ENVIRONMENTAL
MEASUREMENTS
550 Battery Street (1502) San Francisco, ~~CA 94111~~

982-8258

8 October 1968

Miss Elizabeth Ralph
University Museum
University of Pennsylvania
Philadelphia, Pennsylvania

Dear Beth:

It was a great pleasure to again visit with you and Fro, on September 25. I am so pleased that the endeavour we started with Varian several years ago has turned out as fruitful as it has. There have been so many facinating elements to this field of magnetics that I sometimes think a book is in order.

It would appear that the involvement of Dr. Ginzton into an interest in archaeology is most beneficial for your future relationship there. There is probably little else I can do to help magnetically!

The possibility of other remote sensing techniques being applied to archaeology is, of course, very real. At the Society of Exploration Geophysicists in Denver last week, it was revealed that significant halos of mercury were measured over a variety of ore deposits. Apparently both Hg and I_2 are extremely volatile and appear on the surface. It is not obvious what will help over digs--though phosphates may be the initial reporting molecule. Let's keep it in our mind.

SO_2
NO_2
I_2

It was certainly good to see both you and Fro. I shall not write to him and add to the weight of paper on his creaking desk, but please thank him for the time and remind him I would like to help the Museum in anyway I might.

I look forward to seeing you during your visit to the Bay Area in mid-December.

Best personal regards,

Lee Langan

Return to EKR

ENVIRONMENTAL MEASUREMENTS 550 Battery Street (1502) San Francisco, CA 94111
982-8258

January 14, 1969

Miss Elizabeth Ralph
University Museum
University of Pennsylvania
33rd and Spruce Streets
Philadelphia, Pennsylvania

Dear Beth:

It would be a pleasure to work with you once again in the possible development of another new technique in the use of science for archaeological exploration. It is so difficult to define many of the variables in a program of this nature, but perhaps I can outline an intent and some guidelines.

Environmental Measurements would be willing to supply field personnel, study the problems involved, and to supply whatever correlation spectroscopy equipment is at its disposal. We would do so, at least in the early experimental phases, for the support of our costs only. That is, travel,daily expenses and some amount to cover personnel salaries. I cannot commit Barringer Research, but I would encourage them to study the geochemical situation on the same basis. Should an appropriate mask be deemed feasible I am sure they would produce this mask on a shared basis with the University Museum. The degree of share would depend upon the other potential uses of the mask.

The success of the use of correlation spectroscopy in any exploration technique depends, of course, on the availability of some volatile compound which is indicative of the remains being sought. At this time you have considerably more of an understanding of what compound might be applicable. It is further necessary, if we are to use the sun as an energy source that the spectra be available within an energy "window". We can only investigate various compounds to determine this. I am told that phosphorus is volatile and might be a usable tracer.

Enclosed you will find a preliminary data sheet, a current price list and an abstract describing some airborne tests conducted by Barringer in 1968. I have also asked that a copy of Dr. Barringer's paper on the remote sensing of chemical compounds be forwarded to you. (I am out.)

I suggest the best way to start a program of this nature is to have Dr. John Walker visit the University and to plan from this visit. The only significant expenditure that I could foresee would be the requirement of a specialized mask. Should we get to this stage, of course, it would mean that we have some hope of the success of the application. The type of costs involved in the production of a new mask are considerably less than those required in the development of new electronic instruments -- such as cesium magnetometers. The basic instrumentation exists now, the mask is simply an adaptation. Five thousand dollars would buy some worthwhile effort.

I hope that the above information is sufficient for your proposal. Do not hesitate to give me a call if you have any questions. My best regards to Dr. Rainey.

Sincerely,

Lee

Lee Langan

LL:bjb

Enclosures

ASCA

ENVIRONMENTAL
MEASUREMENTS, INC.

215 Leidesdorff Street
~~550 Battery Street (TH2x)~~ San Francisco, Calif. 94111

(415) 982-8258

December 19, 1969

Mr. Frolich Rainey
UNIVERSITY MUSEUM
University of Pennsylvania
33rd and Spruce Streets
Philadelphia, Pennsylvania 91904

Dear Fro:

In my wanderings I came across a technique which may solve one of your technical problems at Syberis. If you are interested in further information, please just jot so on this letter, return it and I'll look up the details.

There is a means of economically freezing the earth around the sides of excavations in very moist or water conditions. A coolant is passed through pipes layed in closely spaced drill holes. The adjacent ground thereby freezes forming a reliable barrier to the flow of water and a wall and base for the construction site. A reasonably large area can be protected from the inflow of outside water.

I do not know the economics of the technique; I saw it in use in the construction of buildings in the Minneapolis area this winter. Apparently it was developed by a German. (They may have an archaeological interest and assist in your explorations!)

It is always interesting to follow the successes of the University Museum, and I look forward to helping sometime in the future. Best greetings to you and your family during the holidays and, of course, to Beth. I hope to see you sometime in 1970.

Sincerely,

Lee

Lee Langan

LL:bjb

ENVIRONMENTAL
MEASUREMENTS
550 Battery Street (1502) San Francisco, CA 94111

ATMOSPHERIC INVESTIGATIONS & RESEARCH

An ability to measure certain gaseous constituents within the air has been demonstrated using the technique of correlation spectroscopy. Based on the phoenomena of molecular absorption (or emission), instruments have been produced to measure single components of the atmosphere on a continuous basis. Unique compound quantitative determinations, even minute amounts, are measured over a distance between the energy source and the instrumentation.

Correlation spectrometers have been produced in four basic configurations. Each is used to measure the quality of the air from a different vantage.

1) A "stack monitor" measures the flow of gas within a smokestack under very high temperature and particulate conditions. Artificial light passes the diameter of the stack near its base and is reflected from a mirror to the instrument telescope.

2) A "remote sensor" can surveil the output of the stacks from a distance or monitor over long path lengths. This battery-operated instrument utilizes the sun as the source of energy and gathers the light by means of a tripod-mounted telescope. It actually measures the concentration of the particular compound between the sun and the telescope.

3) A modified remote sensor has been installed in a small two-engine aircraft. The source of energy is the sunlight reflected from the earth's surface. Flight-line information can produce synoptic profiles, perimeter surveys and even contoured indications of pollution concentrations.

4) An "ambient monitor" is a hybrid device which has some characteristics of existing air monitoring instruments but uses the techniques of correlation spectroscopy for measurement. The air is drawn into a chamber, and an artificial light is used as the source of energy. The information provides an indication of the air quality at a point or, when the device is moved, along a line.

The very newness of this technology and the variety of configurations produced since the initial prototype (in 1965) place it in an early stage of development. Nevertheless, the data are useful to those organizations that are probing the problems associated with air pollution. Now SO_2, NO_2 and I_2 can be measured routinely. An ability to measure additional compounds, a large number of which are critically important to a number of applications, is being continually investigated.

In an endeavor to foster the applications which will use this unique monitoring device, Barringer Research has joined with Environmental Measurements to provide the use of the correlation spectrometer for investigations and surveys. Remote sensing instrumentation is being offered together with operating personnel. It is anticipated that, in this fashion, the early production instrumentation can be used most flexibly and that potential applications of the instrument can be investigated at the least cost.

The complete airborne installation, owned by Barringer Research, is offered on a daily lease basis. This fee includes the crew, system installation, operational expenses and maps resulting from the gathered data.

The ground remote sensing configuration is available in a mobile laboratory. This installation is suitable for operating, using the sun or artificial light as the energy source, to obtain long-path measurements during daylight or night time operations. Fees are based on daily operations, and information is provided on the concentrations along the path length and the location of the instrument and path-ends.

Services are provided from a choice of three programs:

1) Retainer: This requires a guaranteed number of days of operation over a fixed period of time; a base fee is charged plus a fixed fee for each day of operation.

2) Daily charge: The fee declines over the number of consecutive days used.

3) Job basis: The specific goals are outlined and a quotation is made.

Ferrying time to move the equipment to the site of operations is charged on a mileage basis; per diem expenses are charged for personnel. Depending on foremat desired and report requirements, data reduction is charged on a daily or job basis. Standard map production is included in the fee for the airborne equipment.

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ATMOSPHERIC INVESTIGATIONS & RESEARCH

Correlation Spectrometer, Vehicle, Two Personnel

The following fees are applicable for the use of this service. A report is furnished which includes the basic concentration information and the location of operations. Additional data handling is optional.

Daily Operations:

First day	$500.00
Second & third day, each	450.00
Fourth & fifth day, each	400.00
Sixth day, and additional days of consecutive operation	360.00
Ferrying charge, per mile	0.15
Per diem, for each operator	25.00

Retainer Option:

Six-month base fee	1000.00
Twenty days minimum, each	360.00
One-year base fee	2500.00
Thirty days minimum, each	360.00
Ferrying, per diem, as above	

Barringer Aircraft, System Installation, Three Personnel

The following fee is applicable to the charter of this service. Maximum flying time per day is six hours. Personnel operate on a full time basis, subject to weather and government regulation restrictions. Aircraft base is Toronto, Ontario; ferrying is from there normally. Per diem, all aircraft costs and the preparation of maps in a standard profile presentation are included.

Daily Operations $2000.00

Prices are subject to change without notice; they are $US.
Preliminary Price Sheet - A.I.R. November 1968

Barringer Correlation Spectrometer for Airborne Surveys

Synopsis by: Lee Langan
Environmental Measurements, Inc.
August, 1968

ABSTRACT

A new device has been developed called the correlation spectrometer which is capable of remotely measuring a variety of pollutants from airborne altitudes. Experimental surveys have been carried out over Washington, D.C., Toronto, Los Angeles, and San Francisco which verify the potential application of this instrument to surveillance programs. The equipment is described and the results of experimental surveys are given.

I. The Correlation Spectrometer

The problem of the remote sensing of gases can be approached by making use of the characteristic optical absorption or emission spectra exhibited by virtually all gases. The absorption bands may occur in the ultra violet, visible or infrared spectrum. Virtually all of Barringer's work to date has been on gases such as sulphur dioxide, nitrogen dioxide and iodine which absorb in the UV and visible spectrum and can be remotely sensed using natural daylight as an illumination source. The use of infrared wavelengths are, however, perfectly feasible and work in this region is currently commencing.

An initial instrument developed for the remote sensing of gases has been termed a "correlation spectrometer". Incoming radiation from the region that is being observed is collected in a telescope and dispersed through a spectrometer of the grating or prism type. The spectrum of the radiation is projected onto an optical mask which carries a photographic replica of the spectra of the gas being detected. An oscillating refractor plate (or some other suitable means) is used to vibrate the spectrum across the mask, and the output of the photodetector behind the mask is sensed for the presence of a beat signal. If there is correlation between the incoming radiation and the mask, there will be a beat signal -- as the dispersed radiation vibrates periodically in and out of phase with the mask. Lack of a beat signal indicates the sought-after spectrum is absent. An automatic gain control keeps the average output of the photodetector constant so that the amplitude of the beat signal becomes a quantitative measurement which is not affected by fluctuations in light level.

The basic function of the instrument is based on the Beer-Lambert law of absorption as follows:

$$I = I_o e^{-a^{\lambda} cl}$$

When I_o = incident light intensity

a^{λ} = absorption coefficient as a function of wavelength

c = concentration

l = pathlength

The correlation function produced by the oscillatory motion of the spectrum may be described in a much simplified form:

$$\text{Modulation Ratio} = M = \frac{I_o e^{-a_1 cl} - I_o e^{-a_2 cl}}{I_o e^{-a_1 cl}}$$

Where a_1 = the average minimum absorption coefficient

a_2 = the average maximum absorption coefficient

or,

$$M = 1 - e^{(a_2 - a_1)cl}$$

For small values of cl this expression is very nearly linear. It should be noted that this instrument measures the product cl and that the basic unit of the "ppm-meter", a concentration of one part per million over a one meter pathlength has been designated as the standard unit. The use of data in this form will be discussed later.

In one version of the system, oscillation of the spectrum is achieved by switching two quartz refractor plates, set at different angles, alternately into the light beam. The plates are mounted on one tyne of an electrically driven tuning fork to maintain high stability. The output of the photomultiplier is connected to a highly precise automatic gain control system to maintain constant DC level and is phase-detected in synchronism with the tuning fork to measure the AC level or beat signal. The use of synchronous detection ensures high sensitivity and the ability to detect very weak beat signals buried in noise.

When the instrument is used in its remote sensing mode, illumination is provided by reflected and scattered natural daylight. Thus, in the downward looking mode illumination is provided by the sun and, in addition, the whole sky since it is scattering sunlight. Light passes down to the surface of the earth through the atmosphere and is reflected back up to the instrument located in an aircraft or spacecraft. In this double pass through the atmosphere, the light is impressed with the absorption spectra of the gases present to an amount dependent upon their absorbtivity, the pathlength and concentration.

II. Airborne Installation of the Correlation Spectrometer

Initial tests of an airborne installation were made in August, 1967 from a helicopter using a ground remote sensing instrument so as to be able to look obliquely downwards at the ground. These tests showed that the light levels were adequate and that the instrument could distinguish between high and low levels of sulphur dioxide over built-up areas.

An airborne system was accordingly designed for use in a fixed wing aircraft, the sensor head is mounted on a fixture fastened to the seat rails. Incorporated in this fixture is a rotatable fiberglass tube which supports a set of mirrors for directing the instrument's line of sight down to the ground. Reflected light from the ground enters the sensor's optical system through a quartz window in a starboard pod; it is then reflected off a 45° mirror and passes to a second 45° mirror where it is reflected up into the sensor head. Another 45° mirror is mounted on the port side of the aircraft. A camera is used to provide a single channel photograph of the target area in the visible (for flight path recovery).

A separate lever is provided for an independent 90° rotation of the sensor outboard mirror (which is double surfaced) to permit the sensor to look either down at the ground for normal measurements or at the sky above the aircraft for calibration purposes.

A very important parameter in determining concentration, when using an instrument which reads in ppm-meters, is an accurate measure of optical pathlength over which the measurement is made. In the airborne case with the instrument pointed at the ground the reflected light reaching the instrument will contain components of light which have come from different parts from the sky and, hence, the distances they have travelled through the atmosphere or gas layer, before reaching the ground, will differ. A simplifying assumption in a computerized mathematical derivation is that of spherical symmetry of the sky radiation component. This assumption, which enormously simplifies the mathematical approach is considered to introduce little error in the final result. The treatment of radiative transfer, for the case of a cloudless sky and the aircraft completely above the gas layer, shows the net effective pathlength is equivalent to Hm where H is the height of the gas layer and m is the pathlength multiplier. "m" can be taken from a derived curve, given the sun zenith angle. Since this angle is readily available from meterological tables at the time and place of the survey, this is a convenient solution. It can be shown that the mathematical treatment of the overcast case is identical to that for cloudless sky except that the direct sun component is ignored.

The procedure followed then, in operation of the airborne sensor system, is to fly the aircraft over the target area above the gas layer, zero the instrument output with the sensor looking at the sky, and then to record the instrument output with the sensor looking at the ground. The instrument reading then represents average pathlength times the average gas concentration below the level of the aircraft. The incremental sensitivity of the instrument may be measured by simply inserting a reference cell temporarily into the calibrate position and recording the reading. For most cases a single point (one-cell) calibration will suffice, but for very heavy gas burdens a two-cell calibration is necessary.

Since the instrument is fundamentally a density measuring device and uses a reference cell calibrated at one atmosphere in 68°F, appropriate corrections must be made using average air temperatures and pressures attained at the time of the flight.

III. Flight Tests

A. The results of the initial Aero Commander sulphur dioxide survey along the Toronto waterfront readily identify individual plumes from the generating stations and shoreline industry. A comparison of the different runs showed very similar profiles with parts of the recording, particularly the peak value of some plume signals (superimposed on the background), repeating within 10%.

B. An SO_2 profile was obtained over Lake Ontario during a spiral decent from 15,000 feet to 500 feet. In this case the sensor was zeroed on the water at an altitude of 500 feet before climbing to 15,000 feet for the descent. The purpose of this experiment was to examine the performance of the sensor in measuring the vertical distribution characteristics of sulphur dioxide in the lower atmosphere. The descent was centered over a very heavy plume originating at the steel-making complex in Hamilton, and the presence of the plume produced undulations in the profile as the aircraft passed back and forth over it. There was little change evident in the average value of the profile until the aircraft reached 3,000 to 4,000 feet indicating that the total vertical burden of sulphur dioxide was below 4,000 feet. The rate of descent was held constant at 500 feet/minute and, apart from plume modulations, the total vertical burden appears to fall off almost linearly with decreasing altitude, indicating no obvious tendency of the sulphur dioxide to stratify on this day.

C. In December, 1967 average concentrations were obtained during a survey of the Washington, D. C. boundary. The prime purpose of this survey was to measure the mass transport of sulphur dioxide across state boundaries. Measurements along the Potomac River which define the southwestern limits of the District of Columbia were not possible because of heavy air traffic and legal flight restrictions. The aircraft altitude for the survey was chosen so as to coincide with the top of the haze layer, i.e. the inversion interface, as judged by visual observations, and at the same time consistent with the altitude allocations of air traffic control. Sky conditions were exceptionally good for the flight because the haze layer was quite well defined to the eye and the sky was completely clear of cloud. Instrument calibrations were performed generally at the beginning and/or end of each leg of the three-sided pattern. At each calibration the instrument was zeroed against the sky and the incremental sensitivity measured using the reference cell when looking at the ground. Aircraft pressure, altitude, position over the ground and air temperature were noted at regular intervals. Following the flight, the strip chart was analyzed and the average vertical burden in ppm-meters was determined for each leg of the pattern.

A typical calculation of the average sulphur dioxide concentration for each leg is as follows:

$$\text{ppm} = \frac{\text{ppm-meters (instrument reading)}}{\text{m factor x aircraft height}} \times \frac{460 + T(°\text{F})}{530} \times \frac{14.7}{P(\text{psia})}$$

$$= \frac{112}{3.05 \times 2140} \times .907 \times 1.17$$

T = 18°F
P = 12.6 psia

ppm = .018

The airborne results were then used to calculate the total transport or mass flow rate of sulphur dioxide across the western and eastern boundaries and the differences taken as the rate of production of sulphur dioxide in the Washington area.

