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REPORT ON THE THIRD NAVAL FUEL DEPOT TOKUYAMA REFINERY

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I. INTRODUCTION

The Third Naval Fuel Depot, at TOKUYAMA, was inspected by the Petroleum Section of the U. S. Naval Technical Mission to Japan during the period 30 October - 2 November 1945. This report records and summarizes the technical information obtained during this visit. The following Japanese personnel connected with the Depot assisted in supplying the information presented herewith.

Rear-Adm.	I. WATANABE	Head of Depot.
Captain	E. MOTOYOSHI	Director of Gen. Dept.
Captain	S. MATSUNAGA	Director of Refining Dept.

II. HISTORY AND ORGANIZATION

A Naval coal briquetting plant was established at TOKUYAMA in 1905, shortly after the close of the Russo-Japanese War, to supply this fuel to the fleet. Starting about 1920, Naval vessels were gradually equipped with boilers burning heavy fuel oil. In 1921 the name of the plant at TOKUYAMA was changed to the Naval Fuel Depot, and oil refining and research departments were established. In 1940-41, all research work was transferred to OFUNA and in April, 1941, the Depot at TOKUYAMA was designated as the Third Naval Fuel Depot.

The Third Naval Fuel Depot at TOKUYAMA was gradually expanded into one of the most modern and best equipped crude oil refineries in Japan. The plant was completely owned by the Navy and operated under the supervision of commissioned Naval petroleum specialists. The first crude oil pipe-still in Japan, a Trumble unit, was installed at TOKUYAMA in 1920. The plant was designed to operate on imported crude oil and tremendous storage facilities were installed. It was stated that prior to the war approximately 1,250,000 tons of crude oil, mostly from California, were in storage at TOKUYAMA. Although this stock was supplemented by imports of East Indies crude, the storage apparently was exhausted by the end of 1944.

The refinery suffered a major explosives raid on 10 May 1945, and was put completely out of action.

Total peak employment at the refinery was about 3,000.

Maximum total crude capacity was 1,500 kl/day, equivalent to 9,500 bbls/day.

III. DESCRIPTION OF REFINERY

A. General

The Tokuyama refinery was a complete, modern crude refinery equipped to carry on crude distillation, thermal cracking, iso-octane manufacture by butene polymerization and hydrogenation, hydrocracking, and the manufacture of lube oils, greases, synthetic methanol, and tetra-ethyl lead. A map of the refinery area showing location of the several units is given by Plate I(F). The refinery had excellent protected harbor facilities for handling incoming and outgoing tanker shipments. Extensive storage facilities were provided within the refinery area and in the nearby hills (refer to Figure 1(F)). Total storage capacity prior to removal of some of the tanks during the war was 1,400,000 metric tons.

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Details on the various units are given below.

B. Crude Distillation Units

Three continuous crude stills were installed. The first was a Trumble unit purchased from the U. S. in 1920 with capacity of 350 kl/day; the second, a U. S. Foster type unit with capacity of 350 kl/day; and the third, a two-tower unit designed by the Navy with capacity of 800 kl/day Total capacity was 1,500 kl/day based on California crude. Typical yields were as follows:

Aviation Gasoline	20%
Motor Spirit	3%
Kerosene	5%
Light Oil	8%
Heavy Oil	63%
Loss	1%
Total	100%

A close fractionation plant consisting of two 26 plate columns, each with a charge capacity of 200 kl/day, was installed for preparation of aviation and special naphtha cuts. A pipe-still unit of 200 kl/day capacity equipped with a 4 plate flash tower and a 19-plate column was also installed for re-running miscellaneous stocks.

A vacuum distillation pipe-still, operating at 60mm Hg., and with capacity of 80 kl/day, was built for preparation of lube oil stocks.

All of the above equipment, as well as the cracking unit described below, was constructed by the FUJINAGATA Shipyard.

C. Cracking Units

The first cracking unit was installed about 1933 and was essentially a Cross unit, except that the design was modified by the Navy to eliminate the high pressure reaction chamber by increasing volume of the furnace tubes. Charge capacity of this unit was 250 kl/day.

