LRTAP - 1/73

Technical Note
07.09.1973

AIRCRAFT MEASUREMENTS
PRESENT STATUS AND PLANS

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1 INTRODUCTION

Aircraft sampling of sulphate aerosol and sulphur dioxide is part of the voluntary programme in the first measurement phase of the OECD project "Long Range Transport of Air Pollutants".
In the second measurement phase, which will start in 1974, coordinated aircraft sampling is expected to become a part of the regular measurement programme.

The present paper gives a summary of the technical status with respect to aircraft sampling facilities in the participating countries. Based on this knowledge and discussions with representatives of the participating countries, an outline plan for the organization of an extended airplane sampling programme in the second measurement phase is presented.

Within the LRTAP project the aircraft measurements are to serve several different purposes:

1) To verify and correct sulphur dioxide and particulate sulphate concentration fields predicted by the atmospheric dispersion model. Aircraft measurements are a necessary supplement to the ground stations as most of the long range transport of air pollutants often takes place at elevations

up to 1000 - 2000 m.a.s.l. Because a one-layer atmospheric dispersion model is used, the aircraft measurements and samples should, if possible, be taken so as to be representative of the average concentration from the surface up to the top of the mixing layer.

2) To obtain vertical profiles of pollutant concentrations under representative transport situations. Such profiles may be used together with meteorological data to analyse the transport in more detail. The profiles may also allow more direct estimates of the relative importance of sinks, e.g. dry deposition etc, under actual weather situations.

3) The distribution of elemental sulphur in the gaseous and particulate phases, and the concentration of sulphate and acid in cloud droplets, are particularly important for the understanding of the precipitation processes. As these are initiated in the free atmosphere, the samples and measurements should be taken from aircraft in order to be representative.

4) Simultaneous sampling and chemical analysis for other constituents such as gaseous ammonia, and ammonium, nitrates, etc in the particulate phase, are required in order to explain the difference in the composition of rain water and air samples collected at ground stations.

5) Measurements of the distribution of sulphur between the gaseous and the particulate phase, taken in the same airstream with a time interval and displacement of 6 - 12 hours, should be made to estimate the conversion rate of sulphur dioxide to sulphuric acid and sulphates.

In the first measurement phase aircraft sampling has been limited to sulphur dioxide and particulate sulphates, and main emphasis has been on the development of reliable methods. In the second measurement phase collection of relevant data through a coordinated measurement programme should be given priority.

2 PRESENT TECHNICAL STATUS

Methods for sampling and analysis of air pollutants were discussed at a meeting in Frankfurt 27th - 28th April 1973 between aircraft measurement groups from Western Germany, the United Kingdom, the Netherlands, Sweden, and Norway (1). At present the methods for determination of sulphur dioxide are based on the analytical procedure of West and Gaeke (TCM) or on the oxidation to sulphate and analysis by the barium-perchlorate Thorin method. For sulphate aerosols, XRF or the Thorin method is used. Other methods are under consideration.

The detection limits for sulphur dioxide are 1 - 3 $\mu g/m^3$ for 30 min. sampling periods. For 10 min. sampling periods the detection limits are correspondingly higher. Methods for sulphate in aerosols have a sensitivity of better than 1 $\mu g/m^3$. Somewhat lower detection limits may be obtained with methods now being tested. This may result in shorter sampling periods.

The technical status in the participating countries is summed up in the following.

Western Germany

The group at Frankfurt University has long experience in aircraft measurements. Aircrafts used are a twin engine Beech Queen Air and a single engine Dornier. Both aircrafts are owned by the government through the DFLVR. Sulphur dioxide is determined by the TCM method, using parallel sampling trains, one of which has a prefilter loaded with chromium dioxide. The amount of sulphur dioxide is deduced from the difference, thus avoiding negative values due to interference from ozone or nitrogen oxides.

A separate sampling train with filter is used to collect sulphate aerosol. The larger aircraft is also equipped with Royco particle counter and condensation nuclei counter. Direct recording instrumentation for sulphur dioxide, and methods for nitrogen oxides and ozone are tested.

The United Kingdom

Aircraft measurements in the United Kingdom are carried out by the Atomic Energy Research Establishment (AERE) at Harwell, and by the Warren Spring Laboratory (WSL) at Stevenage.

At AERE aerosols are collected on a Whatman 41 filter, backed with an inert filter with low flow resistance and a Whatman 41 filter impregnated with a potassium carbonate - glycerol solution to collect sulphur dioxide.

