THE UNIVERSITY OF MICHIGAN

College of Engineering
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ATMOSPHERIC DIFFUSION STUDY AT THE ENRICO FERMI NUCLEAR REACTOR SITE

First Progress Report

Technical Installation and Preliminary Analysis

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PREFACE

This report presents the details of the instrumentation for the fluorescent particle tracer system installed at the Enrico Fermi plant site. Data from the summer and fall diffusion experiments are given along with a qualitative estimation of the diffusion. There are no quantitative results available at this time. Such results will be given in the next report with a discussion of the winter and spring experiments.

The University of Michigan Research Institute as well as the authors wish to make the following acknowledgments: to the M. A. Hanna Company of Cleveland, Ohio for providing the radar set at no cost to the University; to the late Mr. Arvy W. Wagner for allowing the project to use his own personal radio transmitter and receiver at the plant site; to Mr. Dwight Meeks for use of his tape recorder; to Dr. W. A. Perkins and Mr. F. X. Webster of Stanford University Aerosol Laboratory for loaning the fluorescent particle apparatus and for consultation when needed; to Raytheon Manufacturing Company of Waltham, Massachusetts for locating the radar and aiding in making it operational; to Power Reactor Development Company for aiding in the development of the bivane; to Lt. Michael J. Menadier, Weather Services Offices at the Grosse Ile Naval Air Station, for allowing the hourly weather observations to be copied and for doing the synoptic map analysis; to Col. W. R. Schaal and Capt. John Doty of the 127th Tactical Reconnaissance Wing of the Michigan Air National Guard based at Detroit-Metropolitan - Wayne County Airport for photographing the smoke plume and developing the film; to Mrs. Anne C. Rivette for typing the report; and to supporting personnel of the Meteorological Laboratories for collecting the data and putting it into useable form.

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ABSTRACT

The purpose for holding such a study and the general methods of approach to complete the study are presented. The various tracers that could be used and the reasons for selecting the fluorescent particle technique are discussed. The fluorescent particle system and the installation at the Enrico Fermi site are described in detail. Experimental runs were held on the 5th and 6th of August 1959 and the 27th and 28th of November 1959. The observations are discussed and a qualitative estimation of diffusion is made. How quantitative estimations of diffusion can be made is outlined; and finally, the work to be completed in the future is presented.

I. PURPOSE OF THE STUDY

This project was initiated in order to study atmospheric diffusion over Lake Erie under meteorological conditions that would prohibit good diffusion. Such action was deemed necessary because of the great number of effects that the lake has on the meteorological parameters being observed on the tower at the plant site. Analysis of these lake effects may be found in the first three progress reports of the climatological project in progress at the reactor site (1), (2), (3).

Coincident with the growing concern over air pollution as an important factor in the health of the nation, there has come an increasing willingness on the part of enlightened groups to design and locate new facilities in such a way as to minimize ground level concentrations of effluent wastes. Such groups enlist the aid of meteorologists who specify what dispersion patterns can be anticipated in the neighborhood of the plant under diffusion conditions that may vary from excellent to very poor.

Many new electrical power generating plants, powered by nuclear reactors which might possibly emit radioactive material into the atmosphere from time to time, as well as many other industrial plants which discharge wastes into the air, are being located beside a natural water supply such as a river or along a lake shore. Thus one of the major problems confronting the meteorologist is that of specifying diffusion patterns at a site where existing theories developed for land trajectories have little if anything to offer as a guide.

There is almost a complete void in the fundamental knowledge of the diffusion of contaminants released to the atmosphere at shoreline installations. In addition, there has been little if any research in progress which will provide the basic information on atmospheric dispersion needed now and in the future in the design of nuclear reactors and other industrial plants along the shores of lakes and wide rivers, where the atmosphere is in a state of transition.

Diffusion in transitional states has been defined as the condition when the field of atmospheric turbulence exhibits marked variation in time or space or both. At a shoreline there are marked horizontal variations in turbulence. Air flowing from land over a cool water surface, as in spring, becomes increasingly stable and experiences reduced mechanical turbulence over the relatively smooth water surface. In the autumn the water is relatively warm and the air leaving the land may develop instability and thermal turbulence over the water, leading to enhanced diffusion. This is but one example of the many types of diffusion in transitional states.