The second unit was a U. S. design conventional Cross Unit, utilizing a reaction chamber (40 kg/cm2 working press.) constructed in Japan, with capacity of 250 kl/day, and the third unit was a Gyro unit of 160 kl/day capacity. Typical yields on these units, presumably from gas oil, were as follows:

Stabilized Gasoline	40%
Fuel Residue	45%
Gas and Loss	15%
Total	100%

Cracked gasoline was sent to a vapor-phase clay treating plant equipped with re-run tower. A portion was also sent to the hydrogenation plant.

D. Iso-octane Plant

Iso-octane was manufactured by the polymerization of butylenes and hydrogenation of the polymer. Liquid cracked stabilizer overhead of the following composition was charged to the feed preparation system:

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C_1	0%
C_2	2%
$C_3^=$	20%
C_3	35%
$C_4^=$	15%
C_4	25%
C_5	3%
Total	100%

Ethane and lighter were separated in the first column, operating at 20 kg/cm^2 and reduced temperature, and sent to the tetra-ethyl lead plant. Liquid propane and propylene were separated in the next tower and sent to a small hydrogenation unit where propylene was converted to propane at 200°C and 20 kg/cm^2 over a catalyst composed of 50% NiO and 50% acid clay. Maximum output was 5 kl/day of 98% propane for use in lube oil refining.

The butane-butylene bottoms from the propane separator was charged to the polymerization reactors operating at 170°C and 40 kg/cm^2 and utilizing Navy type phosphoric acid catalyst consisting of 15% H_3PO_4, 5% Japanese acid clay, and 80% $BaSO_4$. The reactors were of the tubulor type, cooled with superheated water on outside of tubes.

The butylene polymer was hydrogenated at 200°C and 5 kg/cm^2 over a Nickel catalyst. Reactors were of the tabular type cooled with superheated water on outside of tubes.

The plant was designed by the Navy and manufactured by KOBE SEIKOSHO. Output of hydrogenated product was about 6 kl/day.

E. Cracked Gasoline Hydrogenation Plant

A hydrogenation plant was installed in 1934 for the processing of 80 kl/day of cracked gasoline. Hydrogenation was accomplished over one of the following catalysts:

Catalyst A		Catalyst B	
NiO	50%	NiO	14%
Acid Clay	50%	MoO_3	43%
		MgO	43%

Reaction conditions were 330-350°C, 100 kg/cm^2, circulating 5.5 m^3 of H_2 per kl of oil. Two reactors were employed containing a total of 2,000 kg of catalyst. A comparison of feed and product oils follows:

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		Cracked Gasoline	Hydrogenated Oil
Vapor Press. (kg/cm^2)		0.5	0.6
Distil-lation	IBP (°C)	40	38
	10%	62	63
	50%	104	105
	90%	148	149
	97%	168	170
Octane No.	Clear	72	
	0.1% Lead		87

F. Kerosene Hydrocracking Plant

A hydrocracking unit was installed for the manufacture of aviation gasoline from straight run gas oils boiling from 200-300°C. Reaction conditions were 420-470°C, 200 kg/cm^2 using a catalyst with composition of 14% NiO, 43% MoO_3, and 43% acid clay. A yield of 35-40% of aviation gasoline with 87-91 octane number (0.1% tetra-ethyl lead) was obtained. Oil charge capacity of the unit was 2.5 kl/hr.

The hydrocracking unit was designed by the Navy, based on extensive research work at TOKUYAMA and OFUNA, and constructed by the Kobe Seiko Co.

G. Hydrogen Manufacture

Hydrogen for the several plants, (1-octene hydrogenation, kerosene hydrocracking, cracked gasoline hydrogenation and methanol manufacture), was made from two sources; by cracking of waste gas (methane) from No. 3 Gyro Unit, and from water gas.

The methane cracker was designed and constructed by the Mitsubishi Kakoki Co. to charge 1,500 m3/hr cracking over an iron oxide catalyst (an ore imported from England and containing about 180% iron), in the presence of steam. A checker brick regenerative heating system was utilized for heating the gas to the required temperature. Operation of this unit was found to be very difficult due to heavy carbon deposits and variations both in the amount and quality of the charge gas.

The main source of hydrogen was water gas generated from TAGAWA semi-anthradte.

Two 750 m3/hr. generators were designed and constructed by the Mitsubishi Kakoki Co. and four 500 m3/hr. generators designed by the Navy and constructed by the Ishii Iron Factory. Difficulties with ash removal were encountered with both types.

