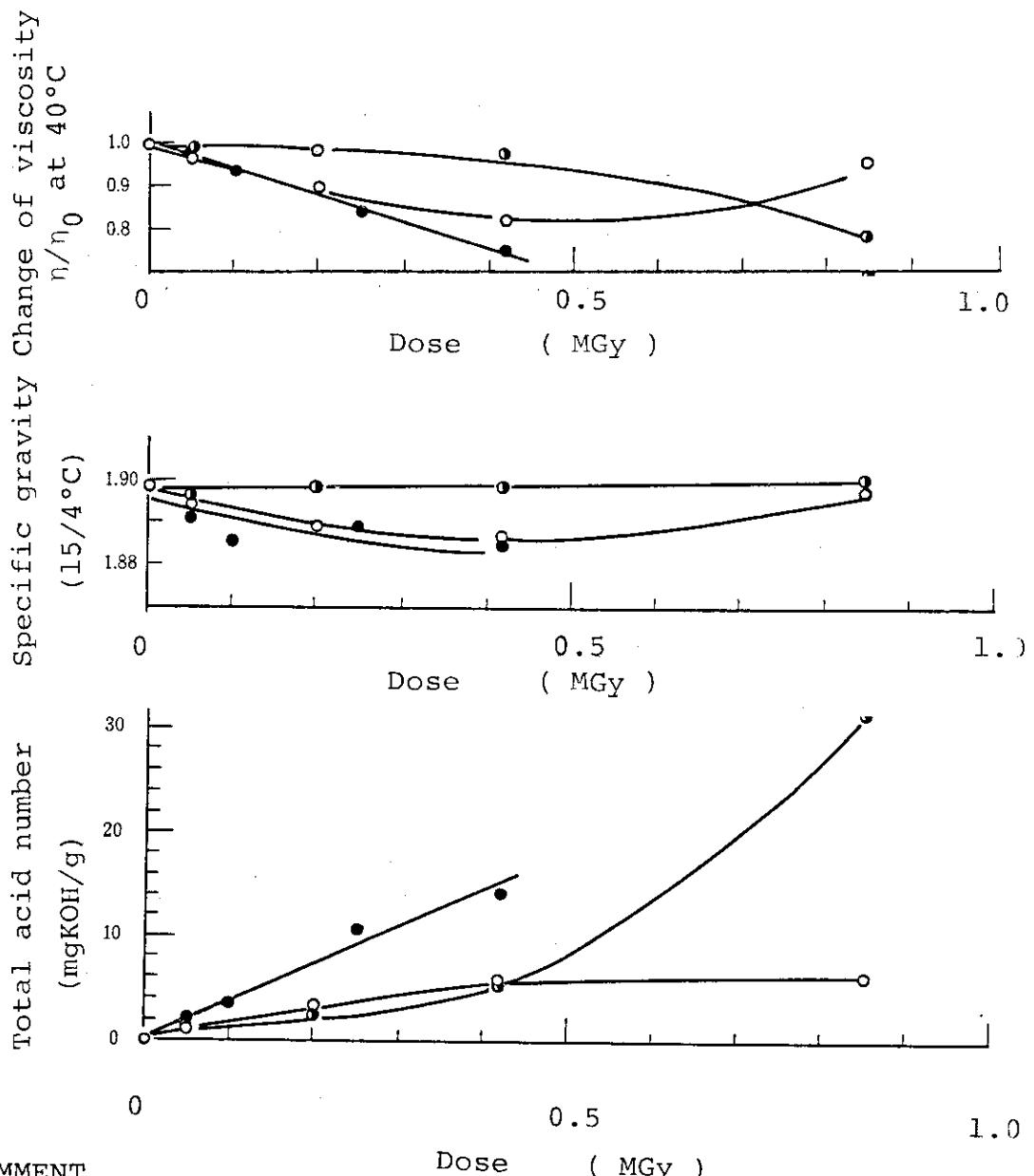
OIL NAME : Perfluoropolyether

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in vacuum	0.05	113	0.90		1 (-)	L0.5
	0.2	118	3.28		1 (-)	L0.5
	0.42	124	5.74		1 (-)	L0.5
	0.85	103	6.14		1 (-)	L0.5
in bubbling oxygen	0.05	116	1.92		1 (-)	L0.5
	0.1	124	3.39		1 (-)	L0.5
	0.25	116	10.7		1 (-)	L0.5
	0.42	113	14.2		1 (-)	L0.5
in air	0.05	114	0.99		1 (-)	L0.5
	0.2	118	2.26		1 (-)	L0.5
	0.42	110	5.48		1 (-)	L0.5
	0.85	120	31.6		1 (-)	L0.5

COMMENTIRRADIATION CONDITION

OIL NAME : Perfluoropolyether

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENT

Symbol: ○ in vacuum, ● in air, • in bubbling oxygen.

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Perfluoropolyether

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	(40°C)	(100°C)	n/n_0 (40°C)	(100°C)
<u>in air</u>							
8.5	0.85	1.885	64.30	9.167	0.78	0.86	
2.6	0.85	1.882	65.58	8.39	0.80	0.99	
0.85	0.85	1.883	64.46	8.14	0.78	0.77	
0.43	0.85	1.884	66.05	8.49	0.80	0.80	

OIL NAME: Perfluoropolyether

DOSE RATE EFFECT

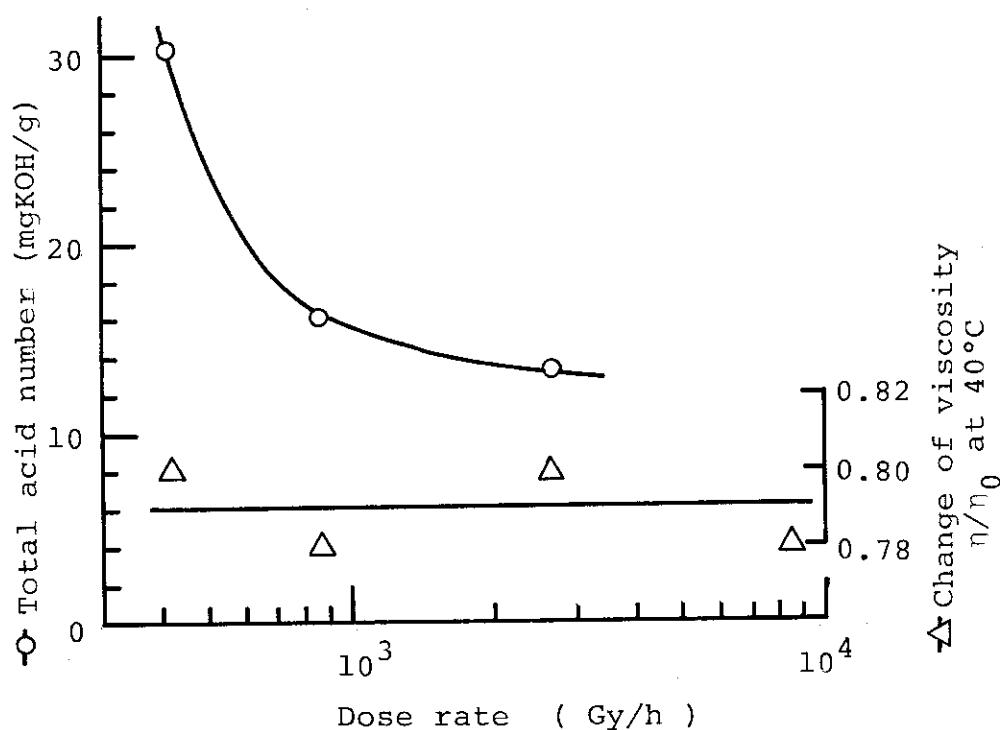
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
<u>in air</u>						
8.5	0.85	120	31.6		1(-)	L0.5
2.6	0.85	104	13.32		1(-)	L0.5
0.85	0.85	92	15.76		1(-)	L0.5
0.43	0.85	98	30.50		1(-)	L0.5

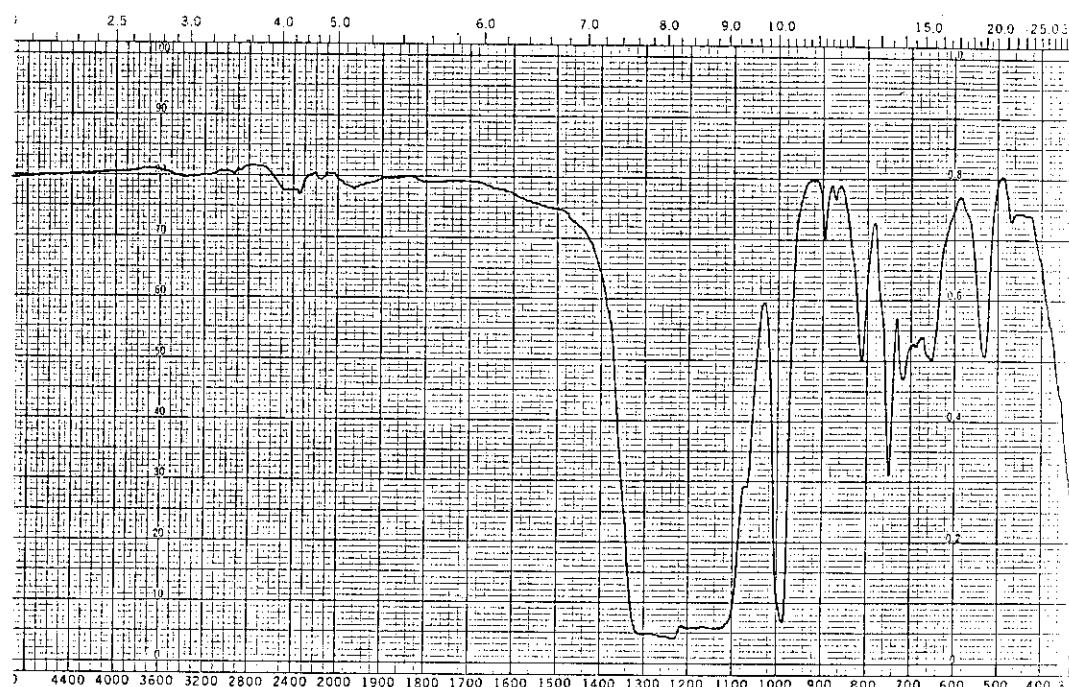
OIL NAME: Perfluoropolyether

DOSE RATE EFFECT

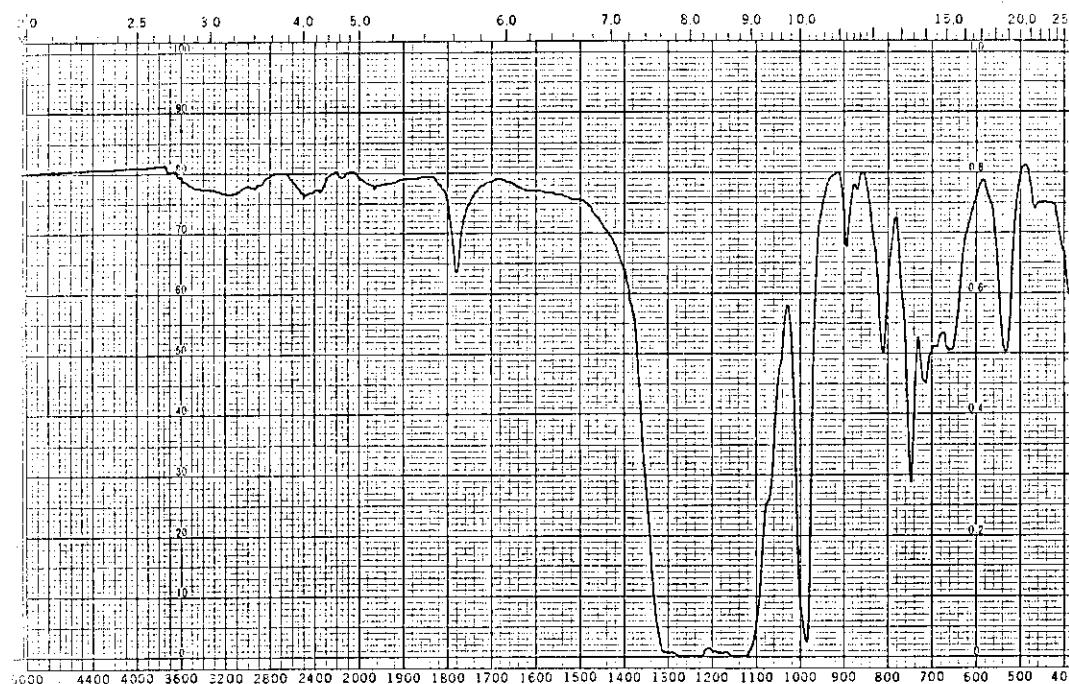
(in air, total dose 0.85 MGy)

COMMENTIRRADIATION CONDITION

OIL NAME: Perfluoropolyether



Infrared spectrum (original)

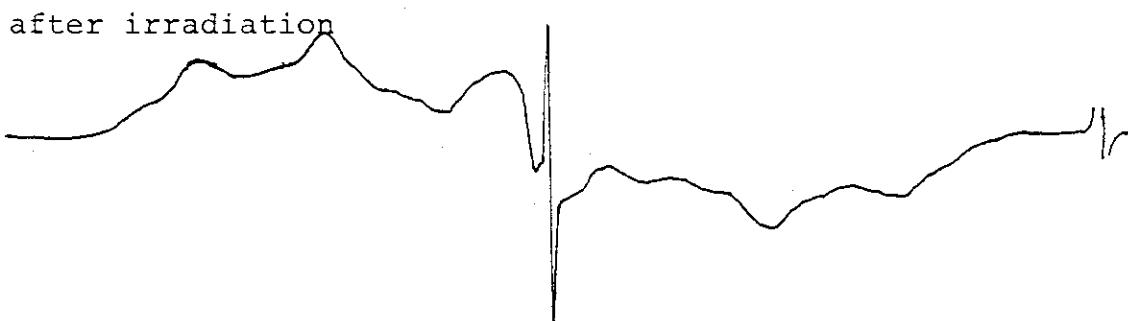


Infrared spectrum (1 MGy in air)

OIL NAME : Perfluoropolyether

IRRADIATION CONDITION

Temp.: -196°C Dose 9.3kGy in Vacuum

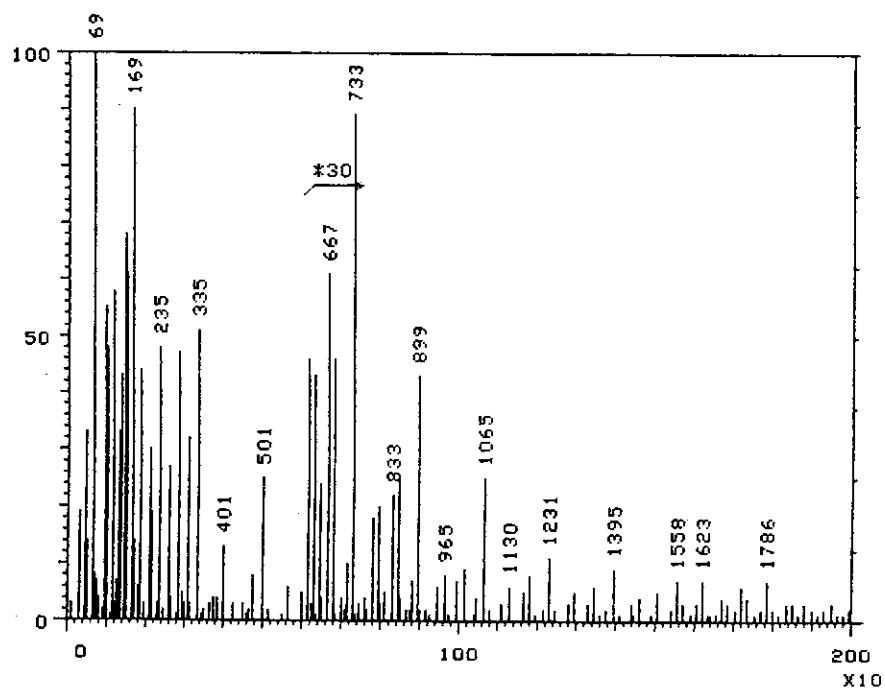


50

<u>ESR CONDITION</u>	Sweep range(Gauss): ± 250	Power(μW): 1
	Modulation width(100kHz, Gauss): 2 at -196°C	

<u>G[R·]</u>	<u>after irradiation</u>	<u>after Photo breach</u>
	3.4	3.1

OIL NAME: Perfluoropolyether



(original)

The mass spectrum of Perfluoropolyether.

3.7 Aromatic oils

- 3.7.1 Dialkyl benzene
- 3.7.2 Mono-alkyl diphenyl ether C-14
- 3.7.3 Mono-alkyl diphenyl ether C-16
- 3.7.4 Mono-alkyl diphenyl ether C-18
- 3.7.5 Di-alkyl diphenyl ether C-16
- 3.7.6 m-(m-Phenoxyphenoxy)diphenyl
- 3.7.7 Pentaphenyl ether
- 3.7.8 mix-Alkyl diphenyl ether
- 3.7.9 mix-Phenoxyphenoxy diphenyl
- 3.7.10 mix-Poly phenyl ether

OIL NAME: Dialkyl benzene

STRUCTURE OR FEATURE: R- \emptyset -R, R:alkyl C-12, \emptyset :benzene ring.

MOLECULAR WEIGHT: 400

VISCOSITY at 40°C: 37.30×10^{-6} m²/s (5.704 $\times 10^{-6}$ m²/s at 100°C)

VISCOSITY INDEX: 90 SPECIFIC GRAVITY(15/4°C): 0.890

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 208

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6}$ m ² /s (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	n/n_0 (40°C)	n/n_0 (100°C)
in vacuum	0.2	0.880	29.35	4.900	1.03	1.00	
	0.5	0.880	30.46	5.070	1.07	1.04	
	1.0	0.889	37.30	5.704	1.30	1.17	
	3.0	0.891	41.61	6.125	1.45	1.25	
	5.5	0.891	43.48	6.596	1.52	1.35	
	9.0	0.894	55.37	7.946	1.94	1.62	
	20.5	0.907	228.5	20.15	7.99	4.12	
in bubbling oxygen	0.05	0.890	29.00	4.892	1.01	1.00	
	0.23	0.890	29.61	4.944	1.04	1.01	
	0.5	0.890	30.93	5.109	1.08	1.04	
	0.98	0.893	32.90	5.219	1.15	1.07	
	2.9	0.898	38.10	5.556	1.33	1.13	
	4.4	0.903	43.60	6.033	1.52	1.23	
	9.4	0.914	67.23	7.715	2.35	1.58	
	18		148.7	12.11	5.20	2.47	
	28	0.957	365.5	20.31	12.8	4.15	
	0.05	0.886	28.56	4.864	1.00	0.99	
in air	0.2	0.887	29.14	4.886	1.02	1.00	
	0.5	0.887	30.00	5.090	1.05	1.04	
<u>IRRADIATION CONDITION</u>							

OIL NAME : Dialkyl benzene

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	(40°C)	(100°C)	n/n_0 (40°C)	(100°C)
in air	1.00	0.893	31.56	5.187	1.10	1.10	1.06
	3.1	0.891	42.91	6.256	1.50	1.50	1.28
	5.0	0.892	41.08	6.303	1.44	1.44	1.29
	7.7	0.894	47.37	6.855	1.66	1.66	1.40
	10.5	0.898	56.09	7.580	1.96	1.96	1.55
	20	0.909	122.1	12.94	4.27	4.27	2.64
	30	0.914	268.0	21.20	9.37	9.37	4.33

COMMENTIRRADIATION CONDITION

OIL NAME : Dialkyl benzene

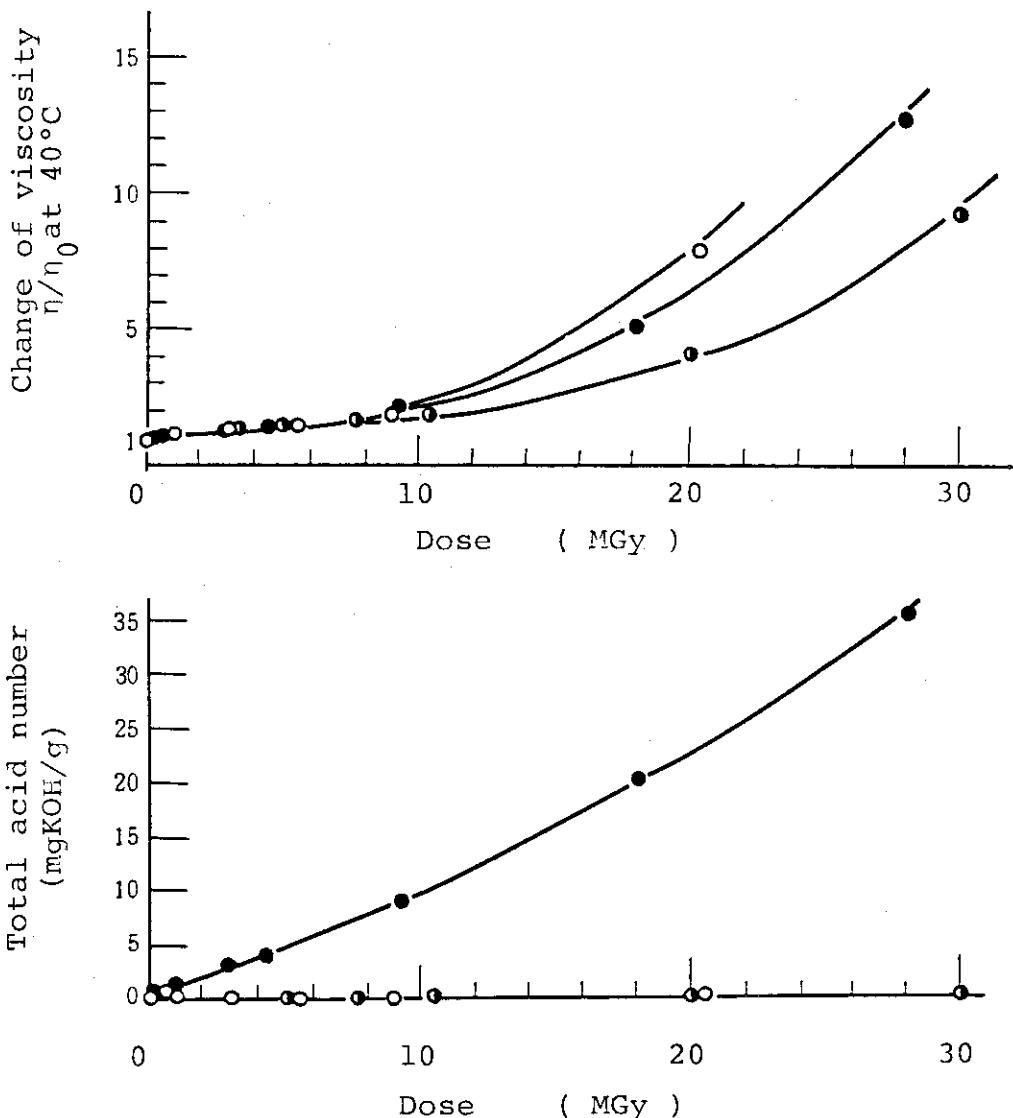
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	0.2	83	0.42	206	1(1/2)	L1.0
	0.5	89	0.77	208	2(-)	1.5
	1.0	88	0.42	218	2(1/2)	L2.0
	3.0	90	0.37	208	3	L3.0
	5.5	103	0.19	188	5	5.5
	9.0	110	0.10	172	6	6.5
	20.5	102	0.11	170	7	7.0
in bubbling oxygen	0.05	86	0.17	206	2(-)	L1.5
	0.23	85	0.34	206	3(1/2)	2.5
	0.5	89	0.65	206	4(-)	L3.5
	0.98	83	1.24	206	4(1/2)	L4.0
	2.9	71	3.00	208	5(-)	L6.0
	4.4	74	4.18	198	6(-)	L6.5
	9.4	71	9.19	145	6(-)	L6.5
	18	59	20.3			
	28	52	35.5	142	7(-)	7.0
in air	0.05	87	0.05	218	1(1/2)	L1.0
	0.2	84	0.14	208	2(1/2)	L2.0
	0.5	95	0.22	206	3(1/2)	L3.0
	1.0	91	0.14	214	4	4.0
	3.1	92	0.17	206	7(-)	7.0
	5.0	100	0.13	218	4	4.5
	7.7	99	0.16	214	4	4.5
	10.5	97	0.35	208	5(-)	L5.0
	20	99	0.22	206	5(-)	L5.0
	30	94	0.32	208	5	6.0

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Dialkyl benzene

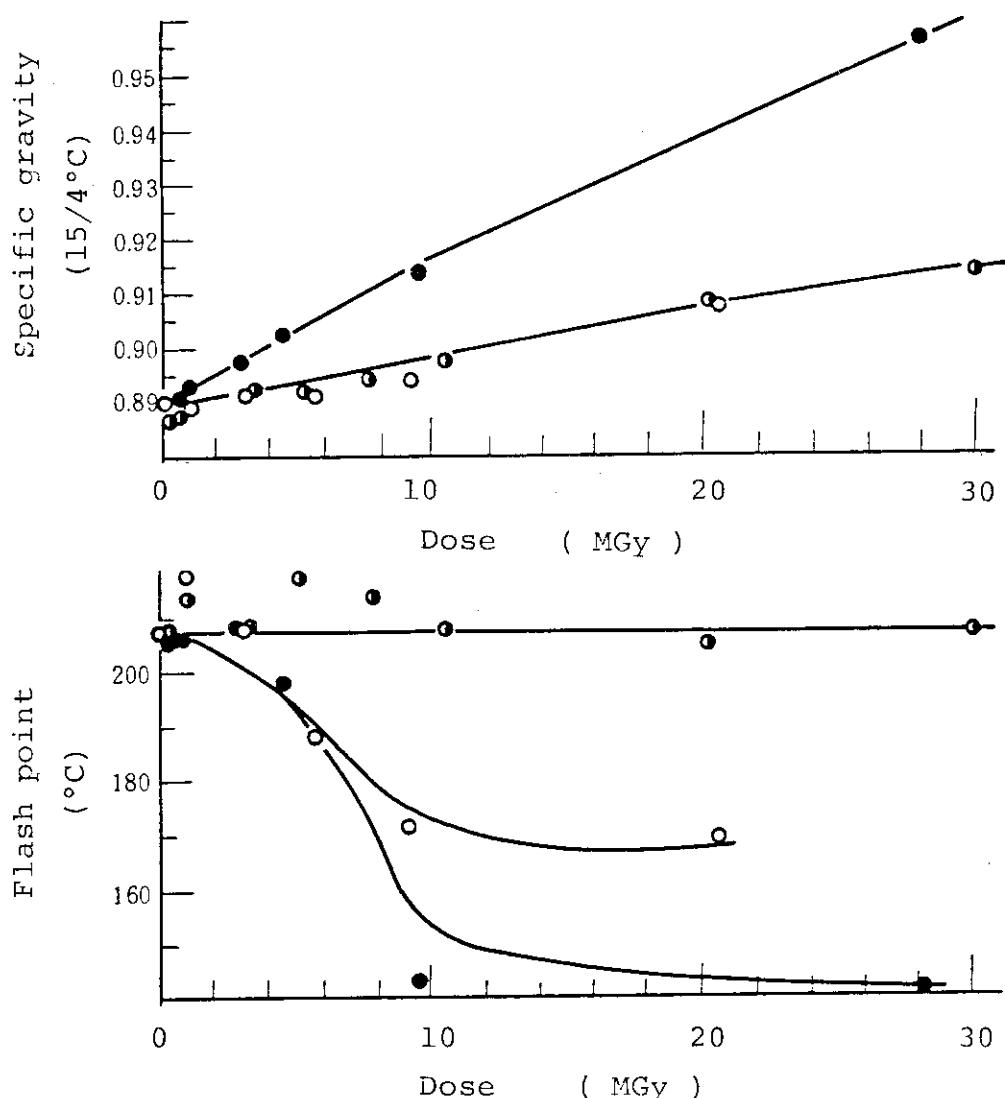


Symbol: O in vacuum, ● in air, • in bubbling oxygen.

COMMENTIRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Dialkyl benzene



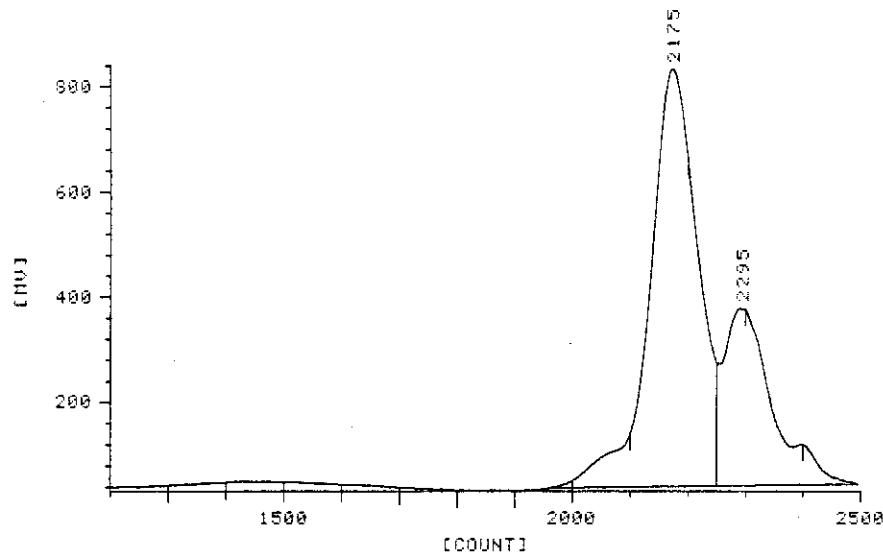
Symbol: ○ in vacuum, ● in air, • in bubbling oxygen.

COMMENT

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Dialkyl benzene

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/09 13:39 JOB FILE 1

SAMPLE NO. 0 NAME: 9 - O

SERIAL NO. 0049

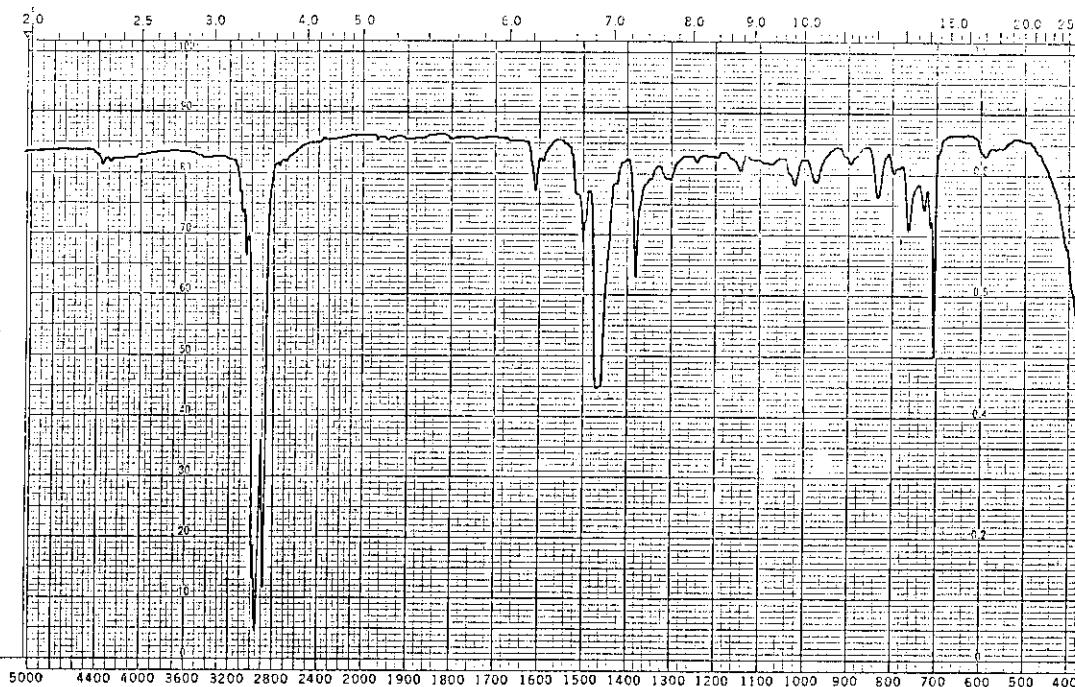
CH.NO 1 METHOD 2

PEAK NO. 1		BASE	MN	MW	MZ	MU	
START	TOP	END	MN	MW	MZ	MU	
C	1960	2175	2250	5.64860E+02	5.69718E+02	5.75449E+02	5.69716E+02
U	35.4	832.8	270.9	MW/MN	MZ/MW	AREA	AREAN
M	1012	558	491	1.01	1.01	7.65129E+04	69.37

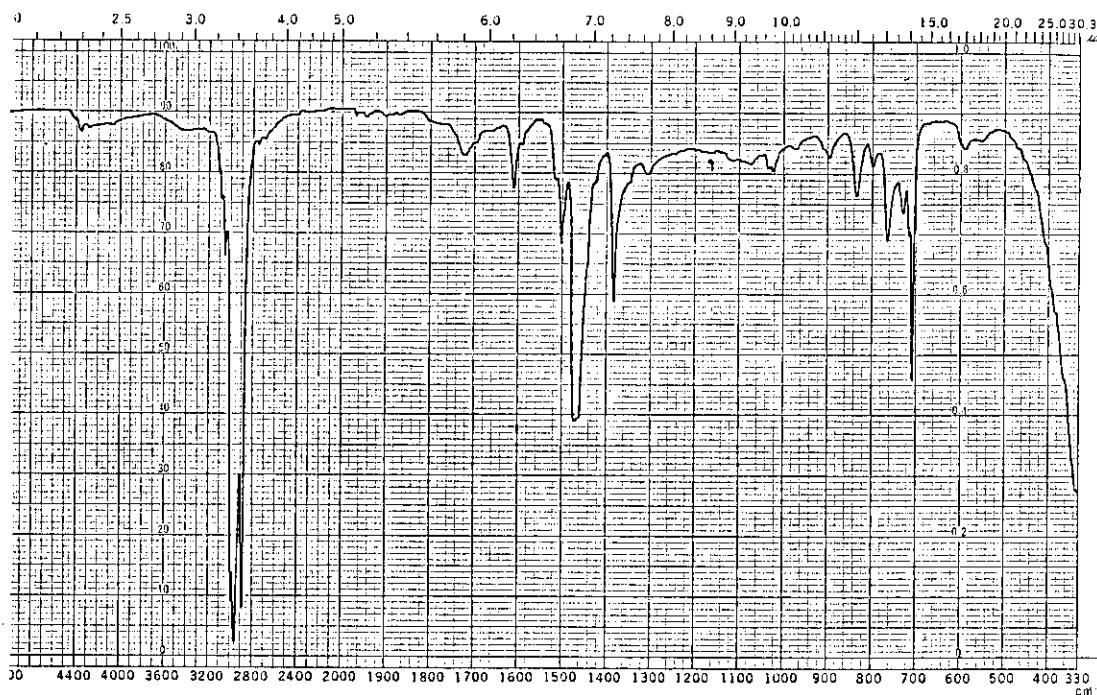
PEAK NO. 2		VALLEY	MN	MW	MZ	MU	
START	TOP	END	MN	MW	MZ	MU	
C	2250	2295	2495	4.36679E+02	4.39968E+02	4.42959E+02	4.39967E+02
U	270.9	375.3	43.3	MW/MN	MZ/MW	AREA	AREAN
M	491	455	296	1.01	1.01	3.37827E+04	38.63

TOTAL		MN	MW	MZ	MU		
START	TOP	END	MN	MW	MZ	MU	
C	1960	2175	2495	5.18264E+02	5.29977E+02	5.41761E+02	5.29975E+02
U	35.4	832.8	43.3	MW/MN	MZ/MW	AREA	AREAN
M	1012	558	296	1.02	1.02	1.10295E+05	100.00

OIL NAME: Dialkyl benzene



Infrared spectrum (original)



Infrared spectrum (3.21 MGy in bubbling oxygen)

OIL NAME : Dialkyl benzene

IRRADIATION CONDITION

Temp.: -196°C

Dose 11kGy

in Vacuum

after irradiation

after photo breach

50

ESR CONDITION Sweep range(Gauss): ± 250 Power(μ W): 1

Modulation width(100kHz,Gauss): 2 at -196°C

G[R.]

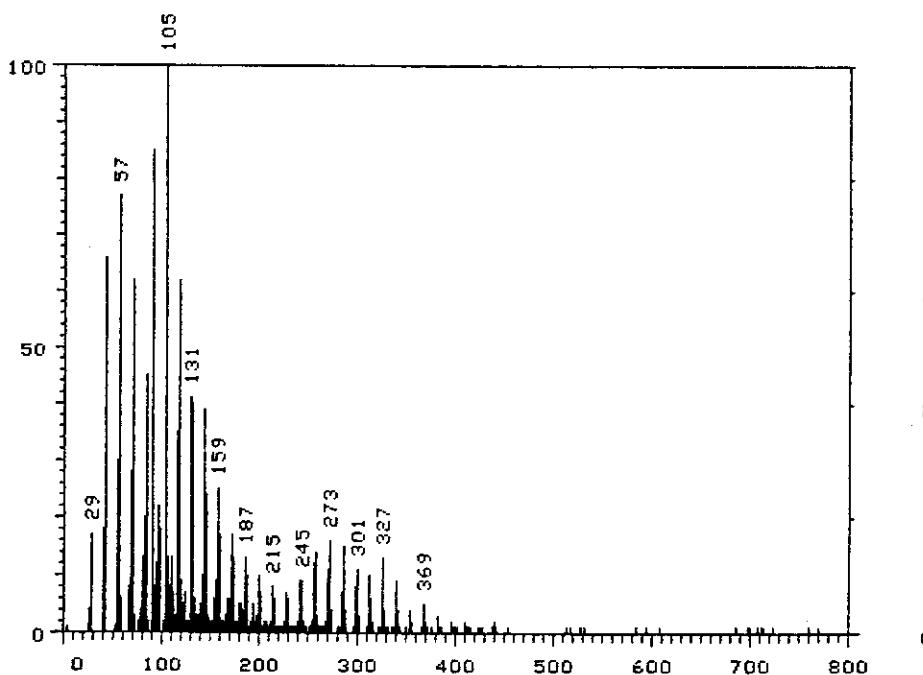
after irradiation

2.3

after Photo breach

1.1

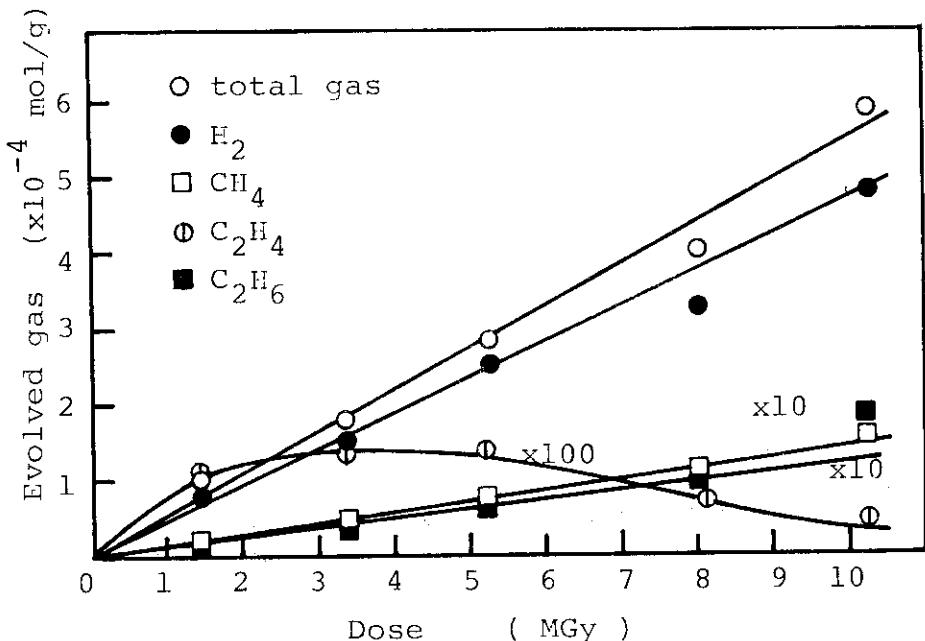
OIL NAME: Di-alkyl benzene



(original)

The mass spectrum of di-alkyl benzene.

OIL NAME : Dialkyl benzene

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	5.2×10^{-1}
$G(H_2)$	4.6×10^{-1}
$G(CH_4)$	1.5×10^{-2}
$G(C_2H_6)$	1.3×10^{-2}
$G(C_2H_4)$	7.7×10^{-3}

AMOUNT OF TOTAL EVOLVED GASES

$$10 \text{ MGy} \quad 5.4 \times 10^{-4} \text{ mol/g}$$

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: Mono-alkyl diphenyl ether C-14

STRUCTURE OR FEATURE: R- \emptyset -O- \emptyset , R:alkyl C-14, \emptyset :benzene ring.

MOLECULAR WEIGHT: 366

VISCOSITY at 40°C: 18.61×10^{-6} m²/s (3.924x10⁻⁶ m²/s at 100°C)

VISCOSITY INDEX: 104 SPECIFIC GRAVITY(15/4°C) : 0.938

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C) : 242

COLOR: UNION 1(-) , ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	n/n_0 (40°C)	n/n_0 (100°C)
in vacuum	1.0	0.905	20.83	4.012	1.12	1.02
	2.8	0.939	22.80	4.349	1.23	1.11
	4.8	0.943	26.12	4.720	1.40	1.20
	8.3	0.948	35.63	5.790	1.91	1.48
	22	0.962	136.7	15.31	7.35	3.90
in bubbling oxygen	0.05	0.939				
	0.21	0.939	18.80	3.818	1.01	0.97
	0.5	0.939	19.23	3.917	1.03	1.00
	0.98	0.940	19.95	3.963	1.07	1.01
	2.9	0.946	24.03	4.489	1.29	1.14
	9.0	0.962	43.32	6.197	2.33	1.58
	18	0.983	116.1	11.35	6.24	2.89
	27	1.011	357.1	20.64	19.2	5.26
in air	0.5	0.941	18.93	3.867	1.02	0.99
	1.0	0.941	19.61	3.948	1.05	1.01
	3.0	0.943	22.02	4.200	1.18	1.07
	5.0	0.944	26.21	4.730	1.41	1.21
	10.5	0.945	32.58	5.467	1.75	1.39
	20	0.957	64.39	8.673	3.46	2.21
	30	0.963	121.9	13.15	6.55	3.35

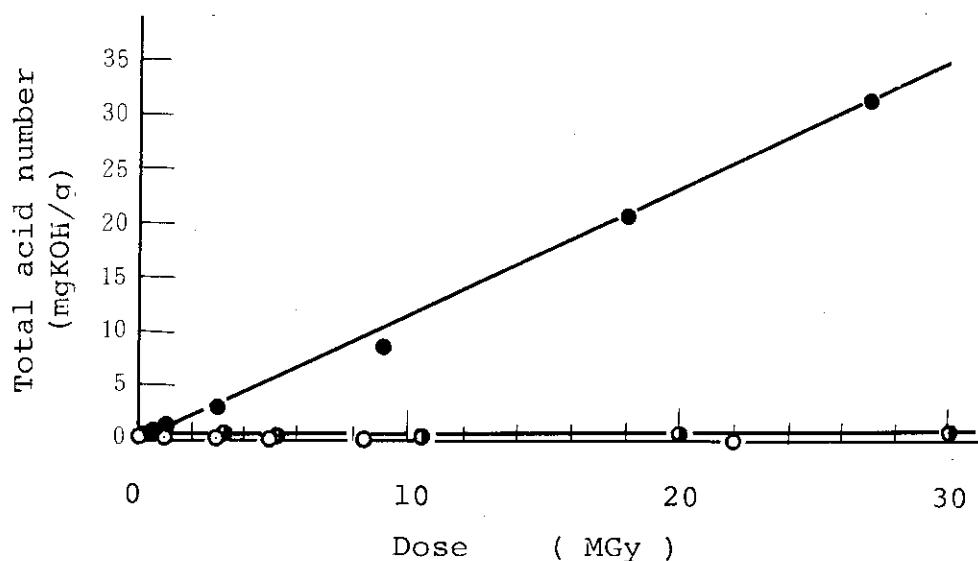
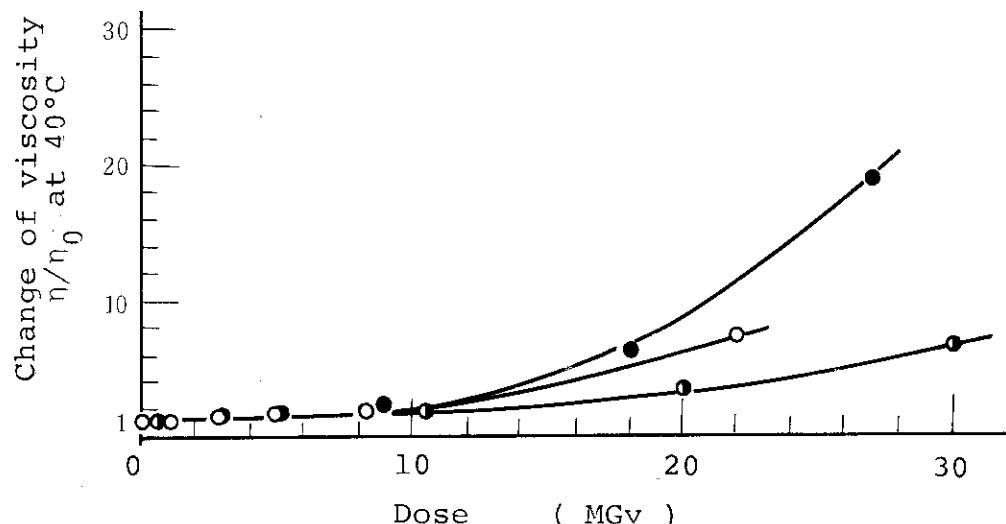
OIL NAME : Mono-alkyl diphenyl ether C-14

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in vacuum	1.0	80	0.00	204	2 (-)	L2.0
	2.8	96	0.00	208	3 (-)	2.5
	4.8	97	0.00	196	3 (1/2)	4.0
	8.3	103	0.00	176	3 (1/2)	4.0
	22	115	0.00	164	6	6.0
in bubbling oxygen	0.05		0.06	228	1 (-)	L0.5
	0.21	87	0.12	228	2 (1/2)	L2.0
	0.5	95	0.30	204	3	L3.0
	0.98	88	0.61	200	4 (-)	L4.0
	2.9	96	2.83	222	5	5.5
	9.0	85	8.47	188	7 (-)	6.5
	18	80	21.0	160	6	6.0
	27	59	31.8	158	7	7.0
in air	0.5	93	0.05	238	1 (-)	L0.5
	1.0	92	0.07	228	1 (1/2)	L1.0
	3.0	88	0.12	220	2	L1.5
	5.0	97	0.20	206	2 (1/2)	L2.0
	10.5	103	0.23	208	3 (-)	L2.5
	20	107	0.65	200	4 (-)	L3.5
	30	102	0.74	224	3 (1/2)	L4.0

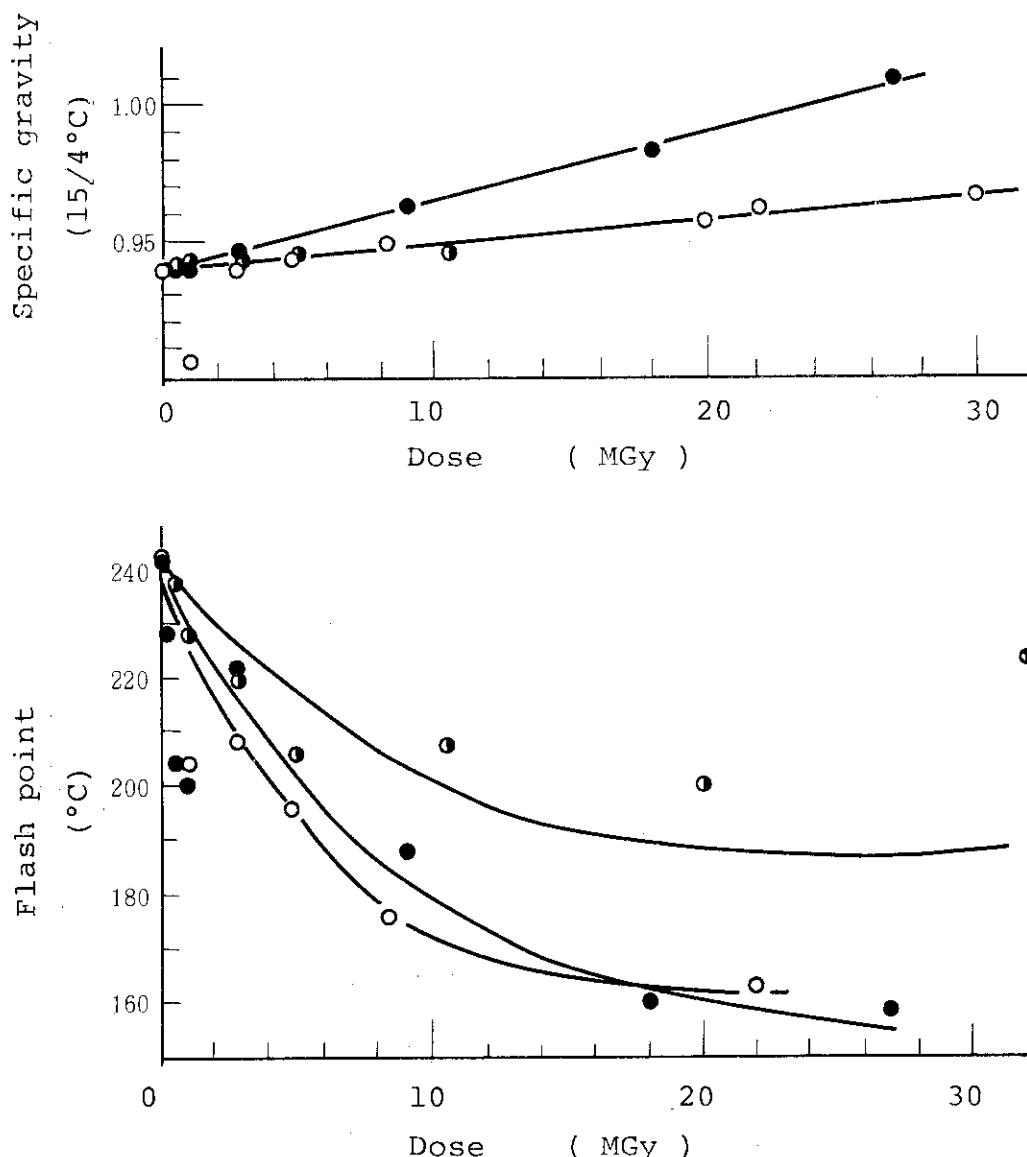
COMMENTIRRADIATION CONDITION

OIL NAME : Mono-alkyl diphenyl ether C-14

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONSymbol: \circ in vacuum, \bullet in air, \blacksquare in bubbling oxygen.IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME : Mono-alkyl diphenyl ether C-14

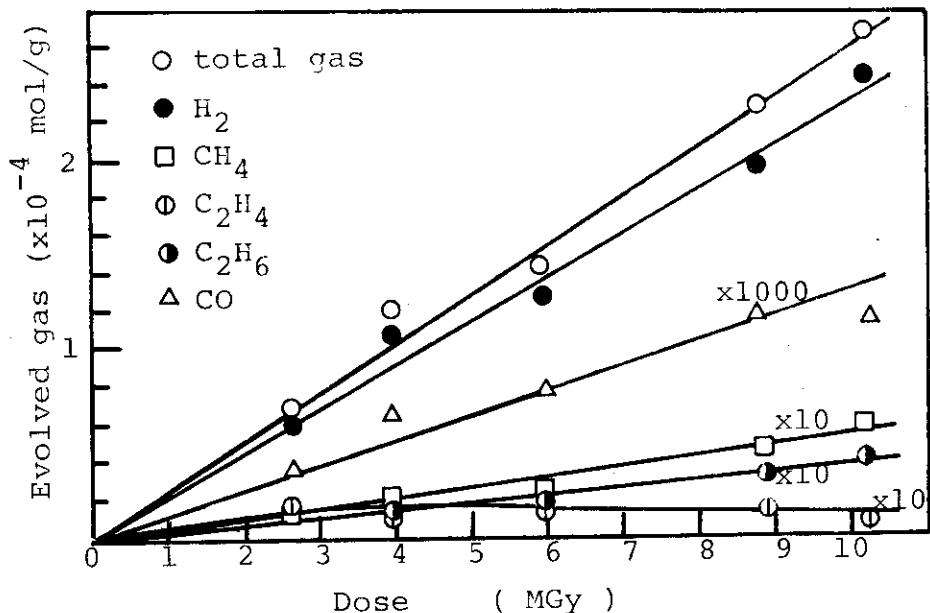
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENT

Symbol: ○ in vacuum, ● in air, • in bubbling oxygen.

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME : Mono-alkyl diphenyl ether C-14

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	2.6×10^{-1}	$G(C_2H_4)$	4.2×10^{-3}
$G(H_2)$	2.3×10^{-1}		
$G(CH_4)$	5.5×10^{-3}		
$G(CO)$	1.2×10^{-4}		
$G(C_2H_6)$	4.5×10^{-3}		

AMOUNT OF TOTAL EVOLVED GASES

$$10 \text{ MGy} \quad 2.6 \times 10^{-4} \text{ mol/g}$$

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: Mono-alkyl diphenyl ether C-16

STRUCTURE OR FEATURE: R- \emptyset -O- \emptyset , R: alkyl C-16, \emptyset : benzene ring.