Since data could not be obtained along the southwestern boundary of Washington, for purposes of analysis the Washington area was considered to include Arlington County and the eastern part of Alexandria, and the input flux across the total western side of the resultant square assigned the same sulphur dioxide concentration as that measured along the northwest leg. The total inflow of sulphur dioxide was based on the flow rate across the line which is the projected breadth of the Washington area at an angle normal to the incident wind. Then:

volume flow = projected length x inversion height x wind velocity x SO_2 concentration

Then for leg 1,

inversion height = 2155 meters (average of 4 traverses)
wind speed (average) = 10 meters/second
air temperature (average) = -6°C
air pressure (average) = 12.6psia

and sulphur dioxide volume flow = $19{,}750 \times 2155 \times 10 \times 0.019 \times 10^{-6}$
= $8.07\ m^3/sec$ @ -6°C and 12.6 psia
= $7.10\ m^3/sec$ @ STP

SO_2 mass flow = $7.10 \times 2.93 \times 10^3$
= 20.8×10^3 gms/sec (SO_2 density = 2.93 gms/litre at STP)
= 82.4 tons/hour

Similarly for leg 2, the inversion height is 2169 meters and the total outflow is 26.8 tons/hour.

And for leg 3, with an inversion height of 1856 meters, total outflow is 111.7 tons/hour.

The total production in the Washington area is, considering the skewed relationship of the political boundaries to the wind direction, therefore:

inflow = 82.4 tons/hour
total outflow = 138.5 tons/hour
SO_2 production = 56.1 tons/hour

D. Data developed in flights over Los Angeles and the San Francisco Bay Area concentrated on NO_2 measurement.

These results demonstrated the synoptic value of the technique for monitoring air quality conditions rapidly over large areas. In addition to speed of data collection, resolutions comparable to existing methods of air monitoring, and the ability to measure continuous conditions over an area, the aircraft was able to gather data in inaccessible areas. Presentation of the results are in flight-path profiles which depict variations in ppm-meters along a given traverse.

Initial analysis logic allows these instrument readings to be reduced, at least to a first order, to concentrations in parts per hundred million. When these results were compared to nearby control district data, the correlation was consistant. In general, the airborne data, which represents an average concentration throughout the air column, was lower than nearby ground measurements.

Parallel flight traverses, repeated paths and geographically determined paths were flown. The data are consistant and, it would appear, closer flight paths could result in contourable concentrations.

IV. Discussion of Results of Airborne Pollution Surveys

The Toronto waterfront survey (A) and the spiral descent (B) very clearly demonstrate the ability of the remote sensor to detect sulphur dioxide using solar energy reflected from the earth's surface. The Washington results (C), however, provide the first opportunity for quantitative comparison with standard air pollution monitoring equipment. A comparison showed the ground measurements taken near the center of Washington to be three to four times higher than the airborne averages. The Los Angeles/San Francisco (D) data is similar. This appears to be a reasonable comparison considering the long path averaging of the airborne measurements. A more meaningful comparison is not possible without much more detailed information concerning the diffusion patterns of the contaminent over the city. There is little doubt that the concentration variations shown in the airborne data are realistic.

The hourly production of 56.1 tons/hour in Washington by measurement is of particular interest when compared with the total hourly production based on known sulphur dioxide emission inventories. The hourly production, based on an annual industrial, power and motor vehicle load which is assumed constant, plus a heating load which is dependant on the ambient ground level temperature, was calculated to be 20 tons/hour or about 64% lower than the measured value of 56.1 tons/hour. Again the comparison is by no means discouraging, particularly in view of some of the approximations made. The mass balance calculation ignores SO_2 production in the Alexandria, Virginia area although this was no doubt included in the measurement. Also, no account is taken of hourly variations in fuel consumption; the heating load in particular would tend to be higher than the 24-hour average during the morning of the survey.

An aspect of the remote sensing technique that requires considerably more study is the radiation transfer equation. The mathematical model developed to date is applicable to airborne surveys conducted entirely above a pollutant layer. A more complete solution is required which will permit convenient pathlength determinations when a substantial gas layer exists above the aircraft. It will then be possible to carry out complete three-dimensional profiling of pollutant distributions over very large areas conveniently and economically. Relative data can be obtained even now, of course.

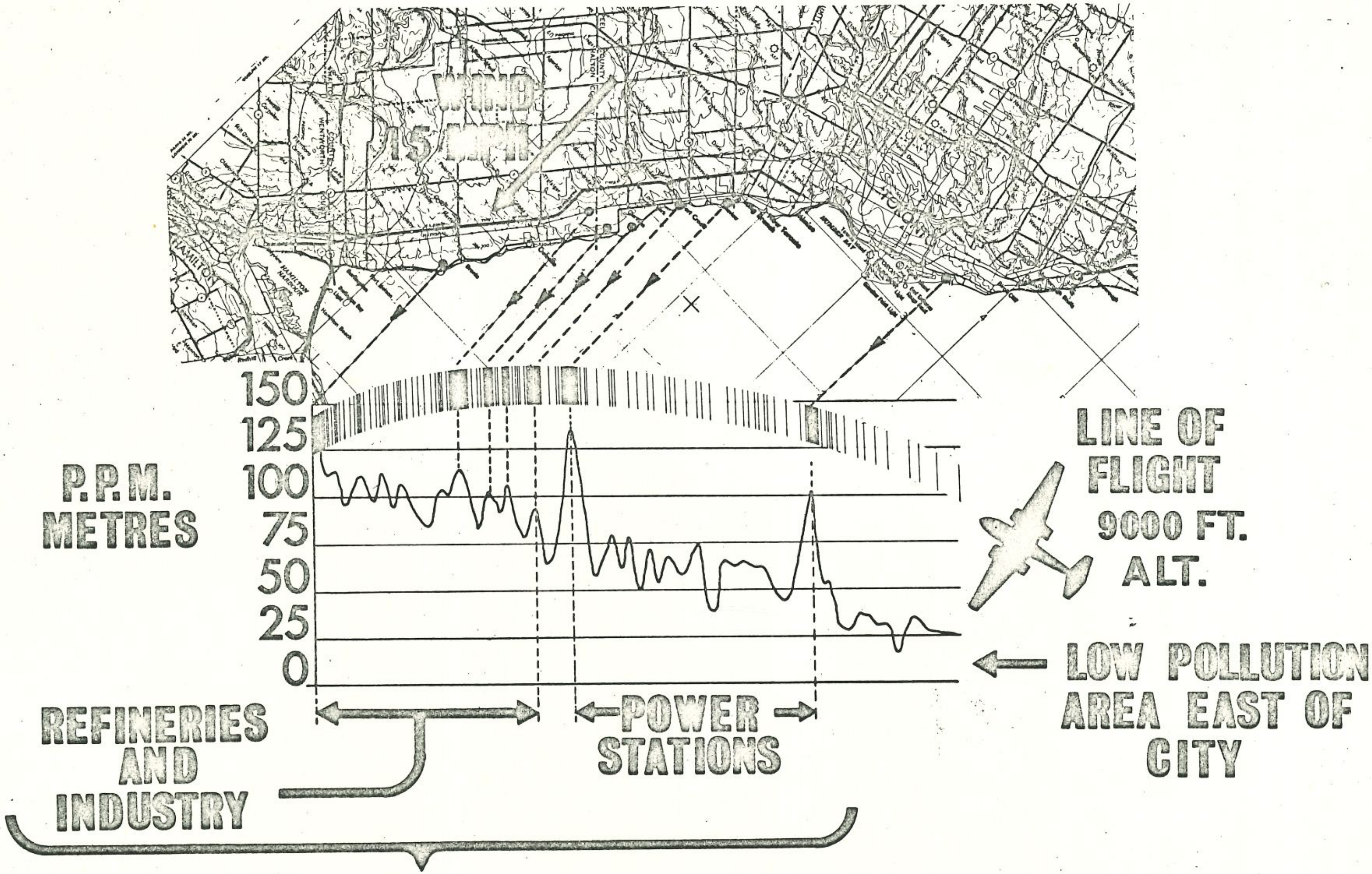
Present performance appears quite adequate for large plume and mass transport sutdies, the performance in detection of point sources of low level sulphur dioxide or nitrogen dioxide emissions and high resolution mapping of complex diffusion patterns require a faster system response and an improved signal-to-noise ratio. Studies and instrument improvements to date have indicated that substantial gains can be obtained within the present system configuration.

The very long effective pathlength that is realized with a remote sensor in a high flying aircraft offers a very real advantage in the measurement of trace gases in the atmosphere which are well diffused. For example with a 10 ppm-meter threshold sensitivity and an effective pathlength of say 5,000 meters, which is not unusual, the instrument can detect concentrations as low as two parts per billion.

Details on particular surveys and instrument operation are available on request. Attached photographs and sketches refer to portions of this review.

SULFUR DIOXIDE CONCENTRATION

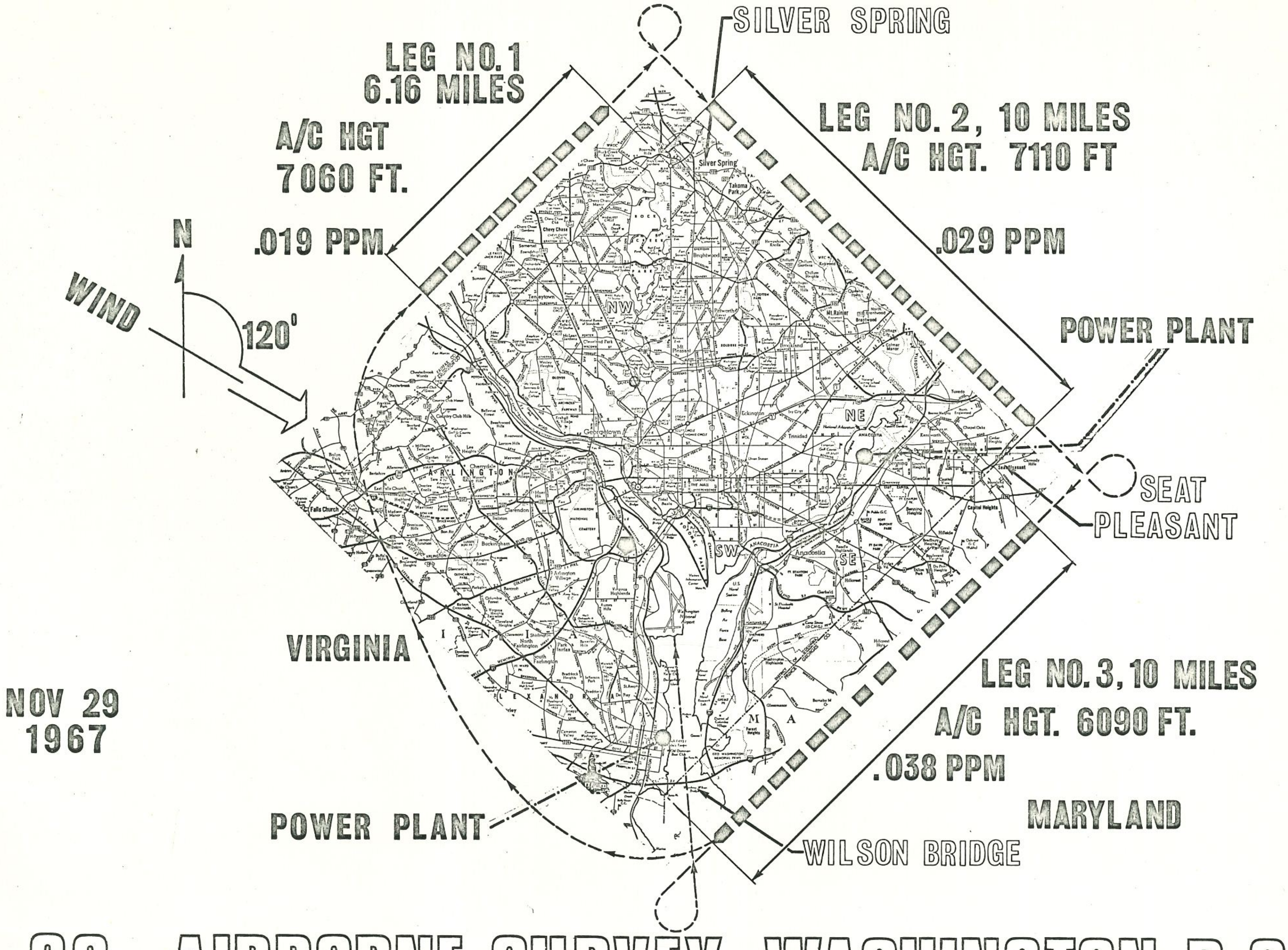
TOTAL VERTICAL BURDEN



POLLUTION DOWNWIND

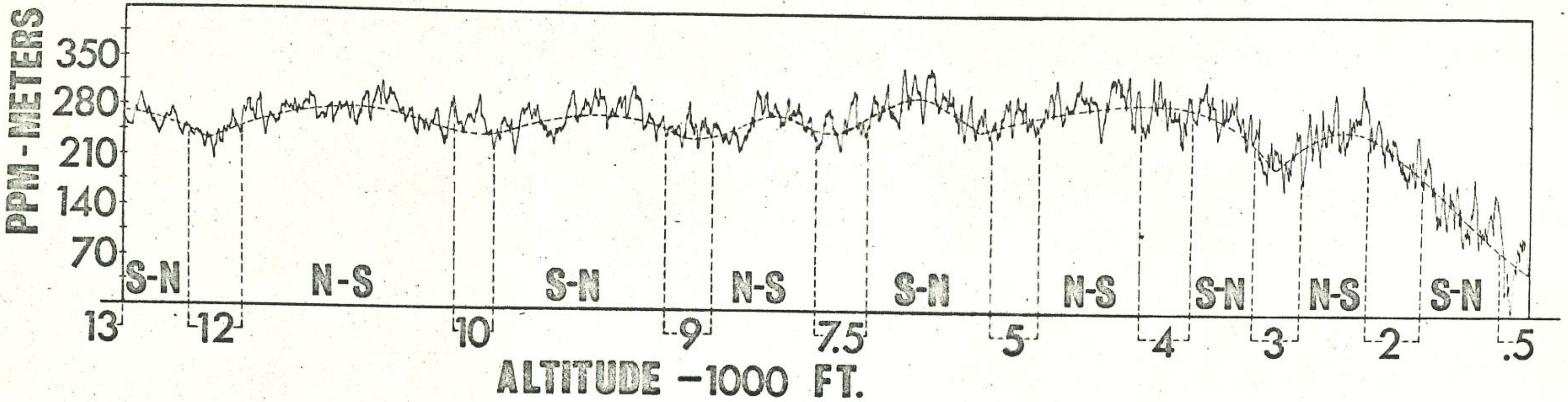
FROM CITY AND INDUSTRY

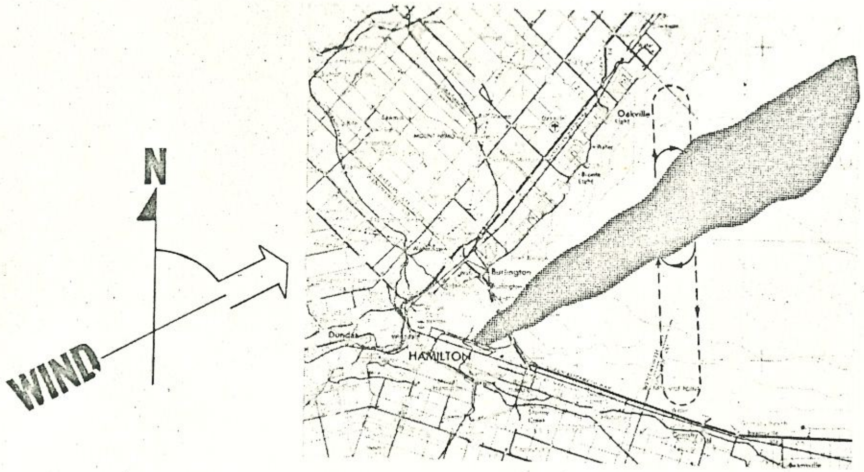
TORONTO NOV 15 1967

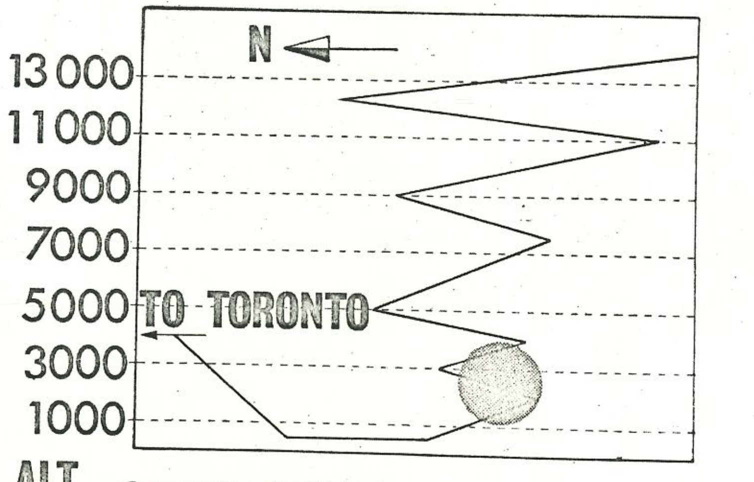


NOV 29
1967

SO$_2$ AIRBORNE SURVEY WASHINGTON D.C.







CROSS SECTION THROUGH PLUME

SO$_2$ PROFILE OVER LAKE ONTARIO

"CHEMICAL ANALYSIS BY REMOTE SENSING"

By

A. R. Barringer

Presented as a Highlight Session at
The 23rd Annual ISA Instrumentation Automation Conference
October - 1968

"CHEMICAL ANALYSIS BY REMOTE SENSING"

By

A. R. Barringer

1. INTRODUCTION

The work described in this paper is the outcome of a research program aimed at developing techniques for detecting and analyzing certain vapours from spacecraft and aircraft. A primary goal has been the development of new approaches to mineral exploration and earth resource surveys; however, the techniques which have been developed have proven to have wide application to other areas such as air pollution surveys.

The problems of mineral exploration are increasing as the demands for raw materials are stepped up and there is a continual requirement for more efficient methods of locating mineral resources. Amongst the possible new approaches of interest are those of detecting gaseous dispersions in the soils and atmosphere overlying mineral and oil deposits. Interest in this area was perhaps first stimulated by Russian geochemical studies of the dispersion of anomalous mercury contents in the rocks and soils overlying base metal and precious metal ore deposits.[1,2,3,4,5.] This work led subsequently to development in the West of atomic absorption techniques for the detection of mercury vapour in trace quantities, mainly for the analysis of soils, but also for the measurement of mercury and of mercury over ore deposits[6.] and work in this area is currently being pursued by the U.S. Geological Survey [7] and also by the writer and his colleagues.[8] This work cannot be considered to be remote sensing in the strictest sense if the term is used to define analysis without physical contact, but it nevertheless remains a form of remote sensing since identifications of distant targets are made by analysis of trace dispersions in the atmosphere.

