CHAPTER 6 MEASUREMENT OF TEMPERATURE

Temperature itself is not directly concerned with atmospheric diffusion, but the vertical distribution of temperature near the ground is closely concerned with diffusion of pollutants. As described in CHAPTER 5, the atmospheric stability is obtained more accurately from the vertical distribution of temperature:

The long term monitoring of vertical distribution of temperature is usually carried out by installing thermometers at different heights of the high tower and detect the inversion layer occurred in the sphere near to the ground mostly at hight time. In case the high tower is used for such measurement, the maximum height will be around 200 meters. In order to measure the vertical distribution of temperature at higher place exceeding 200 meters, the low layer sonde is used, equipped with wireless telemeter in the balloon, which makes measurement possible for the height of about 2 km from the ground. However this system costs much for long term monitoring.

In this study, the continuous monitoring has been conducted at MP-1, installing thermometers at 1.5, 10, and 40 meters from the ground, for measuring the inversion layer which might have occurred near the ground. Unfortunately the data for 40 m high could not be obtained and so the vertical distribution of temperature has been analyzed by 1.5 and 10 m data.

The measurement has been conducted for one year, from July 15th 1981 to July 14th 1982, installing nickel resistance thermometers which measured and recorded instantaneous values of temperature. The daily check of instruments have been conducted by JTC and the maintenance has been carried out by Japanese team once every 3 months.

II-6-1 Measuring Methods of Temperature

For meteorological observation of temperature, the glass thermometer has been used since long, but for obtaining the data of time series progress of temperature, the metal resistance self recording thermometer has been used. At present, nickel resistance and thermister thermometers have been developed and widely used.

The resistance thermometer indicates' temperature by electrical signal which is converted and automatically recorded by recorder. The sensor is installed with ventilating device which supply the fresh air to the sensor and it is designed to be covered by shelter to avoid the impact from direct solar radiation. II-6-2 Thermometer Used in This Study

The thermometer used in this study is nickel resistance thermometer which is widely used in environmental monitoring stations of Japan.

The specifications of the thermometer are shown in Table II-6-1 and the outview is shown in Picture II-6-1.

Sensing body	
Sensing device Measuring tange Currency	Nickel resistance 100 at 0 ⁰ C 0 ⁰ C to +60 ⁰ C accuracy <u>+</u> 0.5 ⁰ C 5 mA
Ventilating tube	
Туре	Double tube with ventilation
Flow speed	5 - 6 m/s
Materials	anti-corrosion aluminium casting anti-corrosion alumina-alloy
Painting	silver color melanin fuse painting
Fan motor	Type:FC-100B AC100 V 50/60 Hz
	Currency: 0.15/0.18 A

Table II-6-1 Specifications of thermometer

The instrument is composed by sensor, converter and recorder, as shown in Picture II-6-1.

The sensor measures temperature by fluctuation of electrical resistance caused by temperature fluctuation, and it is covered by shelter to avoid the impact from direct and indirect solar radiation, together with the ventilated air. The resistance fluctuation at the sensor is recorded by recorder through the converter which converts the resistance fluctuation to temperature fluctuation.

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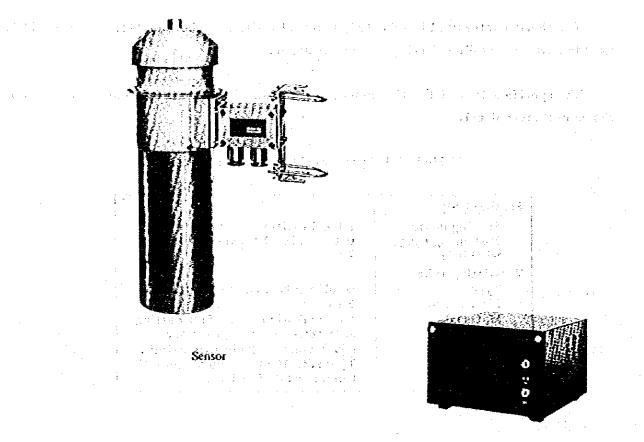
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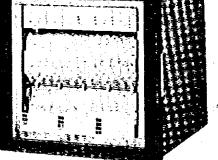
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Recorder

Picture II-6-1 Outview of thermometer

II-6-3 Measurement

The thermometer used in this study had been inspected by the Meteorological Agency of Japanese Government which is effective for 5 years. Therefore the calibration of instruments were not necessary during the survey period.

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II-6-3-1 Installation

The thermometer is generally installed in flat open area where no obstacles like buildings and trees are located. The pole for installation of thermometer is erected on the firm foundation prepared by concrete arrangement. In this study, the thermometer have been installed at the same pole with the anemometer of MP-1.

11-6-3-2 Connection

Connection of cable is performed by the order of sensor, arrestor, converter and recorder. As described in the above, the sensor measures the temperature by resistance fluctuation. So the attention should be given to the length of cable between sensor and converter. Because the resistance of cable itself will give the impact on the sensitivity of sensor. Therefore the resistance of cable itself should not exceed 2 Ω, by adjusting the cable length between sensor and converter. 구 문 소설 문 구 sandara et l

In this study, the length of cable was 13 m and the diameter of the cable was 2 mmp.

II-6-3-3 Loading of chart

The recorder for thermometer used in this study is the same type with SO2 analyzer. The chart is loaded as described in II-3-3-3. ·II-6-3-4 Calibration

As mentioned above, the instruments had been calibrated and inspected by the Japanese Authorities which is effective for 5 years. However, for the measurement of temperature difference, even the small error of measured value should be avoided, and so the regular adjustment has been performed once every 3 months. The adjustment has been conducted, using another standard thermometer (Assmann thermometer) for comparison.

11-6-3-5 Automatic measurement en sen der die greef verbande die state die sender der menste weite die state sollte state.

Turn the function switch of converter to ON. After turning power supply switch of recorder to ON, adjust the recording pen to the present time on the chart, and automatic continuous measurement will be commenced.

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II-6-3-6 Maintenance

For the sound and proper operation of thermometer, the maintenance is carried out according to the items and frequency mentioned in Table II-6-2.

	Items			Freque	ncy	
	Items & contents	Day	Week	1 Month	3 Month	Year
Sensor	 abnormal noise of air pump cleaning of shelter 				2 ÷	
Recorder	 chart advance, time slip of chart, ink shade replacement of chart ink supply 	X 44				
Calibra- tion	Adjustment after comparison by Assmann thermometer	1 <u>12</u> 12 12		10.4	ः इत्य स्टब्स् X	
Power & cable	loose and or disconnection of cal	olė: x ∵	1. A.			1 A.

And white the state of phases is a well the transmission Table II-6-2 Items and frequency for maintenance

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II-6-4 Maintenance and Results of Measurement

and the constraint of the star wanter-The measurement of temperature has been conducted for one year, from July 15th 1981 to July 14th 1982, at 1.5 and 10 m high from the ground of MP-1 shown in Fig. II-1-1.

During the above period, the daily check and calibration have been carried out by JTC and Japanese team respectively. A good and so appears at the day of the of appearing the

11-6-4-1 Maintenance and the second and the provide the second seco

· · (1) Daily check

According to the items and frequency mentioned in Table II-6-2, the thermometers installed at MP-1 have been daily checked by JTC. Items for daily check are as follows. Built and a second of the second states and the second

- 1. 1. 1. 1. "我们是这个人的是一些人们的事,我们们的确实,是我们来自己的意思我们的事实还是我们的事,我们的这一个,这个人的是你。"
- (a) confirmation of abnormal noise of air pump
- confirmation of chart advance (Ъ)

(c) confirmation of time slip of the chart

(d) confirmation of ink shade and supply of ink

(e) confirmation of loose or disconnection of cable

The calibration of thermometers have been carried out by Japanese team once every 3 months, for the sound and proper operation of instruments.

The calibration has been performed by setting Assmann thermometer at the side of installed thermometers, comparing the indicating values of each thermometer, and took note on the form shown in Table II-6-4, as the results of inspection.

The results of calibration of thermometers are shown in Table II-6-3 and the instruments are found satisfactory during the survey period.

Times	Thérmometers	Values (^o C)	Assmann values (°C)
lst Calib.	1.5 m	30.2	30.2
	10.0 m	30.1	30.1
2nd Calib.	1.5 m	30.3	30.8
	10.0 m	30.3	30.2
3rd Calib.	1.5 m	27.5	27.6
	10.0 m	27.7	27.7
4th Calib.	1.5 m	30.2	30.4
	10.0 m	29.4	29.4
5th Calib.	1.5 m	28.8	28.8
· · · · ·	10.0 m	28.4	28.4

Table II-6-3 Results of calibration of thermometers

II-6-4-2 Temperature

(1) Reading of chart of thermometer

As shown in Fig. II-6-1, the instantaneous values of temperature at 1.5 m and 10 m high from the ground are recorded on the same chart by different colors of ink. Further, due to the replacement of electrical parts of the instruments, the ink colours have been changed on the way as shown in Table II-6-4.

Survey périod Height	From 01:00 of July 15th to 10:00 of October 30th 1981	From 11:00 of October 30th 1981 to 24:00 of July 14th 1982
1.5 m	Réd	Black
10.0 m	Black	Řed
Contraction of the second s		

Table 11-6-4 Ink colour of recorder of thermometer

The full scale of the chart is 0 to 60° C and the value of each exact full hour has been read by the unit of 0.1°C as the value of temperature.

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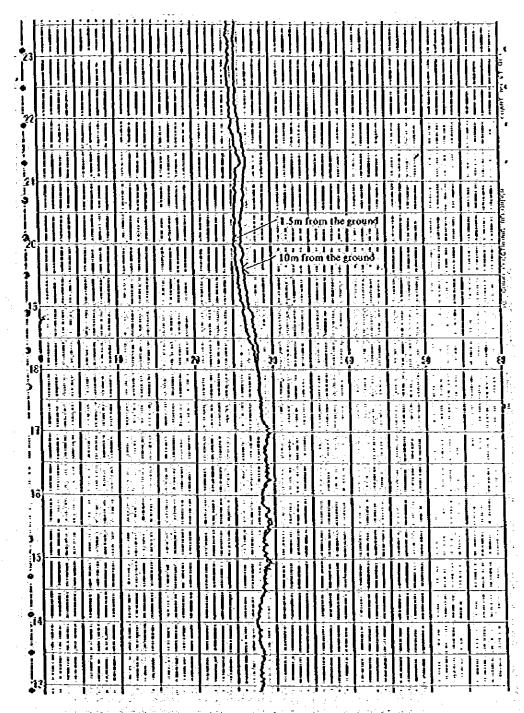


Fig. II-6-1 An example of recording of temperature

(2) Results of measurement

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The effective measurement time of temperature measured at 1.5 and 10 m high from the ground were 8,753 hours for 1.5 m and 8,755 hours for 10 m, both of which are exceeding standard of effective monitoring stations in Japan.

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The raw data of temperature measured at 1.5 m and 10 m high from the ground are shown in ANNEX and an example of recording is shown in Table II-6-5.

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Table I-6-5 An example of recording of one hour value of temperature

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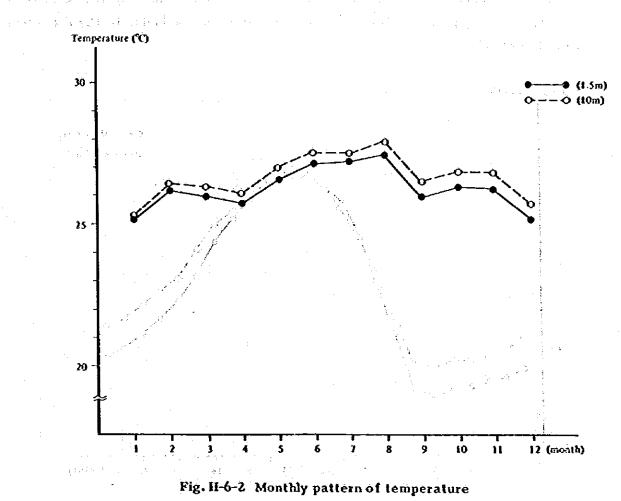


Fig. II-6-2 shows monthly pattern of temperature and from the figure, the temperature of 10 m is higher about $0.3-0.4^{\circ}$ C in each month.

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The hourly pattern of temperature is shown in Fig. II-6-3. From the figure, there found no difference between 1.5 m and 10 m in daytime, but the temperature of 10 m in nighttime is higher about $0.5-0.6^{\circ}$ C than that of 1.5 m. It is due to the reflection from the ground.

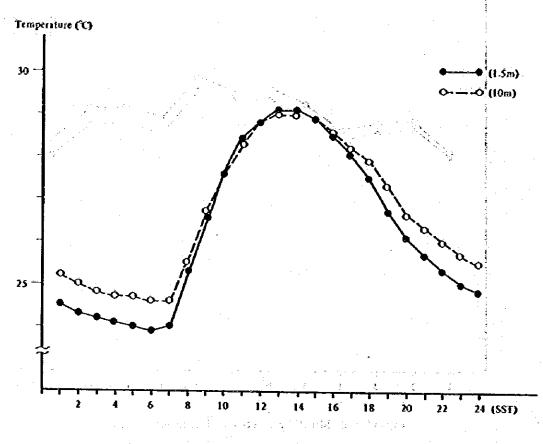


Fig. II-6-3 Hourly pattern of temperature

Table II-6-6 shows the average temperature of 1.5 m and 10 m classified by season and day/night. From the table, the temperature of 10 m is found higher about 0.3° C than that of 1.5 m.

Table II-6-6	Average	temperature b	y seasón	and day/night	
--------------	---------	---------------	----------	---------------	--

Unit (°C)

	Sou	therly N	lonsoon	No	therly N	Monsoon	Ye	arly Ave	rage
Height	Day time	Night	Through day	Day time	Night	Through day	Day time	Night	Through day
1.5 m	28.3	25.2	26.6	27.5	24.3	25.8	28.0	24.8	26.3
10 m	28.4	25.9	27.0	27.6	24.8	26.1	28.0	25.5	26.6

CHAPTER 7 MEASUREMENT OF VERTICAL DISTRIBUTION OF WIND DIRECTION AND VELOCITY

In the atmospheric layer of up to about 2 km, the wind velocity is smaller in the lower layer due to fluid viscosity resistance of ground roughness and atmospheric fluid, by which the vertical slide of wind velocity and turbulence of wind are generated.

When the ground surface is heated by solar radiation, the convection is caused and wind turbulence is generated. The reaching height of convection is equal to the height of mixed layer. In the atmospheric boundary layer, the wind direction, velocity and temperature are largely fluctuating to the vertical directions and the wind turbulence is generally larger than free atmosphere of high sky. The diffusion of pollutants is in most cases limited in the boundary layers and so the measurement of vertical distribution of wind direction and velocity is one of the important factors in the environmental study.

In this study, the measurement of vertical distribution of wind direction and velocity has been conducted at two points within the survey area although the term was only limited to two days. The measurement has been carried out at MP-2 and MP-6, tracing the balloon by Theodolite upto the height of 2,000 meters, and recording the wind direction and velocity of each 100 meters, on June 23rd and 24th of June 1981.

II-7-1 Measuring Methods of Upper Layer Wind

There are two other methods to measure the atmospheric upper layer, which are (1) to install the anemometer at the high position of tower and (2) to release the captive balloon installed with the specially designed anemometer. However, when the tower is used, maximum height will not be more than 200 or 300 meters and in case of captive balloon, it will be not more than 500 meter. Therefore for the measurement of further higher layer, pilot balloon method is most common although there are some other methods which are using sonde, sonic lader and airplane.

11-7-2 Measurement of Vertical Distribution of Wind Direction and Velocity in This Study

In this study, the pilot balloon method has been employed, from the objectives of measurement and other economical reasons.

