II-2-2-2 Primary particle - man made sources

(1) Stationaly source

As shown in Table II-2-2, the dust produced by combustion, particulate matter by pulverising, fume bymetal smelting processes are emitted from the stationary sources in various types and forms.

Table II-2-2 Particulate matter generated from stationary source

Facility	Kinds of emission
Boiler	Cinders, flyash, fume and smoke
Cement kiln	Clinker dust, dust
Ore calcinating furnace	Metal oxide, flyash, mineral powder, fume, dust
Blast furnace	Mineral powder, coke powder, slag dust, dust
Ferroalloy furnace	SiO_2 dust, dust
Steel manufacturing open-hearth furnace	Ferrooxide, dust
Ceramic furnace	Flyash, dust
Steel convertor	Dust
Cement kiln	Dust
Cupola	Dust
Coke oven	Powder dust
Metal silicone furnace	SiO_2 dust
Carbon black furnace	Dust
Wastes incinerators	Dust, flyash
Coal carbonization furnace	Tar mist
Sulfuric acid plant	Sulfuric acid mist
Zinc plating	Zinc oxide, ammonium fume, powder dust
Mineral pulverization, screening, powder disposal transportation equipment	Dust, powder dust
Street paving material disposal furnace	Dust, SiO_2 dust, tar mist

The dust and smoke are produced by the incomplete combustion but the emission volume, size distribution, metallic components and so on are widely different by the types of fuel, combustion condition, object materials, installation of dust collecting facilities and son on.

The particulate matter is mainly produced in the processes of physical pulverising and their sources are storage yards, construction sites and so on. Diffusion of the particulate matter is closely related to the size distribution, surface area and contained humidity of the accumulated substances, together with wind velocity of the area.

(2) Automobile

Generation of particulate matter by automobile driving are

(a) particulate matter contained in emission gases
(b) friction of tires and pavement
(c) winding up the substances laid on the road by driving automobiles

(a) Particulate matter contained in emission gases

In the process of fuel combustion, carbon and organic substances are produced by non-hydrogen decomposition and polymerization. When the light oil is used as fuel, sulpher contained generate the sulfate, and nitrate by nitrogen oxide. The metal elements are also emitted which are contained in the fuel and lubricating oil. In case of diesel engine, the emission gases contain 80-90% of carbon, 2-5% of hydrogen, about 1% of nitrogen and 2-5% of sulpher.

(b) Friction of tires and pavement

The particulate matter is produced by driven automobiles which are accompanied by friction of tires and pavement. The generating volume and the sizes of the particulate produced by automobiles are not studied yet but according to the experiments conducted in the tunnels, rubber particles are found about 4-7% of the total volume of particulate matter.[22)]

(c) Winding up the substances laid on the road by driving automobiles

The substances laid on the road are winded up by driving the automobile and diffused in the ambient. The volume of diffused particulate is widely different by the conditions, paved or not, and cleaned or not.

(3) Others

The particulate matter is also produced and emitted from aeroplanes and steamers. In the case of aeroplane, the emission volume is widely different by types of engines, flight conditions (idling, approaching, take-off). In the case of steamers, it is also widely different by navigating conditions including tonnage, types of engine, and so on.

II-2-2-3 Secondary particle

The gaseous substances such as SO_2, H_2S, NO_x, NH_3, HC etc. convert to solid and liquid particulate matter in the ambient, by photochemical and thermochemical reaction and sometimes adhere to other substances, and are removed by rain and so on.

Gas to particle conversion processes are complicated. The gaseous and liquid particulate convert into new type of particulate which is defined as homogeneous nucleation process. And gaseous particulate is just condensed and kept being gaseous state which is defined as heterogeneous nucleation process.

(1) Generation of inorganic particulate matter

The main components of inorganic secondary particles are sulferic acid ion, nitric acid ion, ammonium ion and so on. The reaction from SO_2 to sulfate is;

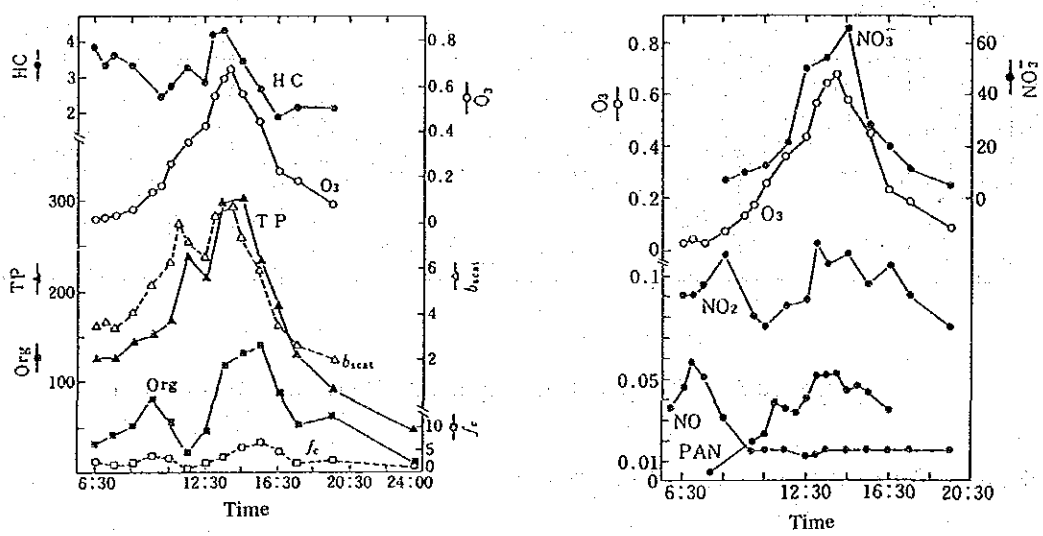
(a) Oxidization by hydrocarbon and O_3
(b) Direct photo-oxidization
(c) Oxidization of SO_2 by catalystic application to dried particulate (Pb, Fe, Al etc.)
(d) Oxidization of SO_2 by catalystic activities of Fe and Manganese contained in the liquid drops.

The particulate of sulfate generated by homogeneous and heterogeneous nucleation processes are growing with sulferic acid vapour existing in the ambient. Also they convert into the particulate of sulferic ammonium by neutralization reaction with ammonium in the ambient. The speed or time required for conversion from gaseous SO_2 to particle SO_4^{--} depends on concentration of Ozone, humidity, catalystic substances existing in the ambient, but according to the recent data obtained through monitoring, the values are 0.1 - 10%/h[23], and the higher values are obtained in daytime than nighttime, and summer season than winter.

Oxidizing processes of NO_2 to HNO_3 are complicated but nitric acid is volatile with higher vapour pressure, and so generated nitric acid particles are evaporated and are existed in the ambient as nitric acid vapour. In case the concentration of gaseous nitric acid is high, particulate of $NaNO_3$ is produced by chemical reaction with sea salt particles. This particulate of $NaNO_3$ have the similar size with sea salt particles, and the size distribution of NO_3^- shows higher peak in the side of coarser particles in summer. Also in winter, NH_4NO_3 produced by neutralization reaction with ammonia and nitric acid generated by heterogeneous nucleation processes are mostly composed by NO_3^- ion and show the peak in the side of finer particles. When the reaction with sea salt particles and nitric acid is promoted, hydrogen chloride gas is produced and the chlorine contained in the particles decrease. So when the volume of Na and Cl contained in the total particulate are compared, the Cl volume decrease compared with Cl^-/Na^+ of the sea water. This phenomenon is called as chlorine loss.

(2) Generation of organic particulate matter

Compared with the cases of generation processes of inorganic particulate matter, smaller number of studies have been conducted on the generating processes of organic particulate matter. The generating processes are (a) organic gases convert into particles by physical and chemical reaction, (b) after emitted into the ambient as high temperature gases, they are cooled and condensed into particles (c) the process absorbed and adhered by finer particles in the ambient. Fig. II-2-2 shows the results of study by Grosjean et al.[6], conducted at the occasion of photochemical air pollution on the 25th July 1973. The figure illustrates the variation of concentration of several items of substances. From the figure, it is confirmed that the concentration of NO_3^- organic compounds, and total particulate matter increase with Ozone.



HC: gaseous hydro-carbon
TP: total aerosol
Org: organic aerosol
b_{scat}: light scattering coefficient by aerosol
fc: aerosol HC/gaseous HC

Fig. II-2-2 Variation of pollutants in PASADENA

II-2-3 Removal Mechanism of Particulate Matter

The removal of particulate matter in the ambient is

(a) wet removal which the particulate is removed by cloud particle produced through rain-fall process, crystal ice and rain drop, and

(b) dry removal which the particulates reach to the ground by natural fallout and turbulent transportation.

For the discussion on particulates concentration in the ambient of the global scale, the removal mechanism of particulate matters of the sea face areas should be considered.

Fig. II-2-3 shows the removal mechanism of particulate matters in the ambient. From the figure, it is characteristic that the removal mechanism of the particulate matter is quite different depending on the particle sizes.

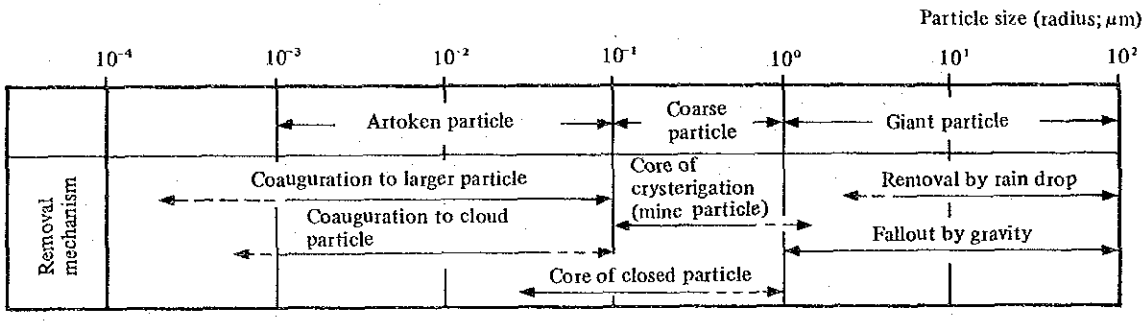


Fig. II-2-3 Removal mechanism of particulate in ambient

II-2-3-1 Removal by coagulation

Aitken particles smaller than 0.1 microns are transported for long distance by Brownian motion, and they are condensed into bigger components by coagulation of each particles in the processes of diffusion. This process is called as coagulation.

Fig. II-2-4 shows the size distribution of particulate is variating with time lapse by coagulation.[24)]

The numerical concentration of particulate under 0.01 microns decreases within a few hours, and the particulate size corresponding to the peak value of numerical concentration is changing to the bigger size with time lapse. However, the bigger particulate of more than 0.1 microns is not influenced by coagulation and no changes of numerical concentration are identified. The coagulated Aitken particles are gradually removed from the ambient by adhering to larger particles and cloud particles through diffusion processes.

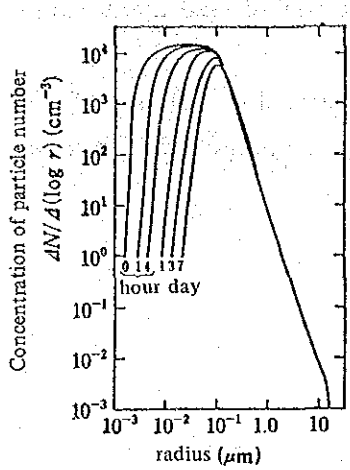


Fig. II-2-4 Size distribution variation of particulate matter by coagulation

II-2-3-2 Removal by sedimentation and fallout on ground surface

Fig. II-2-5 shows the time required to reach the respective height on the assumption that the particulate matters are fallen from the height of 55 km.[25] From the figure, the time required for the particulate of 10 microns in radius to reach to the ground from the height of 15 km is about 12 days but in the case of particulates of 1 micron is 2.8 years, 0.1 micron is 112 years and 0.01 micron is 1,530 years.

These figures are calculated on condition of being standstill, and so in the actual turbulent conditions, more time is required than that of calculation. Under the circumstances, the removal of fine particulates will not be effectively expected by gravity. But the particulate matters which are not easy to be fallen are transported by turbulent transportation to the nearby area of the ground, and by Brownian motion, inertial collision and other various migration, they reach to the ground.

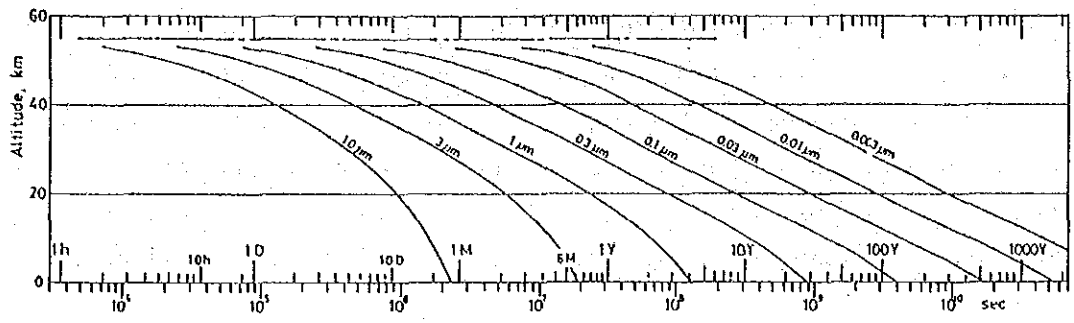


Fig. II-2-5 Time required for sedimentation of particulate matter

The measurement of sedimentation volume of the particulate matters have been carried out in various ways, and an example of such measurement is shown in Table II-2-3.

Table II-2-3 An example of study on sedimentation speed Vd of particulate matter

Researcher	V_d (cm/s)	Particle size (μm)	Deposition surface	Reference
Chamberlain (1953)	2.1 1.1 0.5	16 16 16	Grassland	u = 9.2 m/s u = 3.2 m/s u = 1.1 m/s
Eriksson (1959)	0.7 1.6		Ocean Land soil	Scandinavia Chloride
Small (1960)	0.5 (0.2-3.4)		Land soil	Norway Radio active particle
White et.al. (1970)	5.6 4.7 3.0 7.1 0.8	Na K Ca Mg P	Soft & hard woods complex	Over evaluated
Esmen et.al.	0.5D	0.1-10	Filter Glass slides	
Chamberlain et.al. (1972)	0.06 u_* 0.12 u_*	20-30	Cereals plants	Dry & wet
Pierson et.al. (1973)	0.1-0.6		Land soil	23 trace elements
Cawse (1974)	1.3 0.22 (0.45) 0.50 (0.50) 1.1 0.56 (0.45) 0.30 (1.0) 0.29 0.62	Al As Cd Cr Cu Fe Mn Ni Pb Ti V Zn		
Hart et.al. (1974)		Na, Ca, Mg, K, P, NO_3	Pine trees	Depositions under trees / Depositions = 3-16 on open fields
Clough (1975)	3.4 7.3 11 61 100 0.74 1.1 0.75 12.7	30 4 3	Grassland Grassland Grassland Dry moss Wet moss Grassland Grassland Dry moss	Dry u_* = 37 cm/s Dry u_* = 87 cm/s Wet u_* = 87 cm/s Dry u_* = 37 cm/s Dry u_* = 37 cm/s
Abrahamsen et.al. (1976)		SO_4^{2-}	Pine trees	Deposisions under tree / Depositions on open fields = 2
Dovland et.al. (1976)	0.16 0.68		Snow	Pb SO_4^{2-}
Fritschen et.al.	0.07 0.46	3	Fir	
Prahm et.al. (1976)	0.4		Atlantic ocean	SO_4^{2-}
Krey et.al. (1977)	0.5			
Wesley (1977)	0.6	0.0^{5}-0.1	Open field, grassland	u < 2 m/s

$$Vd = \frac{\text{flux}}{C}$$

where: flux; sedimentation volume ($g/cm^2.S$) per unit time and unit area

C; concentration (g/cm^3) of sedimentation particle at 1 meter high from ground

II-2-3-3 Removal of Particulate Matter by Rainfall

The most effective removal mechanism for finer particles under 10 microns which are not influenced by gravity fallout is the removal by rainfall. These processes are usually classified in two which are rainout and washout. The rainout is defined as removal mechanism occurred in the cloud and the washout is defined as the process under the cloud layer to remove particulates with rainfall drops.

(1) Removal by raindrops under the cloud base (Washout)

Washout is the removal mechanism that the particulate matters are removed with rainfall drops by diffusion and inertial collision processes. Fig. II-2-6 illustrates the curve of parameters, rainfall intensity and rainfall continuing time. According to the sequences shown by dotted line and arrow mark, the removal rate of particulate matters by particle sizes are obtained under the voluntary condition.

From the figure, the removal of particulate matter by rainfall is more effective for giant particles of over 4-5 microns, and for Aitken particles it is not so directly contributed.