The fact that many lakes and rivers form state and national boundaries which raise interstate and international legal problems only emphasizes the need of fundamental studies. Thus, it is clear that a comprehensive investigation of the nature of atmospheric diffusion in transitional states and especially at shorelines is required.

The present report gives information on two sets of diffusion measurements in transitional states made near Monroe, Michigan.

II. GENERAL PLANS FOR THE EXPERIMENTAL RUNS

The major purpose of this project is to assess atmospheric dispersion when turbulence and mixing are limited. The study was not to be continuous but to be conducted only during a given period of a day or so at a time. Data were to be collected during each of the four seasons of the year to show the seasonal variations. The final conclusions would then be based on one or preferably two days of data each season for a total of 8-12 experimental runs.

To further complicate a difficult measuring program, observations could be taken only when the University staff and student personnel were available. That is to say that the fall, winter, and spring experiments had to be conducted during vacation periods such as Thanksgiving, Christmas, between semesters and Spring Vacation. The net result was that observations were taken during periods when diffusion was either good or bad. Fortunately, measurements have been made under both extremes.

Diffusion was to be studied at distances of from 5-25 miles over both land and water. This meant that an airborne sampler would be the only answer to the problem of how to sample adequately. Blimps, helicopters, and airplanes were considered. It was decided to use an airplane mainly because one was readily available. Blimps are not numerous enough and cost entirely too much. In fact, Goodyear had only one blimp available for contract work and it was based in Miami, Florida. Although helicopters have been used in diffusion studies, it was thought that under the stable conditions desired for these experiments, the whirling blades of the helicopter might disturb the atmosphere too much.

After deciding upon the use of an airplane for sampling, the problem arose of how to locate the plane, especially when over the lake. A radar seemed the only plausible solution, so a radar set was procured and installed at the site. The antenna was mounted on a platform which was attached to the already present meteorological tower. The radar set enabled the staff at the plant site to position the plane by knowing the bearing and the distance that the plane was from the site. Height of the aircraft was to be determined by the plane's altimeter.

The radar could not be used for sampling close to the plant site because of the ground clutter caused by the buildings. To remedy that situation, theodolites were used to track the plane in order to get a bearing on it and also to track the smoke plume and measure its width. Two theodolites have been available for such use.

The tracer used, zinc-cadmium sulfide, is invisible to the human eye after being dispensed by the aerosol generator, so it was thought that by expelling puffs of smoke from an oil-fog generator, the plume of the tracer could be followed both on the ground and by the plane. At the contractor's request, only short puffs of smoke were to be released, although the passage of time has allowed this restriction to be relaxed.

The only way to coordinate such a diverse and widely spread experiment was to have a good communication system. A two-way radio is used for plane-to-ground and ground-to-plane contact. Sound powered telephones are used for tower-to-ground and ground-to-tower contact. All of these conversations are tape recorded. Tape recording offers the advantage of having an accurate time scale for determining when various occurrences happened since the tape moves at a constant rate of speed.

Meteorological data are available from the tower installation: wind speed and direction at three levels, bivane data from two levels, and lapse rate measurements up to 100 ft. Aerometeorgraph readings, dry bulb temperatures, and altimeter readings are available from the plane. Hourly surface observations and map analysis are available from Grosse Ile Naval Air Station as well as emergency helicopter rescue if required.

The Michigan Air National Guard has kindly volunteered aerial reconnaissance photographs of the smoke plume when measurements are being taken in an effort to aid in estimating the diffusion regime.