The method is to measure the wind direction and velocity from the relation between elevating height and floating distance of balloon, tracing by Theodolite the balloons adjusted to have the same elevating speed.

II-7-3 Measurement

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II-7-3-1 Gas charging

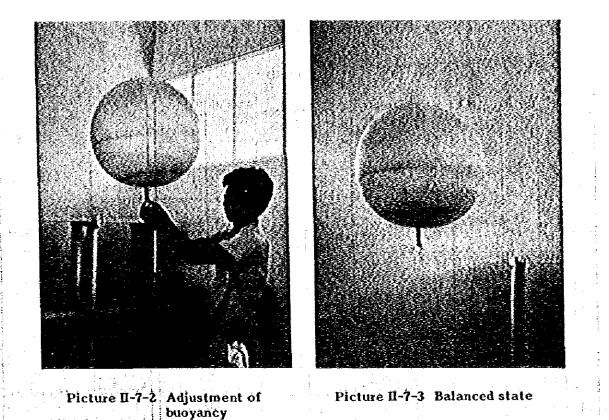
The rubber balloon is charged by helium gas as shown in Picture II-7-1, and adjust the helium gas volume by floating valve which has the weight of 55.7g, as shown in Picture II-7-2, until the balloon is kept in balance. (Picture II-7-3)

When the above charging processes are completed, the balloon has the buoyancy of 55.7g and its elevating speed is about 100 m/40 s in the atmosphere between the ground and 2 km high.



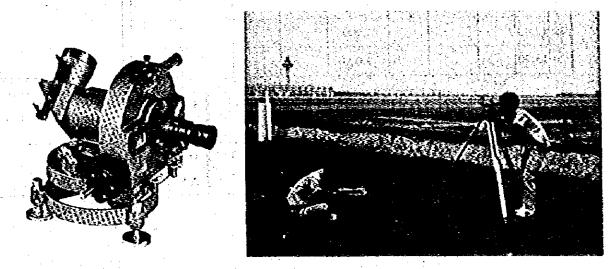
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II-7-3-2 Tracing of balloon by Theodolite

The Theodolite of Picture II-7-4 is kept on the three-legged stand and kept balance by the level. The fixing value of magnetic needle is loosen and after adjusting the needle to be directed to the north, the telescope is directed to due north and adjust the angle indicator to zero. The released balloon is traced through telescope, noting altitude and azimuth angles of each 40 seconds on the form of Table II-7-1, as shown in Picture II-7-5. The specifications of Theodolite are shown in Table II-7-1.



Picture II-7-4 Theodolite

Picture II-7-5 Tracing balloon by Theodolite

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Table II-7-1 Form for recording altitude and azimuth angles

	Min.	Eleva-			Horizontal			Wind di-	Wind ve-	Survey	
\ 0.	& sec.	tion angle	Azimuth angle	Height	distance (m)	X coor- dinate	Y coor- dinate	rection	locity 1	No.	
1	0:40				100			(°)	(m/s)	Date	81
-										Tímé	
2	1:20				200	·				Name of surveyor	
3	2.00	-			300	in dia 1999. Ang ang ang ang ang ang ang ang ang ang a				Ground	
4	2:40				400					wind velocity	(m/s
5	3:20				500					Cloud amount	
6	4:00				600					& form	
7	4:40		<u></u>		700					Weather	
_										Balloon weight	20 gr.
8	<u> </u>			1 - p 4 	800			· · · · ·		Buoyancy	55.7gr.
9	6:00				900					Ascending	150 m/mi
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6	10:40	-			1,600						
7	11:20				1,700						n i se standaria. Na setembri se se
8	12:00		· · · ·		1,800						
9	12:40				1,900						• .
	13:20					· · · ·			·		, ,
	13.20				2,000						

PILOT BALLOON SURVEY RECORD

Reasons of survey suspension

Sun	Disturbed by direct sun beam	Ent.	Entered into cloud
B.B	Balloón búrst	Obst	Obstacled by cloud
A G	Accident of ground instruments	0.5	Out of sight
D.G	Disturbed by ground obstacles	AR	Another reason

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· · · ·	Table II-7-2	Specification	of Theodolite

Main telescope and find	ing telescone		
-	Main telescope 45 m/m		Toleranc <u>+</u> 5%
Magnification	18.5 X	4 X	+5%
Resolving power	under 3.5*	under 12"	
Field of vision have a second	2.5 ⁰	10.50	<u>+</u> 5%
Image	Inverted	inverted	ga esta sur
Visual dia. of large hair ring	32'	2 ⁰	<u>+</u> 10%
Visual dia. of small hair ring	16	58'	<u>+</u> 10%
Horizontal circle and v		<u></u>	***
	Horizontal circle	• Vertical circle	
Diameter	140 m/m	140 m/m	
Min. division	30'	30'	2 g 2 g 2 g 2 g 2 g 2 g 2 g 2 g 2 g 2 g
Min. reading	30'	30'	

II-7-4 Elevating Speed of Balloon

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The elevating speed of the balloon is deviating in a certain extent by the atmospheric status and height, but it is determined generally by weight and buoyancy of the balloon.

From several experiments, the equation has been obtained to express the elevating speed as a function.

The resistance of elevating balloon is represented by the equation

$$R = \langle \pi \rho I^2 V^2 \left(\frac{\nu}{V} \right)^n \left(\frac{\kappa}{\rho V^2} \right)^{1-m}$$

Equation II-?-1

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where; ρ ---- air density

r ---- radius of balloon

---- μρ

 μ ---- statical viscosity coefficient of air dP

x ---- coefficient of elasticity of air at $\rho \frac{dr}{d\rho}$

V ---- transferring speed of balloon

f ---- constant for resistance of balloon surface

n,m --- experimental constant

When gas density charged in balloon is σ , the empty weight of balloon is W, buoyant force is L, buoyancy is Q and these are expressed by the unit of gram and balloon is globe, the following equation for buoyancy is obtained.

$$Q = \frac{4}{3} \pi (\rho - \sigma) gr^3$$
 Equation 11-7-2

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Equation II-7-3

Equation II-7-4

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where: g ---- acceleration of gravity

When the buoyant force of balloon and air resistance is balanced, the relation of Equation II-7-3 is resulted.

$$\mathbf{R} = (\mathbf{Q} - \mathbf{W})\mathbf{g} = \mathbf{I}$$

From the above 3 equations, the elevating speed of balloon is obtained as Equation II-7-4.

$$V = K_o (1 - ats + b\Delta Ps - cZ) \left[\frac{L}{(L + W)^3} \right]^{\frac{1}{2m - n}}$$

where;

$$K_{0} = \left[\left(\frac{4}{3}\right)^{2-n} \pi^{-(n+1)} \left(g\xi^{-1}\right)^{3} \left(\frac{g}{g-R\delta}\right)^{3(m-1)} \mu_{0}^{-3n} \right]$$

$$\times \rho_{0}^{-(3m-2n-2)} \left(1 - \frac{\sigma_{0}}{\rho_{0}}\right)^{2-n} \cdot P_{0}^{3(m-1)} \right]^{\frac{1}{3(2m+n)}}$$

$$a = \frac{2(n+1) - 3(m - \alpha_{n}T_{0})}{3T_{0}(2m-n)}$$

$$b = \frac{2n - 1}{3P_{0}(2m-n)}$$

$$c = \frac{g(2n-1)}{3RT_0(2m-n)} - a\delta$$

Z = height from the ground

R = atmospheric constant

 δ = temperature decreasing rate

t = temperature by centigrade, $\Delta P = P - P_0$

$$P = atmospheric pressure$$

 $P_0 = 760 \text{ mmHg}, T_0 = 273^{\circ}$

$$^{\circ}$$
 = 760 mmHg, T_0 = 273° in the factor of the fact

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 $\{ f_{ij}, j_{ij} \} \in \{ j_{ij} \}$

Mr. Y. Ishino has determined the constant value from the experiments and monitoring data as follows:

$$K_0 = 46.02$$
, $n = 1$, $m = 1.591$, $a = 0.0011$, $b = 0.0002$, $C = 0.000012$.

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In this calculation, unit is all based on m, g, min., ^OC. Therefore, as the empirical formula of Equation II-7-4, the Equation II-7-5 is obtained.

$$V = 46.02 (1 - 0.0011 ts + 0.0002 \Delta Ps - 0.000012Z) \times \left[\frac{L}{(L + W)^3}\right]^{\frac{1}{2.182}}$$
 Equation II-7-5

The elevating speed V of the balloon is different by temperature, atmospheric pressure and height, but the error caused by these factors are small. Therefore, the buoyant force when atmospheric pressure is 760 mmHg and temperature is 0°C, is obtained by equation II-7-6.



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en en la sente de la companya de la set de companya de la companya de la companya de la companya de la company En la companya de la c e de sal de L'é buoyant force by gram de tresse sales des la compactación de secondadas en a and the second Q = L + WW = empty weight of balloon

7-2-214-21 In this study, calculation has been based on equation II-7-6.

4-8-**1**1-6-14-92-4

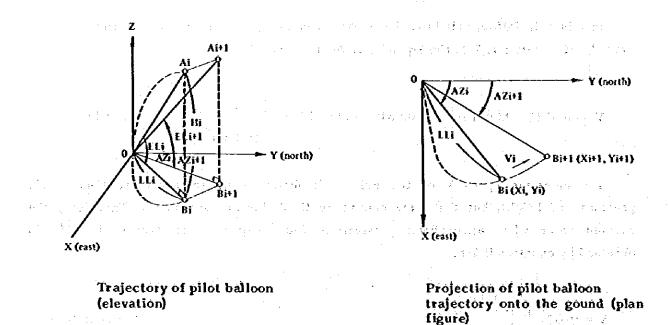
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II-7-5 Calculation Methods of Wind Direction and Velocity

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The average wind direction and velocity of each 100 meter layer are calculated from measured altitude and azimuth angles as follows:



Pilot balloon elevates by the speed of 100 m/40 s and reaches to Ai point after 1 second. The altitude and azimuth angles measured from the releasing point are AZi and Eli respectively. As the elevating speed of balloon is 100 m/40 s, the height Hi(Ai - Bi) is obtained by Equation II-7-7.

$$Hi = i \times \frac{100}{40} (m)$$
Equation II-7-7

The horizontal distance LLi (O-Bi) is obtained from altitude angle by Equation II-7-8.

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The co-ordinates projected Ai point on the ground is obtained from horizontal distance LLi and azimuth angle AZi by equation II-7-9.

Xi = LLi sin AZi Yi = LLi cos AZi

Equation II-7-9

Equation II-7-8

n - 160

The average wind velocity of after i + is from point i is obtained from Pythagorean theorem by Equation II-7-10.

$$i = \frac{(Xi + 1 - Xi)^2 + (Yi + 1 - Yi)^2}{40}$$
 (m/s) Equation II-7-10

In transit observation, north is 0° and measure azimuth angle in clockwise. Wind direction WDi is obtained by Equation II-7-11.

$$WDi = \tan^{-1} \left(\frac{Xi + 1 - Xi}{Yi + 1 - Yi} \right)$$

Equation II-7-11

II-7-6 Results of Measurement

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AT two points of MP-2 and MP-6, the measurement of average wind direction and velocity of each 100 meter layer has been conducted on the 23rd and 24th of June 1981, during 08:00 to 17:00 hour, by pilot balloon and Theodolite upto the height of 2,000 meter from the ground. The results of measurement are described.

The horizontal trace charts of every exact full hour are shown in Fig. II-7-1-(1) to -(7).

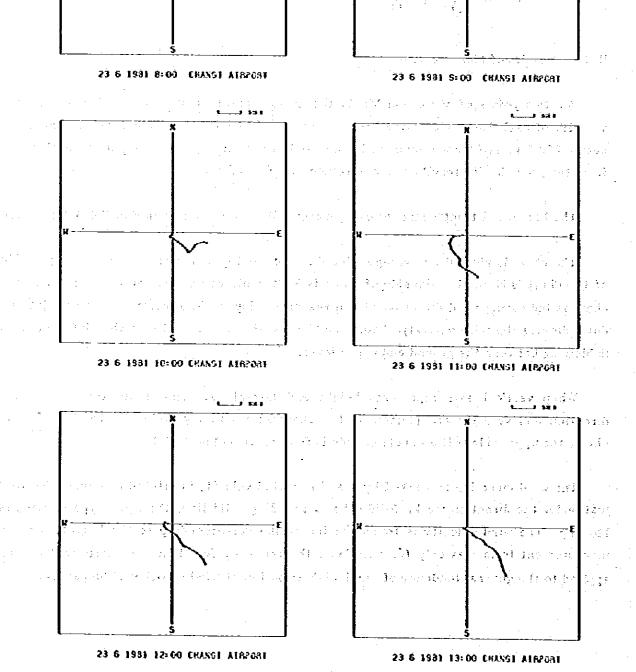
The chart is plotted by average wind direction and velocity of each hour. Upper side of the chart is N and bottom side of chart is S. The direction between dot and dot in the chart is indicating wind direction of the respective layer. The distance between dot and dot indicates the wind velocity. From the figures, it is confirmed that the different wind is blowing between the ground and upper layer.

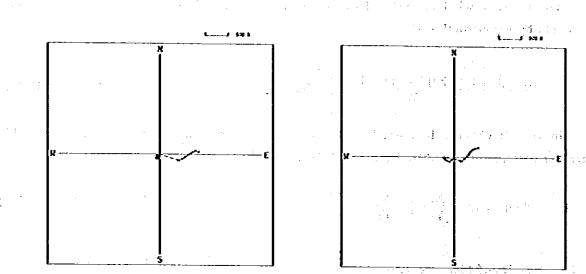
When vertical axis represents height and lateral axis represents time, the wind direction and velocity are plotted on the chart shown in Fig. II-7-2-(1) to -(4). In the chart, the upper side is N and bottom side is S, as same as Fig. II-7-1.

The wind direction is marked by (and the wind velocity is printed as number located just under the direction mark. Inside the surrounding solid line, the same type of wind is blowing. The wind velocity is found not increasing corresponding to the height. As the measurement term was only for two days, the tendency found in the charts will not be applied to the general tendency of vertical distribution of wind velocity of Singapore.