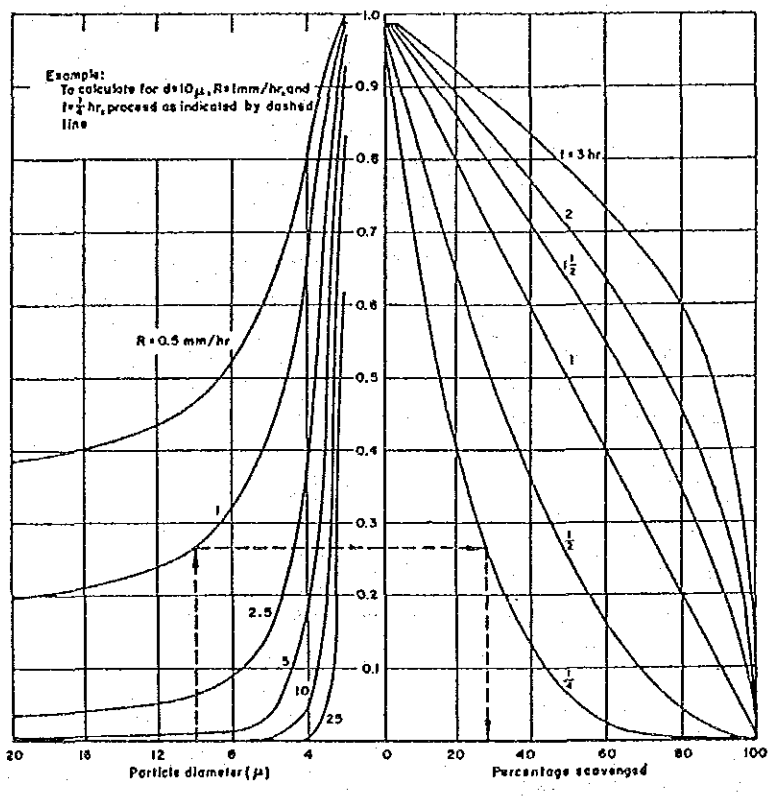


Fig. II-2-6 Ratio of particulate matter contaminated with rainfall by inertial collision

(2) Rainout in cloud process

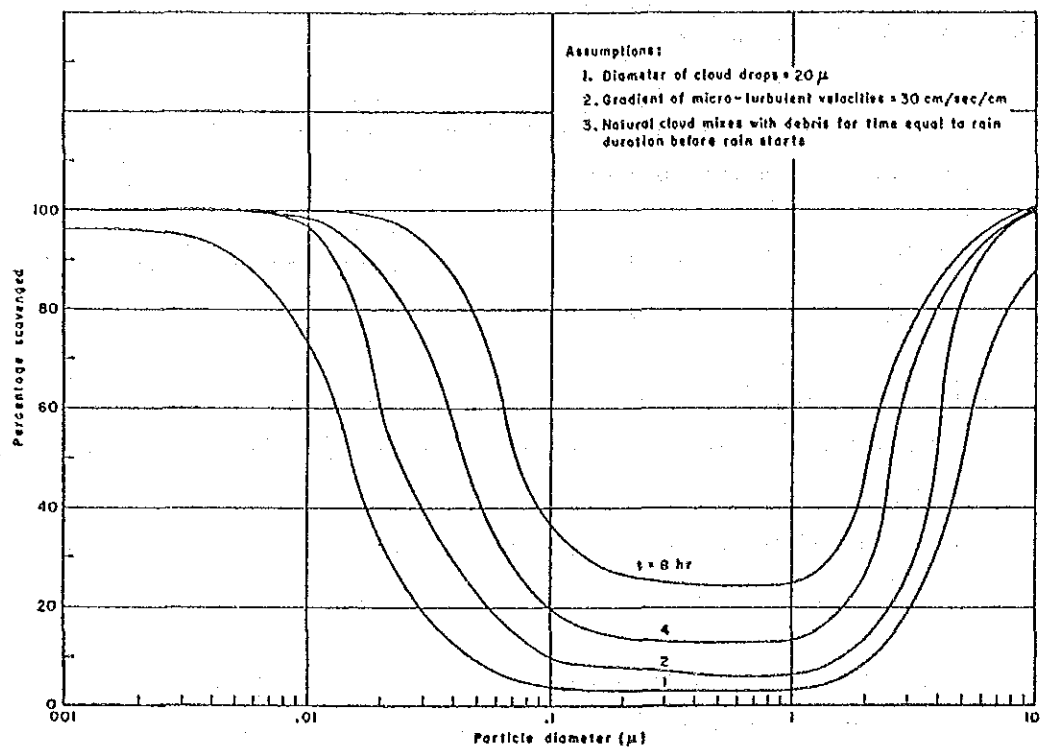
The rainout is the generic name of removal mechanism occurred in the cloud and the following physical processes are considered to be.

(a) The process which the particulate matters are functioned as the core when the cloud particles are generated.

(b) The coagulation of the particulate matters into cloud particles by Brownian motion, including the coagulation caused by turbulent flow in the ambient.

(c) The particulate matters gathering each other in the processes of their vapor flowing to the cloud particles.

Fig. II-2-7 shows the comprehensive results of particulate matters by rainfall, being rainfall continuing time as parameter with rain-intensity R, speed slope w vertical to flow line, radius of cloud particle Vt, and cloud water volume being fixed, (Greenfield[26]). It is clear from the figure that gathering by raindrops are effective for the particulate matter bigger than 2 microns and gathering by cloud particles is effective for smaller particulate than 0.1 micron. And both processes are found not effective for the particulates of intermediate sizes.



Radias of cloud particle: 10 μm
Rainfall intensity: 2.5 mm/hr.
Cloud water volume: 0.4 x 10^{-6}g/cm^3
Turbulence speed gradient vertical to flow line: 30 cm/sec.cm

Fig. II-2-7 Removal rate of particulate matter by rainfall

II-2-3-4 Extinction of particulate matter on sea surface

It is considered that the removal mechanism of the particulate matter on the sea surface is quite different from that of the land surface, but it is not identified yet. Toba[27] has reported that fine water particles and giant sea salt cores produced by wave motion are always exist in the vicinity of the sea surface, and they are repeating evaporation and coagulation processes.

II-2-4 Suspending Time of the Particulate Matter

The suspending time of the particulate matter in the ambient depends on the removal mechanism but generally the components of the particulate matter in the vicinity of the emission sources are simple. In the cases transported long from the sources, the components are complexed because of the various processes, such as coagulation between particles, chemical reaction of the particles, gathering into the cloud particles, evaporation of cloud particles and so on. It is therefore desirable to estimate the suspending time of the particulate matter from components and sizes, considering the development of the processes after generation of the particulate matter, although it is very difficult.

Fig. II-2-8 shows the averaged suspending time of the particulate matter in the various height of the ambient by Flohn[28].

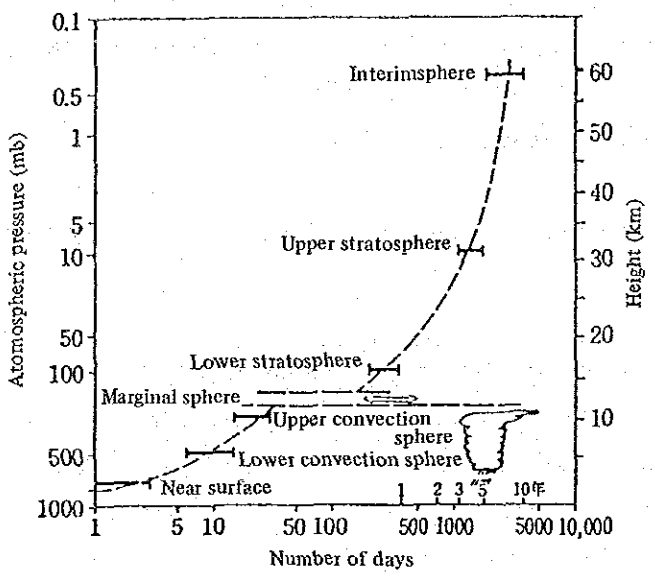


Fig. II-2-8 The averaged suspending time of the particulate matter in the various height of the ambient

In the convection sphere where the removal mechanism is effective by cloud and rainfall processes, the averaged suspending time is very short compared with that of stratosphere. The suspending time in the convection sphere is about 1 to 2 weeks but in the stratosphere, it is found 1 to 3 years. Further it is recently studied the averaged suspending time of the particulate matter using radio-active substances as tracer from the fact that the radio-active substances are easy to be collected or gathered by particulate matter.

CHAPTER 3 MEASURING METHODS OF PARTICULATE MATTER AND ENVIRONMENTAL STANDARD

II-3-1 Measuring Methods of Particulate Matter

There are many kinds of measuring methods of particulate matter but in this report, some typical methods employed in major countries will be described.

II-3-1-1 Classification of measuring methods

The measuring methods of particulate matter are classified into 6 as shown in Table II-3-1.

Filter contamination method is to induce air through white filter, to measure permeation rate from reflection rate of contaminated filter, and to convert such rate into weight concentration by calibration curve previously prepared. It is usually called as Smoke Method and it has been long employed in European countries. This method has been recommended in OECD countries and mainly in England. In the United States, this method is arranged to automatic and continuous system using tape filter.

Filteration method is to suck air by pumping through filter, and to measure the weight of substances collected by filter. This is one of the most basic methods and depending on the sucking volume, it is called as high volume and low volume methods. The boundary volume of these is 6 m^3/h.

Light scattering method is to scatter the light on the suspended particulate matter and to convert into weight concentration on the assumption that the intensity of scattered light is correlated to weight concentration.

Beta ray absorption method is to light the Beta ray on the filter of round spot and to convert the permeated Beta ray intensity into weight concentration, on condition that weight concentration is correlated with permeated Beta ray intensity.

Piezo balance method is to oscillate a pair of crystal oscillater by its characteristic frequency, to collect the object particles on the surface of oscillater and to measure the fluctuation of frequency which is correlated with weight concentration.

Size distribution method is based on the same principle with the filtration method and the particulate is collected in several categories of the particulate sizes.

Table II-3-1 Classification of measuring methods of particulate matter

Monitoring method	Monitoring instrument	Principle	Size range	Remarks
Filter contamination method	Smoke sampler (OECD method)	o Suck air through white filter. Usually 24 hours. Contamination of filter is measured by reflection index meter. Value is converted to international smoke unit (ug/mg). Simple mechanism and fitted to continuous monitoring	0 to 20-30 μm	o Widely used in European countries. Method recommended by OECD. Air sucking speed is low and sample is limited to inhalable particles. The results of monitoring is influenced by black color substances, and not indicating real weight. Limited range of chemical analysis is possible even by small quantity of sample
	Tape sampler (ASTM method)	o Same with OECD method. Sample collected on filter automatically forwarding with 2-6 hours interval. Contamination is evaluated by transparancy index and expressed by haze unit (COH) usually, but some cases, by reflection index (RUDS)	0 to 40 μm	o Flow rate is larger than OECD method. Effective sampling of inhalable particles is possible by method employed in USA. Fitted for continuous monitoring.
Filtration sampling method	High volume sampler	o Air is sucked through glass fibre filter usually by turbine blower. Collected sample is weighed under constant temperature and humidity. Most widely used and in West Germany membrane filter and rotary pump are employed.	0.1 to 80-100 μm	o Widely used in USA. Particulate larger than inhalable particle is apt to be collected, and not fitted for monitoring in dirty places. Sampling is usually for 6 days with 24 hours cycle. Obtainable enough sample for chemical analysis.
	Low volume sampler	o Principle is same with high volume sampler, but flow rate is far samller and designed to be fitted for long term air sucking.	0 to 20-30 μm	o Flow rate is smaller than high volume sampler and possible to sample inhalable particles effectively. In Japan, used with cyclon type separator or multi-stage separator to cut the particles larger than 10 microns.
Light scattering method	Digital dust analyser	o By light scattering, directly measure particulate as aerosol. Individual particles are counted and measure particles size or integrate the scattered light from a certain volume of air.	0.5 to 10 μm	o Used as monitor of SPM in Japan in some extent. But calibration is always necessary and evaluation impossible to compare with direct weight method.
Beta ray absorption method	Beta ray absorption mass monitor	o Particulate matter is collected on filter for a certain time (usually 30 min.) continuously. Beta ray irradiated and a part of energy is absorbed. Weight conc. is determined by Beta ray intensity transmitted.	0 to 20 μm (filter system)	o Instrument cost is usually expensive. In West Germany, used for monitoring. Important instrument to study short time variation of particulate.
Piezo balance method	Piezo balance mass monitor	o Based on piezo oscillator method. The weight of particles accumulated on oscillator proportionally change by vibration number, and weight conc. is determined by this relation.	0.01 to 10 μm (electrostatic system) 0.3 to 20 μm (impactor system)	o This method is high sensitive, but defects in electrostatic collection index and impacts of humidity to sample. Detection of weight without removing substances accumulated on quartz is limited.
Particle separating method	Cascade impactor	o Particulates are classified into several stages by impaction. Weight of each substance is directly weighed.	0.5 to 20 μm	o Conc. in certain range of particle size is evaluated. Used in USA but not widely used.
	Dichotomos sampler	o Known as vertical impactor. Particulate is separated to 2 size range and each particle is collected on filter and weighed.	0 to 30 μm	o Used in USA for monitor of sulfate. Under consideration to be used for monitoring particulate matter in USA.

The above-mentioned measuring methods have more or less merit and demerit and selection of the methods for monitoring the ambient concentration depends on the conditions of the respective countries and sites.

Table II-3-2 shows the instruments employed for monitoring of ambient concentration of particulate matter in major countries.

Official instrument of Japanese regulation is low volume sampler installed with the function of separating particles over 10 microns. But it is not fitted to measure the short time concentration and so the digital dust analyser, Beta ray dust analyser and Piezo-balance analyser are also used together with low volume sampler which are able to measure the hourly concentration.

In the United States, EPA type high volume sampler is commonly used. This instrument is able to collect enough volume of particulate matter for chemical analysis because of high suction rate. It is also useful to identify the chemical components of the particulate matter. But this method is to measure the total particulate matter including all sizes of particulate and so the concentration measured by this instrument is mainly dominated by the larger particulate.

Further the selection of filter is important because of the fact that glass fibre filter mainly used in the States absorbs more acid gases and it has the possibility to increase the apparent weight. This method requires more man-power for replacing filter and flow rate checking, and it is not fitted to measure the short time concentration like hourly value.

For measuring of short time concentration in the States, AISI tape sampler is used. This instrument is useful to study hourly variation of short time average concentration but it is only evaluated by the unit COH (Coefficient of Haze).

As the instruments for monitoring short time concentration, the digital dust analyser, Beta ray analyser and Piezo-balance analyser are used as described in the above. But in order to obtain the scientific results, the measured values should be confirmed for correlation with the values obtained by filtration method before operation.

Table II-3-2 Outline of instruments used for monitoring of ambient concentration of particulate matter in major countries

Name of country	Japan			
Instrument	Low volume sampler	Digital dust analyser	Beta ray dust analyser	Piezo-balance dust analyser
Principle and mechanism	1. Particulate suspending in the ambient is sucked by low volume pump and weighed the particulate collected on filter. 2. Sucking pump, separator (cyclon or multi-stage) filter holder and flow rate detector	1. Particulate is introduced in the black box, light radiated and generate scattered light. Intensity of scattered light is well proportional with particulate quality and quantity if forms, size and relative refraction index of particulate are same. By measuring intensity of scattered light, weight concentration of particulate is obtained. 2. Detector, power unit & so on.	1. Beta ray irradiated by radioactive isotope is absorbed by particulate matter collected on filter. The principle is based on fact that Beta ray intensity and weight of particulate matter are well correlated. 2. Sucking pump, Beta ray source, detector	1. A pair of quartz oscillator is oscillated by peculiar vibration count and collect particulate accumulated on detection element. Increase of weight of detection element is electrically measured and obtain quality & quantity of particulate matter together with air volume sucked under constant flow rate. 2. Sampling part, pressure part, recorder and etc.
Size range	0 to 10 μm	0.5 to 10 μm	0 to 10 μm	0 to 10 μm
Sampling time	24 hours or its integral number multiplied	1 hour	1 hour	1 hour
Monitoring condition	1. Air flow rate ... 1.2 m^3/h 2. Filter ... initial collecting index over 99% against aerosol of diameter 0.3 μm. Glass fibre filter or pore size 1-3 μm of nitrocellulose or acetyl-cellulose membrane filter 3. Desication ... desicating for 24 hours under temperature 20°C and relative humidity 50%. 4. Detection limit ... flow rate 0.5 l/min, balance 0.1 mg	1. Sensitivity ... 1 cph (average size - 0.3 m, aerosol 0.67 $\mu g/m^3$, SPM 1 $\mu g/m^3$) 2. Monitoring range ... 1 to 10^4 cph 3. Precision ... ±10%	1. Flow rate ... 18 l/min 2. Range ... 0 to 5 mg/m^3 3. Sensitivity ... 1 pulse 1 $\mu g/m^3$	1. Flow rate ... 1 l/min 2. Range ... 0 to 50 mg/m^3 3. Sensitivity ... 1 $\mu g/m^3$
Characteristics	1. Filter should be carefully selected. Quartz filter is more desirable than glass fibre filter from absorption rate of acid gas. 2. Desirable to maintain the condition of constant temperature and humidity for long hours. 3. Attention should be given to capacity of separator and its handling method.	1. Not well corresponding with weight concentration, and deviating spatially and timely. 2. Increase of humidity promotes expansion of particles and relative concentration increase. Remarkable when mist and rain. 3. Intensity of scattered light largely influenced by particulate size. Instrument is most sensitive at around 0.3 μm and at 1 μm, maximum sensibility decline to 1/10.	1. 24 and 48 hours average concentration by low volume sampler are well correlated but not enough sensitive for monitoring at low concentration area as detection limit for 1 hour concentration is 20-25 $\mu g/m^3$. 3. Influenced by humidity	1. Very much high sensitive. Good for low concentration but detect any precipitation (water). 2. Long continued operation is impossible because detection elements should be cleaned up after short time operation.

Table II-3-2 Outline of instruments used for monitoring of ambient concentration of particulate matter in major countries (Cont'd)

Name of country	USA and Canada	USA	West Germany		U.K. and Spain
Instrument	EPA high volume sampler	AISI tape sampler	LIB high volume sampler	Beta ray absorption type automatic sampler	BS smoke sampler
Principle and mechanism	1. Air sucked through filter by high volume pump. weight concentration of particulate matter suspending in air is obtained from weight of sampled particulate and sucked air volume. 2. Shelter, filter holder, pump, flow meter, timer and so on.	1. Air separated at 40 μm particles by small cyclon pass through round spot of filter tape. Filter tape is automatically forwarded at interval of one hour or more. Contaminated round spot is irradiated and its refraction index or transmitting rate is measured. Concentration is evaluated by unit of COH. 2. Sampling probe, filter holder, timer, flow meter, air pump, control system and etc.	1. Air containing particulate matter is collected on filter. Round shape - filter holder is fixed by frame and installed at about 1.5 m from the ground directing downward. 2. Called as LIB filter method. Sucking pump, gas flow meter with thermometer, timer, muffler, cooler, filter holder, frame and etc.	1. Round spot of filter tape is forwarded automatically in the fixed interval. Contaminated spot is irradiated by Beta ray and a part of energy and SPM absorbed by filter absorb such radiation. Intensity of Beta ray transmitted and weight concentration is correlated. 2. Sampling probe, filter holder, Beta ray irradiation facility, amplifier and etc.	1. Air is sucked by low volume pump through white filter. Contamination on filter is measured by refraction index meter and converted into weight concentration ($\mu g/m^3$) by calibration curve previously prepared. 2. Sucking pump, flow meter, filter holder, funnel & etc.
Size range	0.1 to 100 μm	0 to 40 μm	0.5 to 80 μm	0 to 20 μm	0 to 20-30 μm
Sampling time	24 hours	1 hour or its multiplied integral number	24 hours	1 to 3 hours	24 hours
Monitoring condition	1. Air flow rate ... 67.8 to 102 m^3/h 2. Filter ... glass fibre filter having collecting capacity over 99% against particulate of 0.3 μm in diameter. 3. Desicating condition ... Temp. 15-35°C (Canada = 20-30°C) relative humidity less than 50% for 24 hours 4. Detection limit ... flow meter - 0.03 m^3/min balance - 0.1 mg 5. Reproductivity ... about 3%	1. Air flow rate ... 0.42 m^3/h 2. Filter ... applicable if relatively low resistance against air flow and high in collecting capacity 3. Sampling time ... avoid contamination over 0.3 in photochemical density 4. Measure weight by high volume sampler in parallel.	1. Flow rate ... 15.6 to 16.8 m^3/h 2. Filter ... glass fibre or membrane filter having collecting capacity over 99% against 0.3 μm particulate at 16 m^3/h 3. Desicating condition ... after desicating 24 hours, kept in weighing room conditioned at 20°C and relative humidity 50%. 4. Detection limit ... conc. 10-13 $\mu g/m^3$	1. Air liquid ... 1.2 m^3/h 2. Range ... 5 to 11,000 $\mu g/m^3$ 3. Beta ray cell ... Kr85 (50mCi)	1. Flow rate ... 0.08 m^3/h 2. Filter ... high quality white cellulose paper having smoothy surface. For example, Whatman No.1 3. Funnel ... glass of 40 mmφ at 60° angle. Root inside diameter - 6.5 mmφ 4. Precision ... ±10%
Characteristics	1. Most of glass fibre filter in market - over 7.5 Ph acid gas absorbed by filter and apt to increase of appearance weight 2. Separator is not used. Data influenced by large size particulate. Monitoring site gives important influence on data precision. 3. Error of flow rate is considered to be more than 10% 4. Obtainable enough volume of sample for chemical analysis	1. Possible to monitor short time concentration automatically 2. At conversion to weight concentration, calibration curve largely influenced by nature of aerosol	1. Desirable to collect after separation, as larger particles are collected 2. Selection of filter	1. Monitoring short time concentration automatically and output results immediately. 2. Well corresponding to weight concentration but not precise in low concentration 3. instrument cost is expensive.	1. Not identified collecting efficiency and collected particulate size. 2. Particultes adhere to wallof sucking holes 3. Whatman No.1 filter does not collect submicron particulate. 4. Sample volume is small, and impossible chemical analysis.

