No. 53

THE STUDY ON ENVIRONMENTAL EFFECTS OF COAL FIRING POWER STATIONS AND INTEGRATED STEEL MILL IN THE REPUBLIC OF SINGAPORE (PARTICULATE SURVEY)

NOVEMBER 1985

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

It is with great pleasure that I present this Study Report on the Environmental Effects of the particulate matters arising from the Planned Coal-Fired Power Stations and the Integrated Steel Mill to the Government of the Republic of Singapore. (The Reports on the water pollution and the air pollution have already been submitted to the Government of Singapore.)

This report embodies the results of a series of field surveys which were carried out in Singapore from November, 1983 to September, 1984 by a Japanese survey team commissioned by the Japan International Cooperation Agency following the request of the Government of the Republic of Singapore to the Government of Japan.

The survey team, headed by Mr. Kihachi Inagaki had discussions on the Project with the officials concerned of the Government of Singapore.

I sincerely hope that this report will be useful as a basic reference for environmental assessment and protection measurers in Singapore.

I wish to express my deep appreciation to the officials concerned of the Government of the Republic of Singapore of their close cooperation extended to the survey team.

November, 1985

Keisuke Arita

KEISUKE ARITA
President
Japan International Cooperation Agency

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SUMMARY & RESULTS

SUMMARY & RESULTS

(I) Outline of Survey

The Government of the Republic of Singapore requested the Government of Japan to extend the technical cooperation pertaining to the environmental effects of coal firing power stations and integrated steel mill which were proposed to be established in the new industrial areas.

Upon above request, Japan International Cooperation Agency (JICA) has sent a preliminary survey mission in December 1980 and entered into agreement with the Government of the Republic of Singapore on the scope of work including survey items, survey methods, time schedule and so on.

Japanese survey team has conducted the study on water quality during February to December 1981, particularly on Chemical Oxygen Demand (COD) and thermal effluent. This study has been reported in February 1982 with the official report.

Following to the study on water quality, the Japanese team has carried out the field survey on air quality, in terms of Sulpher Dioxide (SO_2) during July 15th 1981 to July 14th 1982 (one year) by automatic and continuous monitoring instruments. The results of simulation on SO_2 have been reported in July 1983.

In 1982, the Government of the Republic of Singapore has requested the Government of Japan to conduct the study on particulate matter in order to make the environmental study more comprehensive, and in June of 1983, the additional study has been agreed to conduct between two countries.

Based on the agreement, the field survey and simulation for the particulate matter have been carried out during December 1983 to July 1985.

The field survey on the particulate matter has been conducted in two ways, which are (1) short term survey to monitor the particulate matter concentratively by setting up many monitoring stations throughout the island (4 times a year: December 1983, March-June-September 1984), and (2) long term field survey to monitor the ambient concentration of the particulate matter for comparatively long period (from December 7, 1983 to December 6, 1984) by automatic and continuous monitoring instruments.

In parallel with the above long term field survey, SO_2 wind direction & velocity, solar & net radiation and temperature have been monitored for one year by automatic and continuous monitoring instruments.

Through the period of the above field survey, the training on the maintenance and repairing methods have been provided to Singapore counterpart.

Further for identifying the chemical components of the particulate matter, the sampled filters obtained through short term field survey have been brought back Japan and analysis of metal elements, anion and carbon have been conducted in Japan.

The monitored data through the above-mentioned field survey have been processed and analyzed in Japan during June 1984 to July 1985. The data on the emission volume from the coal firing power stations and integrated steel mill have been input and together with the processed and analyzed data, simulation of future concentration of the particulate matter has been carried out by ambient diffusion model.

In addition to the above, the assumption of contribution by sources has been applied to the study by receptor model which is recently developed, using the analytical results of chemical components of the particulate matter.

The report has been compiled comprehensively and the total flow of the study is shown in Fig. (I), and Table (I)-1 shows outline of the field survey. Table (I)-2 shows the time schedule of the field survey.

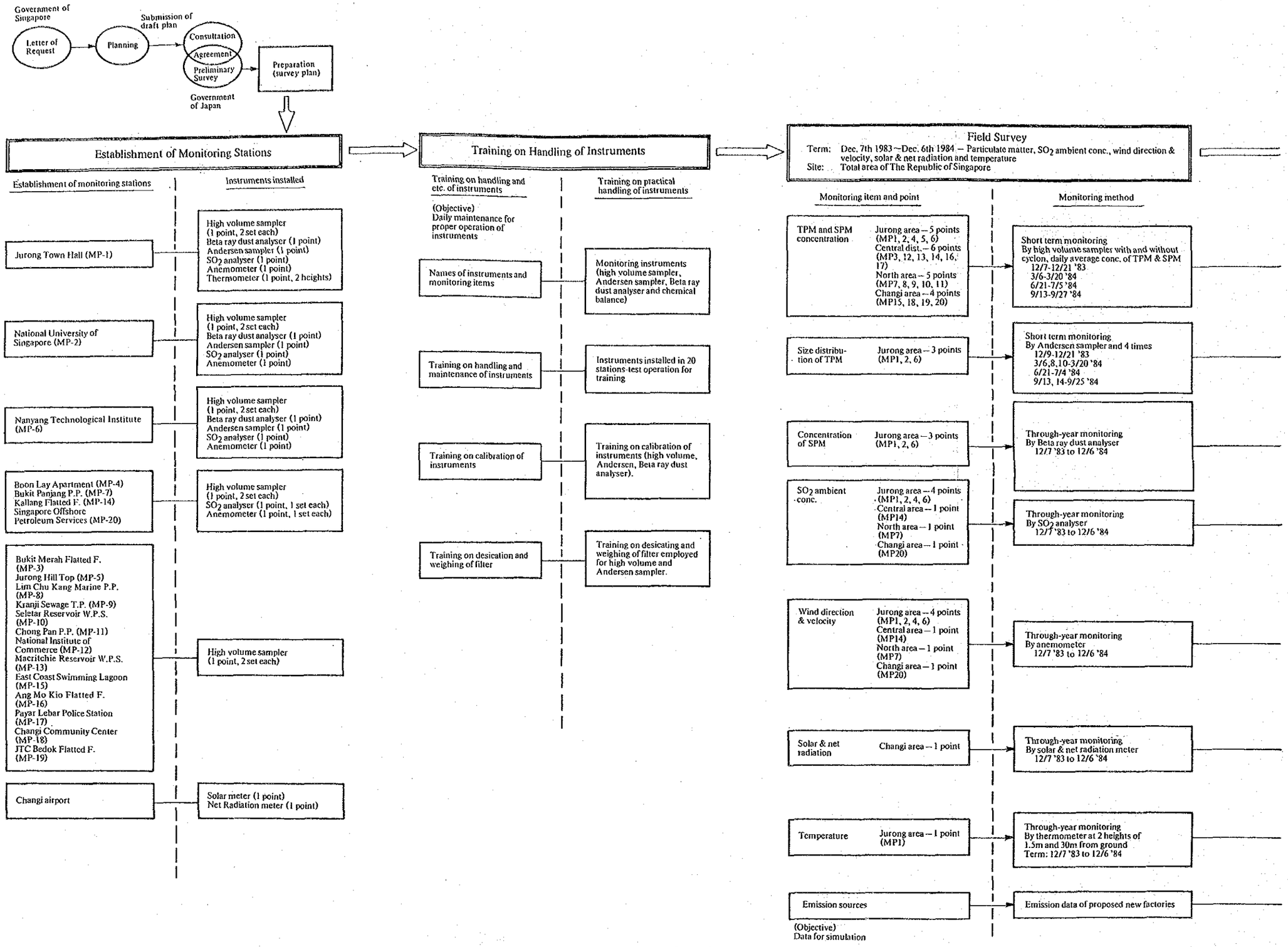


Fig. (I)-1 Flow chart of environmental sutdy

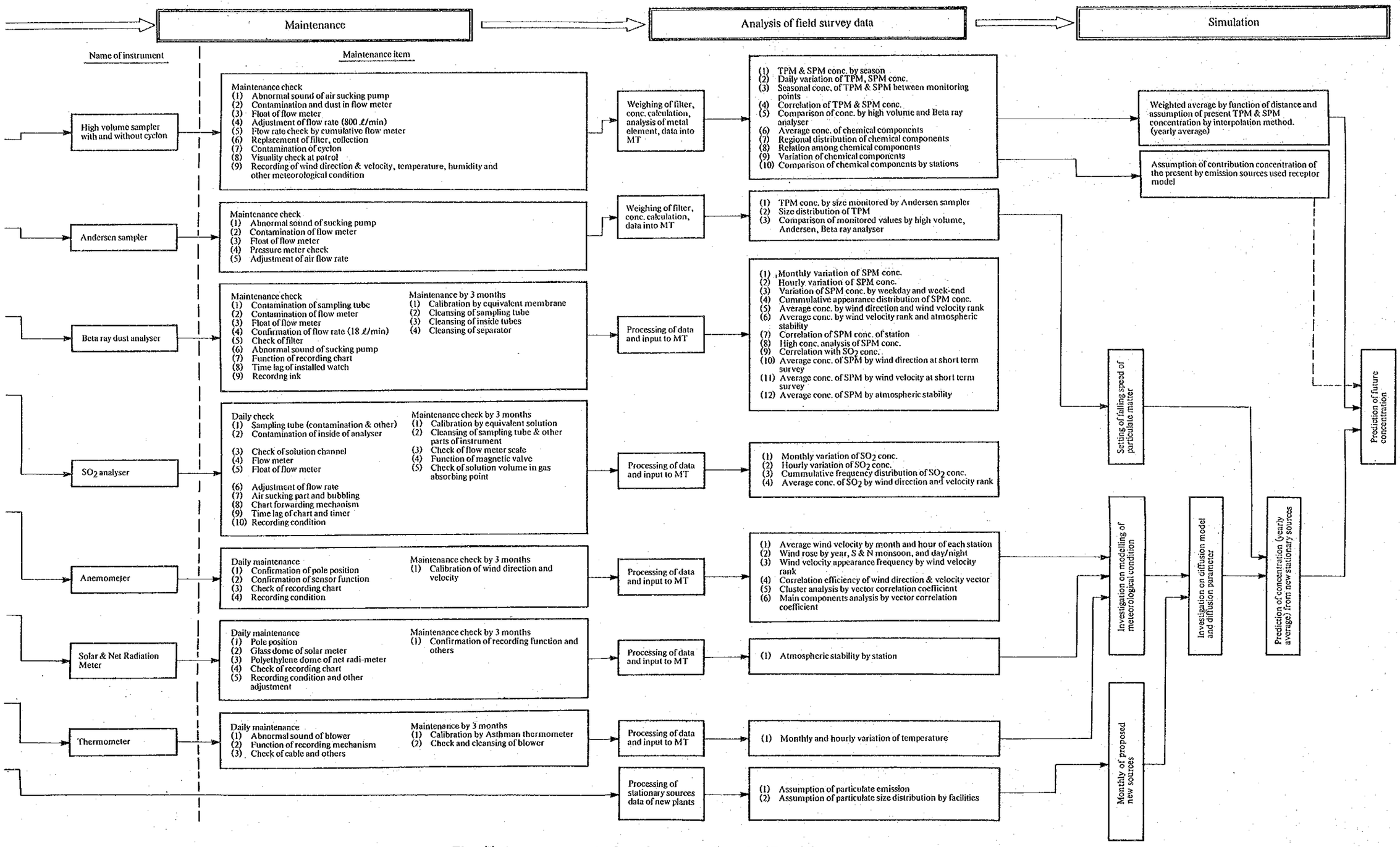


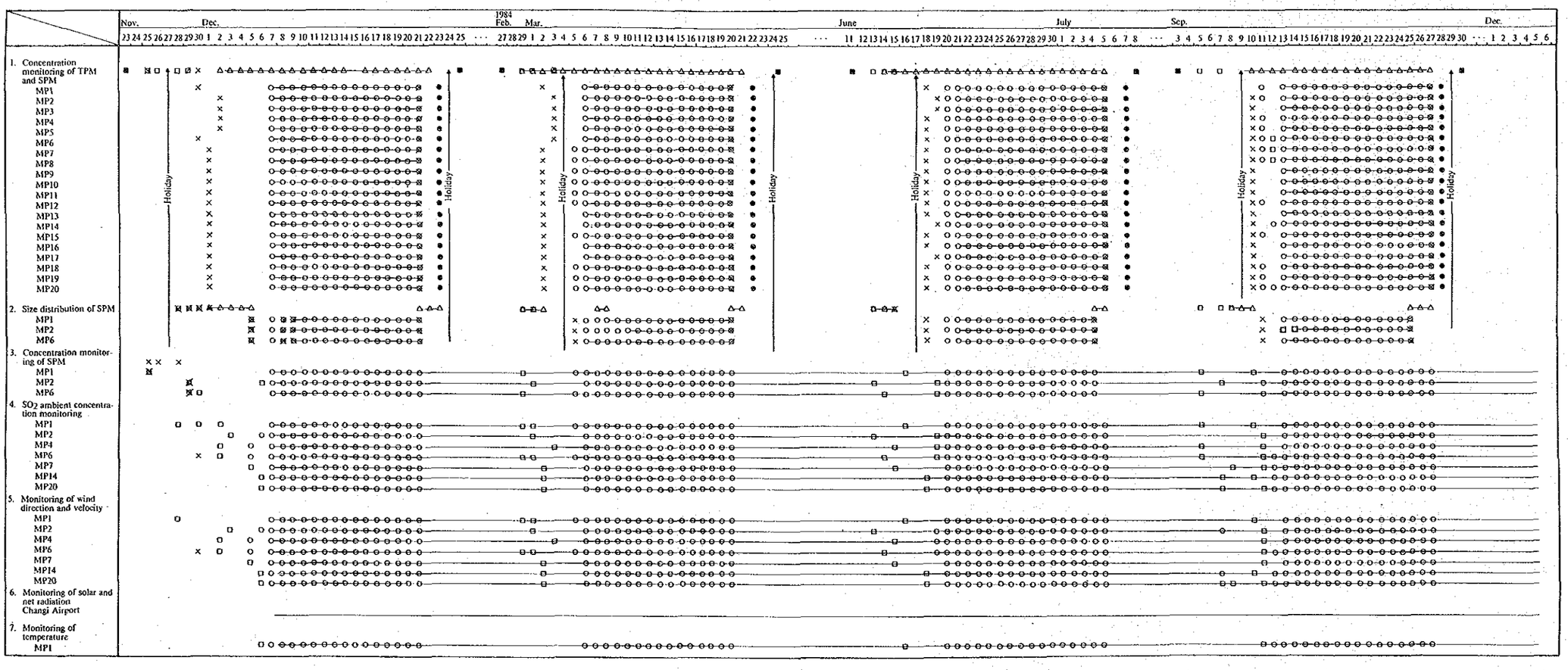
Fig. (I)-1 - Flow chart of environmental sutdy (Cont'd)

Table (I)-1 Outline of field survey

	Survey item	Survey point	Monitoring height	Survey period	Survey method	Training on handling of instruments
Short term survey	1. Monitoring of TPM and SPM concentration	Jurong area Jurong Town Hall (MP-1) 20 m from ground National University of Singapore (MP-2) 27 m from ground Boon Lay Apartment (MP-4) 36 m from ground Jurong Hill Top (MP-5) 15 m from ground Nanyang Technological Institute (MP-6) 1 m from ground Central district Bukit Merah Flatted Factory (MP-3) 27 m from ground National Institute of Commerce (MP-12) 18 m from ground Macritchie Reservoir Pumping Station (MP-13) 1 m from ground Kallang Flatted Factory (MP-14) 18 m from ground Ang Mo Kio Flatted Factory (MP-16) 18 m from ground Paya Lebar Police Station (MP-17) 1 m from ground North district Bukit Panjang Police Post (MP-7) 1 m from ground Lim Chu Kang Marine Police Post (MP-8) 1 m from ground Kranji Sewage Treatment Plant (MP-9) 1 m from ground Seletar Reservoir Pumping Station (MP-10) 1 m from ground Chong Pang Police Post (MP-11) 3 m from ground Changi area East Coast Swimming Lagoon (MP-15) 3 m from ground Changi Community Center (MP-18) 6 m from ground JTC Bedok Flatted Factory (MP-19) 18 m from ground Singapore Offshore Petroleum Services (MP-20) 1 m from ground	Dec. 7-21, 1983 Mar. 6-20, 1984 June 21-July 5, 1984 Sept. 13-27, 1984	High volume samplers were set up at monitoring stations and monitored daily average value. (Initial 12 days monitored TPM & SPM by quartz filter. Remaining 2 days only monitored TPM by polyphlone filter)	Names of instruments' parts. Training on handling, calibration and repairing of instruments
	2. Survey on size distribution of particulate matter	Jurong area Jurong Town Hall (MP-1) 20 m from ground National University of Singapore (MP-2) 27 m from ground Nanyang Technological Institute (MP-6) 1 m from ground		Dec. 9-21, 1983 Mar. 6, 8 and 10-20, 1984 Sept. 13 and 14-25, 1984	Setting up Andersen sampler and monitored average size distribution of 12 days	Names of parts. Training on handling, calibration, measuring principle and repairing of instrument.
	3. Chemical analysis of TPM	Jurong area Jurong Town Hall (MP-1) 20 m from ground National University of Singapore (MP-2) 27 m from ground Boon Lay Apartment (MP-4) 36 m from ground Jurong Hill Top (MP-5) 15 m from ground Nanyang Technological Institute (MP-6) 1 m from ground Central district Bukit Merah Flatted Factory (MP-3) 27 m from ground National Institute of Commerce (MP-12) 18 m from ground Macritchie Reservoir Pumping Station (MP-13) 1 m from ground Kallang Flatted Factory (MP-14) 18 m from ground Ang Mo Kio Flatted Factory (MP-16) 18 m from ground Paya Lebar Police Station (MP-17) 1 m from ground North district Bukit Panjang Police Post (MP-7) 1 m from ground Lim Chu Kang Marine Police Post (MP-8) 1 m from ground Kranji Sewage Treatment Plant (MP-9) 1 m from ground Seletar Reservoir Pumping Station (MP-10) 1 m from ground Chong Pang Police Post (MP-11) 3 m from ground Changi area East Coast Swimming Lagoon (MP-15) 3 m from ground Changi Community Center (MP-18) 6 m from ground JTC Bedok Flatted Factory (MP-19) 18 m from ground Singapore Offshore Petroleum Services (MP-20) 1 m from ground	Collection of TPM for carbon analysis Dec. 14-15, 1983 Mar. 14-15, 1984 June 26-27, 1984 Sept. 20-21, 1984 Collection of TPM for metal element and ion Dec. 19-20, 1983 Mar. 19-20, 1984 July 3-4, 1984 Sept. 25-26, 1984	TPM sampled by high volume sampler brought back Japan for chemical analysis of the components. Chemical analysis on carbon, metal element and ion. Carbon analysis by quartz filter, and other by polyphlone filter.	
Through-year monitoring	4. SPM concentration monitoring	Jurong area Jurong Town Hall (MP-1) 22 m from ground National University of Singapore (MP-2) 24 m from ground Nanyang Technological Institute (MP-6) 2 m from ground		Dec. 7, 1983 - Dec. 6, 1984	Beta ray dust analyser. Monitored continuously one hour average value	Names of parts. Training on handling, calibration, measuring principle and repairing of instrument.
	5. Monitoring SO_2 ambient concentration	Jurong area Jurong Town Hall (MP-1) 20 m from ground National University of Singapore (MP-2) 24 m from ground Boon Lay Apartment (MP-4) 38 m from ground Nanyang Technological Institute (MP-6) 2 m from ground Central district Kallang Flatted Factory (MP-14) 20 m from ground North district Bukit Panjang Police Post (MP-7) 2 m from ground Changi area Singapore Offshore Petroleum Services (MP-20) 2 m from ground		Dec. 7, 1983 - Dec. 6, 1984	SO_2 analyser based on solution conductivity method. Monitored one hour average value continuously	Training on calibration by equivalent solution, and maintenance
	6. Monitoring of wind direction and velocity	Jurong area Jurong Town Hall (MP-1) 30 m from ground National University of Singapore (MP-2) 30 m from ground Boon Lay Apartment (MP-4) 44 m from ground Nanyang Technological Institute (MP-6) 10 m from ground Central district Kallang Flatted Factory (MP-14) 28 m from ground North district Bukit Panjang Police Post (MP-7) 10 m from ground Changi area Singapore Offshore Petroleum Services (MP-20) 10 m from ground		Dec. 7, 1983 - Dec. 6, 1984	By propeller type anemometer, continuous monitoring of 10 minutes average of wind direction and velocity.	Training on calibration and maintenance of instrument
	7. Monitoring solar and net radiation	Changi area Changi Airport	1.5 m from ground	Dec. 7, 1983 - Dec. 6, 1984	Continuous monitoring of 1 hour average values by solar meter and differential type net radiation meter.	Training on calibration and maintenance of instrument
	8. Monitoring of temperature	Jurong area Jurong Town Hall (MP-1)	1.5 m from ground 30 m from ground	Dec. 7, 1983 - Dec. 6, 1984	Nickel resistance thermometer, continuous monitoring of instantaneous value.	Training on calibration and maintenance of instrument

Table (I)-2 Time schedule of field survey

— : Monitoring period
△ : Desicating and weighing of filter
◎ : Training on handling and maintenance of instruments
× : Setting up and withdrawal of instruments
□ : Calibration and adjustment of instruments
○ : Checking of instruments and replacement of filter
■ : Travelling day
● : Calculation of particulate concentration

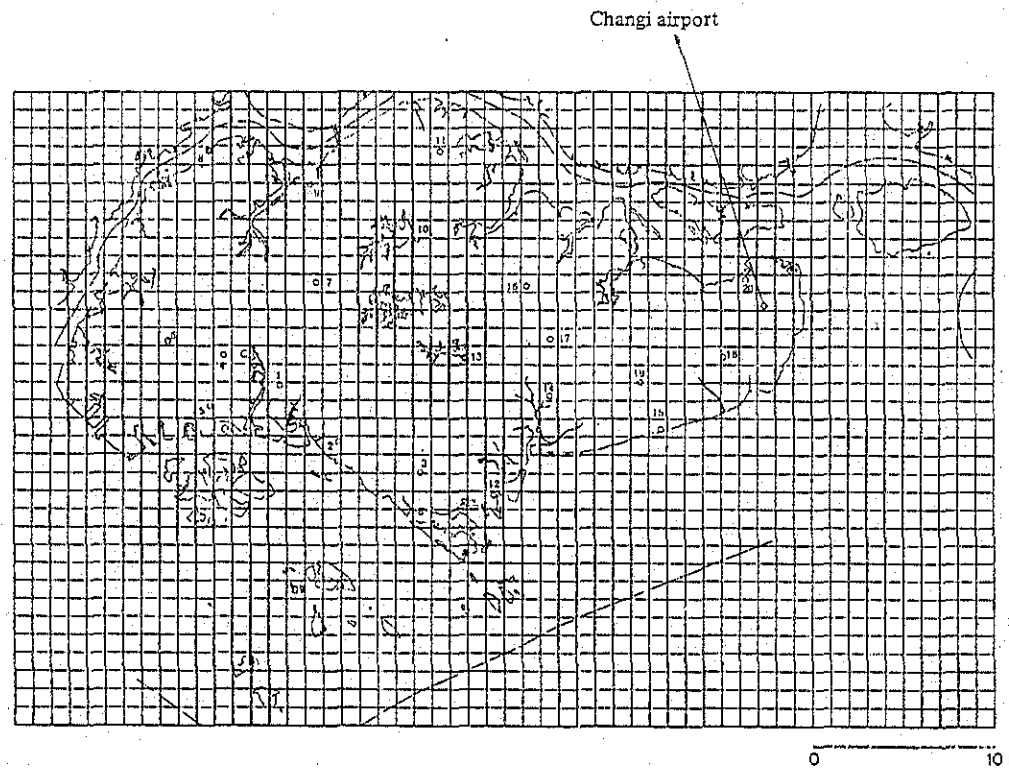


(II) Summary of Field Survey

The field survey is consisted of (1) short term field survey to monitor the particulate matter at as many points as possible for identifying the concentration distribution of the particulate matter in the object area, and (2) long term field survey to monitor variation of the particulate concentration in comparatively long term.