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Fig. II-7-1-(1) Horizontal trace chart by pilot balloon





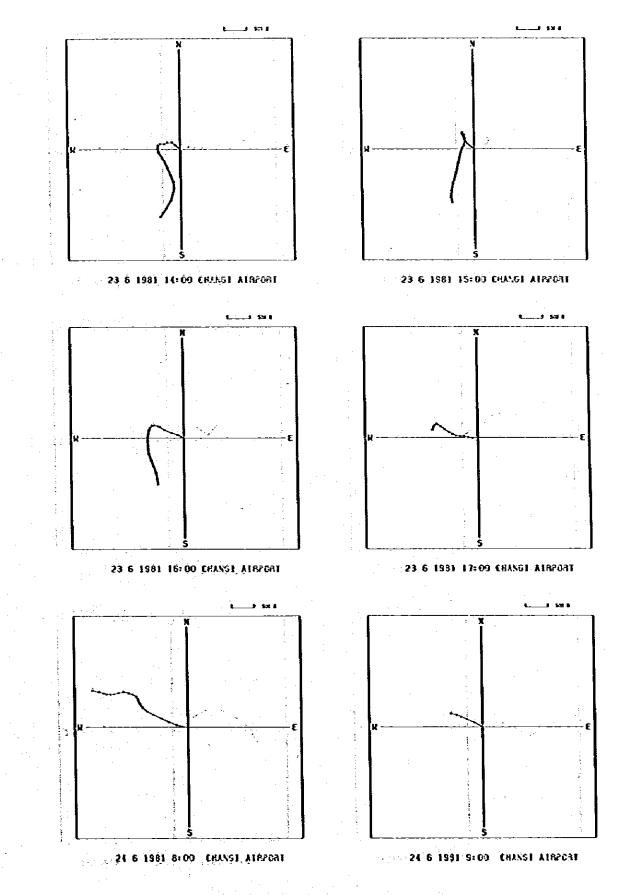
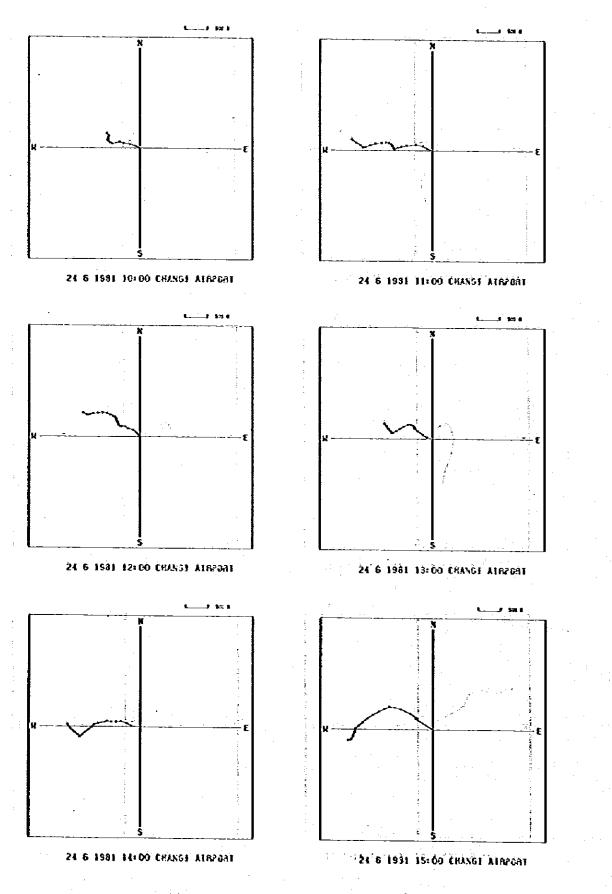


Fig. II-7-1-(2) Horizontal trace chart by pilot balloon





11 = 164

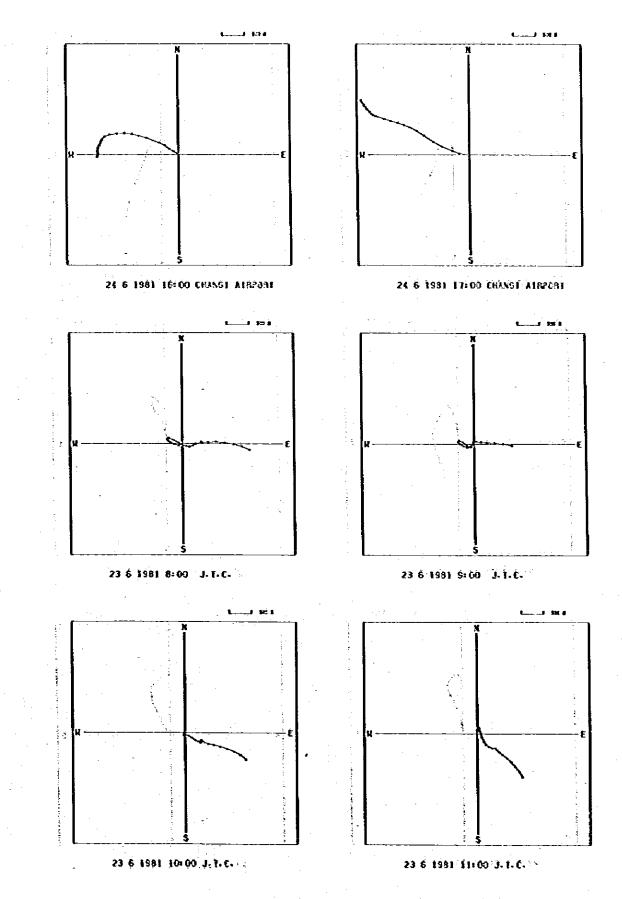
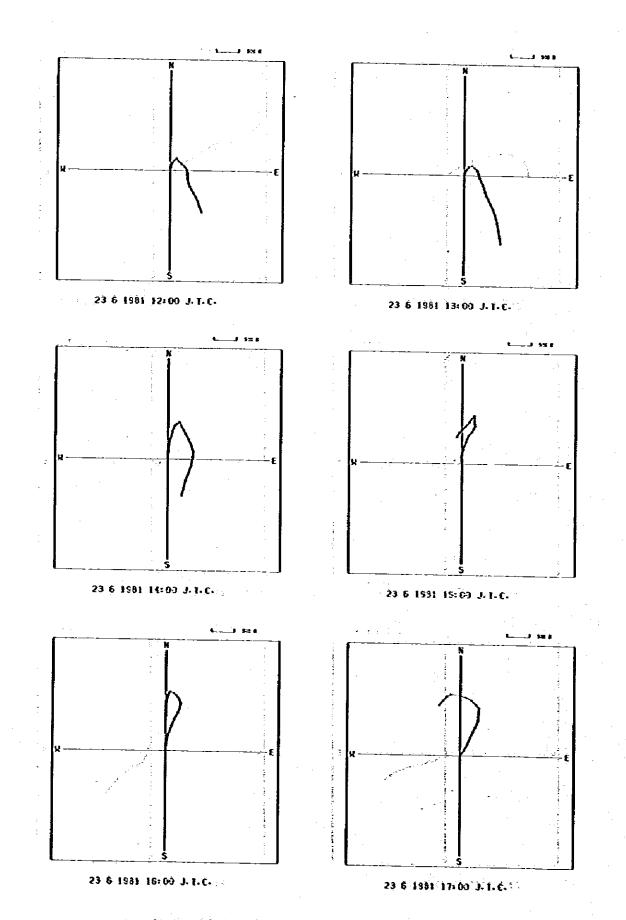
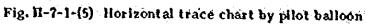


Fig. II-7-1-(4) Horizontal trace chart by pilot balloon

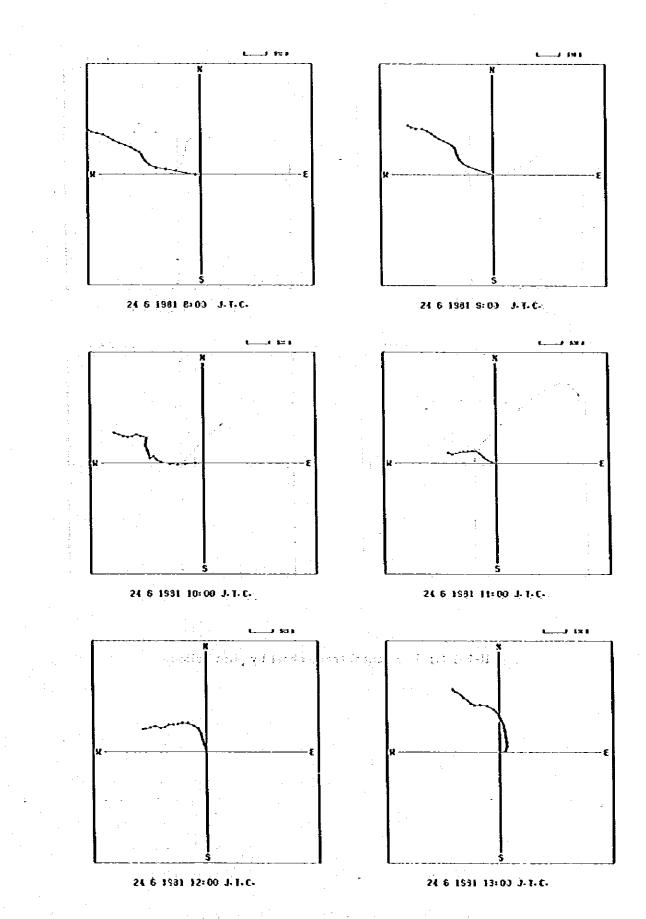
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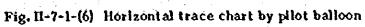




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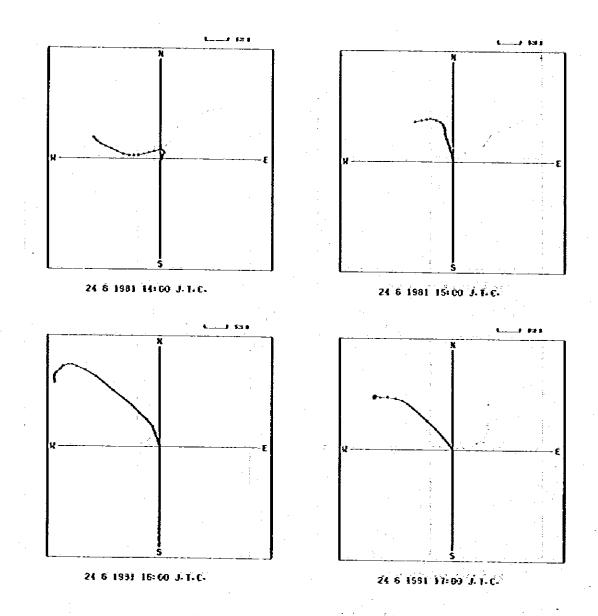
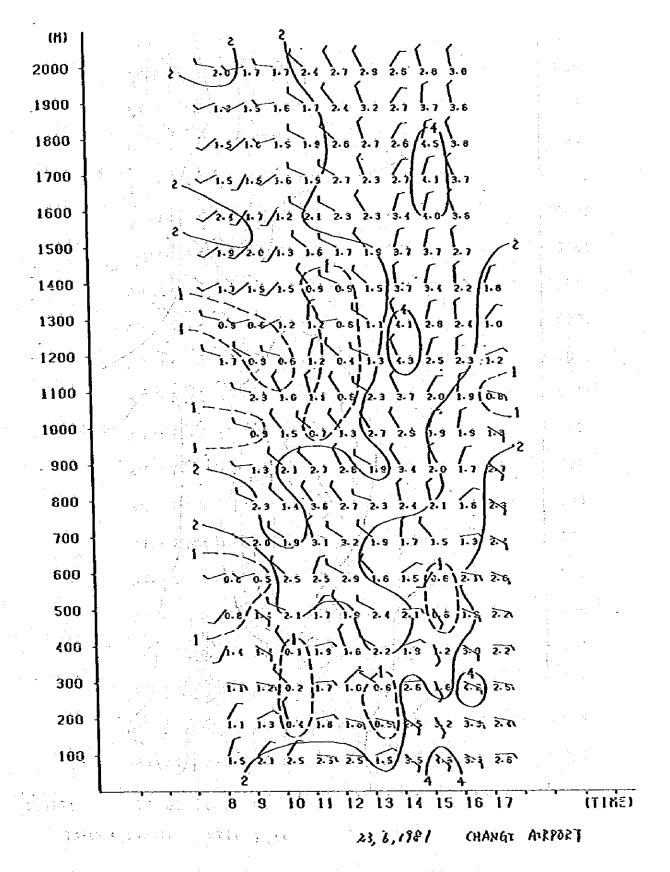
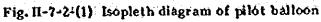


Fig. II-7-1-(7) Horizontal trace chart by pilot balloon

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(H) 2000 3.6 1980 2.0 ģ 1800 1 D N 1.2 Ns Ò 1700 2.0 3 1.9 1.5 1 Ż 1.8 1600 2.0 2.8 10.3 2.5 1.0 1.8 i de la constante de la consta 1500 2.6 3.1 2.5 1.9 1.2 í. š 2.8 0.9 1400 3.0 3.3 2.6 2.3 1.7 1.9 2.1 2.8 1300 23 2.1 2.3 3.5 2.4 1.3 2.81 2.3 1200 \$ 2.2 3.9 3.1 3.7 ž'n 1.5 1.5 1100 1.5 2.0 3.8 ŻŚ A.2 1.5 1000 ≯.ż 6.6 1.1 1.1 ÷, 2.2 3.3 900 ۶.s ک 12.1 2.9 1.51 3.5 ò Ś 800 کرہ 1.9 3.0 4.0 3.8 ħş ا بن ج 8 0.4 780 3.7 25 11. 1 3. 2 1. 3 2.3 1.8 600 3. a 2.0 1.112.8 2.2 3.3 3.8 2.8 0 500 3.0 2.0 3.3 1.2 1.6 1.5/2.6 3.4 3.3 6. 400 1.2 2.5 2.8 2.5 5.2 3.5 <u>ት</u>ፍ 300 1.5 3.2, 3.3 3.51 2.3 209 1 ?>∘ 3.6 3.3 2.4 È. 100 2.7 3 5.か た 5.51 8 9 10 11 12 13 14 15 16 17 (ŤIKÉ) (HANGE AIRPORT 24,6,1181

Fig. 11-7-2-(2) Isopleth diagram of pilot balloon

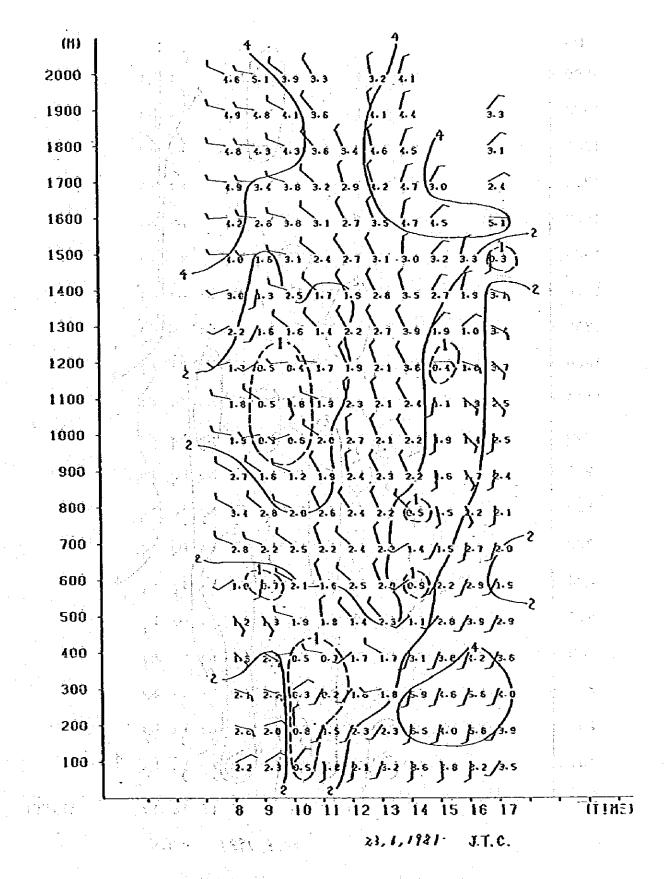


Fig. II-7-2-(3) Isopleth diagram of pilot balloon

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(H) 2000 2.2 2.5 16, 5 3.6 5 1900 3.2 2.7 2.6 Ňι \sim Ô 1800 3 3 3.31 2.51 10.2 1700 3-5 3. 2 2.4 2. 9 16. 3 2.2 3-3 1600 25 2,2 0.4 3.3 \mathbf{x} 2.5 зq 1500 3.4 2.7 26 \geq रे-इं i). 7 1400 3.9 2.9 3. 3 3.6 2.1 0.7 2. 2 2 8 1.5 2,6 1300 2.7 2.2 2.1 3.0 2.3 1.8 3-5 ìŚ Ż. 1.9 1200 tis \mathbf{X} 2.8 2.0 3.2 3.3 2.5 2.3 Ĩ. ż. 1100 2.1 2.2 1.01 3.1 Ż <u>کې</u> ł, 1.7 ₽×3 4.1 1000 3.1). 1.6 2.8 4.1 1. Q.E ŝ, Ŕ 900 1.1 3.0 2.4 20 Ó ٩. 2.5 7 3 2 3.3 890 46 2.5 23 1.5 2.1 λŚ 2.2 3 ξ.ε <u>}</u>.{ 700 λŝ 1.1 2.6 1.\$ 6.1 Ż 9 600 3.6 2.5 23 1 1.3 3.0 3 9 1.3 ł 500 <u>}</u>,3 5.3 3.6 . 1 \$.8 400 5.5 1.5 1.21 Ş 65 łŧ . 2 300 5.81 1.5 1.5 e 2.5 <u></u>ή.3 . S Ś 200 1.11 5.6 5.2 2.8 h. 1 1002.8 († 1.) \$ 8 9 10 11 12 13 15 16 17 14 (T18E) 24, 6, 1981 J. T. C .