In reviewing other volatiles aside from mercury which are present in the earth and which might be candidates for non-contact remote detection, it became apparent that iodine was an ideally suited element. Iodine has a complex absorption spectrum in the visible region, it is forty times more volatile than mercury, and is known to be present in the earth's atmosphere. Anomalous atmospheric occurrences of iodine have been reported to occur over coastline areas and in the vicinity of kelp beds.[9,10] Iodine is also notably associated with oil field brines and oil source rocks[11] and there is evidence to suggest a possible association with certain classes of mineral deposits.[12] Accordingly, the writer submitted a proposal to NASA in 1964 for the construction of an optical system for the remote sensing of iodine from orbital altitudes. This proposal ultimately led to a program which has supported some of the development work outlined in this paper. Although the correlation spectrometer was originally designed to detect gases of interest for the earth sciences, its most intensive development has recently been directed towards air pollution monitoring requirements. A family of devices has been produced for both ground and airborne remote sensing applications as well as on-stream monitoring in hostile environments such as inside stacks and flues.

The successful development of the correlation spectrometer has more recently also led to the development of a new device called the Transform Correlation Interferometer which shows great promise for infrared applications.

The Correlation Spectrometer

The basic principles of the correlation spectrometer have been described in earlier papers by the writer and his colleagues,[13,14,15] and a similar instrument has been described by Williams.[16] An instrument developed by Bottema, Plummer and Strong for use in making spectral measurements of Venus from a balloon platform also bears similarities to the correlation spectrometer although the techniques of signal processing differ.[17]

The operation of the correlation spectrometer, a diagrammatic representation of which is shown in Figure 1, can be summarized as follows.

Reflected or scattered radiation from a distant source is collected in a telescope and dispersed through a spectrometer of the grating or prism type. The spectrum of the radiation is projected onto an optical mask which carries a photographic replica of the spectrum of the gas being detected. An oscillating refractor plate or some other suitable means is used to vibrate the spectrum across the mask and the output of the photodetector behind the mask is sensed for the presence of a beat signal. If there is a correlation between the incoming radiation and the mask, there will be a beat signal as the dispersed radiation vibrates periodically in and out of matching with the mask. Lack of a beat signal indicates the sought after spectrum is absent. An automatic gain control keeps the average DC output of the photodetector constant so that the amplitude of the beat signal becomes a quantitative measurement which is not affected by fluctuations in light level. Masks and spectra for sulfur dioxide, nitrogen dioxide and iodine are shown in Figure 2.

The basic function of the instrument is based on the Beer-Lambert Law of Absorption as follows:

$$I = I_o e^{-a_\lambda c\ell}$$

When I_o = incident light intensity

a_λ = absorption coefficient as a function of wavelength

c = concentration

ℓ = pathlength

The correlation function produced by the oscillatory motion of the spectrum may be described in a much simplified form -

$$\text{Modulation Ratio} = M = \frac{I_o e^{-a_1 c\ell} - I_o e^{-a_2 c\ell}}{I_o e^{-a_2 c\ell}}$$

Where a_1 = the average minimum absorption coefficient

a_2 = the average maximum absorption coefficient

or,

$$M = 1 - e^{(a_2 - a_1)}$$

For small values of $c\ell$ this expression is very nearly linear. It should be noted that this instrument measures the product of $c\ell$ and that the basic unit of the "ppm-meter", a concentration of one part per million over a one meter pathlength, has been designated as the standard unit.

The correlation spectrometer can make use of natural daylight as an energy source for detecting vapours which have characteristic absorption spectra at wavelengths which are present in daylight. The spectrometer can also be operated with artificial light sources placed at distances of 1,000 feet or more from the sensor in order to measure gas concentrations in the intervening path.

When the remote sensor is used in an aircraft, measurements are made of the total quantity of gas lying in the pathlength of the received radiation. The telescope of the remote sensor is pointed vertically at the ground and scattered radiation from the sky is reflected back to the aircraft from the area in the field of view of the instrument. The effective resolution of the correlation spectrometer in an aircraft is a function of the acceptance angle of the telescope and the height of the gas layer. In practice pollutants are generally confined beneath the inversion layer and spatial resolution is effectively of the order of a few hundred feet. Profiles obtained when flights are traversed across pollution sources such as power stations and large industrial complexes show pronounced peaks.

The remote sensing technique may also be used on the ground for measurement of pollutant concentrations being emitted from smoke stacks. Comparisons are made between the total gas concentration measured when looking at the sky alongside the plume with readings taken through the plume. In order to compute the gas concentration being emitted, referred to S.T.P., it is necessary to know the diameter of the stack, the approximate temperature of the emitted gas, the approximate distance from the stack, a haze scattering index, and the calibration factor.

Verification of the basic validity of the technique when used for measuring sulfur dioxide has been carried out using a 1 meter sample cell. Plots of gas concentration versus output voltage have been made using both daylight and artificial light sources at varying intensities. Precise reproducibility of the calibration curve can be obtained for a given type of light source through light intensity variations of up to thirty db. as shown in Figure 3. Calibration, however, is necessary at two points on the calibration curve when using natural daylight as a source, due to variations in spectral gradient in the ultraviolet which occur in the vicinity of the sulfur dioxide absorption bands. The rapid attenuation of light that occurs in the vicinity of 3,000 Å varies in slope according to time of year and the time of day and has a significant affect on sensitivity. The instrument is therefore provided with calibration cells which contain sealed amounts of gas which can be inserted into the light path to provide references.

When measuring emissions from stacks it is necessary to take into account broadening of the bandheads in the absorption spectrum associated with elevated temperatures. This broadening has the effect of reducing sensitivity as shown in Figure 4. Corrections for broadening can be inserted at the same time as corrections for thermal expansion enabling S.T.P. figures to be obtained in a single operation.

Airborne Tests of the Correlation Spectrometer

Development of an airborne version of the Correlation Spectrometer has been sponsored by the National Aeronautics and Space Administration and installation has been made in an Aero Commander aircraft (Figure 3, Figure 4). Extensive flight tests have been carried out, some of which have been made with additional support from the National Air Pollution Center of the Department of Health, Education and Welfare. Surveys to date consist of a limited number of profiles over cities such as Los Angeles, San Francisco and Chattanooga. The majority of the work has been connected with the study of sulfur dioxide and nitrogen dioxide pollution, although some flights have been made for iodine concentrations off the coast of Maine as part of a preliminary investigation of earth resource applications.

Typical examples of nitrogen dioxide profiles are shown in Figure 7. In this survey, carried out under NASA sponsorship, repeated traverses were made from off-shore Long Beach, California eastwards over Los Angeles. These flights indicated that despite the dynamic condition of pollution, repeat flights in fairly close time proximity yielded a substantially similar picture. It will be noted that there is a rapid build-up of nitrogen dioxide as the coastline is crossed and the aircraft traverses the refineries in the vicinity of Long Beach. Figure 8 shows a survey in the San Francisco area in which the traverse over the Bay shows considerably lower values of nitrogen dioxide than the shoreline traverse over freeways and built up areas. A distinct peak can be seen where the profile crosses the Bay Bridge carrying heavy traffic across the water.

Flights carried out over Chattanooga Tennessee, for the Department of Health, Education and Welfare also produced some most interesting results. Figure 9 shows the heavy nitrogen dioxide build-up over the chemical manufacturing area in the center of Chattanooga, and the profiles indicate the mode of dispersion of this pollution. Similarly the dispersal of sulfur dioxide in a plume generated by the Widow's Creek Power Plant in Tennessee can be tracked readily with the Correlation Spectrometer as shown in Figure 10.

The concentrations of pollutant that are measured with the airborne monitor provide a mean value which represents the average between ground level and the inversion layer. Measurements made during ascents and decents indicate that pollution tends to be substantially trapped beneath the inversion layer. Knowledge of the total vertical burden of gas enables some unique calculations of mass transport to be carried out. Thus, if a major pollution source such as a city is circumnavigated under known meteorological conditions, it is possible to determine the tons per hour of pollutant entering the city on the upwind side and the tons per hour exiting on the downwind side. The differential provides an indication of the total amount of pollutant being generated by the city (Figure 11). A preliminary survey carried out for the Department of Health, Education and Welfare around the perimeter of Washington, D.C. tended to verify the validity of this approach. Figures obtained were somewhat higher than the calculated tonnage, but were nevertheless sufficiently close to be encouraging. Surveys of this type do require reasonably uniform meteorological conditions over the area of survey and also good visibility. The technique offers considerable promise for the future in various types of air pollution studies both from aircraft and possibly from spacecraft. Proposals have been submitted for a multi-gas system capable of monitoring the world-wide distribution of selected pollutants in order to determine factors such as pollution build-up, distribution of air sheds and the movement of high altitude pollution derived from aircraft.

Preliminary work has been carried out on the detection of iodine concentrations over kelp beds using the airborne installation. The same instrument as that used for SO_2 and NO_2 surveys was employed following the necessary substitution of an iodine mask and the re-setting of the spectrum grating to cover the appropriate portion of the spectrum between 5,000 and 6,000 Å. Iodine concentrations in the atmosphere are very low compared with concentrations encountered in the case of SO_2 and NO_2 and signal to noise ratios were enhanced by operating the instrument in sideways looking mode instead of the normal downward looking operation. Special windows were inserted in the side of the fuselage and the aircraft was flown at 2,500 feet to 3,500 feet with the spectrometer pointed at approximately 10° below the horizontal. This maximized the pathlength in the lower atmosphere and minimized background noise. Inevitably the equipment has low spatial resolution when used in this mode, but nevertheless the technique was quite satisfactory in establishing the presence of variable iodine backgrounds. Figure 12 shows the build-up of iodine that occurs in the vicinity of Matinicus Island off the coast of Maine which is apparently associated with a strong build-up of kelp lying in the vicinity of this island. Figure 13 shows a larger portion of the Maine Coast in which repeated flights confirmed the build-up of iodine along the kelp rich coastline. These results are qualitative since they cannot be referred to a specific pathlength, and calibration between flights is subject to certain errors connected with changes in ambient lighting conditions. Nevertheless, the records obtained repeatedly established that atmospheric iodine concentrations do increase over the coastlines and in particular over kelp rich areas. The next steps in the program will be to improve the sensitivity of the instrumentation for iodine measurements and to examine concentrations of iodine vapour occurring around sources of primary fish food over the oceans, and in the vicinity of oil fields and mineral deposits. The iodine association with oil fields is attributed to the fact that oil is derived from marine organisms and marine life tends to concentrate iodine up to 100,000 times compared with the levels in sea water. For this reason, the oil field brines which are closely associated with accumulations of oil, are generally rich in iodine. Association of iodine with mineral deposits is believed to be due to the tendency of halogens to be concentrated in the ore forming fluids.

Studies of liquid inclusions in metalliferous ores and deep thermal brines carrying high metal contents both indicate the close connection between chlorides and other halogens in the ore forming processes. For this reason, the remote sensing of iodine concentrations from aircraft and spacecraft has a significant potential application in a number of different earth resource areas.

Ground Level Remote Sensing Measurements

Considerable effort has been expended in studying the problem of measuring stack emissions from a distance. Encouraging results obtained during early phases of the program on some stacks were offset by measurements which showed substantial errors on other stacks. This has led to extensive studies of the physics of the problem and some of the important factors which have been defined are as follows:

1. Sensitivity of the instrument changes according to the spectral gradient of the light scattered from the sky.
2. The temperature of the emitted gas effects the amount of broadening in the absorption spectrum and hence the sensitivity of the instrument.
3. Light scattered between the plume and the instrument by aerosols "dilutes" the percentage modulation caused by the absorption spectrum of the gas, giving rise to low readings.
4. Turbidity in the plume caused by heavy particulate loading scatters light within the plume and can cause low readings.
5. Wind conditions can distort the shape of the plume and cause errors in measurement.

The mode of operation of the remote sensing instrument is to set up the equipment as closely as possible to the stack and to site the telescope at a point immediately alongside the stack in order to take background readings against the sky. Readings are next taken through the plume at a point just above the top of the stack and below the level of moisture condensation. Observations are made at two or more known ranges in order to extrapolate back to zero distance and eliminate haze scattering effects. Good results have been obtained with stacks when working under suitable meteorological conditions. The present state of the art calls for a plume which is rising reasonably straight and has a Ringelmann value of less than two.

As methods of taking into account the various parameters which affect the accuracy of readings are refined, it is anticipated that the precision of remote stack measurements will increase. There is widespread application for this type of measurement, not only for the obvious one of surveillance of stack emissions, but for monitoring processes occurring in hostile environments from considerable distances. The feasibility of using this technique, for example, in studying processes in steel furnaces and perhaps controlling the steel making process by the characteristic emissions of the gases being evolved, is one area worthy of study. Numerous other examples undoubtedly exist.

The Scattering Problem

The problem of radiation being scattered in the lightpath between the remote sensor and the target is obviously an important aspect for consideration. A preliminary evaluation of this problem was given in an earlier paper[15] and work on a comprehensive mathematical model of the atmosphere is continuing. In the meantime, a number of practical techniques of estimating scattering are being studied. These include a method for monitoring at three or more wavelengths in the UV, variations in light level intensities reflected from the ground vertically below the aircraft or spacecraft. Light variations are caused by differences in the reflectivity of the terrain materials being traversed and are modified by aerosol scattering. Figure 12 shows that spectral reflectivity curves of different types of terrain in the ultraviolet tend to be fairly flat although absolute reflectivities vary quite considerably from one material to another. Figure 15 shows how contrast between various terrain materials remains relatively flat in the UV. For this reason simultaneous measurements of high altitude contrast values along the flight line profile at three or four wavelengths in the ultraviolet spectrum provides a means of estimating the contribution of scattered light versus light reflected from the earth's surface. An alternative method would be to measure the light received at several wavelengths when looking at a surface of known spectral reflectivity characteristics such as the ocean or bodies of fresh water. The problem here is to find calibration targets sufficiently close to special regions of interest such as large cities. In many cases bodies of water large enough to make photometric measurements will not be close enough to these areas. Preliminary evaluation has been carried out on the ground of a method of estimating scattering using two large panels, one of high reflectivity and one of low reflectivity. Light intensity measurements are made at several wavelengths in the UV and visible while viewing these panels through the remote sensor optics at differing ranges. Variations of contrast with range enable the scattering function to be computed. A graph of some typical measurements is shown in Figure 16.

Measurements Inside Stacks

The principle of correlation spectrometry has been applied to the measurement of sulfur dioxide concentrations inside stacks without pre-treatment of the gases. Techniques have been developed for passing a collimated beam of light through a probe into the stack and reflecting the light from a mirror back out through the probe to a correlation spectrometer (Figure 17). The problem of maintaining optical surfaces clean inside the stack has been solved by the use of air curtains and it has proven feasible to achieve maintenance free operation without loss of light for many weeks in heavily polluted, high temperature environments. Typical calibration curves for a sensor of this type are shown in Figure 18. These comparisons were made in an oil fired incinerator stack in which accurately calibrated flow rates of sulfur dioxide were introduced. A wide variety of conditions were created by varying flue gas temperatures and introducing heavy particulate concentrations. Good agreement was obtained between the gas introduced and the instrument measurements of concentration after the appropriate corrections were made for temperature.

A number of design problems are involved in constructing equipment for this application due to the excessive temperatures and temperature gradients to which the spectrometer body is exposed on the outside of the stack. Temperature gradients in particular can cause warping in the spectrometer assemblage and consequent drift so that the design has to take into account this and many other factors in order to achieve stability.

There are a number of advantages in making in-situ measurements of stack effluents without resort to wet chemistry, since the approach provides an instant readout which can be used in control applications. For example, when the equipment is placed downstream from pollution removal devices, it can be used to control the supply of chemicals necessary to the pollution removal process to keep gas levels down to a pre-set level.

Miscellaneous Applications

The possibility of using remote sensing techniques for monitoring reactions in hostile environments appears to be manyfold. Experiments carried out in the copper refinery of Noranda Mines at Gaspe in Quebec showed how the end point of roasting operations on the sulphide ore can be readily determined by monitoring sulfur dioxide effluents in the flue gases. In this case remote sensing measurements can be made from some distance away from the intense temperatures of the furnace and flue. It is also possible to program the instrument to monitor intermediate reaction products in a reaction vessel even if these products are not stable compounds. Masks can be prepared for pre-set conditions which may occur at critical points in reactions, thereby providing a new element of control.

The monitoring of toxic gases is another obvious area of application. A beam of light for example could be projected through a large workshop to sense the presence of a particular vapour anywhere in the area and provide warning. Overheating of electrical installations and generators could be detected in this fashion by sensing the volatile organic components given off by overheated insulation materials.

Not only can the technique be applied to vapours, but also to the complex infrared spectra of organic materials. The use of frustrated internal reflectance measurements of liquids in on-stream applications is possible using optical techniques similar to those used today in refractometers. Multiple components could be measured in liquids in this fashion.

The direct measurement of isotopic composition of certain gases also appears feasible by correlation spectrometry. The spectral shifts that can be observed for many isotopes in their high resolution absorption spectra could be programed with suitable electronics so that correlation measurements could be made simultaneously for the direct measurement of isotopic ratios.

Transform Correlation Interferometry

The concept of real time correlation for pre-selected spectra by analogue techniques is also applicable in the field of Fourier Transform spectroscopy. This type of spectroscopy developed by Fellgett, Gebbie, Mettz, Connes'[18-35] and others makes use of the large light throughput of the Michelson Interferometer to examine infrared spectra at high sensitivity. Interferograms are prepared of the spectra by scanning the differential pathlength of the interferometer and photometrically recording the output. The interferograms are passed through a Fourier Transformation process in a digital computer to yield normal spectra. The writer and his colleagues have developed an automatically correlating Michelson Interferometer which correlates against pre-programed interferograms. The concept differs from previous work in scanning interferometry in that no attempt is made to obtain a computer derived transform, since the interferogram is as unique a fingerprint as the spectrum. The modification made to the Michelson Interferometer is a simple one in which pathlength scanning is achieved by rotating the compensator plate in the interferometer as shown in Figure 19. This compensator plate is attached to a magnetic drum which carries the recorded interferograms. In order to program the instrument an initial pathlength difference is set up which is appropriate for the gas being detected. Scanning about this pre-set fixed path difference is carried out by rotating the compensator plate. The necessary initial pathlength difference is determined by computing the transforms of the spectra of the gases or by carrying out a long path scanning on the interferometer to derive the total interferogram directly. The use of fast Fourier Transform techniques in the computer have enabled the first procedure to be adopted very conveniently and a typical transform obtained in the computer for methane is shown in Figure 20.