MOLECULAR WEIGHT: 394

VISCOSITY at 40°C: 21.21×10^{-6} m²/s (4.261×10^{-6} m²/s at 100°C)

VISCOSITY INDEX: 105 SPECIFIC GRAVITY(15/4°C): 0.934

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 230

COLOR: UNION 1(-), ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
in vacuum	1.0	0.935	22.94	4.474	1.08	1.05
	3.0	0.936	26.18	4.937	1.23	1.16
	5.3	0.937	29.13	5.377	1.37	1.26
	9.0	0.942	40.72	6.625	1.92	1.55
	18	0.949	82.48	10.90	3.89	2.56
in bubbling oxygen	0.05	0.933	21.42	4.478	1.01	1.05
	0.21	0.933	21.65	4.320	1.02	1.01
	0.5	0.934	21.89	4.305	1.03	1.01
	0.98	0.935	22.51	4.333	1.06	1.02
	2.8	0.940	27.60	4.799	1.30	1.13
	4.3	0.945	32.74	5.439	1.54	1.28
	9.2	0.958	55.92	7.482	2.64	1.76
	17.5		153.6	13.15	7.24	3.09
in air	27	0.952	445.9	25.44	21.0	5.97
	0.5	0.933	21.84	3.968	1.03	0.93
	1.0	0.936	22.57	4.394	1.06	1.03
	3.0	0.936	25.72	4.852	1.21	1.14
	5.0	0.940	29.55	5.203	1.39	1.22
	16.28	0.946	61.54	8.542	2.90	2.00
	20.91	0.952	97.56	11.67	4.60	2.74
	30	0.956	172.0	17.27	8.11	4.05

OIL NAME : Mono-alkyl diphenyl ether C-16

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

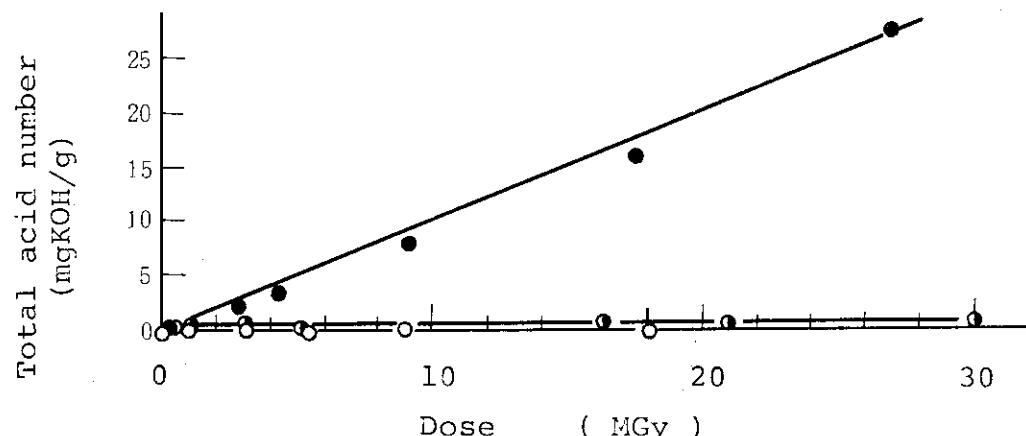
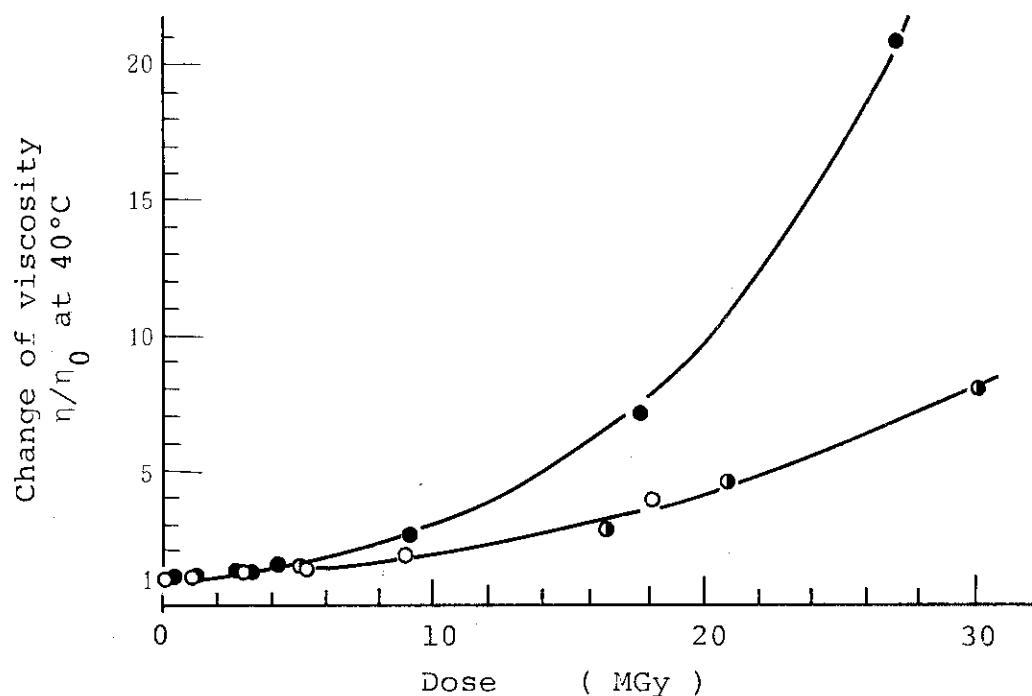
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	106	0.00	230	1(1/2)	L0.5
	3.0	114	0.00	228	2(1/2)	2.0
	5.3	120	0.00	212	3	3.0
	9.0	116	0.00	206	4	4.0
	18	119	0.00	180	5	5.0
in bubbling oxygen	0.05	123	0.08	222	1(-)	L0.5
	0.21	156	0.11	224	2(-)	1.0
	0.5	102	0.23	222	3(-)	L2.5
	0.98	97	0.46	222	4(-)	L3.5
	2.8	90	2.40	248	5(-)	L5.5
	4.3	100	3.90	234	6(-)	L6.0
	9.2	94	8.10	200	7(-)	6.5
	17.5	73	16.3			
	27	73	27.9	170	8	7.5
in air	0.5	56	0.02	244	1(-)	L0.5
	1.0	103	0.07	232	1(1/2)	L1.0
	3.0	111	0.10	230	2(-)	L1.5
	5.0	106	0.23	218	2(1/2)	L2.0
	16.28	110	0.62	216	3(1/2)	L3.0
	20.91	108	0.62	208	4(-)	L3.5
	30	108	0.78	234	4(-)	3.5

COMMENTIRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME : Mono-alkyl diphenyl ether C-16

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

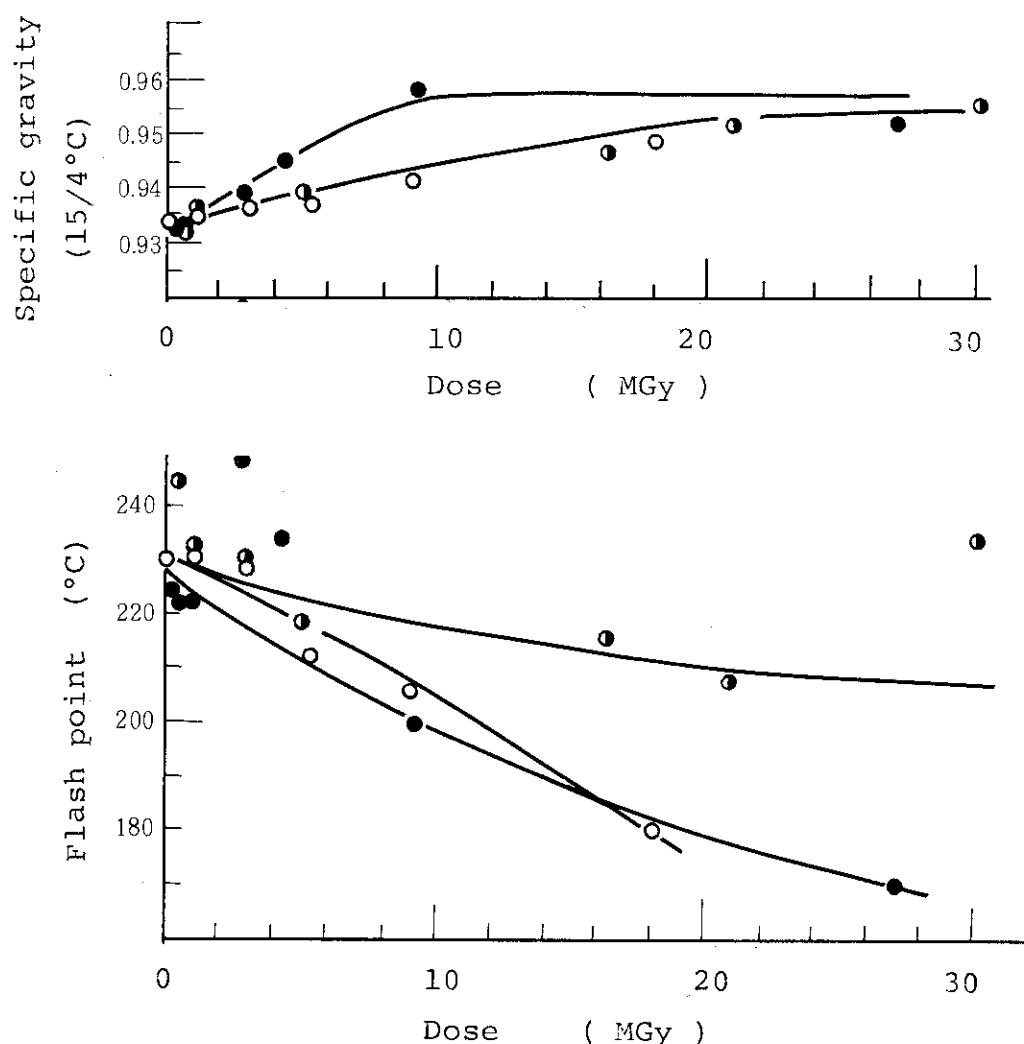


COMMENT

Symbol: \circ in vacuum, \bullet in air, \bullet in bubbling oxygen.

IRRADIATION CONDITION

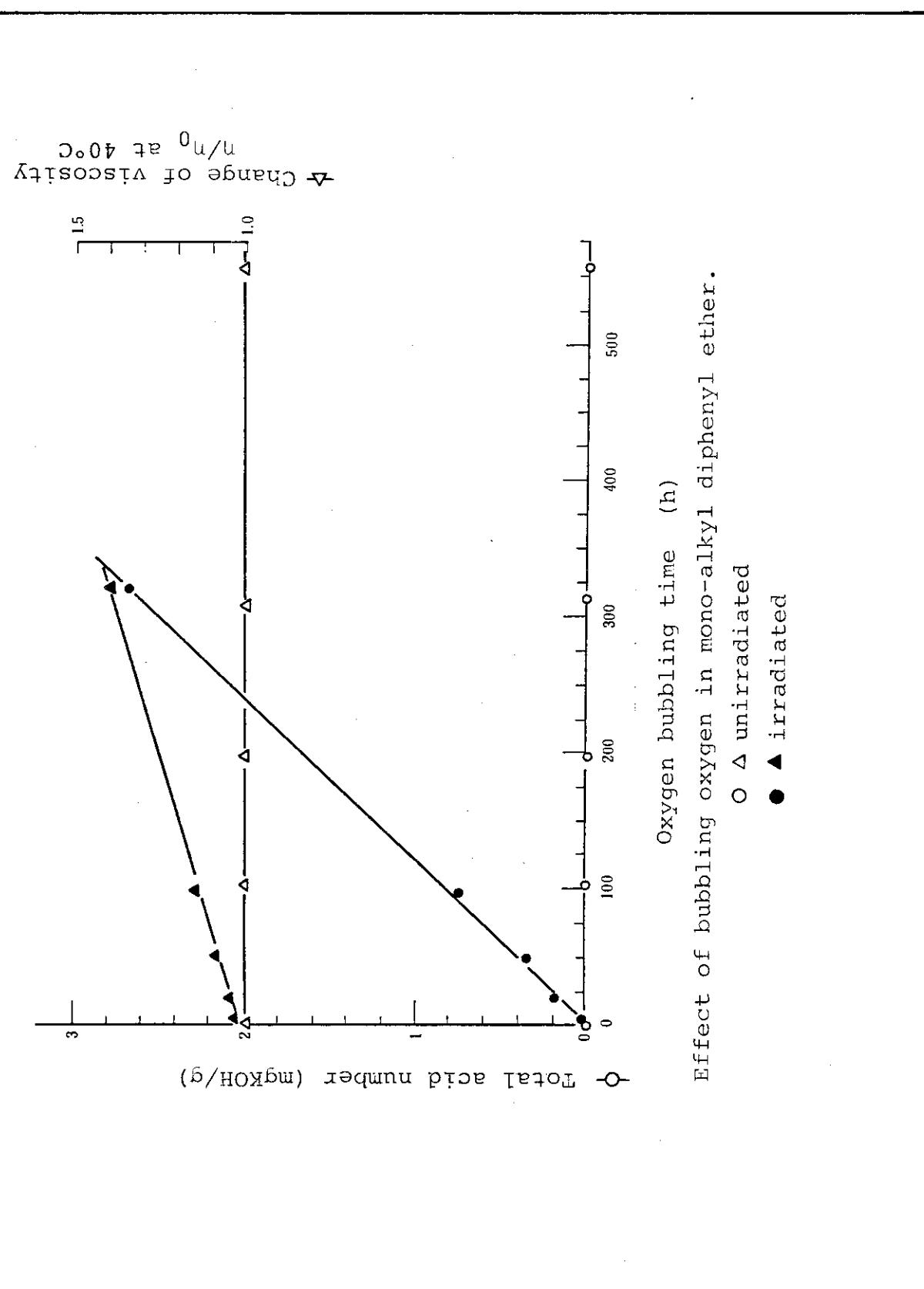
OIL NAME : Mono-alkyl diphenyl ether C-16

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENT

Symbol: ○ in vacuum, ● in air, ● in bubbling oxygen.

IRRADIATION CONDITION

OIL NAME: Mono-alkyl diphenyl ether C-16



OIL NAME: Mono-alkyl diphenyl ether C-16

DOSE RATE EFFECT

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (15/4°C)	Viscosity (40°C)	η/η_0 (40°C)	η/η_0 (100°C)
<u>in air</u>						
20	1.0	0.937	22.72	4.406	1.07	1.03
10	0.98	0.935	22.51	4.333	1.06	1.02
5.0	1.0	0.935	22.62	4.411	1.07	1.04
1.0	1.0	0.937	22.85	4.439	1.08	1.04
0.7	1.0	0.934	22.12	6.345	1.04	1.49
0.5	1.0	0.936	22.80	4.442	1.07	1.04
<u>in bubbling oxygen</u>						
10	0.05	0.933	21.42	4.478	1.01	1.05
10	0.21	0.934	21.65	4.320	1.02	1.01
10	0.5	0.934	21.89	4.305	1.03	1.01
10	0.98	0.935	22.51	4.333	1.06	1.02
10	2.8	0.940	27.60	4.799	1.30	1.13
10	4.3	0.945	32.74	5.439	1.54	1.28
3.0	0.65	0.935	22.33	4.333	1.05	1.02
3.0	1.0	0.935	22.92	4.385	1.08	1.03
3.0	5.15	0.938	24.62	4.637	1.16	1.09
1.0	0.5		21.84	4.283	1.03	1.01
1.0	1.03	0.935	22.62	4.388	1.07	1.03
1.0	1.53	0.936	23.48	4.482	1.10	1.05

OIL NAME: Mono-alkyl diphenyl ether C-16

DOSE RATE EFFECT

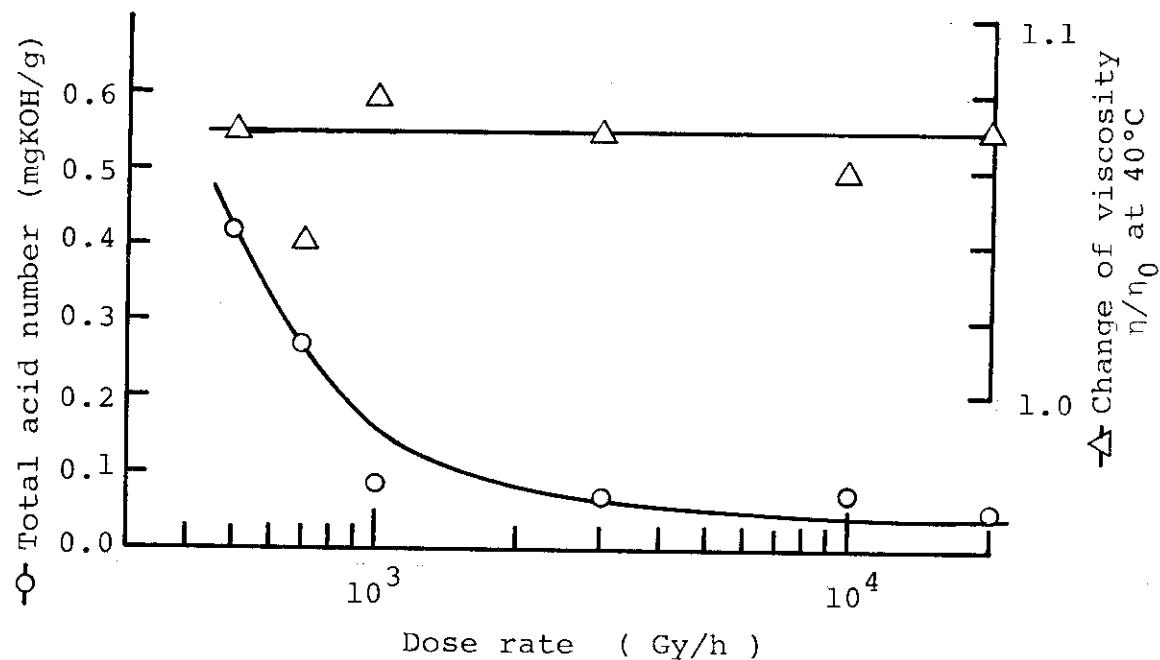
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Dose rate [kGy/h]	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
<u>in air</u>						
20	1.0	103	0.05	220	1(1/2)	L1.0
10	0.98	97	0.46	222	4(-)	L3.5
5.0	1.0	103	0.07	236	1(1/2)	L1.0
1.0	1.0	104	0.08	242	2(-)	L1.5
0.7	1.0	268	0.27	226	2(-)	L1.5
0.5	1.0	105	0.42	240	2(1/2)	L2.0
<u>in bubbling oxygen</u>						
10	0.05	123	0.08	222	1(-)	L0.5
10	0.21	156	0.11	224	2(-)	1.0
10	0.5	102	0.23	222	3(-)	L2.5
10	0.98	97	0.46	222	4(-)	L3.5
10	2.8	90	2.40	248	5(-)	L5.5
10	4.3	100	3.90	234	6(-)	L6.0
3.0	0.65	100	0.45	218	3(1/2)	L3.0
3.0	1.0	98	0.65	222	4(-)	L4.0
3.0	5.15	103	2.06	214	4	4.0
1.0	0.5	101	0.30	232	3	2.5
1.0	1.03	101	0.58	222	4(-)	L3.5
1.0	1.53	101	0.54	214	4(1/2)	5.0

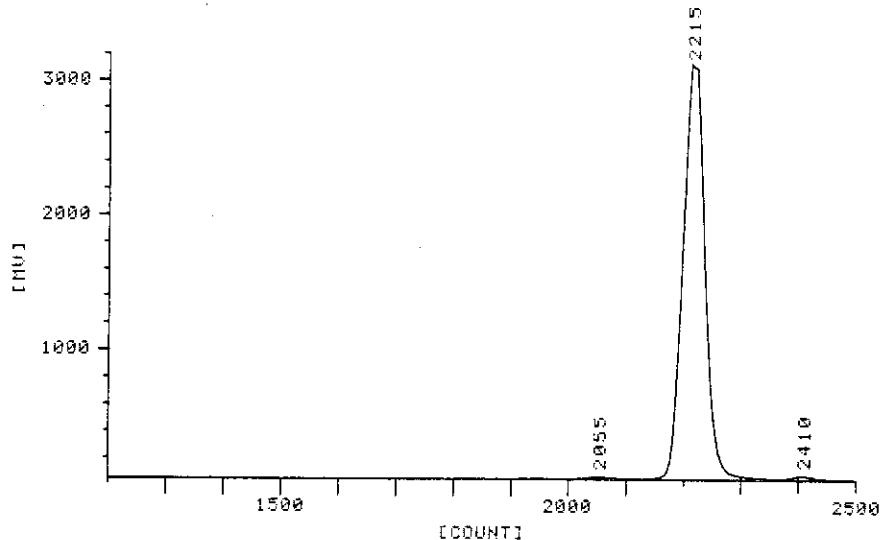
OIL NAME: Mono-alkyl diphenyl ether C-16

DOSE RATE EFFECT

(in air, total dose rate 1 MGy)

COMMENTIRRADIATION CONDITION

OIL NAME: Mono-alkyl diphenyl ether C-16

MOLECULAR WEIGHT DISTRIBUTION (original sample)

06/07/09 14:15 JOB FILE 1

SAMPLE NO. 0 NAME: 10-1 SERIAL NO. 0050

CH.NO 1 METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2010	2055	2120	7.17126E+02	7.19430E+02	7.21729E+02	7.19435E+02	
U	42.6	57.1	43.3	MW/MN	MZ/MW	AREA	AREAP%	
M	833	726	621	1.00	1.00	8.26217E+02	0.58	

PEAK NO.	VALLEY	START	TOP	END	MN	MW	MZ	MU
C	2120	2215	2360	5.19871E+02	5.19460E+02	5.20032E+02	5.19458E+02	
U	43.3	3114.0	45.3	MW/MN	MZ/MW	AREA	AREAP%	
M	621	520	405	1.00	1.00	1.39653E+05	98.46	

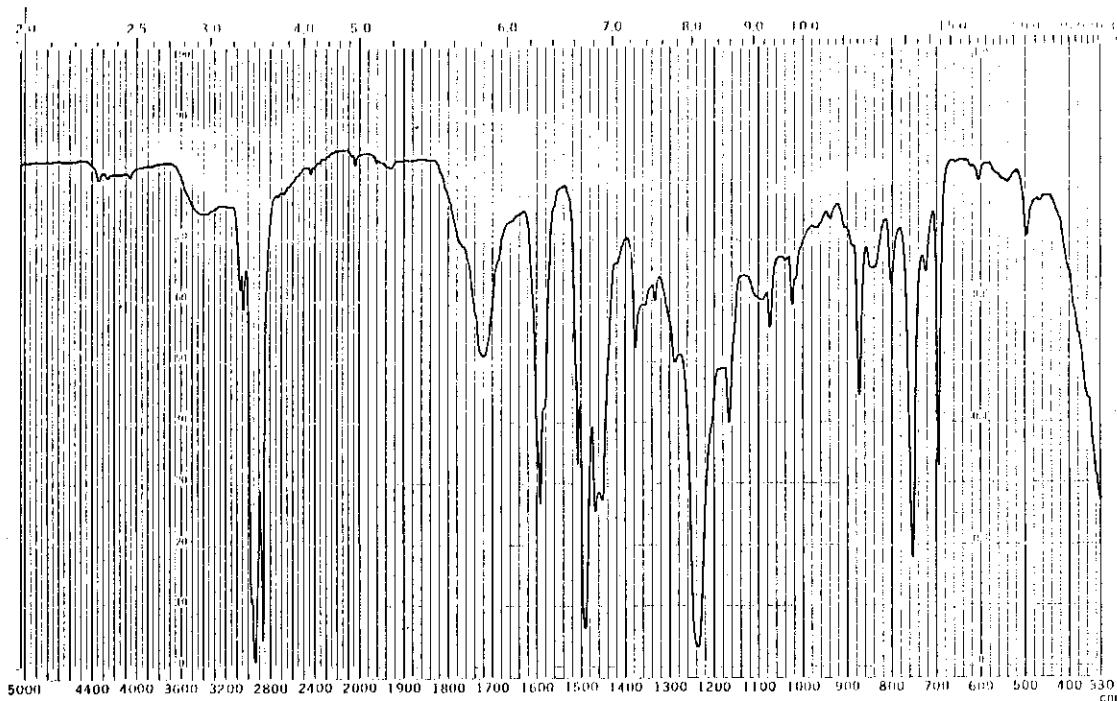
PEAK NO.	VALLEY	START	TOP	END	MN	MW	MZ	MU
C	2360	2410	2495	3.64784E+02	3.65839E+02	3.66851E+02	3.65838E+02	
U	45.3	69.6	38.9	MW/MN	MZ/MW	AREA	AREAP%	
M	405	365	296	1.00	1.00	1.35934E+03	0.96	

TOTAL	START	TOP	END	MN	MW	MZ	MU
C	2010	2215	2495	5.17609E+02	5.19152E+02	5.20626E+02	5.19151E+02
U	42.6	3114.0	38.9	MW/MN	MZ/MW	AREA	AREAP%
M	833	520	296	1.00	1.00	1.41838E+05	100.00

OIL NAME: Mono-alkyl diphenyl ether C-16

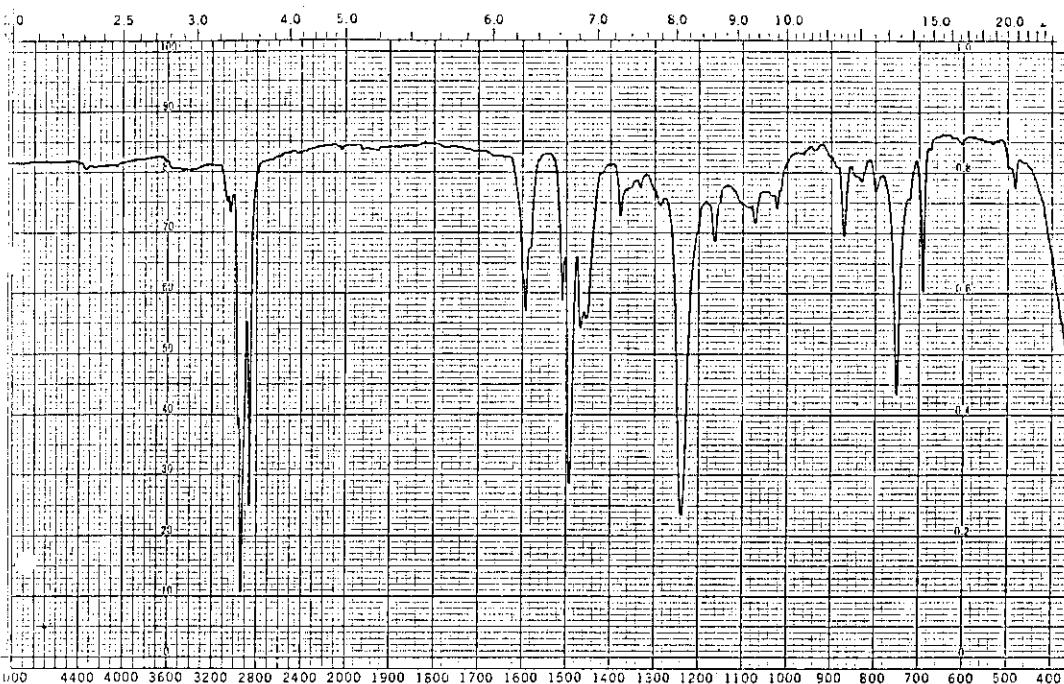


Infrared spectrum (original)



Infrared spectrum (20 MGy in bubbling oxygen)

OIL NAME: Mono-alkyl diphenyl ether C-16



Infrared spectrum (20 MGy in vacuum)

OIL NAME : Mono-alkyl diphenyl ether C-16

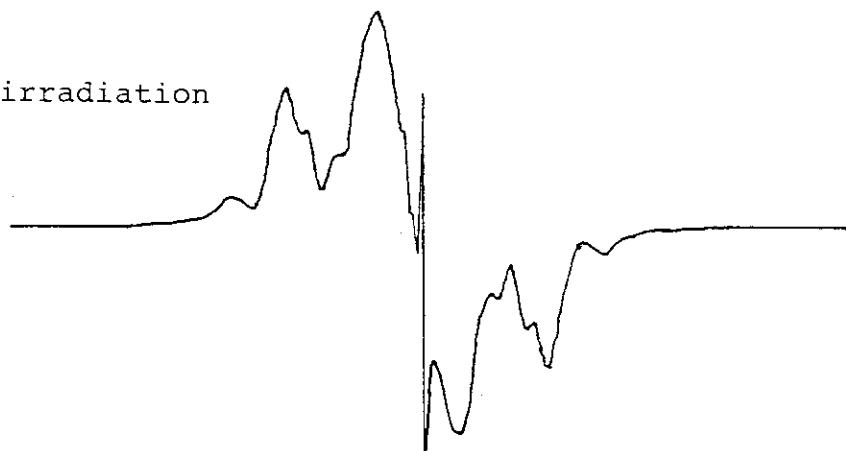
IRRADIATION CONDITION

Temp.: -196°C

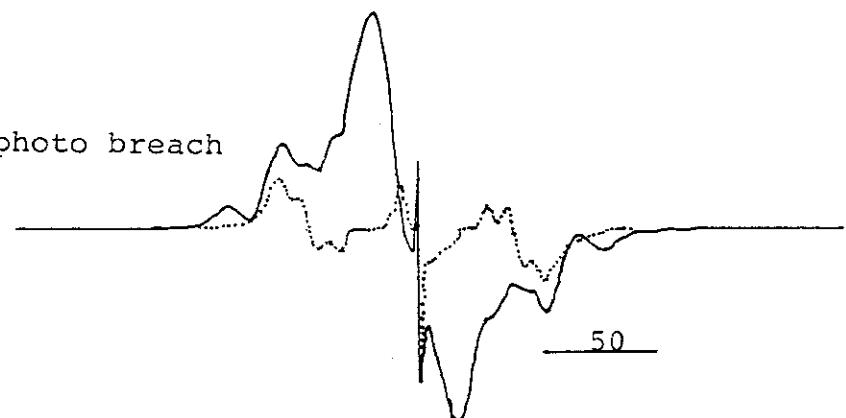
Dose 112kGY

in Vacuum

after irradiation



after photo breach

ESR CONDITIONSweep range(Gauss): ± 250 Power(μW): 1

Modulation width(100kHz,Gauss): 2 at -196°C

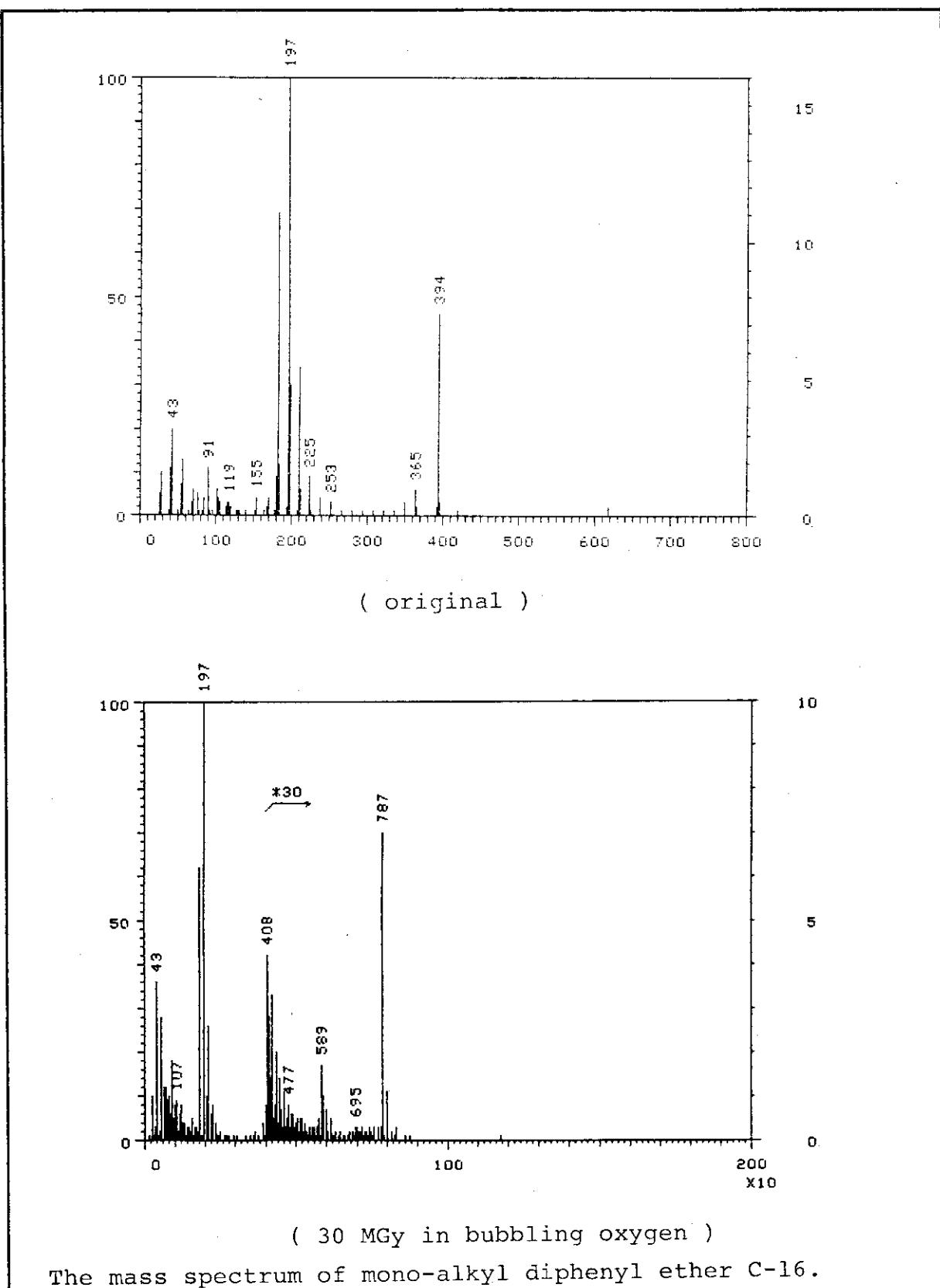
G[R.]