II-3-1-2 Recent development of measuring methods

As described in II-3-1-1, the measuring methods employed in major countries have merit and demerit. So improvement and development of the measuring methods are under progress. Table II-3-3 shows the recent development in major countries.

EPA type high volume sampler used in the States collects total particulate matter in the ambient and now the improved high volume sampler is under development which collects only inhaled particulate (under 15 microns) by installing separator. The collecting efficiency of the separator depends on the type, flow rate and wind velocity. At present the separator which is capable to cut the larger particles over 15 microns is under development. Besides the above, Dichotomous Sampler is also under development which collects the particles by separating fine particle of under 2.5 microns and coarse particle of 2.5 to 15 microns.

EPA has been conducting measurement of inhaled particulate by the conventional high volume samplers and newly developed instruments. These data obtained are compared and studied. The results of these studies are expected to be reported by EPA in the near future which will be of great concern for many researchers involved in the issue.

Table II-3-3 Innovation and development of monitoring methods of particulate matter in major countries

Country	Japan	USA		Canada	West Germany	U.K.	France
Present instrument	Low volume sampler with separator, Digital dust analyser Beta ray dust analyser, Piezo-balance dust analyser	EPA high volume sampler, AISI tape sampler		EPA high volume sampler	LIB high volume sampler, Beta ray dust analyser	BS smoke sampler	Smoke sampler, Beta ray dust analyser, high volume sampler or low volume sampler
Instrument under innovation	-	High volume sampler with separator	Dichotomas sampler	Dichotomas sampler and Beta ray dust analyser	Conventional sampler Low volume sampler	Conventional sampler	Piezo-balance type sampler
Contents	-	(Principle) Air inducing inlet of conventional EPA high volume sampler is innovated to collect particulate smaller than 15 microns. Air in slit of inlet and impactor chamber impact on impactor board through acceleration nozzles and particulate over 15 microns is removed (Problems) 1. Removing efficiency depends on flow rate and mechanical forms of separator (length of accelation nozzle and shape of shelter) 2. Particulte size cut depends on wind velocity	(Principle) Remove particulate over 15 microns at inlet and separate air to two by low volume sampler. At present, separation size is under 2.5 microns and 2.5-15 microns. Filter replacement methods are (1) manual and (2) automatic. (Problems) 1. Separation at 15 microns depends on wind velocity. 2. Difficult in handling of filter automatically collected. 3. Sampler's cost is expensive.	(Testing point) Dichotomas sampler, mainly used in USA, and Beta ray dust analyser, widely used in many countries with good results, are under testing stage.	(Testing point) 1. As innovated standard method, low volume method is under consideration in which low volume pump (1.5~3 m^3/h) is employed, setting air sucking speed at 1.25 m/s. The draft method was compiled in 1979. 2. Innovating LIB high volume sampler, compact sampler is under development, 3. Under EPA assignment, automatic filter system is under development. Flow rate is 3 - 5 m^3/h, and filter is selective for 1 - 99 hours sampling but 24 hours desirable.	(Testing point) 1. Millipoise membrane filter is used 2. Filter placed in file and enlarge funnel 3. Install gas flow meter in back of pump	(Testing point) As same with Japan, new sampler based on piezo balance is under development.

II-3-2 Environmental Standard of Particulate Matter

The environmental standards of air quality are implemented by concentration of air pollution substances considering comprehensively the effects on the human health, animals and plants. The evaluation standard of these effects is called criteria. The most important factor among criteria is the health effect on human being by air pollutants.

The particulate matter and coexisting SO_2 have been pointed out to be the pollutants giving the impact on human health. Many researches have been reported the particulate matter together with sulpher dioxide have had the impact on respiratory desease. These researches have been directed to the health impacts caused by the particulate matter existing in the air with sulpher dioxide, and researches on the effects only by the particulate matter are quite few. Table II-3-4 shows criteria published in 1969 by Department of Health, Education and Welfare.[29] These recommendation values have been set up based on the data obtained in the States, and referring to English data. The present US standards are regulated by these criteria. Table II--3-5 shows Japanese criteria set up in 1970.[30] These recommendation values were fixed based on the data of major countries, adding the data obtained in Japan. As shown in Table II-3-6, the criteria for particulate matter have been set up in major countries. The environmental standards of major countries based on these criteria are shown in Table II-3-7.

The particulate size covered by these regulations are different according to the measuring methods employed by the respective countries. EPA type high volume method used in the States and Canada covers particulate sizes of 0.1 to 100 microns. As described in the above, EPA high volume sampler collects the total particulate and so the environmental standards are for the total particulate matter. LIB high volume sampler used in West Germany and Sweden collects the particulate of 0.5 to 80 microns.

BS standard method or smoke method of OECD are considered that the maximum particulate sizes are 20 to 30 microns. Japan is only one country regulating particulate matter of under 10 microns.

Most of the major countries are regulating total particulate matter or the particulate of 20-30 microns.

The mechanism of the particulate matter inhaled in human has recently been studied by many researchers[31) 32) 33)].

From epidemiological point of view, the relation with the particulate sizes is defined as follows;

over 10 microns:	caught at nasal cavity and or pharynx
5-10 microns:	90% reach to respiratory organs and alveoli, and sedimentation (sedimentation rate is highest in 2-4 microns)
0.5-5 microns:	sedimentation rate gradually decreasing rate of 0.5 microns is 25-30%
under 0.5 microns:	sedimentation rate increase again

From the above, the particulate of under 10 microns is considered to be most influential to the respiratory organs. Japanese standards are based on these epidemiological impact.

EPA is now reviewing the health effects of the particulate matter putting the emphasis on the inhaled particulate and fine particulate, the sizes of these being over 15 microns and 2.5 microns respectively. So far the study has found that the particulate matter of under 10 microns reaches to the respiratory organs and gives impacts. But it is also found that the particulate of about 15 microns reaches to the respiratory organs when the air inhaled through mouth[34]. It is further found that the sedimentation rate at alveoli fluctuates at 3 microns, and size distribution and chemical composition also variate at 2 microns[34].

Table II-3-4 USA criteria pertaining to total particulate matter

Objective	Time	Item	Concentration ($\mu g/m^3$)		Effects	Recommendation value
			TSP	SO_2		
Health	Daily average		Over 750	Over 715	Increase of patients and death (U.K.)	-
			Over 300	Over 630	Acute turn to worse of chronic bronchitis patients (U.K.)	
			Over 200	Over 250	Increase of workers' absence by sickness (U.K.)	
	Yearly average value	Arithmetic average	Decline 140 to 60	-	Decrease of workers' phlegm (U.K.)	80 ($\mu g/m^3$) (Yearly geometric average value)
			100 - 130	Over 120	Increase of respiratory disease of children living in the district	
		Geometric average	Over 100	Sulfation level: over 30 mg/cm^2. month	Increase of death rate of aged people over 50 (U.K.)	
			80 - 100	Sulfation level: over 30 mg/cm^2. month	Possiblity to increase of death rate of aged people over 50 (U.S.A.)	
Solar radiation	-		150 - 100	-	Decrease of solar radiation in middle and high latitude area. Summer - 1/3, Winter - 1/2 (U.S.A.)	-
Visuality	Yearly geometric average value		150	-	Decrease of visuality to 5 miles (U.S.A.)	150 ($\mu g/m^3$)
Substances	Yearly geometric average value		60 - 180	Co-exist with SO_2	Corrosion of steel and zinc (U.S.A.)	60 ($\mu g/m^3$)
Public concern	Yearly geometric average value		70	Co-exist with other pollutants	Public concern on pullotion provoked.	-

Table II-3-5 Criteria for particulate matter in Japan

Item / Time		Concentration ($\mu g/m^3$) SPM	Concentration ($\mu g/m^3$) SO_2	Effects	Recommendation value
-		600	-	Visual distance below 2 km. Increase of number of people who complaining of discomfort and unhealthy circumstance.	For particulate below 10 μm, (1) one hour average value of continuous 24 hours value, - 100 $\mu g/m^3$, and (2) one hour value - 200 $\mu g/m^3$
		150	-	Visual distance comes below 8 km, and visual flight difficult	
Daily average value		150	District of SO_x concentration exceeding established ambient	Increase of death among infant and aged persons (Japan)	
One hour average value		300			
Yearly average value	Arithmetic average	100		Increase of number of patients of bronchitis compared with other areas below 100 $\mu g/m^3$ (Japan)	
		100		Increase of throat trouble of children (Japan)	
	Geometric average	Increase from 80 to 100	Sulfation level: over 30 mg/cm^2. month	Increase of total death rate (U.S.A.)	
	Arithmetic average	Innovated from 140 to 60	-	Decrease of workder's phlegm (U.K.)	

Table II-3-6 Recommendation value of particulate matter in the major countries

Evaluation time	Country or organization (year)	Concentration ($\mu g/m^3$) 0 100 200 300	Remarks
1 hour average	Japan (1970)	○	Below 10 microns
24 hours average	Japan (1970)	○	Below 10 microns 1 hr. average of 24 hr. continuous monitoring
	Canada (1971)	⊙	Maximum acceptable limit
	WHO (1979)	⊙——⊙	
Yearly geometric average	USA (1969)	⊙ ⊙ (1) (2)	(1) Substances (2) Health
	Canada (1971)	⊙ ⊙ (1) (2)	(1) Maximum desirable limit (2) Maximum acceptable limit
	WHO (1979)	⊙—⊙	Yearly arithmetic average

○ : Suspended particulate matter (SPM)

⊙ : Total particulate matter (TPM)

Table II-3-7 Environmental standard of particulate matter in major countries

Country	Date	Environmental standard	Satutory M. method	Nature of environmental standard
Japan	January/1972	For particulate under 10 microns 0.1 mg/m^3 (24 hours average) 0.2 mg/m^3 (one hour average)	Low volume method (relative concentration monitoring method)	Desirable level to be maintained for protecting human health. Political target desirable to be attained in early stage
USA	April/1971	Primary standard 0.075 mg/m^3 (yearly geometric average) 0.26 mg/m^3 (24 hours average) Secondary standard 0.06 mg/m^3 (yearly geometric average) 0.15 mg/m^3 (24 hours average)	EPA high volume method	Primary standard is air quality level necessary to protect public health, taking enough safety rate. Secondary standard is air quality level necessary to protect public walfare from the effects of known and proposed impact of pollutatnts
Canada	May/1974	Maximum desirable level 0.06 mg/m^3 (yearly geometric average) Maximum acceptable level 0.07 mg/m^3 (yearly geometric average) 0.12 mg/m^3 (24 hours average) Maximum tolerable level 0.40 mg/m^3 (24 hours average)	EPA high volume method	Maximum desirable level is final target of air quality, and it is basis of pollution control policy for non-contaminated areas, and also basis for development of control technology. Maximum acceptable level is practical standard of Canada to protect fully the impacts on soil, flora & fauna, substances, water, visuality, individual comfortness and welfare. If pollution exceeds this level, regulatory Authorities take preventive counter-measures. Maximum tolerable level is concentration to be recovered immediately to protect from air quality to influence on way of living and health of public.
Sweden	August/1976	SPM- same level with USA smoke - 0.04 mg/m^3 (winter seasonal average Oct. - Mar.) 0.12 mg/m^3 (24 hours average)	LIB high volume method OECD smoke method	Same with USA
Spain	April/1975	0.130 mg/m^3 (yearly average) 0.202 mg/m^3 (monthly average) 0.3 mg/m^3 (24 hours average)	BS smoke method (EPA high volume method)	Desirable level.
West Germany	August/1974	Particulate under 10 microns 0.10 mg/m^3 (yearly arithmetic average) 0.20 mg/m^3 (24 hours average) Particulate over 10 microns 0.20 mg/m^3 (yearly arithmetic average) 0.40 mg/m^3 (24 hours average)	LIB high volume method (Beta ray absorption method)	Einvironmental standard is for protecting from impacts, danger and disadvantage on human health, flora & fauna, othe substances. For newly sited factories, tolerable level is applied to prevent impacts on environment which has the character of marginal level.
USSR, Bulgaria, Czechoslovakia, Finland, Rumania		0.15 mg/m^3 (24 hours average) 0.5 mg/m^3 (30 minutes average)		Maximum permissible concentration is pollutant concentration, detectable of response to standard and comprehensive test by human and experimental animals.
Poland		For particulate under 20 microns Special designated area (part & etc.) 0.075 mg/m^3 (24 hours average) 0.20 mg/m^3 (20 minutes average) Designated area 0.20 mg/m^3 (24 hours average) 0.60 mg/m^3 (20 minutes average)		
Israel		0.075 mg/m^3 (yearly average) 0.2 mg/m^3 (24 hours average)		
Italy	July/1966	0.3 mg/m^3 (yearly average) 0.75 mg/m^3 (2 hours average)		
Algentine		0.5 mg/m^3 (30 days average)		

CHAPTER 4 ASSUMPTION METHODS OF SOURCE CONTRIBUTION RATE OF PARTICULATE MATTER

To clarify the correlation between emission source and ambient concentration of the air pollutants, the source model has been developed based on the condition that aerosols (SO_2 and others) emission volume from the source will be kept in the ambient in the same volume. However as for the particulate matter, the same diffusion models are not able to be applied because of the facts that the particulate matter emitted from various sources, the secondary particles are produced by chemical reaction in the ambient and modelling of the removal mechanism is not yet confirmed. It is generally understood that simulation method is now under development. Among them, the receptor model has been developed which is the method to assume the emission sources from the various information of the ambient particulate matter such as concentration of the respective elements, ion concentration, particle size and forms.

In this chapter, the problem points of the source model applied for particulate matter and assumption methods of source contribution rate by receptor model are described.

II-4-1 Problem Points of Source Model Applied for Particulate Matter

Source model is the method to estimate the ambient concentration and their contribution rate at the certain points (mesh, station & etc.) based on the data on emission intensity, conditions (stack height, emission gas volume & etc.) and meteorological condition (wind direction & velocity, atmospheric stability and so on). For concentration calculation, plume model, puff model and numerical model (diffusion factors are complicated) are widely used.

These diffusion models are applicable for environmental assessment which are necessary for establishment of environmental protection plan and location plan for new industries. These models are able to evaluate the above said plans and they are also able to evaluate the environmental impacts by the respective sources even when several sources are emitting the same types of pollutants. But as mentioned above, these models are not applicable for the assumption of ambient concentration and their contribution rate of the particulate matters due to the reasons mentioned hereafter.

(1) Ambient concentration

The instruments to measure short time (at least 1 hour) concentration of particulate matter by particle size are not yet developed. It is therefore impossible to clarify the correlation between meteorological data and particulate concentration.

(2) Emission source

It is difficult to clarify the wide range emission sources, and generating mechanism of secondary particles quantitatively.

(a) Stationary source

The weight concentration is easy to obtain, but the data on size distribution by facilities, type of fuels, operational conditions, dust collecting facilities and so on are not easy to obtain.

(b) Automobile

The generation of particulate matter by automobiles is composed by the particles contained in the emission gases, the friction of tyres itself, the friction of pavement and winding up the particles on the road by automobiles. It is very difficult to classify these particles quantitatively.

(c) Ships and aeroplanes

It is not identified the emission of particulate from these in terms of size distribution and weight concentration.

(d) Particulate generating facilities

It is difficult to obtain the data of emission from cement manufacturing, quarrying, steel mills, coal yards, reclamation sites and so on.

(e) Natural background source

It is difficult to clarify quantitatively the volume of particulate generated by volcano eruption, sea salt, dust storm, seeds of plants and so on.

(f) Others

It is not known the contribution by outdoor burning of the wastes and so on.

(3) Prediction model

It is necessary to develop the new model which includes gravity fallout of the particulate, generation of secondary particles, removal mechanism of particulate and so on.

II-4-2 Receptor Model

The receptor model is the method to identify the source and their contribution rate based on the data on chemical composition, particle size, concentration variation, particle form and so on which obtained at the certain point and a certain period. This method is recently highlighted and many studies have been carried out.

This method has the advantage of being able to identify the source and contribution rate without considering meteorological and geographical conditions, being able to identify the new sources and sources difficult to obtain the data, and being able to evaluate the emission source condition particularly for high concentration sources. But on the other hand, the receptor model is not able to identify the respective sources like source model, and it is to identify the type of sources. It is therefore impossible to evaluate the respective source when the several sources are emitting the same type of chemicals. The evaluation by this receptor model is only limited to the area of monitoring stations and it is also impossible to predict the future conditions.

The receptor model can be classified to morphological observation, physical analyzing method and chemical analyzing method, as shown in Fig. II-4-1.