In the short term field survey, monitoring has been conducted for 14 days each of 4 times a year (December 1983, March-June-September 1984). At 20 monitoring stations shown in Fig. (II)-1, total particulate matter (TPM) and suspended particulate matter (SPM) have been monitored by high volume sampler in terms of daily average values. And at MP-1, 2 and 6, the monitoring of size distribution of the particulate matter has been conducted by Andersen sampler (average value of 12 days).

Besides the above, chemical components (33 elements, anion, elemental carbon and organic carbon) have been analyzed in Japan by the samples collected TPM for each one day of each field survey. (20 points x 4 field survey)



MP1	Jurong Town Hall
MP2	National University of Singapore
MP3	Bukit Merah Flatted Factory Block 1
MP4	Boon Lay Apartment Block 200
MP5	Jurong Hill Top Restaurant
MP6	Nanyang Technological Institute
MP7	Bukit Panjang Police Post
MP8	Lim Chu Kang Marine Police Post
MP9	Kranji Sewage Treatment Plant
MP10	Seletar Reservoir Water Pumping Station
MP11	Chong Pang Police Post
MP12	National Institute of Commerce
MP13	Macritchie Reservoir Water Pumping Station
MP14	Kallang Flatted Factory Block 3
MP15	East Coast Swimming Lagoon
MP16	Ang Mo Kio Flatted Factory Block 5001
MP17	Paya Lebar Police Station
MP18	Changi Community Center, 16 km Changi Road
MP19	JTC Bedok Flatted Factory
MP20	Singapore Offshore Petroleum Services

Fig. (II)-1 Monitoring stations for TPM, SPM at short term field survey

In the long term field survey, monitoring of SPM, SO_2, wind direction & velocity, solar & net radiation and temperature have been conducted for one year from December 7th 1983 to December 6th 1984, each in terms of the hour average values. Table (II)-1 shows monitoring items in each monitoring station.

Table (II)-1 Monitoring items by stations

Monitoring point	Monitored item	Monitored period	Monitoring method
MP-1 to 20	TPM	Each 14 days 1st-4th field survey	Daily average by high volume sampler
	SPM	Each 12 days 1st-4th field survey	Daily average by high volume sampler with cyclon
	Metal element, negative ion, carbon	Each 1 day of 1st-4th field survey	Neutron activation, X-ray fluorescence, ion-chromatography, differential thermal
MP-1, 2 & 6	Size distribution of TPM	Each 12 days 1st-4th field survey	12 days average by Andersen sampler
	SPM	12/7 '83 to 12/6 '84	One hour average by Beta ray analyser
MP-1, 2, 4, 6, 7, 14 & 20	SO_2	- ditto -	One hour average by SO_2 analyser
	Wind direction & velocity	- ditto -	10 min. trans. average by anemometer
MP-1	Temperature	- ditto -	Thermometer at 2 heights
Changi airport observatory	Solar & net radiation	- ditto -	One hour average by solar & net radiation meter

(II)-1 Summary of Short Term Field Survey Results

(1) TPM and SPM concentration by high volume sampler

Table (II)-2 and Fig. (II)-2 show seasonal average concentration of TPM and SPM monitored by high volume sampler. From the survey results, concentration at MP-7 (Bukit Panjang Police Post) and MP-17 (Paya Lebar Police Station) are found high compared with other stations. The results are suggesting that these two stations are located near to main road side of heavy traffic and they are influenced by automobile emission gas and particulates winded up by the traffic. No remarkable difference can be seen in the concentration of other 18 stations.

When the concentration is compared by each field survey of 1st to 4th, the higher concentration is indicated at the monitoring points located in the south and south/west areas (MP-1, 2, 3, 4, 5, 6, 12, 13 and 14) at the 2nd field survey.

As shown in Fig. (II)-3, wind rose of the 1st is NNE, 2nd is NE and SW sharing, 3rd is SE and 4th has no dominant direction. When the relation between concentration and wind direction is investigated, no correlation can be found with Jurong industrial district. So the reason why higher concentrations are shown in the south and south/west areas at the 2nd field survey is considered to be mainly depending on natural backgrounds such as soil and sea salt particles together with the secondary particles reacted from the gaseous substances. These are widely dispersed and considered to contribute much more than particulate from the industrial activities.

The ratio between SPM and TPM is found not constant and different by stations and monitoring date, and they are deviating in the range of 30 to 70%. It means contributing sources are quite different by monitoring stations and date, because the size distribution of the particulate is different by sources.

Table (II)-2 Seasonal average concentration of TPM and SPM monitored by high volume sampler

Monitoring stations	TPM ($\mu g/m^3$)					SPM ($\mu g/m^3$)				
	1st survey	2nd survey	3rd survey	4th survey	Average	1st survey	2nd survey	3rd survey	4th survey	Average
MP 1	60.3	99.3	51.9	62.9	68.6	28.5	47.0	25.4	34.6	33.9
MP 2	54.9	64.4	51.0	42.4	53.2	34.9	31.3	25.8	26.1	29.5
MP 3	52.7	79.8	60.6	73.8	66.7	28.0	42.6	21.7	33.0	31.3
MP 4	79.7	91.5	65.0	60.5	74.2	40.4	52.1	29.6	36.0	39.5
MP 5	78.5	95.4	67.0	72.0	78.2	41.8	43.2	21.7	31.1	34.5
MP 6	54.1	86.9	67.7	57.0	66.4	33.2	44.8	28.9	27.0	33.5
MP 7	102.2	144.2	145.8	146.2	134.6	51.1	63.6	55.4	51.8	55.5
MP 8	43.0	77.0	91.8	67.1	69.7	29.3	39.0	42.8	34.6	36.4
MP 9	49.0	90.8	101.9	91.3	83.3	26.8	47.5	42.1	43.0	39.9
MP10	50.5	65.3	54.2	45.9	54.0	28.0	33.1	28.4	22.6	28.0
MP11	55.1	81.2	97.1	78.1	77.9	33.3	39.6	49.0	39.4	40.3
MP12	61.7	96.8	56.6	60.9	69.0	27.3	34.6	20.5	27.0	27.4
MP13	40.2	75.5	58.6	55.7	57.5	21.1	39.9	27.9	31.9	30.2
MP14	52.9	74.4	63.0	62.9	63.3	25.6	41.7	31.1	34.7	33.3
MP15	39.8	56.1	37.8	44.9	44.7	20.1	28.9	16.2	23.6	22.2
MP16	44.5	83.1	85.4	76.3	72.3	20.5	43.0	34.7	37.9	34.0
MP17	103.2	120.1	67.2	81.7	93.1	39.5	53.6	36.7	41.3	42.8
MP18	56.7	63.9	59.4	73.8	63.5	31.1	30.1	27.3	41.0	32.4
MP19	67.8	61.7	59.0	61.7	62.6	32.5	29.9	29.5	31.1	30.8
MP20	41.5	54.1	81.9	76.1	63.4	17.0	24.0	24.3	32.5	24.5

Remarks: concentration is average value of 12 days

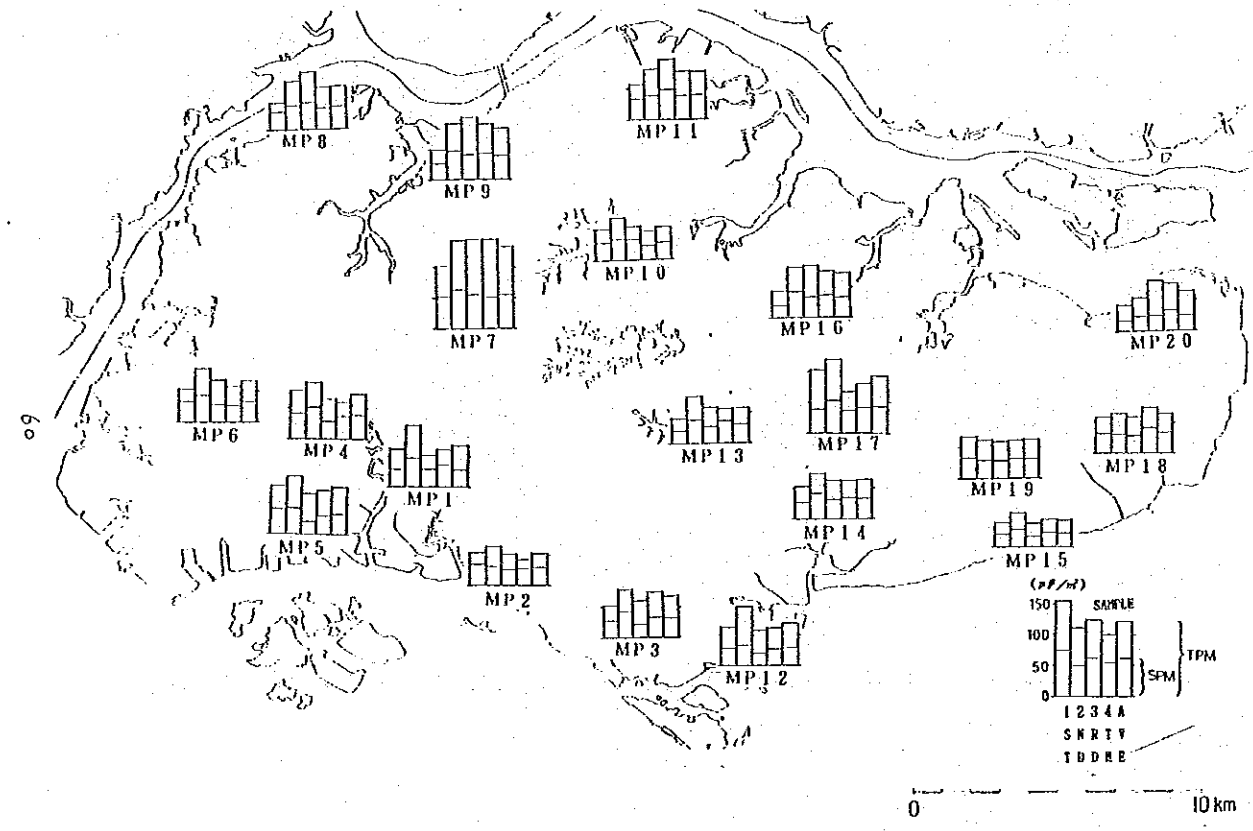


Fig. (II)-2 Seasonal average concentration of TPM and SPM monitored by high volume sampler

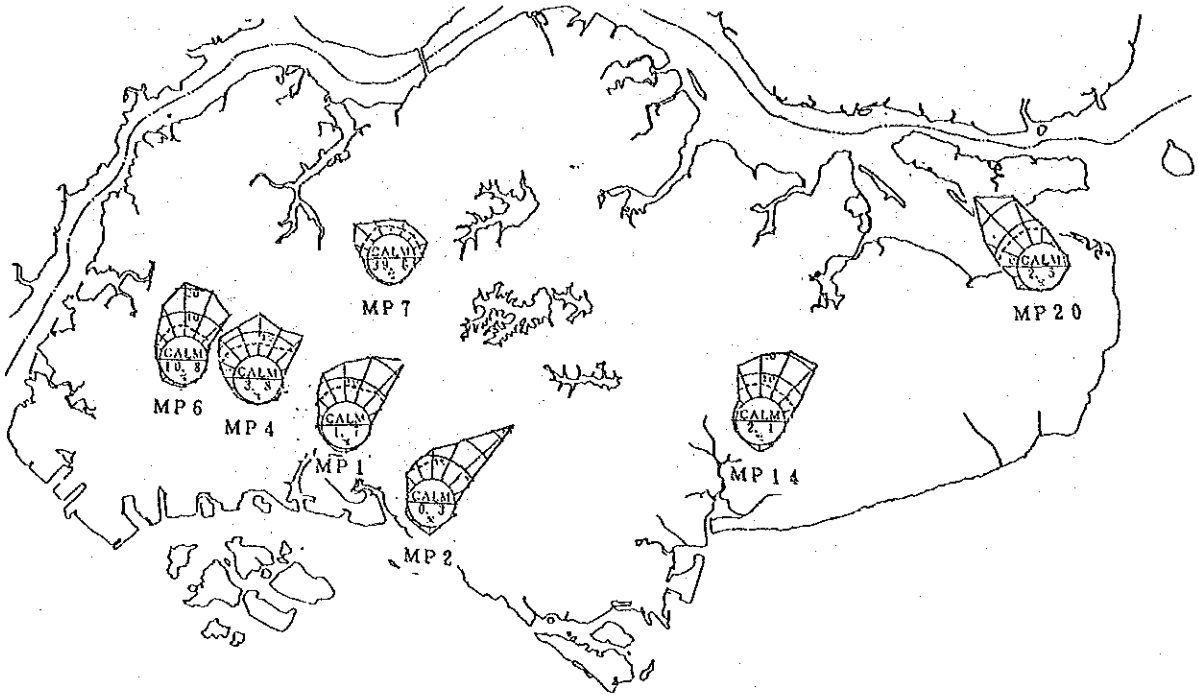


Fig. (II)-3-(1) Wind rose of short term field survey (1st field survey)

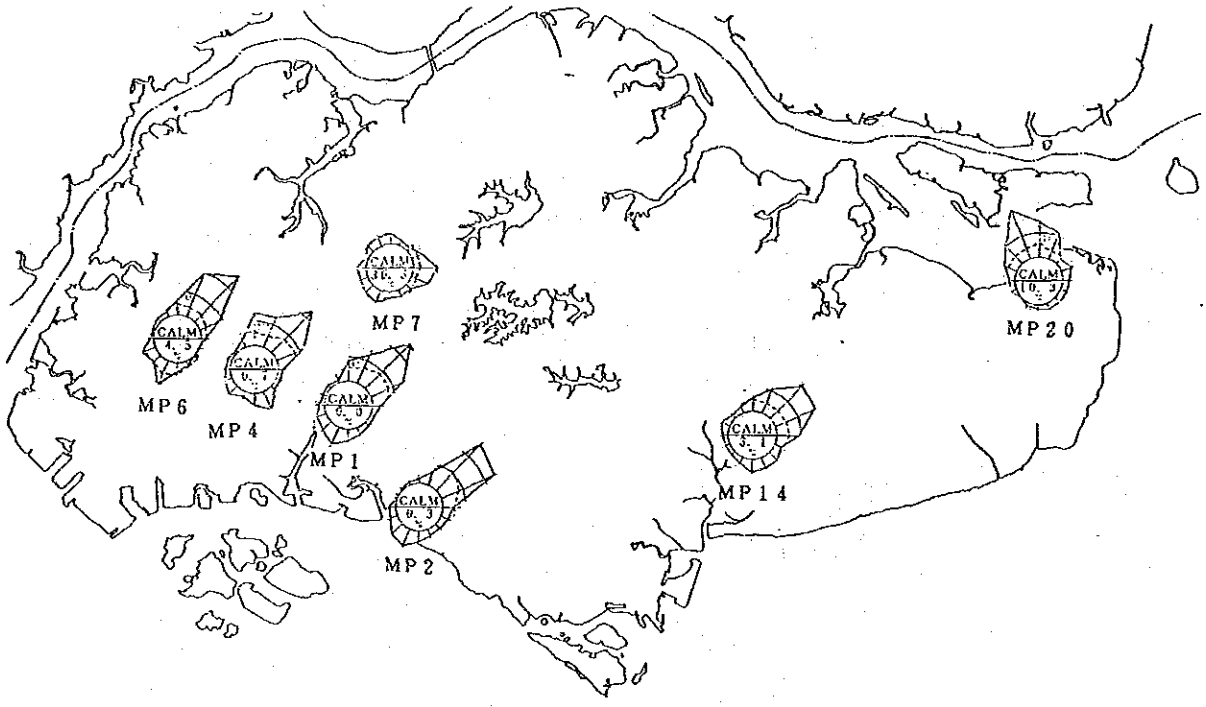


Fig. (II)-3-(2) Wind rose of short term field survey (2nd field survey)

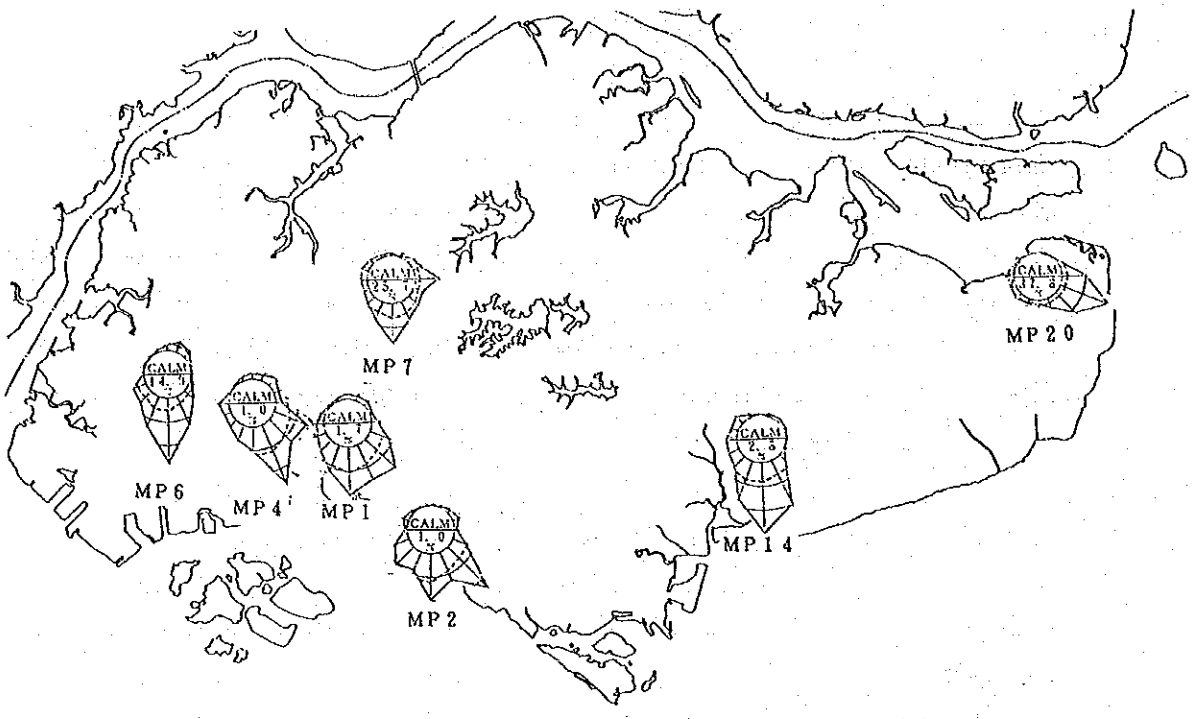


Fig. (II)-3-(3) Wind rose of short term field survey (3rd field survey)

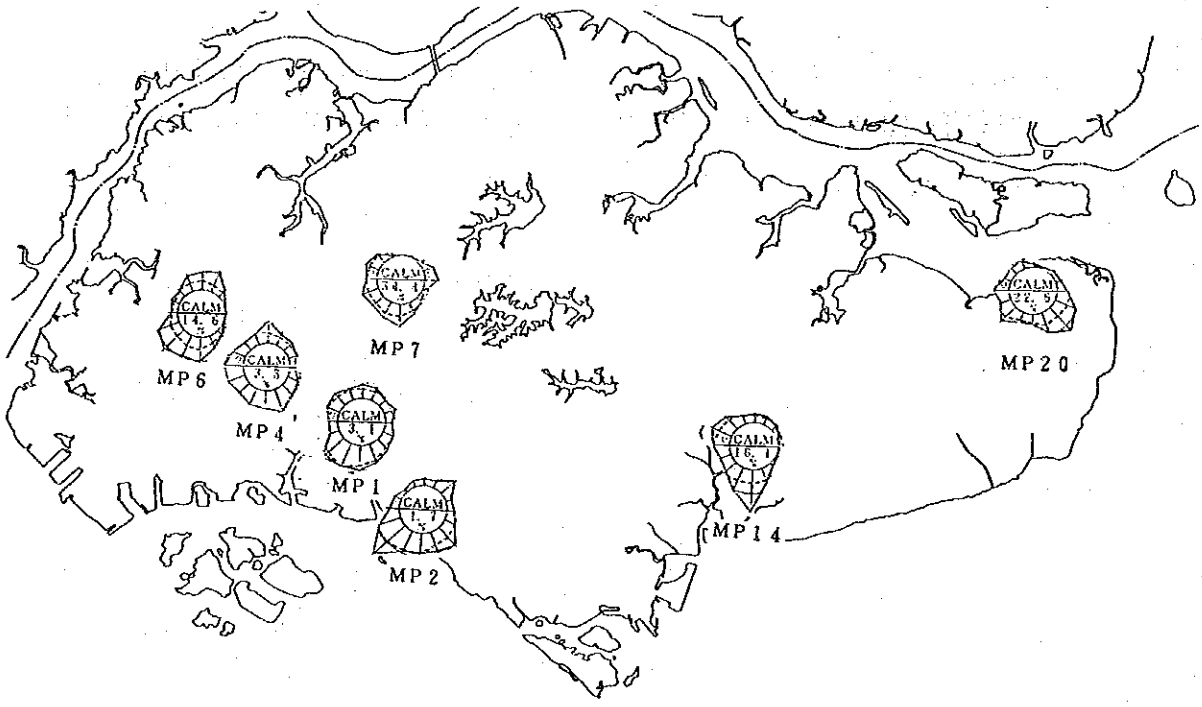


Fig. (II)-3-(4) Wind rose of short term field survey (4th field survey)

(2) Size distribution of TPM by Andersen sampler

Table (II)-3 and Fig. (II)-4 show concentration of the particulate matter by size monitored at MP-1, 2, and 6 (average of 12 days). From these results, particles under 2.1 microns (fine particles) are 60%, particles between 2.1 to 11 microns (coarse particles) are 30%, and the remaining 10% is particles over 11 microns. The size distribution of the particles shows in most cases the peaks at 0.4 micron and 4 microns. And at around 1 micron, the bottom is found. These 2 mountains type distribution of the particles are quite similar to the results of monitoring conducted in many countries including Japan.