Fig. II-7-2-(4) Isopleth diagram of plot balloon

PART III SURVEY ON EMISSION SOURCES

The accurate emission sources data of the survey area is one of the important items for environmental assessment, as same as the data of ambient concentration of pollutants.

In this study, the survey on stationary sources and vessels' emission have been carried out and based on these data, the present (1981) and future (1990) SO₂ concentration have been estimated.

CHAPTER 1 COLLECTION OF EMISSIONS SOURCES DATA

For the estimation of SO₂ ambient concentration, the present emission from the existing factories and future emission from the proposed factories are to be estimated comprehensively.

In the first place, the present emission sources data have to be collected and the data thus obtained have to be compared with the data obtained from field survey, described in PART IL. After the consistency of the above two data is confirmed, the estimation of total emission including future emission from the proposed factories is to be performed. Thus the survey on present and future emission sources are one of the important factors in the environmental assessment.

10-1-1 Stationary Sources

The present emission sources data have been collected by JTC from the existing factories, based on the form of questionnaire prepared by Japanese team.

The emission sources data are the important materials as the input data to evaluate the present ambient concentration and so JTC has been requested to collect as much data as possible. Items investigated and form for questionnaire are shown in Table III-1-1-(1) to -{4}.

The questionnaire after modified have been sent by JTC to 61 factories and plants enumerated in Table III-1-2 and the detailed data of emission sources have been collected. Number of factories classified by type of industry, stacks and facilities are shown in Table III-1-3. Thus the data of 175 facilities and 131 stacks have been collected as the emission sources data of the present (1981).

	Remarks			-	. *				: 1			۰,			• • •		1	-			Lor A
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Desultu-	efficien- cy (g)								- 12			1	2.4	Ē		<u>.</u>	5		[5.25	10 - 10 - 1
								<u>-</u>	-					<u> </u>							(;;; ;;;
Sulfur content	of used fuel and raw mate rials (f)		1.1.1	4 	: 	:		=; ;	•				19. A		s i y		1. A.A.		2		Ore, Petroleum, Salt Cake
Gravity of	used fuel and-raw ma- terials (e)										2							14		of Facilities.	n Ore. Petrol
er hour)	Normal					-			- - -	<u>.</u> ;							<u></u>		- 1	wate.	a (**#** Iro
Consumption rate (per hour)	ot thei and raw materials (d) Rating Operating Norma max. max.							, 2 . 3	-		4 			21 21	-11.2 13.3					n I for a Cl old fuel or	and raw materials (e.g., Iron
Conmuny	Rating Max.			-						· · ·				÷۲.			:@* - 		1 1), see Anna Sustion of 4	tc) and r
	rype of rule and rew meterials used by/ with the facility (c).									- ;										.Cas Producer, Blast Numare, Kib, etc), see Annex I for a Classification of Facilities. Ther combustion, and Ke/m ⁴ /h for combustion of solid fiel or wasts.	val Oli. LPC, PUB Can. Electricity, etc) and raw mat
Facility's date of com- mencement of operation						nder en en en Stangele innerge				ang Paganasa Sang Paganasa Sang Paganasa Sang Paganasa						lan Set			uni Oil-LPC.		
	burning rate (b)		- 	2	. 1		· .				 				• • •			1. 1.	 • • •	(e.g., Boller	ber, Heavy F and Rew Mat
	Type of facility (a)	n na an Sao 11 Ab									e for state				. .	test	Please list the Auels (e.g., Fleavy F Classification of Fuels and Raw Mat				
	Sertal	-			2.4.4. 2.4.4.	•	.* . :						_		·- ·	- 			•	Noteri (a)	ន៍បីរ ទ

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Table III-1-1-(2) Questionnaire for emission sources' data

Table III-1-1-(3) Reference for Questionnaire

ANNEX 1: CLASSIFICATION OF FACILITIES

ANNEX 1: CLASSIFICATION OF FACILITIES	
Boiler	
Boiler (for utility)	4
Boiler (for air-conditioning)	
Gas Producer	
Gas Heating Furnace	
Roasting Furnace	
Roasting Furnace (for refining of copper, lead, zinc)	
Sintering Furnace	
Sintering Furnace (for refining of copper, lead zinc)	
Calcining Furnace	
Calciner (for manufacturing phosphorus, phosphoric acid, & phospho	ric fertilizer)
Galciner (for manufacturing sodium tripolyphosphate)	
Pellet Baking furnace	
Blast Furnace	
Blast Furnace (for refining of copper, lead, zinc)	
Converter	
Converter (for refining of copper, lead, zinc)	
Open Heart Furnace	
Metal Smelting Furnace	
Melting Furnace (for refining of copper, lead, zinc)	
Smelter (for manufacturing phosphorus, phosphoric acid, and phosph	oric fertilizer)
Smelter (for manufacturing lead pigment)	
Metal Rolling Furnace	
Metal Heat Treatment Furnace	
Metal Forging Furnace	
Petroleum Heating Furnace	
Catalyst Regenerator	
Sulfur Recovering Furnace	
Kiln	
Cement Kiln	
Brick Kiln	
Lime Kih	
Alumine Kiln	
Pottery Kiln	
Glass Melting Furnace	

Table III-1-1-(4) Reference for Questionnaire

ANNEX 2: CLASSIFICATION OF FUELS AND RAW MATERIALS

FUEL	
Heavy Fuel Oil	
Crude Oil	~ 100 MeV and ~ 100
Naphtha	jan ann an san an an an tart
Light Oil	
Kerosene	an a
Black Liquor	a a fair a f
	galier estates estates a substances
Coke	and the set of the set of the set of the
LPG	ter de la arte de la destruction de
LNG	and a the second second second
Cracking Gas of Napl	hthä seesse on state of the seese
Coke Öven Gas	a galta a Balt i ka a ang t
Blast Furnace Gas	
Converter Gas	
Off Gas	para 200 Berry Constant
Town Gas	4.5×1
Rich Gas	
Petroleum Refinary	Gàs e e concernado à la concernativa quest
Electricity	en gebeerde gebeure gebeure gebeure van de gebeerde gebeerde gebeerde gebeerde gebeerde gebeerde gebeerde gebe
Waste Oil	search dia secondaria da an
Digestion Gas	n. Na shekara ka shekara taka waka waka
Hydrogen	(1+1) = (1+1) + (1+1
Methancl	ta da ser en la contra de la tradición de la contra de la c
Wood	an a la gréfic de
Acrylic Acid Waste	
Acrylic Acid Off Ga	Ś

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Table III-1-1-(4) Reference for Questionnaire (Cont'd)

ANNEX 2: CLASSIFICATION OF FUELS AND RAW MATERIALS

RAW MATERIAL	en e
Iron Ore	
Récovered Sulfur	
Petroleum for Refining	
Salt Cake (Sodium Sulfate)	
Sulfur for manufacturing Sulfuric Acid	and appendix a second
Reactor	· · · · · · · · · · · · · · · · · · ·
Reactor (for manufacturing phosphorus,	phosphoric acid and phosphoric fertilizer)
Reactor (for manufacturing sodium tripo	olyphosphate)
Reactor (for manufacturing lead pigmen	(1)
Direct Heating Furnace	
Aggregate Dryer	
Raw Cement Material Dryer	
Raw Brick Material Dryer	Millional (127)
Casting Mold Dryer	
Detergent Dryer	
Dryer	
Dryer (for refining of copper, lead, zinc)	
Dryer (for manufacturing sodium tripoly	
Dryer (for manufacturing lead pigment)	
Active Carbon Manufacturing Furnace	
Electrolytic Refining Furnace of Alumir	nium a Baralana
	norus, phosphoric acid and phosphoric fertilizer)
Reverberatory Furnace (for manufactur	
Coke Oven	

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Table III-1-2 List of factories collected emission data

Names of factory and enterprise
DRAGON POLY-FOAM INDS (S) PTE LID
DUNLOP SINGAPORE SON BHD
BERLI JUCKER (S) COSMETICS (PTE) LTD
METAL PRINTERS (S) PTB LTD - End - Print - Edde - Edde
HITACHI KOKI (\$) PTE LTD and the structure of the structure structure structure of the structure stru
WESTERN RUBBER (PTE) LTD
TECK CHIANG METAL MFR PTE LTD I HAR AN ANT THE ALL
REPCO MANUFACTURING PTB LTD
CERAMIC WORKS (PTE) LTD and a submission of the
UIC CHEMICALS PTE LTD and a straight the state of the straight and the
UIC MARCHON (PTE) LTD Royal dam the Reference of the ray
INTERNATIONAL STEEL ROPES (PTE) LTD
MALAYSIA STEEL PIPE MANUFACTURING CO (PTE) LTD
CALTEX (ASIA), LTD 199 (200) and strength of the analytic field
TROPICAL TIMBER INDS LTD and a tendents of a store after a for
ANGLO AMERICAN CORPN SDN BHD
SIGMA METAL CO LTD AND AN THERE AND THE STATESTICS
TOHO RUBBER PROCESSING CO PTE LTD
SINGAPORE FOLEX CORPN PTE LTD
EVERGREEN TIMBER PRODUCTS CO (PTE), LTD
BEECHAM (MANUFACTURING) SINGAPORE PTE LTD
YEOW SAN (POLYFOAM) PTE LTD THE REAL AND AND THE
HUME INDUSTRIES (S) LTD BER BER BERKER ENDER AND A SECOND
THE CHEMICAL CORPORATION OF SINGAPORE PTE LTD
SERVALL CASTINGS PTE LTD - 2020 SED TO ADDE DE LA SEC
BROADWAY ENTERPRISES (PTE) LTD
SINGAPORE NAGAI PTE LTD
PLASPAC (PTF) LTD
HERCULES RUBBER & CHEMICAL INDS (PTE) LTD
B&O INDS PTE LTD
GREENLAND TIMER INDS PTE LTD
CROWN ALLIANCE PTE LTD
SINGAPORE CLAY PRODUCTS (PTE) LTD
METALS & ORES PTE LTD
FIRST ROLLING MILLS (S) PTE LTD

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Table III-1-2 List of factories collected emission data (Cont'd)

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Type of industry	Number of factories	Number of stacks	Number of facilities
Electric Power Ind.	3	6	17
Petroleum	4	47	68
Petrochemical	1	1	2
Chemicals	8	13	·15
Pharmaceutical	3		· · · · · · · · · · · · · · · · · · ·
Rubber	4	4	5
Non-Metalic	3	4	4
Food	1	1	2
Textile	3	4	1
Miscellaneous	3	7	8
Machine Tools	1	1	2
Iron & Steel	1	5	5
Fabricated Metal	6	14	14
Consumer/Industrial Electric Ind.	1992 1 4 993	6	7
Öthers	19	15	15
TOTAL	61	131	175

Table III-1-3 Number of factories, stacks and facilities classified by type of industry - 3 f - 4

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성상 위험 관문

As for the emission sources' data for the future (till 1990), the collection of information by questionnaire was found impossible, and so the following arrangements - : **:** : . . . have been made. 이 밖에서 이 사람들이 많다. 나는 것이 가지?

(1) Coal firing power stations and integrated steel mill which will be sited in Pulau Seraya and Tekong. The factors related to the emission of pollutants had been mentioned in SCOPB OF WORK and Minutes of Meetings. 机动物 法根据过度 网络白垩合 1.1.1

(2) For the existing factories in 1981, the growing rate up to 1990 FY estimated by EDB (Economic Development Board) has been applied as shown in Table III-1-4. e tel tra de la Alexandra de la Calencia de la Cale

(3) For the expanding plan of the existing power plants, the information has been given by PUB (Public Utility Board) as shown in Table III-1-5.

III - 9

Type of industry	Growing rate
Electric Power Ind.	as developing plan
Petroleum	1.55 %
Petrochemical	9.20 9. 20
Chemicals	3.40
Pharmaceuticals	3.95
Rubber	1.54
Non-Metalic	1.66 **** 4 4 **
Food	2.49
Textiles	1.53
Miscellaneous	1.96
Machine Tools	4.27
Iron & Stéel	2.49
Fabricated Metal	2.49
Consumer/Industrial Electrical	Ind. 3.40

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Table III-1-4 Growing rate of production output classified by type of industry (1981 - 1990)

(from EDB information)

Table III-1-5 Outline of facilities under expanding plan

Name of factories	Proposed commis- sioning date	Facilities
Seneko Power Station-Phase III	June 1983	250 MW x 1 (oil firing)
<u> </u>	December 1983	250 MW x 1 (oil firing)
Seraya Power Station	1987	250 MW x 2 (oil firing)
	1988	250 MW x 1 (oil firing)
	1990	250 MW x 3 (coal firing)
Tekong Power Station	1990	350 MW x 2 (coal firing)
Tekong Integrated Steel Mill	1990 - Alexandre	Grate Kiln
	1990	Reheating Furnace
Sumitomo Petrochemical	1983	Boiler x 2 (oil firing)

III-1-2 (Vessels

Emission volume of SO₂ from the vessels corresponds to the operation status (anchoring, loading, entered, cleared and navigation), type of vessels and their tonnage. Therefore the data collected for vessels' emission is necessary to be classified by type, tonnage, entered, cleared and navigation.

In this study, the basic information has been obtained from PSA (Port of Singapore Authority) through JTC as shown in Tables III-1-6 and III-1-6-7. The estimation of the future status of the vessels are described in the next chapter of this report.