Mixed gas from the generators was sent to the water gas conversion plant where CO was converted to CO_2 with steam by passing over the Nippon Kasei Co. patented iron oxide catalyst at 470°C. Two units, one of 2,400 m3/hr., and the other of 1,200 m3/hr. charge capacity, were provided. Typical gas composition before and after conversion were as follows:

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	Charge	Converted Gas
CO_2	8%	29%
CO	30%	2%
H_2	54%	62%
CH_4CN_2	7%	6%
C_nH_{2n}	1%	1%
Total	100%	100%

In the case of the cracked gasoline hydrogenation plant, "converted" gas was purified by removing CO_2 in a medium pressure tower operating at 16 kg/cm^2 and a high pressure tower at 110 kg/cm^2. CO remaining in the gas was removed by washing with cupric formate solution under pressure of 110 kg/cm^2.

In the case of the kerosene hydro-cracking unit, a different system was employed: the CO^2 was removed by washing first with water at 30 kg/cm^2; then with 8% caustic solution. The gas was then liquified, using ammonia and nitrogen refrigerating cycles, and relatively pure (98.5%) hydrogen prepared by fractionation at -210°C.

H. Lubricating Oils and Greases

Three lubricating oil plants were installed, a Barisol de-waxing plant of 30 kl/day charge capacity, and two 160 kl/day Duo-Sol extraction plants equipped with propane-de-asphalting equipment. A simplified flow chart for lubricating oil manufacture at TOKUYAMA is given by Figure 2(F).

As part of the dispersal program, one of the Duo-sol plants was being dismantled, prior to end of the war, for shipment to FUKAGAWA.

A small grease plant of 2 ton/day capacity was also installed.

I. Synthetic Methanol

A plant, designed by the Navy to produce 2 kl/day of methanol from water gas, was installed. The composition of the water gas was adjusted to H_2:CO ratio of 2:1 by passing over an Fe_2O_3 catalyst at 200 kg/cm^2 and 400°C. The gas was cooled, desulfurized, CO^2 removed by water scrubbing, and sent to the reactor containing CuO : U_3O_8 of 92 : 5 mol ratio catalyst and operating at 250°C and 150 kg/cm^2. Recirculation of reactor exit gases was employed to increase yields.

J. Ethyl Fluid Plant

A plant for producing 150 kl/year of ethyl fluid was installed. Ethyl chloride was made by reacting ethanol with HCl at 140°C and atm. press. in the presence of a 60% $FeCl_3$ solution. The ethyl chloride was reacted with sodium-lead amalgam (10% by wt. of sodium) in a one cubic meter closed stirring-type autoclave under conditions of 50-70°C, 5-7 atm. press., and 12 hours reaction time. The crude product was filtered to give 45% of theoretical yield of 97% purity tetra-ethyl lead. Ethylene bromide from the Toyo Soda Co., and stabilizer were added to give a

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product of the following composition:

Tetra-ethyl lead	63-64%	
Ethylene Bromide	35-34%	
Kerosene	1-1.2%	
Dye	0.14%	(Sudane Blue G)
Stabilizer	0.1%	(Hydrazo-benzene)

Some difficulties were encountered due to solidification of lead dust and in prevention of lead poisoning.

K. Pine Root Oil

Towards the end of the war preparations were made for the refining of pine root oil, especially for the preparation of aviation gasoline therefrom. A batch type distillation plant of 50 kl/day crude pine root oil charge capacity was constructed. The refining plan was to prepare cuts from the crude oil boiling up to 85°C. from 185-250°C, and heavy oil. The light naphtha was to be either hydrogenated or reformed over Japanese acid clay in "Simplified" catalytic reforming units. The middle cut was to be either hydrocracked in the existing units, or catalytically cracked in a simplified type unit. One hydrocracking urn was made and an aviation gasoline with clear octane of 71 and 93 octane with 0.15% T. E. L. was produced.

IV. REFINERY THROUGHPUT

Table I(F) summarizes the source of raw materials consumed at TOKUYAMA. Table II(F) summarizes the amounts of these materials used during the war years. It will be noted that the production of finished products slumped off badly during 1945, due primarily to shortage of crude.

V. QUALITY OF PRODUCTS

Products were made to meet Navy specifications, and were blended as follows:

A. Aviation Gasoline

Grade No. 2 was made of 50% straight run gasoline from California Crude and 50% of iso-octane, plus 0.15% T.E.L.