II-4-2-1 Morphological observation method

Morphological observation method is to assume the source from the size of particulate, color, form, surface characteristics, and optical nature. This method is most effective to identify the source from tree's cellulose and pollen. But for the analysis by this method, a quite many number of particles have to be observed which means it takes time and cost. And it has also a disadvantage that sensibility is not enough for identifying the organic particles contained in high level in the non-crystalite particles.

II-4-2-2 Physical analyzing method

(1) Trajectory line analyzing method

This method is to identify the source by following up the trajectory line from the monitoring point to windward in order, based on the data of wind direction and velocity.

This method is often employed to identify the source when the pollutants concentration reached to high level. This method is rather simple but contribution of the certain source is not able to evaluate quantitatively.

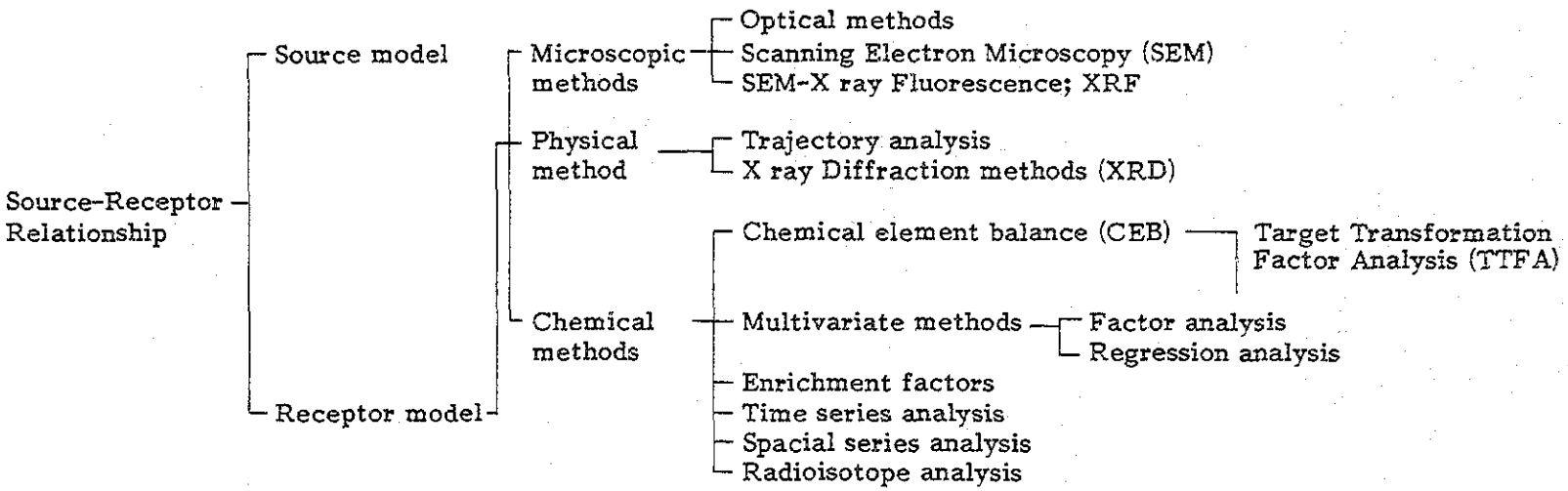


Fig. II-4-1 Contribution rate assumption methods of particulate matter

(2) X ray analyzing method

This method is to identify the crystalite particle quantitatively, such as crust mineral, cement dust, potassium carbonate, and so on. But it is not fitted for non-crystalite particle and fine particles.

II-4-2-3 Chemical analyzing method

(1) Radio isotope method

This method is based on the principle that $^{14}C/^{12}C$ of carbon compounds are measured and it is used for the apportionment of crude oil and other carbon. The physical half life of ^{14}C is 5,730 years and so the crude oil is identified as not contained ^{14}C from the fact that crude oil has been stored and accumulated for several hundred million years[35].

(2) Concentration factor method

This method is to measure the concentration factor of the element i contained in the particles and to evaluate the impact by the emission sources, as shown in the following equation. If the data for chemical components at the emission sources are available, the quantitative analysis is also possible.

$$EFi = \frac{(Ci/Cs)\ \text{aerosol}}{(Ci/Cs)\ \text{reference}}$$

where; concentration ratio between fine element i and standard element s.

(3) Time series analysis and space distribution analysis

These methods are to assume the emission source from the time series correlation of particulate weight and chemical components, and from space distribution of chemical components concentration and chemical components at the emission sources. The method itself is rather simple and easy, but it is not fitted to identify the particular sources and quantitative assumption.

(4) Chemical components method

The method was proposed by Miller & et al.[36] and it is to estimate the emission sources quantitatively by statistical processing of chemical components of the particulates at the monitoring point and emission source.

(5) Multivariate analysis

Multivariate analysis methods are main components analysis, factor analysis, regression analysis, cluster analysis and so on. These methods are all to obtain the information related to the emission sources from the variation between many samples collected for chemical components concentration of the particulates. For these methods, advance information on the type of sources and chemical components are not required. These methods have been further improved into TTFA method (Target Transformation Factor Analysis)[37] which is to estimate the emission sources contribution rate quantitatively. This TTFA method is recently highlighted among researchers.

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PART III
FIELD SURVEY

PART III FIELD SURVEY

The present concentration level of the pollutants are necessary to be surveyed in the first place for the environmental study.

In this study, the short term field survey and long term field survey have been conducted.

In the short term field survey, many number of stations have been established in the object area, installing monitoring instruments and the field survey has been carried out 4 times a year.

In the long term field survey, through-year monitoring of ambient concentration of particulate matter has been conducted.

Besides the above, monitoring of SO_2, wind direction & velocity, solar & net radiation and temperature have been monitored in order to clarify the correlation of particulate with SO_2 and meteorological conditions. In addition to the above, the analysis of metallic elements, anion and carbon has been conducted for identifying the chemical components of the particulate matter.

CHAPTER 1 ESTABLISHMENT OF MONITORING STATIONS

In this study, the ambient concentration of particulate matter has been monitored, setting up as many stations as possible. The concentration at each mesh point has been estimated by interpolation method and the additional concentration has been calculated which will be resulted by siting of coal firing power stations and integrated steel mill. These two concentrations of the particulate matter have been polimerised and the ambient concentration of the Republic of Singapore in future (1990) has been predicted. Taking into consideration the dominant wind direction, geographical conditions, distribution of emissions sources, land development plan and etc., 20 stations have been selected and established.

III-1-1 Location of Monitoring Stations

As shown in Fig. III-1-1 and Table III-1-1, 20 monitoring stations have been set up to cover the total area of Singapore main island.

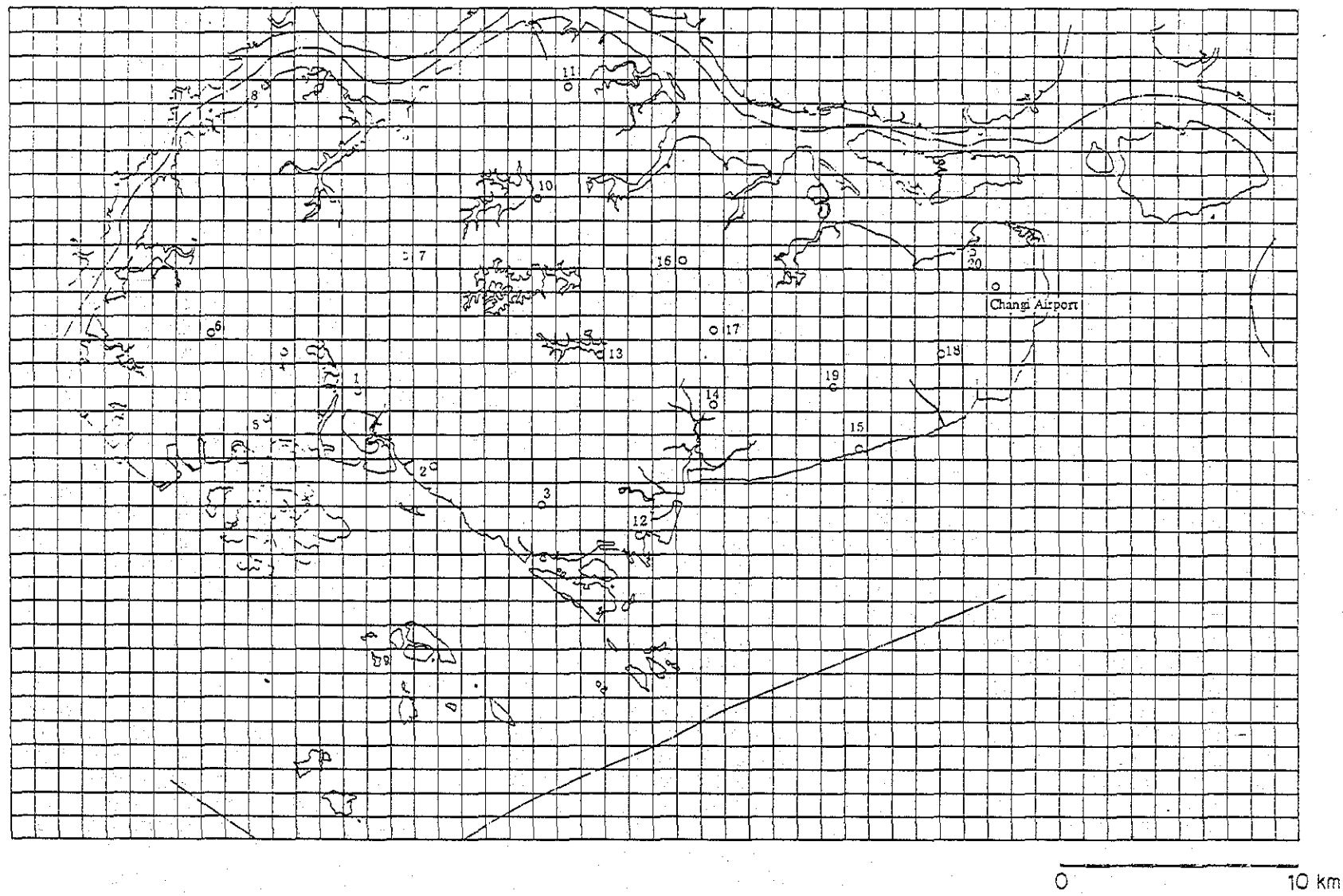


Fig. III-1-1 Location of monitoring stations

Table III-1-1 Number and name of monitoring stations

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

III-1-2 Monitoring Items at Monitoring Stations

The monitoring items of the respective stations are shown in Table III-1-2.

Monitoring of Total Particulate Matter (TPM), Suspended Particulate Matter (SPM), size distribution of TPM, metal elements of TPM, anion, carbon analysis, SO_2, wind direction & velocity, temperature and etc. have been conducted.

Besides the above, solar and net radiation have been monitored at Changi Airport Observatory and those data for one year have been supplied by Met. Service through JTC.

Table III-1-2 Items monitored at monitoring stations

Station	Item	Period	Method
MP-1 to MP-20	TPM	Each 14 days of 1st to 4th field survey	Daily average values by high volume sampler
	SPM	Each 12 days of 1st to 4th field survey	Daily average values by high volume sampler with cyclon
	Metal elements, anion & carbon	Each 1 day of 1st to 4th field survey	Neutron activation analysis, X-ray fluorescence analysis, ion chromatography & differential thermal analysis
MP-1, 2, and 6	Size distribution of TPM	Each 12 days of 1st to 4th field survey	Average values of 12 days by Andersen sampler
	SPM	Dec. 7, 83 to Dec. 6, 84	Hourly average values by Beta ray dust analyser
MP-1, 2, 4, 6, 7, 14, 20	SO_2	Dec. 7, 83 to Dec. 6, 84	Hourly values by solution conductmetry SO_2 analyser
	Wind direction & velocity	- do -	10 minutes average values by anemometer
MP-1	Temperature	Dec. 7, 83 to Dec. 6, 84	Instantaneous values by Nickel resistance thermometer at 2 heights
Changi Airport	Solar & net radiation	- do -	Hourly average values by solar & net radiation meter

III-1-3 Outline of Monitoring Stations

Total 20 stations, MP-1 to MP-20, have been set up. The establishment of the stations and installation of instruments have been carried out under full cooperation of JTC.

The outline of monitoring stations are described.

III-1-3-1 MP-1, Jurong Town Hall

Jurong Town Hall is situated in the east side of Jurong industrial district and built on the top of small hill (about 15 m above the sea level) surrounded by many trees. To the north east, about 100 meters from the building, Jurong Town Hall road is running.

Monitoring station was established on the roof top of the building (about 20 m high) and monitored TPM and SPM by high volume samplers, size distribution of particulate by Andersen sampler, wind direction & velocity by anemometer (installed on the top of pole of 10 m), and temperature by thermometers (installed in 2 heights of 1.5 and 30 m).

The Beta ray dust analyser, SO_2 analyser and recorder for the anemometer were installed in the reserve room located in the roof top of the building, and these instruments have been operated through the year to monitor SPM, SO_2 and wind direction & velocity.

Location of the station is shown in Fig. III-1-2, and Picture III-1-1 shows the instruments installed in the station.

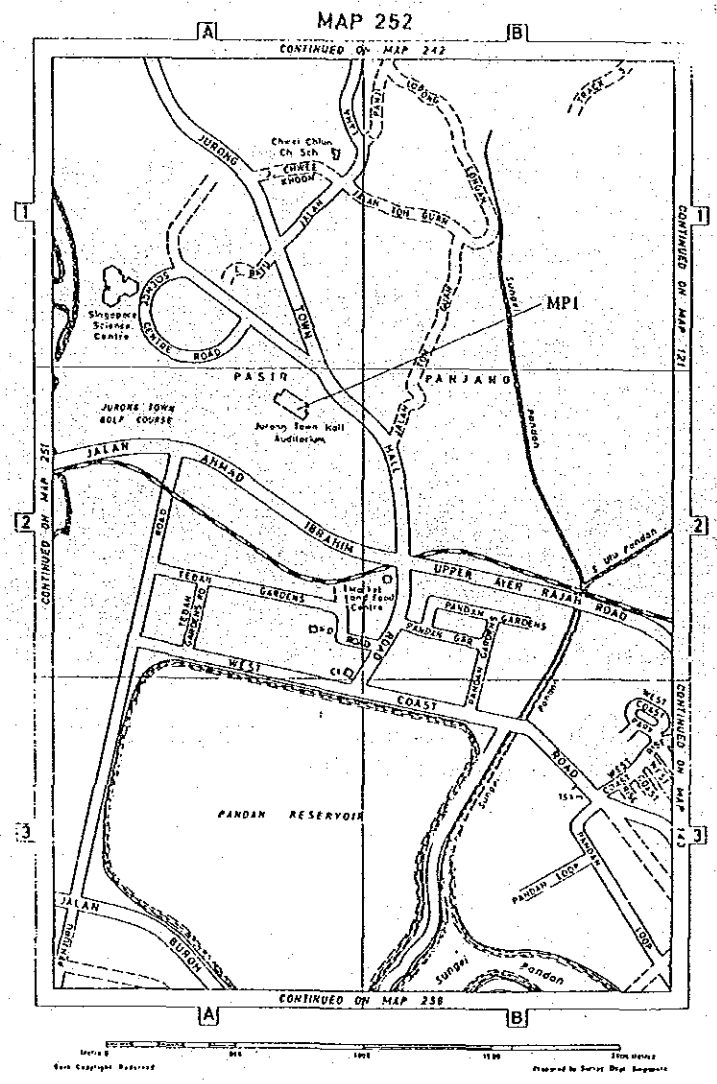
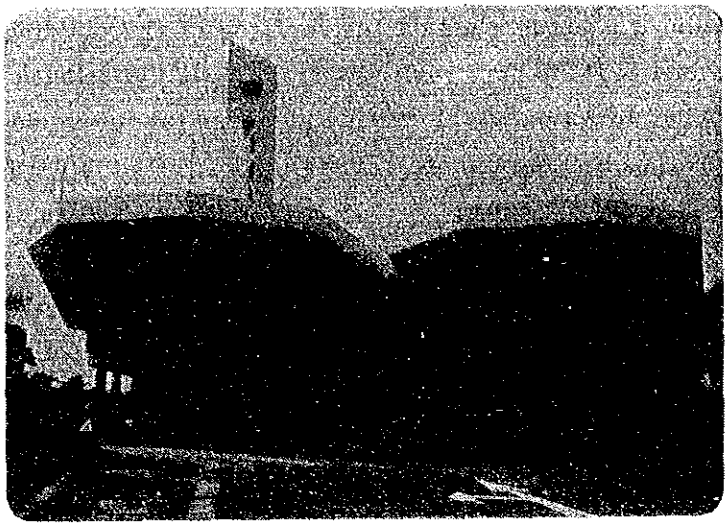
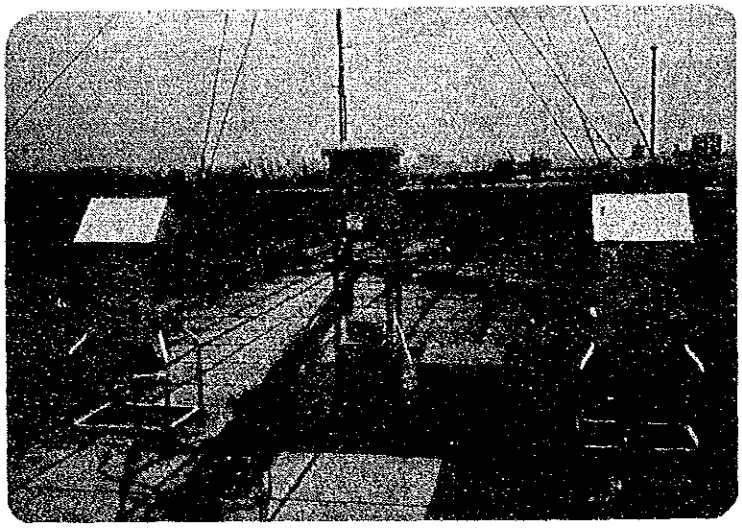