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	the second	All Ve	ssels (in N	umber)	5 d 1967		
		1980		e en la companya	1981	in € , B+ i s	
Type of vessel		Annual	2nd Qtr	Jan/Jun	lst Qtr	2nd Qtr	Jan/Jun
All types	Number	24,877	6,164	12,425	6,193	6,577	12,770
	'000 NRT	155,167	37,367	75,352	38,337	44,268	82,605
Coastor &	Number	13,407	3,355	6,807	3,220	3,440	6,660
Freighter	'000 NRT	41,592	10,401	21,056	9,858	10,628	20,486
Sémi-Container	Number	1,880	458	917	535	566	1,101
& Container	'000 NRT	19,166	4,648	9,287	5,221	5,536	10,757
Tanker	Number	5,192	1,294	2,552	1,309	1,379	2,688
	'000 NRT	79,737	18,903	37,573	19,844	24,408	44,252
Bulk Carrier	Number	1,000	266	525	209	273	482
	'000 NRT	11,334	2,690	5,774	2,328	2,764	5,092
Öthers	Number	3,398	791	1,624	920	919	1,839
	'000 NRT	3,338	725	1,662	1,086	932	2,018

Table III-1-6 Number of vessels entered and cleared classified by type of vessels

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TYPE OF VESSELS ENTERED

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1YPE OF VESSELS CLEARED

All Vessels (in Number) 1980 1981 Type of vessel Annual 2nd Qtr Jan/Jun lst Qir 2nd Qtr Jan/Jun 24,820 All types Number 6,191 12,392 6,136 12,683 6,547 000 NRT 155,369 37,886 75,305 37,305 80,976 43,671 Coastor & Number 13,393 3,368 6,804 3,200 6,609 3,409 '000 NRT 10,421 Freighter 41,497 21,027 9,893 10,499 20,392 Semi-Container Number 455 915 573 1,106 1,883 533 & Container '000 NRT 19,206 10,775 4,537 9,197 5,195 5,580 Tanker 5,167 1,304 2,536 1,283 1,374 2,657 Number 000 NRT 80,189 19,476 37,770 19,059 23,734 42,793 **Bulk Carrier** Number 991 266 513 205 274 479 000 NRT 11,187 2,729 5,675 2,098 000**,**5 5,088 Others Number 3,386 798 1,624 - 915 917 1,323 000 NRT 5,290 223 1,654 1,060 868 1,928

Table III-1-7 Number of vessels entered and cleared classified by tonnage

	All	Vessels (in	Number)	p kan sa	e deal t	an An Anna an Anna Anna Anna Anna Anna A
Capacity of vessel (in NRT)	1980	-	•	1981		
(Annual	2nd Qtr	Jan/Jun	<u>1st Qtr</u>	Znd Qtr	Jan/Jun
All Capacity	24,877	6,164	12,425	6,193	6,577	12,770
Under 1,000	8,806	2,158	4,353	2,237	2,287	4,524
1,000 - 1,999	2,568	654	1,320	650	689	1,339
2,000 - 3,999	2,385	843	1,703	846	938	1,784
4,000 - 5,999	3,440	890	1,775	772	823	1,59
6,000 - 7,999	2,386	578	1,201	586	624	<u>الأرامة</u>
8,000 <u>- 9,999</u> - 1	941	235	463	237	283	52
10,000 - 14,999	1,387	329	671	376	383	75
15,000 - 19,999	373	92	177	109	119	22
20,000 - 29,999	471	119	248	114	122	23
30,000 - 39,999	555	139	260	145	138	28
40,000 and above	565	127	254	121	171	ZŻ

VESSELS ENTERED BY CAPACITY OF VESSEL (IN NRT)

VESSELS CLEARED BY CAPACITY OF VESSEL (IN NRT)

in the state of the second s		Vessels (ir	Number)	na Na sa sa sa		
Capacity of vessel (in NRT)	1980	in di Angli Visita		1981		
	Annual	2nd Qtr	Jan/Jun	<u>1st Qtr</u>	2nd Qir	Jan/Jun
All Capacity	24,820	6,191	12,392	6,136	6,547	12,683
Under 1,000	8,793	2,169	4,344	2,189	2,293	4,482
1,000 - 1,999	2,550	647	1,307	655	673	1,328
2,000 - 3,999	3,378	849	1,711	855	935	1,790
4,000 - 5,999	3,444	898	1,780	767	808	1,575
6,000 - 7,999	2,379	580	1,189	582	624	1,206
8,000 - 9,999	932	237	461	243	281	524
10,000 - 14,999	1,386	334	668	367	394	761
15,000 - 19,999	360	88	173	107	120	222
20,000 - 29,999	465	121	242	ै 🔬 े 116 ,	. i 🚊 118	234
30,000 - 39,999	552	137	260	144	136	280
40,000 and above	572	131	257	111	165	276

CHAPTER 2 ESTIMATION OF SO2 EMISSION

Based on the emission sources' data obtained from stationary sources and vessels, SO₂ emission volume have been estimated as described hereunder.

III-2-1 Stationary Sources

M-2-1-1 Estimation methods of SO₂ emission

(1) The present

Sulfur contained in the fuel is oxidized in the process of combustion and most of them are discharged as SO_2 . Therefore, SO_2 volume emitted from the stationary sources are calculated from fuel consumption rate and sulfur contents of fuel of each facility by following equations.

$$Q_s = W \times \frac{S}{100} \times \frac{64}{32}$$

= W ÷ gravity × $\frac{S}{100} \times \frac{64}{22.4}$

(when unit of sulfur is weight %)

(when unit of sulfur is volume %)

Where; Q_s : yearly SO₂ emission volume (kg/yéar)
W : yearly fuel consumption rate (kg/year)
(= hourly fuel consumption rate x yearly operation hours)
S : Sulfur content of fuel (%)
(64 : SO₂ molecular weight
32 : mulecular weight of sulfer

22.4 f volume of 1 mol in normal combustion)

In this study, SO_2 emission volume has been calculated by the above equation. However, SO_2 emission from Sulfur Plant Incinerator, Sulfur Acid Plant, Kiln & etc., are not obtainable from the equation, because SO_2 generated by combustion is absorbed into the products by the reaction of the production processes. For these exceptional cases, SO_2 emission is usually estimated from SO_2 concentration and gas volume measured by the respective facility and by the following equation.

 $Q_{s} = \hat{G} \times \hat{C}_{s} \times 10^{-6} \times \frac{64}{22.4} \times 10^{-6} \times$

111 × 14

where; Q_s : yearly SO₂ emission volume (kg/year)

G : yearly flue gas volume (Nm³/year)

(= measured gas volume [Nm³/hr] x yearly operation hour [hr/year])

 C_s : measured SO₂ concentration (ppm)

In this study, the collected data indicated zero for SO_2 measured concentration in these exceptional facilities and so the emission volume were calculated as zero. As for the flue gas volume, the indicated values in questionnair have been adopted and when the values are not indicated, calculated values were adopted which were calculated from fuel consumption rate, theoretical gas volume and other factors.

Further, in order to confirm the accuracy of indicated values, the comparison with the calculated values has been performed and when some doubts are found in the indicated values, the calculated values were adopted. Table III-2-1 shows the results of comparison between indicated and calculated values.

	s volume	
	Ċ,	•
•.	of fluc	
	values	
	calculated	
	put	
	indicated :	
	50	5
	2.1 Comparison of indicated and calculated values of flue gas volume	
	Table III-2.1	

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Name of factoria Type of facilities Instructure induction Instructure induction Instructure induction 16. UCC CHEMICALS 1 Bolter 66794 Colorance with theoremult behaviore induction induction 11. UUC MARCHON 1 Bolter 6430 6.307 2.33 X Consult gear values of the induction induction 24. THE CHEMICALS 1 Bolter 3.430 6.307 4.33 X Consult gear values of the induction induction 24. THE CHEMICAL CO 2 Acti plant 1.141 - - 2.33 X Consult gear values of the induction induction 24. THE CHEMICAL CO 2 Acti plant 2.300 0.31 X Theoremetric gaa values of the induction 24. THE CHEMICAL CO 1 Matting fundee 2.3 1.37 0.33 2.33 0.30 24. METALS a OPERS 1 Matting fundee 2.30 0.31 2.33 0.31 2.4100 -4100 -4100 24. METALS a OPERS 1 Matting fundee 2.33 0.31 0.31 2.41	L				101	1. N	Ratio	-their					
UIC CKENTCALS 1 Bolar Jandersed Landersed Landersed <thlanders< th=""><th></th><th>NABO OF RECOVER</th><th>No.</th><th>-</th><th></th><th></th><th>Ind./Call</th><th>VALUE</th><th></th><th></th><th></th><th></th><th></th></thlanders<>		NABO OF RECOVER	No.	-			Ind./Call	VALUE					
UIC CREMICALS 1 Boiler 465 234 1403 ZUC CREMICALS 1 Suider plant 1,1A1 - - 32 ZUC MARCHON 1 Suider plant 1,1A1 - - 32 xx ZMS CHEMICALS 1 Netry Suider plant 1,1A1 - - xx ZMS CHEMICAL CO 2 Anti plant 2,600 6,307 6,323 x ZEOWN ALLIANCE 1 Meetal hasting furnace 543 1,072 0.28 xx ZEOWN ALLIANCE 1 Meetal hasting furnace 334 3,733 0.10 xx METALS & ORES 1 Meetal hasting furnace 335 0.01 0.13 xx METALS & ORES 1 Chass melting furnace 335 0.13 0.14 xx MOELL OLL 1 Beller 7,003 14,900 0.04 xx MOELL OLL 1 Beller 7,703 14,900 0.04 xx MOELL OLL 1 Beller 7,703 14,900 0.04		-	4. s. r		In defated	CAICWATED						laure.	
Z Dryser Zo.603 6.307 4.23 x UIC MARCHON 1 Sulfer plant 1,1Ai - - - - x TWE CHEDRICAL CO 2 Actid plant 1,1Ai - - - x TWE CHEDRICAL CO 2 Actid plant 2.460 - - - x CROWN ALLIANCE 1 Matting funnece - - - x x CROWN ALLIANCE 1 Matting funnece - - - - x CROWN ALLIANCE 1 Matting funnece - - - - - x Since 2 Actid plant - - - - - - x x Since 2 2.400 - - - - - - - - - - - - x x Since - -	30.	UIC CHEMICALS	7	Doi)ler	465	X	1.03		Difference wit Celculated vali	a meorence gan se adopted			. 1
UIC MARCHON 1 Sufer plant 1,441 - - X TWE CHEDRICAL CO 2 Acted plant 442 530 0.63 X TWE CHEDRICAL CO 2 Acted plant 2.4600 - - X CEROWN ALLIANCE 1 Matting furnace 52 166 0.12 X METALS & ORES 2 Need bacting furnace 32 954 0.03 X S Dover 3 Dryer 4 Mestal hasting furnace 314 3.139 0.010 S Dover 3 Dryer 4 Mestal hasting furnace 314 3.139 0.010 S Dover 3 Dryer 4 Mestal hasting furnace 314 3.139 0.010 S Dover 3 Dryer 4 Mestal hasting furnace 315 0.13 0.16 S Dover 1 Dryer 3 Dryer 4 Mestal hasting furnace 10.013 0.16 S Dover 1 Dover 316 Dryer 0.01 0.05 X MOBIL OIL 1 Destarg furnace 2.6.330 0.16 0.16 X MOBIL OIL 1 Destarg furnace <td< th=""><th></th><th></th><th>N</th><th>Dryer</th><th>26,663</th><th>6,307</th><th>4.23</th><th>×</th><th>Generally gas</th><th>rolume is larger th</th><th>an theoretic</th><th>al volume in drye</th><th></th></td<>			N	Dryer	26,663	6,307	4.23	×	Generally gas	rolume is larger th	an theoretic	al volume in drye	
TME Dollar 442 530 0.63 x TME TME Actic plant 2,600 - - 0.63 x CROWN ALLIANCE 1 Matting furnace 2,600 - - 0.63 x METALIS 0 2 Metal basting furnace 543 1,972 0.28 x METALIS 1 Metal basting furnace 334 3,339 0.10 x 5 Dryve 8 Metal basting furnace 134 3,339 0.10 x 6 Beller 1 Class moliting furnace 134 3,339 0.10 x MOBIL 1 Beller 7,003 14,500 0.045 x MOBIL 1 Rasting furnace 17,700 0.045 x x MOBIL 1 Beller 7,003 14,505 0.016 x MOBIL 1 Rasting furnace 2,574 3,436 0.05	1			Sulfer plant	1,141	1		×	Theoretical ga	volume unceloute	stable-		
TME CHEMATICAL CO Z Add plant 2,400 - × CEROWN ALLIANCE 1 Matting furnace 543 1,972 0.28 × METTALS & ORUSS 1 Metal bantug furnace 22 166 0.12 × 3 Dryee 3 271 0.01 9 0.02 4 Metal bantug furnace 334 3,339 0.01 0.01 5 Dryee 3 26.035 1 Class molting furnace 10 313 0.01 5 Deline 1 Deline 7,003 14,596 0.63 × 5 Molini 1 Deline 7,703 14,599 0.03 × 6 Deline 1,7,801 10,913 11,999 0.66 × 7 MOBIL 1 Raatug furnace 2,574 3,5170 0.66 × 8 Kantuce 2,5336 3,5170 0.66 0.65 <	<u> </u>		e3	Bother	.244	530	0.83	×					T
CROWN ALLIANCE 1 Malting furnace 543 1,972 0.28 METALS & ORES 1 Metal basting furnace 22 186 0.12 2 Boiler 3 2 10 3 0.01 3 Dryes 4 371 0.01 0.01 4 Metal hasting furnace 314 3,139 0.01 0.01 5 Boiler 314 3,139 0.01 0.01 0.01 5 MOBIL <oil< td=""> 1 Basting furnace 314 3,133 0.01 0.01 5 MOBIL<oil< td=""> 1 Basting furnace 1,7003 18,450 0.05 0.05 6 Basting furnace 1,7801 20,979 0.66 x 7 MOBIL<oil< td=""> 1 Reasting furnace 1,7301 0.045 x 8 MOBIL<oil< td=""> 1 Reasting furnace 2,574 3,6170 0.66 x 7 MOBIL<oil< td=""> 1 Reasting fu</oil<></oil<></oil<></oil<></oil<>	2	THE CHEMICAL CO	14	Acid plant	2,800			×	Theoretical ga	- volume unceloul	rable		T
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Z Boller 17 954 0.02 3 Dryer 4 Metal hasting furnace 334 3.339 0.10 4 Metal hasting furnace 334 3.339 0.10 314 0.03 5 Beiler 10 314 3.7313 0.10 314 0.03 5 Sching furnace 0.034 37.313 0.13 0.03 3.43 5 Statug furnace 7.003 14.56 0.43 3.7313 0.43 6 Bealue 7.703 14.56 0.43 3.7313 0.46 7 Kaatug furnace 26,336 35.473 0.46 × × 6 Kaatug furnace 17.700 20,977 0.46 × × 7 Kaatug furnace 2.574 3.456 0.75 × × 6 Kaatug furnace 2.574 3.456 0.75 × × 11 Granting furnace 2.574 3.456 </th <th>X</th> <th></th> <th>-</th> <th>Metal beating fumace</th> <th>22</th> <th>186</th> <th>0.12</th> <th></th> <th>14 - 4 - 19 1 - 19</th> <th>19-</th> <th>- 013</th> <th></th> <th></th>	X		-	Metal beating fumace	22	186	0.12		14 - 4 - 19 1 - 19	19-	- 013		
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• Moeal haering furnace 334 3,339 0.10 \$Exilor 1 Class Exilog furnace 1.0 315 0.03 0.16 \$EXIVCANPORE CLASS 1 Class Exilog furnace 6.43.4 37,313 0.16 315 \$EXIVCANPORE CLASS 1 Beiler 7,903 14,576 0.42 37,313 0.16 x \$Exerting furnace 1,7801 26,379 0.461 x x x \$Exerting furnace 17,801 20,979 0.461 x x x \$Exerting furnace 17,801 20,979 0.46 x x x \$Exerting furnace 10,313 11,999 0.46 x x x \$Exerting furnace 15,027 18,940 0.45 x x x x \$Exerting furnace 2,574 3,456 0.75 x x x x x \$Exerting furnace 2,574 3,456 0.76 x			~~ 	Dryer	4	371	10"0		·	ð.	- ou		
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SINCAPORE CLASS 1 Class Editing furnace 6434 37.313 0.16 NORTZON FAPER. 1 Beller 7,003 14.576 0.46 × MOERL 1 Kasting furnace 26,336 35,173 0.41 × S Kasting furnace 17,301 20,979 0.45 × S Kasting furnace 10,313 11,999 0.46 × S Kasting furnace 2,574 3,456 0.45 × S			ۍ 	Dotler	10	318	0.03			ð-	tto =		T
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MORIL OIL I. Reacting furnace 25,336 35,173 0.61 x 2 Keacting furnace 17,801 20,979 0.65 x 3 Kaacting furnace 10,313 11,999 0.65 x 4 Kaacting furnace 10,313 11,999 0.65 x 5 Kaacting furnace 10,0313 11,999 0.65 x 6 Heating furnace 10,027 18,940 0.65 x 7 Kaating furnace 2,574 3,456 0.75 x 9 Heating furnace 2,574 3,132 0.75 x 10 Keating furnace 2,574 3,132 0.75 x 10 Keating furnace 2,3677 0.75 x x 11 Cennerting furnace 2,374 3,132 0.75 x 12 Sulfur plant 2,177 1,890 1.15 x 12 Fune eteck 330 -	\$		-	Boiller	7,903	18,596	0.42		1 N.	÷.	rto -		
2 Heating furnace 17,301 20,979 0.85 x 3 Kaating furnace 10,313 11,999 0.86 x 4 Keating furnace 10,313 11,999 0.86 x 5 Heating furnace 4.392 5,176 0.85 x 6 Heating furnace 16,027 18,940 0.85 x 7 Keating furnace 2.574 3,456 0.75 x 9 Heating furnace 2.362 3,132 0.75 x 10 Keating furnace 2.365 2.16,079 0.85 x 11 Centracting bular 44,053 9,470 0.49 x 12 Sulfur plant 2,177 1,890 1.15 x 7 12 Flares tack 330 - - - - - 13 Sulfur plant 2.177 2.0,070 0.05 - - - 14 Flares tack 330 - - - - - -	3			Heating furnace	26,336	35,173	18.0	×	•	· · ·	۰۰ د بور بور		· · ·
Kaating furnace 10,313 11,999 0.86 × Kaating furnace 4.392 5,176 0.85 × Kaating furnace 4.392 5,176 0.85 × Kaating furnace 1.6,027 1.8,940 0.65 × Kaating furnace 2,574 3,456 0.75 × Kaating furnace 2,574 3,456 0.75 × Kaating furnace 2,574 3,456 0.75 × Kaating furnace 2,3657 3,456 0.75 × Kaating furnace 2,32,556 236,977 0.15 × Kaating furnace 72,306 95,407 0.16 × Suldur plant 2,177 1,890 1.15 × 7 Flare etack 330 • • × 7 Flare etack 330 1.152,734 0.72 × 7 Flare etack 330 • × × 7 Connarting furnaci	; 		4	Heating furnace	17,801	20.979	0.85	×			••		
Kaating furmace 4.392 5,176 0.45 × Raating furmace 16,027 16,940 0.45 × Haating furmace 2,574 3,456 0.75 × Reating furmace 2,02,556 236,979 0.65 × Suifur plant 72,306 95,407 0.16 × Suifur plant 2,1177 1,600 1.15 × 7 Raating furmace 330 • 9,476 0.49 × 7 Suifur plant 2,1177 1,600 1.15 × 7 7 Raating furmace 86,750 122,734 0.72 × 7 7 Suifur plant 230 9.070 0.03 × 7 7 28,750 1.122		-		Heating furnace	10,313	11,999	0.86	×				·.	
Raating furnace 16,027 18,940 0.65 x Heating furnace 2,574 3,456 0.74 x Reating furnace 2,574 3,456 0.75 x Reating furnace 2,574 3,456 0.75 x Reating furnace 2,574 3,456 0.75 x Reating furnace 2,05,556 226,979 0.45 x Suithr plant 72,306 95,407 0.46 x Suithr plant 2,1177 1,490 1.15 x 17aeoretical gas volume Sharting furnace 330 - - - x 1.15 Flare stack 330 - - - x 1.15 Raating furnace 56,750 1.22,734 0.72 x 1.26,070 Fare stack 330 - - - - x Raating furnace 56,750 1.22,734 0.72 x 7.26,070			•	Heating furnace	262**	5,176	0.65	×			: ::; :	• :	
Haating furnace 2,574 3,456 0.74 × Heating furnace 2,352 3,132 0.75 × Heating furnace 2,356 3,132 0.75 × Kaating furnace 2,356 3,132 0.75 × Kaating furnace 2,25,576 3,132 0.75 × Kaating furnace 72,356 35,407 0.45 × Kaating furnace 72,356 35,407 0.76 × Suilvir plant 2,117 1,890 1.15 × 7 Flare stack 330 - - × 7 7 Rating furnace 56,750 12,2,734 0.72 × 7 7 Rating furnace 56,750 12,2,734 0.72 × 7 7	-		5	Reating furnace	16,027	16,940	\$\$* 0	×					
Reacting furmace 2.362 3,132 0.75 x Heating furmace 2.356 3,132 0.75 x Keating furmace 202,556 236,977 0.45 x Keating furmace 202,556 236,977 0.45 x Keating furmace 72,306 95,407 0.46 x Keating furmace 20,177 1,890 1.15 x Theoretical gas volume Stuthur plant 2,177 1,890 1.15 x Theoretical gas volume Flare stack 330 - - x Theoretical gas volume Kaating furmace 66,750 122,734 0.72 x Theoretical gas volume Conservating bolder 2a,177 26,070 0.03 x Theoretical gas volume	-		•	Heating furnate	2,574	3,456	0.74	×		· · ·	.	ŗ	• • • •
Raating furnace 202,556 236,979 0.45 × Kaating furnace 72,306 95,407 0.45 × Generating bollar 44,053 9,476 0.49 × Flare stack 2,177 1,890 1.15 × 7 Flare stack 330 • • × 7 7 Flare stack 330 • • × 7 7 Kaating furnace 66,750 12,2734 0.72 × 7 7 Fare stack 330 • • 0.72 × 7 Fare stack 330 • • 0.72 × 7 Connacting furnace 66,750 12,2,734 0.72 × 7			4	Reating furnace	2,362	3,132	0.75	т. ж		, N			
Kaating turnace72.30695.4070.76×Cenerating boliar41.05349.4760.49×Suldur plant2,1771.8901.15×Flare stack330*×7Hasting turnace66.750122.7340.72×Conserting turnace66.750122.7340.72×			¢	Reating furnace	202,556	236,979	0.85	×		 	e A Ref. Ref.	· ·	
Centerating boliar 44.053 49,476 0.489 × Sulfur plant 2.177 1.890 1.15 × 7.200 retical gas volume Flare stack 330 • X 7.200 retical gas volume Haating furmace 86,730 122,734 0.72 × 7. Centerating boliar 2.4.177 2.6,070 0.03 × 5			9	Meating furnace	72,306	95,407	0.76	×	1	ir tu			~
Suthin plant 2,177 1,890 1.15 × 73accetical gas volume Flare stack 330 • * 73accetical gas volume Flare stack 330 • * 73accetical gas volume Flare stack 330 • * 73accetical gas volume Flare stack 350 • * 75accetical gas volume Flare stack 350 • 0.72 × 7 Conserating bolier 2a.177 26,070 0.03 × 5			H	Cenerating botter	14,053	+0°476	60.0	×		-			
Flare stack 330 • X Theoretical gas volume Flare stack 330 • Yare stack 350 V X X Theoretical gas volume Reating furnace 86,750 122,734 0.72 X V V			11	Sulfur plant	2,177	1,890	1.15	×	3 - 120 121	1			
Plare stack 330 • × × Reacting furmace 86,750 122,734 0.72 × Conservating boliler 24,177 26,070 0.03 ×	•	- :	â	Flare stack	330	•		x	-	ivolume anulov i			
Reacting furnace 86,750 122,734 0.72 × 5 Conservating boller 24,177 26,070 0.03 × 5			41	Flare stack	330	•		×	 	j	-		
Cenerating boller 24,177 26,070 0.03 x			15	Heating furnate	88,750-	122,734	0.72	×			 52		
			16	Cenerating boller	24,177	26,070	0.93	×					٦