Grade No. 1 was made of 80% of straight run from California Crude and 20% of iso-octane, plus 0.15% T.E.L.

Grade 91 was 76 octane straight run California naphtha plus 0.15 T.E.L.

Grade 87 was 70 octane straight run naphtha plus 0.15% T.E.L.

Grade 85 was 65-70 octane straight run naphtha plus 0.15 T.E.L.

Grade 70 was thermally cracked gasoline with no T.E.L.

B. Motor Gasoline

Grade No. 1 was either straight run or cracked gasoline with no T.E.L (octane about 50).

Grade No. 2 was a blend of No. 1 with 10% by vol. of ethanol.

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Grade No. 3 was similar to No. 1 except wider cut.

C. Kerosene

Kerosenes were straight run cuts, acid-treated, and caustic-washed.

D. Gas Oil

Untreated straight run cuts with boiling range of 240-300°C were prepared for use in diesel engines.

E. Heavy Oil

Grade No. 1 is Tarakan crude used for slow speed diesels.

Grade No. 2 is made from 40% of Tarakan crude and 60% of FUSHUN Shale oil. Cetane number is greater than 50.

F. Fuel Oil

Fuel oils were either straight run or cracked resid, or blends of same. No preheater fouling difficulties were reported.

G. Lubricating Oils

The scheme of manufacture of the various lubricating oils is shown by Figure 2(F). Topped crudes were imported from the U. S. No additives were added to aviation lubricating oil. Only one grade of aviation lubricating oil (120) was made, and in winter time it was necessary to heat the oil prior to aircraft takeoffs. Lubricating oil was changed every 40 hours, and was reclaimed by civilian companies. If the reclaimed oil was up to specifications, it would be used again in aircraft engines.

Diesel engine lubricating oil was made from U. S. crude and no additives were used. Turbine oil was made from Sakhalin crude, and contained paraflow as a pour point depressant.

H. Greases

Only three grades (#1, 2, 3) of cup grease were manufactured, employing calcium soaps from whale oil fatty acids. Other greases were obtained from the NIPPON Oil Co.

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Table I(F)
SOURCE OF RAW MATERIALS THIRD NAVAL FUEL DEPOT, TOKUYAMA

California Crude	American (Via Kure Military Supply, Tokuyama Branch)
East Indies Crude	Shipped from the South (Producing district unknown)
Aviation 91 Gasoline	Shipped from the South (Producing district unknown)
Aviation 87 Gasoline	Shipped from the South (Producing district unknown)
Motor Gasoline	Domestic (Nippon Oil Company, Ltd.)
Shale Heavy Oil	Manchurian (South Manchurian Railway Company, Ltd.)
Iso-Octane	Korean (Nippon Nitrogen Company)
Alcohol	Domestic (Toa Fuel Co. - Via Hiroshima Local Fuel Station)
Ethyl Fluid	Domestic (Nippon Soda Co. Ltd., Hodogaya Chemical Co. Ltd.)
Raw Materials for Aircraft Lubricating Oil	American (Via Kure Military Supply, Tokuyama Branch)
Raw Materials for Lubricating Oil	American (Via Kure Military Supply, Tokuyama Branch)
Sakhalin Heavy Oil	Sakhalin (Northern Sakhalin Fuel Co. Ltd.)
Fatty Acid	Domestic (Nippon Grease Co. Ltd.)
Paraflow	Domestic (Asahi Electric & Chemical Co. Ltd.)
Tagawa Coal	Domestic (Mitsui Bussan Co. Ltd. - Via Nippon Coal Co. Ltd.)
Cokes	Domestic (Mitsubishi Kasei Co. Ltd. - Via Nippon Coal Co. Ltd.)
Raw Methanol	Korean (Nippon Nitrogen Co. Ltd.)
Ingot Lead	Domestic (Nippon Metal Control Distribution Co. Ltd.)
Ethylene Bromide	Domestic (Toyo Soda Co. Ltd.)
Bromine	Domestic (Toyo Soda Co. Ltd.)
Ethyl Chloride	Domestic (Naniwa Gosei Co. Ltd.)