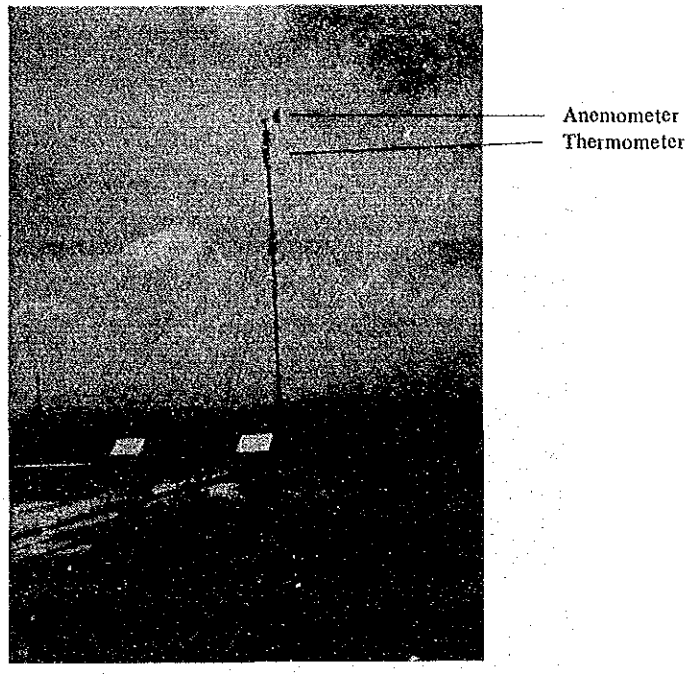
Fig. III-1-2 Location of monitoring station-MP-1



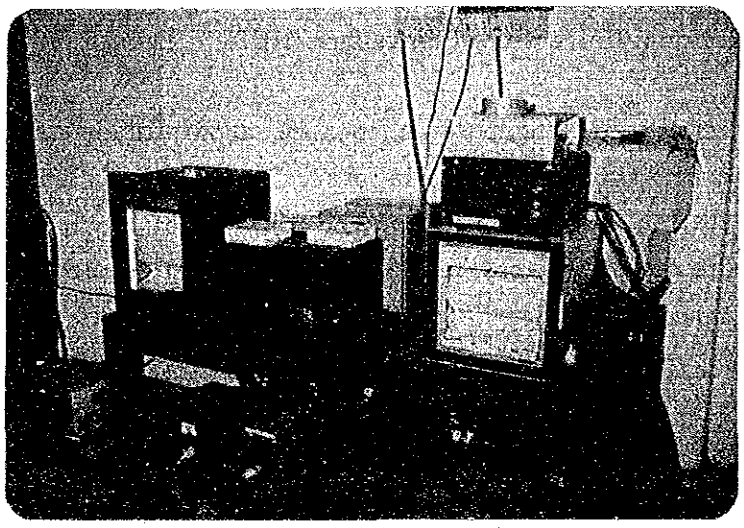
Picture III-1-1-(1) Panoramic view of MP-1 (Pole on roof top is seen)



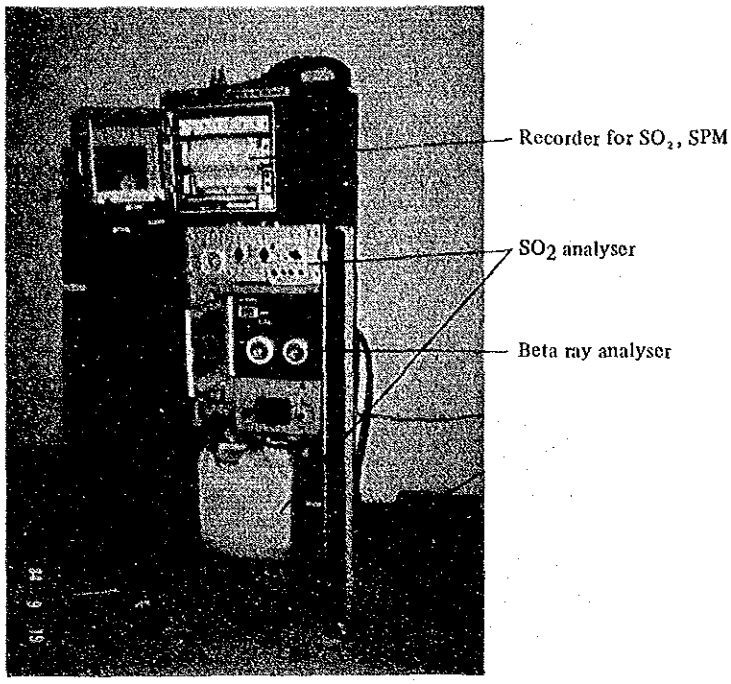
Picture III-1-1-(2) High volume sampler (left-TPM, right-SPM) and Andersen sampler installed in MP-1



Picture III-1-1-(3) Anemometer and thermometer installed on the pole top of MP-1



Picture III-1-1-(4) Recorder for wind director & velocity and for temperature at MP-1



Picture III-1-1-(5) Beta ray analyser and SO_2 analyser (MP-1)

III-1-3-2 MP-2, National University of Singapore (NUS)

National University of Singapore is located about 10 km south/east of Jurong Industrial district and it is in the residential area. The campus is almost fully covered by green trees. The station was established on the roof top of the laboratory of Dr. K. K. Chin who is the professor of environmental engineering department of NUS (15 m high and building height-27 m)

At this station (MP-2), TPM and SPM were monitored by high volume samplers, size distribution of particulate by Andersen sampler, wind direction & velocity by anemometer. Beta ray analyser, SO_2 analyser and recorder for anemometer were installed in the above said laboratory for monitoring SPM, SO_2 and wind direction & velocity (Pole height - 3 m) for one year.

Location of station is shown in Fig. III-1-3, and Picture III-1-2 shows monitoring instruments installed in this station.

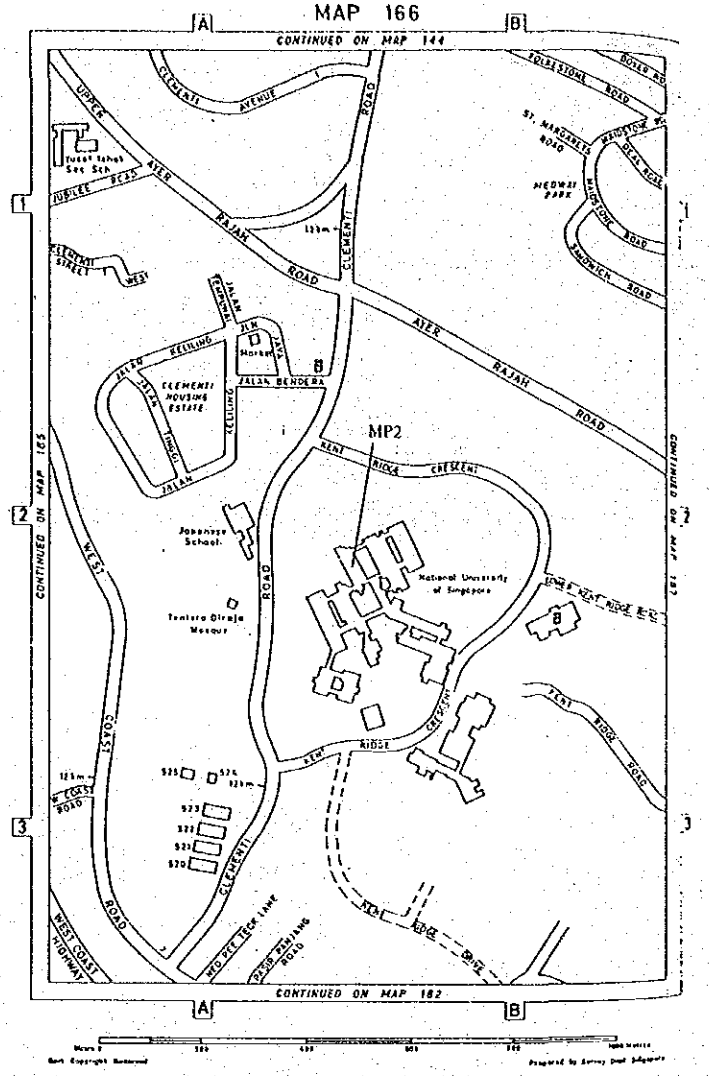
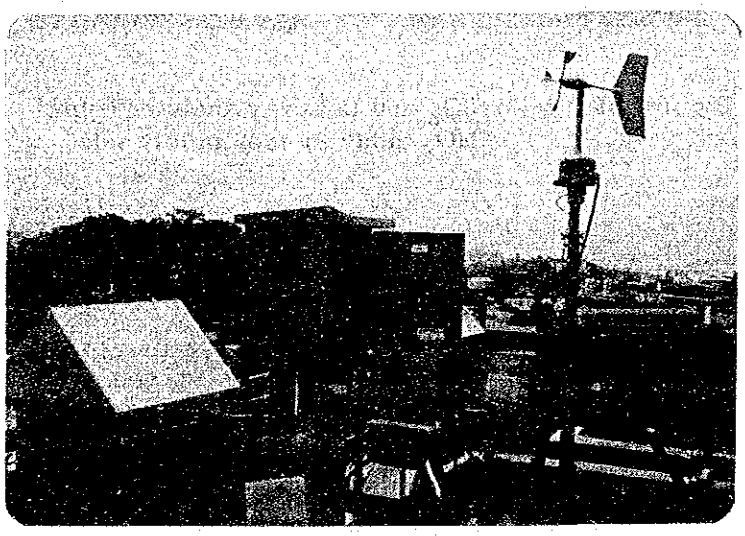
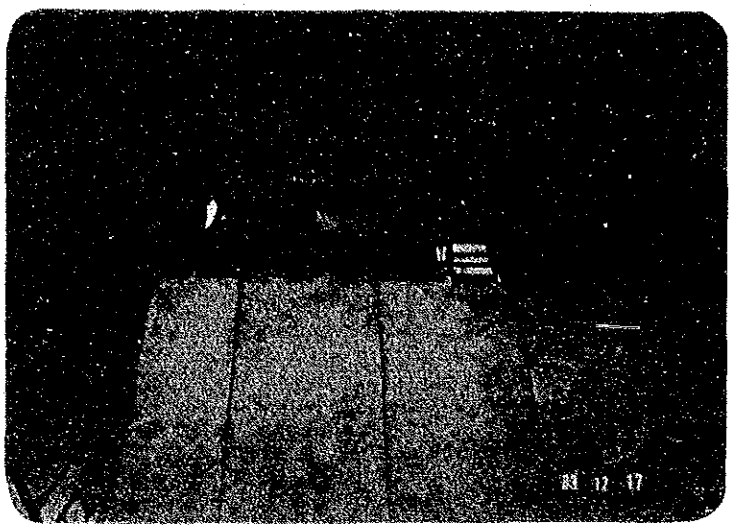


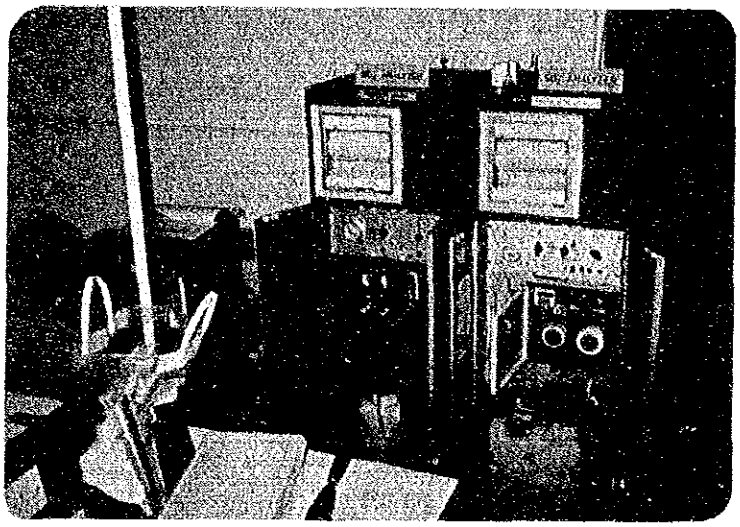
Fig. III-1-3 Location of monitoring station (MP-2)



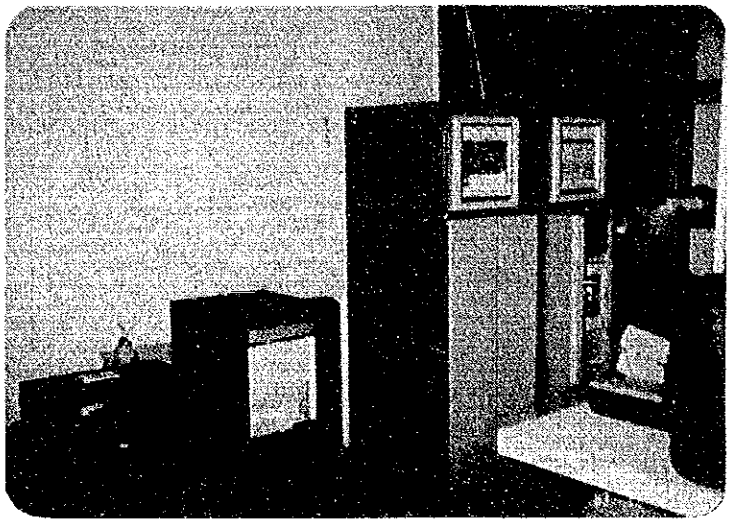
Picture III-1-2-(1) High volume sampler (for TPM), Andersen sampler, high volume sampler (for SPM) and anemometer, from left to right



Picture III-1-2-(2) Instruments installed on roof top



Picture III-1-2-(3) SO_2 and Beta ray analyser (right)
NO_x analyser seen in left side



Picture III-1-2-(4) Recorder for wind direction & velocity (left)

III-1-3-3 MP-3, Bukit Merah Flatted Factory

Bukit Merah Flatted Factory is located in south/west end of the urban area and at about 30 m north of the factory, Jalan Bukit Merah road is running.

The monitoring station was established on the roof top of the factory building (about 27 m high).

TPM and SPM have been monitored by high volume samplers.

Location of the station is shown in Fig. III-1-4 and Picture III-1-3 shows monitoring instruments installed.

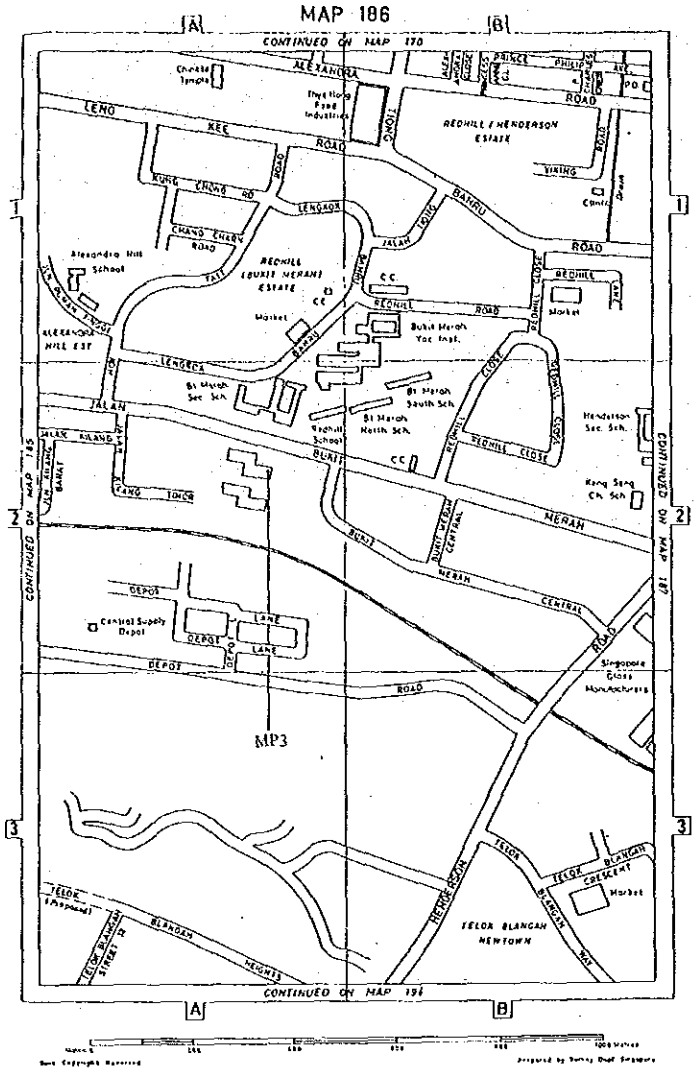


Fig. III-1-4 Location of monitoring station (MP-3)

Picture III-1-3 High volume samplers installed in MP-3 (left-TPM, right-SPM)

III-1-3-4 MP-4, Boon Lay Apartment

Boon Lay Apartment is located in the north of Jurong Industrial District and in Jurong residential area. About 30 m to the south of apartment, Boon Lay road and about 100 m to the east of apartment, Corporation road are running. And about 700 m east, Jurong lake is located.

The station has been established on the roof top of Apartment Block 200 which have 12 stories and about 36 m in height.

TPM and SPM were monitored by high volume samplers installed on the roof top. The sensor of anemometer has been installed on the top of pole (10 m) firmly fixed at the wall side of machine-room. The sensor was connected by cable to the recorder, installed in the landing space extending to the roof top. SO_2 analyser was also installed in the same landing space. Through year monitoring of SO_2 concentration and wind direction & velocity have been conducted.

Location of the station is shown in Fig. III-1-5 and Picture III-1-4 shows monitoring instruments installed.