In general, coarse particles larger than 2 microns are originated from natural background (soil winded, sea salt, volcano ash, botanical seeds and so on) and man-made sources (particulate from mechanical processes, particulate winded up by traffic, combustion facilities). Fine particles smaller than 2 microns are considered to be originated from man-made sources (combustion facilities, internal combustion engines and so on) and secondary particles reacted chemically from the gaseous substances in the ambient.

Judging from these facts, the particulate matter contributing to the concentration at each monitoring station is mainly from natural background.

Table (II)-3 TPM concentration by particle size monitored by Andersen sampler

(unit; $\mu g/m^3$)

Particulate size			1st survey			2nd survey			3rd survey			4th survey		
Classify	Stage	Rank (μm)	MP1	MP2	MP6	MP1	MP2	MP6	MP1	MP2	MP6	MP1	MP2	MP6
Coarse	0	11 -	4.63	1.90	2.29	4.94	2.68	4.35	3.31	1.79	4.66	3.78	2.12	3.61
	1	7.0 - 11	2.34	1.12	1.14	1.72	1.55	1.88	2.09	1.30	2.27	1.58	0.79	1.39
	2	4.7 - 7.0	4.01	1.82	2.70	3.09	2.73	3.34	3.75	2.67	4.20	3.01	2.28	2.54
	3	3.3 - 4.7	3.60	2.84	4.54	5.82	2.35	6.22	3.53	4.81	6.72	5.09	2.07	4.36
	4	2.1 - 3.3	2.34	2.16	2.59	4.33	3.92	4.25	5.11	3.59	4.90	3.80	3.56	3.35
Fine	5	1.1 - 2.1	5.08	2.33	2.78	3.50	2.84	4.88	3.25	2.52	3.71	3.85	2.65	3.42
	6	0.65 - 1.1	1.75	2.94	2.66	2.25	1.29	2.78	1.08	1.18	2.04	2.84	1.37	2.26
	7	0.43 - 0.65	0.93	3.16	4.00	5.34	1.86	7.36	2.27	3.51	5.50	4.37	1.26	5.32
	8	- 0.43	15.29	11.09	10.46	18.39	20.39	17.54	15.91	10.95	13.74	16.99	15.70	12.83
Total			40.0	29.4	33.2	49.4	39.6	52.6	40.3	32.3	47.8	45.3	31.8	39.1

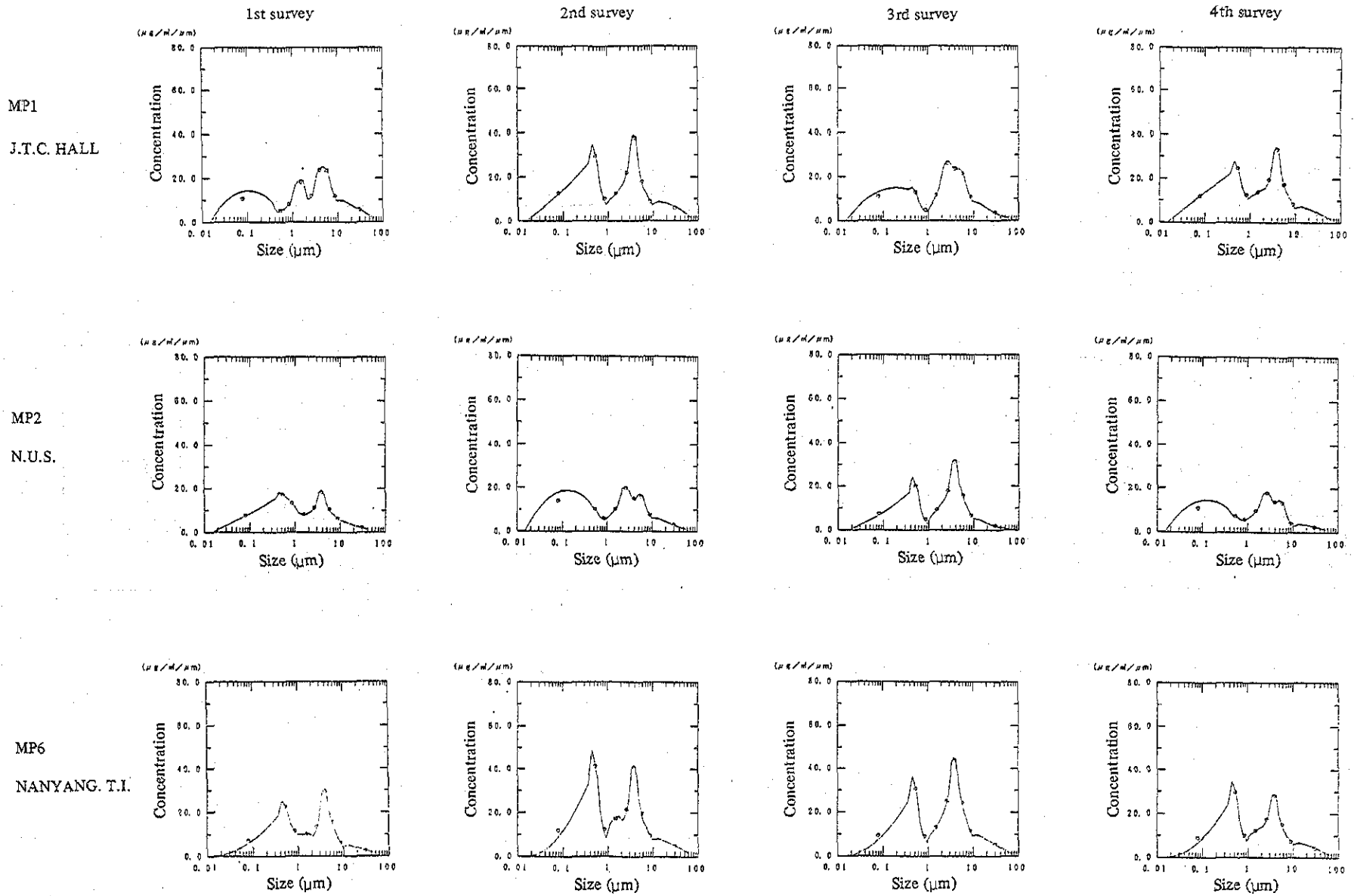


Fig. (II)-4 Size distribution of TPM monitored by Andersen sampler

(3) Chemical components contained in particulate matter

Table (II)-4 shows the results of analysis of 33 metal elements, anion, elemental carbon and organic carbon by neutron activation method, X-ray fluorescence analysis, ion chromatography analysis and differential thermal analysis from the samples collected each one day of 4 times short term field survey by high volume samplers.

From the results, sequence order of concentration of chemical components are found as; C, Si, Cl, SO_4^{2-}, Cl^-, Al - which means the concentration of soil, sea salt particle, secondary particles are comparatively found higher.

Table (II)-5 shows the average concentration of chemical components at the time of 1st to 4th field survey for each monitoring stations.

Characteristics of the regional distribution of chemical components as considered to be main emission sources of the particulate matter are described hereunder.

① Sc, Al, Ti

Concentration of Sc, Al and Ti (soil related substances) is found higher in the north and north/east part of Singapore rather than central urban area. In other areas, concentration level of these substances are in the same level, except MP-7 where abnormally high concentration is monitored due to the heavy traffic.

② Na, Cl, Cl^-

Na, Cl and Cl^- are originated from the sea salt and at monitoring points located near to the coast, higher concentration are monitored. At inland stations such as MP-10 and MP-13, comparatively low concentration is measured.

③ SO_4^{2-}, NO_3^-

Concentration of SO_4^{2-} and NO_3^- which are originated from chemical reaction in the ambient as secondary particles are found comparatively equal throughout the island and this tendency is more remarkable in the case of NO_3^-. Reaction speed from SO_2 to SO_4^{2-} and NO to NO_3^- are not so large. So SO_2 and NO emitted from the sources of far away are diffused and reacted, and it is considered that total Singapore is covered by the same level concentration of these substances.

④ Pb, Br

Higher concentration points of Pb and Br are MP-7, 13, and 17. These points are all located near to the heavy traffic roads and they are considered to be influenced by emission gas from automobiles.

⑤ Organic carbon

Higher concentration points of organic carbon are MP-7, 9, 11 and 17. These points are considered to be influenced by diesel emission gas.

⑥ Ca

Ca is usually originated from road dust and cement concretes. MP-5 and 7 are monitored comparatively high in concentration.

⑦ V

The monitoring points high in concentration of V originated from fossil fuel combustion are MP-1, 4 and 5. In the remaining 17 stations, the concentration level is almost same but the stations located in the east part of island, it is found low.

⑧ Zn, K

The regional distribution of Zn and K originated from waste incineration plant is not found remarkably.

⑨ Mn

Mn is found in high concentration at MP-5. It is considered MP-5 is influenced by the steel mill located in south side.

Table (II)-4 Average concentration of chemical components of particulate matter (average values of MP-1 to MP-20)

Method of analysis		Components	Unit	1st survey		2nd survey		3rd survey		4th survey		Average of four surveys	
				Average	Geometric mean	Average	Geometric mean	Average	Geometric mean	Average	Geometric mean	Average	Geometric mean
Element	Instrument activation analysis	Ag	ng/m³	0.064*	0.063*	0.406*	0.185*	0.143*	0.068*	0.105*	0.071*	0.179*	0.087*
		Al		1665.000	1290.242	2706.000	2113.726	1578.540	841.269	2619.500	1646.097	2142.260	1394.048
		As		6.716	3.318	7.639	4.661	4.263	1.198	6.390	1.362	6.252	2.241
		Ba		15.790*	5.248*	17.200*	7.264*	41.005*	5.197*	27.140*	8.793*	25.284*	6.460*
		Br		85.600	65.144	107.500	93.439	102.050	68.936	99.400	83.389	98.637	76.911
		Ca		1157.000	869.544	2470.500	1871.759	1656.000	844.169	2603.000	1272.344	1971.625	1149.857
		Cd		6.350*	4.327*	5.350*	3.691*	5.050*	3.716*	5.750*	4.295*	5.625*	3.996*
		Ce		1.505	1.069	2.392	2.036	1.607	1.253	1.862	1.368	1.842	1.390
		Cl		4740.000	4643.021	1956.500	1868.831	2995.000	2886.449	3990.000	3828.132	3420.375	3129.179
		Co		0.244	0.130	0.505	0.292	0.316	0.190	1.136	0.283	0.550	0.212
		Cr		4.132	2.382	7.043	5.400	6.159	3.769	7.553	4.155	6.222	3.767
		Cs		0.090*	0.037*	0.097*	0.038*	0.078*	0.029*	0.096*	0.033*	0.090*	0.034*
		Cu		53.750	30.158	109.250	89.671	48.900	29.865	46.150	26.662	64.513	38.307
		Fe		637.500	514.703	1408.000	1087.710	1027.750	639.193	1097.000	749.846	1042.563	719.728
		Hf		0.087	0.038	0.158	0.084	0.083	0.047	0.140	0.054	0.117	0.053
		K		273.500*	130.053*	871.000*	359.946*	475.500	254.822	578.000*	283.667*	549.500*	241.185*
		La		0.325*	0.137*	1.005	0.522	0.568*	0.242*	0.688*	0.247*	0.646*	0.256*
		Lu		0.008*	0.003*	0.011*	0.006*	0.003*	0.002*	0.009*	0.004*	0.008*	0.003*
		Mn		11.805	10.295	34.170	23.730	25.560	13.225	17.705	10.475	22.310	13.564
		Na		1155.000	737.237	1278.500	1104.422	1538.000	1410.670	1999.000	1911.196	1492.625	1217.218
		Ni		9.080*	4.456*	8.890*	5.225*	4.235*	2.007*	9.420*	3.356*	7.906*	3.539*
		Sb		1.803	0.720	3.704	2.151	1.602	0.987	4.291	1.218	2.850	1.168
		Sc		0.182	0.134	0.347	0.264	0.201	0.134	0.318	0.202	0.262	0.176
		Se		0.992	0.525	1.680	1.111	0.436	0.222	1.119	0.951	1.057	0.593
		Sm		0.108	0.067	0.161	0.120	0.088	0.049	0.091	0.041	0.112	0.063
		Th		0.411	0.310	0.612	0.497	0.356	0.259	0.588	0.357	0.492	0.345
		Ti		83.600	42.298	134.500	100.510	97.050	47.248	87.900	33.547	100.763	50.950
		V		20.319	11.018	29.450	27.306	14.405	10.694	12.820	8.519	19.248	12.867
		W		0.589*	0.262*	2.478	1.081	1.307*	0.375*	0.976*	0.279*	1.337*	0.415*
		Zn		57.350	46.025	136.850	98.901	94.625	50.753	78.750	57.032	91.894	60.248
	X-ray flouren-scense	Cd	ng/m³	2.455	1.428	3.180	1.785	3.215	1.685	4.430	2.959	3.320	1.888
		Pb		190.350	89.664	297.250	265.000	244.800	164.766	199.600	101.857	233.000	141.313
		S		1101.500	1019.757	1746.500	1509.244	1253.000	1123.554	1690.000	1465.435	1447.750	1261.694
		Si		7045.000	5186.411	9240.000	7652.980	9762.500	7072.121	13755.000	10224.695	9950.625	7319.381
	Ion chromata-graphy	Cl^-	ng/m³	3310.000	3246.189	1313.000	1236.319	1858.000	1740.169	2825.500	2669.715	2326.625	2077.974
		NO_3^-		530.000	508.918	1649.000	1581.170	666.050	641.654	1457.000	1426.940	1075.512	926.474
		SO_4^{--}		2570.000	2329.472	4515.000	4267.527	1965.000	1812.632	3200.000	2907.022	3062.500	2690.283
	TPM	TPM	μg/m³	48.545	44.033	73.210	67.812	54.410	49.930	90.255	82.711	66.605	59.259
Carbon	Differential thermal analysis	Elemental C	μg/m³	12.345	11.440	18.840	17.323	10.615	8.961	16.095	15.605	14.474	12.903
		Organic C		*4.020*	*3.656*	*4.480*	*3.800*	*3.585*	*2.782*	*5.325*	*4.795*	*4.352*	*3.690*
		Total C		16.365	15.130	23.320	21.274	14.200	11.915	21.420	20.528	18.826	16.751
	TPM	TPM		73.570	70.278	88.745	84.091	70.770	65.735	75.740	72.570	77.206	72.867

Note: (1) 1/10 of value was adopted for averaging with data below detection limit.
(2) * marked when data over 50% are found below detection limit.

Table (II)-5 Average concentration of chemical components (average of 1st to 4th field survey)

	INAA (ng/m³)																	
	Ag	Aℓ	As	Ba	Br	Ca	Cd	Ce	Cℓ	Co	Cr	Cs	Cu	Fe	Hf	K	La	Lu	Mn
MP1	0.05	1353.	9.35	13.	71.	1640.	4.	1.81	3950.	0.35	8.67	0.039	36.	753.	0.119	415.	0.51	0.007	18.2
MP2	0.04	830.	1.08	1.	56.	1268.	3.	0.82	3550.	0.26	1.55	0.022	44.	393.	0.067	158.	0.35	0.001	6.9
MP3	0.16	1093.	1.46	2.	74.	1160.	13.	1.21	3350.	0.29	2.84	0.074	54.	520.	0.068	358.	0.26	0.007	9.0
MP4	0.43	1780.	12.77	21.	79.	2775.	10.	1.85	3650.	0.45	8.35	0.124	34.	1038.	0.089	815.	0.29	0.007	30.0
MP5	0.17	1500.	7.45	13.	71.	4290.	4.	1.63	4650.	0.55	7.70	0.102	88.	1790.	0.058	1213.	0.07	0.005	55.1
MP6	0.06	2123.	12.95	45.	33.	2500.	4.	1.85	3525.	0.51	9.02	0.057	77.	945.	0.134	515.	0.57	0.010	23.6
MP7	0.14	9025.	15.00	22.	268.	4100.	5.	4.60	3400.	0.96	13.80	0.360	106.	3550.	0.355	1198.	1.14	0.024	50.0
MP8	0.25	3193.	11.10	41.	56.	1225.	4.	2.16	3200.	0.35	7.32	0.151	126.	1643.	0.195	955.	1.42	0.010	25.2
MP9	0.06	3393.	15.72	17.	96.	813.	11.	2.48	2950.	0.23	8.25	0.246	77.	1078.	0.140	1023.	0.92	0.009	22.8
MP10	0.06	1273.	3.45	14.	61.	935.	3.	1.14	1758.	0.05	2.17	0.091	89.	563.	0.036	468.	0.32	0.005	11.6
MP11	0.06	3500.	4.88	2.	111.	1633.	4.	3.45	2700.	0.30	4.05	0.137	85.	1305.	0.175	675.	1.88	0.012	19.5
MP12	0.42	1573.	4.92	19.	94.	2275.	4.	1.68	4350.	0.41	6.52	0.032	36.	1025.	0.086	515.	0.56	0.014	24.5
MP13	0.19	1013.	2.12	6.	231.	653.	4.	0.78	2400.	0.10	3.05	0.036	32.	545.	0.066	75.	0.07	0.005	9.2
MP14	0.68	1248.	3.60	14.	88.	1325.	4.	1.51	3700.	0.37	5.35	0.011	56.	633.	0.104	305.	0.80	0.004	13.1
MP15	0.26	843.	3.56	6.	38.	723.	12.	0.97	4825.	0.29	2.53	0.019	45.	341.	0.046	333.	0.07	0.005	9.8
MP16	0.29	2193.	4.92	3.	93.	1588.	4.	1.95	3400.	0.50	7.95	0.028	45.	1010.	0.055	73.	0.58	0.007	20.3
MP17	0.06	2200.	4.60	2.	220.	1270.	14.	1.80	2800.	0.19	5.32	0.071	120.	943.	0.171	388.	0.72	0.120	15.1
MP18	0.05	928.	0.51	15.	78.	640.	3.	0.80	3325.	0.13	1.50	0.029	43.	385.	0.027	475.	0.06	0.001	5.8
MP19	0.06	1465.	3.98	15.	86.	2673.	3.	1.78	3675.	0.43	7.80	0.046	49.	1493.	0.079	478.	1.14	0.002	53.4
MP20	0.06	2325.	1.59	236.	73.	5950.	3.	2.57	3250.	4.27	10.67	0.127	52.	903.	0.275	560.	1.18	0.007	23.0

	INAA (ng/m³)								XRF (ng/m³)						ICA (ng/m³)			TPM
	Na	Ni	Sb	Sc	Se	Sm	Th	Ti	V	W	Zn	Cd	Pb	S	Si	Cℓ⁻	NO_3^-	SO_4^{--}	(μg/m³)
MP1	1615.	14.2	1.35	0.205	1.16	0.116	0.322	71.	27.90	1.6	74.	2.3	157.	1350.	7800.	2725.	1183.	3100.	55.6
MP2	1625.	8.6	0.31	0.099	0.41	0.041	0.154	24.	18.15	0.4	31.	3.0	159.	1108.	3925.	2450.	915.	2200.	32.6
MP3	1630.	6.6	0.62	0.133	0.40	0.057	0.217	26.	18.85	0.1	34.	1.9	115.	1078.	6375.	2400.	838.	2150.	55.3
MP4	2000.	9.5	1.70	0.217	0.89	0.128	0.515	123.	41.25	2.1	105.	5.3	151.	2025.	9425.	2550.	1130.	4275.	76.6
MP5	2325.	18.0	2.47	0.195	1.44	0.101	0.342	107.	43.25	1.2	222.	6.1	163.	3075.	8525.	3275.	1345.	6025.	79.9
MP6	1258.	4.5	2.41	0.250	1.27	0.129	0.372	77.	18.75	2.0	123.	3.3	103.	1835.	10425.	2225.	1313.	3550.	60.0
MP7	1135.	6.5	5.15	1.358	1.22	0.300	1.487	393.	27.00	1.4	150.	5.1	585.	2300.	35250.	2525.	1170.	3750.	153.2
MP8	1575.	6.3	2.74	0.351	2.47	0.127	0.655	101.	17.82	1.4	116.	5.8	159.	1668.	12825.	2000.	1220.	3275.	75.5
MP9	1643.	11.0	2.29	0.361	1.03	0.172	0.825	160.	22.50	1.5	94.	2.7	215.	1650.	16950.	1975.	1325.	3675.	91.8
MP10	1313.	6.8	4.97	0.145	0.63	0.055	0.325	61.	14.85	0.1	50.	2.1	101.	818.	4725.	1050.	723.	2125.	44.0
MP11	668.	1.4	3.81	0.327	1.01	0.188	1.425	97.	14.13	0.7	89.	3.9	293.	1053.	13625.	1748.	1095.	2650.	81.6
MP12	1673.	7.5	3.63	0.232	1.88	0.120	0.417	98.	11.75	2.9	144.	3.5	340.	1525.	9100.	2900.	1223.	3500.	55.3
MP13	773.	4.1	2.45	0.115	0.49	0.053	0.235	49.	24.45	0.2	58.	3.4	524.	1073.	4500.	1505.	828.	2500.	65.4
MP14	1455.	6.9	2.95	0.132	1.11	0.072	0.285	60.	11.05	2.2	70.	1.6	214.	975.	6175.	2385.	933.	2200.	50.4
MP15	2348.	2.2	1.35	0.111	1.34	0.065	0.185	29.	12.10	1.5	45.	3.1	79.	983.	3713.	3325.	1148.	2750.	30.4
MP16	1198.	1.4	11.83	0.237	1.33	0.081	0.457	183.	15.47	2.7	85.	1.9	229.	1148.	9775.	2525.	1233.	2800.	66.9
MP17	1028.	1.7	3.35	0.248	0.38	0.117	0.607	112.	11.27	0.2	88.	2.8	545.	1183.	10600.	1870.	913.	2575.	78.5
MP18	1333.	6.6	0.51	0.085	0.55	0.053	0.217	50.	5.89	0.1	30.	3.0	146.	688.	5025.	2100.	710.	1750.	50.8
MP19	1675.	11.8	2.21	0.180	1.51	0.110	0.337	68.	16.25	1.2	188.	3.2	209.	1833.	7375.	2675.	990.	3475.	58.1
MP20	1588.	22.2	0.89	0.260	0.60	0.150	0.450	129.	12.27	3.0	44.	2.1	172.	1593.	12900.	2325.	1280.	2925.	70.1

(II)-2 Summary of Results of Long Term Field Survey

The effective monitoring time by station and by item is shown in Table (II)-6. Every station and every item are well exceeding the standard (6,000 hours).