The amount of water soluble sulphate in both filters is determined by the barium perchlorate-Thorin method after leaching the filters with deionized water.

A twin-engined Varsity aircraft from the Meteorological Office is used for the sampling flights. The filters are mounted in casettes which are placed in a retractable sampling boom made from light aluminium alloy.

At WSL the TCM method is used for sulphur dioxide. Special precautions have been taken to avoid possible spillage of the corrosive absorption solution in the aircraft. A large military aircraft, (Hastings) is used, and a relatively long PTFE intake tube draws the sample from the nose of the aircraft to the cabin. In addition there are two sampling lines for aerosols with short intake tubes, using different filters for the determination of various constituents of airborne particulate matter.

A prewashed Millipore filter is used for sampling in connection with the determination of chlorine, sodium and ammonium. Sulphate and free acid are determined on a Whatman 40 filter, by XRF and titration respectively.

In cooperation with the Esso Oil Company a direct reading Barringer spectrophotometer for sulphur dioxide has been tested.

Sweden

The aircraft sampling apparatus has been developed for NORDFORSK by the Meteorological Institute at Stockholm University (MISU). The equipment is based on collection of particles by passing a large volume of air through a glass fibre filter. Sulphur dioxide is collected in acid hydrogen peroxide. Both samples are analysed by the barium perchlorate-Thorin method. An integrating nephelometer giving direct recordings of the concentration of aerosols in the 0.1 to 1 μ range has been installed, together with a simple condensation nuclei counter.

Norway

The equipment for sampling used by the Norwegian Institute for Air Research is similar to the Swedish equipment.

Close cooperation is maintained with MISU, and inter-calibration and testing of the reproducibility of the chemical analyses has been carried out.

An automated sampling equipment based on collection of sulphur dioxide on impregnated filters has been constructed and is now being tested.

The Netherlands

Aircraft measurements of ozone have been carried out. In connection with the lower Rhine cooperative study with Germany, the Netherlands will start aircraft sampling in the near future.

France

Aircraft measurements of air pollutants are considered with a strong possibility of realisation in the near future.

No technical details have been disclosed yet, but the CCU will be informed of the progress in due course.

Denmark

Equipment based on the impregnated filter method for sulphur dioxide is under construction at the Danish Atomic Energy Research Center at Risø. The equipment is being installed in a carrier aircraft owned by the Danish Airforce.

Finland

Aircraft sampling by Finland will be carried out using DC3 aircraft from the Finnish Army.

Other countries

Switzerland has declared from the start of this project that the Swiss Government is not able to carry out aircraft sampling. As a compensation, sampling of air at a high level mountain station (Jungfraujoch) is carried out.

Austria will probably not be in a position to undertake aircraft measurements.

3 PRELIMINARY EXPERIENCES FROM 1. MEASUREMENT PHASE

At the Frankfurt meeting the question of which procedures should be recommended as common reference methods for aircraft sampling of sulphur dioxide and particulates was brought up. In the following the conclusions are given with a few comments.

Sampling

It was concluded that the impregnated filter method for collection of sulphur dioxide represented the best combination of sensitivity and simplicity.

The main limitation is the reduced collection efficiency at relative humidities below 30%. The sampling apparatus therefore must be constructed and mounted in the aircraft so as to give only a small (1 - 2^{o}C) preheating of the air sample before it passes to the impregnated filter for sulphur dioxide absorption.

If an aerosol filter is placed in front of the impregnated filter, little or no preheating may, however, lead to wetting of the aerosol filter under conditions with high humidities. This may cause absorption of sulphur dioxide in the aerosol filter.

The main criterium for selecting a filter material for the collection of aerosol sulphate is the blank sulphate content of the filter in relation to the air volume which can be passed through the filter during the sampling period.

Whatman no. 40 or 41 cellulose fibre filters have been found satisfactory and are the natural choice when used as a prefilter in conjunction with impregnated filters.

Glass fibre filters absorb sulphur dioxide more easily at high humidities and require a very high air flow through the filter in order to make full advantage of the low flow resistance and high collection efficiency for this filter material.

Certain qualities of membrane filters may be satisfactory.

Chemical analysis

The aerosol filters and the impregnated filters may be leached with destilled water, and analysed by either the barium perchlorate Thorin method or the isotope dilution method. These two methods are expected to be comparable.