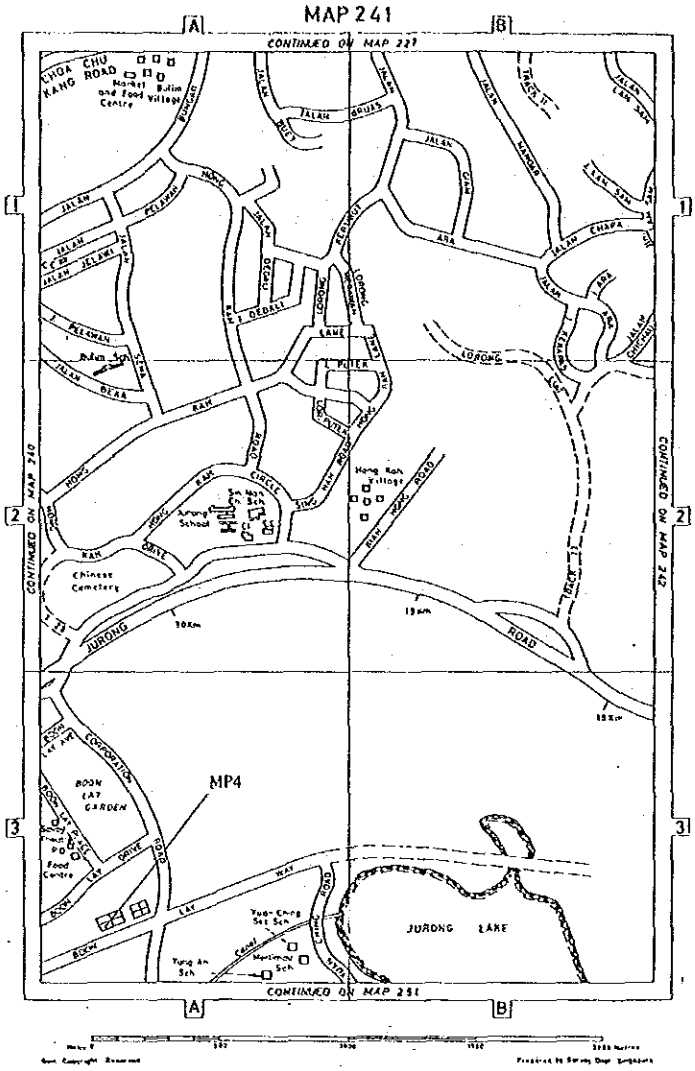
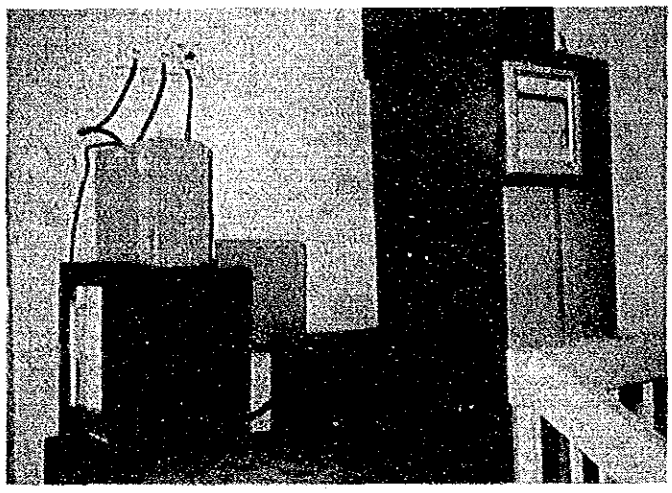


Fig. III-1-5 Location of monitoring station (MP-4)

Picture III-1-4-(1) High volume samplers installed at MP-4 (left-SPM, right-TPM)

Picture III-1-4-(2) Anemometer



Picture III-1-4-(3) Recorder for anemometer and SO_2 analyser

III-1-3-5 MP-5, Jurong Hill Top

Jurong Hill Top is located in almost center of Jurong Industrial district and it is on the top of small hill of about 40 m high of sea level, and next to Jurong Bird Park. About 700 m south of the hill, Jurong Power Station, Iron & Steel Mill are sited.

The station was established on the roof top of the Hilltop Restaurant (about 15 m high), and TPM and SPM were monitored by high volume samplers.

Location of the station is shown in Fig. III-1-6, and Picture III-1-5 shows instruments installed.

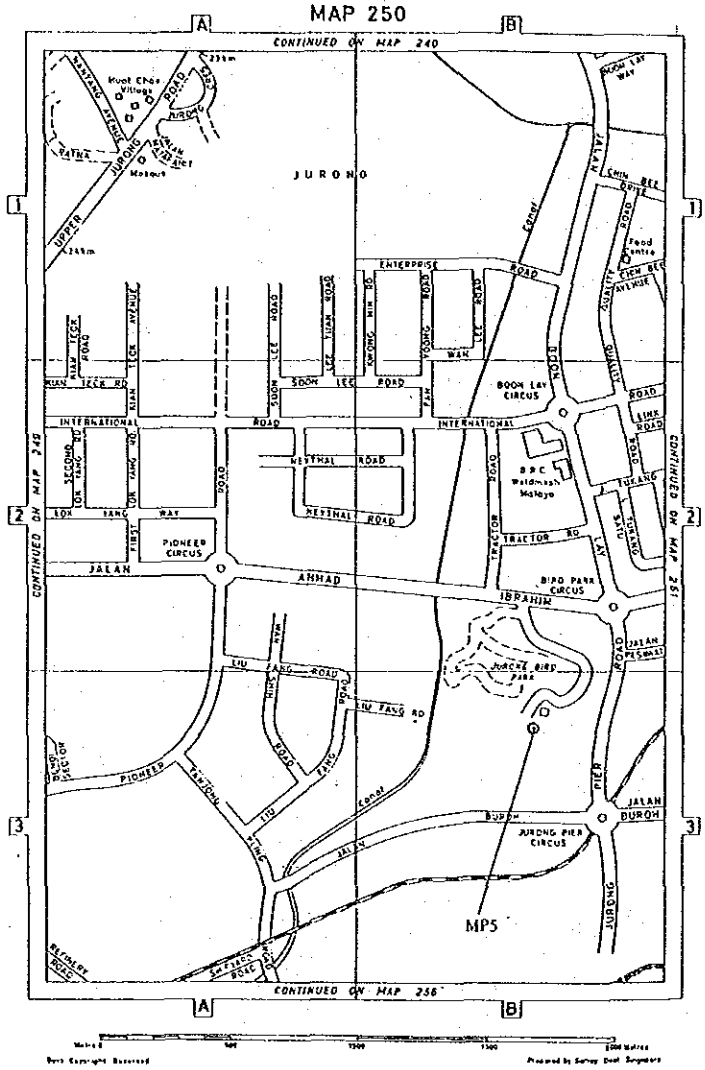
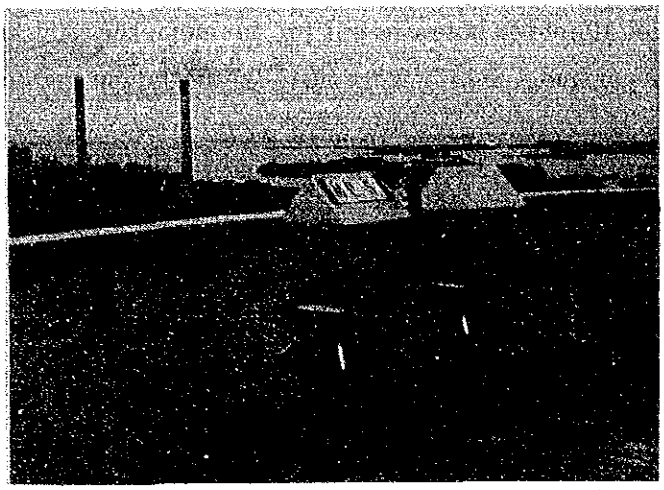
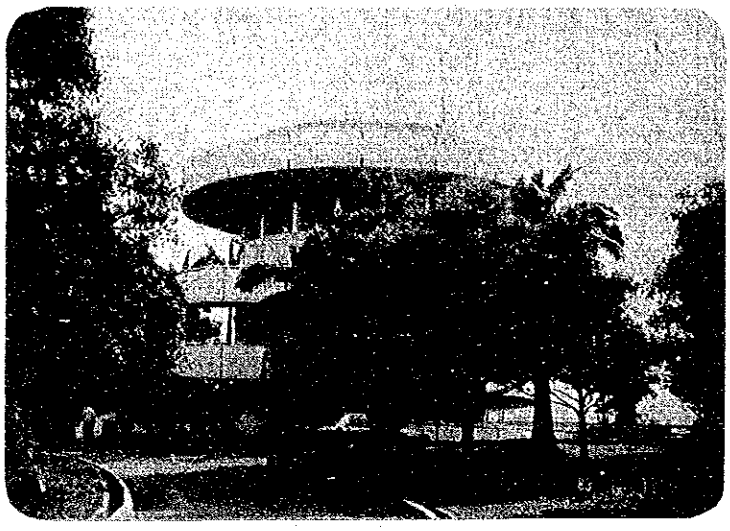


Fig. III-1-6 Location of monitoring station (MP-5)



Picture III-1-5-(1) High volume samplers installed in MP-5 (left-SPM, right-TPM)



Picture III-1-5-(2) Panoramic view of MP-5

III-1-3-6 MP-6, Nanyang Technological Institute (NTI)

Nanyang Technological Institute (NTI) is located about 1 km north/east of Jurong Industrial district, and the campus is covered by trees.

The station was established on the Nanyang Hill (about 40 m of sea level) of the campus, and high volume and Andersen samplers have been set up for monitoring TPM, SPM and size distribution of TPM.

Besides the above, 10 meter pole was set for anemometer, and Beta ray analyser, SO_2 analyser and recorder for anemometer were installed in the garage hut.

The location of the station is shown in Fig. III-1-7, and Picture III-1-6 shows the instruments installed.

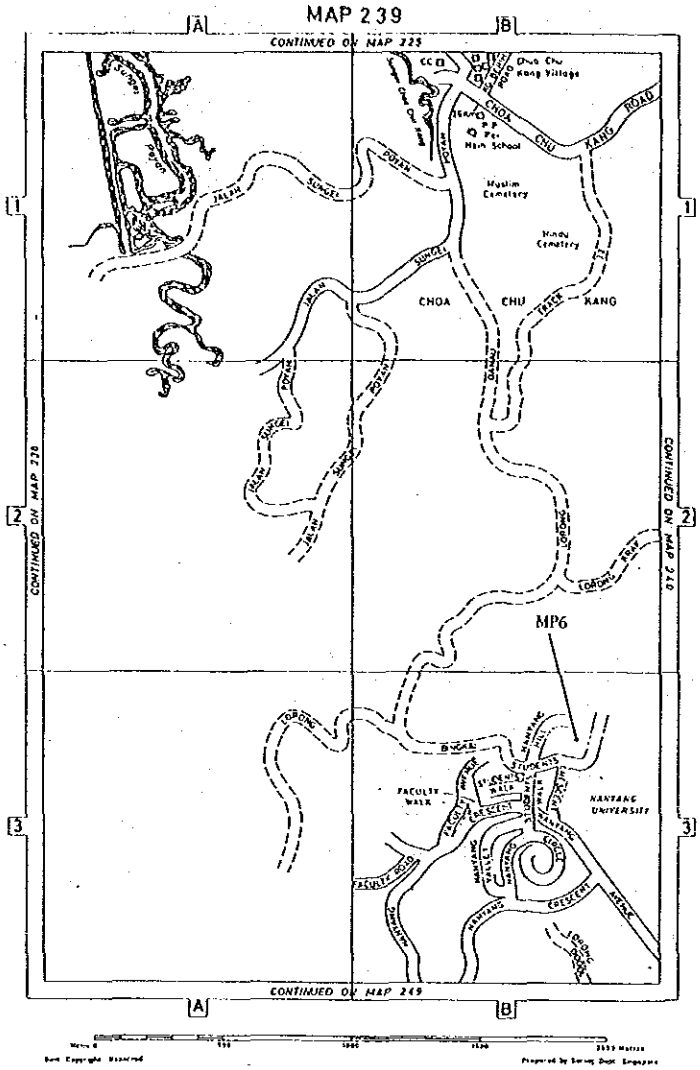
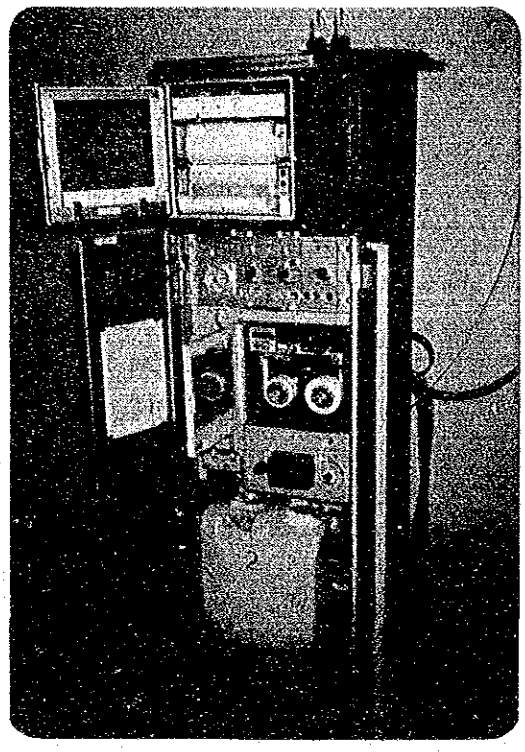
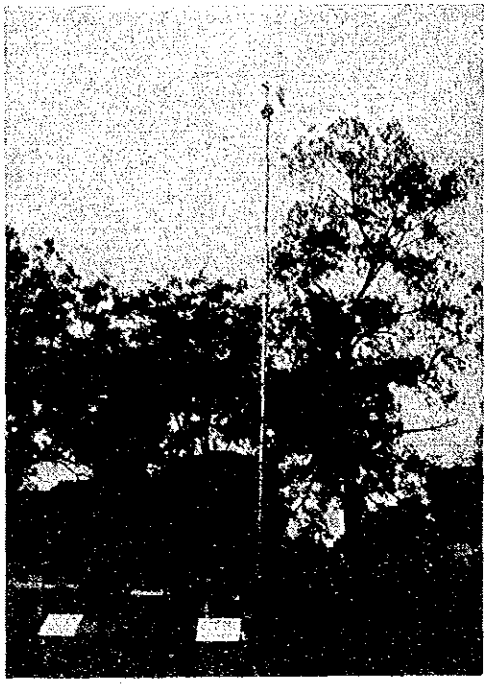


Fig. III-1-7 Location of monitoring station (MP-6)

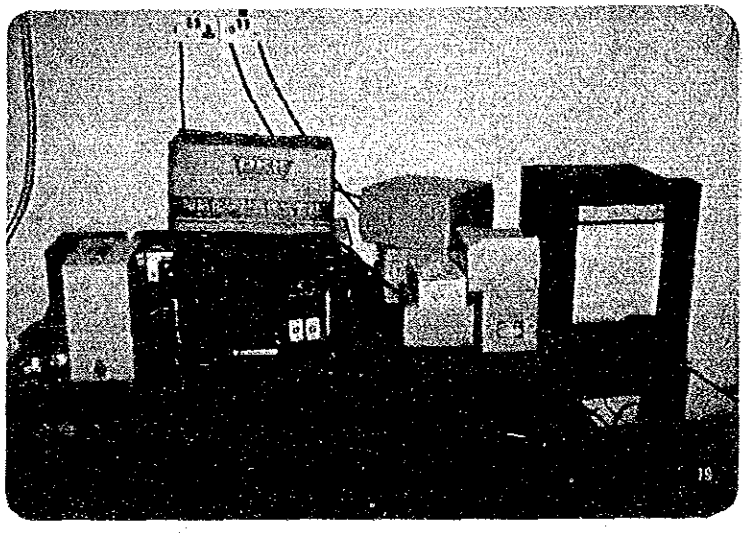
Picture III-1-6-(1) High volume sampler (left-TPM and right-SPM) and Andersen sampler installed in MP-6



Picture III-1-6-(2) SO_2 analyser and Beta ray dust analyser



Picture III-1-6-(3) Anemometer



Picture III-1-6-(4) Recorder for anemometer

III-1-3-7 MP-7, Bukit Panjang Police Post

Bukit Panjan Police Post is located about 8 km north/east of Jurong Industrial district. About 30 m east of the station, the road to Woodlands is running, and about 50 m south, Choa Chu Kang road is running.

The station was established in the central garden of the police post, and TPM & SPM were monitored by high volume samplers. Wind direction and velocity were monitored setting up 10 m pole on the turf, and SO_2 concentration was also monitored, setting SO_2 analyser in the reserve room next to the garden.

Location of the station is shown in Fig. III-1-8 and Picture III-1-7 shows the monitoring instruments installed.

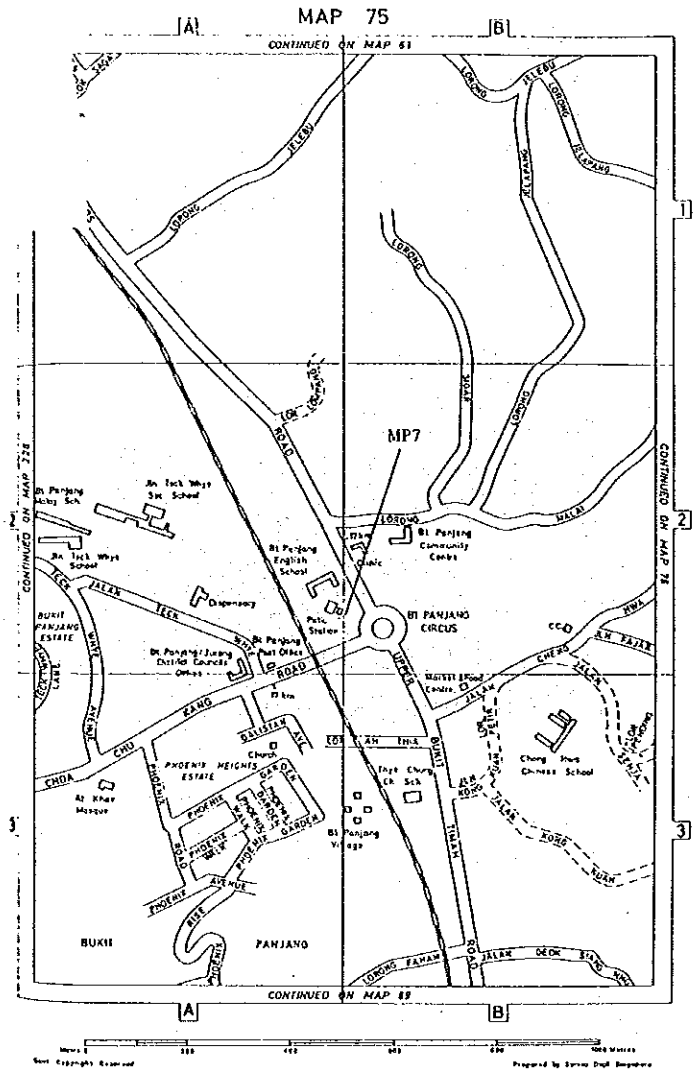
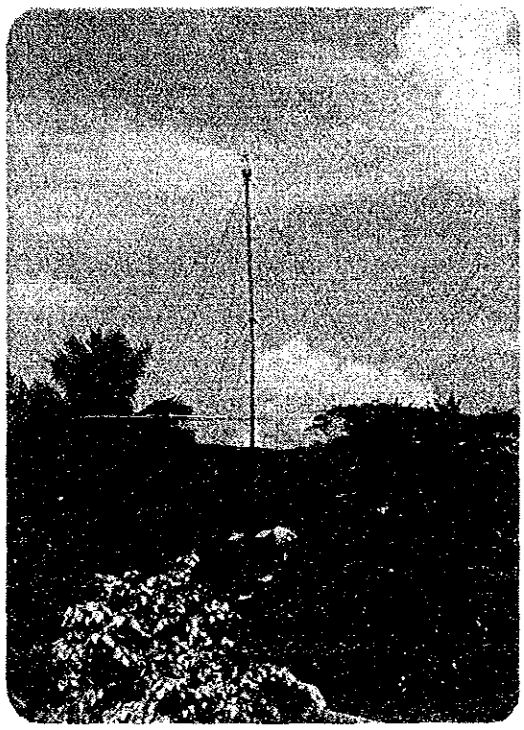
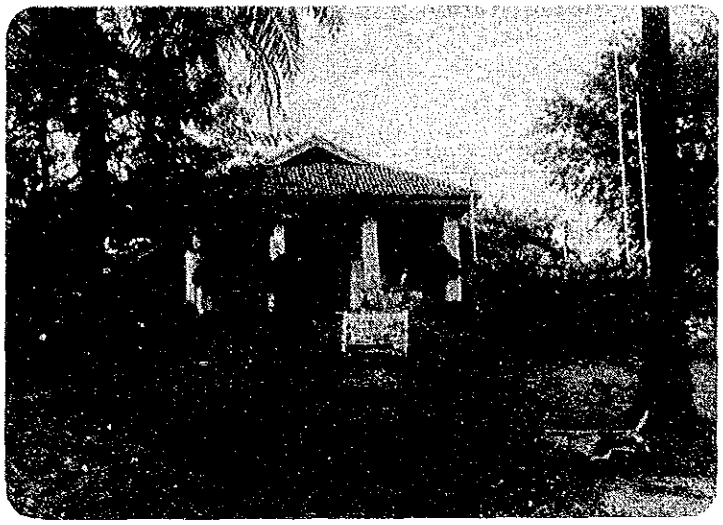


Fig. III-1-8 Location of monitoring station (MP-7)

Picture III-1-7-(1) High volume samplers (left-TPM, right-SPM) installed in MP-7



Picture III-1-7-(2) Pole installed with sensor of anemometer (recorder & SO_2 analyser are installed in the hut behind high volume samplers)



Picture III-1-7-(3) Panoramic view of MP-7

Picture III-1-7-(4) Road seen from police post

III-1-3-8 MP-8, Lim Chu Kang Marine Police Post

Lim Chu Kang Marine Police Post is located in the north/west of Singapore main island, and it is in the end of Lim Chu Kang road. The north side of the police post is facing with The Straits of Johor, and about 500 m south/west is dumping place of the wastes. The station was established in the garden of the police post, and TPM and SPM were monitored by high volume samplers.