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 Base volume (Control) Base volume (Control)<

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The calculated values of flue gas volume have been obtained by the following equations.

$b_{h} = W \times K \times \frac{21}{21 - O_{2}}$	(when unit of theoretical gas coefficient is [Nm ³ /kg])
= W ÷ gravity x K x $\frac{21}{21-O_2}$	(when unit of theoretical gas coefficient is [Nm ³ /1] or [Nm ³ /Nm ³])
	lue of flue gas volume (Nm ³ /hr)
	tion rate in normal condition (kg/hr)
K : theoretical ga (Nm ³ /Nm ³)	as coefficient (Nm ³ /kg) or (Nm ³ /l) or
O ₂ : residual oxyg	en concentration (%)

The supplementary explanation on the above equation is given as follows:

"Theoretical gas coefficient" is the assumed gas volume generated when a unit of fuel is completely burnt by the theoretical volume of air (minimum air for complete combustion of fuel), and it is calculated from combustion reaction of combustible elements contained in the fuel, such as carbon, hydrogen, sulfur and so on.

Table III-2-2 shows equations for combustion reaction of combustible elements, combustion gas volume and so on.

Combustible	tible			-	an a	Comi	Combustible element lkg.	ent lkg.	energy and the second		
cloments		Weight ke based molecular weight	Combu	Combustion by products	roducts	Oxygen o	Oxygen consumption	Residu	Residual nitrogen	Combu	Combustion gas
Name	Symbol	· · ·	Name	_\ Symbol	Volume	Symbol	Symbol Volume		Symbol Volume	Symbol	Volume
 - -		in da az	Carbonic	Ę	S.667kg	ė	2.667kg	ź	8.78kg	Şå	12:45kg
		12kg. 32kg. 44kg 22.4, 22.4Nm ³	acid gas	5	1.867Nm ³		1.867Nm ³	4	7.02Nm ³	2	S.89Nm3
Curbon	ບັ				2:333kg		1.333kg	ş	4.39kg	ୢୖ୵ୠୢ୶	6.72kg
	· .	12kg. 16kg. 28kg 2-x 22.4, 22.4Nm ³	monoxide	8	1.867Nm ³	5	0.933Nm ³		S.SINm ³		5.38Nm3
		$H + \frac{1}{2}O_2 = H_2O$	Water		3%6	2	Skg	ş	26.34kg	Н20 Ж	35.34kg
Hydrogen	I	2kg. 16kg. 18kg 2 x 22.4. 22.4Nm ³	rodev		11.2Nm ³	5	S.6Nm ³		21.07Nm3		32.27Nm ³
· ·		S + 02 = S02	Sulfar		2k8	Ę	3 % 1	ź	3.29kg	2 80 80	5.29kg
Sulfur	ŝ	32kg. 32kg. 64kg. 22.4, 22.4Nm ³	dioxide	S	0.7Nm ³	3	0.7Nm ³		2.63Nm ³		3.33Nm ³
							:			 X	in a an • a <u>a</u> nna •

 $d_{i}(p) \in L^{\infty}(\mathbb{R}^{n}) \xrightarrow{\mathbb{R}^{n}} \mathbb{R}^{n} = L^{\infty}(\mathbb{R}^{n})$

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The theoretical gas coefficient is obtainable from elemental composition of each fuel as shown in Table III-2-2. In this study, the calculated theoretical flue gas coefficient shown in Table III-2-3 has been employed. Further, the coefficient mentioned in the table is the flue gas volume which include water vapour.

Type of fuel	Theoretical flue gas coefficient	Unit
Heavy oil	10.6	Nm ³ /1
Diesel oil	10.0	Nm ³ /1
Heavy naphtha	8.8	Nm ³ /1
Reduced Crude	10.6	Nm ³ /1
Crude oil	10.2	Nm ³ /1
Tail gàs	13.9	Nm ³ /Nm ³
Gas	14.4	Nm ³ /kg
Others (wood)	4.2	Nm ³ /kg

Table III-2-3 Theoretical flue gas coefficient classified by type of fuels

In the actual combustion, more air than theoretical volume is supplied for complete combustion. Therefore the flue gas volume should be corrected with the factor of excess air and $\frac{21}{21-O_2}$ is the correction coefficient. O₂ is oxygen concentration contained in flue gas, and in this study, the assumed values classified by type of facilities shown in Table III-2-4 have been employed.

and the second second			the second second
Call I to the Arman	Type of facilities	Residual óxygen (%)	
	Petroleum Heating Furnace	e stielen 7.0 state	
i - Constant de Al	Boiler (Power Generation)	a service of \$.0 August aver	ata tur
	Boiler	7.0	n substation
.*	Sulfur Plant Incinerator	13.0	1
40 - 1 1 2010 4	Flare Stack the Patienstones	en avag to -6.0 to be at	्रियः १९३ अपितः ।
	Gas Producer	6.0	
	Oil Combustion Furnace	6.0	
	Thermal Fluid Heater	15.0 de de serve	
1 - Dirting	Sadium Silicate Furnace	6.0	
	Sulphuric Acid Plant	10.0	
	Metal Heating Furnace	9.0	
	Reheating Furnace	9.0 a mas	
	Kiln	16.0	
	Dryer	15.0	
	Burner	13.0	
	Glass Melting Furnace	13.0	
	Smelter	14.0	
	Zn. Smelter	18.0	
			ter en

Table III-2-4 Residual oxygen classified by type of facilities

(2) Future

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Future (1990) SO2 émission volume has been estimated both from the present emission sources and the new emission sources which will be sited by 1990.

Future emission volume of SO3 from the existing sources has been estimated by multiplying the growing rate (BDB data) of each industry with their oil consumption rate and the same equations for calculation of SO2 emission volume, described in III-2-1-1, have been applied. In the calculation, consideration has been given to APU regulation that industries or facilities commissioned after 1975 are compulsory to use the oil containing sulfer less than 2% with the exception of SENEKO Power Station.

The growing rate of each industry based on EDB data during the period from 1981 to 1990 is shown in Table III-2-5. The growing rate of electric power industry and petroleum were not based on EDB data, because the detailed information on future developing plan of power stations have been given by PUB and as for the petroleum industry had to make the corrected estimation under the recent international oil situations.

i i i i i i i i i i i i i i i i i i i		stand free	
Type of industry		Growing rate	Rémarks
Electric Power Ind.		いたい部プ教権重要	Data given by PUB
Petroleum		1,55 %	corrected to 1.00%
Petrochemical 0.0	:	1039.20 A als	
Chemicals 0.0	÷		
Pharmaceuticals 0.0	:	- a - 3.95 - set	
Rubber 0,51		1.54	
Non-Metalic		1.66	
Food		2.49	
Textiles		1.53	
Miscellaneous		1.96	A MAR A
Machine tools		4.27	
Iron & Steel		2.49	
Consumer/Industrial Electrical Inc	iustry	3.40	

Table III-2-5 Growing rate of production classified by type of industry (1981 - 1990)

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shown in Table 111-2-64 and the state of the

same methods applied for the present. (200 million of the sources have been estimated by the

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Table III-2-6 Outline of new sources

Name of facility	Proposed date of commissioning	Outliné
Seneko Power Station-Phase III	June 1983	250 MW x 1 (oil burning)
	December 1983	250 MW x 1 (oil burning)
Seraya Power Station		250 MW x 2 (oil burning)
· · · · · · · · · · · · · · · · · · ·		250 MW x 1 (oil burning)
HIR GER ENDERLIGE		250 MW x 3 (coal firing)
Tekong Power Station	1990 - 1990 - 1990	350 MW x 2 (coal firing)
Tekong Integrated Steel Mill		Grate Kiln (coal firing)
	1990	Reheating Furnace (coal)
Sumitomo Petrochémical	1983	Boiler x 2 (oil firing)

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III-2-1-2 Results of estimation of emission volume

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The estimation of SO_2 emission volume results as 226,362 ton/year for the present (1981) and 480,019 ton/year for the future (1990) which is almost 2.1 times of the present.

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Estimated SO₂ emission volume classified by factories and enterprises is shown in Table III-2-7, the emission volume classified by type of industry is shown in Table III-2-8 and the volume classified by type of factories is shown in Table III-2-9.