After the pre-set pathlength difference has been set, the instrument is programed by placing a gas cell filled with the appropriate gas in front of the entrance aperture and recording the output of the detector on the magnetic drum during scanning. The interferometer can now be used to detect the gas for which it has been programed by correlating the recording on the magnetic drum against unknown interferograms. This is done with standard electronic analogue cross-correlation techniques of relative simplicity so that the entire instrument is a compact and simple package.

The great advantage of using rotational methods of pathlength scanning is that backlash errors relative to the magnetic drum are eliminated and high stability performance can be maintained. Where methods of pathlength scanning using linear motions are employed, lack of reproducibility tends to be a problem unless interferometric servo-control is used on the scanning mirror. This can be highly effective, but is complex; a decided disadvantage for both commercial instrumentation and spacecraft equipment.

The state of development of the Transform Correlation Interferometer is less advanced than that of the Correlation Spectrometer described earlier, however, working models have been constructed and the development is considered to show great promise, particularly in the infrared region where light throughput becomes extremely significant.

ACKNOWLEDGEMENTS

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Transform Correlation Spectrometer

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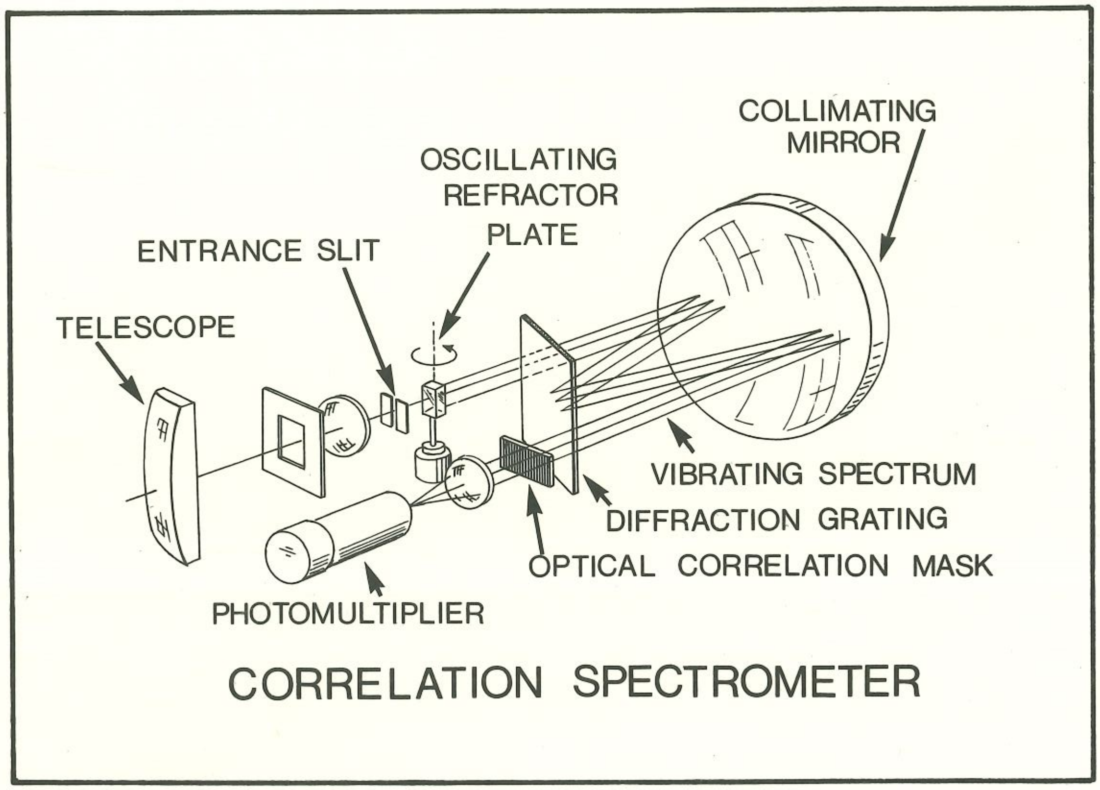
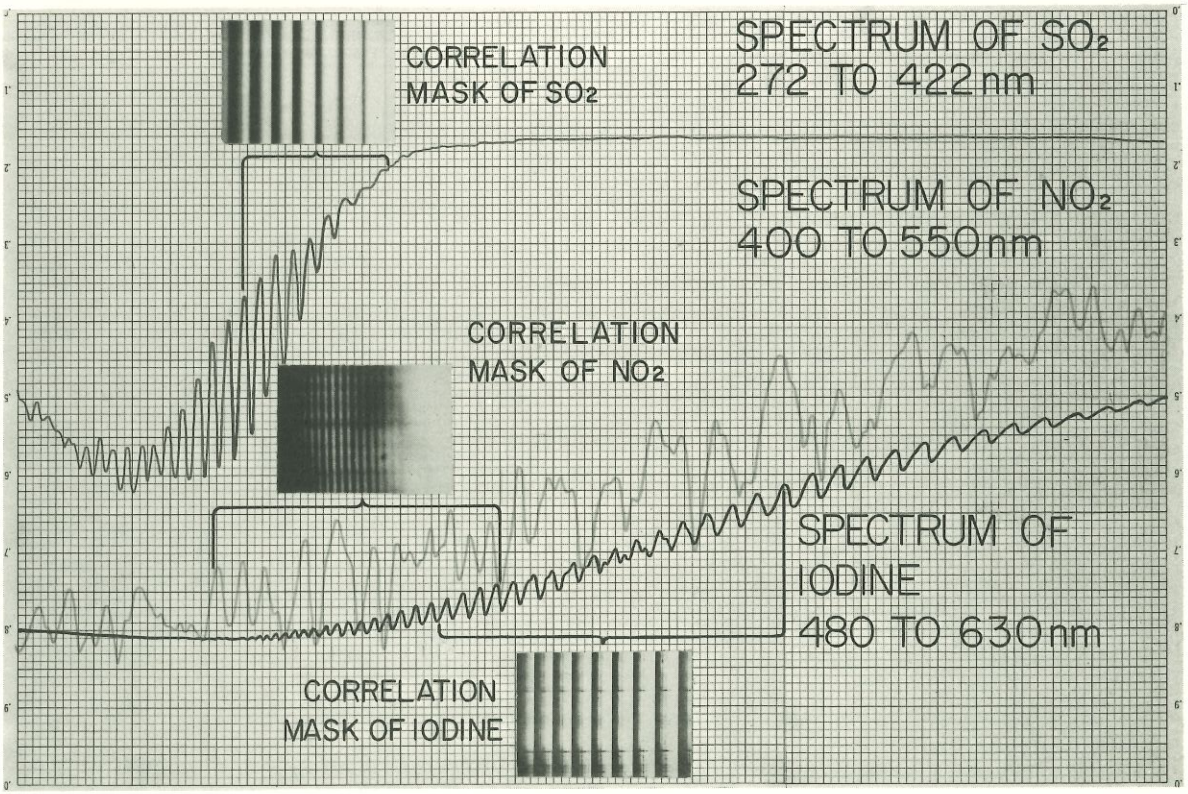


Figure 1



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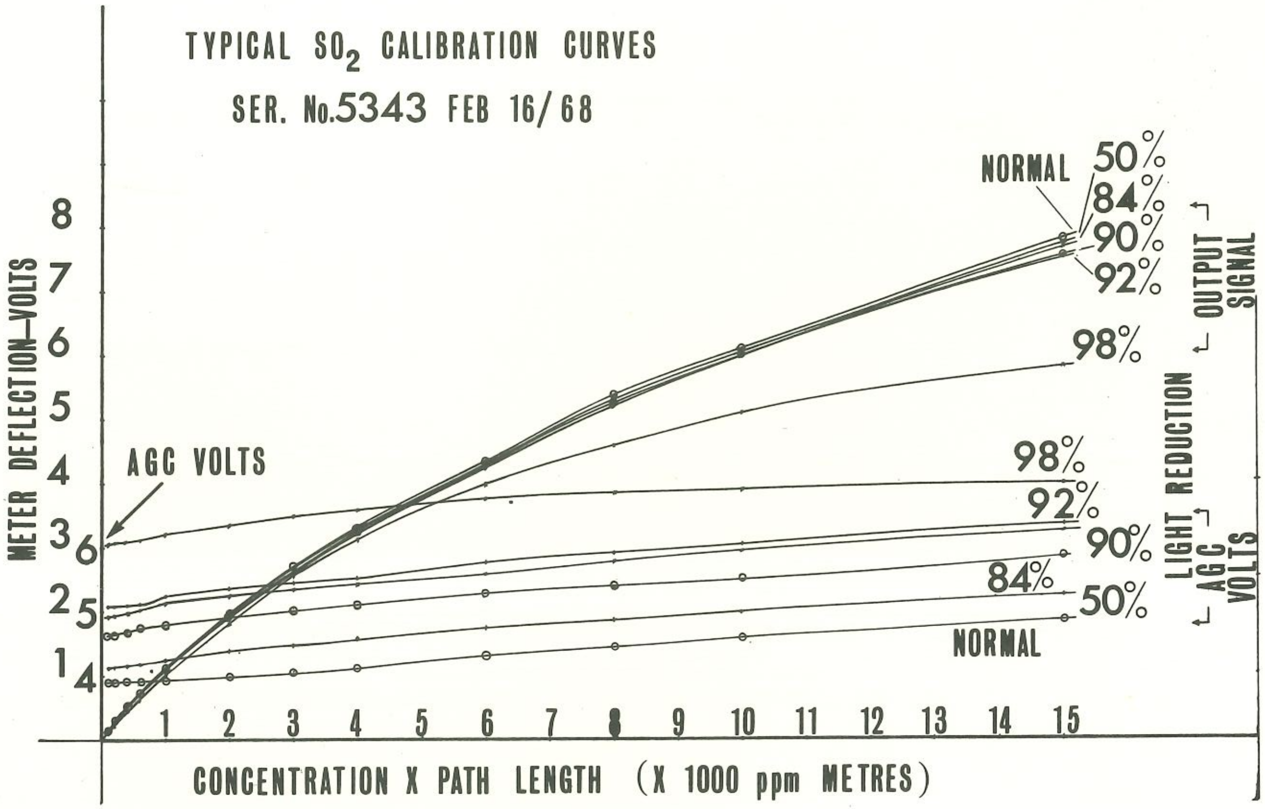

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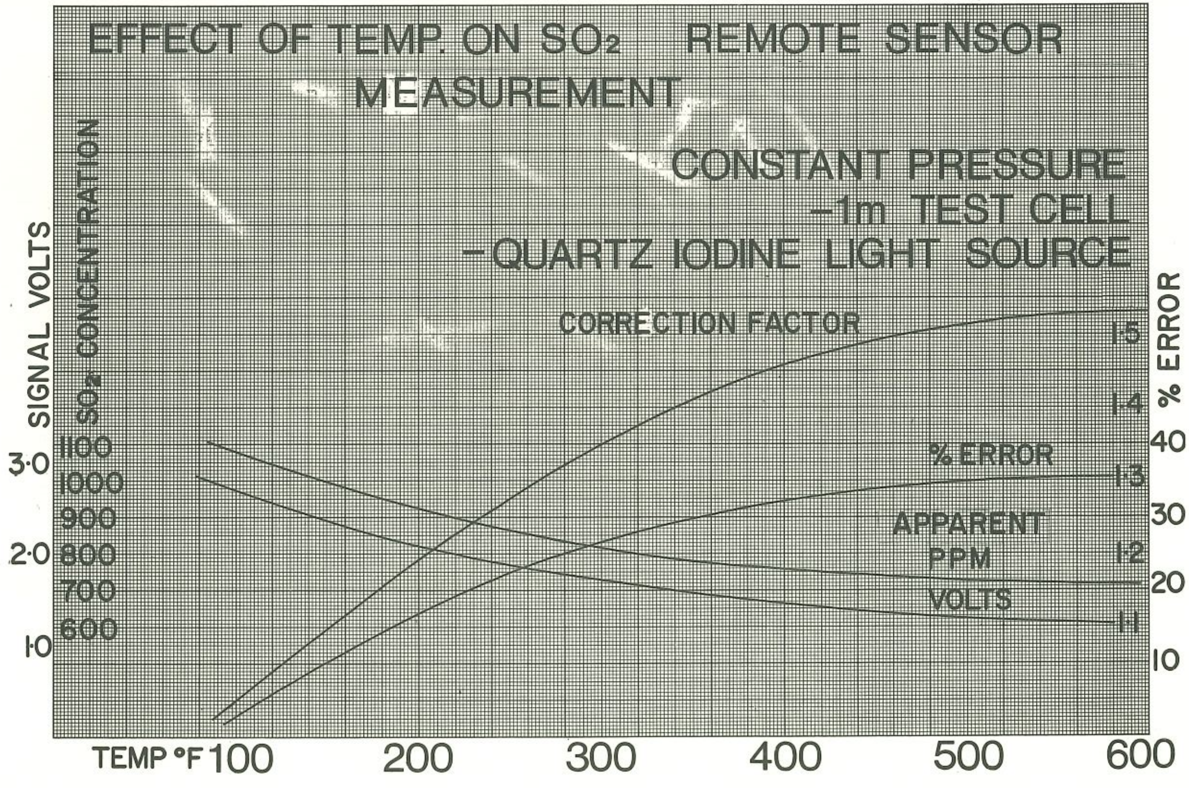
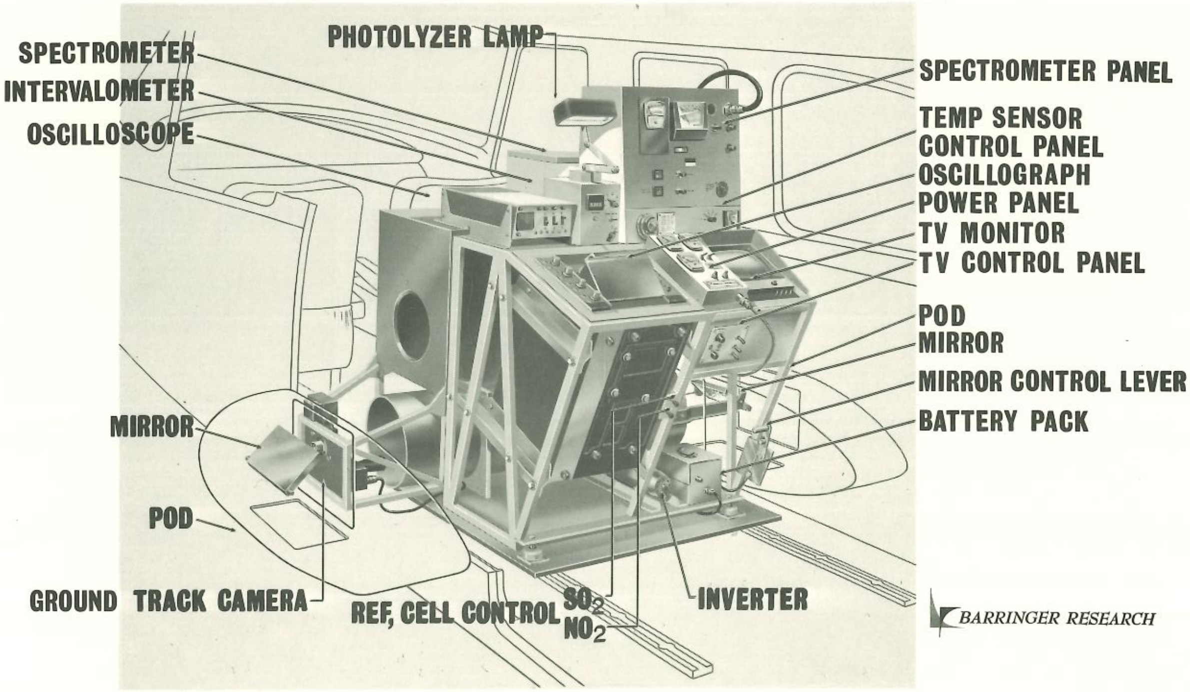