X-ray fluorescence, offering the advantage of being a non-destructive method, was regarded as a useful alternative method for the determination of sulphate collected on the aerosol filter.

Further information was needed concerning the use of X-ray fluorescence for the determination of sulphur dioxide collected on impregnated filters.

The recommendation of the impregnated filter method does not invalidate the other sampling and chemical analysis methods, which, although exacting and difficult to carry out, may still possess advantages under special sampling conditions.

Direct reading instruments

The advantages of using direct reading and recording instruments in connection with aircraft sampling are mainly:

1. Continuous recording makes it possible to register variations within the blocks of air which are integrated in discrete samples. Peaks due to single stack plumes may be identified and separated.

2. Direct reading instruments will enable the crew of the aircraft to decide on the continuation of a sampling flight, selection of the most representative layer etc.

The large scale variations of the concentration of sulphur dioxide and particulate sulphate are followed by corresponding changes in other constituents. Experience has shown that the number of particles and condesation nuclei are good indicators.

Instruments based on the light scattering properties of aerosol particles are readily available. These are either based on the counting of particles in different size groups (particle counter), or directly measuring the amount of scattered light in a selected wavelength region (integrating

nephelometer). In addition there are instruments available which measure the number of condensation nuclei about every second.
The sensitivity of all these instruments are quite sufficient for the detection of aerosol concentrations of 1 - 2 µg per cubic metre.

Together with the total concentration of airborne particulate matter, the number of condensation nuclei also gives qualitative information about the age of the particle population in accordance with Junge's theory for the relative size distribution of aerosols.

These instruments are strongly recommended as supplements to the discrete sampling, in order to observe variations in the aerosol concentration along the sampling route.

Also desirable is a direct recording instrument for sulphur dioxide. At present the detection limit of such instruments is not sufficiently low to replace discrete sampling methods, but some instrument types may be used to detect high concentrations of short duration within the sampling periods.

The flame photometric detector has recently been used in aircraft measurements in the USA by Professor R. A. Rasmussen, Washington State University, Pullman, Washington; and Baird Scientific Co. in Bedford, Massachussets, on a contract with EPA, has developed an instrument with a sensitivity of a few µg SO_2/m , by utilizing the increased efficiency of the chemiluminescent reaction at a cold surface.

A simple instrument based on the coulometric principle, with reduction of iodine to iodide by sulphur dioxide, has been developed by Novak. This has been modified for use in aircraft by Jost's group at Frankfurt University, and is now capable of giving relative sulphur dioxide concentrations down to 8 µg/m^3. For absolute values, comparison with discrete samples is necessary.

The correlation spectrophotometer of Barringer Research may also be useful. It gives a record of the integrated sulphur dioxide and nitrogen dioxide contents of the air above the aircraft. The sensitivity is 1 ppm x meter SO_2.

Other gaseous compounds which may be monitored, include carbon monoxide, carbon dioxide and total hydrocarbons. These may be of interest as tracers of emission from combustion sources. If a fuel with 2% S is used, 10 µg of SO_2/m^3 will correspond to less than 1 ppm increase of the CO_2 concentration (which is about 320 ppm av.), and a few micrograms of carbon monoxide and hydrocarbons. The level of the hydrocarbon concentration will increase significantly compared with the background level.

Meteorological parameters and flight data

Experience has shown that in addition to data giving time and location for the samples collected, other informations frequently are wanted in connection with the interpretation of the analytical results. Temperature and humidity may affect the filters used for sampling, and should be recorded together with air speed and atmospheric pressure.

Further, observations of cloud situation, precipitation, and icing conditions may be important, and it has also been considered to take regular photographs of the clouds etc during sampling. Sometimes the pollution can be directly observed as a dark stain on the clouds. General information of this kind may be obtained from a regular de-briefing of the aircraft crew after measurements.

4 ANALYSIS PROGRAMME

Many of the substances generally known as air pollutants are also emitted from various natural sources, ranging from volcanoes to microbiological activity in soil and surface water. The LRTAP programme is focused on the transport and fate of the sulphur oxides emitted mainly from oil and coal combustion. These products react with other compunds such as ammonia, nitrogen oxides, ozone and water in the form of cloud droplets, and are precipitated with rain or snow at distances up to some thousand kilometers away from the main emission sources.