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From Table III-2-8, it is found that power stations and oil refinary hold 98% for the present and 97.6% for the future. Among them, power stations hold the majority of the emission volume which are 77.1% of the present and 68.2% of the future.

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From Table III-2-9, the same tendency is confirmed that the emission volume from boiler for power generation and petroleum heating furnace for oil refinery are estimated to emit 97.9% of the present and the boiler for power generation, petroleum heating furnace and kiln of the integrated steel mill are estimated to emit 96.4% of the fotal volume in the future.

- APPENDER BATTER BATTER DE BA

Fig. III-2-1 shows ranked diagram of SO_2 emission volume from stationary sources of the present by mesh. From the figure, it is clearly found that the factories and plants are concentrating in Jurong area located in the south west side of Singapore main island.

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Table III-2-7 SO2 emission volume classified by factory and enterprise

:	_	SO ₂ emiss	ion volume	
	No.	Present (1981) (ton/year)	Future (1990) (ton/year)	Names of factory and enterprise
	1	25.9	238.5	DRAGON POLY-FOAM INDS (S) PTE LTD
	2	34.0	52.5	DUNLOP SINGAPORE SON BHD
	3	10.1 ⁸⁸	29.5	BERLI JUCKER (S) COSMETICS (PTE) LTD
•	3 4 ™	0.0	0.0	METAL PRINTERS (S) PTB LTD
	5		0.0	HITACHI KOKI (S) PTE LTD
	⁷ 6 6		3.7	WESTERN RUBBER (PTE) LTD
	7	4.2	10.5	TEĆK CHIANG METAL MFR PTE LTD
	8	0.9	1.8	REPCO MANUFACTURING PTE LTD
	9	0.0	0.0	CERAMIC WORKS (PTE) LTD
	10	10.0	33.9	VIC CHEMICALS PTE LTD IT I DEREN AND INTERNE
	11	9.1	31.0	UIC MARCHON (PTE) LTD
	12	0.9	2.4	INTERNATIONAL STEEL ROPES (PTE) LTD
	13	21.7	54.0	MALAYSIA STEEL PIPE MANUFACTURING CO
				(PTE) LTD
	14	en en 1,3 e e	4.6	CALTEX (ASIA) LTD
1 .	15	0.0	0.0	TROPICAL TIMBER INDS LTD
	16	0.0	0.0	ANGLO AMERICAN CORPN SON BHD
•	17	5.6	39.0	SIGMA METAL CO LTD
- 11	18	61.1	94.3	TOHO RUBBER PROCESSING CO PTE LTD
1	19	0.0	0.0	SINGAPORE FOLEX CORPN PTE LTD
	20	0. 0 😳	0.0	BVERGREEN TIMBER PRODUCTS CO (PTE) LTD
	21	2,8	10.9	BEECHAM (MANUFACTURING) SINGAPORE PTE
	1999 - 1997 1997 - 1997			LTD THE CARTERIAN AND AND THE STREET
	22	······································	171.3	YEOW SAN (POLYFOAM) PTE LTD
	23	56.1	139.8	HUME INDUSTRIES (S) LTD
:	24	2 85.2 m	289.8	THE CHEMICAL CORPORATION OF SINGAPORE
				PTE LTD
	25	0.0	0.0	SERVALL CASTINGS PTE LTD
1.00	56 in		312.6	BROADWAY ENTERPRISES (PTE) LTD
÷.∉.	27	0.0		SINGAPORE NAGAT PTE LTD
	28	δ.3	0.5	PLASPAC (PTF) LTD
	29	4.6	7.0	HERCULES RUBBER & CHEMICAL INDS (PTE) LTD
	30	0.0	0.0	B & O INDS PTE LTD
	31	0.0	0.0	GREENLAND TIMER INDS PTE LTD
	32	21.1	34.9	CROWN ALLIANCE PTE LTD

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Table III-2-7 SO2 emission volume classified by factory and enterprise (Cont'd)

No.	Present (1981) (ton/year)	Future (1990) (ton/year)	Names of factory and enterprise
33	215.9	386.6	SINGAPORE CLAY PRODUCTS (PTE) LID
34	40.7	218.8	METALS & ORES PTE LTD
35	12.4	48.0	FIRST ROLLING MILLS (S) PTE LTD
36	11.3	38.4	SINGAPORE ADHESIVES & CHEMICALS PTE LTD
37	1,529.4	3,838.6	NATIONAL IRON & STEEL MILLS LTD
38	1.8	6.1	BP SINGAPORE
39	401.8	666.1	SINGAPORE GLASS MANUFACTURER PTE LTD
40	0. 0	0.0	SINGAPORE WOOD INDUSTRIES PTE LTD
41	Ò. Ó	0,0	SUNLIGHT TIMBER PODUCTS CO (PTE) LTD
42	0.0	0.0	SOUTHERN WOOD PRODUCTS (PTE) LID
43	Ó.Ó	0.0	INTERNATIONAL WOOD PRODUCTS LTD
44	0.0	0.0	JURONG PLYWOOD CO (PTE) LTD
45	179.5	610.9	SIME DARBY OLEO CHEMICALS LTD
46	0.0	0.0	ASIAN PLYWOOD CO PTE LTD
47	0.0	0.0	STARLIGHT TIMBER PRODUCTS CO LTD
48	18.9	80.8	MITSUBOSHI BELTING SINGAPORE PTE LTD
49	39.4	60.3	MAXIM DYEING & FINISHING FTY PTE LTD
50	343.7	671.9	HORIZON PAPER INDUSTRIES PTE LTD
51	0.0	0.0	MANUFACTURE ELEMENT PREFABRICATE PIE
			LTD
52	114.9	175.9	HONGKONG DYEING AND WEAVING (S) LTD
53	5,623.0	5,529.6	MOBIL OIL SINGAPORE PTE LTD
54	8,131.3	8,131.3	SINGAPORE REFINING CO PTE LTD
55	20,974.0	20,974.0	SHELL COMPANIES IN SINGAPORE
56	12,508.3	12,508.3	ESSO SINGAPORE PRIVATE LIMITED
57	89,229.5	13,1142.9	SENOKO POWER STATION
58	21,518.1	21,518.1	PASIR PANJANG POWER STATION
59	63,761.9	63,761.9	JURONG POWER STATION
61	1,029.1	2,563.5	SUGAR INDUSTRY OF SINGAPORE LTD
56	158.2	309.3	RDC BRICKWORKS TILE WORKS
63	-	78,907.2	SERAYA POWER STATION
64	-	32,000.0	TEKONG POWER STATION
65	-	90,102.9	TEKONG INTEGRATED STEEL MILL
66		4,204.8	SUMITOMO PETROCHEMICAL
TOTAL	226,362.5	480,018.5	

SO2 emission volume

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Table III-2-8 SO2 emission volume classified by type of industry

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A. Control State Sta	te Power Ind. eum-		Number of	Number of	Number of		1	Number of	Number of				Add tional
L N3 N1 N3 N1 N2 N1 N2 N1 N2 N2 </th <th>ric PowerInd. Jeum- chemical-</th> <th></th> <th>factory</th> <th>5</th> <th>facility</th> <th></th> <th>r/y) & % .</th> <th>LACTORY</th> <th>stack</th> <th></th> <th></th> <th>~~~ ~ (A.)</th> <th>SOx volume</th>	ric PowerInd. Jeum- chemical-		factory	5	facility		r/y) & % .	LACTORY	stack			~~~ ~ (A.)	SOx volume
	steum	•	1 2.3 Carl	. 0	- 41			с С т	10-	12 ~ 27	327,330.1	5.84	152,820.6
	chemical		•	47	6.8	47,236.6	20.9	4	214	\ 68	1.641.74	9.8	- -
1 1			7		t i		10.0	2	2			0.9	4,204.8
	iente:		l P	:	2 23	- 436.0				15.	1,327.3	0.3	
					4	37.2	0.02			۲. ۲.	2112	- 0.04 -	-
1 1	1	1	-	i –		102.1	0.05	10 10 10 10 10		\$ 'w ~	157.5	0.03	1 H
			?			638.8	5.0				1,087.6	×	
1 1		- a				1.029.1	3	1		63 	2,563.5		- 1440 - 1
						154.6					. 236.7	0.04.	
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	mer/Industrial)	Lectrical Ind-	-	\$								- 0.05	
			1	150		L	1	19	12.			~ 0°00	
					- 175	220,362.4	Ľ		138	189			247,128.2
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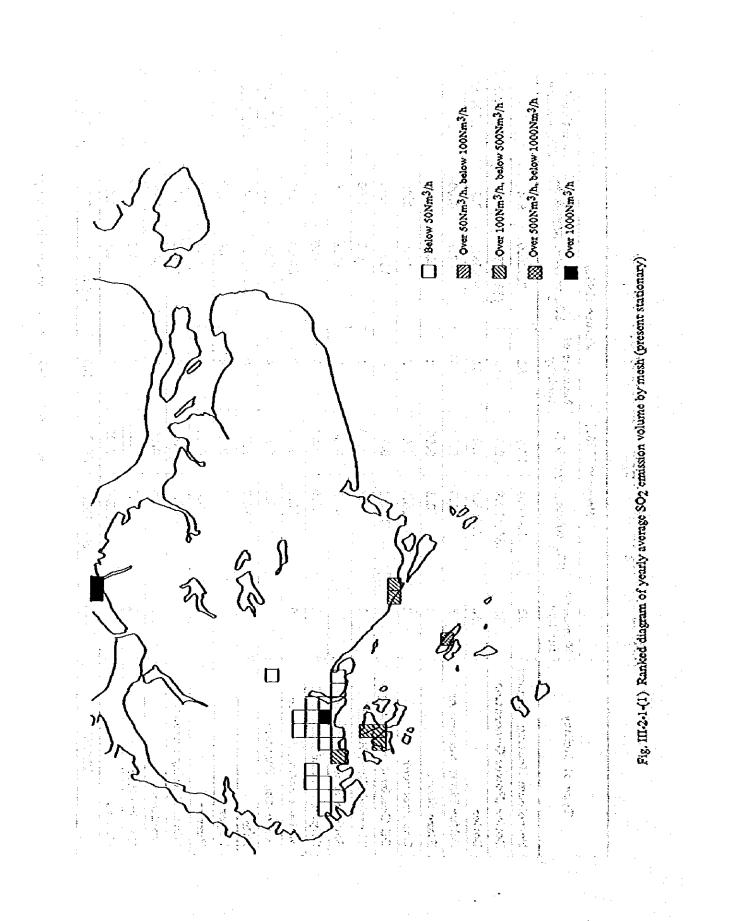
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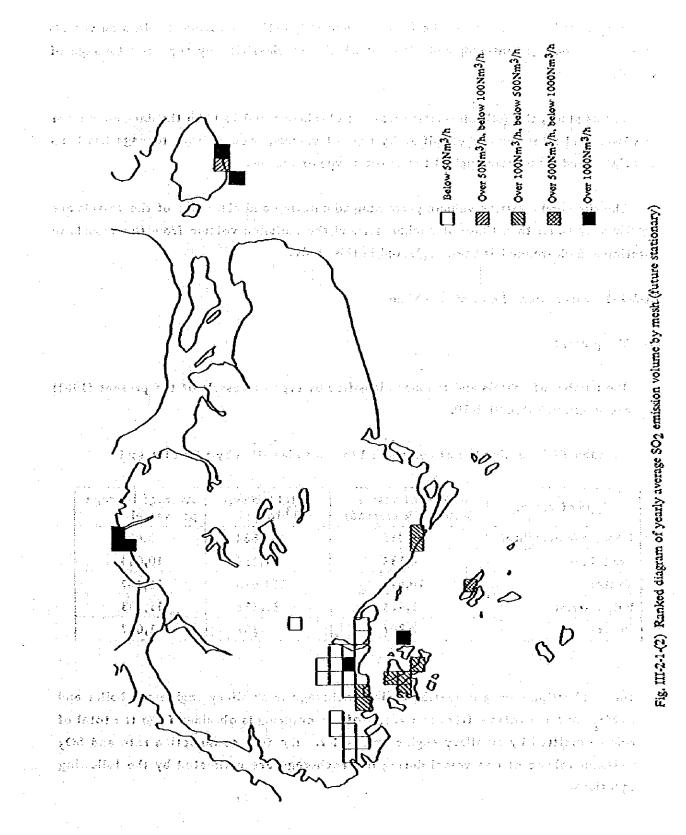
Table III-2-9 SO2 emission volume classified by type of facility