Figure 4

Figure 5

Remote Sensing Air Pollution Monitoring Aircraft



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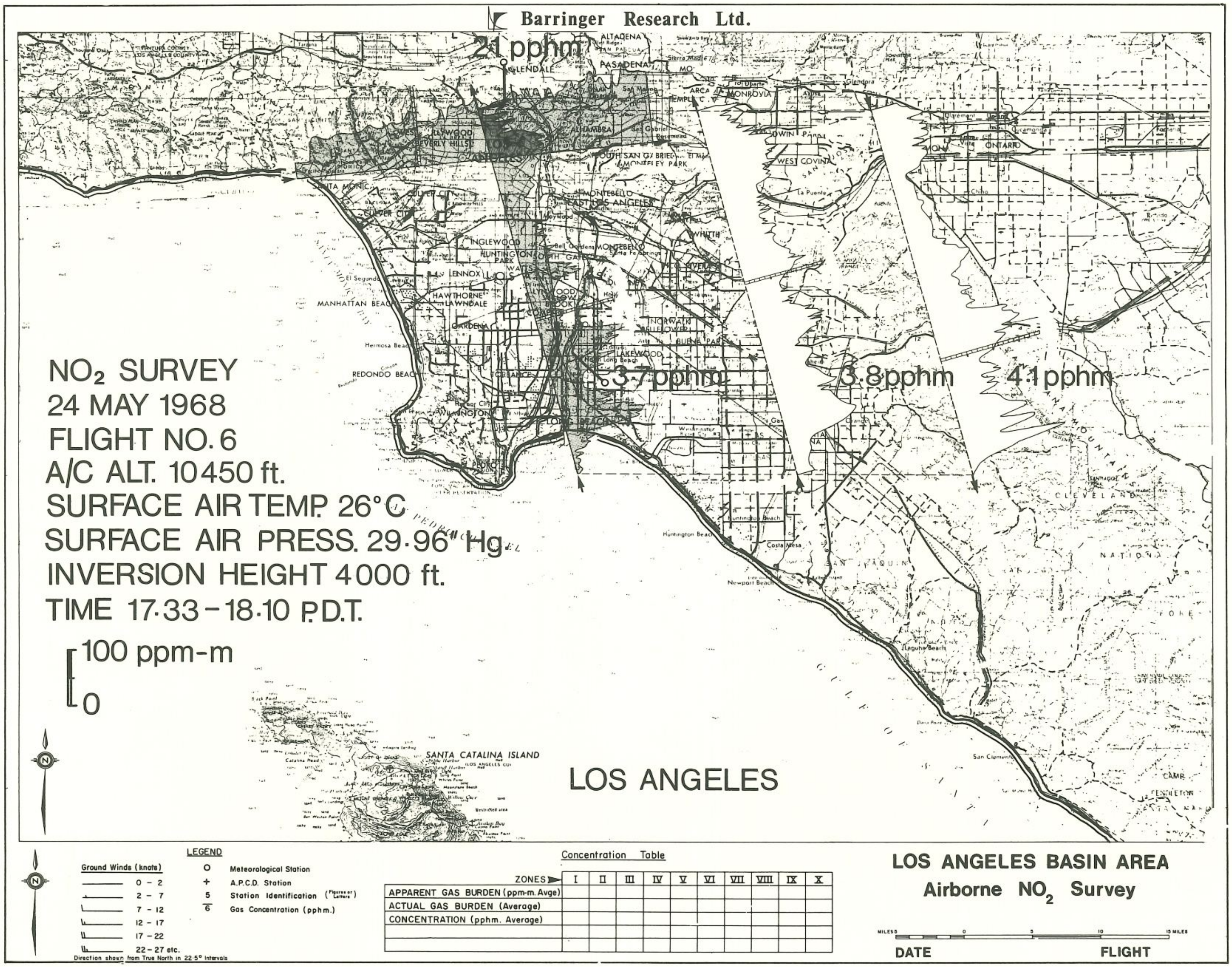
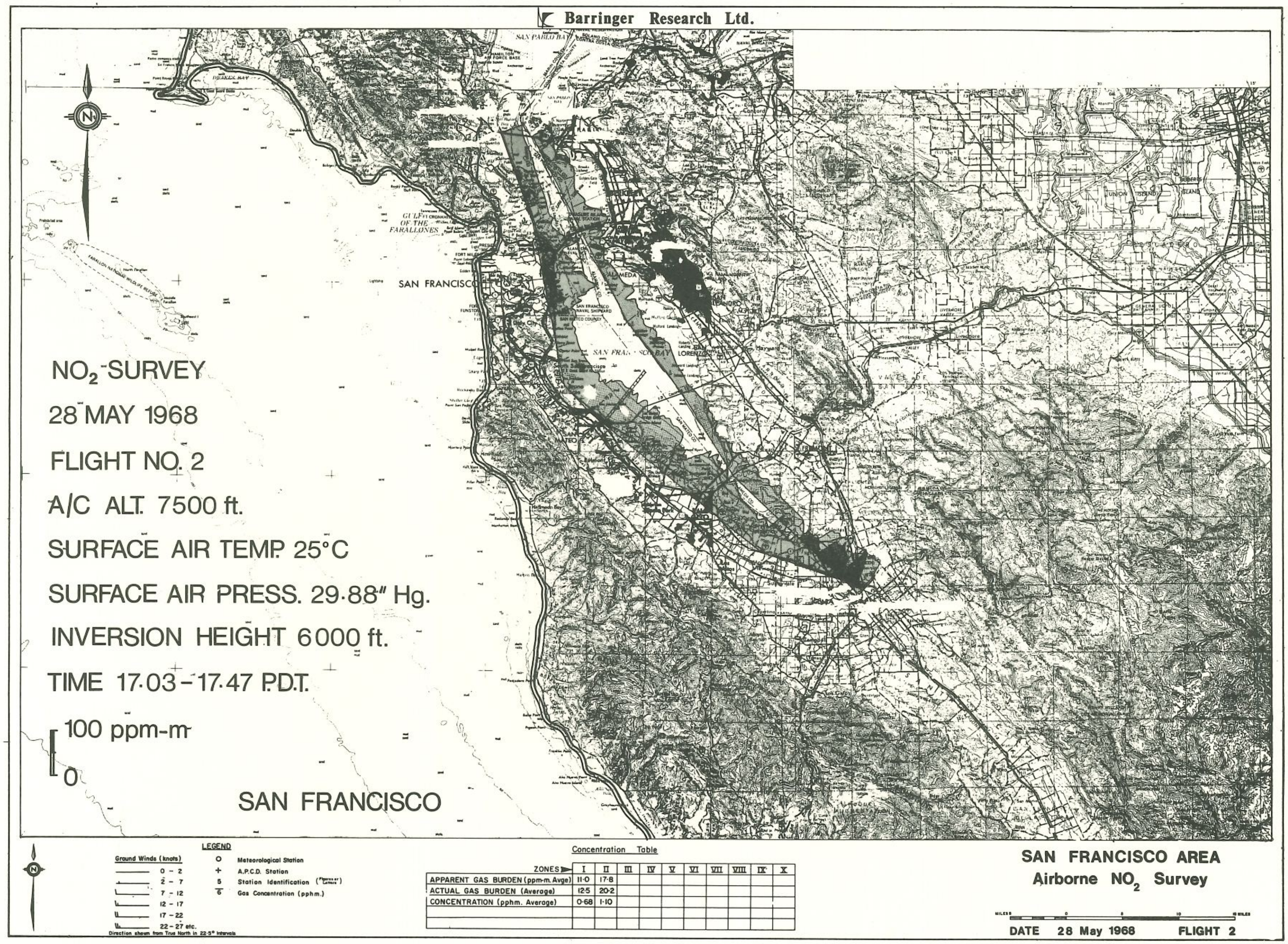

Barringer Research Ltd.
21 pphm
3.7pphm
3.8pphm
4.1pphm
NO₂ SURVEY
24 MAY 1968
FLIGHT NO. 6
A/C ALT. 10450 ft.
SURFACE AIR TEMP. 26°C
SURFACE AIR PRESS. 29·96" Hg.
INVERSION HEIGHT 4000 ft.
TIME 17·33 – 18·10 P.D.T.
100 ppm-m
0
LOS ANGELES
SANTA CATALINA ISLAND
LEGEND
Ground Winds (knots)
0 – 2
2 – 7
7 – 12
12 – 17
17 – 22
22 – 27 etc.
Direction shown from True North in 22·5° Intervals
Meteorological Station
A.P.C.D. Station
Station Identification (Figures or Letters)
Gas Concentration (pphm.)
Concentration Table
ZONES I II III IV V VI VII VIII IX X
APPARENT GAS BURDEN (ppm-m. Avge)
ACTUAL GAS BURDEN (Average)
CONCENTRATION (pphm. Average)
LOS ANGELES BASIN AREA
Airborne NO₂ Survey
MILES 5 0 5 10 15 MILES
DATE
FLIGHT

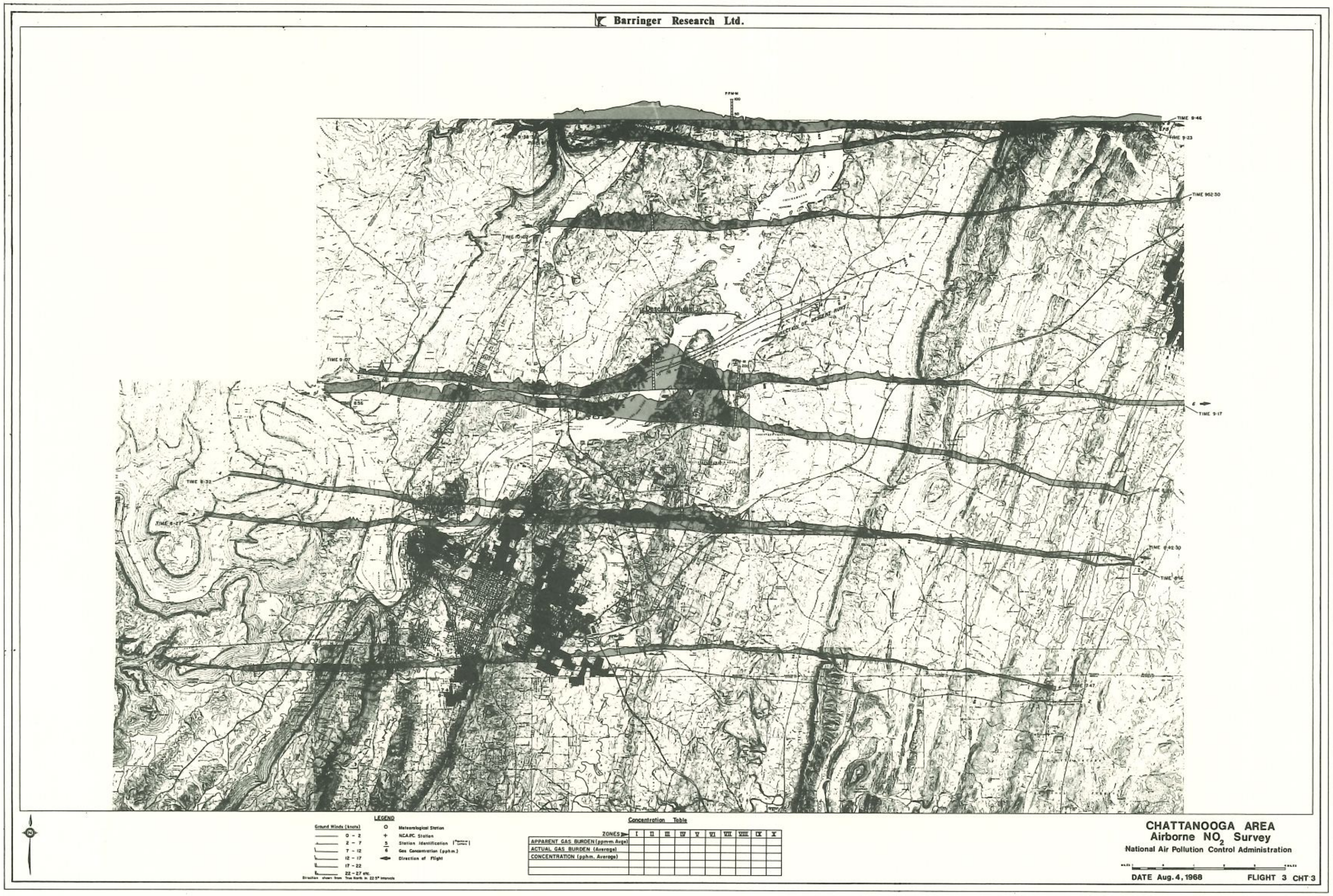
Figure 7



Concentration Table

ZONES ▶	I	II	III	IV	V	VI	VII	VIII	IX	X
APPARENT GAS BURDEN (ppm-m. Avge)	11·0	17·8								
ACTUAL GAS BURDEN (Average)	12·5	20·2								
CONCENTRATION (pphm. Average)	0·68	1·10								

Figure 8

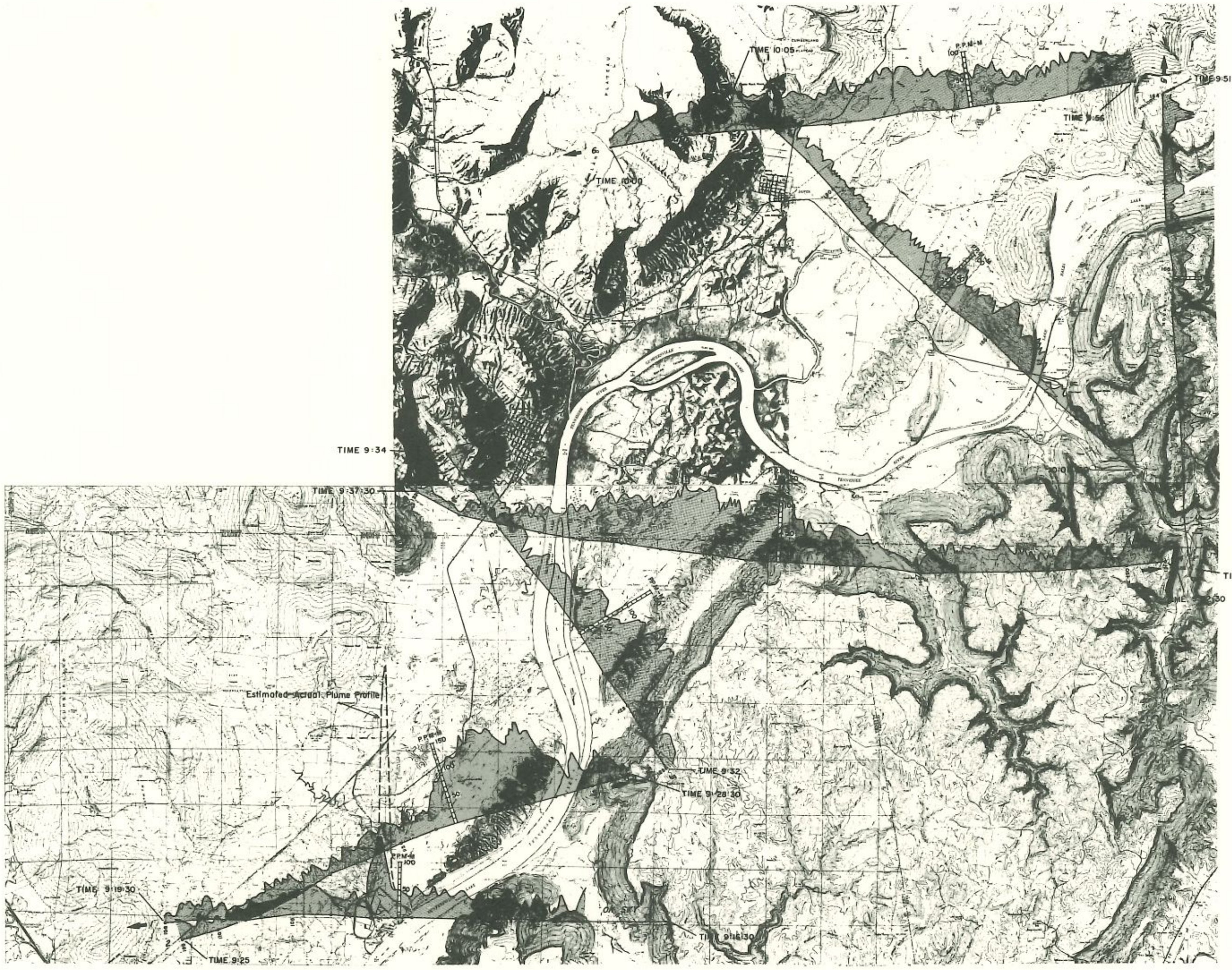


Concentration Table

ZONES	I	II	III	IV	V	VI	VII	VIII	IX	X
APPARENT GAS BURDEN (ppm·m. Avge)										
ACTUAL GAS BURDEN (Average)										
CONCENTRATION (pphm. Average)										

Figure 9

Barringer Research Ltd.



LEGEND

Ground Winds (knots)
0 - 2
2 - 7
7 - 12
12 - 17
17 - 22
22 - 27 etc.
Direction shown from True North in 22.5° Intervals

○ Meteorological Station
+ N.C.A.P.C. Station
5 Station Identification (Figures or Letters)
$\frac{}{6}$ Gas Concentration (pphm.)
← Direction of Flight

Concentration Table

ZONES ►	I	II	III	IV	V	VI	VII	VIII	IX	X
APPARENT GAS BURDEN (ppm-m. Avge)										
ACTUAL GAS BURDEN (Average)										
CONCENTRATION (pphm. Average)										

WIDOWS CREEK PLANT
Airborne SO_2 Survey
National Air Pollution Control Administration