Much of the transport of the air pollutants takes place at altitudes up to 2000 m above the sea level. The rainout processes are also initiated at these levels. Detailed knowledge of the vertical concentration profiles of sulphur compounds under representative weather conditions is therefore desired. These data should be supplemented with additional information such as temperature, humidity, nitrate, ammonium and gaseous ammonia concentrations, because these may serve to characterize the conditions for chemical reactions and rainout probability.

The reactions of the sulphur compounds with other components also influence the dry deposition of particles, as the chemical composition and the size distribution of the particles are altered.

In order to obtain more precise information on which to build the matematical formulations of chemical transformations and deposition prosesses in the atmospheric dispersion models, the measurement of additional components is considered in the second measurement phase. This applies to the ground stations as well as the aircraft sampling. The adequacy of the present aircraft sampling programme has to be considered in this connection. Below is given a discussion of the individual components considered for aircraft sampling, available methods for sampling and chemical analysis, and operational considerations in relation to the LRTAP project.

Sulphur dioxide

The highest concentrations of sulphur dioxide which have been measured at 1200 m.a.s.l. over the Southern part of Norway in connection with long range transport, are 20 - 40 µg of sulphur dioxide per Nm^3. Such high concentrations are rare. In the majority of transport situations the concentration is around 10 $\mu g/m^3$. This shows that in order to obtain realistic vertical profiles etc, a sulphur dioxide 2σ detection limit of 1 - 2 $\mu g/m^3$ is desirable. The relative error may be up to 10%. No commercially available recording instrument seems to meet these requirements at present (see p. 10). Discrete sampling therefore is necessary.

Sulphate aerosol

The main fraction of sulpur in the particulate phase is present as watersoluble sulphate, either as sulphate salts, particularly ammonium sulphate, or as sulphuric acid in droplets. The latter may form through the absorption of sulphur dioxide in cloud droplets. The amount of free acid found on aerosols in Scandinavia in connection with long range transport is variable, from zero to about 50% of the total sulphate content. Sometimes the contribution from nitric acid is considerable.

The concentration of sulphate aerosol ranges from 0.1 - 0.5 $\mu g/m^3$ in Atlantic air and above the atmospheric mixing layer, to 50 $\mu g/m^3$ in polluted air after transportation to the Scandinavian area. Freshly polluted air in urban areas contains usually not more sulphate on particles than corresponding to 5 - 10% of the sulphur dioxide concentrations.

With time the sulphate fraction will increase, somewhat dependent on the atmospheric conditions, and in long range transport situations the ratio measured in Southern Norway and Sweden is typically 1:1.

The requirement to sampling and chemical analysis therefore is to measure concentrations down to less than 1 microgram/m^3, with a 2σ detection limit of 0.5 $\mu g/m^3$, and a relative error of about 10% of the actual amount. Discrete sampling has to be used.

Sampling should be carried out to give the true amount of aerosol. The mass median diameter of sulphate particles seems to be around 0.3 µm, thus isokinetic sampling is not normally required. Deposition of particles in sampling ducts must, however, be considered.

Because air saturated with water vapour is often encountered, and because icing and wetting may occur in clouds, the air intake should be designed to minimize impaction, and the air-stream should be heated to evaporate droplets before collection on the filter. This requires a separate sampling line when impregnated filters are used to collect sulphur dioxide. Humidity should be recorded.

Cloud droplets

In ordinary air the majority of sulphate particles are in the submicron size range. Air of continental origin generally contains a larger number of small size particles than air of maritime origin. When the air is cooled, the particles act as condensation nuclei to form cloud droplets. The water content of clouds is less than 1 ml/m^3 of air. Very few of the particles above 0.1 µ diameter are not used in the formation of these droplets, which usually have mean diameters from 20-40 µm, depending on the water content and the number of particles available.

Some information on the amounts of pollutants which are taken up in cloud droplets, is important for the prediction of the amounts which can be brought down by preciptation. It is therefore desirable to collect cloud water samples for chemical analysis. It seems that this can be achieved by the use of cyclones.

Total acid

This parameter is desirable both in the aerosol samples (< 10 µ) and in cloud water. For the analysis, a cloud water sample of 5 ml is sufficient, provided suitable (inert) materials are used for the sampler and storage containers. This corresponds to about 5 m^3 of air.

Determination of strong acid collected on aerosol filters is more difficult, and requres special filter materials which do not interfere with the sample. Also contamination of the sample filter by ammonia in the air may occur during transport or storage.