Location of the monitoring station is shown in Fig. III-1-9, and Picture III-1-8 shows the instruments installed.

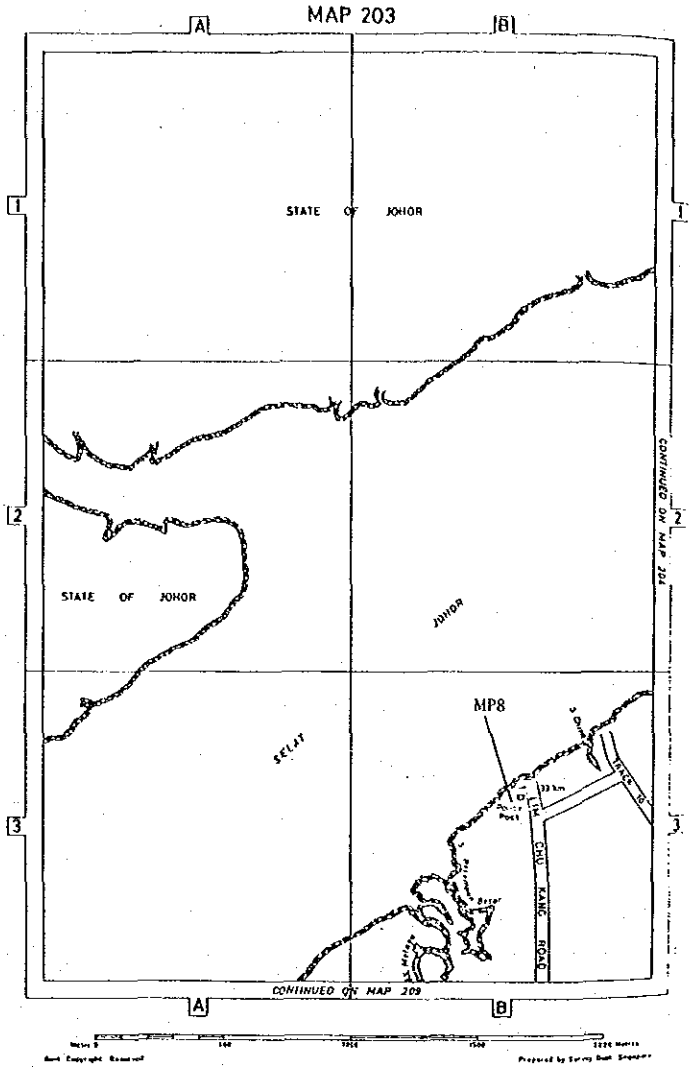
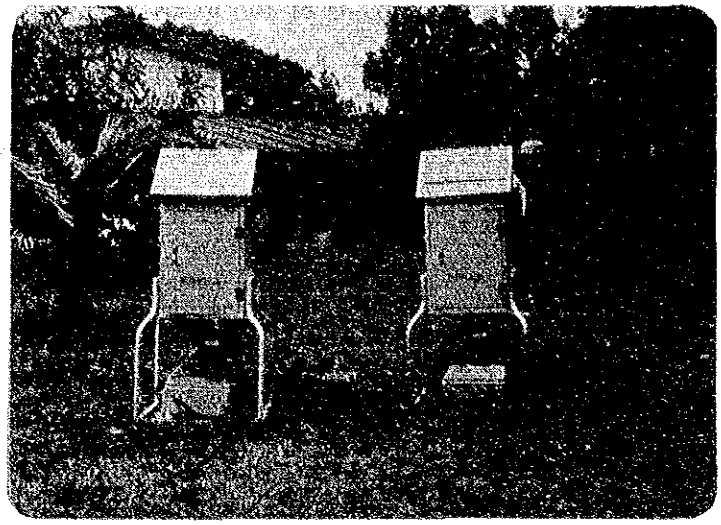
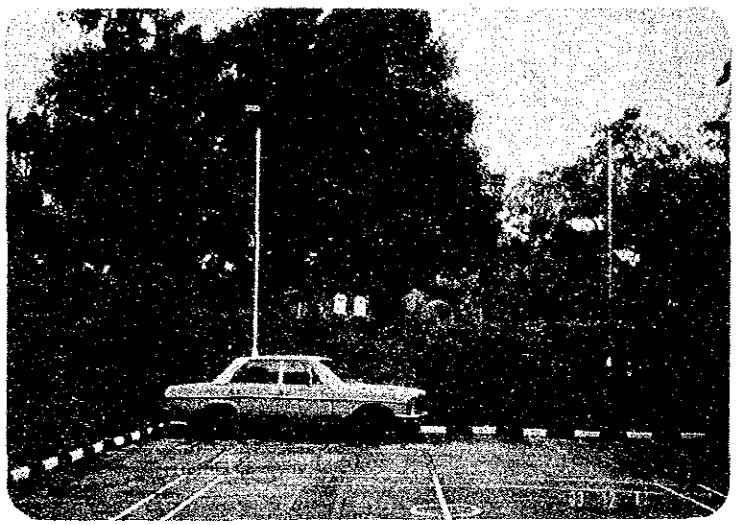


Fig. III-1-9 Location of monitoring station (MP-8)



Picture III-1-8-(1) High volume samplers installed in MP-8 (left-TPM, right-SPM)



Picture III-1-8-(2) Panoramic view of MP-8

III-1-3-9 MP-9, Kranji Sewage Treatment Plant

Kranji Sewage Treatment Plant is located in the north of the center of Singapore main island, and in the immediate west side of the plant, Kranji road is running, and in the east about 800 m from the plant, Woodlands road is running. In the plant, several treatment facilities such as air activation tank, Methane fermentation tank and so on are sited, but as a whole, it is widely developed grass land.

The station has been set up in one corner of the grass land, and TPM and SPM were monitored by high volume samplers.

Location of the station is shown in Fig. III-1-10, and Picture III-1-9 shows the instruments installed.

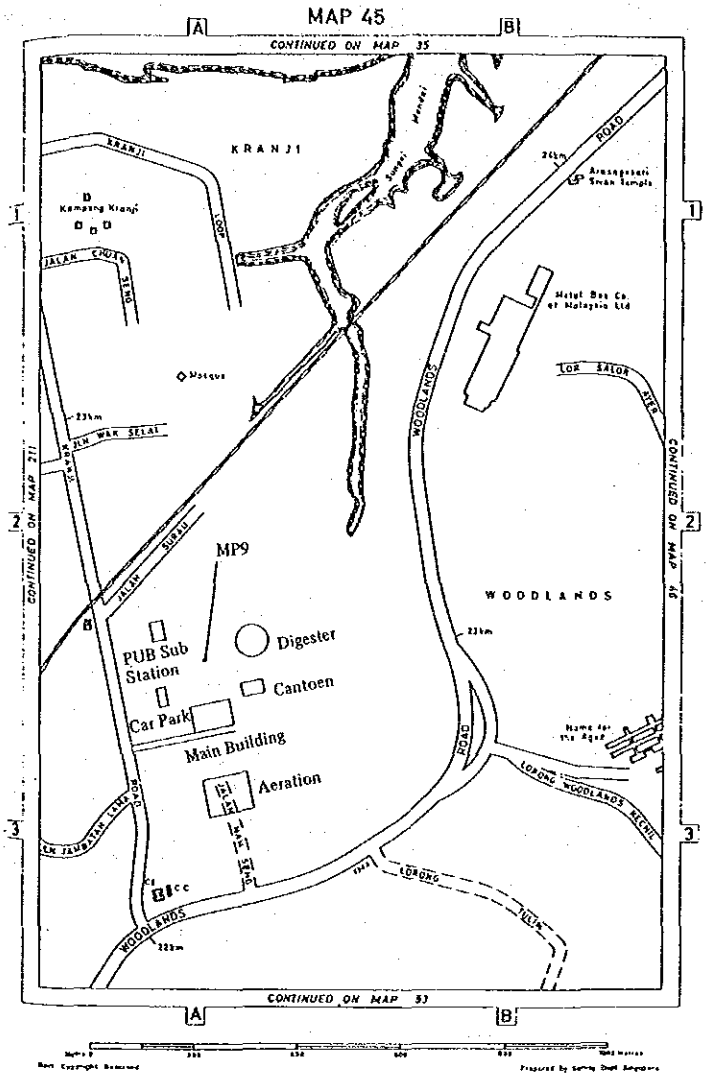
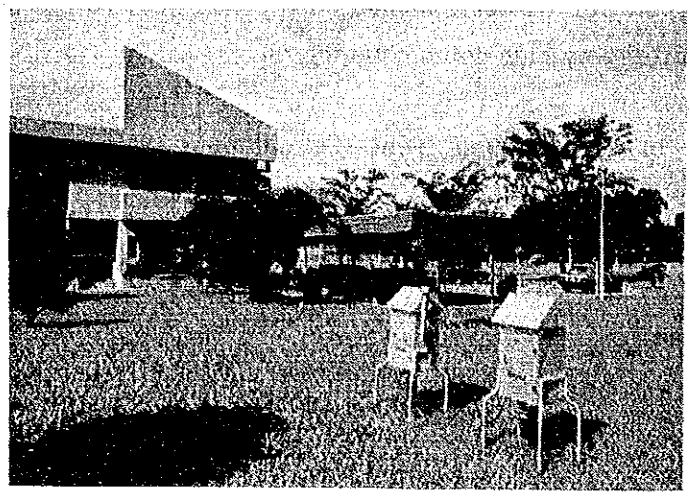
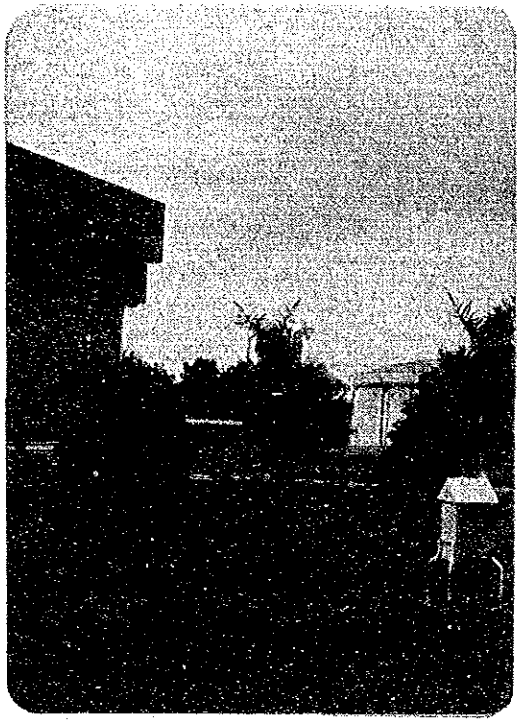


Fig. III-1-10 Location of monitoring station (MP-9)



Picture III-1-9-(1) High volume samplers installed in MP-9 (left-SPM, right-TPM)



Picture III-1-9-(2) View of the plant from MP-9 (Methane fermentation facility seen behind)

III-1-3-10 MP-10, Seletar Reservoir Water Pumping Station

Seletar Reservoir Water Pumping Station is located about 300 m east from the lake, and the surrounding area is covered by turf and trees.

The monitoring station was established on the turf next to the pumping station. TPM and SPM were monitored by high volume samplers.

To north/east of about 400 m from the pumping station, Mandai road is running towards Woodland.

Location of the station is shown in Fig. III-1-11, and Picture III-1-10 shows the instruments installed.

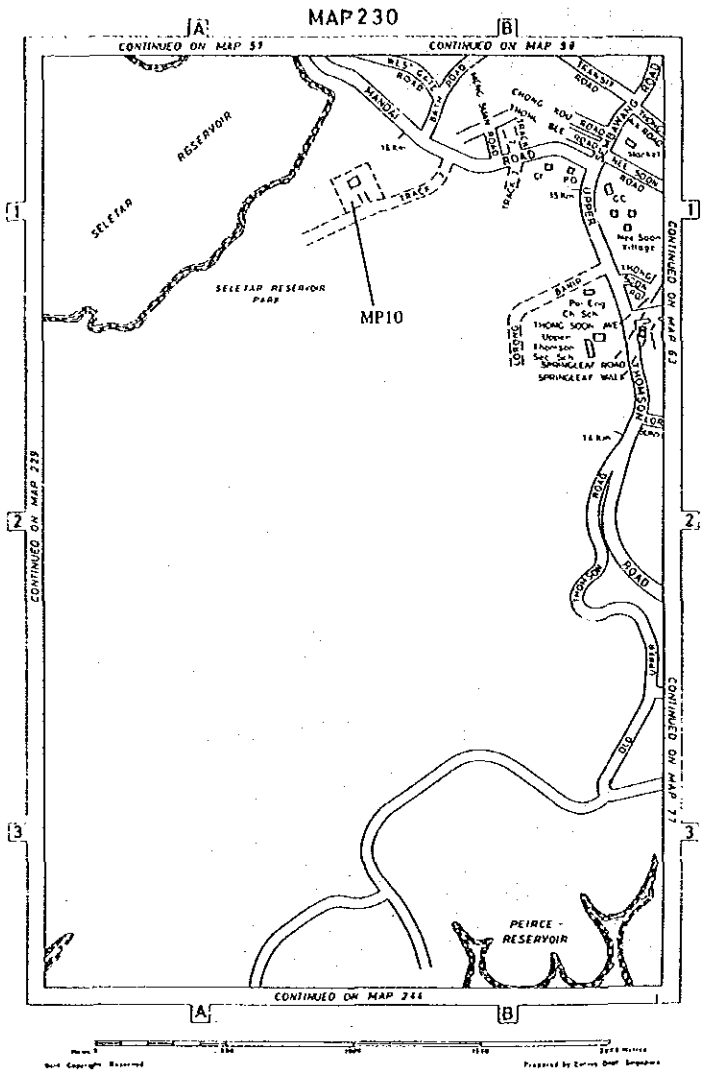
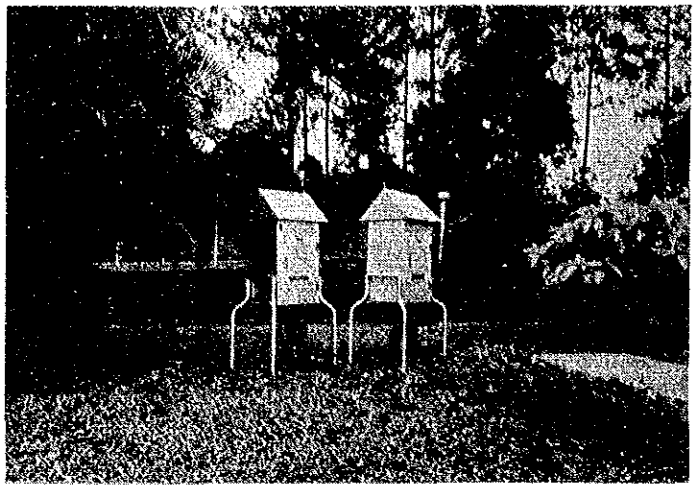


Fig. III-1-11 Location of monitoring station (MP-10)



Picture III-1-10-(1) High volume samplers installed in MP-10 (left-TPM, right-SPM)

Picture III-1-10-(2) Panoramic view of MP-10 (right side of picture is pumping station)

III-1-3-11 MP-11, Chong Pang Police Post

Chong Pang Police Post is located in the north of central island, and Sembawang road and Chanberra road are crossed there.

The station was established on the roof top of police post building, and TPM and SPM were monitored by high volume samplers.

Location of the station is shown in Fig. III-1-12 and Picture III-1-11 shows the instruments installed.