MILES 1 0 1 2 3 4 MILES

DATE Aug. 5, 1968 **FLIGHT 4 CHT 4**

Figure 10

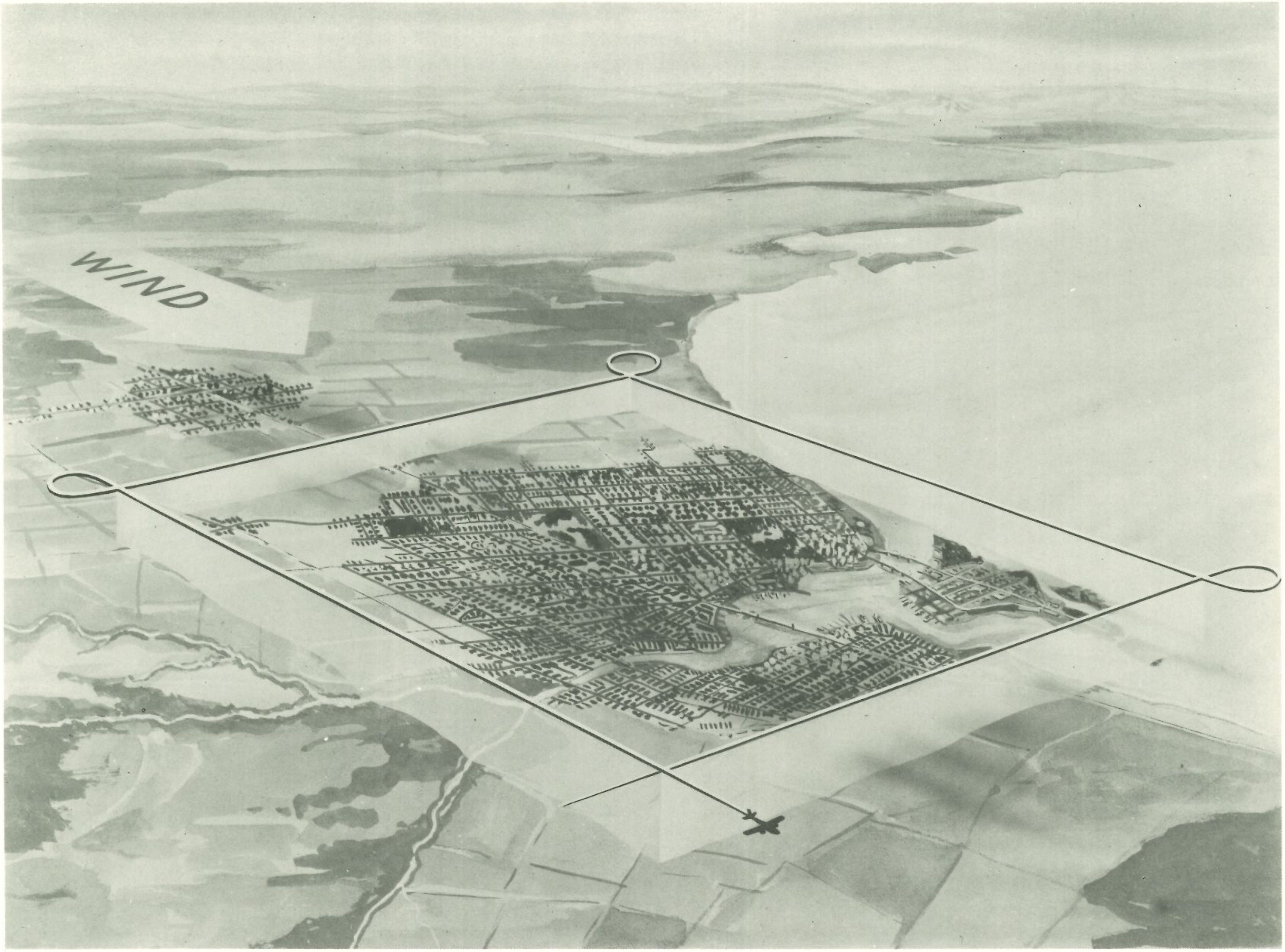
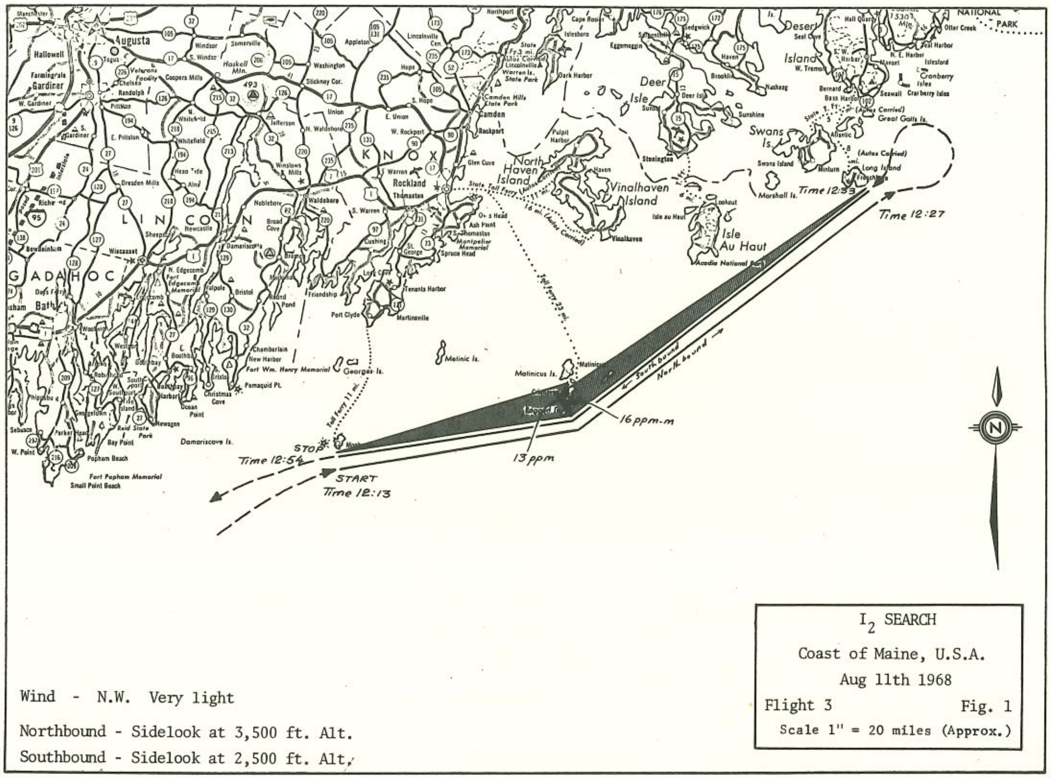


Figure 11

Flight Line Pattern for Determining Pollutant Moss Production of an Area



Wind - N.W. Very light

Northbound - Sidelook at 3,500 ft. Alt.

Southbound - Sidelook at 2,500 ft. Alt.

I$_2$ SEARCH

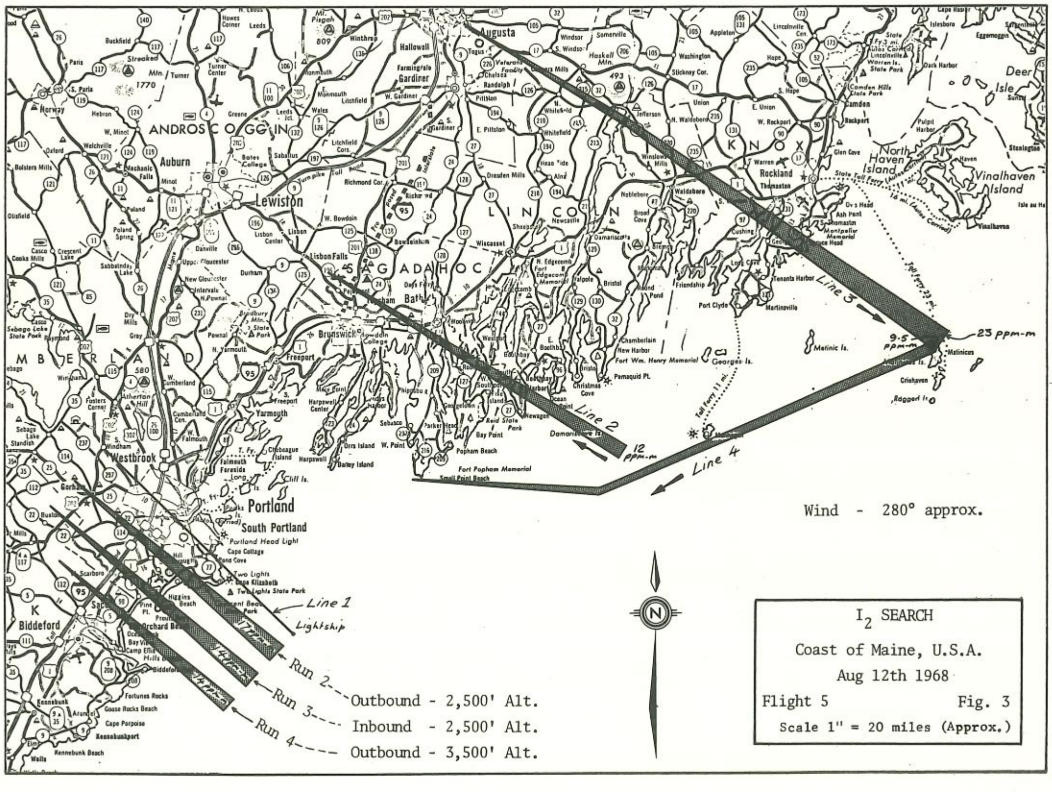
Coast of Maine, U.S.A.

Aug 11th 1968

Flight 3 Fig. 1

Scale 1" = 20 miles (Approx.)

Figure 12



Run 2 - Outbound - 2,500' Alt.

Run 3 - Inbound - 2,500' Alt.

Run 4 - Outbound - 3,500' Alt.

Wind - 280° approx.

I$_2$ SEARCH

Coast of Maine, U.S.A.

Aug 12th 1968

Flight 5 Fig. 3

Scale 1" = 20 miles (Approx.)

Figure 13

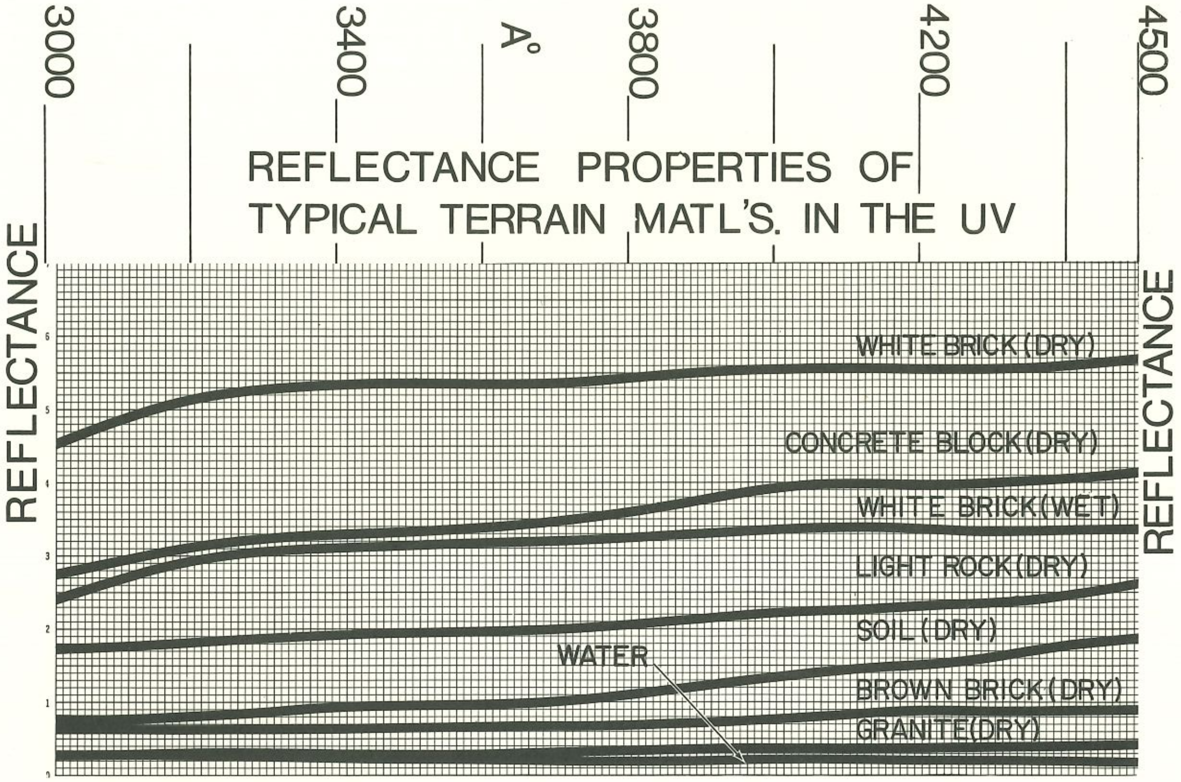


Figure 14

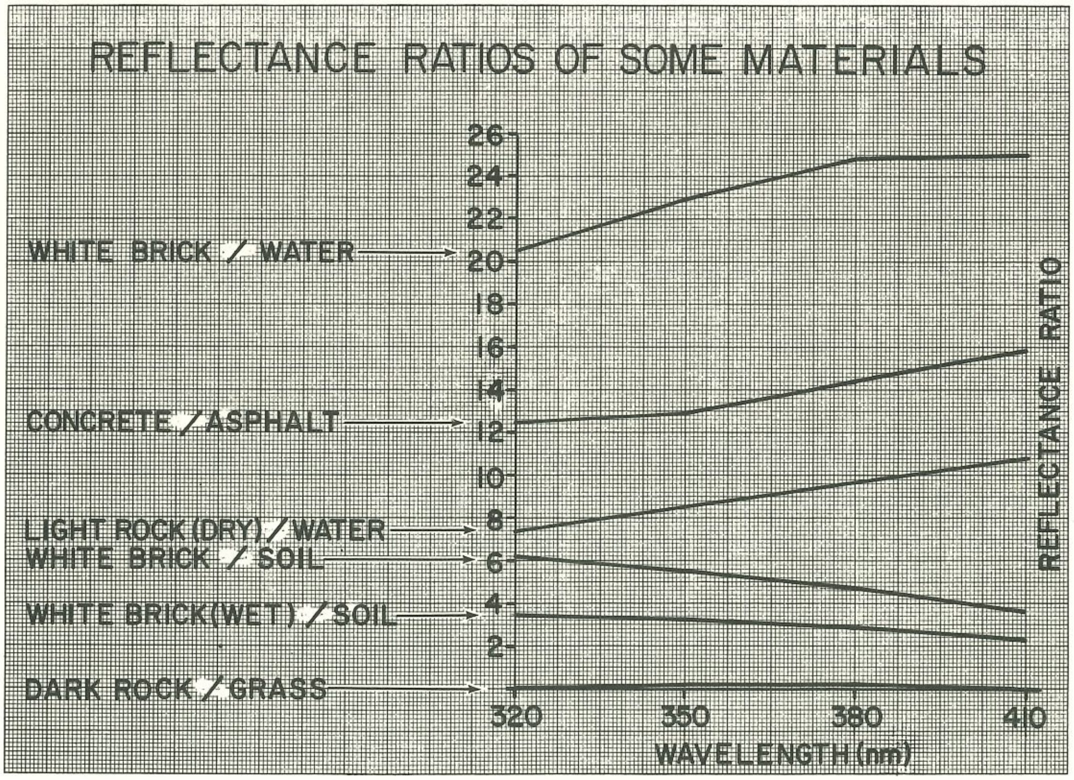


Figure 15

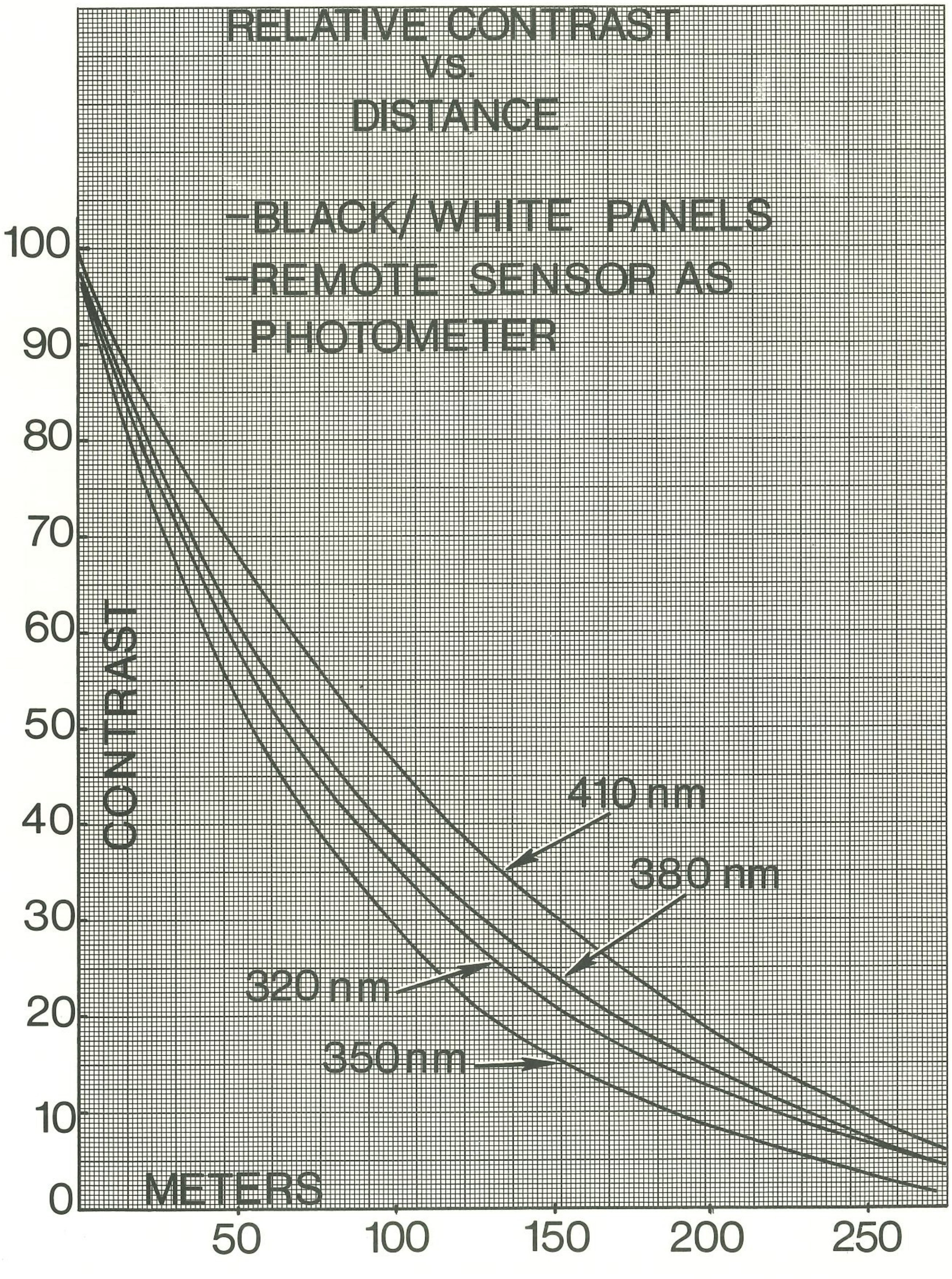
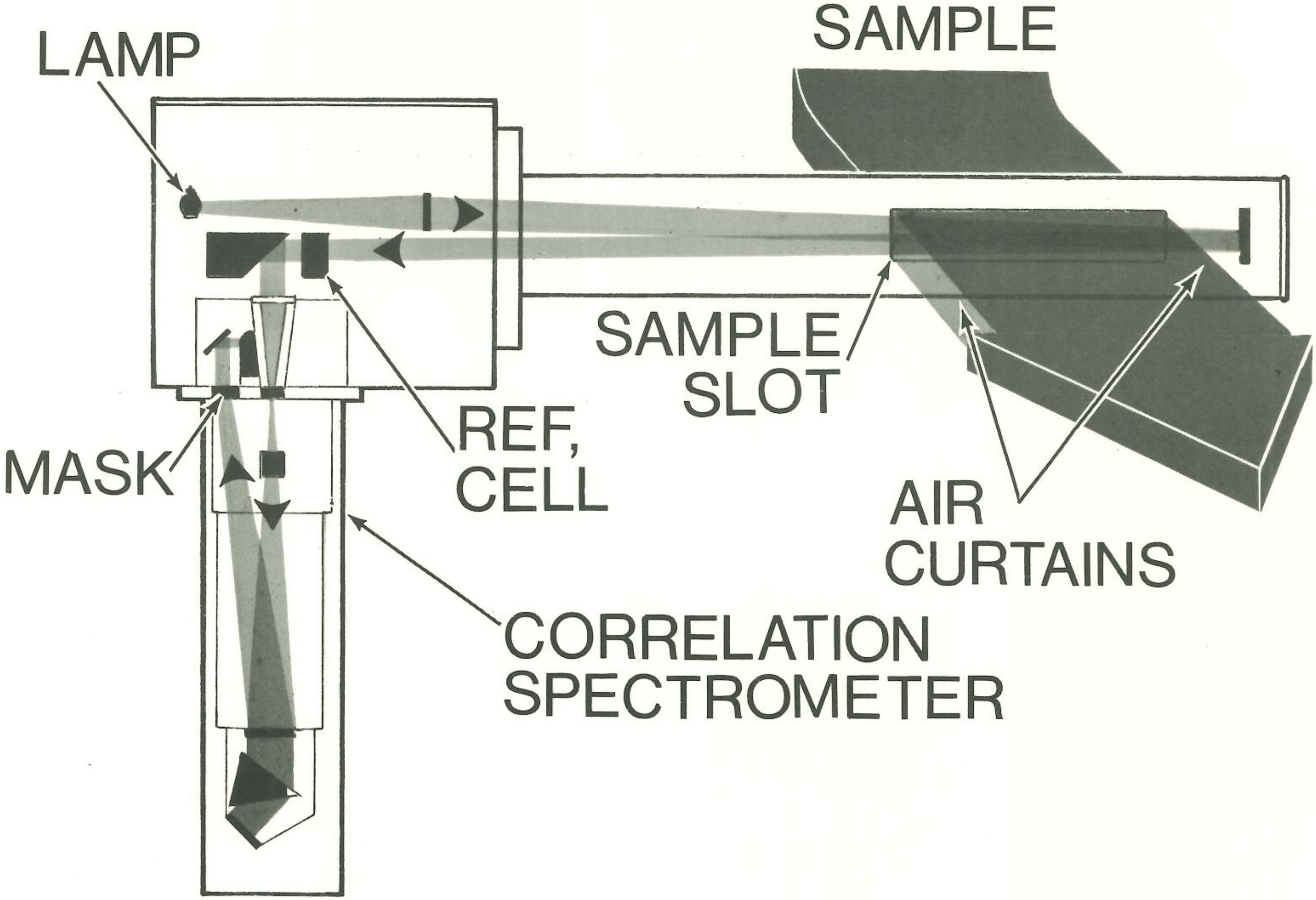