As soon as a time has become available for conducting an operation, then the weather is carefully watched to note if diffusion conditions are likely to be poor and if so, when they will be poor. Measurements can be taken only during the daylight hours, principally because of the hazard of a light plane flying at night in an area of dense air traffic. Poor atmospheric diffusion conditions are wanted but the plane must have at least 1000 ft of ceiling and 3 miles visibility before flight can be made under visual flight rules. Flying under instrument conditions on experimental runs such as has been contemplated is illegal. Prior to the final selection of a date, the plane has to be rigged with all the necessary equipment and the apparatus on the tower is readied; the radio and radar checked out and everything put in operating condition. When satisfactory conditions are forecast, the crew is alerted so that runs can be started as soon after sunrise as possible. Runs are made until it is felt that adequate data have been collected or until some piece of equipment should malfunction. If a preliminary survey indicates that the run has been successful, the experiment is completed. Should one day's operation prove not successful, then it is tried again the next day. Upon successful completion, the equipment is taken down and stored until the next series of runs.

III. SELECTION OF A TRACER TECHNIQUE

1. TYPES OF TECHNIQUES

Air pollution meteorologists have long been concerned with the movements of wind currents that carry air pollutants. Several methods have been developed to follow the action of wind currents in the atmosphere through the controlled release of nontoxic materials which can be described as "tracers." These materials have taken the form of gases, liquids, and solids (the latter two being in a very finely divided state when released.)

The following five tracers were considered for the Enrico Fermi diffusion study:

a. oil fog smoke;
b. sulfur dioxide gas;
c. radioactive materials;
d. uranine dye; and
e. fluorescent particles.

The first four tracers were rejected for the following reasons:

a. Although photography of oil fog smoke may give a good qualitative measure of diffusion, reliable quantitative measurements are very difficult owing to problems in photographing and measuring smoke concentrations against a non-uniform background. It was considered unlikely that suitable smoke concentration measurements could be made beyond one to two kilometers on most days of poor diffusion, whereas measurements were desired up to sixteen kilometers.

b. Although in certain circumstances sulfur dioxide has considerable merit as a tracer, it was rejected for the present study for two main reasons:

(1) possible marked absorption of the gas when it came in contact with the lake, thus raising questions as to the validity of the observations; and

(2) the relative expense of the technique considering the volumes of gas needed for concentration measurements at distances of sixteen kilometers or more.

c. Radioactive tracers were found to be unsatisfactory:

(1) the "red tape" and delivery problems for obtaining such materials have been a serious hindrance on other known projects; and

(2) personnel associated with the AEC recommended the use of tracers other than the radioactive type so as not to disturb natural background studies.

d. The uranine dye tracer technique was seriously considered, but was not chosen because the technique was still under development, with no precise information on the proper size and shape of spray nozzles; the proper pressure range; recommended concentrations of dye material, etc.

2. REASONS FOR SELECTING FLUORESCENT PARTICLE MATERIAL

The fluorescent particle technique was selected for the following reasons:

a. The technique had been used successfully by four different groups and had been proven satisfactory (5) (6) (7) (8) (9).

b. Calculations indicated that under poor diffusion conditions suitable concentration measurements could be made at distances up to 16 kilometers if the emission rate was at 30 gm per minute. The cost was much less than that of other techniques, being approximately $20 per hour.

c. The material is insoluble in water and so would not be absorbed over the lake surface and the particles are so small that gravitational settling is negligible.

d. The needed dispensing and sampling equipment proved to be available on short notice. Mr. Frank Webster and Dr. William Perkins of the Aerosol Laboratory, Stanford University, agreed to recondition, at cost, and loan to the Meteorological Laboratories a fluorescent particle dispenser, three drum samplers for airplanes, a specially equipped microscope with proper mercury lamp, and complete instructions for use of such equipment. They also agreed to conduct acceptance tests on the fluorescent particle material and to act as consultants in any subsequent problems that might arise.

e. There was no hazard to human life when using this material.

IV. FLUORESCENT PARTICLE TRACER-STANFORD UNIVERSITY TECHNIQUE

1. THE TRACER MATERIAL

Zinc-cadmium sulfide fluorescent paint pigment No. 2267, manufactured by the U. S. Radium Corp., Morristown, New Jersey is the tracer material used. It is especially ground for the purpose to a mass mean diameter of approximately 2.7 microns, and is calculated to contain approximately 2.3 x 10^{10} detectable airborne particles per gram. The settling rate of a particle 2.7 microns in diameter with a density of 4 is less than 10 feet per hour. Where airplane samples are taken at 100 ft height intervals usually within 10 to 30 minutes after release it is evident that the effects of settling are insignificant in this case. The normal range in size of countable particles is 1 to 8 microns with 90 percent of the population being under 4 microns in diameter.