Calculated as sulphuric acid the amount of free acid in the aerosol is a fraction of the total sulphate. Less than 10% is probably an insignificant amount in relation to the ratio of acid to sulphate in rain samples.

The detection limit ought to be around 0.2 µg of H_2SO_4 per m^3. This requires a sample of 5 m^3 of air.

Total suspended particulate matter

The measurement of total suspended particulate matter is interesting because, as an indicator of polluted air, the concentration may be followed using nephelometers, particle

counters and condensation nuclei counters. This will give information on the extension of polluted air masses, vertical concentration profiles, and to some degree the age and origin at the material (continental/maritime aerosols).

In connection with long range transport of air pollutants amounts of 10 - 20 $\mu g/m^3$ are typical.

Ammonium and ammonia

A major constituent of particulate matter connected with long range transport, is ammonium sulphate, which may make up for as much as 40% of the material by weight. Much of the ammonium originates from agriculture and biological decay processes, as gaseous ammonia. In the upper atmosphere reactions of nitrogen and nitrogen oxides with hydrogen and water vapour are significant.

This results in a widespread and rather uniform occurrence of ammonia in the atmosphere, typical concentrations being a few micrograms per cubic metre. Near the ground and indoors the concentrations are much higher, sometimes giving rise to serious contamination effects. This ammonia affects the oxidation of sulphur dioxide to sulphates, which is an important parameter in the atmospheric dispersion model. The large amounts of ammonium found in the aersol samples, indicate that the presence of ammonia may be a very important factor in long range transport, which should be more closely investigated.

Gaseous ammonia is conveniently sampled in wet bubblers charged with an acidic absorption solution: 0.01 N sulphuric acid is often used, the absorption is also quite efficient in acid hydrogen peroxide absorbing solution. Chemical analysis is readily made by the indophenol blue method.

Ammonium is analysed by the same method. Some filters (acid-washed Whatman 40) have high blanks, and an acid sample of particles on a filter will almost certainly be contamined to some extent by ammonia from the air.

Nitrogen oxides - nitrate

Measurements in precipitation collected in Southern Norway during situations with long range transport of air pollutants, show that nitrate ions may occur in amounts comparable to the content of sulphate ions. Observations indicate that this happens more often with contaminated air from Western Europe than from Eastern Europe. Corresponding observations made in Western Germany on the ratio between sulphur dioxide and nitrogen dioxide in air, are explained by differences in the type of fuels used and possibly the number of automobiles.

Because the formation of nitrates from nitrogen oxides requires more time than the oxidation of sulphur dioxide, it also seems to be a condition that the air masses move slowly in order to give the reaction time to develop before arriving at the observation point. The long range transport of nitrogen oxides and nitrates therefore should be more closely investigated in connection with the acidity of the precipitation.

Only nitrogen dioxide can be sampled with washbottles at low concentration levels. It is, however, doubtful whether the sampling time can be made short enough to merit use of present methods in aircraft sampling.

Direct recording instruments are based on the chemiluminescence of the reaction of nitrogen monoxide with ozone. Nitrogen dioxide is thermally decomposed or reduced to nitrogen oxide. Commercial instruments are not sufficiently sensitive for measurements in the free atmosphere, where expected concentrations are only a few (2 - 3) $\mu g/m^3$.

Nitrous oxide (N_2O) is also present in the atmosphere, but has a much longer lifetime and is probably not interesting in the present context. Sampling of nitrous oxide using molecular sieves has been reported.

The content of nitrate ions is readily analysed in aerosol samples. Using a suitable filter material, HNO_3 gas may also be retained and analysed.

Other components

A more detailed chemical analysis of aerosol filter samples will give further information concerning the materials transported and their origin. Vanadium is an indicator for certain fuel oils. Lead comes from car traffic, etc. Analyses of these and other elements give information on the past history of the air masses.

A large fraction of the suspended particulate matter from combustion sources consists of soot and condensed hydrocarbons. These components are frequently brought down with precipitation. Also these compounds may be useful as tracers. It may be mentioned that on some occasions the amounts of soot etc collected on filters by aircraft sampling over the North Sea have given a visible darkening of the filters.

Measurements of this type should, however, wait until more information has been collected from high volume samplers now operated at some of the ground stations.

5 ORGANIZATION OF SAMPLING FLIGHTS

The objective of aircraft sampling is to collect data for the verification and adjustment of the atmospheric dispersion models, which have been developed in connection with the LRTAP project.