RELATIVE CONTRAST
VS.
DISTANCE
-BLACK/WHITE PANELS
-REMOTE SENSOR AS
PHOTOMETER
CONTRAST
100
90
80
70
60
50
40
30
20
10
0
METERS
50
100
150
200
250
410 nm
380 nm
320 nm
350 nm

Figure 16



BARRINGER RESEARCH

STACK MONITOR

Figure 17

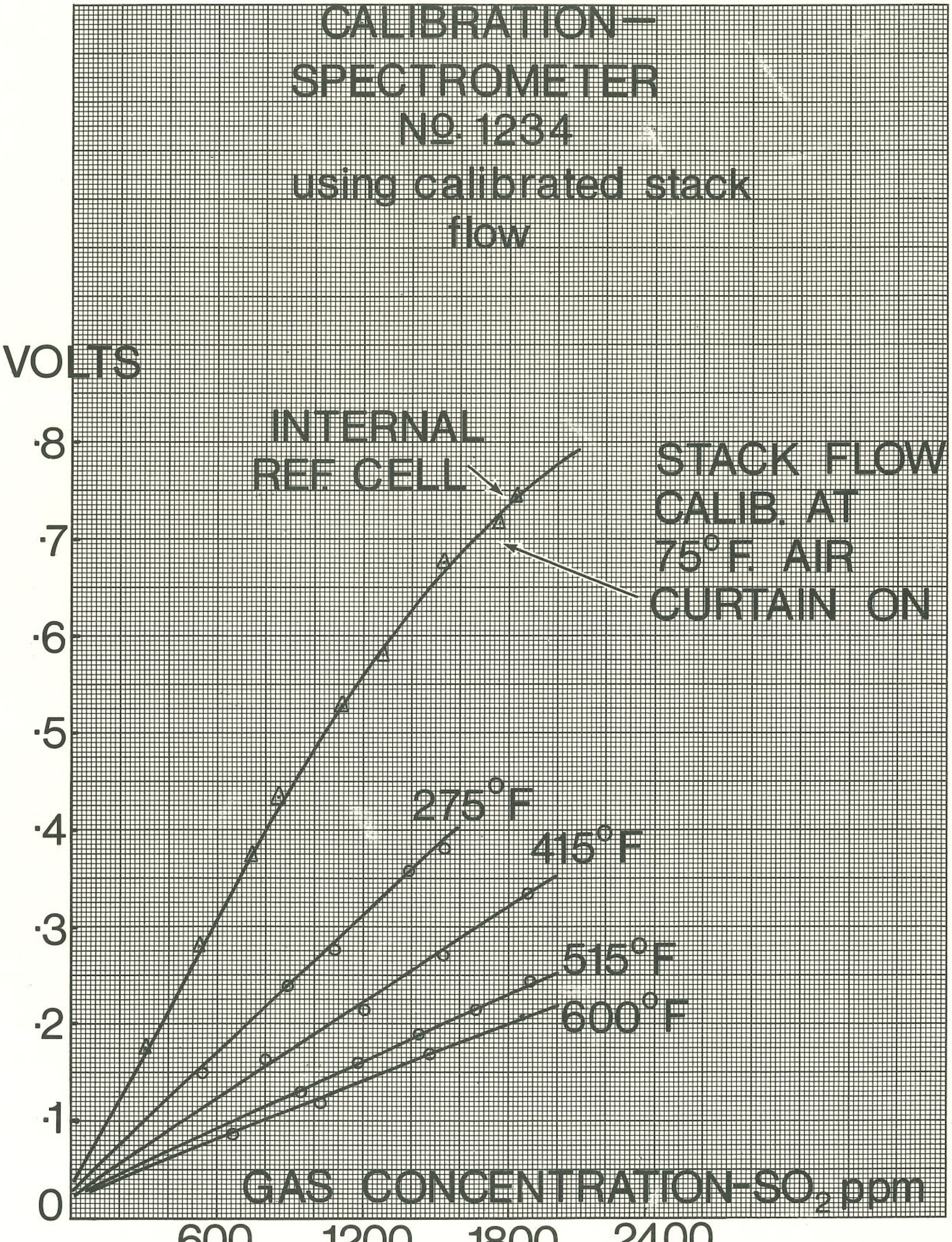

CALIBRATION—
SPECTROMETER
No. 1234
using calibrated stack flow
VOLTS
·8
·7
·6
·5
·4
·3
·2
·1
0
INTERNAL REF. CELL
STACK FLOW CALIB. AT 75°F. AIR CURTAIN ON
275°F
415°F
515°F
600°F
GAS CONCENTRATION-SO2 ppm
600
1200
1800
2400

Figure 18

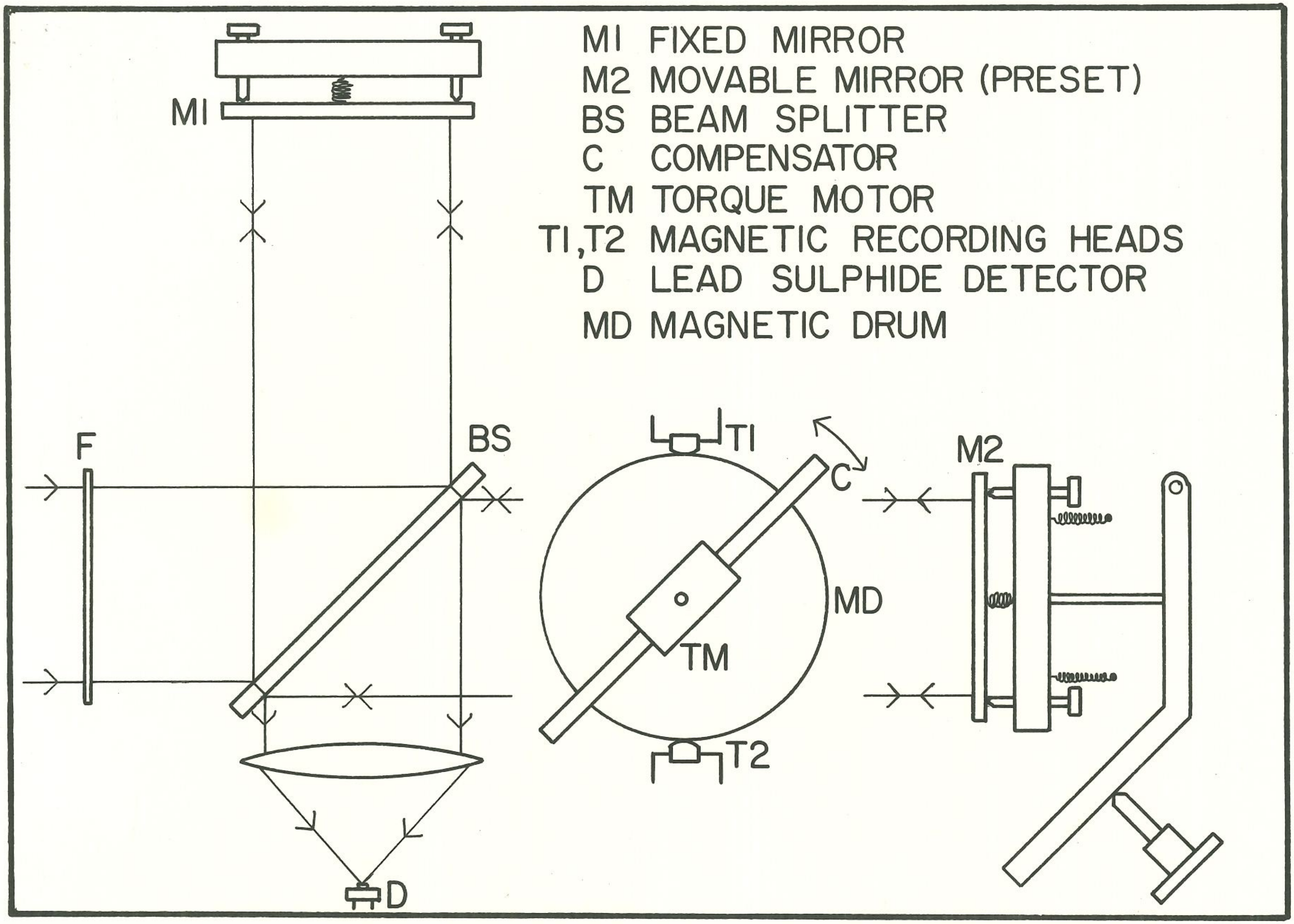

MI FIXED MIRROR
M2 MOVABLE MIRROR (PRESET)
BS BEAM SPLITTER
C COMPENSATOR
TM TORQUE MOTOR
TI,T2 MAGNETIC RECORDING HEADS
D LEAD SULPHIDE DETECTOR
MD MAGNETIC DRUM
MI
F
BS
TI
C
M2
MD
TM
T2
D

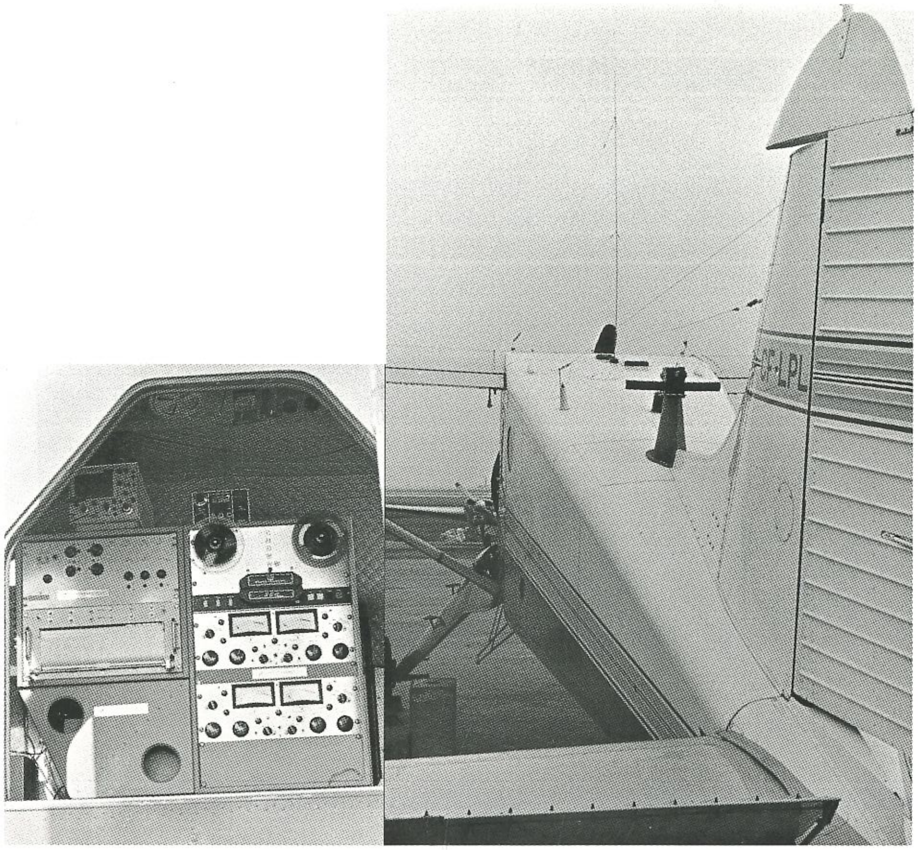
Figure 19

BARRINGER RESEARCH

FALL 1968

Radiophase
Geochemistry
Ocean Magnetics

Radiophase



Radiophase installation, Beaver aircraft. Magnetic coil sensors are mounted just before tail section; vertical electric antenna is over cabin. Inside cabin: Radiophase console (upper left), chart recorder (lower left), tape data storage (right).

The first RADIOPHASE survey contract was completed in July, 1968, for the Province of Quebec. This passive electromagnetic detector is a new airborne exploration device using long distance radio stations for source signals. It complements the active EM systems we have built which continue in heavy use throughout the world: INPUT®, the unique pulsed system we introduced in 1961, and an advanced low-frequency, multi-coil helicopter instrument for sulfide exploration. Now RADIOPHASE demonstrates our continuing commitment to the electromagnetic techniques for remote sensing. Still further advancements, for deeper penetration, are under development; but RADIOPHASE has become operational.

The above photographs show the RADIOPHASE system mounted on and in a Beaver aircraft. A whip antenna for observing the vertical electric field component is mounted above the passenger cabin. Orthogonal coils for obtaining the horizontal magnetic components are mounted, in line with the aircraft axis, on a pylon just before the rudder. A nuclear magnetometer for measuring the earth's magnetic field is trailed from the aircraft.

RADIOPHASE is fundamentally a technique for geologic mapping. It monitors the effect of the earth on the propagation of the ground wave emanating from one of the several VLF radio stations placed around the world for time synchronization in communication and navigational systems. VLF stations broadcast in the 15 to 30 kiloHertz band; for the initial surveys in Quebec, U. S. Navy station NAA (Cutler, Maine) was used (17.8 kHz). The combined features of enormous power output (the Navy's NAA transmits one million watts!) and frequency range make these waves suitable for ground conductivity measurements to considerable depth at distances of thousands of miles from the transmitter.

Operating on the variations in the components of this signal, it is possible to determine the general conductivity of the rocks below. When their conductivity is low, the instrument reflects the characteristics more deeply than previous techniques, achieving penetration depths of down to one-thousand feet.

The transmissions are now being used to detect many types of geological features including faults, shear zones, graphitic horizons, mineralized bands, disseminated sulfides and massive sulfides.

®Registered Trademark

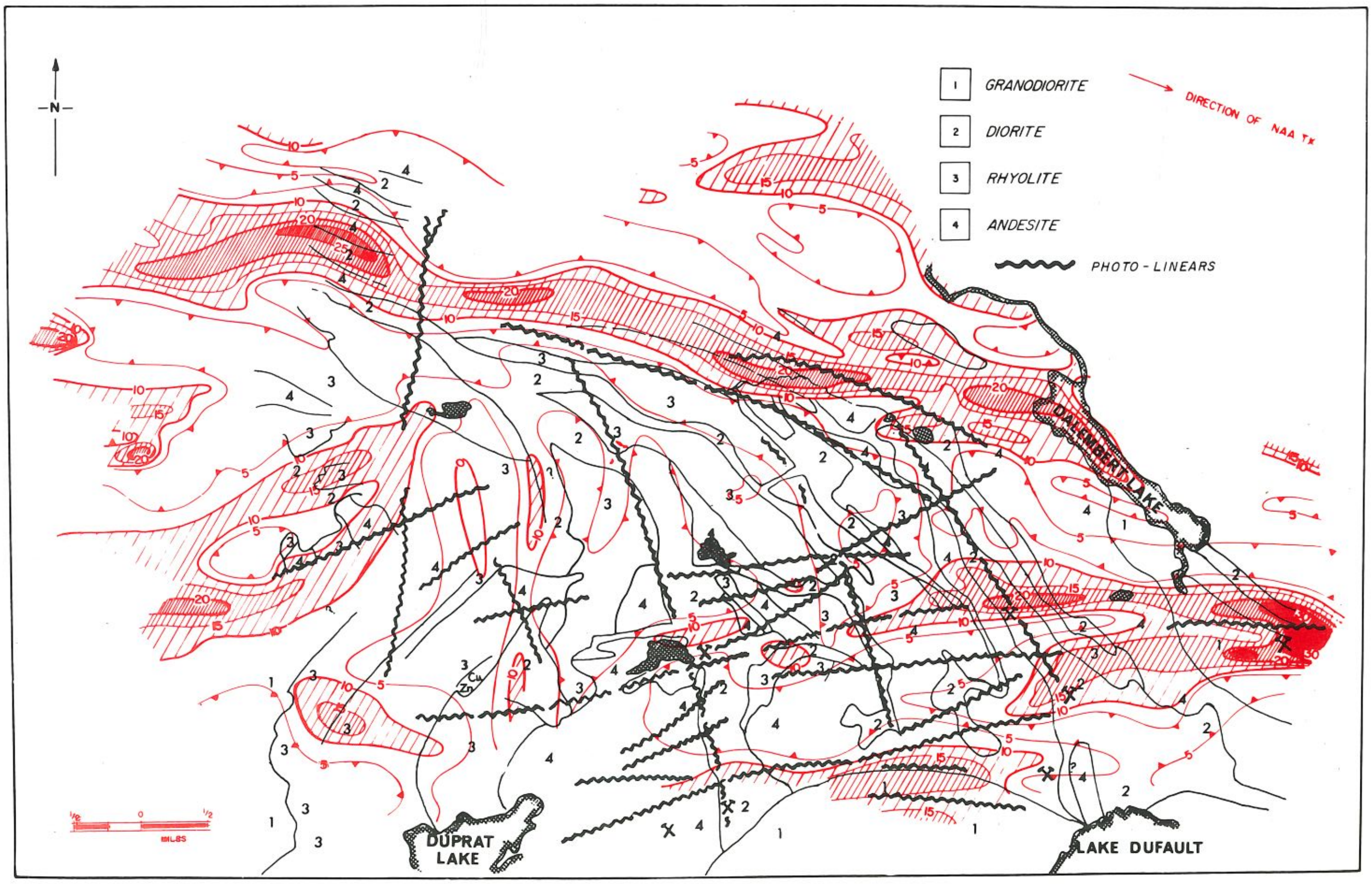
Operation of RADIOPHASE is based on the fact that the phase of the near-earth vertical electric field of the VLF radio waves is only slightly affected by variations in conductivity of the underlying terrain. The VLF magnetic field, on the other hand, is greatly influenced by these variations. This is because eddy currents, which are induced by the primary magnetic field in conductive regions, produce quite significant secondary magnetic fields. These secondary fields have both in-phase and quadrature-phase components with respect to the inducing magnetic field and, thus, also the vertical electric field. Therefore, a measure of the quadrature component of the magnetic field is a measure of the magnetic field produced solely by conductive regions. RADIOPHASE measures both the amplitude and direction of this *secondary field* to provide contour and vector maps which clearly indicate the presence of faulting, fracture zones, and other conductive anomalies. This information is of considerable value in the determination of regional geology as well as the determination of potential mineral deposits.