after irradiationafter Photo breach

1.1

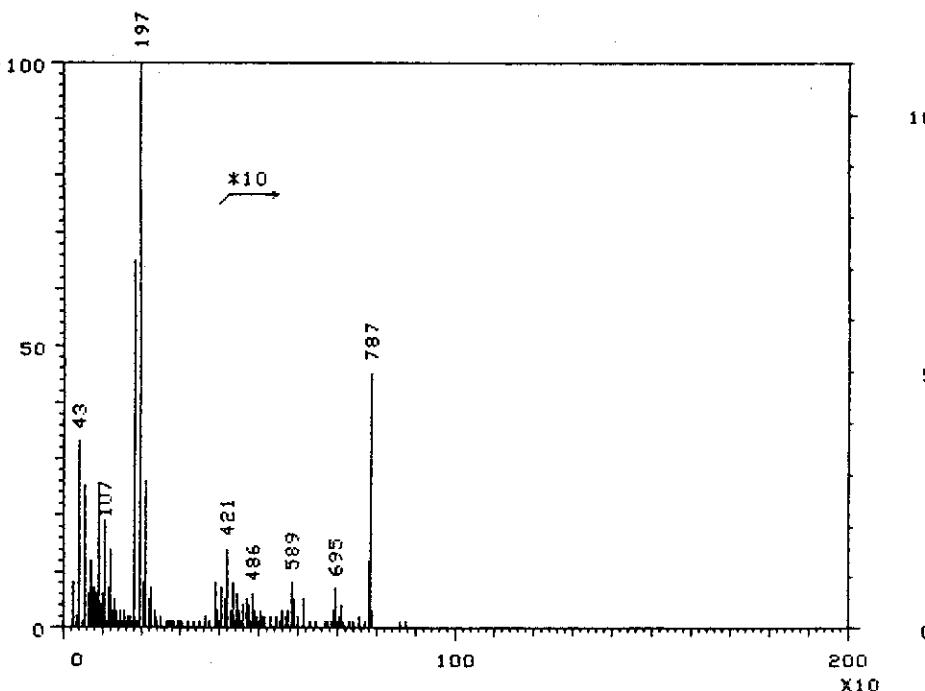
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OIL NAME: Mono-alkyl diphenyl ether C-16



The mass spectrum of mono-alkyl diphenyl ether C-16.

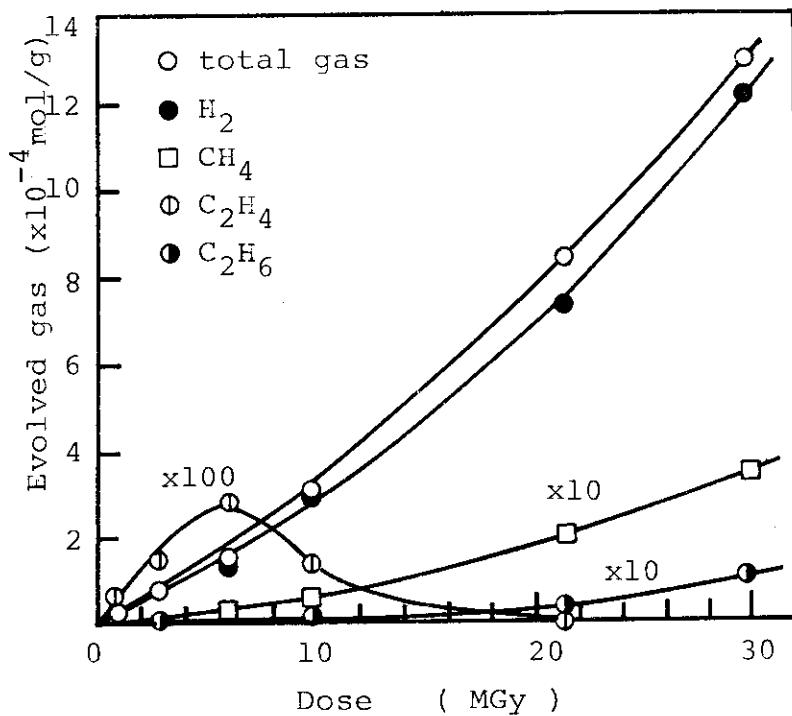
OIL NAME: Mono-alkyl diphenyl ether C-16



(30 MGy in vacuum)

The mass spectrum of mono-alkyl diphenyl ether C-16.

OIL NAME : Mono-alkyl diphenyl ether C-16

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	3.2×10^{-1}	$G(C_2H_4)$	5.1×10^{-3}
$G(H_2)$	2.9×10^{-1}		
$G(CH_4)$	5.1×10^{-3}		
$G(CO)$	9.7×10^{-5}		
$G(C_2H_6)$	2.9×10^{-3}		

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

10 MGy	3.2
20 MGy	7.6
30 MGy	13.0

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: Mono-alkyl diphenyl ether C-16

BREAKDOWN VOLTAGE

times	Measurement	Breakdown voltage (kV)			
		original	1 MGy	5 MGy	10 MGy
1	(V ₁)	45.5	16.9	45.4	45.5
2	(V ₂)	39.1	30.6	43.0	45.5
3	(V ₃)	40.7	17.6	45.3	33.1
4	(V ₄)	45.5	13.0	45.5	40.1
5	(V ₅)	40.0	28.4	45.5	38.7
average (v)		41.3	22.4	44.8	39.4

COMMENTIRRADIATION CONDITION

OIL NAME: Mono-alkyl diphenyl ether C-18

STRUCTURE OR FEATURE: R- \emptyset -O- \emptyset , R:alkyl C-18, \emptyset :benzene ring.

MOLECULAR WEIGHT: 422

VISCOSITY at 40°C: 26.27×10^{-6} m²/s (5.023×10^{-6} m²/s at 100°C)

VISCOSITY INDEX: 119 SPECIFIC GRAVITY(15/4°C): 0.929

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 252

COLOR: UNION 1(-), ASTM L0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
in vacuum	1.0	0.921	28.56	5.324	1.09	1.06
	2.8	0.930	33.74	5.867	1.28	1.17
	4.8	0.931	40.27	6.640	1.53	1.32
	8.3	0.935	56.92	8.580	2.17	1.71
	19.3	0.951	373.2	35.08	14.2	6.98
in bubbling oxygen	0.05	0.926	26.27	5.035	1.00	1.00
	0.2	0.927	26.80	5.080	1.02	1.01
	0.5	0.928	27.40	5.173	1.04	1.03
	0.98	0.924	28.61	5.409	1.09	1.08
	2.8	0.933	34.97	5.721	1.33	1.14
	9.0	0.951	69.58	8.895	2.65	1.77
	18	0.970	182.7	16.34	6.95	3.25
	27	0.992	605.6	33.94	23.1	6.76
in air	0.5	0.927	27.09	5.156	1.03	1.03
	1.0	0.927	28.01	5.274	1.07	1.05
	3.0	0.935	32.73	5.862	1.25	1.17
	5.0	0.933	38.59	6.567	1.47	1.31
	10.5	0.936	53.65	8.194	2.04	1.63
	20	0.946	137.2	15.49	5.22	3.08
	30	0.951	269.6	24.68	10.3	4.91

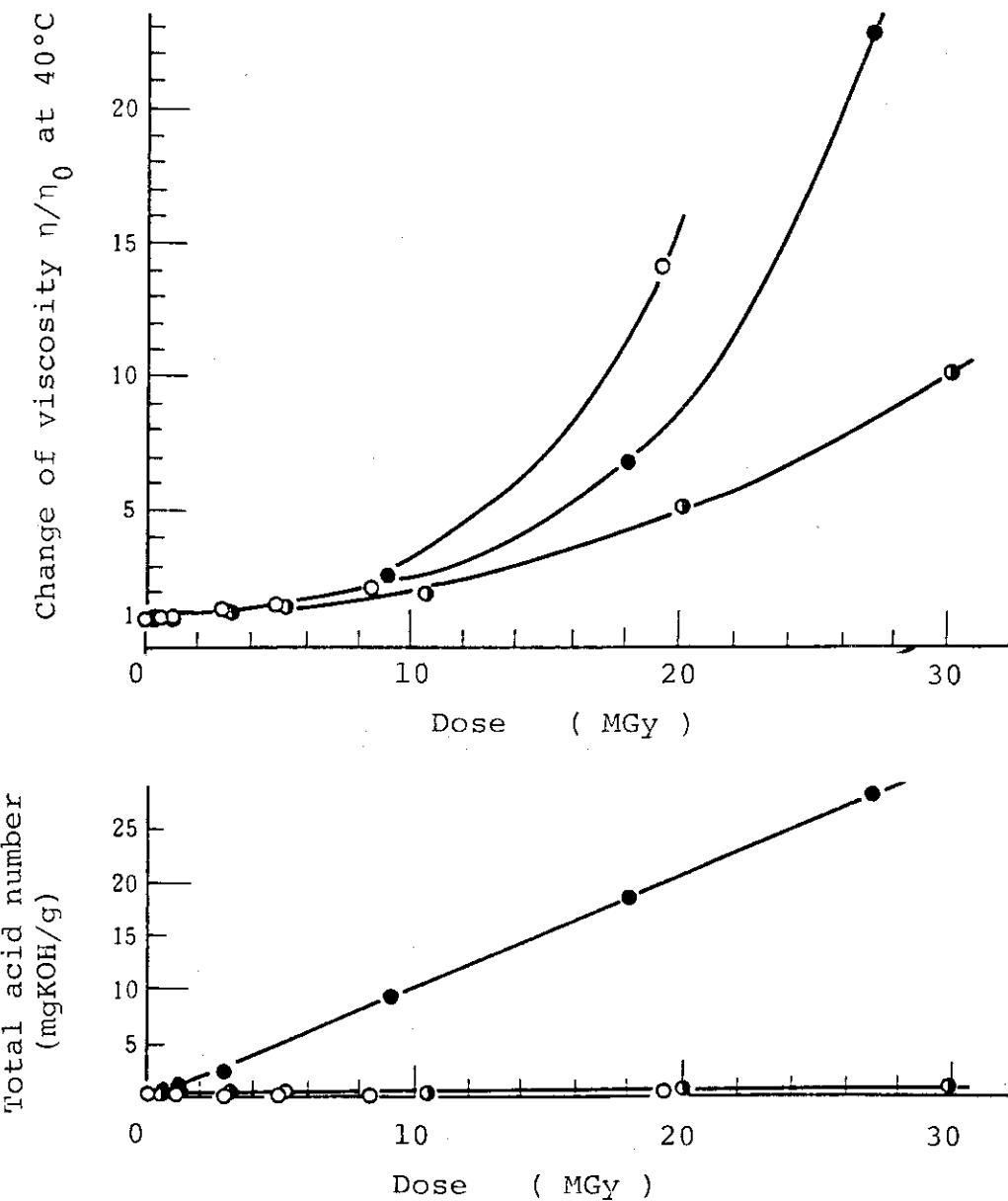
OIL NAME : Mono-alkyl diphenyl ether C-18

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	121	0.00	234	2 (-)	L1.5
	2.8	117	0.00	230	2 (1/2)	2.5
	4.8	119	0.00	200	3 (1/2)	3.0
	8.3	125	0.00	192	4	L4.5
	19.3	137	0.00	174	6	6.0
in bubbling oxygen	0.05	120	0.04	252	1 (-)	L0.5
	0.2	119	0.15	240	2 (-)	L2.0
	0.5	120	0.32	240	3 (-)	L3.0
	0.98	126	0.70	240	4 (-)	L4.0
	2.8	103	2.42	240	5	5.5
	9.0	101	9.17	188	6 (1/2)	6.5
	18	93	18.7	160	6	6.5
	27	87	28.4	164	7	6.5
in air	0.5	122	0.03	252	1 (-)	L0.5
	1.0	122	0.03	242	1 (1/2)	L1.0
	3.0	123	0.11	242	2 (-)	L1.5
	5.0	124	0.13	236	2 (1/2)	L2.0
	10.5	123	0.22	218	3 (-)	L2.5
	20	117	0.50	228	4 (-)	L3.5
	30	116	0.67	232	4 (-)	3.5

COMMENTIRRADIATION CONDITION

OIL NAME : Mono-alkyl diphenyl ether C-18

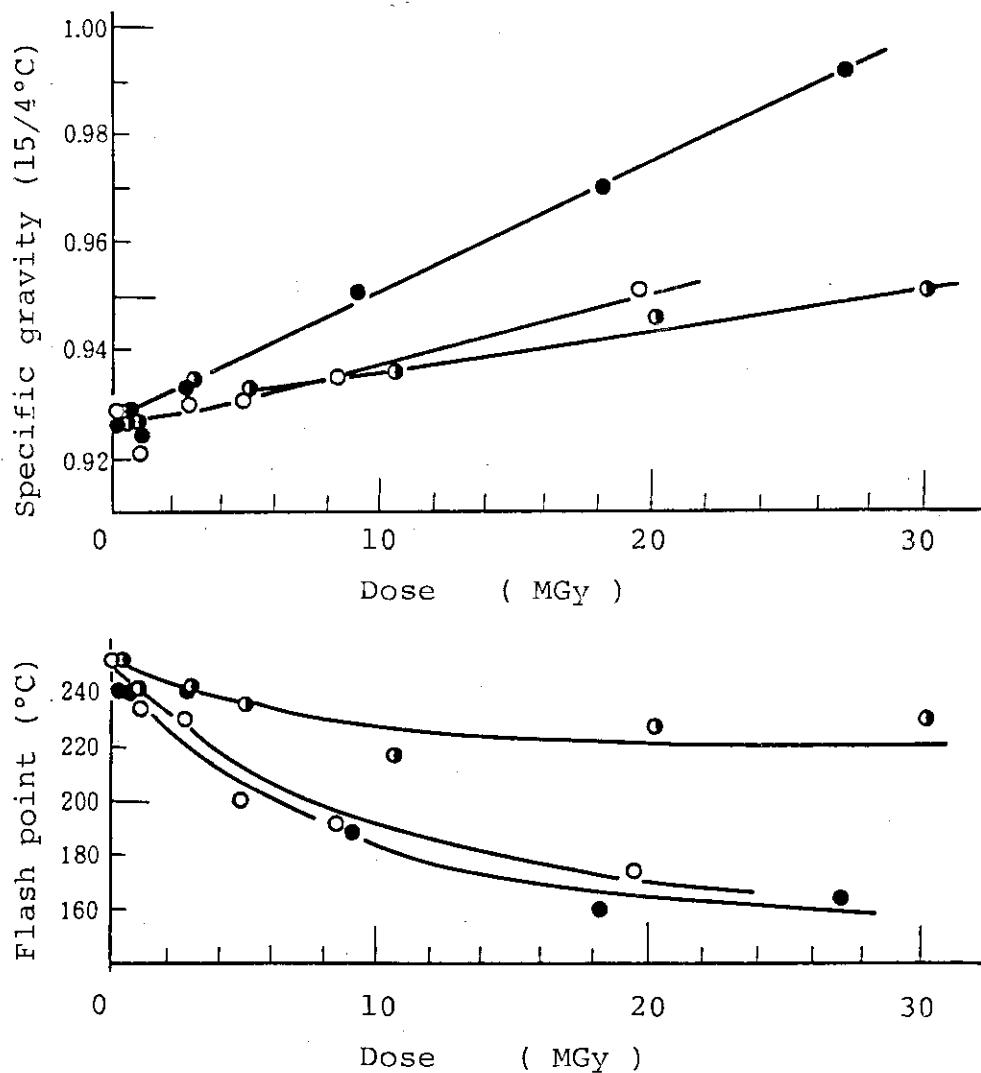
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENT

Symbol: ○ in vacuum, ○• in air, ● in bubbling oxygen.

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME : Mono-alkyl diphenyl ether C-18

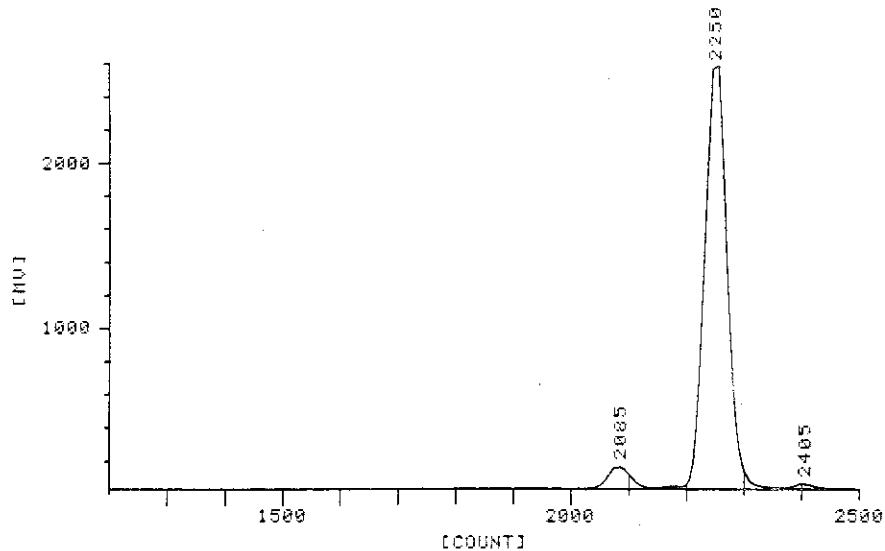
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENT

Symbol: O in vacuum, ● in air, ● in bubbling oxygen.

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Mono-alkyl diphenyl ether C-18

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/09 16:04 JOB FILE 1

SAMPLE NO. 0 NAME: 10 - 4 SERIAL NO. 0052

CH. NO 1 METHOD 2

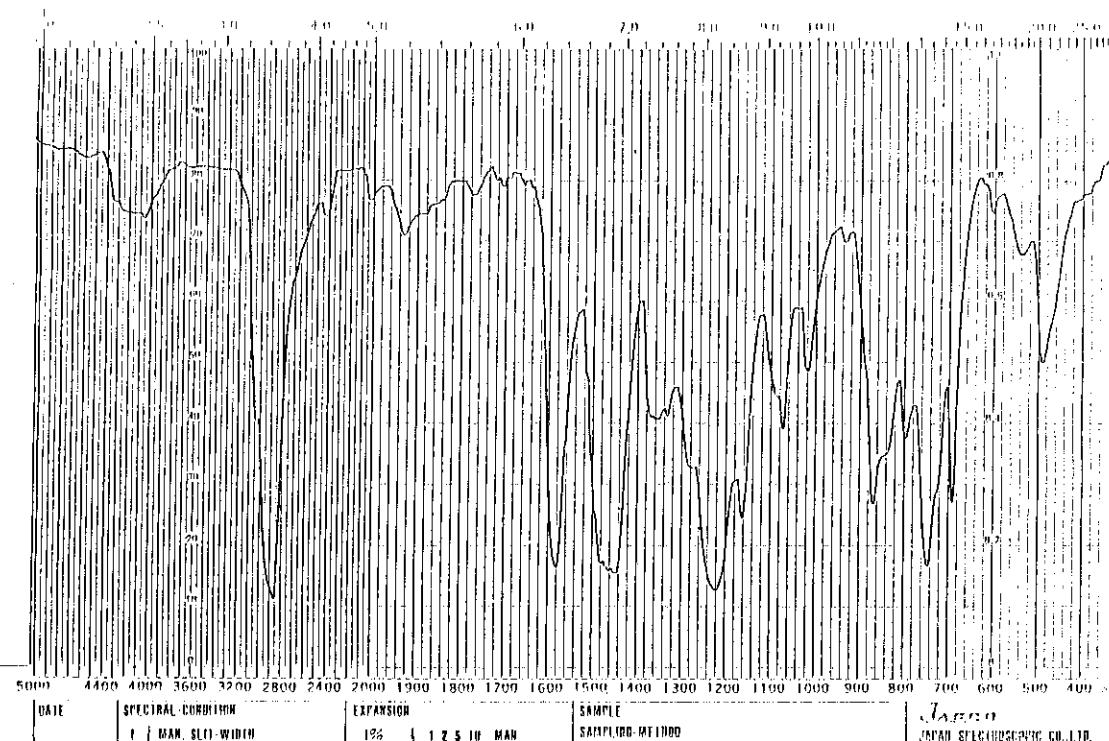
PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2025	2085	2148	2148	6.73030E+02	6.74356E+02	6.75694E+02	6.74355E+02
V	27.0	161.6	29.3	29.3	MW/MN	MZ/MW	AREA	AREA%
M	793	672	596	596	1.00	1.00	6.17330E+03	4.85

PEAK NO.	VALLEY	START	TOP	END	MN	MW	MZ	MU
C	2140	2250	2365	2365	4.89971E+02	4.90519E+02	4.91064E+02	4.90517E+02
V	29.3	2578.9	28.4	28.4	MW/MN	MZ/MW	AREA	AREA%
M	596	491	481	481	1.00	1.00	1.19827E+05	94.06

PEAK NO.	VALLEY	START	TOP	END	MN	MW	MZ	MU
C	2365	2405	2495	2495	3.65038E+02	3.66051E+02	3.67004E+02	3.66050E+02
V	28.4	55.3	21.6	21.6	MW/MN	MZ/MW	AREA	AREA%
M	401	369	296	296	1.00	1.00	1.39979E+03	1.10

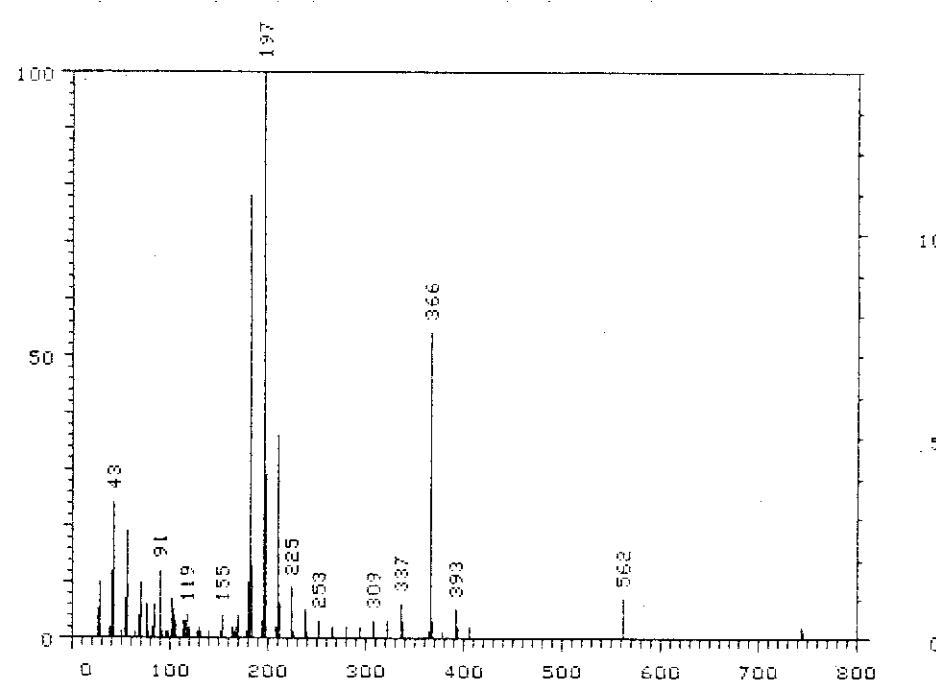
TOTAL	START	TOP	END	MN	MW	MZ	MU
C	2025	2250	2495	4.94630E+02	4.98059E+02	5.02175E+02	4.98058E+02
V	27.0	2578.9	21.6	MW/MN	MZ/MW	AREA	AREA%
M	793	491	296	1.01	1.01	1.27400E+05	100.00

OIL NAME: Mono-alkyl diphenyl ether C-18

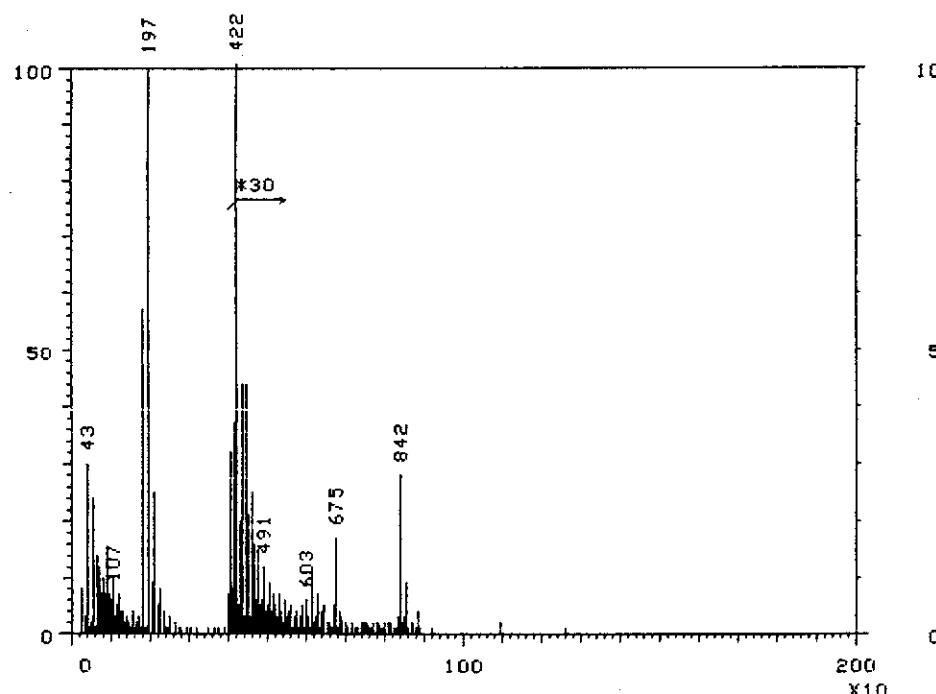


Infrared spectrum (original)

OIL NAME: Mono-alkyl diphenyl ether C-18



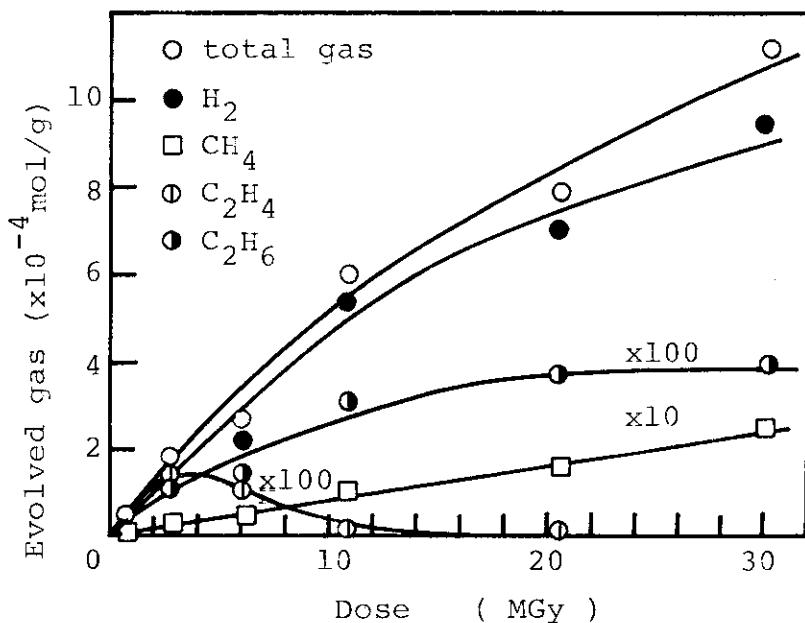
(original)



(30 MGy in bubbling oxygen)

The mass spectrum of mono-alkyl diphenyl ether C-18.