Table (II)-6-(1) Effective monitoring hours of SPM

Monitoring station	Effective hours	Monitoring rate
MP-1	7,642 hours	87.0%
MP-2	8,166	93.0%
MP-6	7,618	86.7%

Remarks: December 7th 1983 to December 6th 1984 = 8,784 hours

Table (II)-6-(2) Effective monitoring hour of SO_2

Station	Effective monitoring hours (hr)	Monitored (%)
MP-1	8011 hours	91.2
MP-2	7645 hours	87.0
MP-4	8229 hours	93.7
MP-6	7515 hours	85.6
MP-7	8302 hours	94.5
MP-14	8011 hours	91.2
MP-20	8445 hours	96.1

Table (II)-6-(3) Effective monitoring hour of wind direction and velocity

Station	Effective monitoring hours		Monitored (%)	
	Wind direction	Velocity	Wind direction	Velocity
MP-1	8,376	8,164	95.4	92.9
MP-2	8,195	8,080	93.3	92.0
MP-4	8,400	8,327	95.6	94.8
MP-6	8,006	8,006	91.1	91.1
MP-7	8,447	8,316	96.2	94.7
MP-14	8,180	8,128	93.1	92.5
MP-20	7,759	8,197	88.3	93.3

Table (II)-6-(4) Effective monitoring hour of temperature

Station	Effective monitoring hours		Monitored (%)	
	1.5 m from ground	30 m from ground	1.5 m	30 m
MP-1	8,121	7,994	92.5	91.0

Table (II)-6-(5) Effective monitoring hour of solar & net radiation

Station	Effective monitoring hours		Monitored (%)	
	Solar radiation	Net radiation	Solar	Net radiation
Changi airport	8,737	8,431	99.5	96.0

(1) SPM concentration by Beta ray dust analyser

Table (II)-7 shows SPM concentration of each station by season and time. From the table, the concentration of night time is found higher than daytime at each station.

This adverse phenomenon will be discussed in the later part of the report, but it is quite clear that the contributing sources are different among SPM and SO_2.

Table (II)-7 Average concentration of SPM by season and day/night monitored by Beta ray dust analyser

(unit: $\mu g/m^3$)

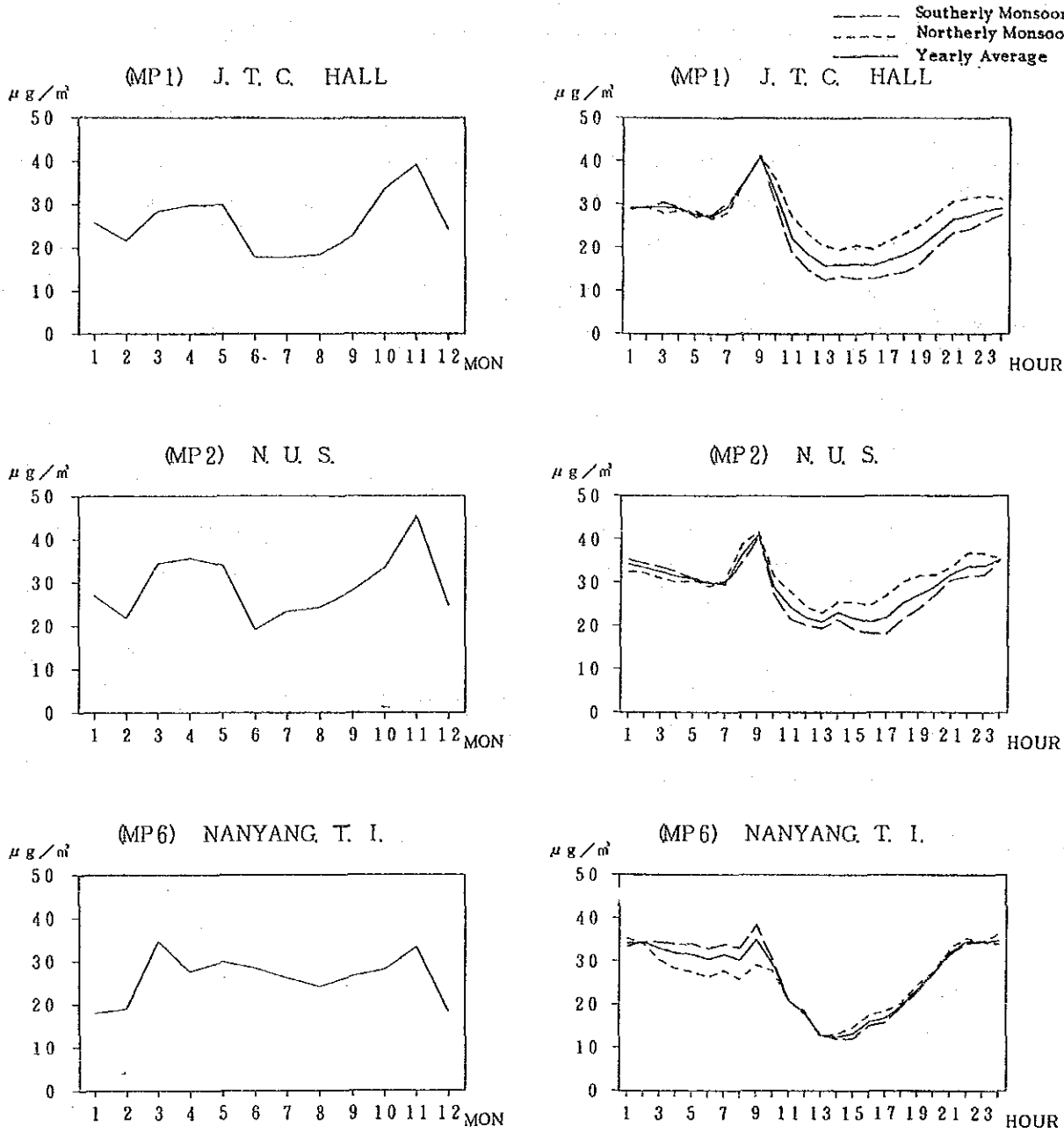
Monitoring station	S. monsoon (4-10)			N. monsoon (11-3)			Annual		
	Day	Night	Total	Day	Night	Total	Day	Night	Total
(1) J.T.C. HALL	20.0	26.3	23.4	26.1	29.0	27.7	22.6	27.4	25.2
(2) N.U.S.	23.8	31.2	27.8	29.1	32.5	30.9	26.0	31.8	29.1
(6) NANYANG.T.I	20.7	32.4	27.1	19.8	30.8	25.8	20.4	31.8	26.6

Day: 7:00 - 17:59

Night: 18:00 - 6:59

Monthly variation and hourly variation of SPM concentration at monitoring stations are shown in Fig. (II)-5.

From the figure, the concentration of March/May and October/November period is found higher at each station. This tendency is similar to that of SO_2. The daily variation pattern is found almost similar among stations, having its peak at 9 o'clock. And no difference between daily variation by season is found.



Monthly average

Hourly average

Fig. (II)-5 Monthly and hourly average of SPM concentration monitored by Beta ray dust analyser

(2) SO_2 concentration

Table (II)-8 shows SO_2 concentration of each monitoring station by seasonal and hourly average values. The concentration of daytime is comparatively higher than night-time. And yearly average values of SO_2 are higher in Jurong area and its surroundings, and are lower in Changi area. These values are found quite similar to the results of previous survey which was conducted during July 15th 1981 to July 14th 1982.

Table (II)-8 SO_2 concentration at each station by season and time

(Unit; ppb)

Station	S. Monsoon (4-10)			N. Monsoon (11-3)			Yearly average		
	Day	Night	Through	Day	Night	Through	Day	Night	Through
(1) J.T.C. HALL	20.6	16.0	18.1	21.3	16.0	18.4	20.9	16.0	18.2
(2) N.U.S.	15.4	12.2	13.7	17.2	12.0	14.4	16.2	12.1	14.0
(4) Boon Lay Apartment	35.0	16.0	24.7	22.3	15.4	18.5	30.1	15.7	22.3
(6) Nanyang.T.I.	21.1	12.7	16.5	15.1	9.2	11.9	18.9	11.4	14.8
(7) Bukit Panjang P.P.	21.6	10.5	15.6	18.7	8.6	13.2	20.4	9.7	14.6
(14) Kallang.F.F.	16.7	12.9	14.6	15.9	11.0	13.2	16.4	12.1	14.0
(20) Singapore offshore P.S.	14.7	9.3	11.7	13.0	8.5	10.5	14.0	9.0	11.3

Monthly variation of SO_2 concentration at each station is shown in Fig. (II)-6. At MP-1, 2, 14 and 20, the peak of concentration is found two times of March/May and September/November. At MP-4, 6 and 7, higher concentration is seen in March/October period and lower in November/February. This tendency is considered to be so by the distance of each station from the Jurong industrial district.

Further monthly variation of SO_2 concentration at MP-1 and 4 are found similar to that of previous survey (1981-82).

Fig. (II)-7 shows hourly variation of SO_2 concentration at each monitoring station. In each station, daytime concentration is found higher than that of nighttime, and particularly at MP-4, 6 and 7 located in the northern side of main emission sources, the above tendency is found remarkable. Further daily variation pattern at MP-1 and MP4 does not show any difference between 2 studies.

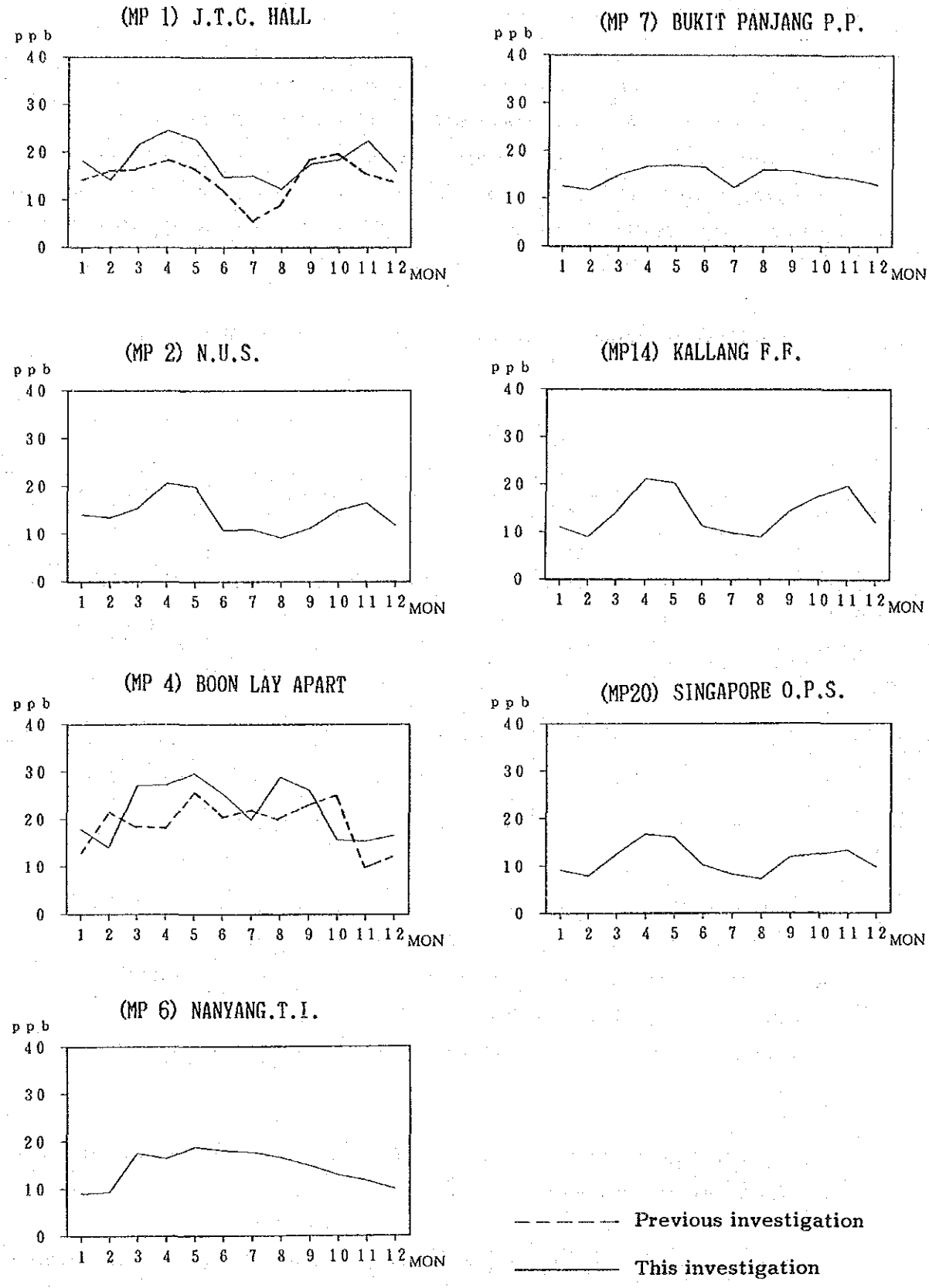


Fig. (II)-6 Monthly variation of SO_2 concentration

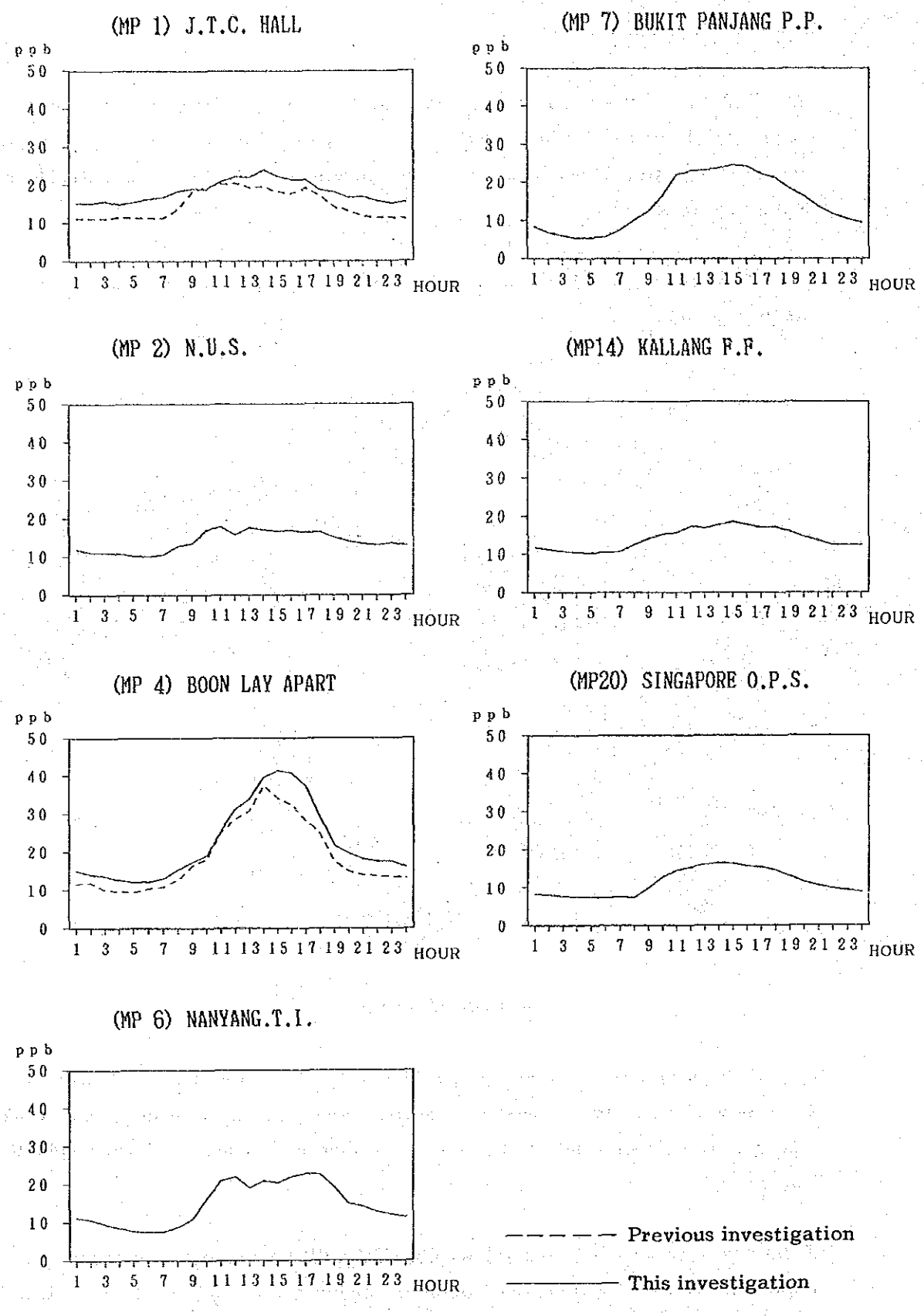


Fig. (II)-7 Hourly variation of SO_2 concentration

(3) Wind direction and velocity

Fig. (II)-8 shows the wind-rose of each station, drawn from yearly appearance frequency of wind direction. From the figure, two dominant wind directions of Singapore are found which are S. Monsoon (April to October) and N. Monsoon (November to March).

Further wind-rose at MP-1 and MP-4 in this study shows similar character with the previous study.

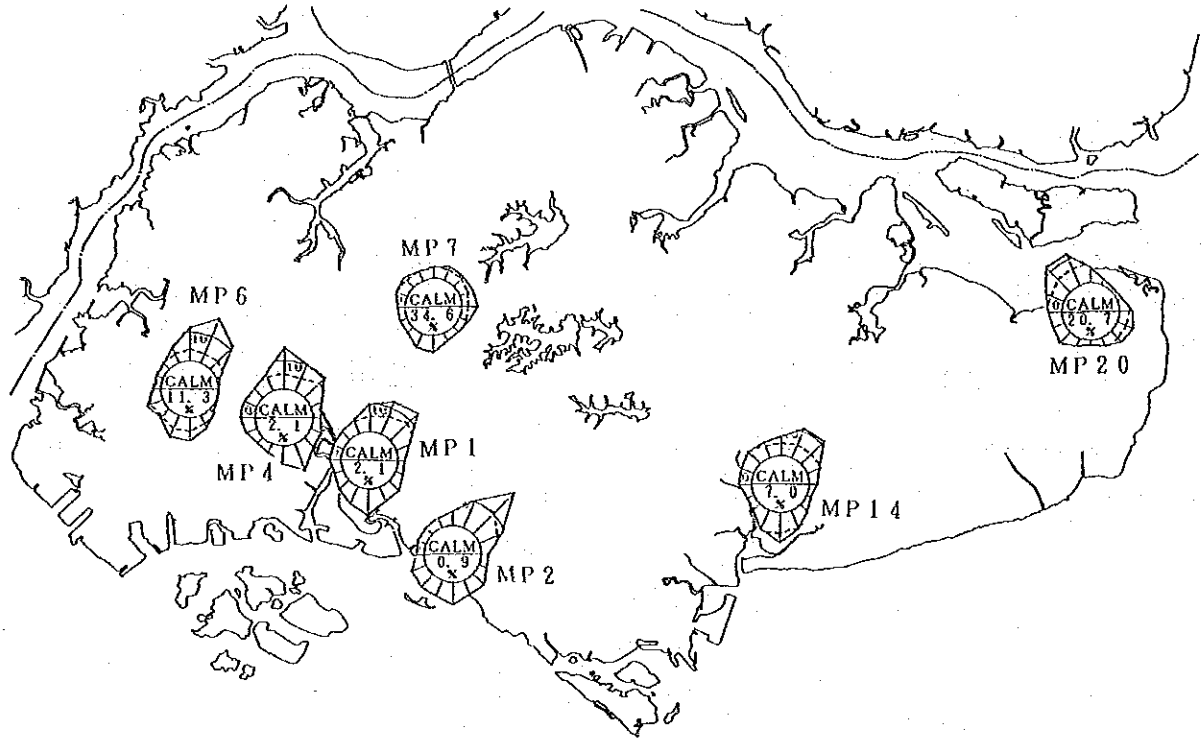


Fig. (II)-8 Wind-rose

Fig. (II)-9 shows monthly average wind velocity of each station. At MP-1, 2 and 20, the wind velocity is found fast during December to February, and weak in March to November. But in other stations, monthly variation of wind velocity is small.