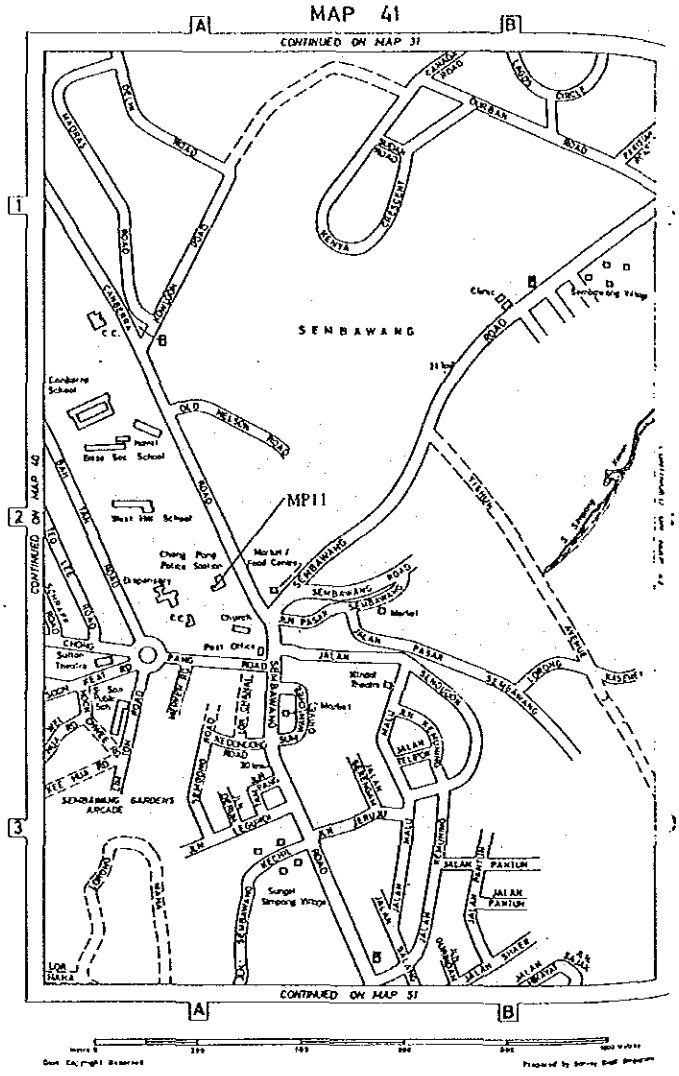
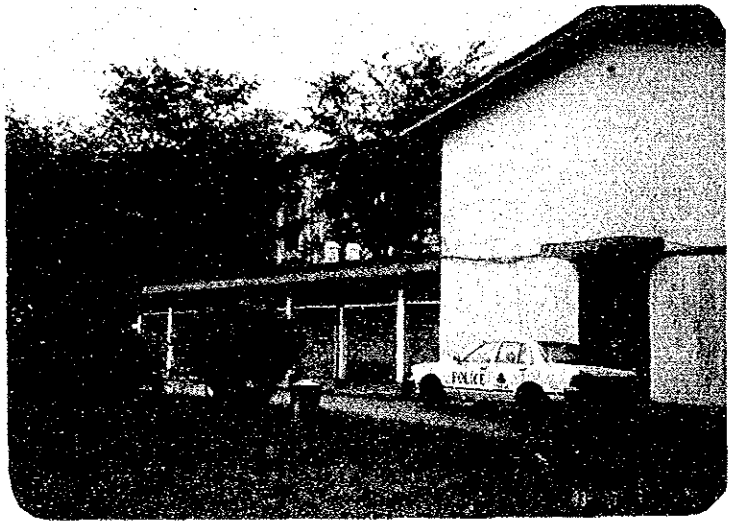


Fig. III-1-12 Location of monitoring station (MP-11)

Picture III-1-11-(1) High volume samplers installed at MP-11 (left-TPM, right-SPM)



Picture III-1-11-(2) Panoramic view of MP-11

III-1-3-12 MP-12, National Institute of Commerce (NIC)

National Institute of Commerce is located in the commercial area surrounded by high stories buildings. In the east side of about 80 m from NIC, East Coast Parkway is running. And it is surrounded by Prince Edward road, Shenton road and Palmer road.

The monitoring station was established on the roof top of 6 stories NIC building (about 18 m high), and TPM and SPM were monitored by high volume samplers.

Location of the station is shown in Fig. III-1-13 and Picture III-1-12 shows the instruments installed.

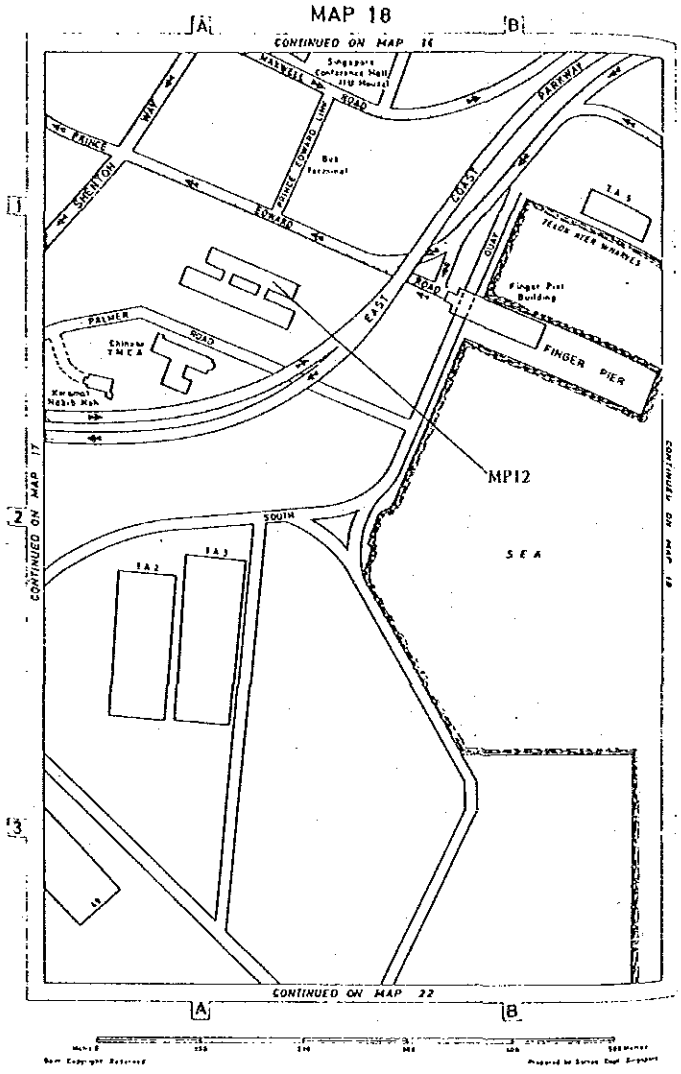
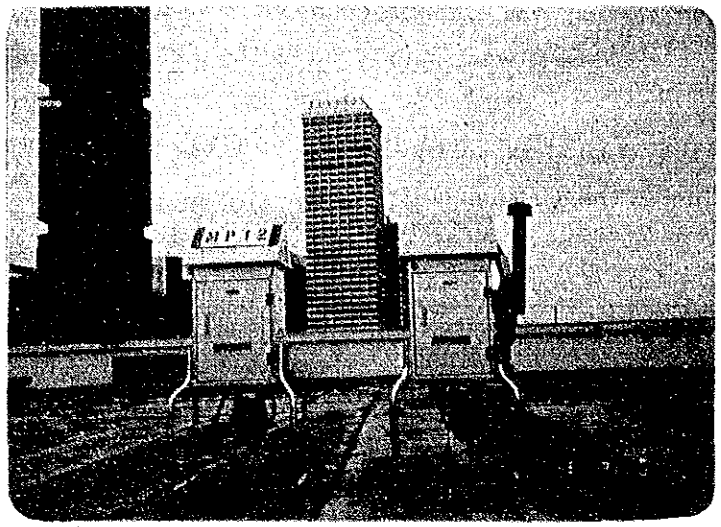
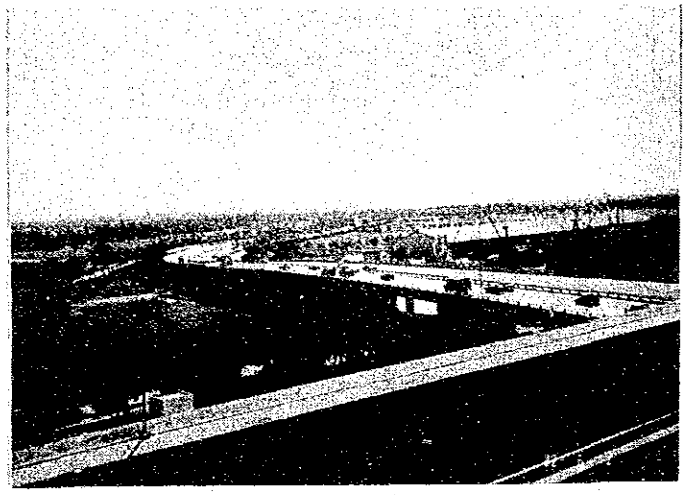


Fig. III-1-13 Location of monitoring station (MP-12)



Picture III-1-12-(1) High volume sampler installed in MP-12 (left-TPM, right-SPM)



Picture III-1-12-(2) Panoramic view from MP-12 (central road is East Coast Parkway)

III-1-3-13 MP-13, Macritchie Reservoir Water Pumping Station

Macritchie Reservoir Water Pumping Station is located in the south/east of the reservoir which is sited almost in the center of the main island, and it is surrounded by many trees. About 20 m to the south/east of the pumping station, Reservoir road is running and about 100 m to the south/east of the Reservoir road, Lornie road is running which has the heavy traffic. About 30 m to the north/east of the pumping station, the car parking is constructed.

The monitoring station was established about 5 m to the south/east from pumping station building. TPM and SPM were monitored by the high volume samplers.

Location of the station is shown in Fig. III-1-14, and Picture III-1-14 shows the instruments installed in the station.

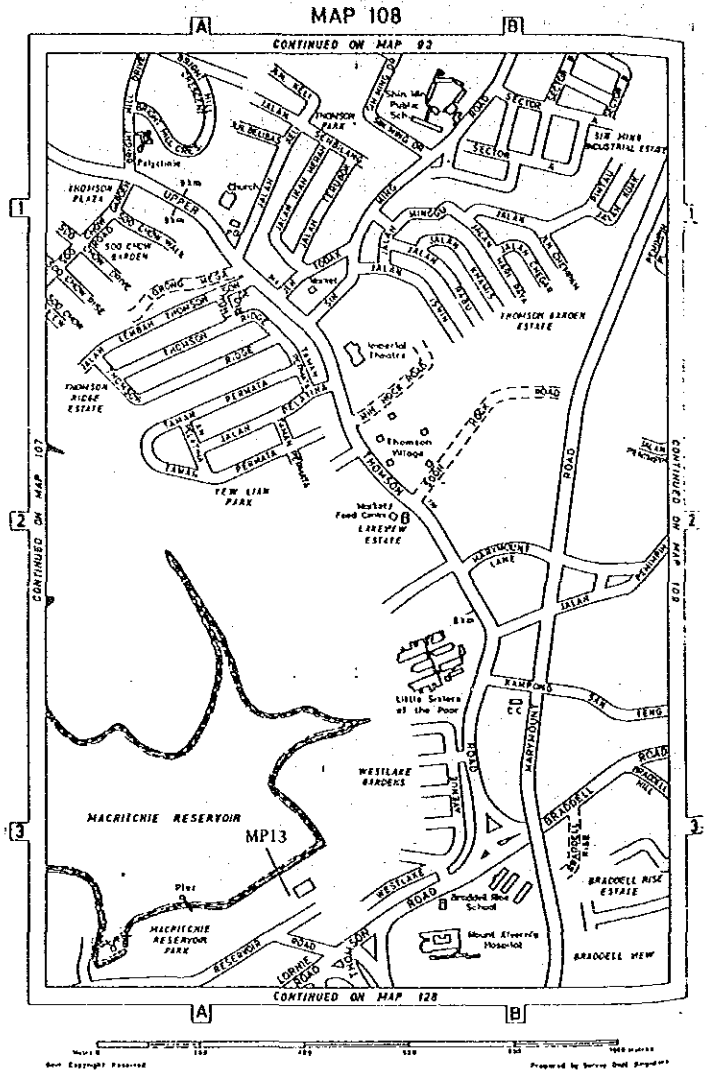
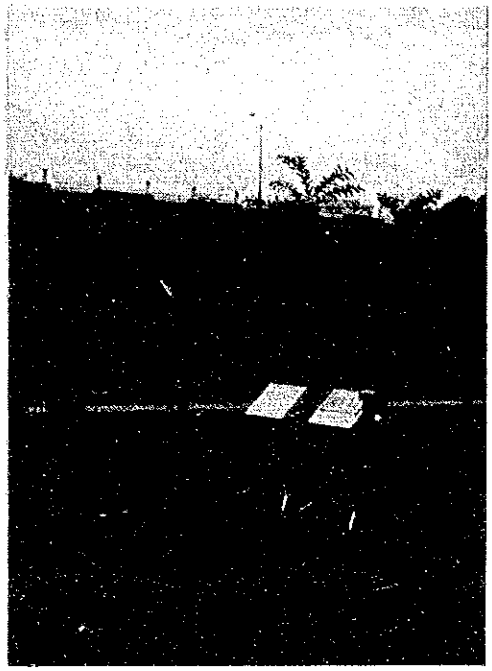


Fig. III-1-14 Location of monitoring station (MP-13)



Picture III-1-13 High volume samplers installed in MP-13 (left-TPM, right-SPM)

III-1-3-14 MP-14, Kallang Flatted Factory

Kallang Flatted Factory is located in the north/east of the city area, and about 2 km north of the National Studium. The highway crossing Singapore main island from west to south is running about 150 m away from the Factory. Many factories and housing apartments are sited in the north, east and west of the Factory.

The monitoring station was established on the roof top of the Block 3 Flatted Factory (about 18 m high).

TPM and SPM were monitored by high volume samplers. For wind direction and velocity, the pole of 10 m long was set up to install the sensor of the anemometer, and the recorder together with SO_2 analyser were installed in the water tank room of the roof.

Location of the station is shown in Fig. III-1-15, and Picture III-1-14 shows the instruments installed.

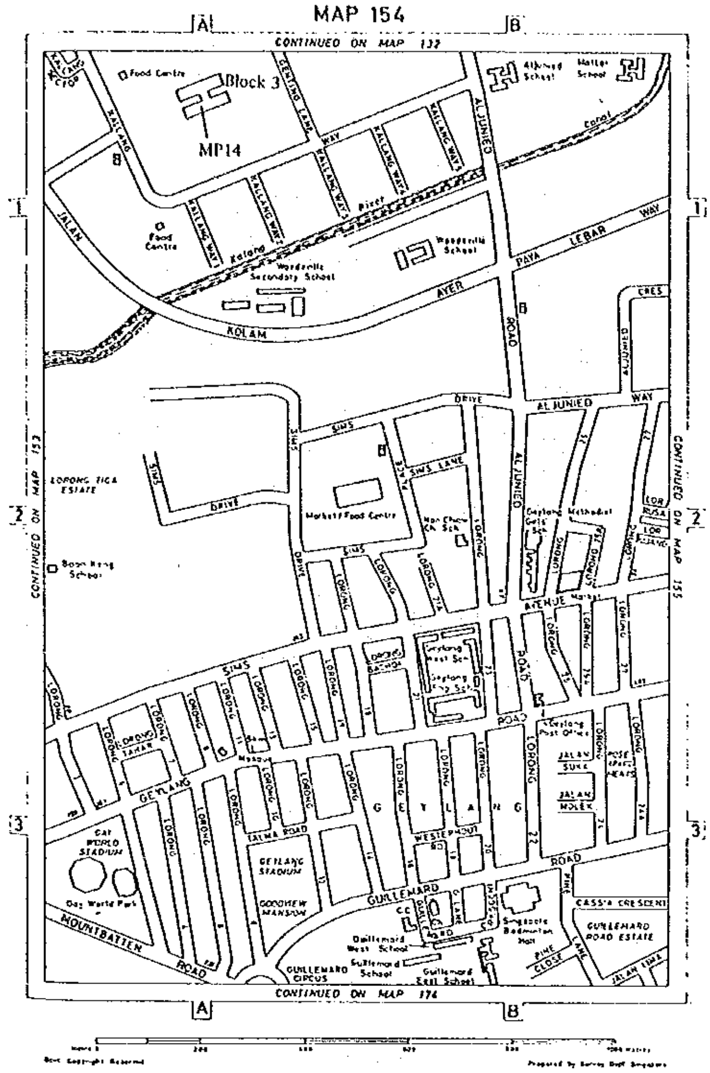
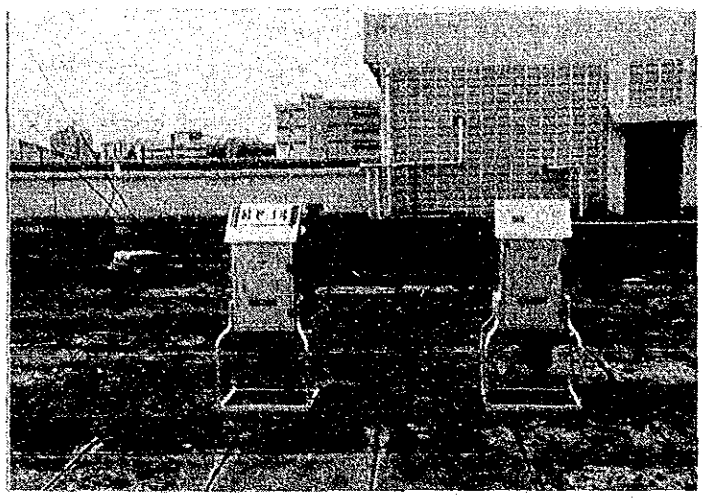
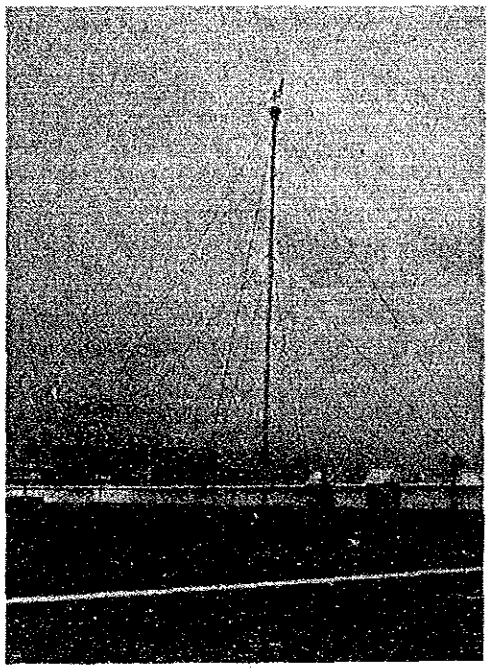


Fig. III-1-15 Location of monitoring station (MP-14)



Picture III-1-14-(1) High volume samplers installed in MP-14 (left-SPM, right-TPM) (SO_2 analyser and recorder of anemometer were installed in the water tank room seen behind)



Picture III-1-14-(2) Anemometer installed in MP-14