OIL NAME : Mono-alkyl diphenyl ether C-18

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	5.6×10^{-1}
$G(H_2)$	5.3×10^{-1}
$G(CH_4)$	8.0×10^{-3}
$G(C_2H_6)$	3.0×10^{-3}
$G(C_2H_4)$	9.7×10^{-3}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

10 MGy	5.2
20 MGy	8.6
30 MGy	10.8

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: Di-alkyl diphenyl ether C-16

STRUCTURE OR FEATURE: R- \emptyset -O- \emptyset -R, R:alkyl C-16, \emptyset :benzene ring.

MOLECULAR WEIGHT: 618

VISCOSITY at 40°C: 84.79×10^{-6} m²/s (11.33 $\times 10^{-6}$ m²/s at 100°C)

VISCOSITY INDEX: 123 SPECIFIC GRAVITY(15/4°C): 0.905

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 294

COLOR: UNION 1(-), ASTM L0.5 .

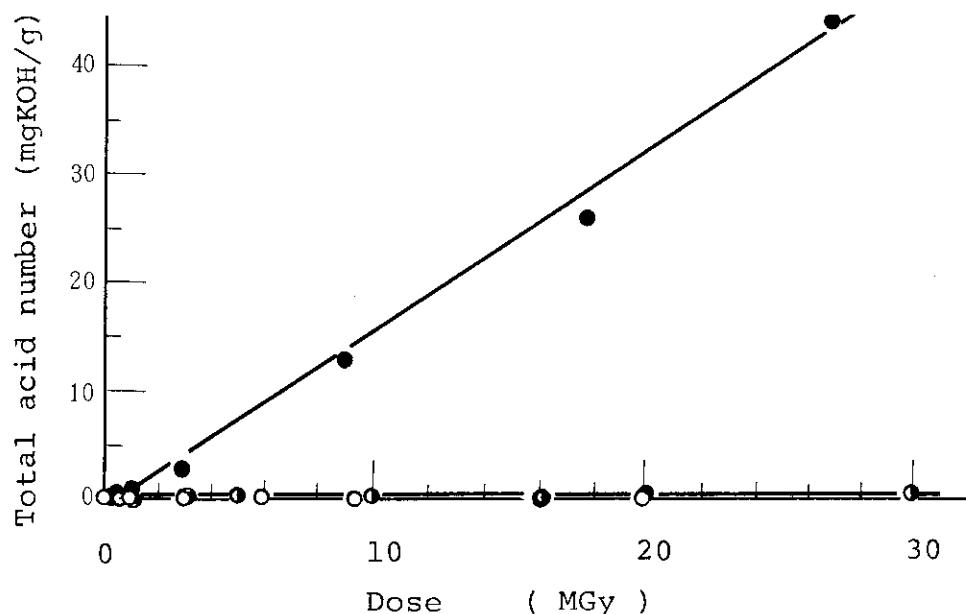
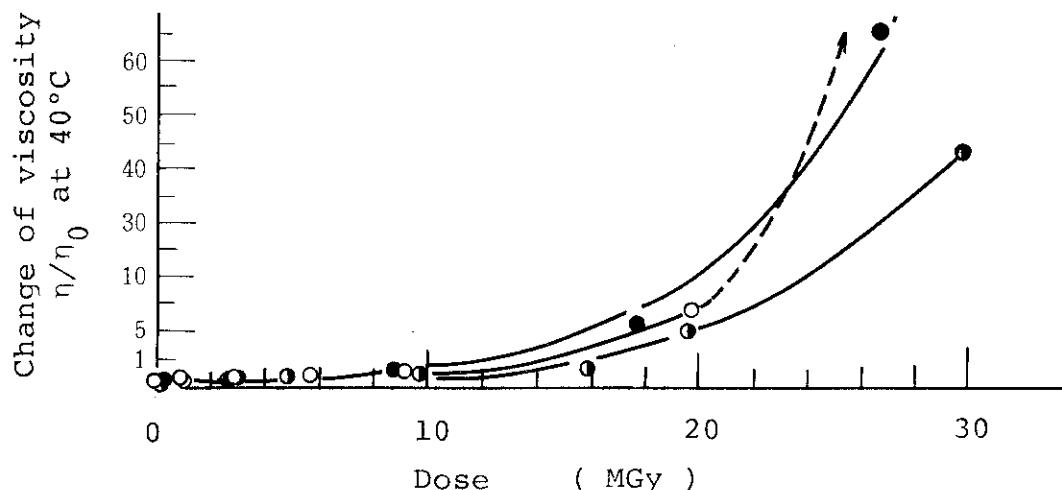
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (40°C)	Viscosity $\eta \times 10^{-6}$ m ² /s (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
in vacuum	1.0	0.906	91.91	12.19	1.08	1.08
	3.0	0.902	107.9	13.80	1.27	1.22
	5.9	0.904	146.5	16.84	1.73	1.49
	9.4	0.909	203.3	22.20	2.40	1.96
	20	0.909	2255	155.2	26.6	13.7
	29.1	gelation				
in bubbling oxygen	0.05	0.900	87.14	11.37	1.03	1.00
	0.21	0.900	88.59	11.65	1.04	1.03
	0.5	0.901	91.27	11.89	1.08	1.05
	0.98	0.903	96.39	12.38	1.14	1.09
	2.9	0.905	118.8	13.74	1.40	1.21
	9.0	0.924	249.6	15.34	2.94	1.35
	18	0.948	930.5	51.95	11.0	4.59
	27	0.979	5623	130.1	66.3	11.5
in air	0.5	0.901	90.72	11.87	1.07	1.05
	1.0	0.904	91.00	11.97	1.07	1.06
	3.0	0.902	108.6	13.61	1.28	1.20
	5.0	0.914	133.0	15.60	1.57	1.38
	10	0.912	193.7	20.66	2.28	1.82
	16.3	0.916	248.6	33.67	2.93	2.97
	20	0.929	856.9	63.33	10.1	5.59
	30	0.927	3699	218.5	43.6	19.3

OIL NAME : Di-alkyl diphenyl ether C-16

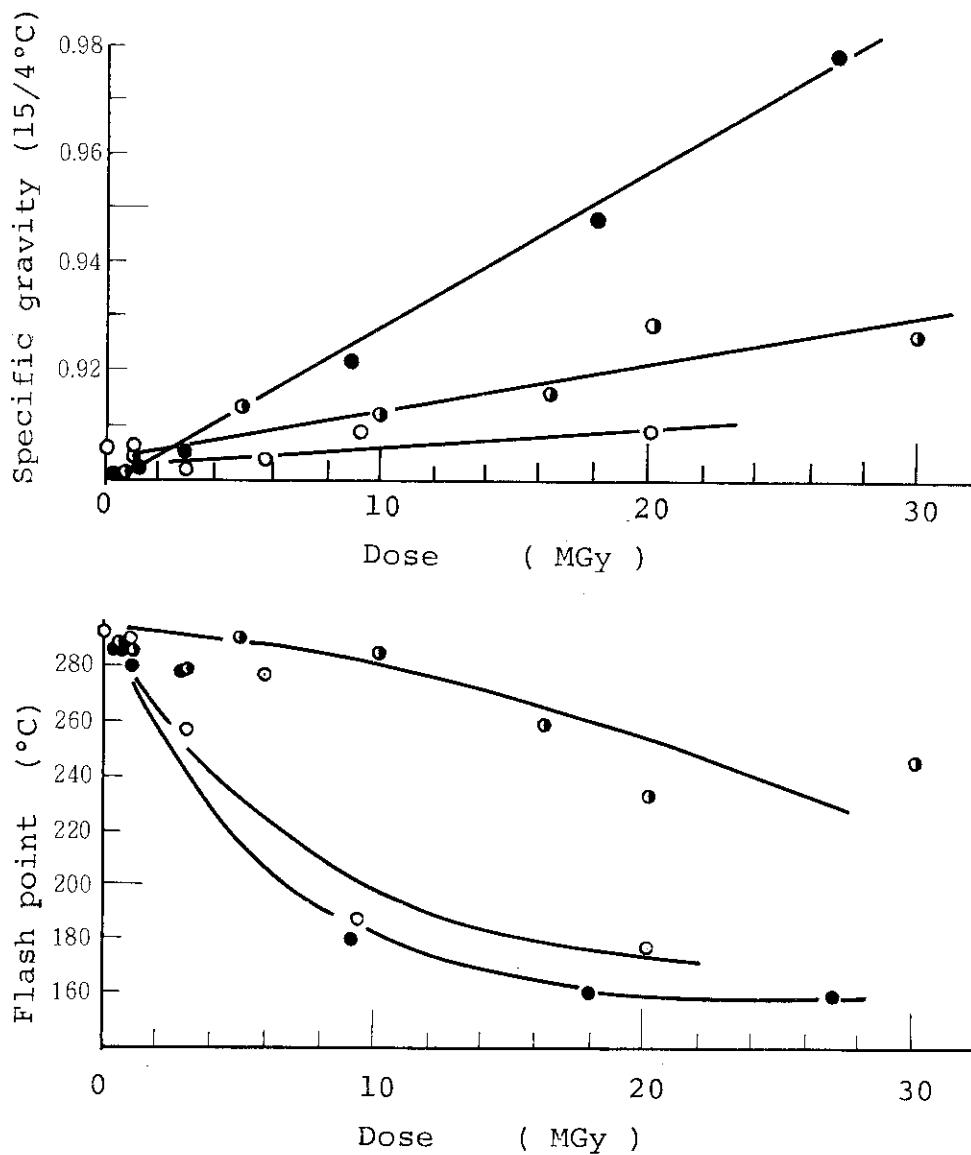
<u>PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION</u>						
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	1.0	114	0.00	292	1 (-)	L0.5
	3.0	128	0.00	258	2 (-)	L1.5
	5.9	124	0.00	278	3(1/2)	3.0
	9.4	132	0.00	188	4	3.5
	20	175	0.00	178	5	5.0
	29.1	gelation				
in bubbling oxygen	0.05	119	0.03	286	2 (-)	L1.5
	0.21	122	0.18	286	2 (-)	L1.5
	0.5	122	0.35	286	2(1/2)	L2.5
	0.98	123	0.75	280	3(1/2)	L3.0
	2.9	113	2.69	278	4 (-)	L4.0
	9.0	38	12.7	180	5	5.5
	18	104	25.8	160	6	6.0
	27	88	44.1	160	7	7.0
in air	0.5	122	0.00	288	1 (-)	L0.5
	1.0	115	0.00	286	1 (-)	L0.5
	3.0	124	0.05	280	2 (-)	L1.5
	5.0	122	0.21	292	2 (-)	L1.5
	10	126	0.16	286	2(1/2)	L2.5
	20	139	0.23	234	4 (-)	L3.5
	30	179	0.34	248	4 (-)	4.0
<u>COMMENT</u>						
<u>IRRADIATION CONDITION</u>						
Dose rate 10 kGy/h.						

OIL NAME : Di-alkyl diphenyl ether C-16

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENTSymbol: \circ in vacuum, \bullet in air, \blacksquare in bubbling oxygen.IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME : Di-alkyl diphenyl ether C-16

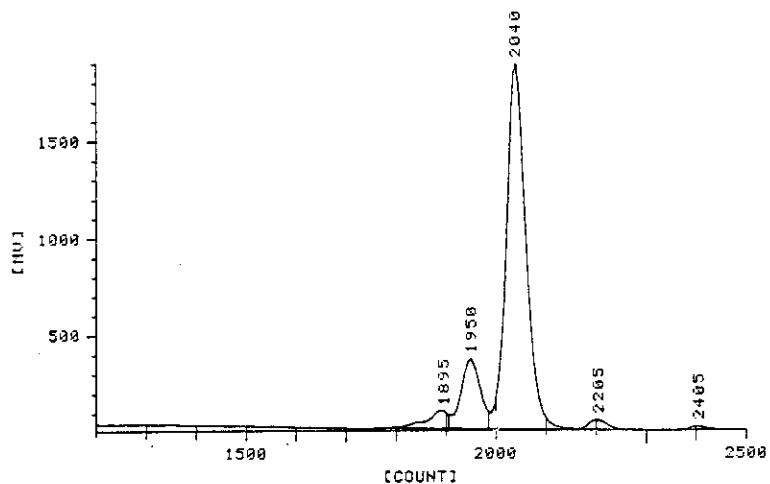
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATIONCOMMENT

Symbol: ○ in vacuum, ● in air, ● in bubbling oxygen.

IRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Di-alkyl diphenyl ether C-16

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/09 15:24 JOB FILE 1

SAMPLE NO. 0 NAME: 10-2 SERIAL NO. 0051

CH.NO 1 METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
1	BASE	1785	1895	1905	1.66349E+03	1.73051E+03	1.80904E+03	1.73051E+03
C	19.5	197.2	85.8		MW/MN	MZ/MW	AREA	AREA%
U								
M	3652	1426	1342		1.04	1.05	4.29556E+03	3.89

PEAK NO.	VALLEY	START	TOP	END	MN	MW	MZ	MU
2	VALLEY	1905	1950	1985	1.07315E+03	1.08095E+03	1.08914E+03	1.08095E+03
C								
U	85.8	373.0	95.8		MW/MN	MZ/MW	AREA	AREA%
M	1342	1059	912		1.01	1.01	1.61224E+04	14.60

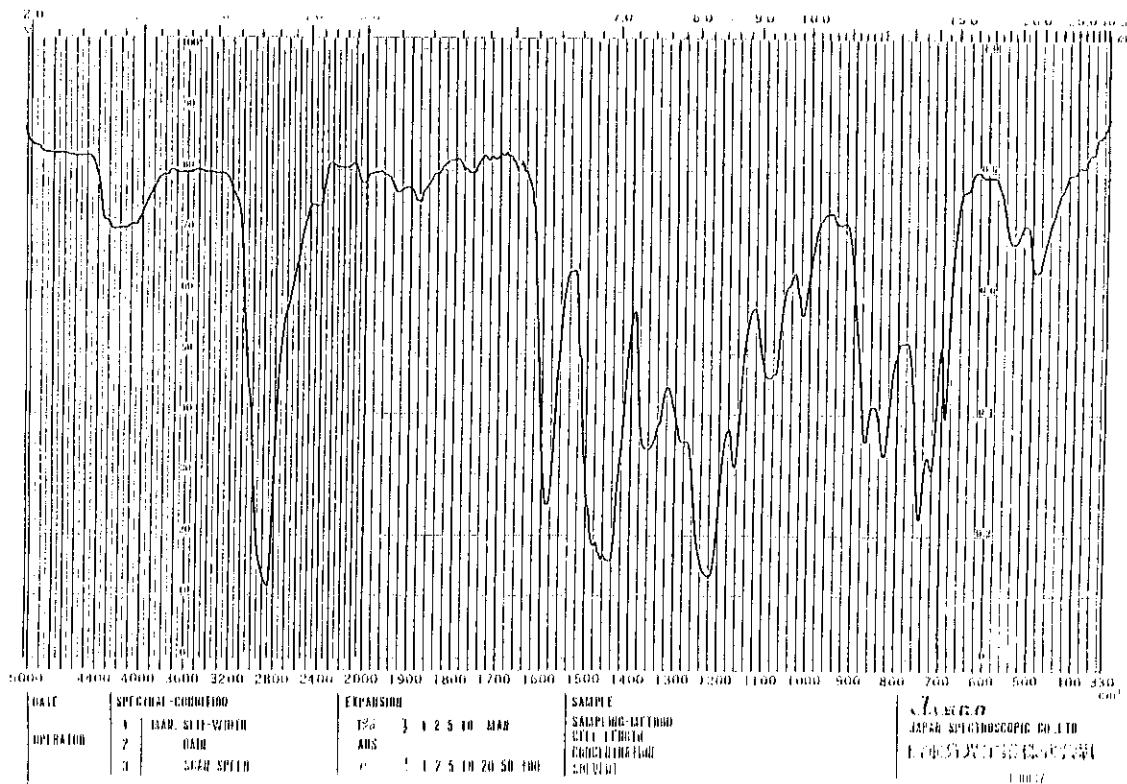
PEAK NO.	VALLEY	START	TOP	END	MN	MW	MZ	MU
3	VALLEY	1985	2040	2155	7.54637E+02	7.57356E+02	7.60085E+02	7.57352E+02
C								
U	95.8	1897.4	9.4		MW/MH	MZ/MW	AREA	AREA%
M	912	757	579		1.00	1.00	8.72110E+04	79.00

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
4	BASE	2155	2205	2255	5.28948E+02	5.29321E+02	5.29692E+02	5.29320E+02
C								
U	9.4	57.4	6.3		MW/MN	MZ/MW	AREA	AREA%
M	579	529	487		1.00	1.00	1.98797E+03	1.80

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
5	BASE	2365	2405	2495	3.67279E+02	3.67812E+02	3.68329E+02	3.67811E+02
C								
U	3.4	25.0	7.0		MW/MN	MZ/MW	AREA	AREA%
M	401	369	296		1.00	1.00	7.76906E+02	0.70

TOTAL	START	TOP	END	MN	MW	MZ	MU	
C	1785	2040	2495	7.93991E+02	8.35634E+02	9.02936E+02	8.35631E+02	
U	19.5	1897.4	7.0		MW/MN	MZ/MW	AREA	AREA%
M	3652	757	296		1.05	1.00	1.10393E+05	100.00

OIL NAME: Di-alkyl diphenyl ether C-16



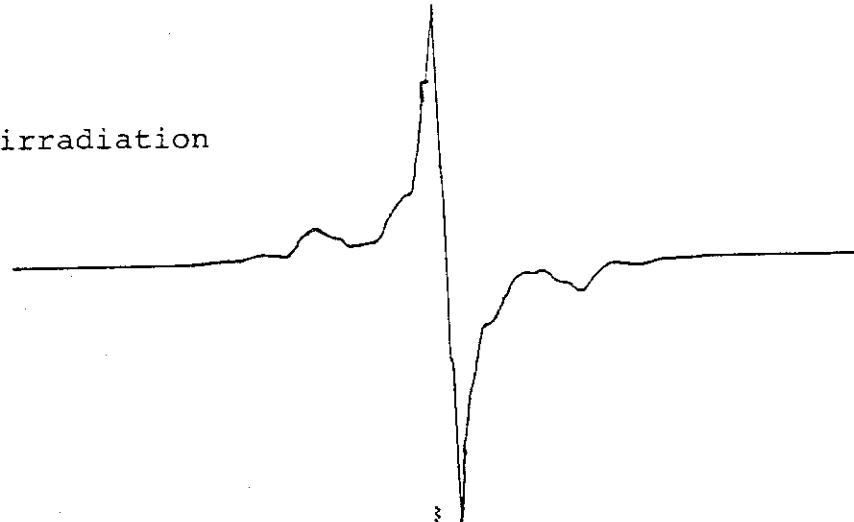
Infrared spectrum (original)

OIL NAME : Di-alkyl diphenyl ether C-16

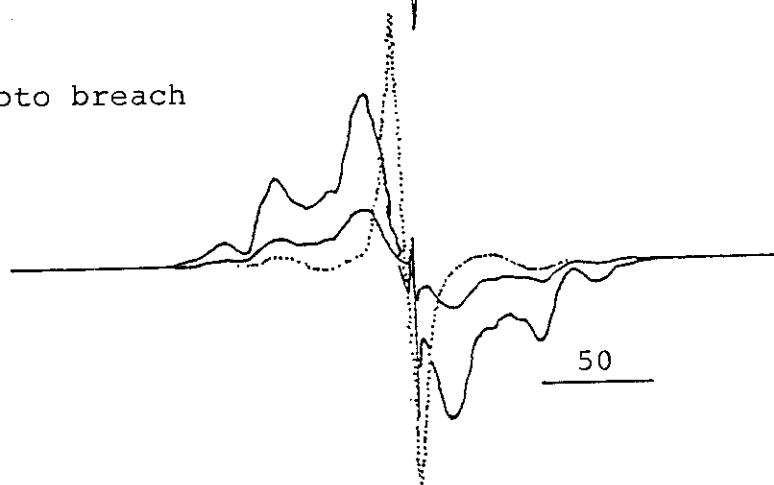
IRRADIATION CONDITION

Temp.: -196°C Dose 10.8kGy in Vacuum

after irradiation



after photo breach

ESR CONDITIONSweep range(Gauss) : ± 250 Power(μW) : 1

Modulation width(100kHz, Gauss) : 2 at -196°C

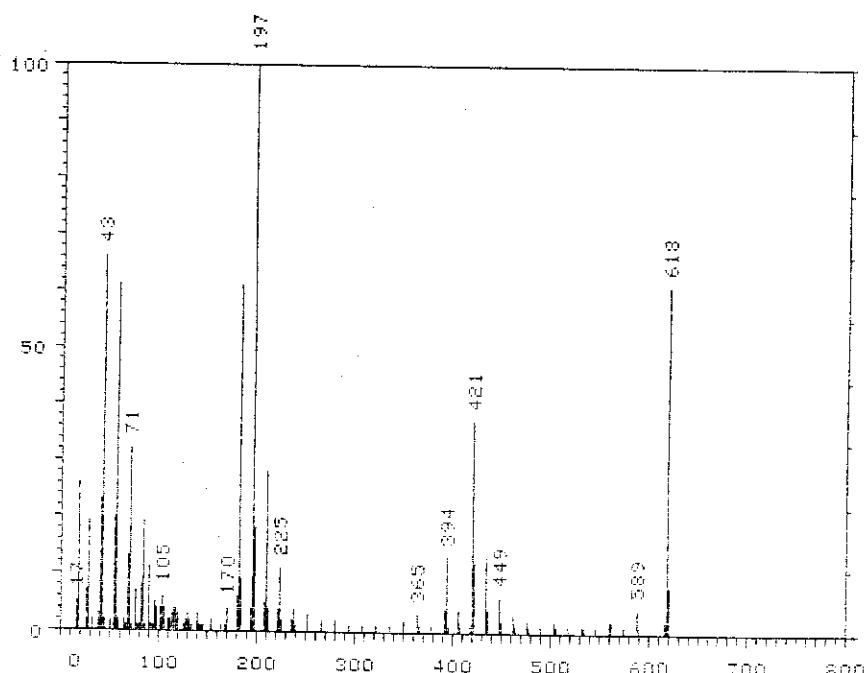
G[R.]after irradiation

1.6

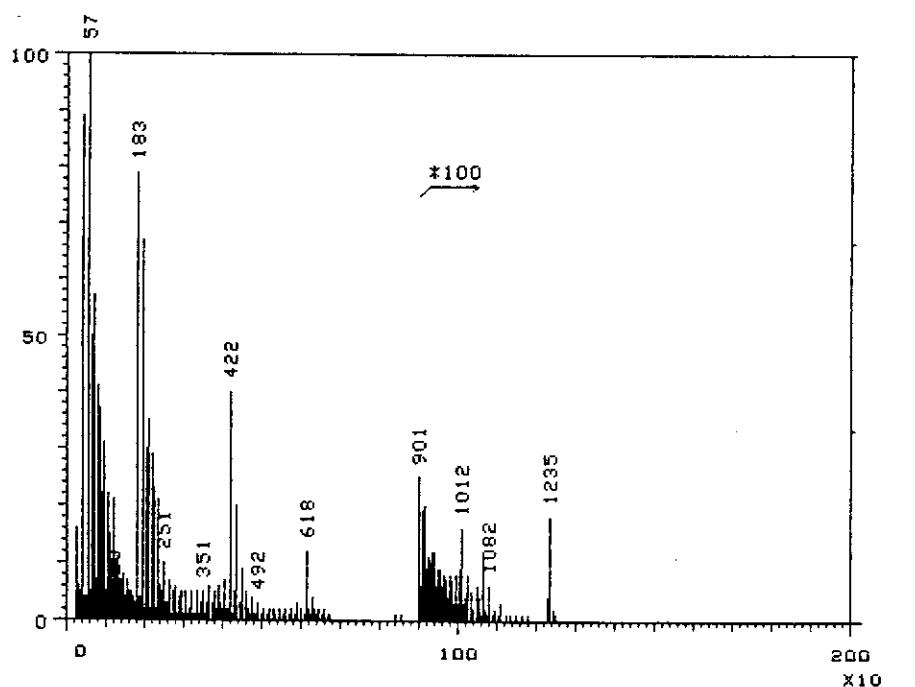
after Photo breach

1.36

OIL NAME: Di-alkyl diphenyl ether C-16



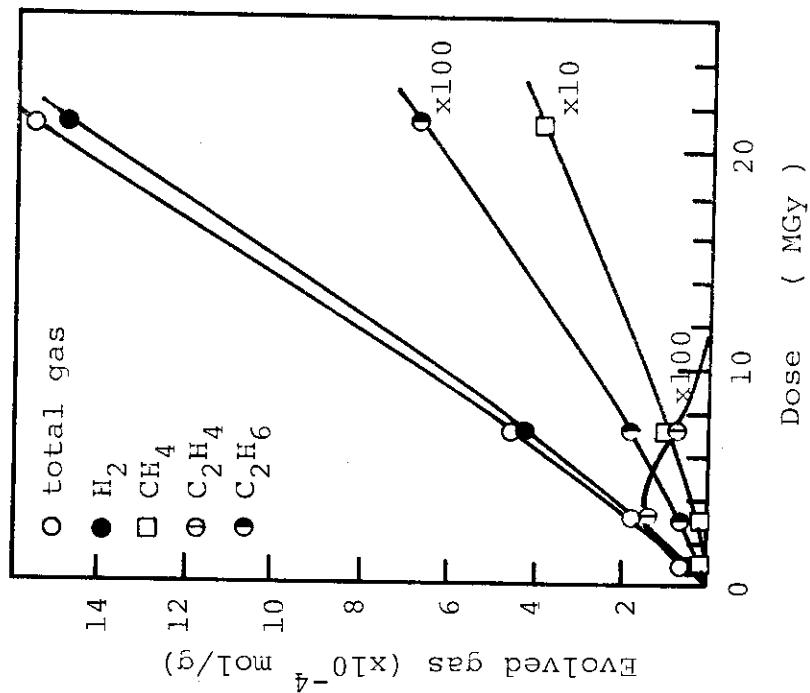
(original)



(30 MGy in bubbling oxygen)

The mass spectrum of Di-alkyl diphenyl ether.