From the average wind velocity by bour (Fig. (II)-10), daytime is found fast and nighttime is weak which are common tendency of each station. When the monthly and hourly variation of wind velocity is compared with the results of previous study, no remarkable change can be seen. (MP-1 and MP-4)

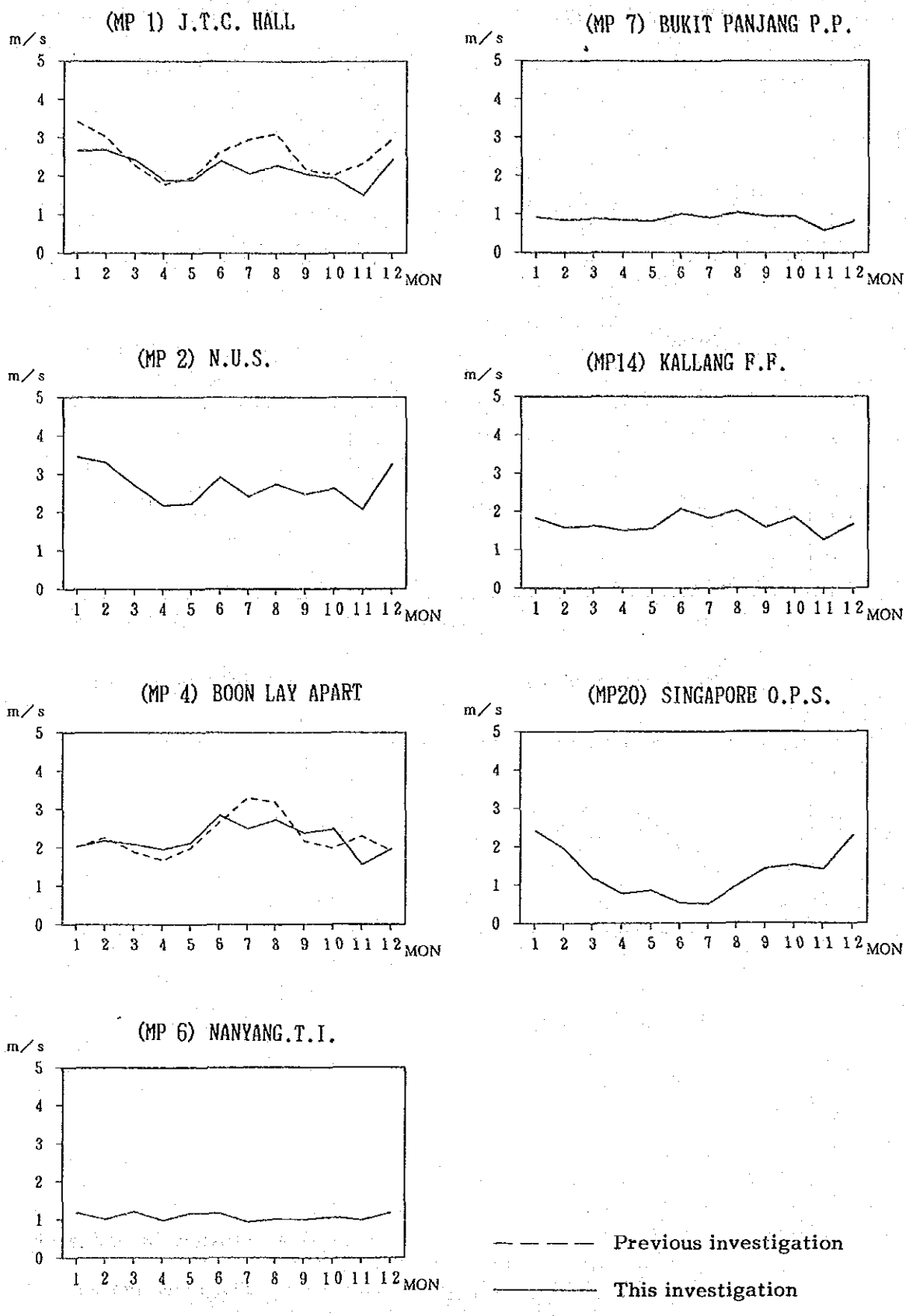


Fig. (II)-9 Monthly variation of wind velocity

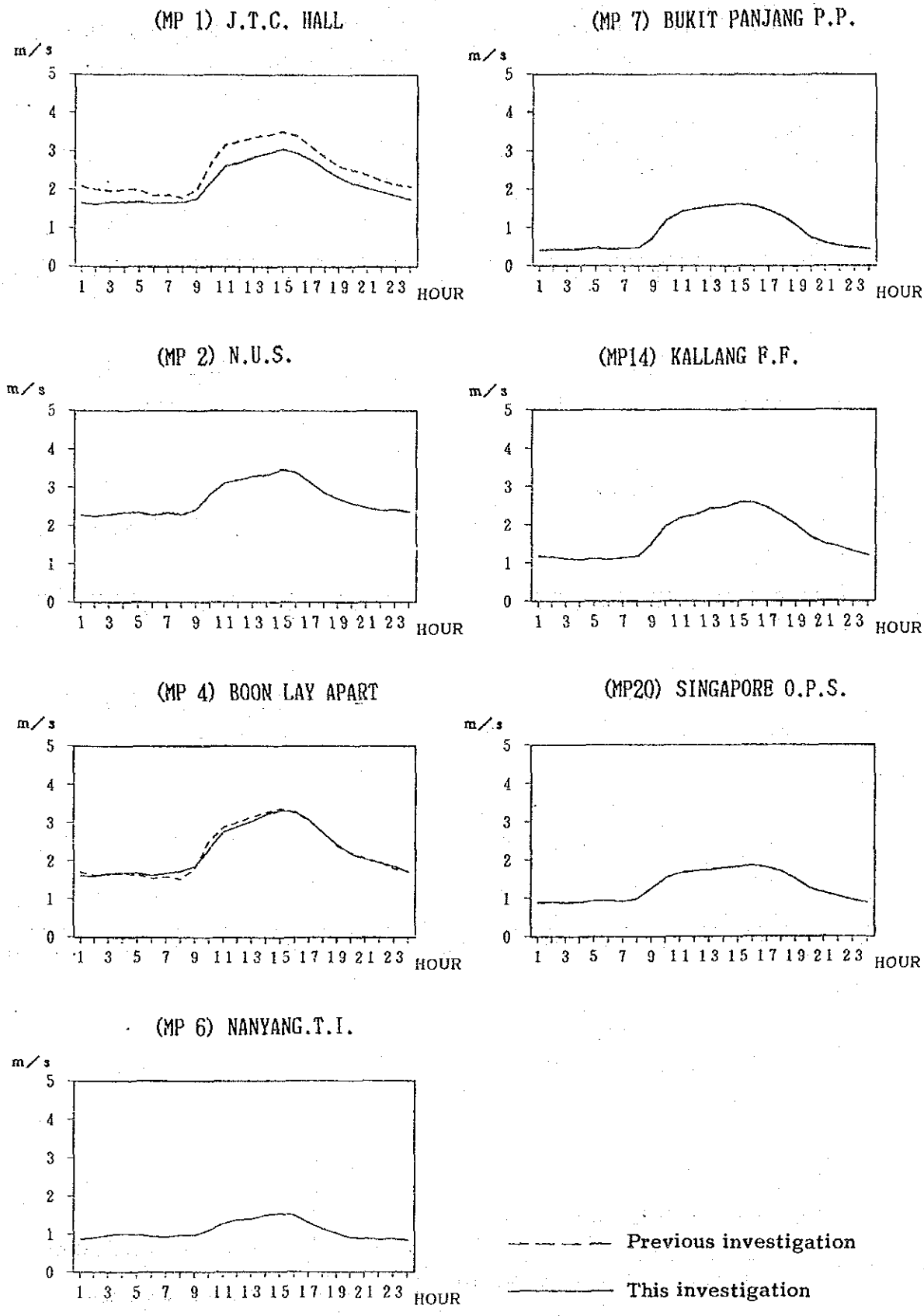


Fig. (II)-10 Hourly variation of wind velocity

(4) Solar & net radiation and temperature

For calculation of concentration in the leeward of stacks and so on, the dispersion of smoke has to be determined quantitatively. For this purpose and for obtaining atmospheric stability closely related to the dispersion of smoke, hourly values of solar and net radiation have been monitored. Atmospheric stability is classified by wind velocity, solar & net radiation.

Fig. (II)-11 shows hourly average of solar and net radiation. From the figure, solar and net radiation in daytime is higher which means atmospheric stability is in the side of unstability. In the nighttime, solar radiation is zero and net radiation is indicating minus value which means atmospheric stability is in the stable side.

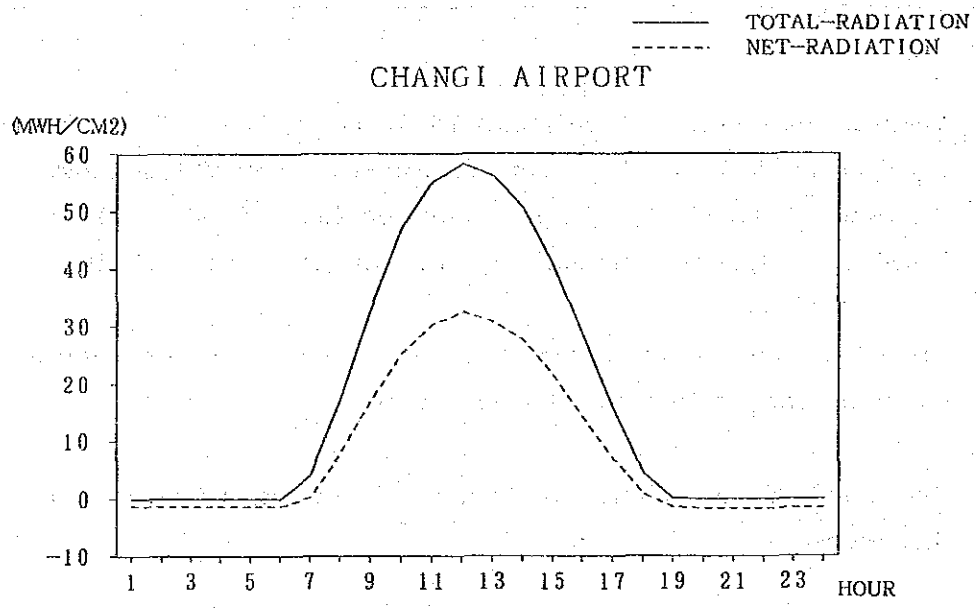


Fig. (II)-11 Hourly variation of solar & net radiation

Table (II)-9 shows appearance frequency of atmospheric stability. In the table, CA to CD are representing atmospheric stability at the calm wind (0 - 0.3 m/s) and it shows atmosphere is more stable from A to D. A to F shows atmospheric stability at the windy condition, and it also means atmosphere is more stable from A to F.

The appearance frequency of atmospheric stability at MP-1 and MP-4 where the wind velocity had been monitored in the previous study (1981-82) is found almost same and no remarkable difference between two studies.

Table (II)-9 Appearance frequency of atmospheric stability

(Unit; %)

Monitoring stations	Calm				Windy					
	CA	CB	CC	CD	A	B	C	D	E	F
(MP1) J.T.C. HALL	0.14	0.35	1.54	0.01	0.40	19.29	13.14	23.02	40.06	2.05
(MP2) N.U.S.	0.06	0.13	0.73	0.01	0.33	17.10	14.23	30.97	34.46	1.98
(MP4) BOON LAY APART	0.11	0.25	1.66	0.01	0.70	18.07	13.29	23.97	39.60	2.34
(MP6) NANYANG.T.I.	0.54	0.99	9.46	0.26	2.53	23.38	5.69	15.56	39.18	2.41
(MP7) BUKIT PANJANG P.P.	0.31	1.13	31.47	1.37	1.33	24.19	4.84	13.38	20.56	1.42
(MP14) KALLANG F.F.	0.13	0.28	6.52	0.11	0.63	22.37	10.30	17.57	39.66	2.43
(MP20) SINGAPORE O.P.S.	0.64	1.22	17.97	0.65	3.02	20.50	7.33	15.48	31.04	2.15

Vertical distribution of temperature is greatly related to the atmospheric stability as well as dispersion of smoke. Table (II)-10 shows temperature difference (T30m-T1.5m) by net radiation rank at calm and windy conditions based on the data at 1.5 m and 30 m from the ground level of MP-1.

From the figure, it shows the common tendency that the atmosphere is more stable the temperature difference is larger.

The atmospheric stability is found well corresponding to the temperature difference.

Table (II)-10 Average temperature difference by net radiation rank

Ranks of net radiation flux (cal/cm^2 hr)	Atmospheric stability	Windy ($u \geq 0.5$ m/s) condition			Calm ($u \leq 0.4$ m/s) condition		
		Hours	Average temperature difference (°C)	Standard deviation (°C)	Hours	Average temperature difference (°C)	Standard deviation (°C)
-3.0 and below	Stable	198	0.98	0.59	3	1.87	0.19
-2.9 ~ 7.9	↕	4832	0.50	0.53	107	0.85	0.60
8.0 and over	Unstable	2168	0.09	0.57	48	0.37	1.01

(III) Summary of Simulation Results of Particulate Matter

The relation between emission sources and ambient concentration of air pollutants, particularly in the cases of gaseous substances such as Sulpher Dioxide and Nitrogen Dioxide, have been determined by the following processes.

(a) obtain the emission sources data of the present and reproduce the present concentration by air diffusion model,
(b) compare the above with the results of field monitoring,
(c) when the correlation between them is confirmed, proceed on for future prediction putting the necessary data, and then
(d) after diffusion calculation, assumption of future contribution by sources are obtained for evaluation.

However, the same processes cannot be applied to the simulation of particulate matter by the following reasons.

(a) the emission sources of the particulate matter are widely distributed and impossible to determine the emission volume from each source. The sources of the particulate matter are soil, sea salt and other natural background besides the particulate from the industrial activities, and other man-made sources.

(b) producing mechanism of secondary particles and removing mechanism are not yet fully identified scientifically.

(c) the new diffusion models should be developed taking the falling by gravity into consideration.

Under the circumstances, the monitored values obtained through the field survey in this study are taken up as the basic data representing the present concentration and diffusion concentration of the proposed coal firing power stations and integrated steel mill are added on the basic data to predict the future concentration.

The concentration of the particulate matter at the mesh points except 20 stations have been assumed by interpolation methods, and further particulate concentration of the proposed new factories have been polymerised on all the mesh points.

As the particulate matter are fallen by gravity in balancing condition between air resistance and gravity, the new diffusion model has been developed taking the fallout by gravity into consideration in this study.

Further, Miller et al. have proposed the assumption method for determining contribution rate by sources used "receptor model", and so in this study, the assumption of contribution rate by sources has been carried out, using the data on analysis of chemical components of the particulate matter.

(III)-1 Emission Volume of Particulate Matter from Coal Firing Power Stations and Integrated Steel Mill

Table (III)-1 shows the emission volume from the coal firing power stations and integrated steel mill, of which was agreed between two countries. As the particulate matter is quite different in diffusion behaviour by the size of particles, the emission volume by the size is also calculated.

Table (III)-1 Emission factors of coal firing power stations and integrated steel mill

Plant & facilities No.		Plant No.	Stack No.	Stack height (m)	Stack diameter (m)	Gas speed (m/s)	Gas temp. (°C)	Gas volume (Nm^3/H)	Treatment facility	Concentration (g/Nm^3-dry)	Particulate volume (kg/h)	Emission volume by size (kg/h)			
												under 2 μm	2-10	10-20	over 20 μm
SERAYA POWER STATION		63	2	183	7.62	25	150	2,650,000	E.P.	0.05	130	44.6	71.0	13.0	1.4
TEKONG POWER STATION		64	1	183	7.36	25	150	2,470,000	E.P.	0.05	120	41.2	65.5	12.0	1.3
TEKONG INTEGRATED STEEL MILL	Grate Kiln	65	1	170	8.97	30	100	5,000,000	E.P.	0.18	900	440.1	288.9	93.6	77.4
	Reheating Furnace	65	2	70	1.45	30	500	63,000	Not installed	0.1	6	4.4	1.3	0.2	0.1
	Electric Arc Furnace	65	3	120	6.0	25	120	1,800,000	Bag filter	0.18	324	140.0	170.1	13.6	0.3

(III)-2 Results of Simulation

Table (III)-2 shows the contributing concentration (yearly average) of TPM and SPM from coal firing power stations and integrated steel mill which calculated by air diffusion model. The largest contributing concentration is found at MP-11 (Chong Pang Police Post) both in TPM and SPM which is located in the north of Singapore. Those concentrations are 0.40 $\mu g/m^3$ of TPM and 0.30 $\mu g/m^3$ for SPM. But in any case, the contributing concentration is very small.

Fig. (III)-1 shows isopleth of contributing concentration by the new factories. The maximum concentration of TPM is 1.27 $\mu g/m^3$ and SPM is 1.04 $\mu g/m^3$. Both are located on the sea about 10 km south of Pulau Tekong.

Table (III)-2 Contributing concentration of coal firing power stations and integrated steel mill at monitoring stations

(Unit; $\mu g/m^3$)

Monitoring stations	TPM All size	SPM Under 10 μm diameter	Concentration for size rank (Unit; $\mu g/m^3$)			
			2 μm <	2 ~ 10 μm	10 ~ 20 μm	20 μm ≦
(MP1) J.T.C. HALL	0.14	0.10	0.05	0.05	0.02	0.02
(MP2) N.U.S.	0.12	0.08	0.04	0.04	0.02	0.02
(MP3) BUKIT MERAH P.P.	0.14	0.10	0.05	0.05	0.02	0.03
(MP4) BOON LAY APART	0.19	0.15	0.07	0.08	0.02	0.02
(MP5) JURONG HILL TOP	0.13	0.09	0.04	0.05	0.02	0.02
(MP6) NANYANG T.I.	0.16	0.12	0.06	0.07	0.02	0.02
(MP7) BUKIT PANJANG P.P.	0.18	0.14	0.07	0.07	0.02	0.02
(MP8) LIM CHU KANG M.P.P.	0.17	0.13	0.06	0.07	0.02	0.02
(MP9) KRANJI SEWAGE T.P.	0.19	0.15	0.07	0.08	0.02	0.02
(MP10) SELETAR R.W.P.S.	0.20	0.15	0.07	0.08	0.02	0.03
(MP11) CHONG PANG P.P.	0.40	0.30	0.15	0.15	0.04	0.06
(MP12) NATIONAL I.C.	0.15	0.11	0.05	0.05	0.02	0.03
(MP13) MACRITCHIE R.W.P.S.	0.15	0.11	0.05	0.05	0.02	0.03
(MP14) KALLANG F.F.	0.17	0.11	0.06	0.06	0.02	0.04
(MP15) EAST COAST S.LAGOON	0.22	0.13	0.07	0.07	0.02	0.06
(MP16) ANG MO KIO F.F.	0.23	0.16	0.08	0.08	0.02	0.04
(MP17) PAYA LEBAR P.S.	0.18	0.12	0.06	0.06	0.02	0.04
(MP18) CHANGI C.CENTER	0.19	0.13	0.07	0.07	0.02	0.04
(MP19) JTC BEDOK F.P.	0.19	0.13	0.06	0.06	0.02	0.05
(MP20) SINGAPORE G.P.S.	0.26	0.21	0.11	0.10	0.02	0.03

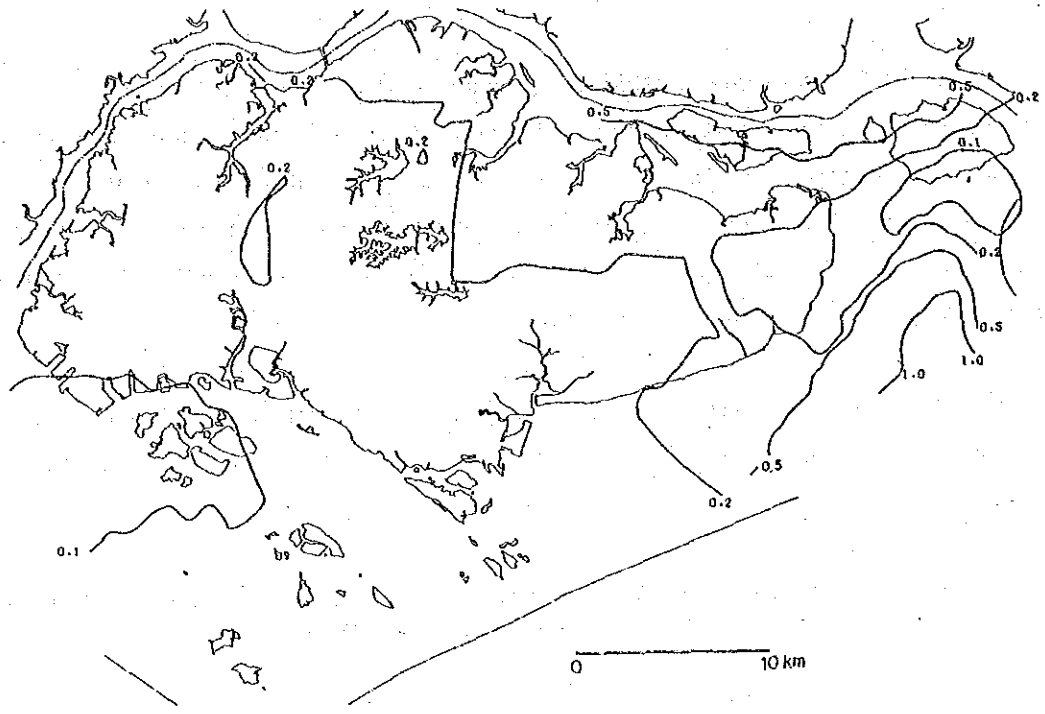


Fig. (III)-1-(1) TPM contributing concentration of coal firing power stations and integrated steel mill ($\mu g/m^3$)

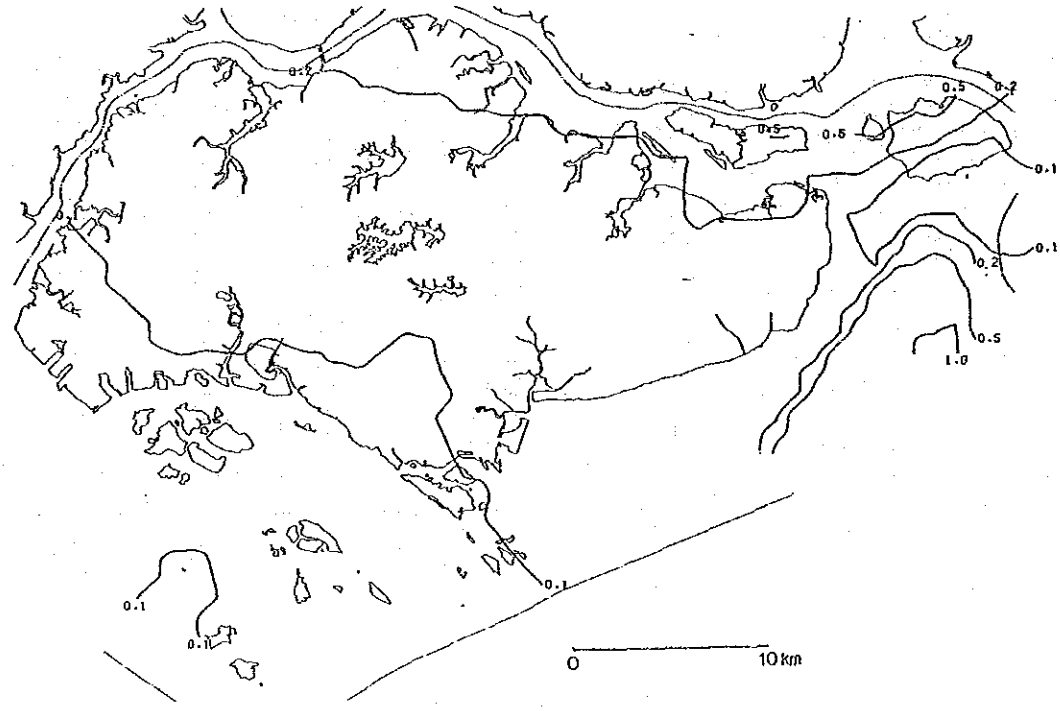


Fig. (III)-1-(2) SPM contributing concentration of coal firing power stations and integrated steel mill ($\mu g/m^3$)

Table (III)-3 shows the present monitored concentration and contributing concentration of coal firing power stations and integrated steel mill, calculated by air diffusion model, and summed up concentration for the future.

From the table, the contributing concentration of the proposed new factories is not more than 1% of the total sources.