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Table II(F)
CONSUMPTION OF RAW MATERIALS THIRD NAVAL FUEL DEPOT, TOKUYAMA

(Kiloliters*)

Name	1941	1942	1943	1944	1945
California Crude	492,000	550,000	260,000	226,000	0
East Indies Crude	0	0	290,000	240,000	12,000
Aviation 91 Gasoline	0	0	24,000	36,000	11,000
Aviation 87 Gasoline	0	0	36,000	24,000	0
Motor Gasoline Materials	0	0	47,000	32,000	1,000
Shale Heavy Oil	70,000	70,000	60,000	45,000	0
Iso-Octane		30,000	64,000	50,000	3,000
Alcohol		425	4,610	7,000	0
Ethyl Fluid	180	220	320	300	0
Lubricating Oils for Aircraft	Unknown	Unknown	Unknown	Unknown	0
Raw Materials for Lubricating Oils	Unknown	Unknown	Unknown	Unknown	200
Sakhalin Heavy Oil	Unknown	Unknown	Unknown	Unknown	1,000
Fatty Acid	0	0	0	Unknown	0
Paraflow	0	0	0	Unknown	0
Tagawa Coal	Unknown	Unknown	Unknown	Unknown	0
Cokes	Unknown	Unknown	Unknown	Unknown	0
Raw Methanol	0	0	0	0	1,000
Ingot Lead		220	320	440	0
Ethyl Fluid	180	220	320	300	0
Ethylene Bromide	0	0	0	55	0
Bromine	0	43	85	0	0
Ethyl Chloride	0	20	50	0	0

* Except for Ingot Lead in tons

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Table III(F)
ACTUAL PRODUCTION OF FINISHED PRODUCTS THIRD NAVAL FUEL DEPOT, TOKUYAMA

(Kiloliters*)

Item	1941	1942	1943	1944	1945
Aviation Gasoline No. 2	0	0	0	0	700
Aviation Gasoline No. 1	0	0	0	0	100
Aviation Gasoline No. 92	100,000	120,000	100,000	0	0
Aviation Gasoline No. 91			100,000	130,000	6,024
Aviation Gasoline No. 87	50,000	80,000	90,000	120,000	7,760
Aviation Gasoline No. 85	20,000	22,000	24,000	40,000	0
Aviation Gasoline No. 70	8,000	5,000	6,000	10,000	41
Gasoline No. 1	5,000	6,000	5,000	4,000	1,200
Gasoline No. 3			7,000	6,000	12
Gasoline No. 2	12,000	14,000	12,000	10,000	12
Kerosene No. 1	2,000	3,000	2,000	2,000	1,052
Kerosene No. 2	11,000	12,000	12,000	11,000	25
Light Oil	4,000	5,000	4,000	3,000	2,484
Heavy Oil	348,000	38,000	42,000	32,000	5,000
No. 120 Aviation Lubricating Oil	Unknown	Unknown	Unknown	4,120	862
Cylinder Oil	0	0	Unknown	4,550	60
Bearing Oil	0	0	Unknown	1,950	40
Grease	0	0	0	500	0
Spindle Oil	0	0	0	Unknown	0
Ethyl Fluid	0	90	130	180	0
Refrigerating Oil	0	0	0	0	50
Ether	0	0	0	130	0
No. 1 Methanol	Unknown	Unknown	Unknown	Unknown	75
Car Lubricating Oil	0	0	0	0	3