OIL NAME : Di-alkyl diphenyl ether C-16

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	4.8×10^{-1}
$G(H_2)$	4.7×10^{-1}
$G(CH_4)$	1.5×10^{-2}
$G(C_2H_6)$	2.2×10^{-3}
$G(C_2H_4)$	4.9×10^{-3}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-4}$ mol/g)

10 MGy 6.6

20 MGy 14.6

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: m-(m-Phenoxyphenoxy)diphenyl

STRUCTURE OR FEATURE: $\text{O}-\text{C}_6\text{H}_4-\text{O}-\text{C}_6\text{H}_4-\text{O}$, C_6H_4 :benzene ring.

MOLECULAR WEIGHT:338

VISCOSITY at 40°C: $124.0 \times 10^{-6} \text{ m}^2/\text{s}$ ($7.473 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: -104 SPECIFIC GRAVITY(15/4°C): 1.162

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 258

COLOR: UNION 1(-) , ASTM L0.5 .

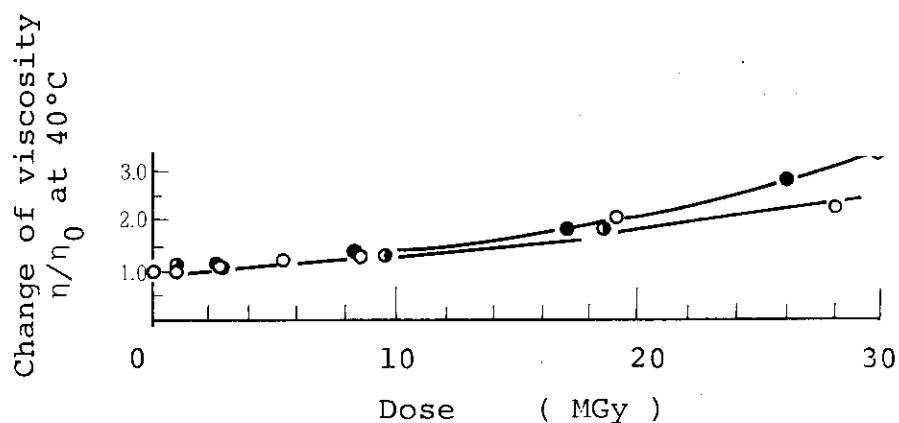
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (40°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
in vacuum	0.9	1.163	122.4	7.493	0.99	1.00
	2.7	1.163	133.3	7.751	1.08	1.04
	5.4	1.162	150.5	8.110	1.21	1.09
	8.5	1.163	159.4	8.696	1.29	1.16
	19	1.166	258.0	10.22	2.08	1.37
	29	1.169	424.8	12.87	3.43	1.72
in bubbling oxygen	0.9	1.163	129.6	7.611	1.05	1.02
	2.7	1.163	138.1	7.792	1.11	1.04
	8.2	1.164	171.3	8.548	1.38	1.14
	17		234.0	9.612	1.89	1.29
	26	1.173	352.4	11.41	2.84	1.53
in air	0.9	1.168	125.5	7.648	1.01	1.02
	2.8	1.163	130.5	7.690	1.05	1.03
	9.5	1.163	162.3	8.240	1.31	1.10
	18.5	1.165	227.2	9.779	1.83	1.31
	28	1.165	285.3	10.67	2.30	1.43

OIL NAME : m-(m-Phenoxyphenoxy)diphenyl

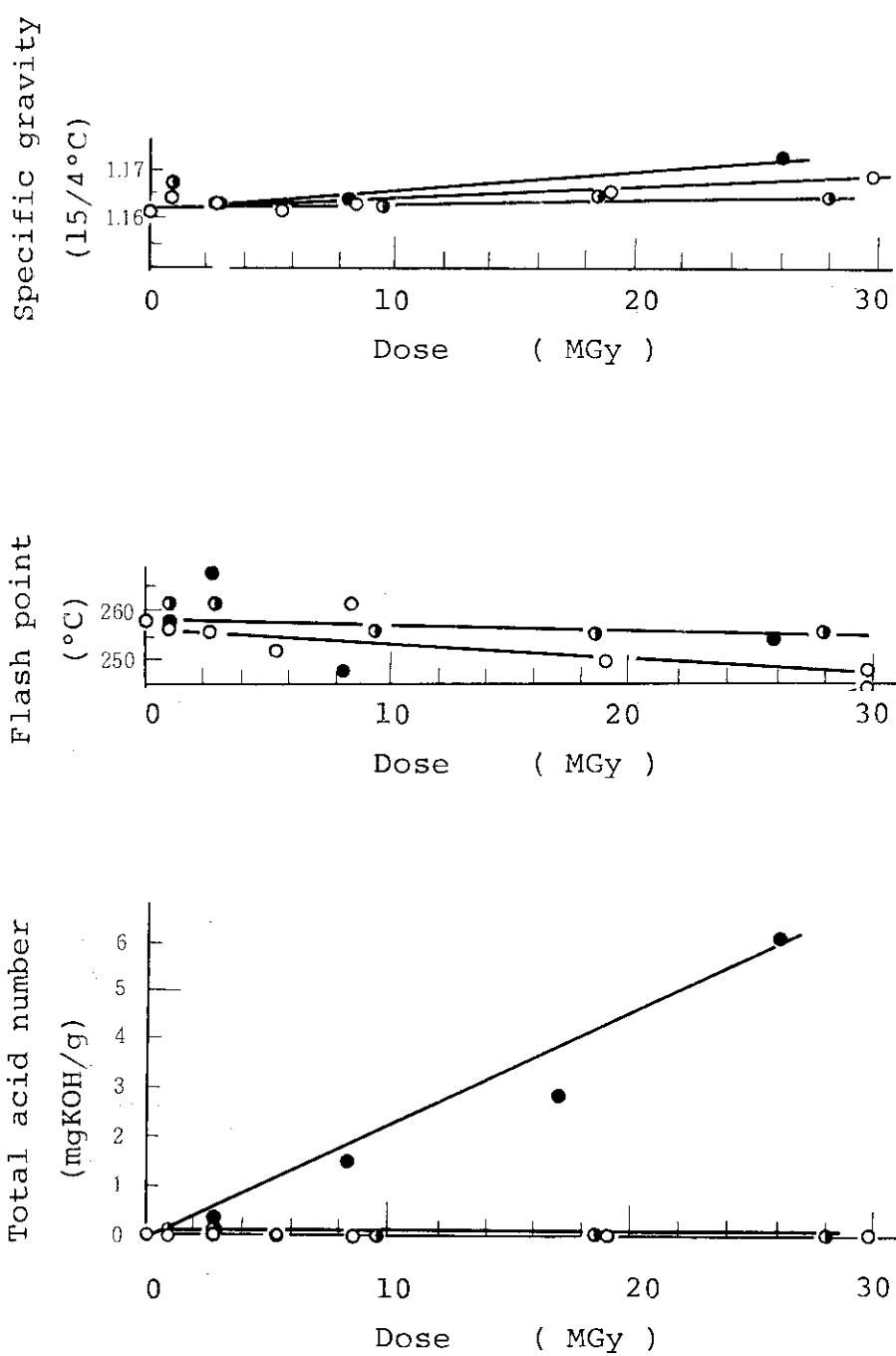
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in vacuum	0.9	-97	0.00	256	1(-)	L0.5
	2.7	-106	0.00	256	1(1/2)	L1.0
	5.4	-115	0.00	252	3(1/2)	3.5
	8.5	-89	0.00	262	2(1/2)	2.0
	19	-154	0.00	250	5	5.0
	29	-182	0.00	248	7(-)	7.0
in bubbling oxygen	0.9	-106	0.21	258	3(1/2)	L3.0
	2.7	-113	0.34	268	5	5.5
	8.2	-125	1.54	248	8(-)	7.5
	17	-160	2.97			
	26	-197	6.23	254	8	8.0
in air	0.9	-92	0.02	262	1(-)	L0.5
	2.8	-102	0.04	262	1(1/2)	L1.0
	9.5	-132	0.04	256	2(1/2)	L2.5
	18.5	-137	0.04	256	4(-)	L4.0
	28	-163	0.04	256	4(1/2)	L5.0



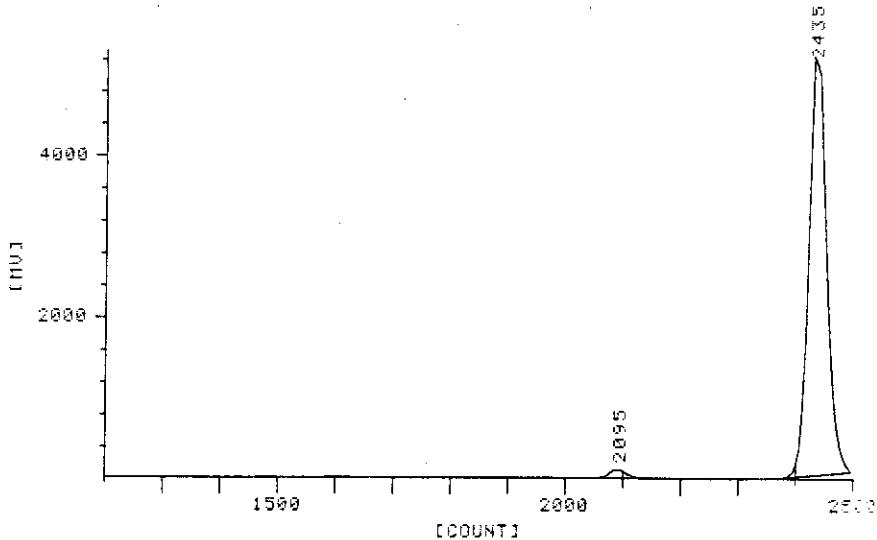
Symbol: O in vacuum, ● in air, ● in bubbling oxygen.

OIL NAME: m-(m-Phenoxyphenoxy)diphenyl



Symbol: ○ in vacuum, ● in air, • in bubbling oxygen.

OIL NAME: m-(m-Phenoxyphenoxy)diphenyl

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/02/20 19:20 JOB FILE 1

SAMPLE NO. 0 NAME: 11-1 SERIAL NO. 0008

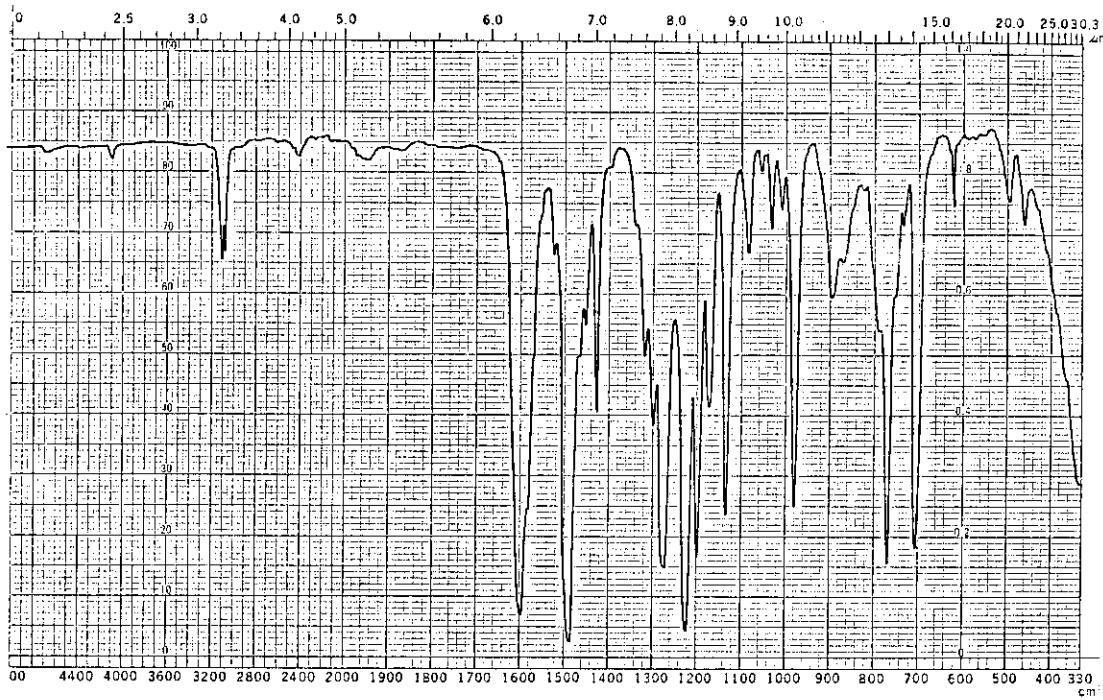
CH.NO 1 METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2045	2095	2150	6.58273E+02	6.58993E+02	6.59711E+02	6.58991E+02	
U	16.8	121.6	15.2	MW/MN	MZ/MW	AREA	AREAP%	
M	746	656	584	1.00	1.00	3.70179E+03	1.90	

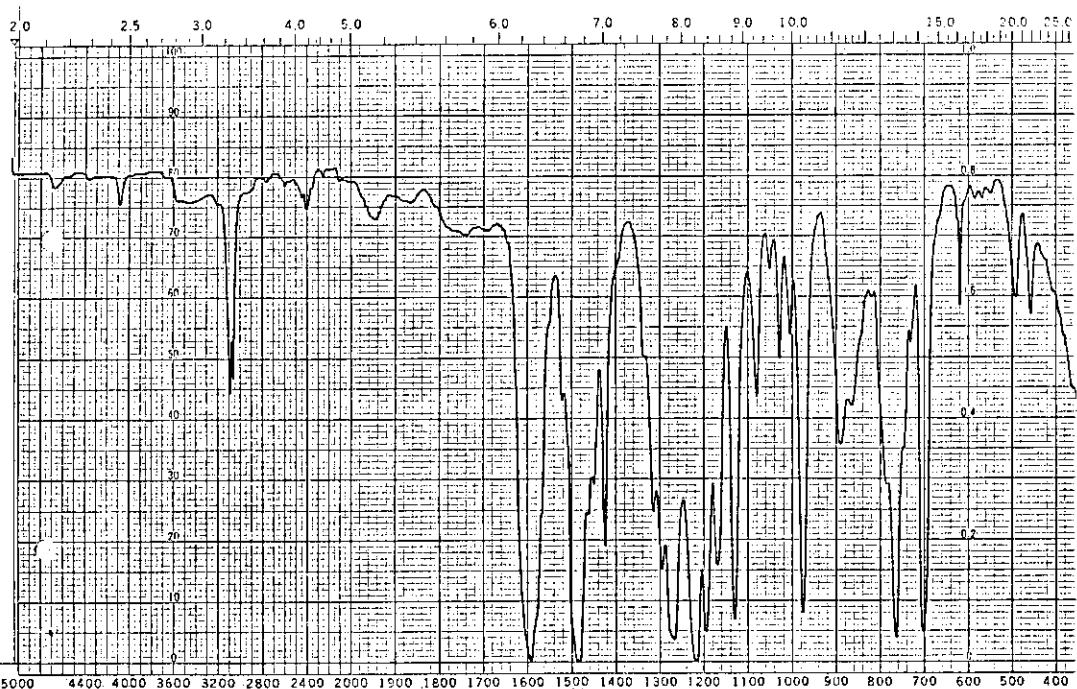
PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MU
C	2365	2435	2495	3.43364E+02	3.43803E+02	3.44234E+02	3.43802E+02	
U	14.2	5158.6	98.9	MW/MN	MZ/MW	AREA	AREAP%	
M	481	345	296	1.00	1.00	1.91248E+05	98.10	

TOTAL	START	TOP	END	MN	MW	MZ	MU
C	2045	2435	2495	3.46512E+02	3.49788E+02	3.55520E+02	3.49787E+02
U	16.8	5158.6	98.9	MW/MN	MZ/MW	AREA	AREAP%
M	746	345	296	1.01	1.02	1.94942E+05	100.00

OIL NAME: m-(m-phenoxyphenoxy)diphenyl



Infrared spectrum (original)



Infrared spectrum(30 MGy in bubbling oxygen)

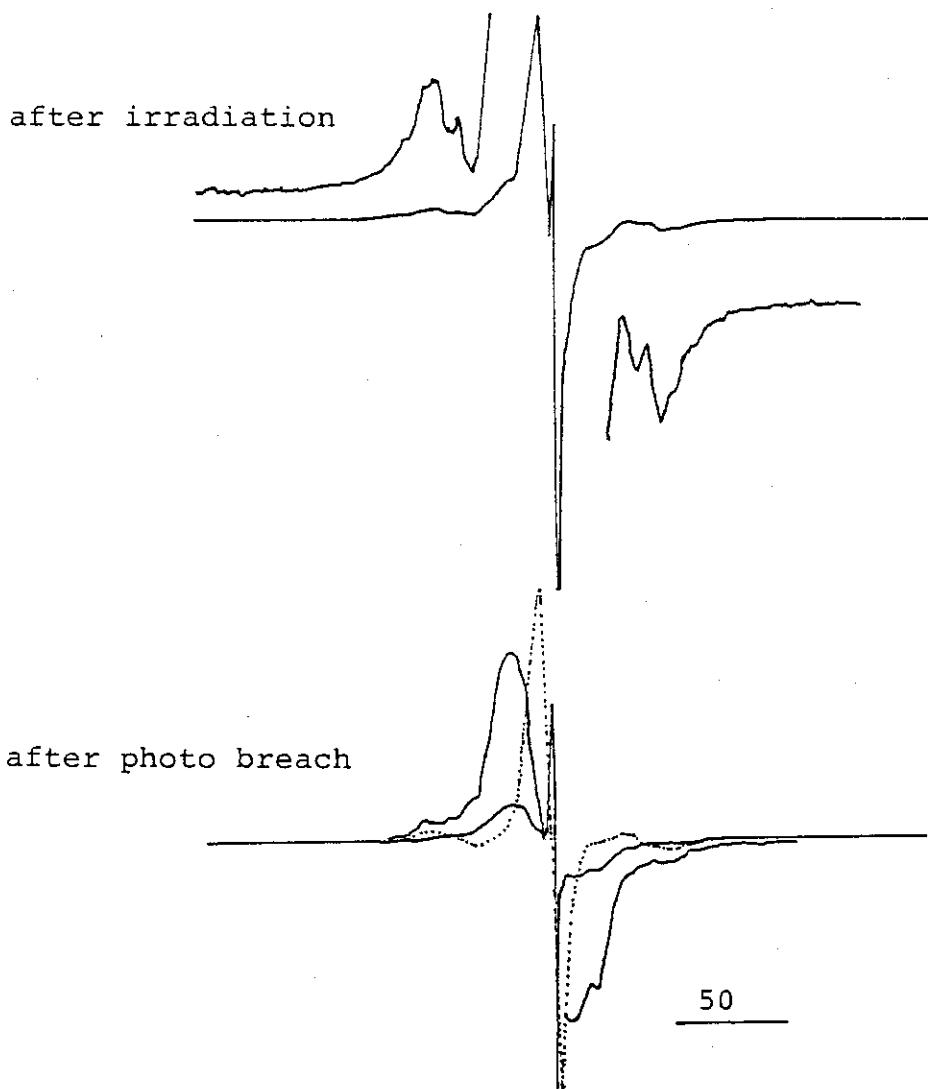
OIL NAME : m-(m-Phenoxyphenoxy)diphenyl

IRRADIATION CONDITION

Temp.: -196°C

Dose 107kGY

in Vacuum

ESR CONDITIONSweep range(Gauss): ± 250 Power(μW): 1

Modulation width(100kHz, Gauss): 2 at -196°C

G[R.]after irradiation

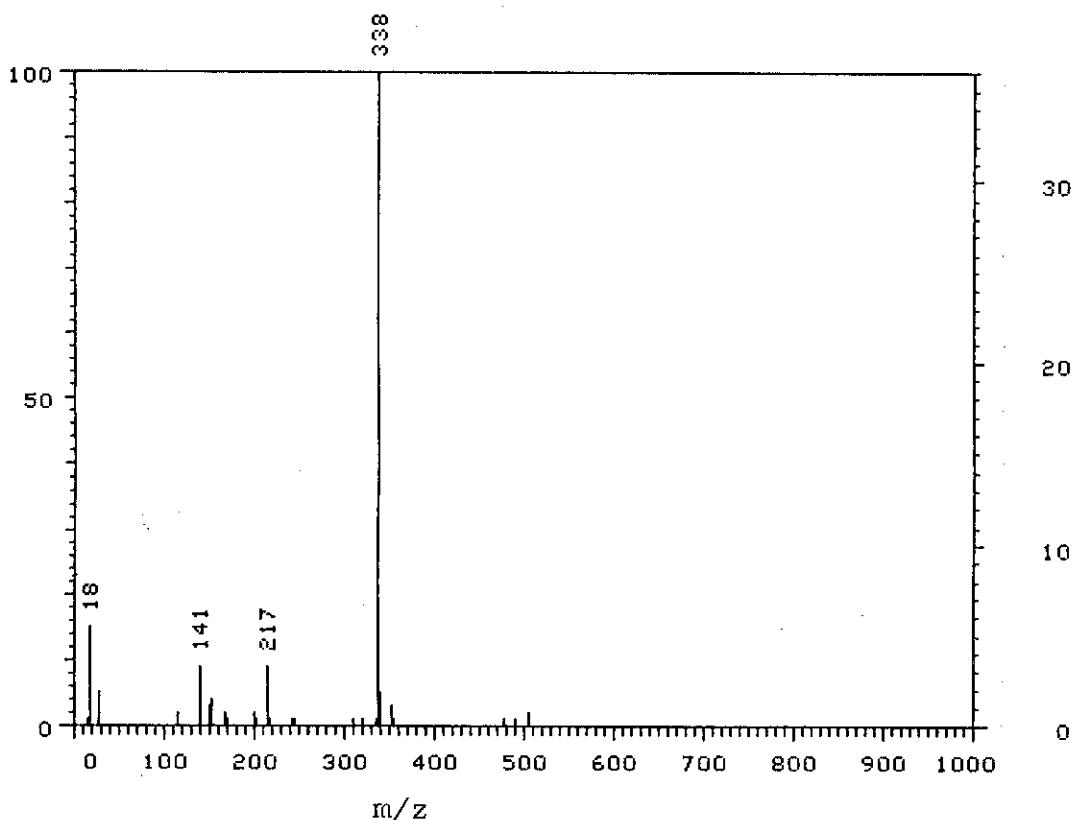
0.11

after Photo breach

0.046

OIL NAME: m-(m-Phenoxyphenoxy)diphenyl

4P2E
SAMPLE NO. : 5 SCAN NO. : 1*30 TIME(MIN): 0.0

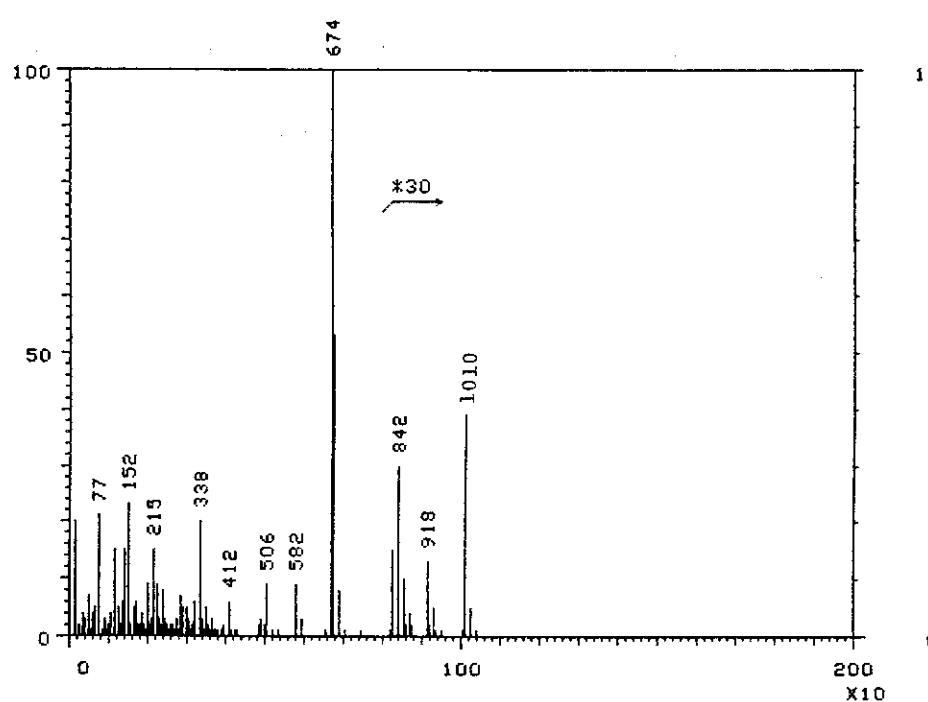


The mass spectrum (DI) of m-(m-phenoxyphenoxy)diphenyl
(original)

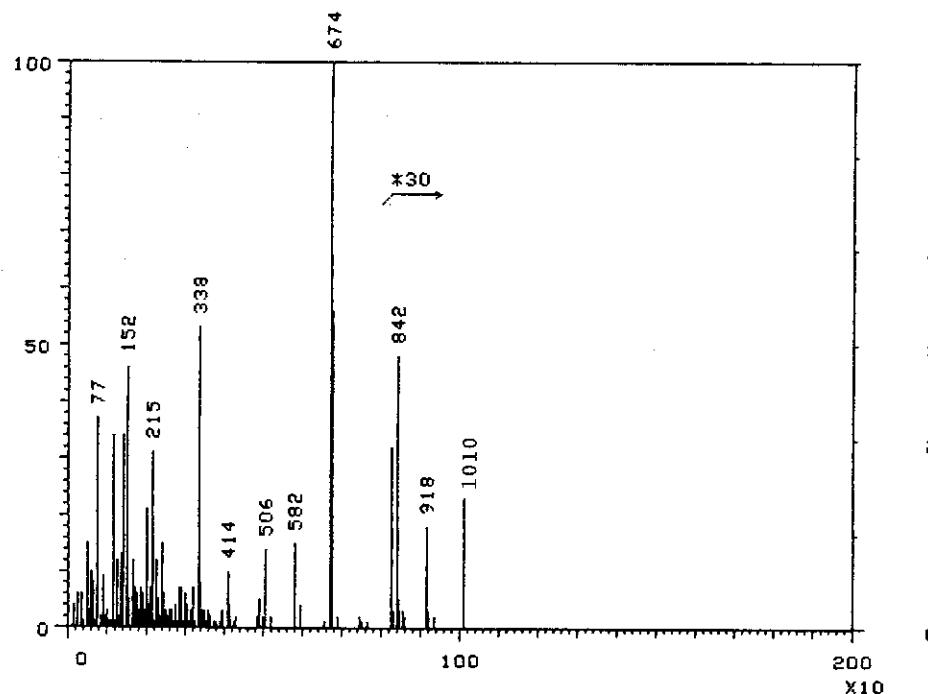
COMMENT

IRRADIATION CONDITION

OIL NAME: m-(m-Phenoxyphenoxy)diphenyl

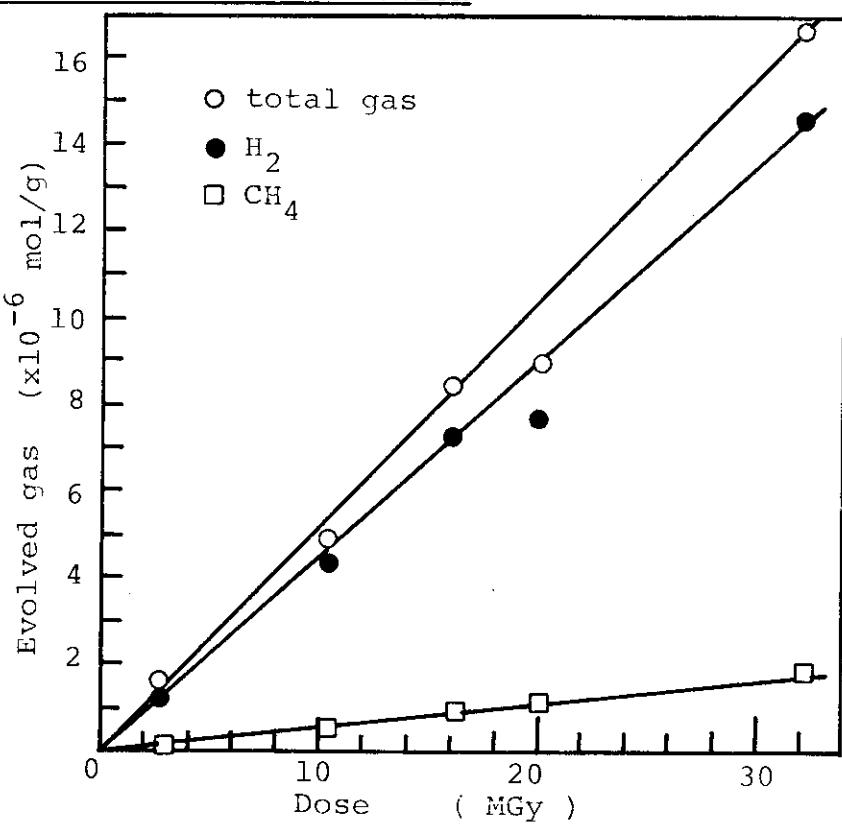


(30 MGy in bubbling oxygen)



The mass spectrum of m-(m-phenoxyphenoxy)diphenyl
(30 MGY in vacuum)

OIL NAME : m-(m-Phenoxyphenoxy)diphenyl

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$G(\text{total gas})$	5.0×10^{-3}
$G(H_2)$	4.3×10^{-3}
$G(CH_4)$	5.8×10^{-4}

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-6}$ mol/g)

10 MGy	5.2
20 MGy	10
30 MGy	16

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: m-(m-Phenoxyphenoxy)diphenyl

BREAKDOWN VOLTAGE

Measurement times	original	Breakdown voltage (kV)		
		1 MGy	5 MGy	10 MGy
1 (V ₁)	45.5	42.6	45.5	45.5
2 (V ₂)	45.5	36.1	43.4	39.4
3 (V ₃)	45.5	45.5	43.7	45.5
4 (V ₄)	45.5	45.5	42.1	45.5
5 (V ₅)	45.5	45.5	45.5	44.5
average (V)	45.5	43.2	43.7	43.7

COMMENTIRRADIATION CONDITION

OIL NAME: Pentaphenyl ether

STRUCTURE OR FEATURE: $\phi-O-\phi-O-\phi-O-\phi-O-\phi$, ϕ :benzene ring.