This crystalline powder is relatively inert, insoluble in water, and essentially nontoxic. When stored in a moisture tight container in a dry atmosphere there should be no deteororation of the material over a period of years. The material disperses well, with a minimum of "clumping."

These fine particles fluoresce brilliantly under strong illumination from a B-H4 mercury arc lamp, which emits chiefly in the region from 3100 A to 4000 A. The fluorescent light appears mainly in the yellow-orange but a sizeable percentage fluoresce in the green.

2. DISPERSAL EQUIPMENT

The dispersal equipment is shown in Fig. 1. It consists of a high speed blower (1) (modified Model 29 Skil Blower); a hopper (2); a stirrer (4); a feed mechanism (5); and a power supply (6) for the three motors.

The blower is powered directly from the 110 volt 60 cycle line. The feed motor and stirrer motors are small high speed D.C. motors geared down to drive their respective mechanisms. The speed of each motor is maintained within narrow limits by the use of individual rheostats and meters connected to a constant voltage D.C. supply.

The hopper holds approximately 2 kg of FP (fluorescent particle) material. The emission rate is adjustable from 30 to 75 gm per min. Refilling of the hopper (2,3) is carried out during operation when more than 2 kg is dispersed, the hopper usually being kept more than 2/3 full.

The feed mechanism is a notched wheel turned by the feed motor. Thus the FP material is not fed as a continuous even stream, but rather at a slightly pulsing rate of about 1/2 cycle per sec. The FP material is sucked