Present (1981) Future (1990) Type of facility Number of scality Solume (v/y) & % Additional scality Petroleum Heating Furnace 52 40,464.4 17.9 52 40,326.0 8.4 Solume (v/y) & % Solume (v/y) & %								
Type of facility Number of SO2, volume (x/y) & % facility facility facility facility % facility facility % facility % Number of SO2, volume (x/y) & % leum Henting Furnace 52 40,464.4 17.9 52 40,326.0 8.4 (Fower Generation) 25 181,110.9 80.0 35 333,979.4 69.6 (Fower Generation) 52 2,265.6 1.0 52 2,335.9 2.1 0.00 Flant Incinerator 3 1.9 0.00 3 2.1 0.00 Stack 1 1.9 0.01 2 16.6 0.00 Stack 1 1.1 1.4 151.3 0.1 4 151.3 0.00 Stack 1 1.1 1.1.5 0.00 1 0.00 0.00 sal/Fluid/Heater 1 1.1.8 0.00 1 0.00 1.2 0.00 0.00 al/Fluid/Heater 1 1.3.6 0.00 1 0.00 1.4 0.00 0.00 0.00 0.00			Prese	nt (1981)	Fut	ure (1990)	- - -	-
Reum Heating Furnace 52 40,464.4 17.9 52 40,326.0 8.4 (Power Generation) 25 181,110.9 80.0 35 333,979.4 69.6 (Power Generation) 52 2,265.6 1.0 52 9,858.9 2.1 Flant Incinerator 3 1.9 0.00 3 2.1 0.00 Stack 2 2.3 0.00 3 2.1 0.00 Stack 2 2.3 0.00 3 2.1 0.00 Stack 2 0.16.6 0.01 2 151.3 0.1 4 151.3 0.03 Stack 1 1.1.8 0.00 1 6.1 0.00 0.05 Stack 1 1.1.8 0.1.4 1 2.1.3 0.05 Mounterion Furnace 1 1 1.1 0.0 0.0 0.0 Mit of Furnace 3 1.365.4 0.0 0.0 1 0.0 0.0	Type of facility	Number of facility	SO ₂ volume (t	/y) & %	Number of facility	SO2 volume (t	/y) & %	Additional SO ₂ volume
(Power Generation) 25 181,110.9 80.0 35 333,979.4 69.6 Plant Incinerator 52 2,565.6 1.0 52 9,858.9 2.1 Flant Incinerator 3 1.9 0.00 3 2.3 0.00 Stack 2 2.3 0.00 2 2.3 0.00 Stack 2 1.51.3 0.01 4 151.3 0.00 Stack 1 1.51.3 0.0 1 4 151.3 0.00 suburtion Funnace 1 1.4.8 0.00 1 6.1 0.00 suburtion Funnace 1 1.1.8 0.00 1 0.01 1.0.0 suburtion Funnace 1 85.2 0.04 1 279.3 0.06 fing Funnace 3 1.385.4 0.0 0.0 0.0 0.0 fing Funnace 3 1.385.4 0.0 4 5.904.0 1.2 fing Funnace 3	Petroleum Heating Furnace	25	40,464-4	17-9	25	40,326-0	8-4	
Flant Incinerator 52 2,265.6 1.0 52 9,858.9 2.1 0.00 3 2.1 0.00 5 5,858.9 2.1 0.00 5 5,858.9 2.1 0.00 5 5,858.9 2.1 0.00 5 5.3 0.00 3 2.1 0.00 5 5.3 0.00 2 2.1 0.00 5 5.3 0.00 2 2.3 0.00 2 2.3 0.00 2 3.0.00 2 3.0.00 3 2.1 0.00 3 2.3 0.00 1 0.00 1 0.00 1 0.00	Boiler (Power Generation)		181,110.9	80.0	35	333,979.4	₹ 69.6 °	152,820.5
Flant Incinerator 3 1.9 0.00 3 2.1 0.00 Stack 2 2.3 0.00 2 2.3 0.00 Stack 2 2.3 0.00 2 1.5.3 0.00 roducer 2 1.5.6 0.01 2 16.6 0.00 mbustion Furnace 1 151.3 0.1 4 151.3 0.05 al Fluid Heater 1 1.8 0.00 1 6.1 0.00 al Fluid Heater 1 0.01 1 0.05 1 0.05 al Stitcate Furnace 1 0.02 0.03 9 279.3 0.06 mic Acid Plant 1 0.05 0.05 9 279.3 0.06 tring Furnace 3 1,365.4 0.05 1.2 1.2 8 fung Furnace 3 1.355.4 0.06 1 279.3 0.06 fung Furnace 3 1.355.4 0.07	Boiler		2,265-6	1.0	52	9,858.9	2.1	4,204.8
Stack 2 2.3 0.00 2 2.3 0.00 2 2.3 0.00 2 2.3 0.00 2 16.6 0.00 2 16.6 0.00 2 16.6 0.00 2 16.6 0.00 2 16.6 0.00 2 15.1.3 0.00 1 0.01 2 0.03 9 15.1.3 0.03 9 15.1.3 0.00 1 0.00 10.00	1.		6°1°	00-0	3	2.1	00-00	
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Heating Furnace 9 62.0 0.03 9 279.3 0.06 tring Furnace 3 1,365.4 0.6 4 5,904.0 1.2 tring Furnace 3 1,365.4 0.6 4 5,904.0 1.2 tring Furnace 3 13.5.7 0.2 10 88,402.2 18.4 8 r 1 10.4 0.00 4 35.0 0.00 1 8 r 1 18.4 0.01 1 666.1 0.1 r 3 21.3 0.01 1 666.1 0.1 melter 1 0.5 0.00 1 1.3 0.00 r 3 21.3 0.01 3 35.3 0.00 r 1 0.5 0.00 1 1.3 0.00 r 1 0.5 0.00 1 0.0 0.0 r 1 0.5 0.00 1 0.0 0.0 r 1 1 1 1.3 0.00 0.0 r 1 0.0 1 0.0 0.0 0.0	Sulphuric Acid Plant	-	0-0	00-00		0.0	0-0	
ting Furnace31,365.40.645,904.01.2\$	Metal Heating Furnace	6	62-0	0-03	ò	279.3	0.06	
9 382.7 0.2 10 88,402.2 18.4 4 10.4 0.00 4 35.0 0.00 r 1 18.4 0.01 1 62.7 0.01 Melting Furnace 1 401.8 0.2 1 666.1 0.1 er 3 21.3 0.01 3 35.3 0.00 olter 1 0.5 0.00 1 1.3 0.00 olter 1 0.5 0.00 1 1.3 0.00 offton 1 0.5 0.00 1 0.0 0.0 offton 1 0.00 1 0.0 0.0 0.0 offton 1 175 226,362.4 100.0 187 480,018.5 100.0	Reheating Furnace	ß	1,365.4	0-6	4	5,904.0	1.2	2,502.9
4 10.4 0.00 4 35.0 0.00 r 1 18.4 0.01 1 62.7' 0.01 Melting Furnace 1 401.8 0.2 1 666.1 0.1 er 3 21.3 0.01 3 35.3 0.00 olter 1 0.5 0.00 1 1.3 0.00 nolter 1 0.5 0.00 1 1.3 0.00 nolter 1 0.5 0.00 1 0.0 0.00 nolter 175 226,362.4 100.0 187 480,018.5 100.0	Kih.	6		0.2	10	88,402.2	18.4	87,600-0
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3 21.3 0.01 3 35.3 0.00 1 1 0.5 0.00 1 1.3 0.00 1 0.0 0.00 1 0.0 0.0 1 1 0.00 1 0.0 0.0 1 175 226,362.4 100.0 187 480,018.5 100.0	Glass Melting Furnace		401.8	0.2	4	666.1	0.1	
1 0.5 0.00 1 1.3 0.00 1 1 0.0 0.00 1 0.00 0.0 1 1 0.00 1 0.00 0.0 0.0 0.0 TAL 175 226,362.4 100.0 187 480,018.5 100.0	Smelter	3	21.3	10-0		35.3	0000	
TAL 1 0.0	Zn. Smelter	F -4		00°0		1.3	0.00	
175 226,362.4 100.0 187 480,018.5 100.0	Others	-	0*0	00-0	-4	5 0°0 100	0-0	
			226,362.4	100-0	187	480,018.5	100.0	247,128.2

Remarks: Future SO2 emission volume include present.

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SO₂ emission volume from the vessels are usually estimated from the data on vessels statuses (anchorage, entered, and cleared) which are classified by type and tonnage of vessels.

In this study, the full information was not obtainable and so from the data on number of vessels and total tonnage classified by type of vessels, each average tonnage has been calculated and those were applied to the total type of vessels.

The time and emission volume pertaining to entering and clearance of the vessels are usually very small than those of anchorage, and the emission volume from the vessels in entering and clearance has been neglected in this study.

10-2-2-1 Estimation of emission volume

(1) The present

The number of vessels and tonnage classified by type of vessels of the present (1981) are shown in Table III-2-10.

			and the second
Type of vessel	Number of vessel (entered & cleared)	Total tonnage (10 ³ ton)	Average tonnage per vessel
Coaster & Freighter	26,458	\$1,884	3,095
Container	4,138	41,438	10,014
Tanker	10,616	171,628	16,167
Bulk Carrier	1,914	21,252	11,103
Others (7,207	7,257	1,007
	and the second		

Table III-2-10 Number of vessels and tonnage classified by type of vessel

The combustion engine operating during anchorage is auxiliary engine and boiler and so SO_2 emission volume from one vessel of one entering is obtained from the total of volume emitted by auxiliary engine and boiler. The fuel consumption rate and SO_2 emission volume of one vessel during her anchorage are estimated by the following equations.

(a) Auxiliary engine

(b)

Fuel consumption rate (kg/vessel) = 0.165 x rated power (PS) x load factor x anchoring hour (H)

SO₂ emission volume = fuel consumption rate (kg/vessel) x sulfur content (%) x $\frac{1}{100}$ x $\frac{64}{32}$ Plue gas volume (Nm³/vessel) = 5.46 x rated power (PS) x load factor x anchoring hour (H) Auxiliary boiler

Fuel consumption rate =

rated fuel consumption rate (kg/v.) x load factor x anchoring hour (H)

SO₂ emission volume =

fuel consumption rate (kg/v.) x sulfur content (%) x $\frac{1}{100}$ x $\frac{64}{32}$

Flue gas volume =

fuel consumption rate x theoretical gas volume (Nm³/kg)

In the above equation, the rating power (PS) means the rating power of auxiliary engine installed in the vessel and the values have been obtained by the equations mentioned in Table III-2-11. The rating power of the auxiliary boiler is also obtained by the equation mentioned in Table III-2-11.

The anchoring hour is the number of hours required for one entering of one vessel and the values mentioned in Table III-2-12 have been applied. The values of sulfur content mentioned in Table III-2-12 have also been applied.

Load factor means the average load rate of auxiliary engine and boiler during anchorage. As for the load rate of auxiliary engine, the values were set up as 0.63 for time of loading work and 0.39 for non-loading time, and estimated percentage of loading work time during anchorage was set up as 0.23. So the average load rate of the vessel under loading work is:

0.39 + (0.63 - 0.39) x 0.23 = 0.445

The average load rate of auxiliary boiler was set up as 0.5.

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As the theoretical flue gas volume, 11.7 Nm³/kg for heavy oil has been applied.

Type of vessel	Rating power & number of auxiliary engine	Rated fuel consumption rate of auxiliary boiler
Coaster & Freighter	7.7× ^{0.4} × 2	0.1 x 0.79
Container	2,2 x 0.6 x 2	0.1 × 0.79
Tanker	10 x ^{0.37} x 2	0.69 x 0.76
Bulk Carrier	7.7 × 0.4 × 2	0.10 x 0.79
Others	1.5 x 0.63 x 3	-

Table III-2-11 Rated fuel consumption rate of auxiliary engine and boiler classified by type of vessel

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() () () ()	Anchor- ing hour- (H)	4	88	?	nganang selapakan di peruanti yang selapakan di peruanti selapakan di peruanti selapakan selapakan selapakan s Anggan tertapakan selapakan selapakan selapakan selapakan selapakan selapakan selapakan selapakan selapakan sel
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t of vesse (1985) and	Ì ₹	0.445	0.445	0.39	n By Colore and Society provident of the second second second second second second second second second second Second second
Table of coefficient of vessels	Auxiliary boller fuel conaumption (kg/hr)	57 145	1,090 157		र होते शेलक हैलाक पु र्व प्रति प्रतिहोत्र कोत्र कालक स्वत्र ता तो तीत्र स्वत्र न तहीं ।
	Auxiliary	192	361		and Antilense at the state of the
П.2-1	Aux Tate				
Table III:2-12	Main engine rated power (PS)	. 3,529	10,598	2,456.5	
	Average M tonnage ra (t/v.)	.3.095- 10.014	16,167	1.007	
	}			_	
gi, wa	Total tonnage (10 ³ t)	81,844		7,257	
	Number of vessel (entered & cleared)	20.458	111	7.207	Alexandre and Alexandre Alexandre and Alexandre and Alexa Alexandre and Alexandre a
	I De recentra de la compañía de la c	reighter			
	Type of vessel	Coaster & Freighter	Tunker	Others	
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•		: •			
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(2) The future

The data on future status of the vessels have not been obtained and so the future emission volume from the vessels have been estimated by the followings.

The number of tanker assumed as the same with the present. For the other types of vessels except the tanker, the growing rate of industrial production (EDB data) has been adopted in estimation. Besides the above, the additional correction to cover the requirements from the newly sited factories have been made by the following equation.

Necessary number = Fuel consumption rate (ton) of vessels Carrying capacity of one vessel (ton) x loading rate

In the above equation, the carrying capacity of the vessel was assumed as 2 times of total tonnage and the average tonnage of the vessel was assumed as the same with the present. The loading rate of tanker and bulk carrier were assumed as 0.85 and 0.65 respectively.

The number of vessels classified by type of vessels are shown in Table III-2-13.

Type of vessel	Number of vessel (entered & cleared) in future	Number of vessel required for newly sited factories
Coaster & Freighter	69,055	
Container	10,800	
Tanker	10,791	175
Bulk Carrier	5,918	923
Others	18,810	

Table III-2-13 Number of vessels classified by type of vessel (future)

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Remarks: Number of vessels required for newly sited factories are included in the future number of vessels.

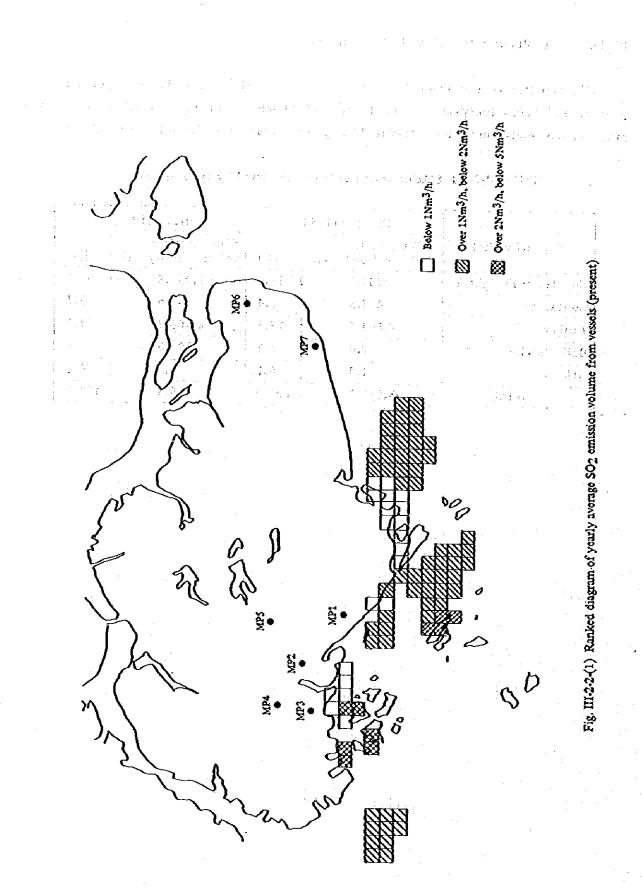
III-2-2-2 Results of estimation of emission volume

 SO_2 emission volume from the vessels have been estimated as 3,917 ton/year for the present and 5,705 ton/year for the future (1990) which corresponds 1.5 times of the present. SOx emission volume classified by type of vessels are shown in Table III-2-14.

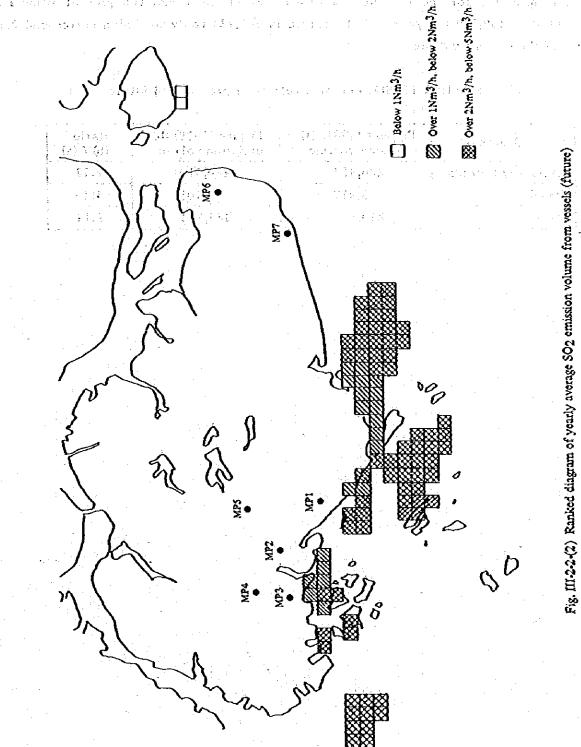
	Present (1981)	1	Future (1990)		
Type of vessel	SOX emission volume (ton/year)	(%)	SOX emission volume (ton/year)	(%)	
Coaster & Freighter	743.5	19.0	1,936.8	33.9	
Container	213.3	5.4	555.6	9.7	
Tanker	2,861.5	73.1	2,908.7	51.0	
Bulk Carrier	97.0	2.5	299.5	5.2	
Others	1.8	0.1	4.7	0.1	
Total	3,917.1	100.0	5,705.3	100.0	

Table 111-2-14 SOx emission volume classified by type of vessel





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III-2-3 Conclusion of SO2 Emission Volume

Table III-2-15 shows the total volume of SO_2 emitted from stationary sources and vessels estimated for the present and future. From the table, the present volume is estimated as 230,279 ton/year and the future is 485,724 ton/year which correspond 2.11 times of the present volume.

Source	Present (1981) (a)	Future (1990) (b)	Ratio
	emission volume	emission volume	(b) / (a)
Stationary sources	226,362	480,019	2.12
Vessels	3,917	5,705	1.46
Total	230,279	485,724	2.11

Table III-2-15 SO₂ emission volume of present and future.