MOLECULAR WEIGHT: 446

VISCOSITY at 40°C: $286.0 \times 10^{-6} \text{ m}^2/\text{s}$ ($12.65 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: -62 SPECIFIC GRAVITY(15/4°C): 1.200

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 282

COLOR: UNION 1(-) , ASTM L0.5 .

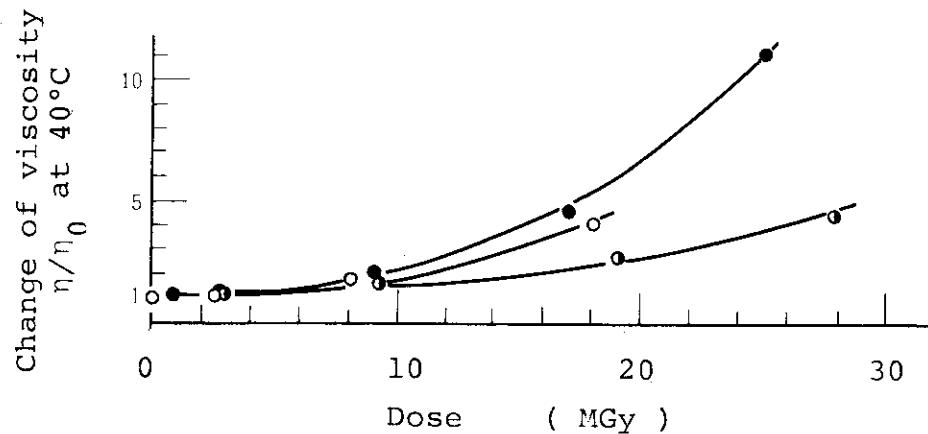
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$	η/η_0	
		(15/4°C)	(40°C)	(100°C)	(40°C)
in vacuum	2.5	1.201	333.9	13.83	1.17 1.09
	5.2	1.203	420.6	14.86	1.47 1.17
	8.0	1.203	514.2	15.96	1.80 1.26
	18	1.212	1186	22.52	4.15 1.78
in bubbling oxygen	0.8	1.197	309.3	12.97	1.08 1.03
	2.7	1.198	354.6	13.80	1.24 1.09
	9.0	1.205	612.8	17.06	2.14 1.35
	17		1321	23.90	4.62 1.89
	25	1.210	3204	33.22	11.2 2.63
in air	2.8	1.198	330.0	13.40	1.15 1.06
	9.2	1.194	451.1	15.10	1.58 1.19
	19	1.203	761.1	18.87	2.66 1.49
	28	1.209	1255	22.81	4.39 1.80

OIL NAME : Pentaphenyl ether

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

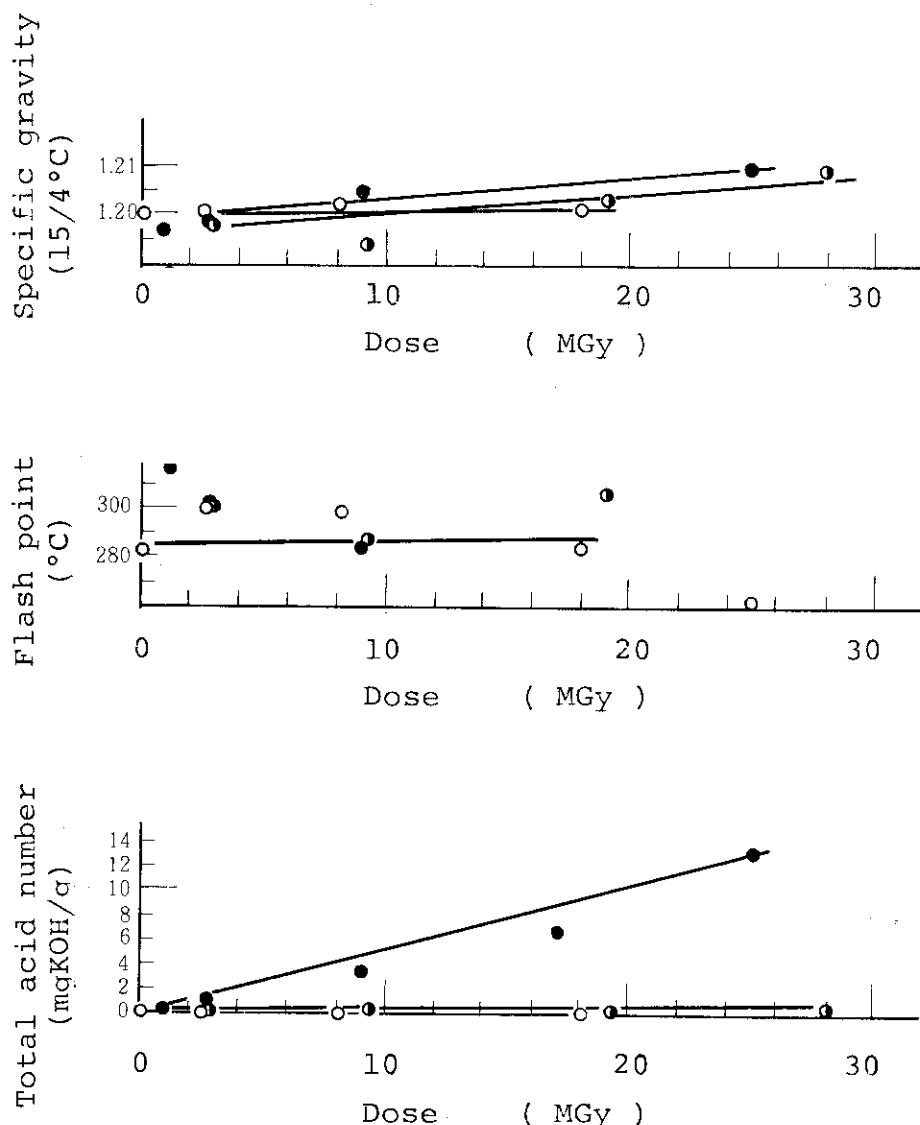
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in vacuum	2.5	-61	0.00	300	7	7.5
	5.2	-90	0.00	290	8	8.0
	8.0	-110	0.00	298	8	8.0
	18	-171	0.00	284	8	8.0
in bubbling oxygen	0.8	-71	0.24	316	5 (-)	L5.5
	2.7	-78	0.95	310	7 (-)	L7.5
	9.0	-126	3.57	284	8	8.0
	17	-169	6.69		8	8.0
	25	-266	13.2	262	8	8.0
in air	2.8	-73	0.06	300	4	L4.5
	9.2	-102	0.31	288	7 (-)	6.5
	19	-136	0.36	306	7 (-)	7.5
	28	-183	0.59		8	8.0



Symbol: O in vacuum, ● in air, ○ in bubbling oxygen.

IRRADIATION CONDITION

OIL NAME : Pentaphenyl ether

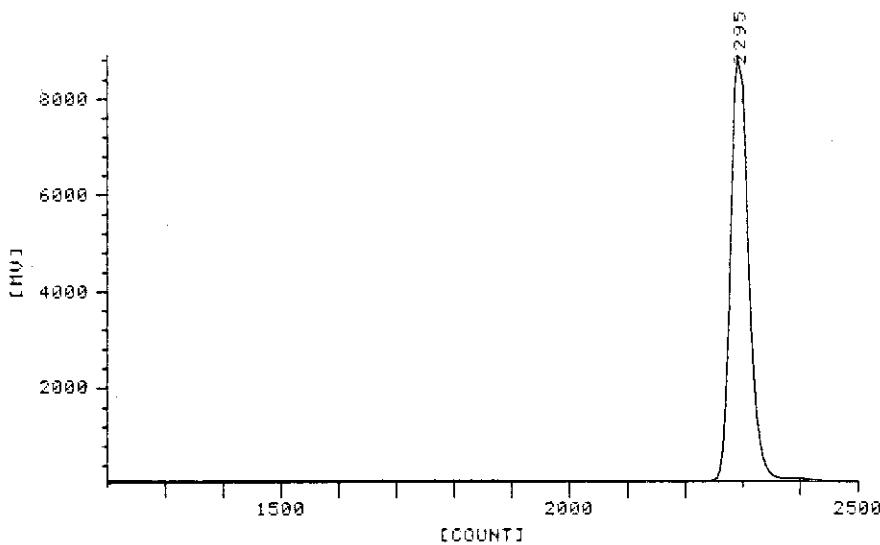
PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Symbol: ○ in vacuum, ● in air, ● in bubbling oxygen.

COMMENTIRRADIATION CONDITION

Dose rate 10 kGy/h.

OIL NAME: Pentaphenyl ether

MOLECULAR WEIGHT DISTRIBUTION (original sample)

86/07/09 17:27 JOB FILE 1

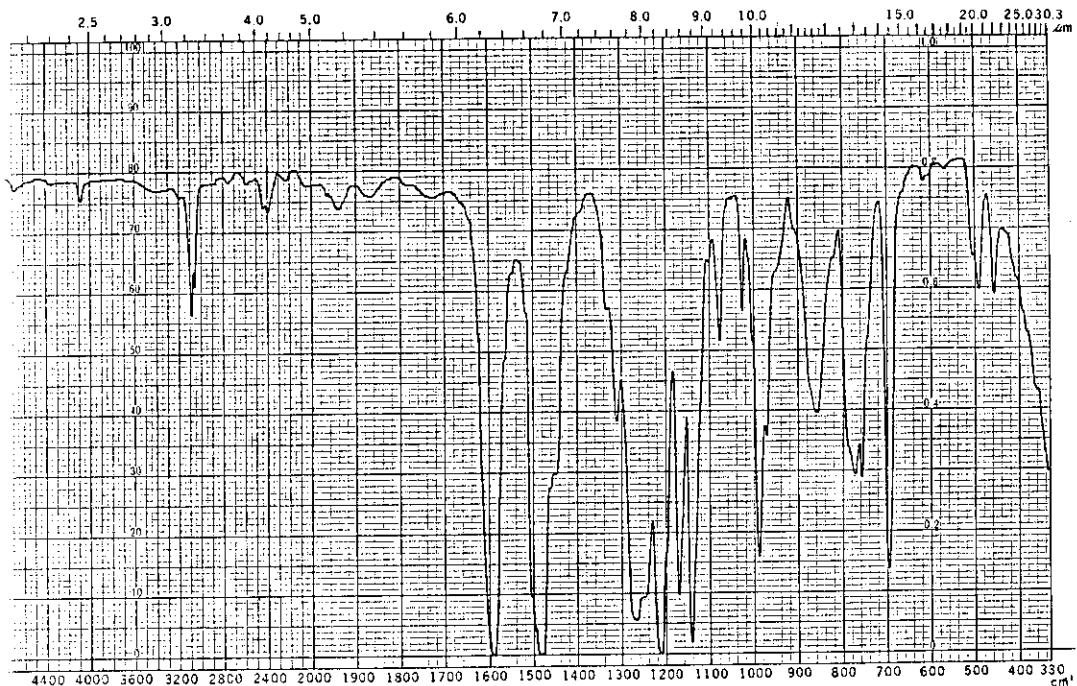
SAMPLE NO. 9 NAME: 11-2

SERIAL NO. 0054

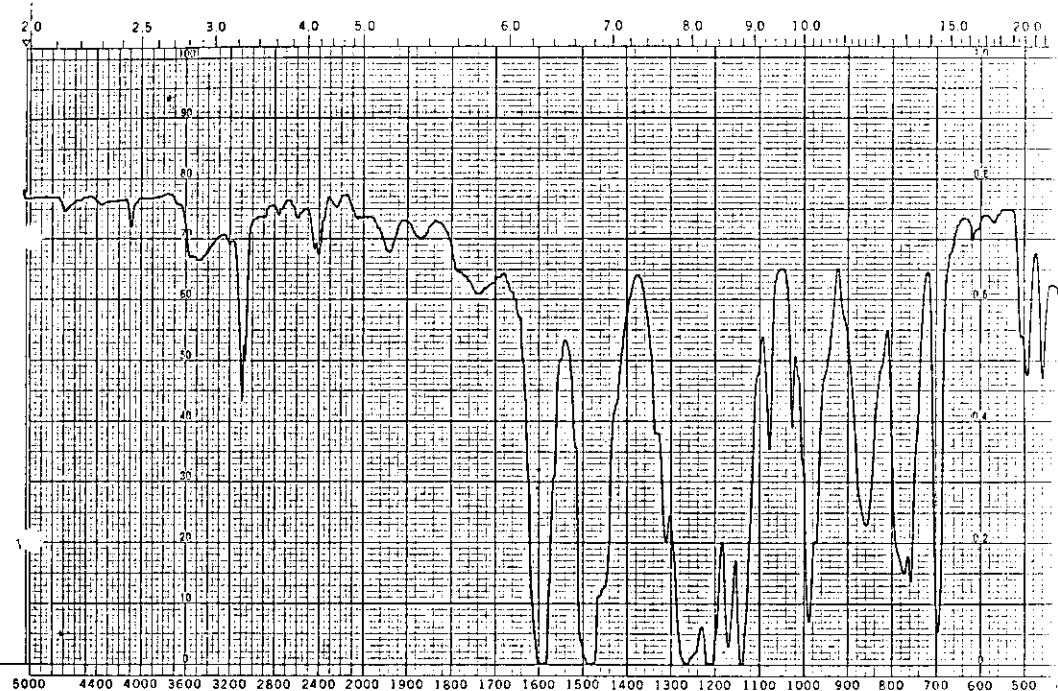
CH.NO 1 METHOD 2

PEAK NO.	BASE	START	TOP	END	MN	MW	MZ	MV
C		2230	2295	2495	4.53161E+02	4.53617E+02	4.54042E+02	4.53616E+02
V		45.6	8541.6	29.7	MW/MN	M2/MW	AREA	AREA%
M		507	455	296	1.00	1.00	3.31097E+05	100.00

OIL NAME: Pentaphenyl ether



Infrared spectrum (original)



Infrared spectrum (30 MGy in bubbling oxygen)

OIL NAME : Pentaphenyl ether

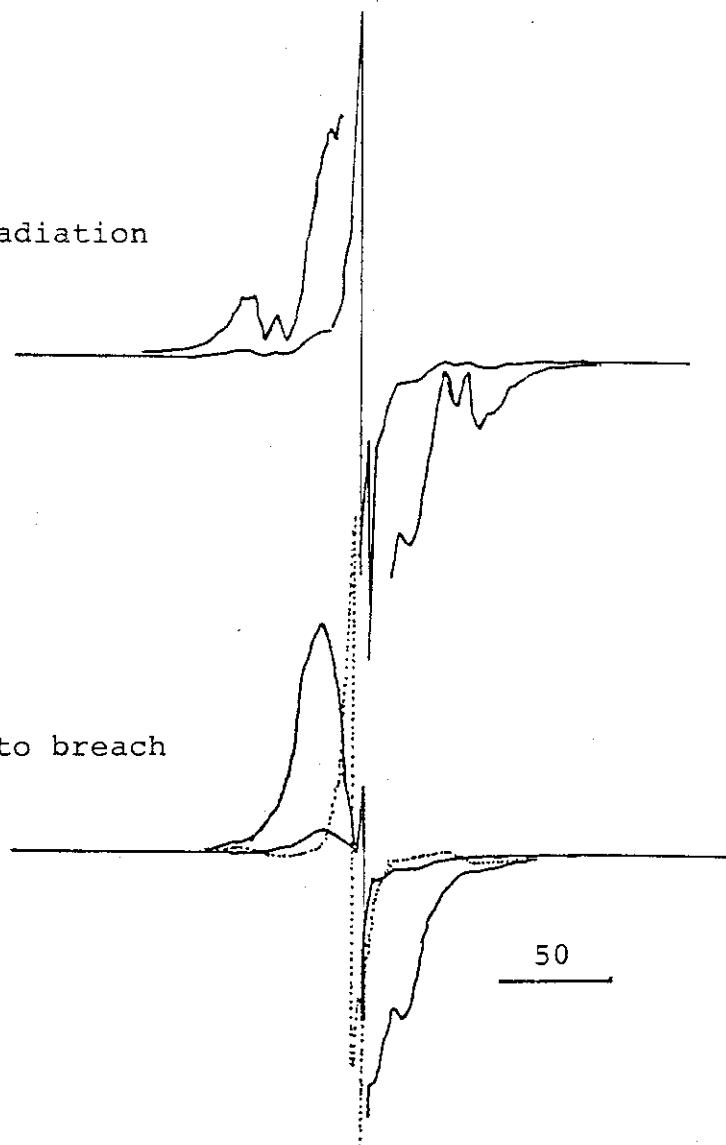
IRRADIATION CONDITION

Temp.: -196°C

Dose 106.5kGy

in Vacuum

after irradiation



after photo breach

ESR CONDITIONSweep range(Gauss): ± 250 Power(μW): 1

Modulation width(100kHz,Gauss): 2 at -196°C

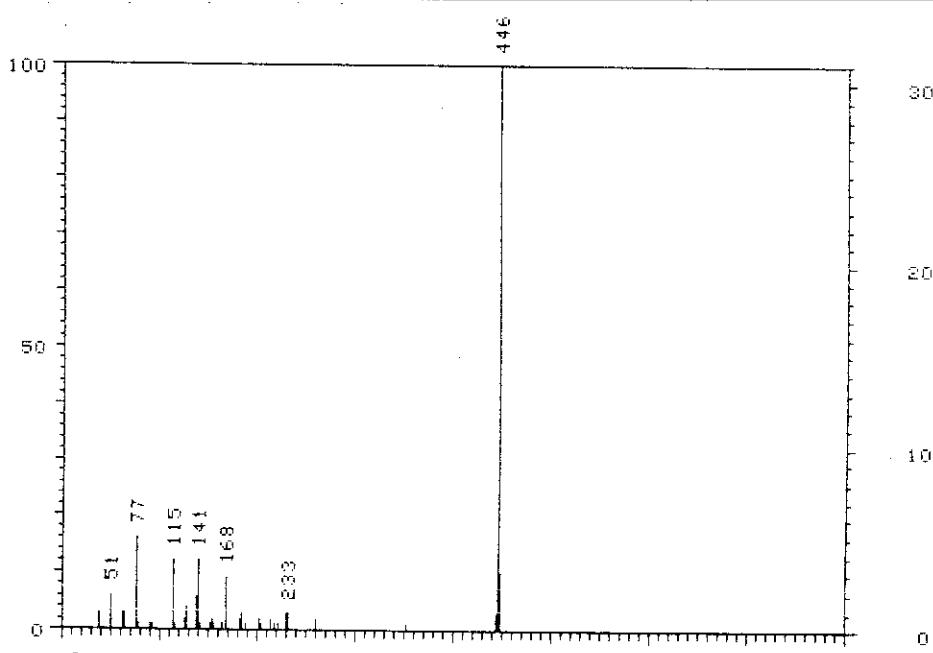
G[R.]after irradiation

0.12

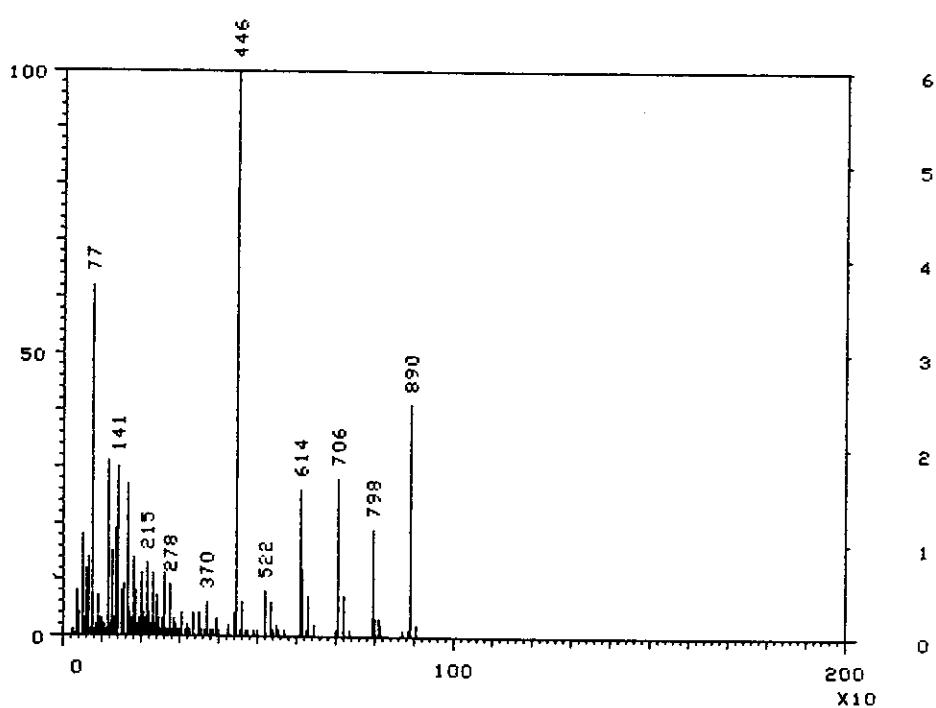
after Photo breach

0.048

OIL NAME: Pentaphenyl ether

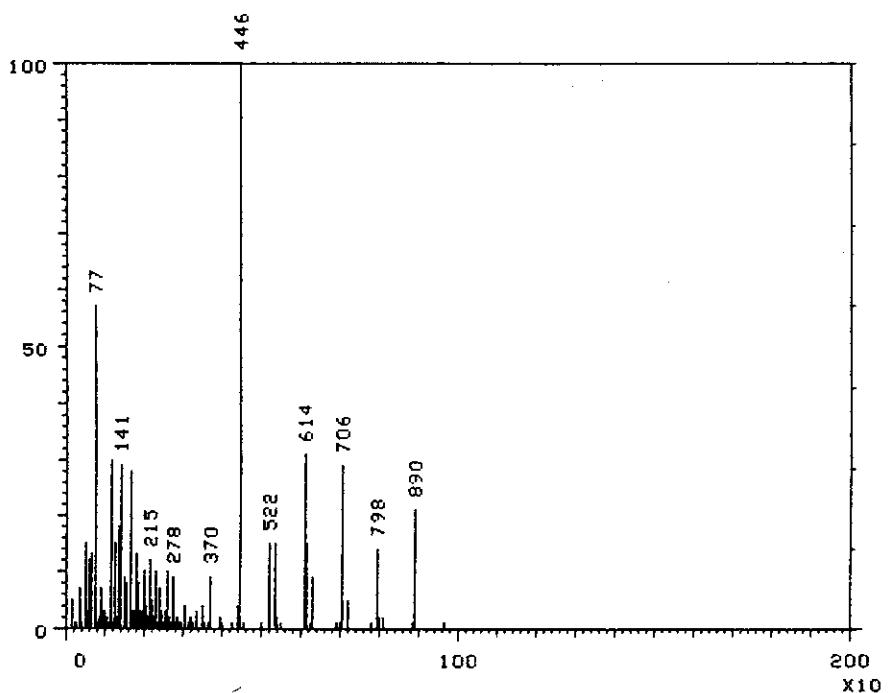


(original)



(30 MGy in bubbling oxygen)
The mass spectrum of Pentaphenyl ether.

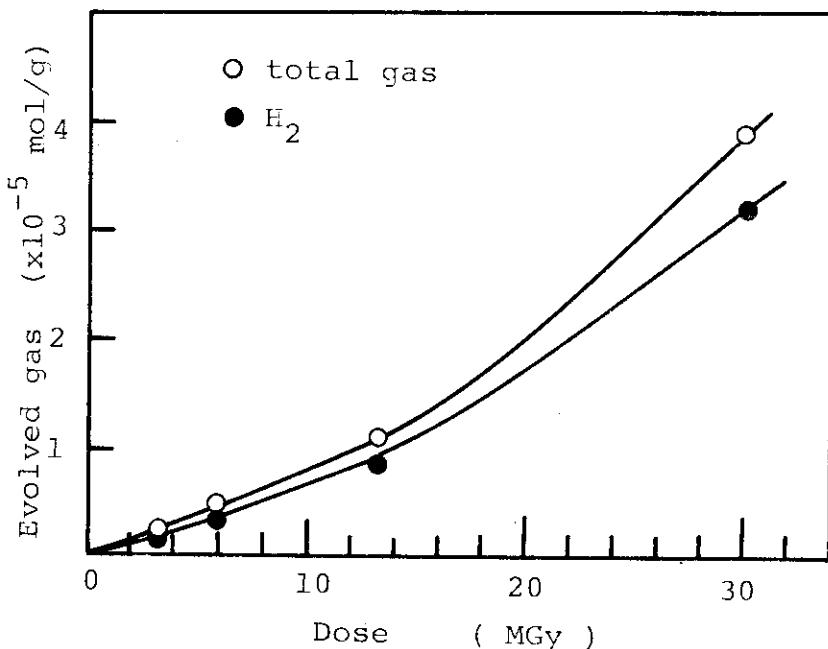
OIL NAME: Pentaphenyl ether



(30 MGy in vacuum)

The mass spectrum of pentaphenyl ether.

OIL NAME : Pentaphenyl ether

RADIATION-INDUCED GAS EVOLUTIONG VALUES OF THE EVOLVED GASES

$$\begin{aligned} G(\text{total gas}) &= 6.6 \times 10^{-3} \\ G(H_2) &= 6.1 \times 10^{-3} \end{aligned}$$

AMOUNT OF TOTAL EVOLVED GASES ($\times 10^{-6}$ mol/g)

10 MGy	8.0
20 MGy	20
30 MGy	39

COMMENTIRRADIATION CONDITION

in vacuum, dose rate 10 kGy/h.

OIL NAME: mix-Alkyl diphenyl ether

STRUCTURE OR FEATURE: R- \emptyset -O- \emptyset , R- \emptyset -O- \emptyset -R*, R:alkyl C-12,14.