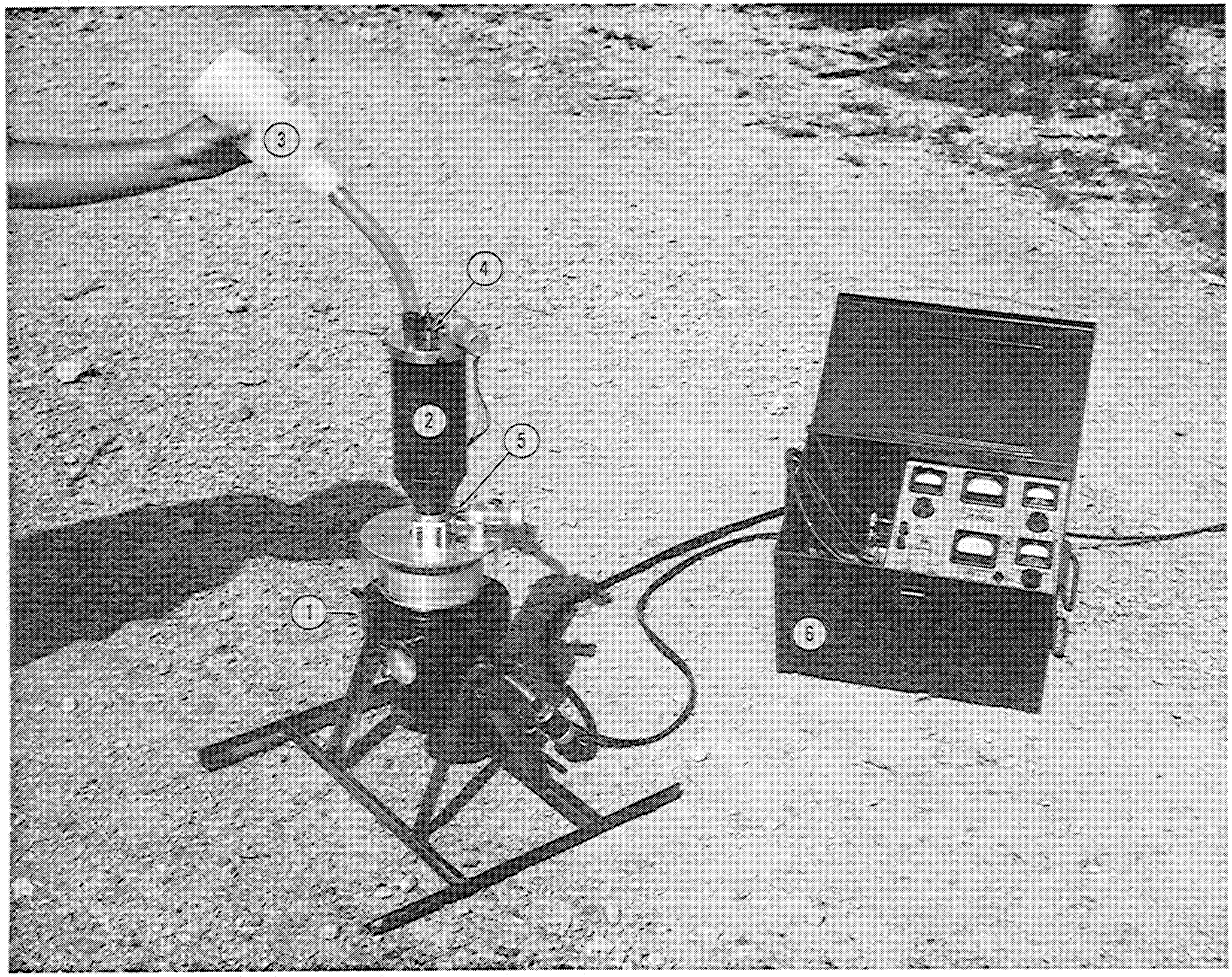

Fig. 1. Aerosol generator and power supply for fluorescent particles: (1) skil blower, (2) hopper, (3) polyethylene bottle for adding FP material, (4) stirrer, (5) feed mechanism, (6) power supply.

into the intake of the blower where there is very great shear; passes through the blower; and is emitted at the exit air velocity of about 18000 ft per min. Tests have shown that the FP material is very largely broken up into individual particles upon leaving the generator, there being an almost neglible mass of material passed out in clumps of two or more particles larger than 1 micron.

The rate of emission of the FP material is quite accurately calculated as the material is weighed out into several polyethylene bottles ((3) of Fig. 1) prior to or during a run; the unused material is weighed at the end of the run; and an accurate record is kept of the period the dispenser is operating.

3. FP SAMPLING EQUIPMENT - THE DRUM SAMPLER

Two views of the "drum sampler" as it is mounted on the airplane are shown if Fig. 2 and 3. The vacuum source and gas meter mounted inside the plane are shown in Fig. 4. A typical drum illuminated by ultra violet light and being examined through the 100-power microscope is shown in Fig. 5.

In Fig. 2 and 3 the mounting of the drum sampler (1) above the aero-meteorograph (3) in a special framework (2) may be seen. Both instruments are outside of the propellor slip stream. The heavy walled vacuum tubing (4) leaving the drum sampler is connected to the vacuum source in the plane. Two wires lead from the rotary solenoid (6) to the synchronous motor timer in the cabin of the aircraft.

Air is drawn through the hollow cone (5) Fig. 5; through a narrow horizontal slit to impinge on a grease coating on the outside face of the drum within the sampler. This drum is prepared by wrapping its perimeter with a single strip of aluminum foil 3/4" wide and coating it with a thin uniform film of viscous grease (Dow Corning Silicone High Vacuum Grease). The fluorescent particles are embedded in this grease by their inertia.

Air leaves the sampler through the rubber tubing; its volume measured by the gas meter (1) Fig. 4; its pressure by the vacuum gauge (2); and thence through the vane type vacuum pump (3), driven by a 24-volt battery-powered motor (4).

Isokinetic sampling is used, that is, the air is drawn through the entrance of the cone at the same speed as the plane is travelling through the air - 90 mph. There is no acceleration or deceleration of the air as it enters the cone so a truly representative concentration of FP material is obtained. The sampling rate is approximately 50 liters per min.