Table (III)-3 Predicted concentration of TPM and SPM at monitoring stations

(Unit; $\mu g/m^3$)

Monitoring stations	TPM			SPM		
	T1 Monitored concentration by high volume sampler	T2 Contributing concentration by new factories	T1 + T2 Future predicted concentration	S1 Monitored concentration by high volume sampler	S2 Contributing concentration by new factories	S1 + S2 Future predicted concentration
(MP1) J.T.C. HALL	68.6	0.14	68.7	33.9	0.10	34.0
(MP2) N.U.S.	53.2	0.12	53.3	29.5	0.08	29.6
(MP3) BUKIT MERAH F.F.	66.7	0.14	66.8	31.3	0.10	31.4
(MP4) BOON LAY APART	74.2	0.19	74.4	39.5	0.15	39.7
(MP5) JURONG HILL TOP	78.2	0.13	78.3	34.5	0.09	34.6
(MP6) NANYANG T.I.	66.4	0.16	66.6	33.5	0.12	33.6
(MP7) BUKIT PANJANG P.P.	134.6	0.18	134.8	55.5	0.14	55.6
(MP8) LIM CHU KANG M.P.P.	69.7	0.17	69.9	36.4	0.13	36.5
(MP9) KRANJI SEWAGE T.P.	83.3	0.19	83.5	39.9	0.15	40.1
(MP10) SELETAR R.W.P.S.	54.0	0.20	54.2	28.0	0.15	28.2
(MP11) CHONG PANG P.P.	77.9	0.40	78.3	40.3	0.30	40.6
(MP12) NATIONAL I.C.	69.0	0.15	69.2	27.4	0.11	27.5
(MP13) MACRITCHIE R.W.P.S.	57.5	0.15	57.7	30.2	0.11	30.3
(MP14) KALLANG F.F.	63.3	0.17	63.5	33.3	0.11	33.4
(MP15) EAST COAST S.LAGOON	44.7	0.22	44.9	22.2	0.13	22.3
(MP16) ANG MO KIO F.F.	72.3	0.23	72.5	34.0	0.16	34.2
(MP17) PAYA LEBAR P.S.	93.1	0.18	93.3	42.8	0.12	42.9
(MP18) CHANGI C.CENTER	63.5	0.19	63.7	32.4	0.13	32.5
(MP19) JTC BEDOK F.F.	62.6	0.19	62.8	30.8	0.13	30.9
(MP20) SINGAPORE U.P.S.	63.4	0.26	63.7	24.5	0.21	24.7

Fig. (III)-2 shows the present mesh concentration estimated by interpolation methods (Fig. (III)-3) and mesh concentration calculated by diffusion calculation are polymerised into isopleth which represents future concentration of TPM and SPM by mesh. Because of the contributing concentration by the proposed new factories are very small, the future concentration is not much changed with the present.

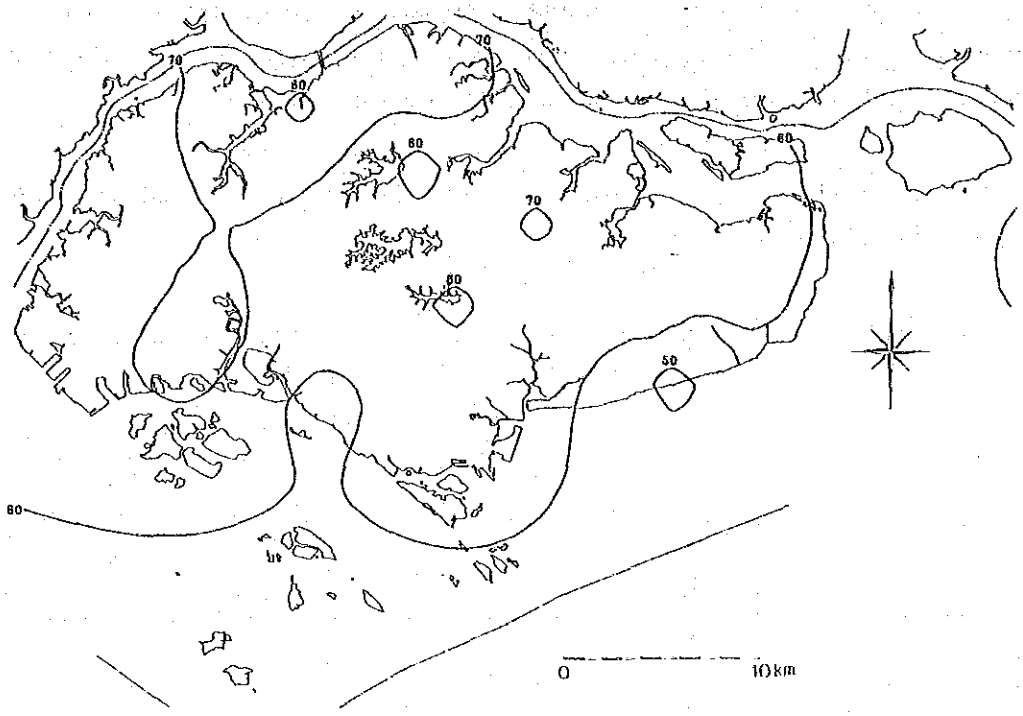


Fig. (III)-2-(1) TPM future predicted concentration

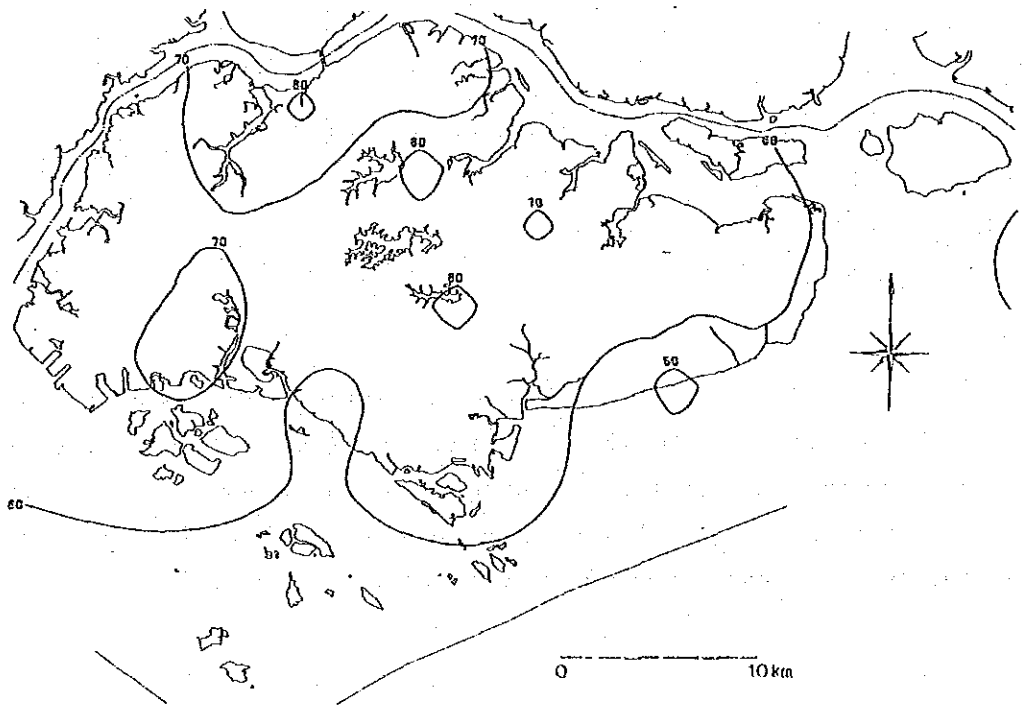


Fig. (III)-3-(1) TPM present concentration

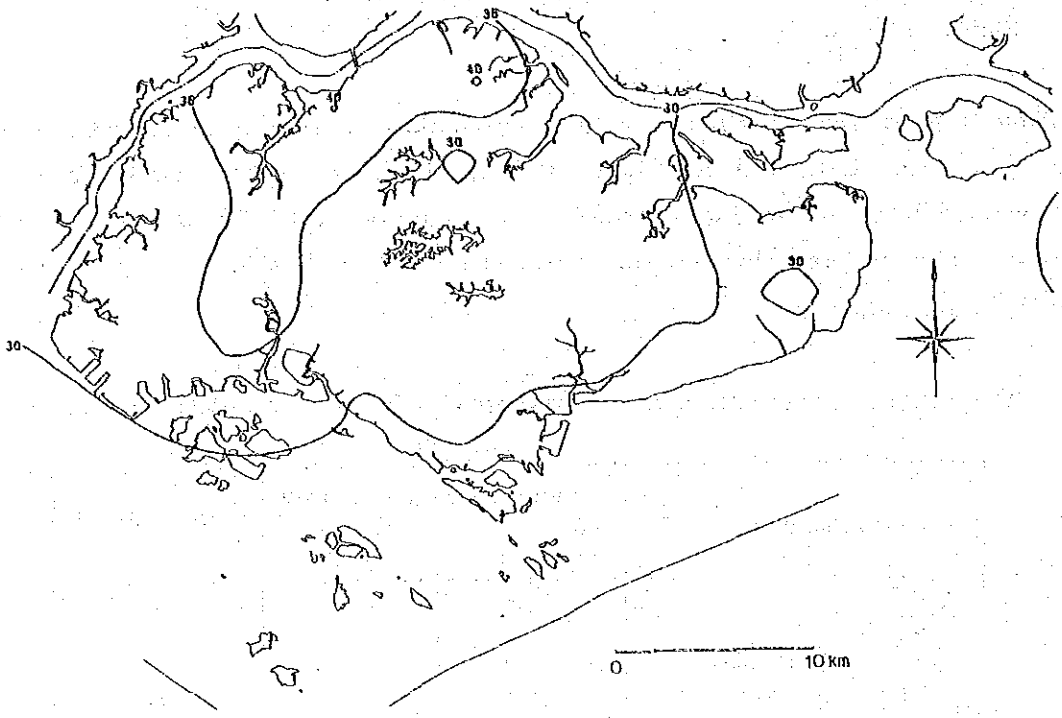


Fig. (III)-2-(2) SPM future predicted concentration

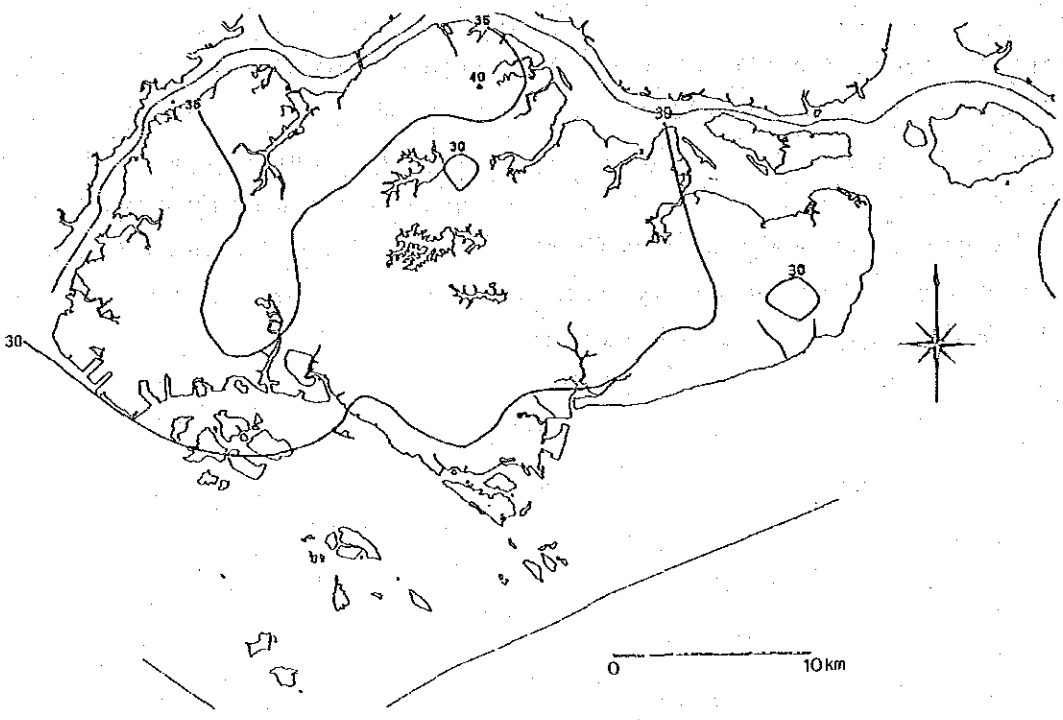


Fig. (III)-3-(2) SPM present concentration

(III)-3 Contribution Rate of Particulate Matter of the Present by Types of Emission Sources

Table (III)-4 shows contribution rate of particulate matter of the present by types of emission sources, estimated by Chemical Mass Balance method (CMB), a method of receptor model, based on the average values monitored at 20 stations and 4 times (seasons) a year through this environmental study. (CMB method is equal to Chemical Element Balance method)

Table (III)-4 Contribution rate of the present by types of emission sources

Emission source	Calculated value ($\mu g/m^3$)	Monitored value ($\mu g/m^3$)	Contribution rate (%)
Soil	17.5	-	26.2%
Sea salt	4.3	-	6.4
Automobile (Gasoline)	1.3	-	2.0
Fuel combustion	1.8	-	2.7
Iron & Steel	1.0	-	1.5
Wastes incineration	0.6	-	0.8
Cemented solids	4.0	-	6.0
Total	30.5	66.6	45.8

From the table, it is identified that contribution of particulate matter is highest in natural sources such as soil, sea salt and so on, and sources of human activities are contributing in low ratio. These results are very much similar to that of Japan. The sources and their contribution rate enumerated in the table are only limited to 45.8% of the total concentration and remaining about 55% is not identified which is assumed to be from automobile (Diesel), secondary particulate and so on, and at the present stage of analytical technology, it is unable to identify.

PART I
INTRODUCTION

PART I INTRODUCTION

CHAPTER 1 THE PROGRESS AND OBJECTIVE OF THE STUDY

I-1-1 The Progress of the Study

In August 1979, the technical assistance consultative meeting was held in Singapore and Jurong Town Cooperation (JTC) who attended in the said meeting has requested Japanese Government to extend its technical assistance for the study on the environmental effects of coal firing power stations and integrated steel mill. Japanese Government has assigned Japan International Cooperation Agency (JICA) to carry out the study proposed by JTC through the Government of the Republic of Singapore.

JICA has sent a preliminary survey mission of 7 members headed by Mr. Ichiro Kikushima, deputy director of Pollution Control Guidance Division, Industrial Location and Pollution Control Bureau, Ministry of International Trade and Industry (MITI) for 13 days from December 8th to 20th 1980 to the Republic of Singapore. The preliminary survey team has discussed the matter with JTC, counterpart of Singapore side, and entered into agreement signing on SCOPE OF WORK and the Minutes of Meetings, in which the following matters were confirmed.

(1) Total time schedule for the environmental study
(2) The description of the study (term, survey items, survey areas & etc.)
(3) The description of simulation (term, simulation items & etc.)
(4) Contribution of Singapore side (cooperation for field survey, collection of data and information materials and so on)

JICA has conducted, according to the SCOPE OF WORK and Minutes of Meetings, the field survey on water quality and simulation works on Chemical Oxygen Demand (COD) and thermal effluents during February to December of 1981. Following to the survey on water quality, the field survey on air quality and simulation related to Sulpher Dioxide (SO_2) have been carried out during June 1981 to March 1982.

Through the progress of the above survey, the Government of Singapore has requested Japanese Government to conduct the additional study on particulate matter in order to make the study more comprehensive in 1982 and the proposal has been approved in June 1983.

Based on SCOPE OF WORK agreed between two countries, the field survey and simulation have been carried out between December 1983 and July 1985.

I-1-2 The Objective of the Study

As a part of environmental study on the effects of coal firing power stations and integrated steel mill, the field survey on the concentration of particulate matter and meteorological conditions have been carried out.

Based on the data obtained through the field survey and emission sources data, the simulation on diffusion of particulate matter has been conducted to predict the environmental concentration of 1990 when the coal firing power stations and integrated steel mill are commissioned.

In addition to the above, the particulate matter has been sampled and chemically analysed. The contribution rate by the type of emission sources have been estimated by receptor model, and also in parallel with the survey, the training on the maintenance of monitoring instruments have been provided to the counterpart officials.

CHAPTER 2 OUTLINE OF THE SURVEY

The correlation between air pollutants emission sources and environmental concentration is obtained by the following processes, particularly for sulpher dioxide and nitrogen dioxide.

The emissions sources located in the survey area are all investigated, and these obtained data are input for obtaining the environmental concentration by atmospheric diffusion model. These calculated values are compared and validated with the valued obtained by monitoring. When the correlation is confirmed by the above processes, the diffusion model and parameters used are identified as being appropriate. Thus the additional or future factors are input to calculate and obtain the contribution rate by the emission sources in future.

However, the above processes are difficult to apply for the case of particulate matter because of the fact that the emission sources of the particulate matter are very wide and complicated. The sources of the particulate matter are (a) natural sources like soil, sea salt particles and so on, (b) man-made sources like factories, automobiles and so on, and (c) secondary particles which the atmospheric aerosol chemically reacted and so on.

Thus the prediction of contribution rate by the sources of particulate matter is difficult because data of emission volume of the particulate are not possible to obtain in the scientific manner.

In this study, therefore, the monitoring stations have been set up as many as possible (20 stations in the object area), the concentration at mesh points beside the monitoring stations have been estimated by the interpolation method, and finally the particulate concentration of the proposed new factories have been polymerised to predict the future concentration at all mesh points covering total Singapore area.

Further, as mentioned in this report, the assumption of contributing rate of the present has been made by the receptor model which analysed the chemical components of the particulate sampled through the field survey.

The field survey has been carried out in two ways; short term survey and long term survey.

The short term field survey has been conducted 4 times a year and each 14 days, in December 1983, March, June and September 1984 respectively.

The long term field survey has been carried out through year; during December 1983 to December 1984.

The daily maintenance of the monitoring instruments have been undertaken by the Singapore side and calibration of the instruments have been conducted by Japanese team.

I-2-1 Survey Area

The survey area in this study covers total area of the Republic of Singapore including the main island and surrounding islands, as shown in Fig. I-2-1 and Table I-2-1.

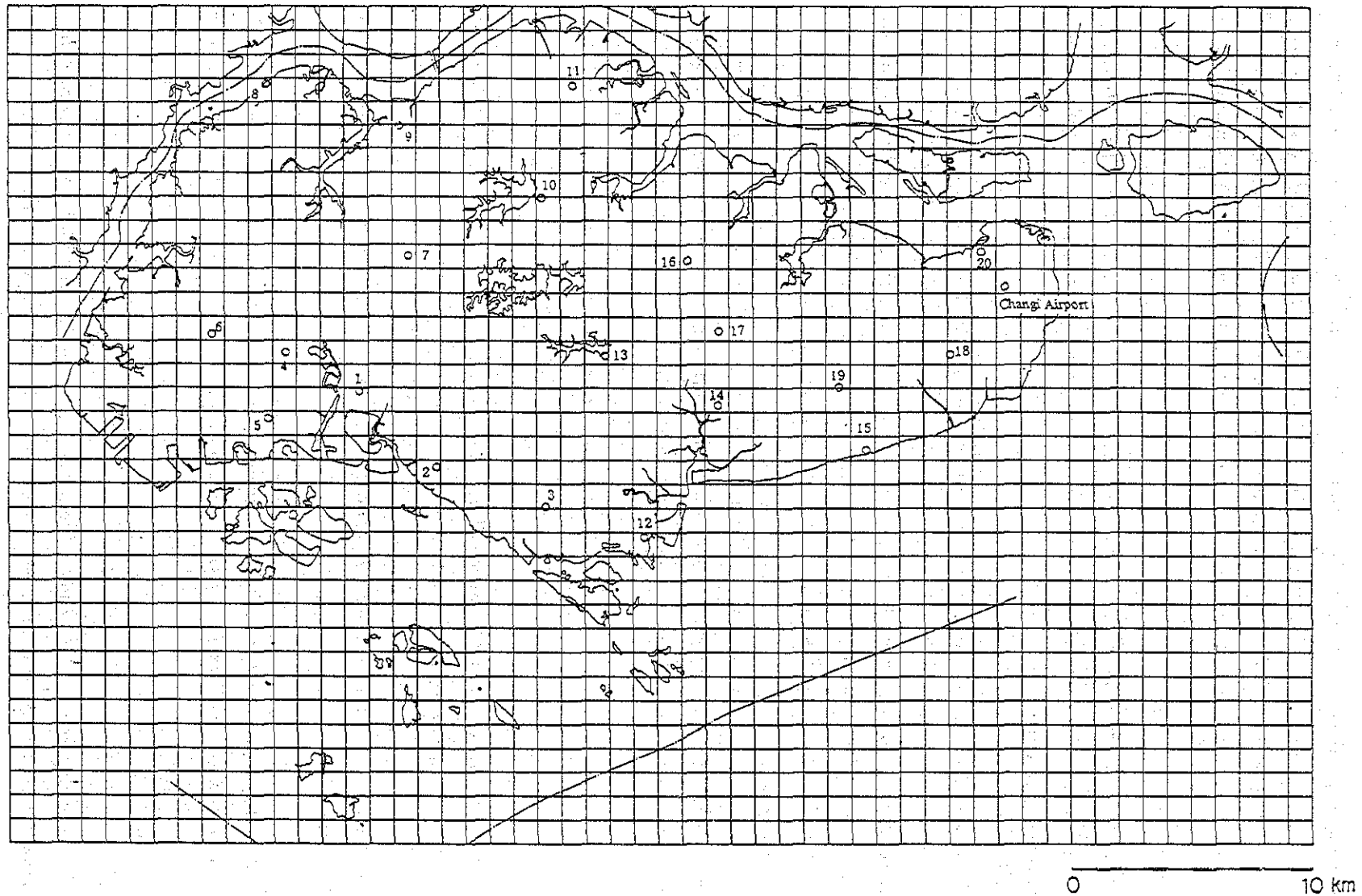


Fig. I-2-1 Survey area and monitoring points

Table I-2-1 Location of monitoring points

MP.	Monitoring points
1.	Jurong Town Hall
2.	National University of Singapore
3.	Bukit Merah Flatted Factory Block 1
4.	Boon Lay Apartment Block 200
5.	Jurong Hill Top Restaurant
6.	Nanyang Technological Institute
7.	Bukit Panjang Police Post
8.	Lim Chu Kang Marine Police Post
9.	Kranji Sewage Treatment Plant
10.	Seletar Reservoir Water Pumping Station
11.	Chong Pang Police Post
12.	National Institute of Commerce
13.	Macritchie Reservoir Water Pumping Station
14.	Kallang Flatted Factory Block 3
15.	East Coast Swimming Lagoon
16.	Ang Mo Kio Flatted Factory Block 5001
17.	Paya Lebar Police Station
18.	Changi Community Center
19.	JTC Bedok Flatted Factory
20.	Singapore Offshore Petroleum Services

I-2-2 Survey Term

(1) Short term field survey

The first field survey	Nov. 23, 1983 to Dec. 25, 1983
The second field survey	Feb. 27, 1984 to Mar. 25, 1984
The third field survey	June 11, 1984 to July 8, 1984
The fourth field survey	Sep. 3, 1984 to Sep. 30, 1984

(2) Long term field survey

December 7th 1983 to December 6th 1984

(3) Chemical analysis of metal elements & etc.