MOLECULAR WEIGHT: 428

VISCOSITY at 40°C: 55.15×10^{-6} m²/s (8.399x10⁻⁶ m²/s at 100°C)

VISCOSITY INDEX: 125 SPECIFIC GRAVITY(15/4°C): 0.900

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 226

COLOR: UNION , ASTM 0.5 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6}$ m ² /s (15/4°C) (40°C) (100°C)	Viscosity η / η_0 (40°C) (100°C)	
in	1.27	0.906	63.11	9.393	1.15
bubbling	2.94	0.908	75.53	10.05	1.37
oxygen	6.02	0.918	107.5	12.12	1.95
	10.16	0.931	183.1	16.67	3.32
in air	0.98	0.901	59.70	8.882	1.08
	2.93	0.903	67.63	9.760	1.23
	5.66	0.904	81.93	11.00	1.49
	9.8	0.909	121.8	14.38	2.21
					1.71

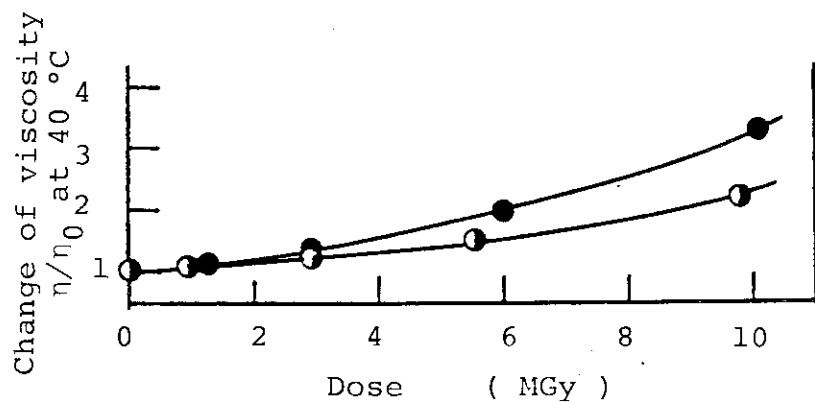
COMMENT

mix. ratio R- \emptyset -O- \emptyset : R- \emptyset -O- \emptyset -R = 58 : 42 \emptyset :benzene ring

OIL NAME : mix-Alkyl diphenyl ether

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

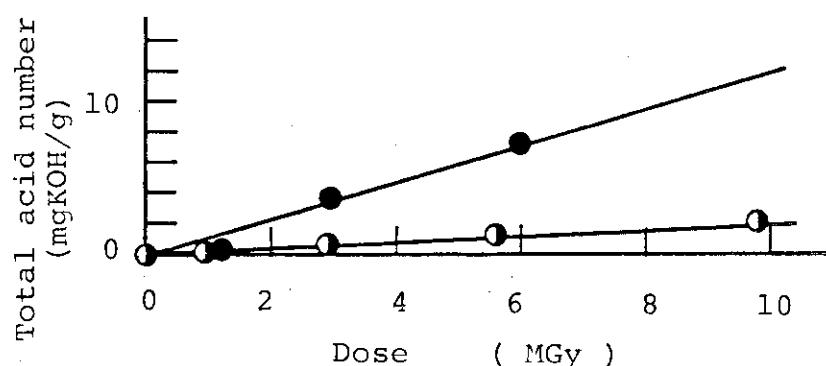
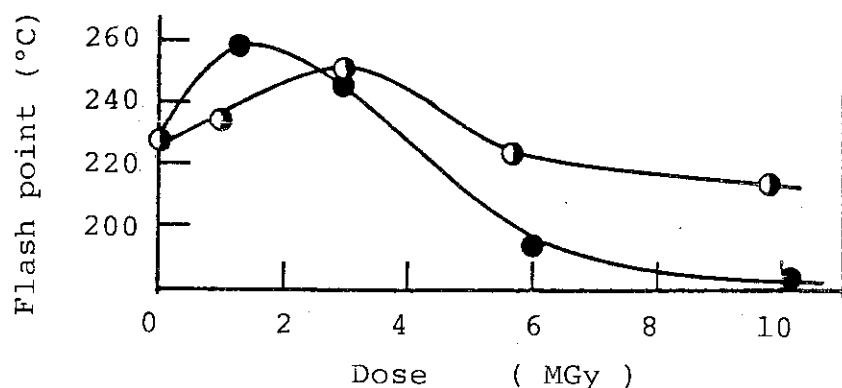
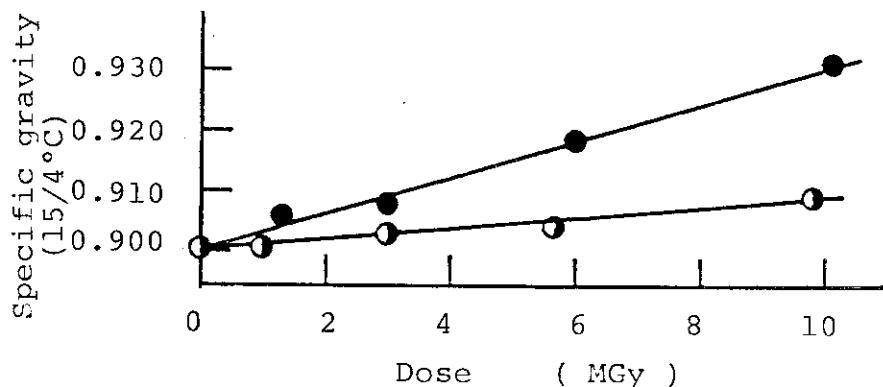
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	Color ASTM
in bubbling oxygen	1.27	129	0.17	258		3.0
	2.94	115	3.66	246		4.0
	6.02	104	7.21	193		4.0
	10.16	96	7.69	183		5.5
in air	0.98	125	0.03	234		1.5
	2.93	126	0.05	250		L2.0
	5.66	122	0.12	224		2.5
	9.8	119	0.23	214		3.5



Symbol: ● in air, ● in bubbling oxygen.

COMMENTIRRADIATION CONDITION

OIL NAME: mix-Alkyl diphenyl ether



Symbol: ● in air, ● in bubbling oxygen.

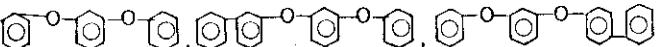
OIL NAME: mix-Alkyl diphenyl ether

BREAKDOWN VOLTAGE

Measurement times	original	Breakdown voltage (kV)		
		1 MGy	5 MGy	10 MGy
1 (V ₁)	24.7	45.5	45.5	40.5
2 (V ₂)	15.2	38.9	45.5	43.7
3 (V ₃)	27.1	34.5	45.5	45.5
4 (V ₄)	20.1	43.9	45.5	45.0
5 (V ₅)	27.5	45.5	45.5	38.2
average (V)	22.5	40.7	45.5	43.1

COMMENTIRRADIATION CONDITION

OIL NAME: mix-Phenoxyphenoxy diphenyl

STRUCTURE OR FEATURE: 

MOLECULAR WEIGHT: 338

VISCOSITY at 40°C: $190.0 \times 10^{-6} \text{ m}^2/\text{s}$ ($8.100 \times 10^{-6} \text{ m}^2/\text{s}$ at 100°C)

VISCOSITY INDEX: -210 SPECIFIC GRAVITY(15/4°C): 1.17

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 240

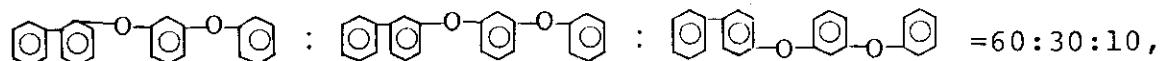
COLOR: UNION , ASTM 0 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity (15/4°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (40°C)	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$ (100°C)	η/η_0 (40°C)	η/η_0 (100°C)
in	0.83	1.17	194.5	8.113	1.02	1.00
bubbling	3.0	1.17	202.6	8.232	1.07	1.02
oxygen	5.4	1.17	216.6	8.586	1.14	1.06
	9.43	1.17	259.7	9.080	1.37	1.12
	20	1.17	368.8	10.47	1.92	1.28
	27.5	1.17	595.5	12.27	2.98	1.52
in air	0.92	1.17	191.9	8.181	1.01	1.01
	2.77	1.17	204.7	8.270	1.02	1.03
	5.27	1.17	210.5	8.330	1.11	1.03
	9.62	1.17	235.9	8.731	1.24	1.08
	20	1.17	302.4	9.530	1.59	1.18
	27.6	1.17	467.8	11.41	2.34	1.42

COMMENT

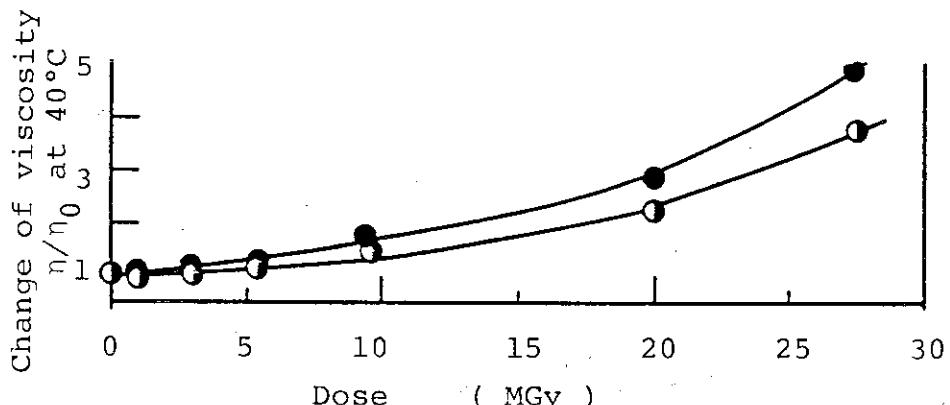
mix. ratio

 = 60:30:10,

OIL NAME : mix-Phenoxyphenoxy diphenyl

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

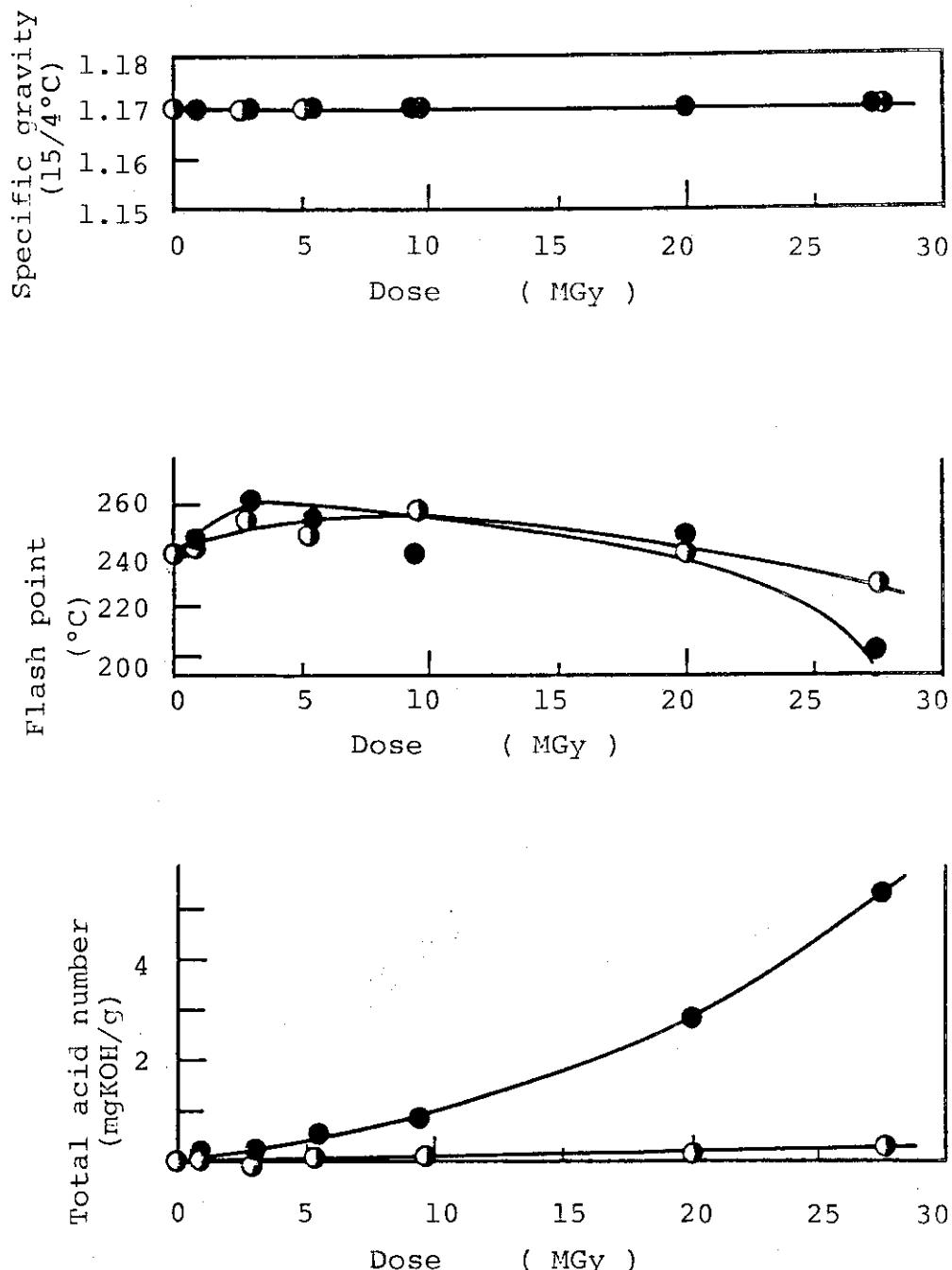
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in bubbling oxygen	0.83	-220	0.21	246		2.5
	3.0	-226	0.22	262		5.0
	5.4	-218	0.54	254		6.5
	9.43	-253	0.89	240		7.5
	20	-293	2.85	248		8.0
	27.5	-393	5.28	202		D8.0
in air	0.92	-206	0.00	244		1.0
	2.77	-226	0.02	254		2.0
	5.27	-233	0.02	248		2.0
	9.62	-243	0.06	258		3.5
	20	-283	0.08	240		5.0
	27.6	-333	0.24	228		6.5

COMMENT

Symbol: ● in air, ○ in bubbling oxygen.

IRRADIATION CONDITION

OIL NAME: mix-Phenoxyphenoxy diphenyl



Symbol: ● in air, ● in bubbling oxygen.

OIL NAME: mix-Polyphenyl ether

STRUCTURE OR FEATURE: mix-Phenoxyphenoxy diphenyl (4P2E) +
Mono-alkyl diphenyl ether C-18,
MOLECULAR WEIGHT: 380

VISCOSITY at 40°C: 42.00×10^{-6} m²/s (5.600x10⁻⁶ m²/s at 100°C)

VISCOSITY INDEX: 50 SPECIFIC GRAVITY(15/4°C): 1.04

TOTAL ACID NUMBER: 0.00 mgKOH/g, FLASH POINT(°C): 254

COLOR: UNION , ASTM 0 .

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

Irradiation condition	Dose [MGy]	Specific gravity	Viscosity $\eta \times 10^{-6} \text{ m}^2/\text{s}$	η/η_0	(15/4°C)	(40°C)	(100°C)	(40°C)	(100°C)
in	0.85	1.04	43.75	5.701	1.04	1.04	1.02	1.04	1.02
bubbling	3.07	1.04	48.31	6.053	1.15	1.15	1.08	1.15	1.08
oxygen	5.55	1.04	54.63	6.340	1.30	1.30	1.13	1.30	1.13
	9.69	1.05	68.10	7.250	1.62	1.62	1.29	1.62	1.29
	20.57	1.06	125.4	9.808	2.99	2.99	1.75	2.99	1.75
	28.35	1.07	326.8	16.77	7.78	7.78	2.99	7.78	2.99
in air	1.05	1.04	43.13	5.608	1.03	1.03	1.00	1.03	1.00
	2.87	1.04	46.51	5.880	1.11	1.11	1.05	1.11	1.05
	5.88	1.04	53.53	6.420	1.27	1.27	1.15	1.27	1.15
	10.44	1.04	61.32	7.030	1.46	1.46	1.26	1.46	1.26
	20.57	1.05	94.66	8.930	2.19	2.19	1.59	2.19	1.59
	28.44	1.05	197.0	13.59	4.69	4.69	2.43	4.69	2.43

COMMENT

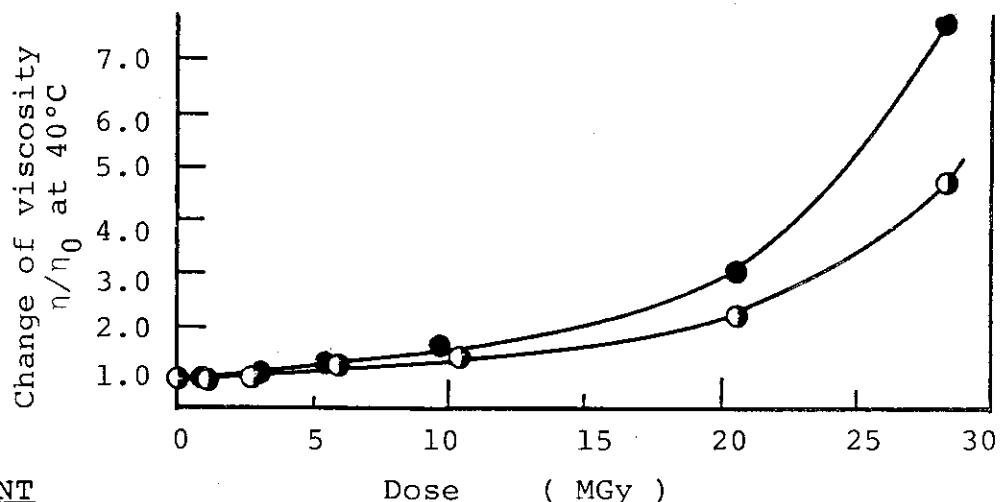
mix. ratio

mix-Phenoxyphenoxy diphenyl : Mono-alkyl diphenyl ether = 50:50

OIL NAME : mix-Polyphenyl ether

PROPERTY CHANGE OF LUBRICANT OIL BY IRRADIATION

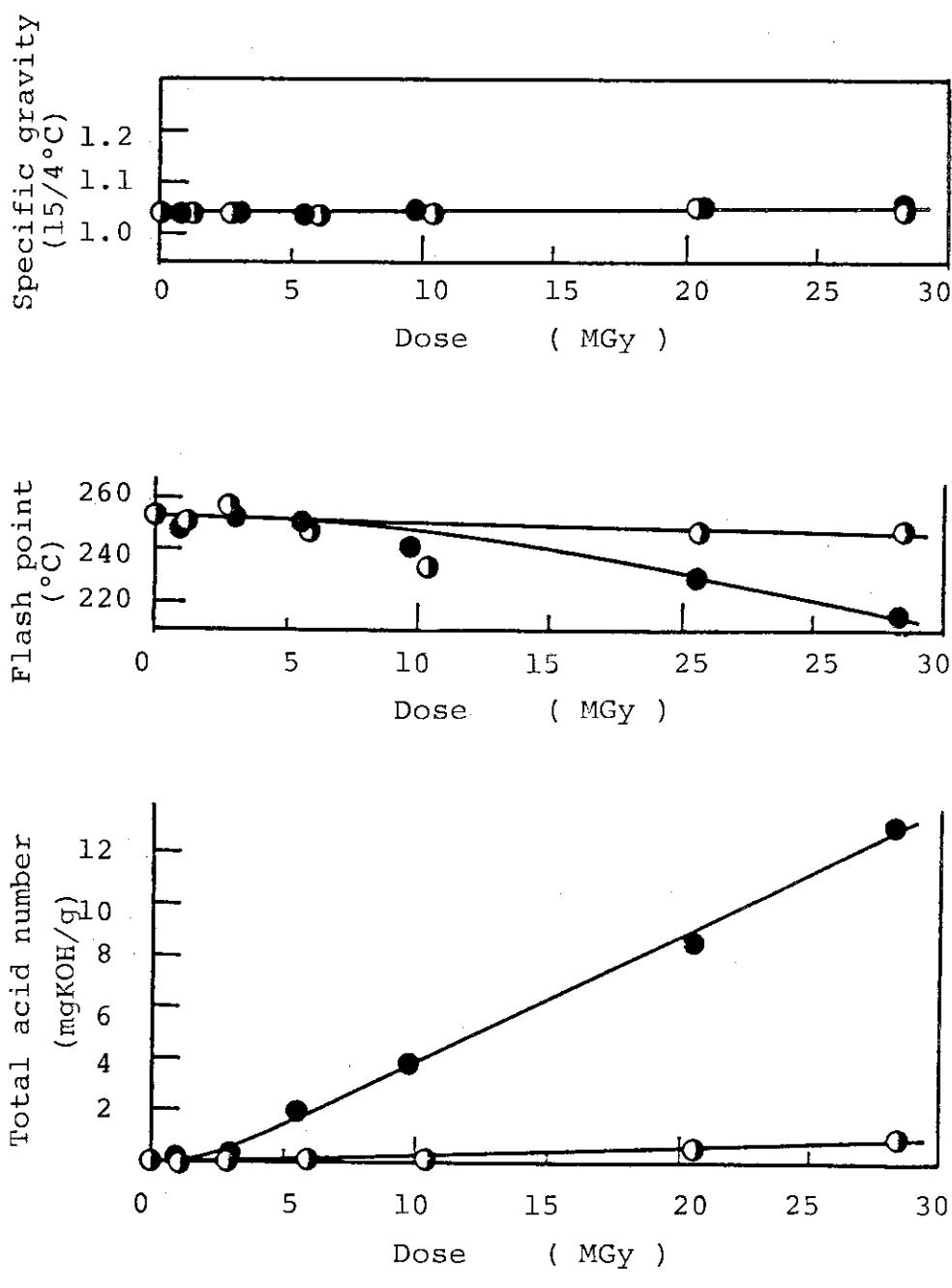
Irradiation condition	Dose [MGy]	Viscosity index	Total acid number [mgKOH/g]	Flash point (°C)	Color union	ASTM
in bubbling oxygen	0.85	51	0.25	248		2.5
	3.07	65	0.34	254		5.5
	5.55	42	1.97	252		6.5
	9.69	48	3.81	242		7.0
	20.57	28	8.50	230		7.5
	28.35	18	13.10	216		D8.0
in air	1.05	64	0.02	252		L1.0
	2.87	50	0.03	258		1.5
	5.88	52	0.08	248		2.0
	10.44	58	0.12	234		2.5
	20.57	53	0.53	248		3.5
	28.44	44	0.90	248		4.5

COMMENT

Symbol: ● in air, ● in bubbling oxygen.

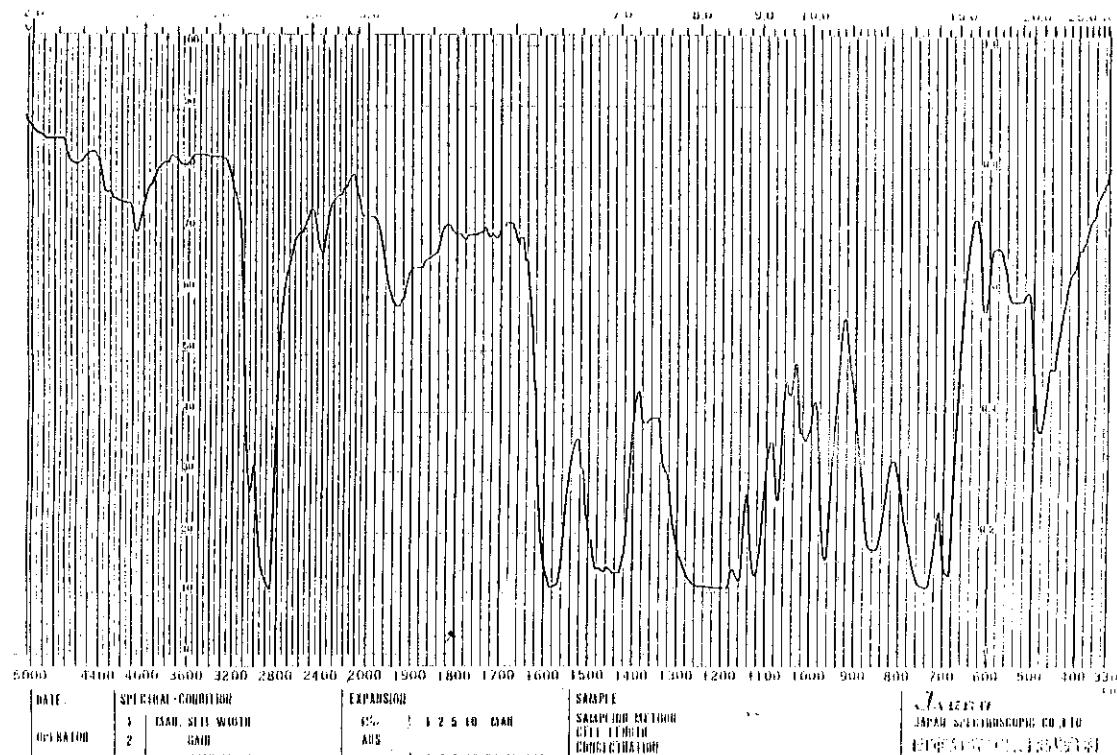
IRRADIATION CONDITION

OIL NAME: mix-Polyphenyl ether



Symbol: ● in air, ○ in bubbling oxygen.

OIL NAME: mix-Polyphenyl ether



Infrared spectrum (original)

4. Conclusion

Data of bulk properties and instrumental analysis were compiled for radiation irradiated oils. Characteristic changes in bulk properties are as follows:

- (1) Almost all kinds of lubricating oils increase their viscosity during irradiation in vacuum, in air, and with bubbling oxygen except poly propylene glycol, polychlorotrifluoroethylene, trifluoropropyl methyl polysiloxane, and perfluoropolyether.
- (2) The viscosity of poly propylene glycol, polychlorotrifluoroethylene and trifluoropropyl methyl polysiloxane increases during irradiation in vacuum and decreases with bubbling oxygen. The viscosity decrease of trifluoropropyl methyl polysiloxane is lower than poly propylene glycol and polychlorotrifluoroethylene.
- (3) Perfluoropolyether is decomposed by irradiation and specific gravity and viscosity decrease under each condition.
- (4) Di-methyl silicone has an inferior radiation resistant ability and solidified at low dosage under each irradiation condition.
- (5) All kinds of the oils except di-methyl silicone show remarkable increase of total acid number with bubbling

oxygen. Esters and fluorinated oils except polychlorotrifluoroethylene increase their total acid number in vacuum and in air.

- (6) Hydrocarbon oils have higher radiation resistant ability than the oils having polar group.
- (7) The lubricating oils having aromatic constituent show remarkable discoloration by irradiation.
- (8) It is clarified that synthetic aromatic lubricating oils are much more stable for irradiation compared with petroleum oils, as they show smaller change of viscosity and total acid number during irradiation.
- (9) The viscosity change of synthetic aromatic oils irradiated in vacuum or under bubbling oxygen below 10 MGy is not remarkable. But over 10 MGy the difference among oils is apparent.
- (10) Aromatic oils having alkyl group have lower radiation resistance than polyphenyl ethers. The more the number of alkyl group is or the more the carbon number of alkyl group is, the larger the change of viscosity and total acid number by irradiation is.
- (11) Polyphenyl ethers have excellent radiation resistant

ability, especially m-(m-phenoxyphenoxy)diphenyl is the most stable for irradiation and oxidation.

- (12) The lubricating oils irradiated under bubbling oxygen show remarkable degradation compared with irradiation in vacuum and in air.
- (13) The behavior of oils irradiated in air at the dose rate of 10 kGy/h is similar to that in vacuum and different that with bubbling oxygen.

Acknowledgement

The authors would like to thank Dr. Naoyuki Tamura, Mr. Kenzo Yoshida, Dr. Waichiro Kawakami, and Dr. Yunosuke Oshima (Japan Atomic Energy Research Institute) for helpful advice and continuous encouragement during this work. The authors are thankful to Mr. Masahito Yoshikawa (Japan Atomic Energy Research Institute) for measuring the breakdown voltage.

The authors would like to thank Mr. Nobumichi Kohno, Mr. Shintaro Kuroiwa, Mr. Mitsuo Hirohama, Mr. Tamio Akada, and Mr. Tsugio Yamamoto (Matsumura Oil Research Corporation) for helpful advice and continuous encouragement during this work. The authors would like to thank Mr. Yoshinobu Fujii, Mr. Toshihiro Kanie, and Mr. Shinichi Asamori (Matsumura Oil Research Corporation) for helpful discussion and assistance with the experimental work.