The present dispersion model is two-dimensional, in the sense that the total amounts of sulphur dioxide and sulphate in the various grid squares are calculated. The sampling of sulphur dioxide and sulphate should therefore be conducted so as to give a measure of the integrated concentration with height for the different grid squares. Often measurable concentrations of these pollutants in the lower part of the troposphere extend up to a height of 800 to 2000 m.a.s.l., depending on the atmospheric conditions.

Therefore, sampling should be conducted at varying altitudes either ascending or descending through the mixing layer. With present techniques the sampling time will usually be 10 to 30 minutes, representing a distance of 50 - 150 km for each sample.

Recording instruments should, if available, be used to obtain maximum information on the vertical concentration profile during sampling flights. Further, the recording instruments may be used to determine the level of maximum concentration, and to obtain some information on small scale variations of the distribution of the air pollutants.

Normally the sampling routes will be organized on the basis of meteorological forecasts and directed along lines normal to the air trajectories. In most cases the sampling will take place at levels below 1500 m, and the flights will have to be carried out under instrumental flying rules, which requires fully instrumented twin engine aircrafts and pilots carrying the necessary certificates.

Under instrumental meteorological conditions the minimum safe altitude accepted by the air control over the sea is usually flight level 45 (the pressure level corresponding to 4500 feet in the standard atmosphere), approximately 1500 m a.s.l. This means that the sampling level of main interest to the project, frequently will be below the lowest level normally accepted by the air control for instrumental navigation. Further, according to experience sampling more often than not, will take place under weather conditions such that instrumental navigation has to be used.

Under instrumental flight rules the air control is responsible for making sure that the aircraft is at a safe level above the ground and keeps a safe distance to other aircrafts. Obviously, if the sampling aircraft flyes below the level normally considered as minimum safe flight level, the air control cannot be responsible for safe ground clearance. This responsibility must rest on the pilot.

On this basis the following procedure has been worked out. The sampling route is selected on the basis of project plans and meteorological forecasts. This forecast indicates the route along which sampling is wanted, the maximum and minimum levels of interest, and the time for starting and completion of the mission. Maximum level of interest for measurements will correspond to a certain flight level. The air authorities are asked to reserve the air space along the sampling route below this flight level for the sampling flights. When sampling takes place the aircraft will operate on instrumental flying rules, but the air control is only responsible for other aircrafts in the area. The pilot will, however, keep the air control currently informed about his position and level. As soon as sampling is completed or broken off, the pilot will report this and return to normal flight rules.

meteorological authorities have a different opinion with respect to the best sampling route, the national institute organizing the aircraft sampling in the country is free to make the modifications believed necessary. Such changes should be immediately reported back to the Central Coordinating Unit, but the national institute has no obligation to wait for acceptance of the new sampling route from the Central Coordinating Unit.

When time permits, it may be advisable to ask for the opinion of the Central Coordinating Unit, but it is believed that in most cases there will be little time for this, and also as the starting hour of the sampling flight comes closer, it will become more and more obvious what will be the best sampling route.

Depending on available aircraft, instrumentation and weather conditions, the sampling should be planned to give information on the distribution of the pollutants within the above mentioned cross section. Normally this will be obtained by slowly ascending and descending through the mixing layer, or by flying at a constant level interrupted by a few vertical sections, or by making the return flight at a different level. The national institute should make a plan for this, but the pilot may have to change this flight pattern if necessary, or if indicated by the recording instruments and the general flight plan.

With respect to type of aircraft, instrumentation to be used, and samples to be taken, it should be remembered that any aircraft sample is better than nothing. Below is listed what is believed to be a satisfactory set of sampling equipment for the purpose. In addition instruments are mentioned which are or may be used in some of the countries.

In addition to the instrumentation mentioned above, use of the following instruments may be advantageous if the instruments are available:

An additional wash-bottle for sampling of gaseous ammonia.

A direct recording instrument for sulphur dioxide (Novak cell, flame photometer, correlation spectrometer).

Combination of different instruments for the registration of particles and condensation nuclei.

Additional chemical analysis of the filter samples on acidity, nitrate ions and other constituents.

Collection and analysis of cloud droplets.

Additional observations of this nature will take place on a voluntary basis. It is believed that before the second measurement phase starts, more information on the utility of these measurements will be available.

REFERENCE

(1) Notes from the discussion of "Airplane sampling" in Frankfurt am Main - 26-27 April 1973.