* Except for Heavy Oil and Grease in tons

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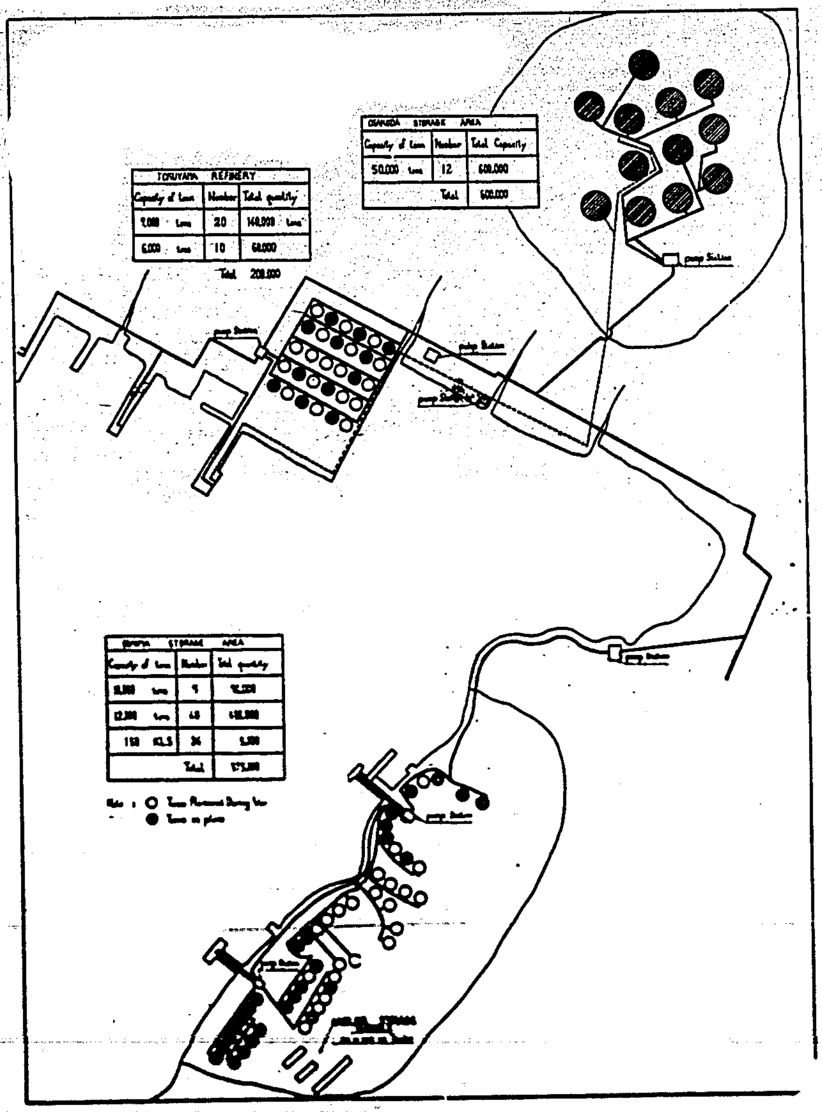

Figure 1 (F)

THIRD NAVAL FUEL DEPOT MAP
OF OIL TANK STORAGE AREAS

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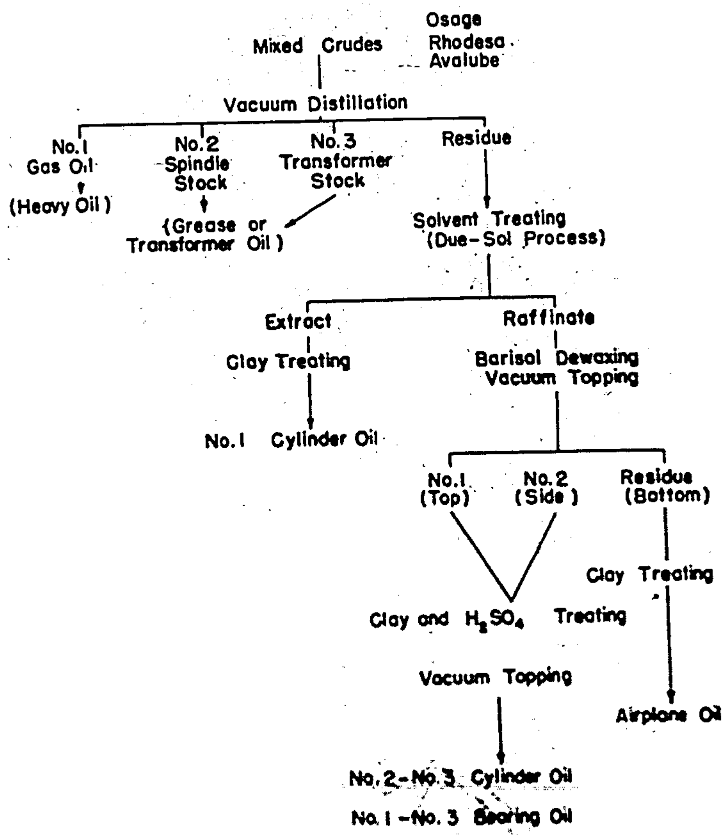