For first field survey	April and May 1984
For second field survey	April and May 1984
For third field survey	August and September 1984
For fourth field survey	October and November 1984

(4) Analysis of field survey data

June 1984 to February 1985

(5) Prediction of particulate matter by atmospheric diffusion model

March, May, June 1985

(6) Assumption of contribution rate by the sources by receptor model

October and December 1984, May, June and July 1985

I-2-3 Outline of Survey Item and Survey Method

I-2-3-1 Field survey

The field survey has been carried out as follows, to obtain the data on the present concentration of the particulate matter.

(1) Short term field survey

(a) Total particulate matter (TPM)

High volume samplers have been set up at MP-1 to MP-20, to monitor daily average value of TPM. (Each 14 days of 1st to 4th field survey)

(b) Suspended particulate matter (SPM)

High volume samplers installed with cyclon have been set up at MP-1 to MP-20, to monitor daily average value of SPM. (Each 12 days of 1st to 4th field survey)

(c) Size distribution of particulate matter

Andersen samplers have been set up at MP-1, 2 and 6 to monitor the size distribution of TPM. (Average value of 12 days)

(2) Long term field survey

(a) Monitoring of suspended particulate matter

Automatic Beta ray dust analysers have been set up at MP-1, 2 and 6. One hour value of SPM concentration has been monitored for one year.

(b) Monitoring of sulpher dioxide (SO_2)

Automatic solution conductmetry SO_2 analysers have been set at MP-1, 2, 4, 6, 7, 14 and 20. One hour average value of SO_2 ambient concentration has been monitored automatically for one year.

(c) Monitoring of wind direction and velocity of ground level

Automatic anemometers have been set at MP-1, 2, 4, 6, 7, 14 and 20. The average values of 10 minutes have been monitored for one year.

(d) Monitoring of solar and net radiation

Data on one hour average values of solar and net radiation for one year have been supplied by Singapore Meteorological Services who monitored the above at Changi Airport Observatory.

(e) Monitoring of temperature

The nickel resistance type thermometers have been set at 1.5 and 30 meters from the ground of JTC and monitored the instantaneous values of the temperature of above 2 heights for one year.

(3) Chemical analysis of metal elements

(a) Analysis of metal elements and anion contained in the suspended particulate matter

The filters sampled the total particulate matter at 20 stations through 1st to 4th field surveys have been brought back to Japan, and 33 metal elements and 3 types anion have been analyzed by neutron activation method, X-ray fluorescence method, and ion chromatography.

(b) Analysis of total carbon and non volatile carbon contained in the total particulate matter

The filters sampled the total particulate matter at 20 stations through the field survey have been brought back to Japan, and total carbon and non volatile carbon have been analyzed by differential thermal method.

(c) Analysis of metal elements in the soil

3 typical types of soil of Singapore have been sampled and supplied by JTC Soil Laboratory, and these samples have been chemically analyzed by neutron activation method and X-ray fluorescence method.

I-2-3-2 Analysis of field survey data

The data obtained through the field survey have been analyzed as follows;

(a) Analysis of long term field survey data

(i) Analysis of meteorological data
Classification by term and time
Average wind velocity
Appearance frequency by wind velocity
Wind rose
Vector correlation coefficient of wind direction and velocity between each monitoring point

Cluster analysis based on vector correlation coefficient
Analysis of main components by vector correlation coefficient
Atmospheric stability
Temperature

(ii) Analysis of SO_2 concentration
Monthly variation of SO_2 concentration
Hourly variation of SO_2 concentration
Cummulative frequency distribution of SO_2 concentration
Average concentration of SO_2 by wind direction and velocity rank

(iii) Analysis of SPM concentration by Beta ray analyser
Monthly variation of SPM concentration
Hourly variation of SPM concentration
Variation of SPM concentration by week days and week end day.
Cummulative frequency distribution of SPM concentration
Average concentration of SPM by wind direction and velocity rank
Average concentration of SPM by wind velocity rank and atmospheric stability rank
Correlation of SPM concentration between monitoring points
High concentration analysis of SPM
Correlation between SPM concentration and SO_2 concentration

(b) Analysis of short term field survey data

(i) Analysis of TPM and SPM concentration by high volume sampler
Average concentration of TPM and SPM by season
Daily variation of TPM and SPM concentration
Correlation between monitoring points of seasonal concentration of TPM and SPM
Correlation of TPM and SPM concentration
Comparison of monitored values of high volume sampler and Beta ray dust analyser

(ii) Analysis of TPM concentration by Andersen sampler
TPM concentration by particle size
Size distribution of TPM
Comparison of monitored values by Andersen sampler, high volume sampler and Beta ray analyser

(iii) Analysis of SPM concentration by Beta ray dust analyser

Average concentration of SPM by wind direction during short term field survey

Average concentration of SPM by wind velocity rank during short term field survey

Average concentration of SPM by atmospheric stability rank during short term field survey

(c) Analysis of chemical components of particulate matter

(i) Average concentration of chemical component
(ii) Regional distribution of chemical component
(iii) Relation between chemical components
(iv) Deviation of chemical component
(v) Comparison of chemical component between monitoring points

I-2-3-3 Future prediction of emission source data

Based on the future development plan of The Republic of Singapore supplied through JTC, emission volume of particulate matter from integrated steel mill (generater boiler, great kiln, heating furnace and electric furnace) and coal firing power stations has been discussed with JTC and other Authorities concerned. The size distribution of particulate matter has been referred to monitoring experiences in Japan which is concerned with diffusion behavior by size of particles. These are all recorded in the Minutes of Meetings signed by JICA and JTC in June 1983.

I-2-3-4 Simulation of particulate matter

The atmospheric diffusion model, developed and applied to the diffusion of gaseous substances (for example-SO_2), is difficult to apply for particulate matter, because of the reasons;

(a) emission sources of particulate matter are too wide to identify

(b) in the ambient, the primary particulate is chemically reacted into the secondary particles

(c) removal mechanism of the particulate is not yet identified.

In this study, the monitored values are agreed to be the basic data for future simulation, and on the present data, emission factors of integrated steel mill and coal firing power stations have been added to predict the future diffusion and concentration of the particulate matter. Further, diffusion model employed in this study is the model considered of gravity fallout of the particulate matter.

The simulation described above cannot identify the contribution rate by emission sources, and so the prediction of contribution rate by sources have been conducted by receptor model which recently developed.

I-2-4 Formation of Field Survey Team

The formation of 1st to 4th field survey team is as shown in Table I-2-2.

Table I-2-2 Formation of field survey team

	Name	Business	Period
1st Field Survey Team	Kihachi Inagaki	Team leader	Nov. 23 to Dec. 25 1983
	Kozo Sakurai	Monitoring	- do -
	Kaoru Nakahashi	- do -	- do -
	Keizo Kobayashi	- do -	- do -
	Hiroaki Toda	- do -	- do -
	Mitsuru Fujimura	- do -	- do -
	Hiroshi Kobayashi	- do -	- do -
2nd Field Survey Team	Kihachi Inagaki	Team leader	Feb. 27 to Mar. 25 1984
	Kazuo Shimizu	Monitoring	- do -
	Naoto Kamiya	- do -	- do -
	Shinichi Okamoto	- do -	- do -
	Tetsuo Noguchi	- do -	- do -
	Setsuo Ono	- do -	- do -
	Hiroshi Kobayashi	- do -	- do -
3rd Field Survey Team	Kihachi Inagaki	Team leader	June 11 to July 8 1984
	Kaoru Nakahashi	Monitoring	- do -
	Norihito Ono	- do -	- do -
	Tsukasa Morimoto	- do -	- do -
	Hiroshi Kobayashi	- do -	- do -
	Hajime Ohgi	- do -	- do -
	Naoki Matsuzaki	- do -	- do -
4th Field Survey Team	Kihachi Inagaki	Team leader	Sep. 3 to Sep. 30 1984
	Takeshi Yamada	Technical supervisor	Sep. 23 to Sep. 29 1984
	Keizo Kobayashi	Monitoring	Sep. 3 to Sep. 30 1984
	Takashi Hinaji	- do -	- do -
	Hiroaki Toda	- do -	- do -
	Tetsuo Noguchi	- do -	- do -
	Hiroshi Kobayashi	- do -	- do -
	Shinichi Misaka	- do -	- do -

I-2-5 Progress of Study

The progress of the study is as follows;

(1) Short term field survey

1st field survey	November 23 to December 25 1983
2nd field survey	February 27 to March 25 1984
3rd field survey	June 11 to July 8 1984
4th field survey	September 3 to September 30 1984

(2) Long term field survey

Through-year monitoring - December 7 1983 to December 6 1984

(3) Training on maintenance and repairing of monitoring instruments

(a) Calibration of instruments and so on.

November 25, 1983 to December 6 1983

(b) Field works for replacement of filter and so on.

December 7 1983 to December 21 1983
March 6 to March 20 1984
June 21 to July 5 1984
September 13 to September 27 1984

(4) Chemical analysis of total particulate matter

Analysis of metal elements, anion and carbon: April, May, August, September, October and November 1984

(5) Processing of monitored data

Processing of data obtained through long term monitoring: June to December 1984

(6) Analysis of data obtained through short term field survey

Analysis of TPM, SPM and etc.: June, July, August, November, December 1984 and January, February 1985

(7) Analysis of data obtained through long term field survey

Analysis of data on SPM, SO_2 and meteorological conditions: January, February 1985

(8) Identification of emission sources data

Identification and analysis of emission sources data: August 1984 and March 1985

(9) Simulation

Prediction by air diffusion model: March, May, June 1985
Assumption of contribution rate by receptor model: October, December 1984 and May, June, July 1985

The detailed progress of the short term field survey is shown in Table I-2-3-(1) to (4)

Table I-2-3-(1) Progress of 1st field survey

Date	Outline of field survey
Nov. 23 (Wed) 1983	Team left Narita at 11:00 by SQ-005 and arrived in Changi at 20:00. Mr. Katayama of Embassy and Mr. Mizobuchi of JICA received the team at the airport
Nov. 24 (Thu) 1983	Team visited Embassy for explaining of outline of study in morning time, meeting at JTC for presentation on proposed study under presence of Chairman of JTC, and discussed on time schedule with JTC officers concerned in afternoon
Nov. 25 (Fri) 1983	Unpacked monitoring instruments transported before team's arrival and checked conditions
Nov. 26 (Sat) 1983	Calibration of high volume samplers, chemical balance, SO_2 analysers and Beta ray dust analysers. In parallel, confirmed key stations location (MP-2 to MP-6)
Nov. 27 (Sun) 1983	Holiday

Table I-2-3-(1) Progress of 1st field survey (Cont'd)

Date	Outline of field survey
Nov. 28 (Mon) 1983	Calibration of high volume samplers, Andersen samplers and SO_2 analysers. Checked other instruments for immediate operation
Nov. 29 (Tue) 1983	Calibration of high volume samplers and Andersen samplers. Numbering of filters
Nov. 30 (Wed) 1983	Weighing of filters before sampling. Setting up instruments at MP-6. Setting up instruments at MP-1 including replacement of sampling tubes & etc.
Dec. 1 (Thu) 1983	Preparatory works of Andersen samplers including weighing of filters for Andersen. High volume samplers set up at 11 stations
Dec. 2 (Fri) 1983	High volume samplers set up at 7 stations. Calibration of chemical balance, anemometers (MP-4 & MP-6). Replacement of equivalent solution for SO_2 analysers installed at MP-1, MP-4 and MP-6
Dec. 3 (Sat) 1983	Weighing of filters for high volume samplers. Replacement of sampling tube & etc. of SO_2 analyser installed at MP-2
Dec. 4 (Sun) 1983	Holiday
Dec. 5 (Mon) 1983	Weighing of filters for high volume samplers. Setting up thermometers in MP-1 at the height of 1.5 and 30 meters. Filming for TV at MP-6 Prepare Andersen samplers setting filters in. At MP-7, maintenance works for SO_2 analyser and calibration of anemometer.
Dec. 6 (Tue) 1983	Weighing of filters for high volume samplers. Calibration of thermometer at MP-1. At MP-14 and MP-20, maintenance works for SO_2 analyser and calibration of anemometer
Dec. 7 to 20 (Wed - Tue) 1983 14 days	Particulate matter (by high volume samplers, Andersen samplers, Beta ray dust analysers) SO_2, wind direction & velocity, temperature were monitored. For 12 days between 7 to 18, quartz type filters were used and remaining 2 days, Polyphlone type filters were used
Dec. 21 (Wed) 1983	Filters collected from all stations in morning and instruments withdrawn from 20 stations in afternoon. Weighing of sampled filters in parallel.
Dec. 22 (Thu) 1983	Cleaning up instruments withdrawn from stations. Adjustment of SO_2 analysers and Beta ray dust analysers. Weighing of sampled filters.
Dec. 23 (Fri) 1983	Weighing of filters sampled by Andersen sampler. Manual calculation of monitoring data. Final meeting with JTC officers
Dec. 24 (Sat) 1983	Holiday
Dec. 25 (Sun) 1983	Team left Singapore by SQ-008

Table I-2-3-(2) Progress of 2nd field survey

Date	Outline of field survey
Feb. 27 (Mon) 1984	Team left Narita at 12:00 by JL-719 and arrived in Changi at 18:30
Feb. 28 (Tue) 1984	Meeting with JTC officers in morning, official visits to Embassy and JICA in afternoon
Feb. 29 (Wed) 1984	Maintenance work of MP-1 and MP-6, checked conditions of SO_2 analyser, Beta ray analyser, and anemometer. Numbering of filters and weighing of filters before sampling
Mar. 1 (Thu) 1984	Maintenance work of MP-1, 2 & 6 Weighing of filters, and calibration of Andersen samplers
Mar. 2 (Fri) 1984	Setting up 20 stations, installing high volume samplers. Maintenance work for MP-7, 14 & 20. Weighing of filters for high volume sampler.
Mar. 3 (Sat) 1984	Maintenance work for MP-4. Weighing of filters. Calibration of high volume sampler at MP-2
Mar. 4 (Sun) 1984	Holiday
Mar. 5 (Mon) 1984	Final checking of SO_2 analysers, Beta ray dust analyser and anemometer. Setting up Andersen samplers at MP-1, 2 & 6.
Mar. 6 to 19 (Tue - Mon) 1984 14 days	Monitoring of particulate matter (by high volume samplers, Andersen samplers, & Beta ray dust analysers) SO_2, wind direction & velocity, temperature and etc. For 12 days between Mar. 6 to 17, quartz type filters were used, and remaining 2 days, Polyphlone type filters were employed. During monitoring period, following instrumental troubles occurred but immediate repairing measures were taken to avoid data shortage or loss. March 7th: Andersen sampler overheated. March 8th: Anemometer at MP-7 indicates abnormal values. Repaired by replacing generator on March 9th. Wind direction found still abnormal. Cable cut found. Completed repairing on 10th. March 10th: Andersen sampler troubled. Changed wiring of transformer.
Mar. 20 (Tue) 1984	Filters collected from all stations in morning, and completed the monitoring by high volume samplers and Andersen samplers. Withdrawn instruments in afternoon. Weighing of filters after sampled.
Mar. 21 (Wed) 1984	Cleaning and adjustment of instruments withdrawn from 20 stations. Weighing filters of Andersen samplers. Manual calculation of particulate concentration and etc.
Mar. 22 (Thu) 1984	Manual calculation of particulate concentration and other desk works.
Mar. 23 (Fri) 1984	Manual calculation of particulate concentration and other desk works. Final meeting with JTC officers. Visits to Embassy and JICA Singapore office.

Table I-2-3-(2) Progress of 2nd field survey (Cont'd)

Date	Outline of field survey
Mar. 24 (Sat) 1984	Holiday
Mar. 25 (Sun) 1984	Team left Singapore by SQ-008.

Table I-2-3-(3) Progress of 3rd field survey

Date	Outline of field survey
June 11 (Mon) 1984	Team left Narita by JL-719 at 12:00 and arrived Singapore at 17:30.
June 12 (Tue) 1984	Meeting with JTC officers in morning, visits Embassy and JICA office for reporting outline of the 3rd field survey
June 13 (Wed) 1984	Preparatory works by 3 divided groups. 1st group-calibration of high volume samplers 2nd group-calibration of chemical balance and weighing of filters for Andersen 3rd group-calibration of Beta ray analyser and SO_2 analyser at MP-2
June 14 (Thu) 1984	Calibration of high volume samplers and Andersen samplers. Weighing of filters. Calibration of Beta ray analyser and SO_2 analyser at MP-6
June 15 (Fri) 1984	Calibration of high volume samplers (MP-2) and weighing of filters. Calibration of instruments at MP-4 and MP-7.
June 16 (Sat) 1984	Overhauled SO_2 analyser and Beta ray analyser at MP-1. Calibration of anemometer and thermometer. Weighing of filters
June 17 (Sun) 1984	Holiday
June 18 (Mon) 1984	Setting up high volume samplers at MP-13, 16, 10, 20, 18, 15 and 12. Setting up Andersen samplers at Mp-1, 2 and 6. Overhauled SO_2 analyser and anemometer at MP-14 and 20. Weighing of filters for high volume samplers.
June 19 (Tue) 1984	Setting up high volume samplers at MP-2, 3, 6, 14 and 17. Calibration of Beta ray analyser at MP-2 and 6. Calibration of SO_2 analyser and anemometer at MP-2, 4 and 6. Weighing of filters for high volume samplers.
June 20 (Wed) 1984	Final check on 20 stations, divided into 4 groups.

Table I-2-3-(3) Progress of 3rd field survey (Cont'd)

Date	Outline of field survey
June 21 (Thu) to July 4 (Wed) 1984 14 days	Particulate matter (by high volume samplers, Andersen samplers, and Beta ray analyser) SO_2, wind direction & velocity, temperature and so on were monitored. For 12 days between June 21 to July 2, quartz type filters were used, and remaining 2 days, Polyphlone type filters were used. During the period, following instrumental troubles occurred but immediate repairing measures were taken to avoid data shortage or loss. June 28th: At MP-14, connector of high volume sampler found disconnected. Repaired. June 30th: At MP-4, SO_2 analyser indicated abnormal values. Repaired including voltage regulator.
July 5 (Thu) 1984	Filters collected from all stations. Instruments withdrawn in afternoon. Weighing of filters after sampled.
July 6 (Fri) 1984	Visits to Embassy and JICA for reporting the completion of 3rd field survey.
July 7 (Sat) 1984	Manual calculation of particulate concentration and other desk works. Final meeting with JTC officers
July 8 (Sun) 1984	Team left Singapore by SQ-008 at 11:15

Table I-2-3-(4) Progress of 4th field survey

Date	Outline of field survey
Sep. 3 (Mon) 1984	Team left Narita by JL-719 at 12:00 and arrived Singapore at 18:40.
Sep. 4 (Tue) 1984	Visits to Embassy and JICA office for reporting of outline of 4th field survey. In afternoon, meeting with JTC officers at JTC under presence of GM (General Maneger).
Sep. 5 (Wed) 1984	Preparatory works, divided into 3 groups. 1st group-numbering of filters and calibration of chemical balance 2nd group-calibration of high volume samplers and Andersen samplers 3rd group-calibration and maintenance works of SO_2 and Beta ray analysers at MP-1 and 6. SO_2 analyser of MP-4 calibrated.
Sep. 6 (Thu) 1984	Holiday (national holiday-HARI RAYA HAJI)
Sep. 7 (Fri) 1984	High volume sampler and Andersen sampler installed at MP-2 calibrated. Chemical balance checked. Weighing of filters for high volume samplers. SO_2 and Beta ray analysers of MP-2 calibrated, and SO_2 analysers of MP-14 and 20 calibrated.

Table I-2-3-(4) Progress of 4th field survey (Cont'd)

Date	Outline of field survey
Sep. 8 (Sat) 1984	Maintenance works for Andersen samplers. Calibration of SO_2 analyser at MP-7. Repaired anemometer of MP-20 which indicated abnormal value for wind velocity
Sep. 9 (Sun) 1984	Holiday
Sep. 10 (Mon) 1984	Calibration of SO_2, Beta ray analysers and anemometer at MP-1. Calibration of SO_2 and anemometer of MP-14. Weighing of filters. Setting up high volume samplers at 20 stations.
Sep. 11 (Tue) 1984	Calibration of Beta ray analyser of MP-2 & 6. Calibration of SO_2 analysers and anemometers of MP-2, 4, 6, 7 and 20. Weighing of filters for high volume samplers. Replaced a part of anemometer of MP-20. Setting up Andersen samplers at MP-1, 2 and 6.
Sep. 12 (Wed) 1984	Calibration of thermometer installed in MP-1. Final checking of 20 stations
Sep. 13 to 26 (Thu - Wed) 1984 12 days	Particulate matter (by high volume sampler, Andersen sampler and Beta ray analyser) SO_2, wind direction & velocity, temperature and etc. were monitored. For 12 days between 13th to 24th, quartz type filters were used and remaining 2 days, Polyphlone type filters were used. On 23rd September, one team member arrived in Singapore. During the period, following instrumental troubles occurred, but immediate measures were taken to avoid data shortage or loss. September 13th: Andersen sampler of MP-2 overheated. Repairing completed on 14th. September 14th: The trouble of Andersen sampler was found due to choking of orifice. Repaired.
Sep. 27 (Thu) 1984	Filters collected from all stations. Instruments withdrawn in afternoon. Weighing of filters after sampled.
Sep. 28 (Fri) 1984	Final meeting with JTC officers.
Sep. 29 (Sat) 1984	Holiday. A team member left Singapore
Sep. 30 (Sun) 1984	Team left Singapore by JL-714 at 10:25

PART II
OUTLINE OF PARTICULATE MATTER

PART II OUTLINE OF PARTICULATE MATTER

The particulate matters in the ambient air are originated from various sources and the particulate size, chemical compositions and their chemical natures are different depending on their sources of emission. The sources of the particulate matters are quite wide, such as the natural background sources (soil, sea salt and so on), the human activities (factories, automobiles & etc.) and the secondary particulates chemically reacted in the ambient.