Initial testing and surveys conducted with RADIOPHASE have indicated great consistency of results. Flight altitudes of about five-hundred feet yield synoptic coverage, as shown in the map view. Lower level flights consistently isolate known ore deposits of conductive material. In many cases interesting correlations are demonstrated between the magnetometer traces and the RADIOPHASE results.

Several other interesting potential applications are indicated. The addition of a horizontal electric field antenna (trailed from the rudder) to the RADIOPHASE system permits measurement of the conductivity in saline and brackish waters, assisting in the determination of the extent of salt water encroachment on estuarial areas. Water pollution can often be detected by conductivity measurements. Permafrost distributions could be outlined, and other engineering assessments associated with rock conductivity should prove useful.

RADIOPHASE, the latest exploration system offered by Barringer Research, should prove a valuable new tool in exploration. Its ease of installation and comparative low cost will add greatly to its appeal.

Duncan McNeill



This map view of the Lac Dufault region of Quebec demonstrates the correlation between photographically observed lineations, geologic lithology and conductivity response (in arbitrary units) as measured by RADIOPHASE. Mineralization is seen to be associated with conductive fault zones. (Note existing mines indicated by crossed picks.) Aeromagnetics (not shown) further discriminate the geologic setting.

Geochemistry

Geochemical activity in the Barringer laboratories increased to an all time high during the summer of 1968. Though this effort has been a significant element of our service to exploration since 1963, this year we placed a facility in the center of the mining activity just south of the Arctic Circle. The Ross River "tent-lab" was quite complete, active and very successfully backed our consulting services in the general area. A consulting geochemist, directing the field season operations, was able to provide the *mandatory* element of this method—the preliminary judgment of field procedure and sampling techniques. He also directed the analytical approach.

In the meantime the preparation of samples, and their analysis by a dozen processes, continued at our permanent laboratory in Toronto (Rexdale). Our year-round staff was supplemented, and working hours were extended.

It is the basic aim of geochemical techniques to trace minute quantities of the metal sought, or an indicative tracer metal, as they increase in their average content per sample. Considering the geologic and geomorphic conditions and the metals being sought, a drainage pattern map can be used to eliminate unfavorable areas and to focus attention on anomalous metal areas of greatest interest. In addition to these drainage sediment surveys, sampling of residual soil, rock sampling and the analysis of vegetation or ground water are proven geochemical approaches in geological exploration programs; particularly when such geochemical approaches are part of the integration of all exploration activities.

Care must be taken in obtaining the sample for analysis. Silt and soil samples should be organic-free and placed in a kraft paper bag. Plastic containers create the environment which leads to chemical reactions that change the character of metal in the sample. The laboratory analytical methods which are chosen will be based on the chemical and physical properties of the metals to be determined, the form in which these metals may occur in the sample, and the levels of detection and reproducibility which are required. Some of the techniques that have become standard in geochemistry include: emission spectroscopy, x-ray spectroscopy, polarography, atomic absorption spectrophotometry and colourimetry. In addition, both partial and total wet-chemical analyses are used.

Many materials "report" to the surface through the overburden or in the drainage. Efforts to analyze these samples often require determinations in minute amounts (to parts in 10^9); even small variations can be significant. Another aspect of geochemistry is the ability to outline metal-rich segments of the earth's crust. Reconnaissance surveys sometimes cover tens to hundreds of thousands of square miles! It is an advantage to be able to look on a regional scale and then to use variations of these principles to isolate areas of greatest interest.

The cost of a geochemical investigation can be small. Unit samples are inexpensive; they pass Custom's points readily; and they can be analyzed to answers in a few days. Several papers on the uses, limitations and cautions of this method of exploration are available. A visit to our laboratories or inquiries for consultation are invited.

We are proud that our contract laboratory is one of the largest in the world and that geochemistry equals geophysics in our service to exploration.

John L. Walker

Pipetting standard solutions for colourmetric determinations.

Geochemistry Laboratory, Rexdale; wet chemical analyses.

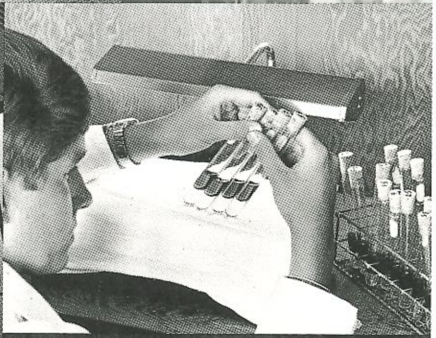
Analysis by infrared spectrophotometry.

Barringer geochemistry field vehicle along Alaskan Highway.

Barringer Mercury Detection Instrument, based on atomic absorption principles.

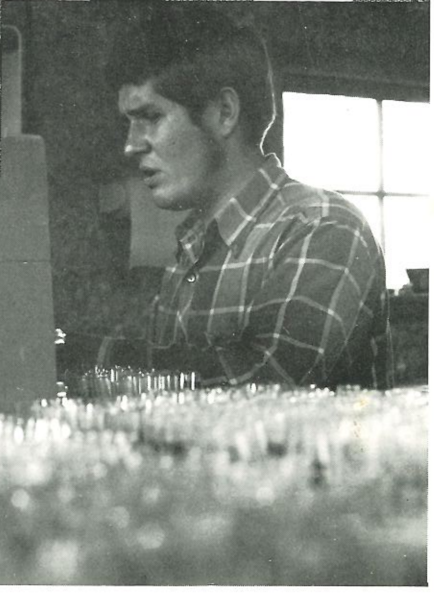
Gas chromatographic determinations.

Comparison of end point metal content, unknown samples to known amounts.



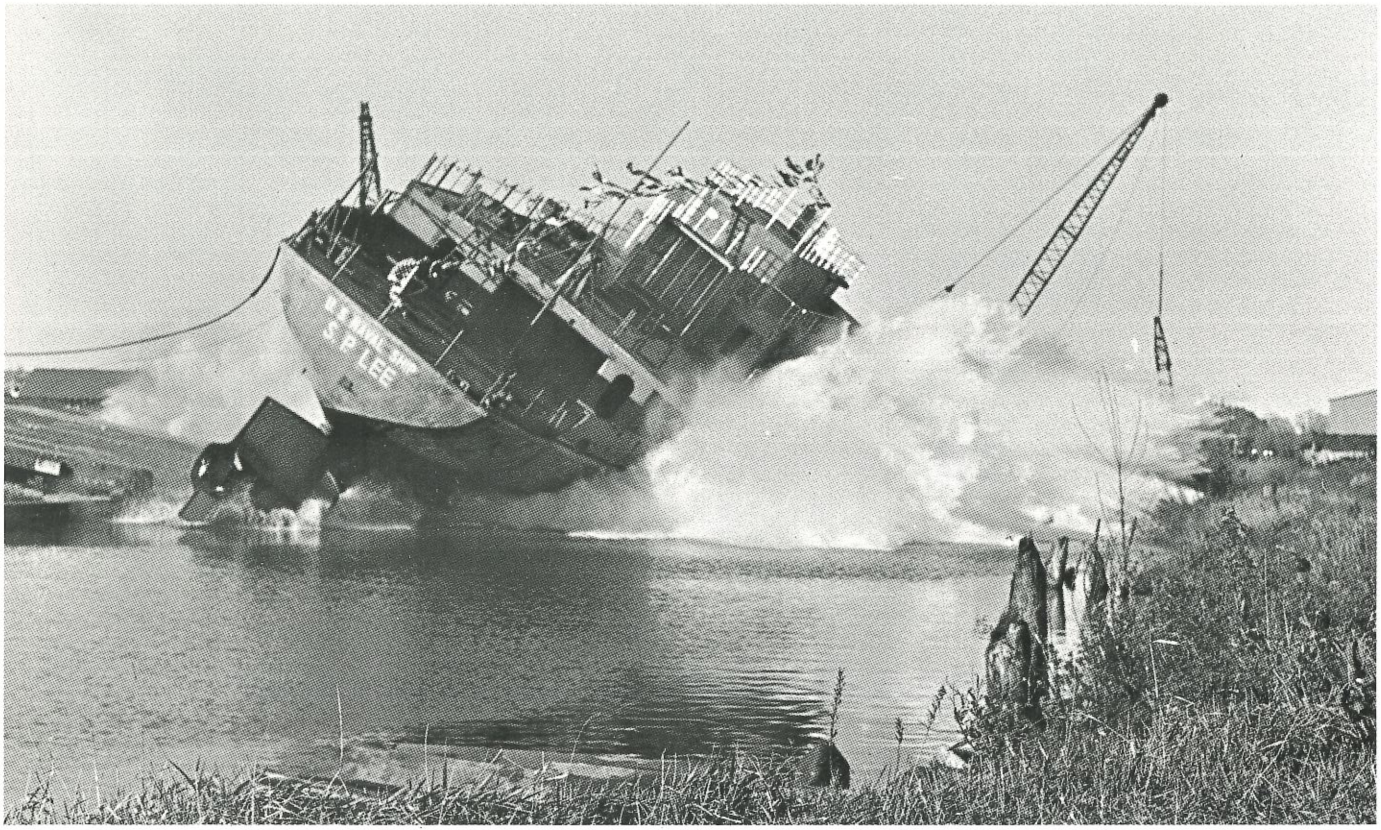
1968 Barringer field laboratory, Ross River, Yukon Territory.

Production analysis at Ross River using atomic absorption spectrophotometer.



Cover: Preparation of buffer solutions for use in colourmetric metal determinations; Rexdale laboratory.

Ocean Magnetics



October, 1967, launching of USNS S. P. Lee (T-AGS 31) at Bay City, Michigan. This hydrographic survey ship is destined to use the new OM-104 nuclear magnetometer.

In March, 1968, Barringer Research was awarded a contract by the United States Naval Oceanographic Office for the construction of two marine magnetometer systems. This event marked the Company's formal entry into the oceanographic industry. To meet the stringent Naval equipment specifications within a short time, it was decided to base the new product design on another Barringer nuclear precession magnetometer, the SM-103 portable instrument, which had just concluded development. In addition an underwater sensor had to be designed, which required a tow cable and special connectors. A production engineering design team was formed and, on September 3, 1968, six months after receipt of the contract, the magnetometers passed final inspection and were shipped to Washington, D.C. on schedule.

As a result of this contract two new products are now available, the Model OM-104 Oceanographic Magnetometer and its Marine Towing System. Both units were designed specifically for severe marine environmental conditions and are an impressive addition to our Earth Sciences product line.

The planning used to achieve the completion of the OM-104 is indicative of changes occurring in our growing Commercial Products Division. Our computer facility was used in planning and maintaining an intricate program based on critical path scheduling. Thus a new product with unique features was designed, developed, produced and tested on a short time scale.

Measurement of the earths' magnetic field at sea, to an absolute accuracy of ± one gamma, is a difficult problem when the marine environment is considered in detail. The towed sensor is exposed to corrosive salt water, constant heavy vibration, frequent shock loads, high hydrostatic pressures and temperature extremes. The on-board magnetometer console fares little better since, in addition to the problems of shock, vibration and temperature variations, there are added tropical or arctic conditions.

The design of the OM-104 was based on the achievement of the required performance reliability under these severe conditions. All circuitry is solid state, with a maximum utilization of integrated circuits throughout. The unit is quite compact, is of extremely rugged construction and weighs less than eleven pounds. All materials used in the construction of the magnetometer were carefully selected for resistance to corrosion, fungus and humidity.

Direct readout of the total earth's magnetic field intensity is available visually on numeric tubes on the face of the instrument. Both analog and binary-coded decimal outputs are available for data recording, and a precession signal test point is suitable for oscilloscope or audio monitoring. World-wide coverage is accomplished by a sixteen-position, overlapping-range switch; tuning is automatic within each 5000-gamma range. The Barringer patented readout technique permits direct measurement and display. A versatile programming system permits a variety of automatic, manual and external triggering alternatives.

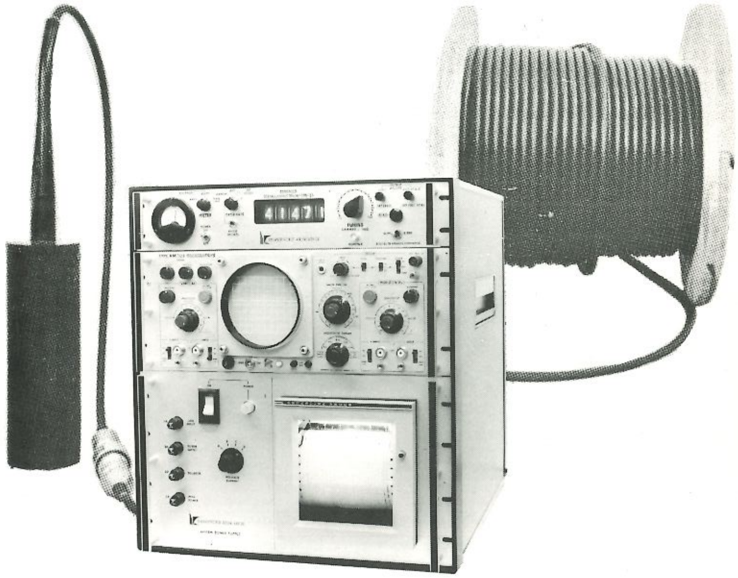
The towing system has several unique features. The sensor itself is constructed entirely of carefully selected non-magnetic materials and is molded into a tough polyurethane jacket. A short length of the tow cable is also molded into the "fish," and a special underwater connector is located on this "pigtail." The purpose of this connector is to provide a quick-disconnect facility for replacement of sensors, to ease shipment of the equipment, to separate metal parts from the point of measurement and to allow the use of non-special tow cables in the event of an emergency.

The sensing head itself is a special three-coil noise-cancelling array which also produces a valuable omnidirectional capability. Physically, the towed sensor was designed internally and externally to withstand extreme and continuous vibration; it has a design depth of 1500 feet. The nature of the sensor is, however, suitable for very deep applications (to 15,000 feet) by a simple "add-on" modification to the rear pressure bulkhead. A cavity in the nose of the sensor can be used for passive preamplification circuitry required for long cable applications. The connector at the pigtail permits the inclusion of batteries and active circuits if this alternative is adopted.

The success of the OM-104 magnetometer is indicated by the fact that an extended product line will be developed around the basic design. It includes an airborne version, a mobile or suitcase magnetometer and a station instrument to cover all applications. It is also suitable for special adaptation in advanced concepts of precession magnetometers.

The nuclear magnetometer has found extensive use at sea. The instruments are installed permanently or temporarily aboard vessels of all sizes. They are towed for petroleum or mineral exploration, for geologic structure and lineament analyses, for broad scale continental drift investigations and for shallow search and salvage operations.

Reginald M. Watts



U. S. Naval Oceanographic Office version of new Barringer Oceanographic Magnetometer. Console includes OM-104 (top 3½ inches), oscilloscope, ac power supply and strip chart recorder. Cable reel has 750 feet of non-magnetic cable; new "fish" has "pigtail" with marine connector.

SPECIFICATIONS

The Model OM-104 Oceanographic Magnetometer is a nuclear (proton) precession instrument designed to measure the total intensity of the earth's magnetic field in the marine environment.

Sensitivity: 1 gamma (1 nano-Tesla)

Range: 20,000 to 100,000 gammas
(16-overlapped switch positions)

Absolute accuracy: ± 1 gamma

Cycle rate: 2-second automatic cycle
(initiated by internal timer, a manual button or an external trigger)

Outputs: Front panel 5-digit display;
BCD 1-2-4-8 code;
Analog channels, potentiometric and galvometric

Physical environment: 0-45° C (—20° C available)
0-95% humidity

Power requirement: 8 amperes, 28 volts dc
(peak, less than 50% duty cycle)

Dimensions:
console: 19" rack; 3.5" x 10"; 11 pounds
marine sensor: 6" (D) x 24"; 18" snout;
6 to 10 foot "pigtail" with connector;
46 pounds

cables: variable, console-to-stern and tow;
maximum length, 1200';
750' cable is normally supplied

Duncan McNeill (B. Sc., Dalhausie University; M. A., University of Toronto) is Senior Physicist in our Research Division. He has directed the development of the Radiophase system and managed the testing and early survey operations of this new technique. His other responsibilities include additional advanced passive electromagnetic systems and electro-optical data handling techniques.

John L. Walker (B. Sc., Aberdeen University; Ph. D., University of London's Imperial College) is Chief Geologist/Chief Geochemist for the Company. He directs the geochemical laboratory at Rexdale and travels throughout the world as a consultant to the mining industry. Dr. Walker provides technical guidance for our field operations and has had extensive experience in Europe, Africa, Australia and North America.

Reginald M. Watts (B. A. Sc., University of Toronto; Royal Military College) is the Product Design Engineer responsible for the USNOO magnetometer project and the OM-104. Presently he is directing new product design for other instruments under development in the Commercial Products Division. Mr. Watts has also been project engineer for Barringer helicopter electromagnetic systems.

The short articles in this, the first issue of a periodical devoted to the activities of Barringer Research, Inc., represent some of our current and continuing activities. We are dedicated to the investigation of our environment through instrumentation and chemical methods. Technical preprints and journal articles are available for more detailed and precise discussions; appropriate data sheets describing our products will be sent on request. We welcome comment and inquiry.

ADVANCED TECHNIQUES AND INSTRUMENTATION FOR THE EARTH SCIENCES

BARRINGER RESEARCH

304 Carlingview Drive
Rexdale, Ontario, Canada
Phone: 416-677-2491
Cable: Baresearch