Figure [illegible] (F)
FLOW SHEET OF LUBRICATING MANUFACTURE
THIRD NAVAL FUEL DEPOT, TOKUYAMA

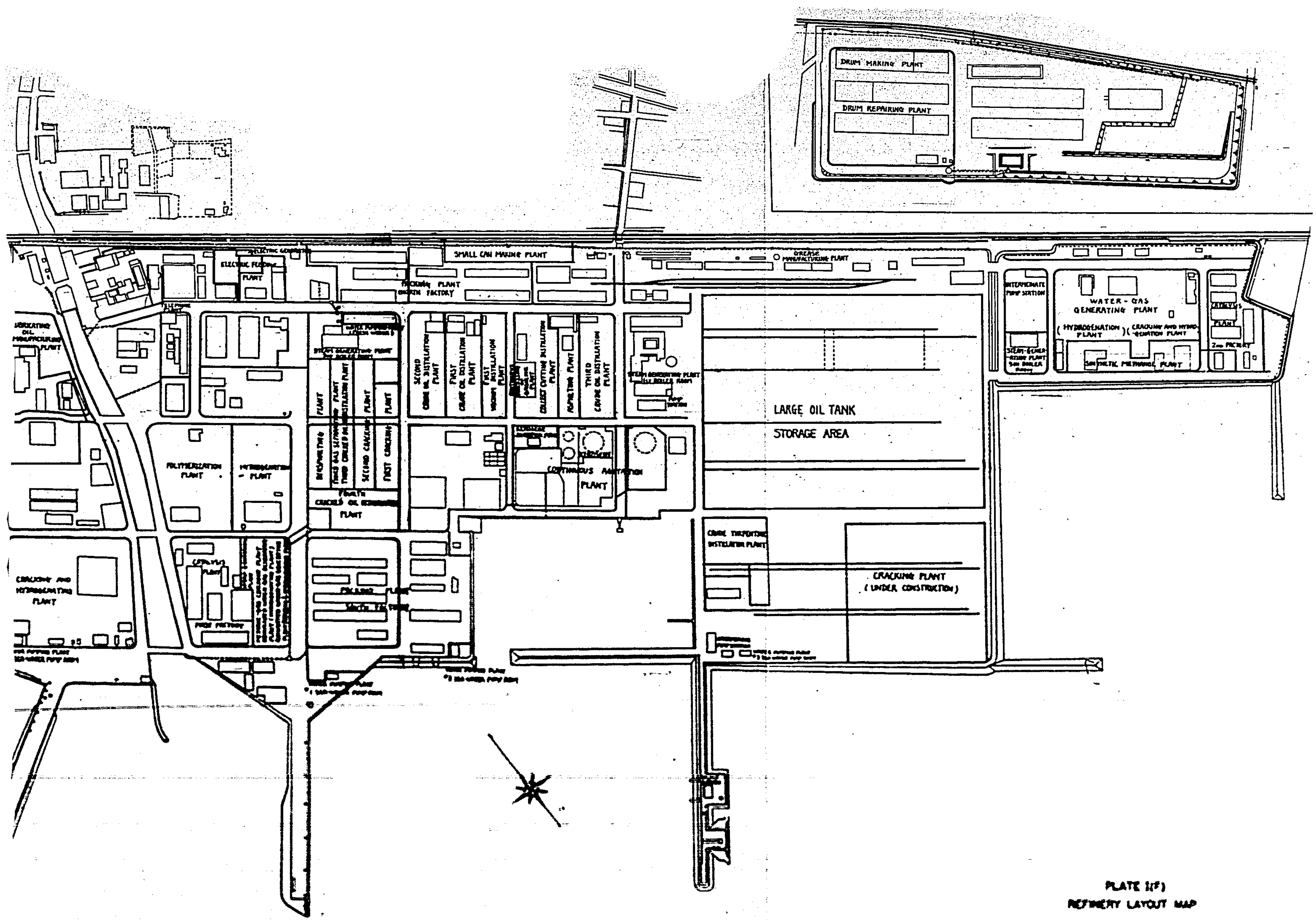
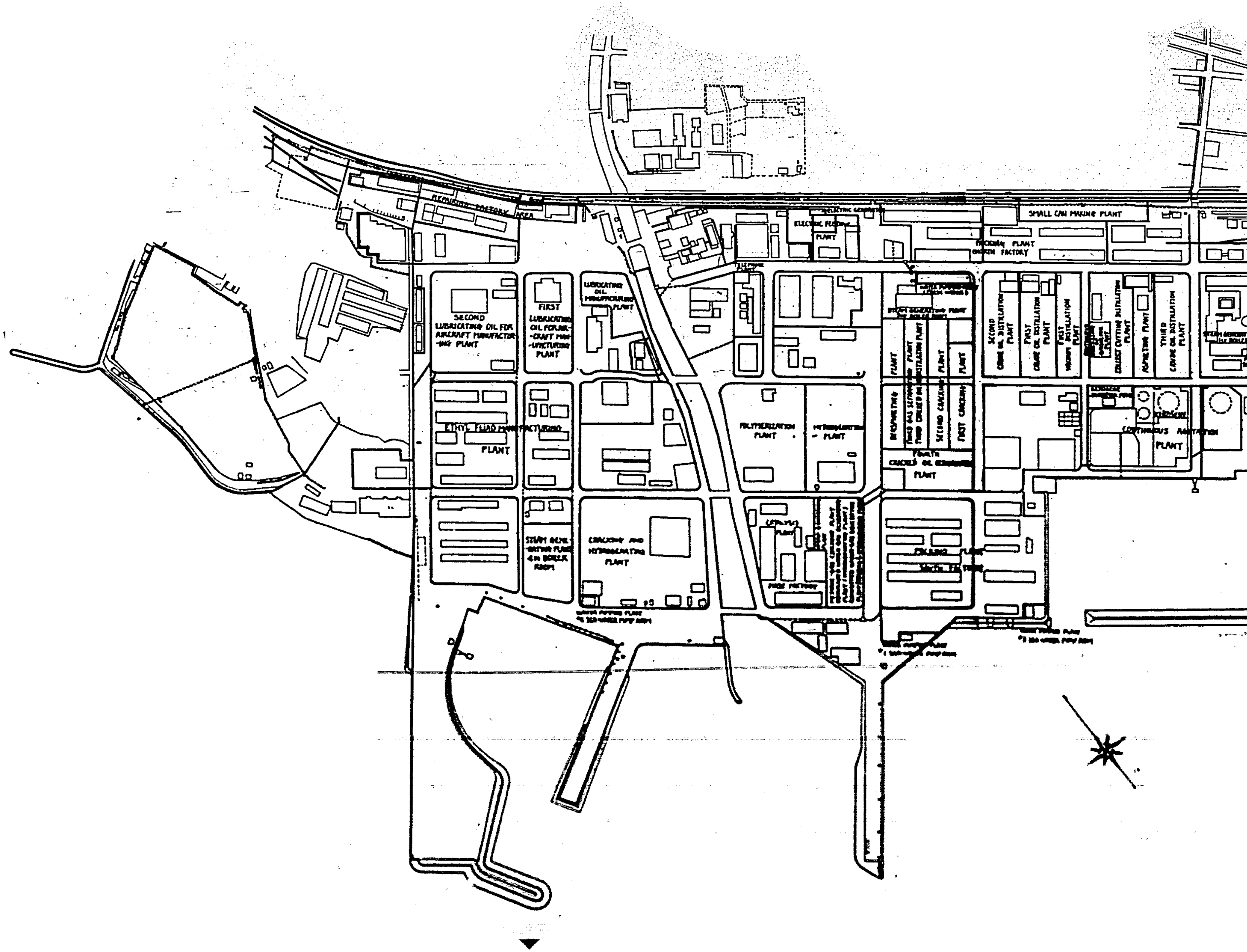


PLATE I(F)
REFINERY LAYOUT MAP


SMALL CAN MAKING PLANT
PACKING PLANT
SOUTH FACTORY
ELECTRIC FEEDING PLANT
SECOND
LUBRICATING OIL FOR
AIRCRAFT MANUFACTUR-
-ING PLANT
FIRST
LUBRICATING
OIL FOR AIR-
-CRAFT MAN-
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ETHYL FLUID MANUFACTURING
PLANT
POLYMERIZATION
PLANT
HYDROGENATION
PLANT
SECOND
CRUDE OIL DISTILLATION
PLANT
FIRST
CRUDE OIL DISTILLATION
PLANT
FIRST
VACUUM DISTILLATION
PLANT
COLLECT CUTTING DISTILLATION
PLANT
ASPHALTING PLANT
THIRD
CRUDE OIL DISTILLATION
PLANT
SECOND CRACKING
FIRST CRACKING
FOURTH
CRACKED OIL REDISTILLATION
PLANT
CONTINUOUS AGITATION
PLANT
CRACKING AND
HYDROGENATING
PLANT
STEAM GENE-
-RATING PLANT
4th BOILER
ROOM
DRUM FACTORY