The relation between emission sources of air pollution substances and their ambient concentration are commonly evaluated by air diffusion models which are based on that emission volume at the emission sites are kept suspended in the ambient. The same diffusion models are also applicable to the particulate matters but further studies and researches are inevitable particularly on the aspects of determination of emission sources, producing processes of secondary particulates in the ambient, removal mechanism of the particulate matters and so on.

The PART II of the report will describe as the basic information on (1) the basic nature of the particulate matters (2) producing and removal mechanisms of the particulate matters, (3) monitoring methods and ambient standards of the particulate matters, (4) assumption methods of contribution rate by the emission sources of the particulate matters and so on.

CHAPTER 1 CHEMICAL AND PHYSICAL NATURE OF PARTICULATE MATTER

II-1-1 Definition and Classification of Particulate Matter

The particulate matter (aerosol) is commonly classified by the generation processes, the chemical & physical nature and so on.

(1) Dust

The dust is defined as the solids suspending in the ambient in various sizes and forms without accompanied by chemical reaction. It is usually generated mainly from pulverising processes including smashing, grinding, drilling and explosion. The most part of dust is more than 1 micron in size but their sizes and forms are quite unequal.

(2) Fume

The fume is defined as the particulate generated from evaporation and coagulation processes of the solids. It is generated mainly from the metal heating, welding, cutting and so on. The fume is suspending in the ambient as oxide by chemical and physical reaction in its generating processes and it is usually a crystal and the sizes are mainly under 1 micron.

(3) Smoke

The smoke is usually generated by the combustion processes and it contains organic substances by incomplete combustion, such as ash, water and so on. It is colored particulate and each particulate is round shaped but sometimes they coagulate into flock.

(4) Mist

Generally it is defined as fine liquid particulate. It is generated from evaporation and coagulation processes of the liquids, and it is diffused in the ambient by pulverising and spraying of the liquids. The sizes are quite unequal, depending on the generating processes.

It is defined in Japan that the suspended particulate matter (SPM) is the fine particulate under 10 microns and the total particulate matter (TPM) is the coarser particulate exceeding 10 microns. SPM is suspending in the ambient for comparatively long term than TPM. Due to the possible health effects on respiratory organs, the environmental standard is implemented on SPM concentration.

Besides the above, and in the field of meteorology, it is classified as follows, putting emphasis on the sizes of the particulate.

(1) Aitken particle ... 0.001 - 0.1 microns
(2) Large particle .... 0.1 - 1 microns
(3) Giant particle .... 1 - 100 microns

Further it is also classified from the standpoint of visibility and color.

(1) Fog

It is fine water drop suspending in the ambient and vertical visibility is less than 1 km.

(2) Mist

It is also fine waterdrop suspending in the ambient but visibility is over 1 km.

(3) Haze

It is fine and dry particulate suspending in the ambient. The color is blueish purple in the dark background and it is yellowish brown in the bright.

The classification by the emission sources are shown in Fig. II-1-1. It is classified into two categories; natural sources and man made sources or Anthropogenic sources. Further, it is also classified by generating mechanism as primary particle and secondary particle. The primary particle is emitted into the ambient directly from the sources. The primary particle from the natural sources are sea salt particle, soil particle, volcanic ash and so on.

The primary particle from the man made sources is the particulate matter emitted from factories, power stations, iron & steel mills and so on.

The secondary particle is represented by sulpher compounds such as SO_2, H_2S and etc., nitrogen compounds such as NO_x, NH_3 and etc., and botanic Hydro-carbon like TERPANE which are produced in the ambient by photochemical reaction followed by various chemical reaction. The sizes of the secondary particles are mostly under 0.1 microns which belongs to Aitken particle. The chemical components of these secondary particles have not been fully studied but it is presumed from their generating processes that they are mainly sulfate, nitrate and hydrocarbon compounds.

Direct source → aerosol	Natural source	Sea (sea salt particle)
		Ground surface (wind dust)
		Universe (meteoric dust)
		Forest fire (burnt substances)
		Volcanic eruption (volcanic ash)
	Man-made source	Farming (wind dust, slash & burnt agriculture)
		Combustion (ash, smoke)
		Urban & industrial activities (particulate matter, smoke)
		Transportation (emission gas, soil winding up)
Indirect source → gas → aerosol	Natural source	Botanic activities (terpane)
		Sulpher cycle (botanic life, H_2S etc.)
		Nitrogen cycle (botanic life, NH_3 etc.)
		Volcanic gas (SO_2, H_2S etc.)
	Man-made source	Sulpher compounds (SO_x)
		Nitrogen compounds (NO_x)
		Hydrocarbon (emission gas, solvents)

Fig. II-1-1 Classification of particulate matter by the emission source

II-1-2 Physical Nature of Particulate Matter

The particulate matter in the ambient are composed by many types of particles different in sources and diffusion behaviours. The physical and chemical nature of the particulate matter is fully concerned with human health, visibility, and climatic conditions. Fig. II-1-2 shows the classification of particulate matter by physical nature, by Lapple[1].

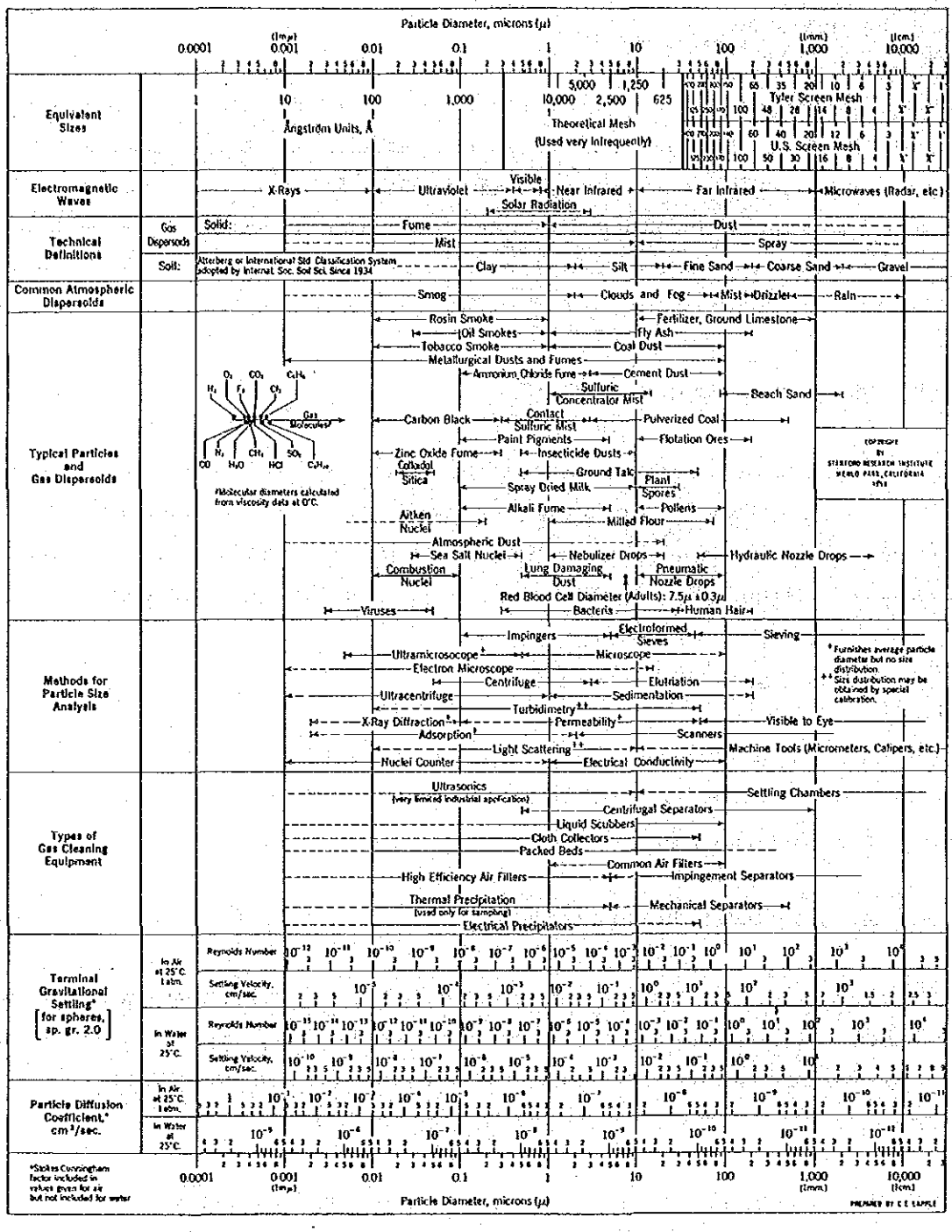


Fig. II-1-2 Physical character of particulate matter

II-1-2-1 Particle size

The particulate matter, as shown in Fig. II-1-2, has very wide variation in sizes, from oligomer of about 0.002 microns to sandy particles of about 500 microns, which corresponds to the difference of 10^5 in sizes and 10^{15} in volume. The particulate matter of about 0.1 microns is almost equal to mean free path of aerosol and the wave of visible beam. It is therefore quite different in dynamic treatment and physical phenomenon between the particles of over 0.1 microns and under 0.1 microns.

II-1-2-2 Density of particulate matter

The gravity of the particulate matter shows quite different values from that of their original substances through coagulation processes in the ambient. The gravity is generally in the range of 0.1-10 g/cm^3. The particulate matter in the ambient has wide variation in gravity by coagulation and absorption of the particles in their generating processes.

II-1-2-3 Forms of particulate matter

The forms of the particulate matter in the ambient have the wide range as they are originated from various sources. It is generally suspended in the air in the various irregular forms (round, chain and so on).

II-1-2-4 Size distribution in the ambient

The sizes of the particulate matter suspended in the ambient are widely distributed by the different generating sources as mentioned in the previous clauses. Fig. II-1-3 shows the size distribution of the particulate matter by generation and removal processes together with their main original sources (Whitby et al.[2])

The size distribution based on the surface area is divided into 3 modes in the figure. The coarse particles of over 2 microns are originated from the primary particles of natural background and man made sources. The fine particulate matter smaller than 2 microns are generally composed by the primary particles from man made sources and the secondary particles chemically reacted in the ambient.

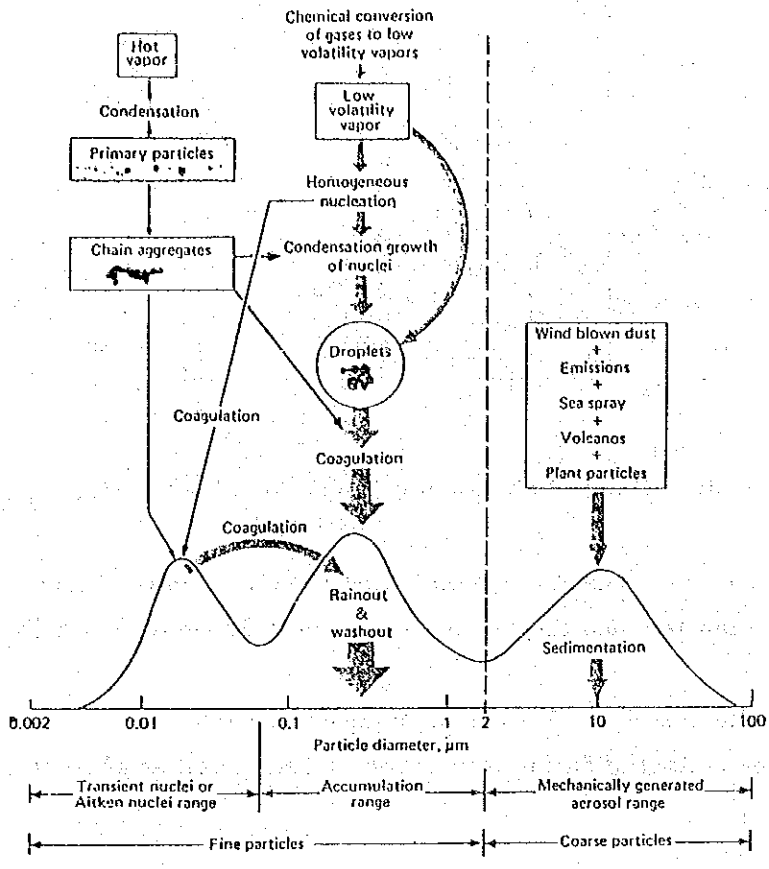


Fig. II-1-3 Size distribution of particulate matter in the ambient

II-1-3 Chemical Composition of Particulate Matter

The chemical composition of the particulate matter in the ambient is not identical. When the particulate matter is divided by 2 microns, the fine particulate is composed by C, Pb, V, Br, SO_4^{-2}, NO_3^- and etc. which are directly related to the combustion processes, and SO_4, NO_3 mist and etc. which produced from gaseous elements in the ambient. On the other hand, coarse particles are composed by the substances such as sand, sea salt, volcanic ash which are originated from the natural sources and their main elements are Si, Ti, Al, Fe, Na, Cl and etc., as shown in Fig. II-1-4.

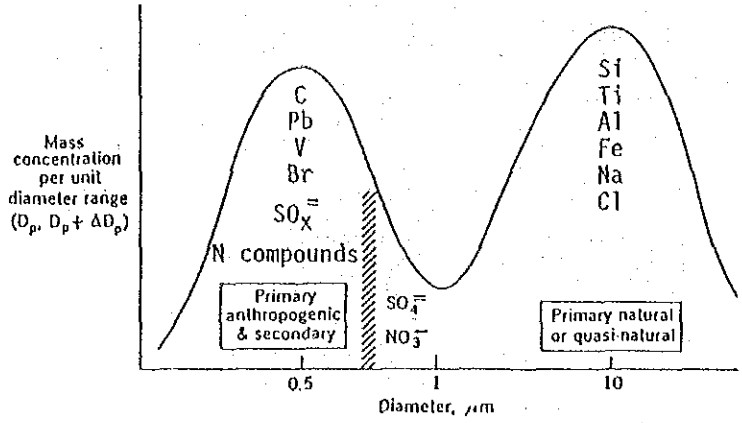


Fig. II-1-4 Size distribution and chemical composition of suspended particulate matter

Table II-1-1 shows the results of monitoring of sulfate, nitrate and organic substances in the particulate matter, and their composing rate in Japan and USA (by Sakamoto[3]).

Table II-1-2 illustrates the results of analysis by Countess et al. for 113 samples of particulate matter collected during November 11 to December 21 1978 at the occasion of Denver smog.

From the table, the particulate matter under 2 microns of the urban areas are mainly composed by sulfate, nitrate, organic carbon, elemental carbon and so on.

Table II-1-1 Chemical composition of particulate matter (Sakamoto 1982)

Site	Date	Size	SPM (g/m^2)	SO_4^{2-} (%)	NO_3^-, (%)	Organics (%)	Authors	Ref.
Pasadena (California)	9/20/72 12:00-14:00		79	4	5	43	Hidy et al. (1975)	4, 5
Pomoma (California)	9/20/72 12:00-14:00		178	13	26	24		
Pasadena (California)	7/25/73 9:30-17:30		220	14	9	35	Grosjean & Friedlander (1975)	6
Pasadena (California)	9/22/72 7:30-12:35	below 1 μm	157	11	1	15	Schuetzie et al. (1975)	7
West Covina (California)	7/23-24/73 21:21-21:21	below 3.5 μm	144	30	1	25	Cronn et al. (1975)	8
Denver (Colorado)	11/11-12/11/78	below 2.5 μm 2.5~30 μm	40 51	10 2	15 2	22 7	Countess et al. (1980)	9, 10
Denver (Colorado)	11/11-12/11/78	below 2.5 μm	36~55	8~19	6~14	18~35	Heisler et al. (1980)	11, 12
Urawa (Saitama)	8/7-8/78		133	7	1	17	Sakamoto et al. (1980)	13
Urawa (Saitama)	5/27-6/17/80	below 2.0 μm above 2.0 μm	42 66	19 5	3 6	17 4	Sakamoto et al. (1980)	14
Great Smoky Mountains (Tennessee)	9/21-26/78	below 2.4 μm	24	48	ND	14	Stevens et al. (1980)	15

Table II-1-2 Chemical composition of particulate matter in Denver (Countess et al 1980)

Component	Fine aerosol fraction		Coarse aerosol fraction	
	(μg/m^3)	(%)	(μg/m^3)	(%)
Observed mass	36.53	100	50.91	100
$(NH_4)_2SO_4$	5.39	13.6	1.22	2.4
NH_4NO_3	7.90	20.0	1.53	3.0
Apparent organic C	8.54	21.6	3.69	7.3
Apparent elemental C	6.04	15.3	1.71	3.4
Non-$SO_4^=$S	0.98	2.5	0.34	0.7
Pb salts	2.57	6.5	1.01	2.0
Trace elements[a]	0.19	0.5	0.15	0.3
H_2O	1.91	4.8	2.46	4.8
Σ[b]	33.52	84.8	12.11	23.9
Soil(28.5%Si)	2.86	7.2	32.37	63.6
Σ[c]	36.38	92.0	44.48	87.5
Soil(20%Si)	4.07	10.3	46.13	90.6
Σ[d]	37.59	95.1	58.24	114.5

[a] Includes oxides of V, Zn, Ba, and excess fine Al.
[b] Sum of above eight components.
[c] Sum of b plus soil (28.5% Si).
[d] Sum of b plus soil (20% Si).

CHAPTER 2 GENERATION AND REMOVAL MECHANISM OF PARTICULATE MATTER

II-2-1 Generated Volume of Particulate Matter in Global Scale

Table II-2-1 shows the results of assumption by Ellsaesser[17] on generating volume of particulate matter (smaller than 5 microns) in global scale by natural and man made sources.

From the figures in the table, it is assumed that particles from natural sources are 69% of the total volume, and the secondary particles are 45% in the global scale.

The man made generation of soil particles mainly depends on desertization promoted by farming and pasturage prevailing in the dry areas of the world. The man made generation of forest fire is by slash and burn agriculture. The assumption on generating volume of particulate matter in global scale is just a result of rough calculation, and it is not so scientific, but the generating volume from these various sources will increase corresponding to the increase of the world population. And such situation will possibly give impacts on the climatic conditions in the global scale.

Table II-2-1 Generating volume of particulate matter of global scale

	Volume under 5 microns (10^6 ton yr^{-1})	
	Natural	Man-made
Primary particle		
Sea salt particle	500	
Soil particle	100	150*
Forest fire	5	60*
Volcano	25	-
Factories, power stations Incinerator etc.	-	30
Sub-total 870 (100%)	630 (72%)	240 (28%)
Secondary particle		
Sulpher compounds	335	200
Nitrogen compounds	60	35
Hydrocarbon compounds	75	15
Sub-total 720 (100%)	470 (65%)	250 (35%)
Total 1590 (100%)	1100 (69%)	490 (31%)

* Indirectly concerned with human activities

II-2-2 Generation Mechanism of Particulate Matter

II-2-2-1 Primary particle - natural sources

(1) Sea salt particle

The most of the sea salt particles are generated by the burst of foams produced on the sea surface. The generating mechanisms are generally understood as following two cases;

(a) Many number of foams are produced in the white crested waves and burst on the sea surface when they diffuse into air as jet drops. The foams of 100 - 1,000 microns in sizes are changed into jet drops of 10 - 100 microns, about one tenth of the original size.

(b) Another generating mechanism is that the film cap of the foams having over 300 microns in diameter are burst into about 100 film drops.

Further, the spray dispersed from the waves are usually rather big in sizes and they are fallen down to the sea within short time.

These sea salt particles increase by the wind speed and they are transported from the coastal area to the inland areas, sometimes for long distance.

(2) Soil particle

The soil particles in the ambient are generated from weathered rock, pulverized rock byblowing sand and dried land surface curled up by wind. According to the experiments by Bagnold[18], the particles of 40 microns in radius are most easy to be transported. The bigger particles and also smaller particles are not easy to be transported due to heavy in weight and adhesive respectively. This was confirmed by Junge & Janicke[19] who studied the soil particles transported from Sahara desert on the Atlantic Ocean. According to the study, most of the soil particles flown from Sahara Desert are 1 - 20 microns in sizes which is correlated to the study by Bagnold. The soil particulates reacted into aerosol are usually transported for long distance and it will be confirmed by the fact that yellow sand generated in the northern part of mainland China is monitored in Japan.

(3) Volcanic particle

The particles produced by volcanic eruption are solid substances, like volcanic ash, and gaseous substances such as H_2O, SO_2, H_2S and so on. The volcanic ash is usually monitored in high concentration just after the eruption and fallen down in short time. The gaseous secondary particles are suspended for long and give impacts rather for long period. Fig. II-2-1-(a) shows yearly variation of sulferic acid ion (SO_4^{--}) existed in the height between 18.3 to 19.8 km and 15.2 km in the southern hemisphere. In the figure a, the names of volcano erupted and their latitude are described and in the figure b, the concentration of sulferic acid ion and their yearly variation in the northern hemisphere are described. From these, variation of sulferic acid ion concentration in the stratosphere is confirmed being closely related to volcanic eruption.

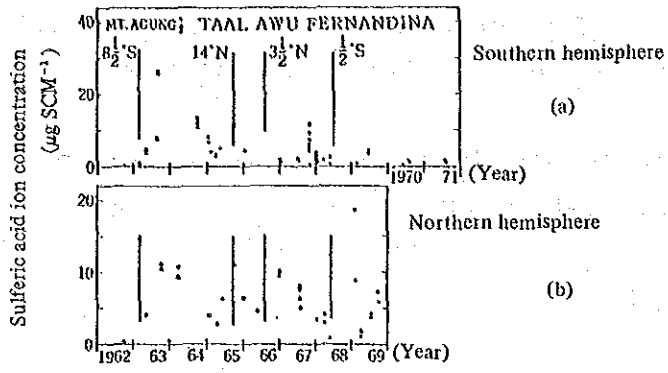


Fig. II-2-1 Yearly variation of sulferic acid ion concentration in stratosphere

(4) Forest fire

The forest in the tropical areas have been burnt for agricultural purpose and CO_2 and carbon of incomplete combustion have been generated in high concentration for which serious attention has been extended. The results of analysis of the particles produced by forest fire are 50% of organic substances such as Benzen, 40% of carbon and 10% of mineral substances. These substances promote the generation of secondary particles as the catalyst of conversion from gases to particles. And they give the influence on the global abnormal temperature by the absorption and reflection of sunlight.[21)]

(5) Others

Besides the above, comparatively great volume of sulpher, organic substances and other particles are generated from plants growing in the land and sea areas of natural background. The sulpher botanically generated is oxidised into SO_2 and finally reacted into sulfate. H_2S is produced by unaerobic bacteria and Sulferic Methyl is generated from land soil, sea weeds and fallen leaves. Volatile organic substances are mostly Terpane by the plants. It is also confirmed by the experiments used radioactive substances that the particulate matters are produced and emitted from plants.[21)]