In sampling the air for FP material, the plane flew on arcs of circles of radius 2, 4, and 8 km. Samples were taken at elevations of 100, 200, 400, 600, and 800 ft above the lake level. Sampling periods of 15, 30, and 60 seconds were generally used for the 2, 4, and 8 km arcs respectively. This

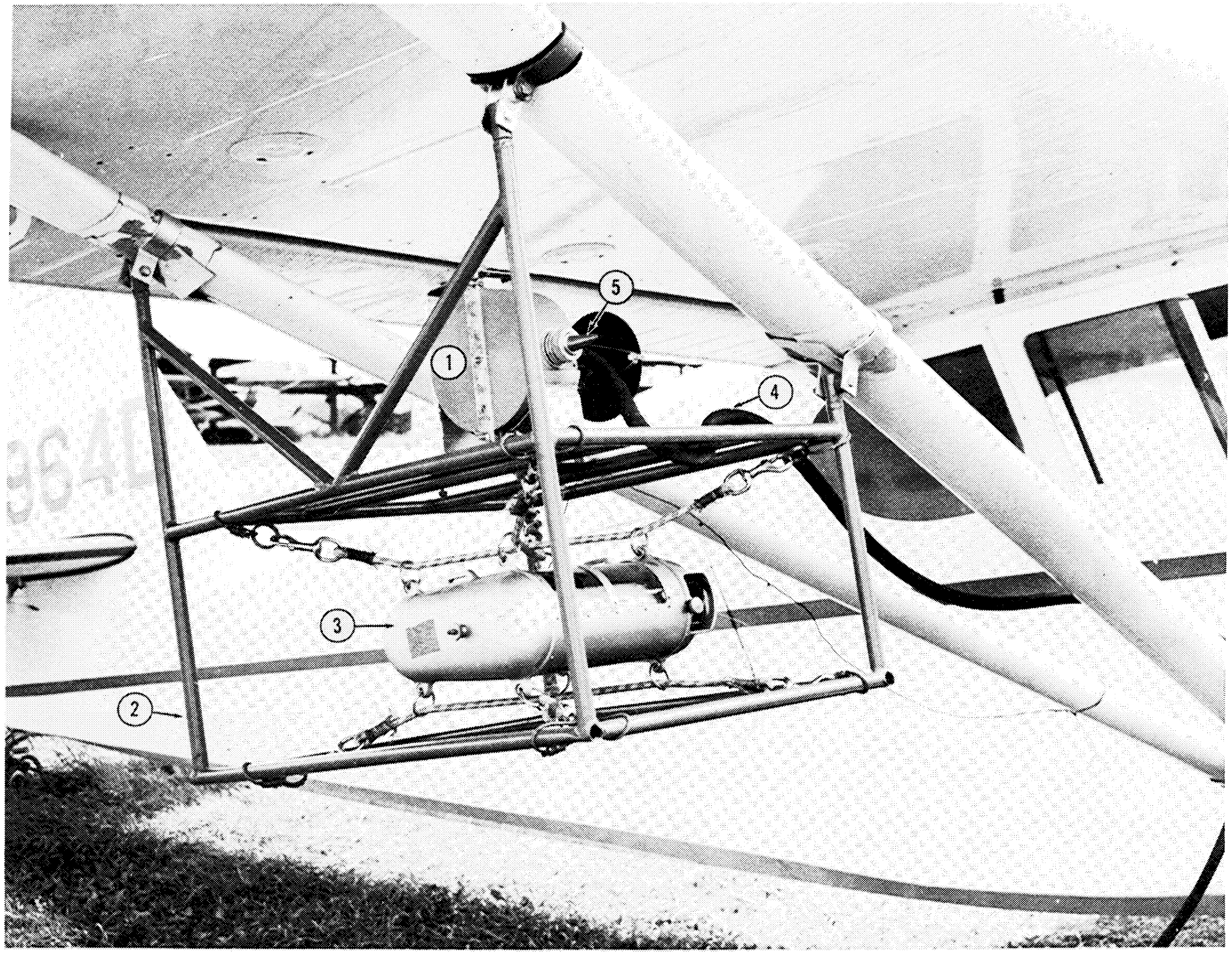

Fig. 2. Aerosol sampler and aerometeorograph mounted on wing of Stinson Flying Station Wagon: (1) sampler, (2) supporting frame, (3) aerometeorograph, (4) vacuum hose, (5) isokinetic cone.

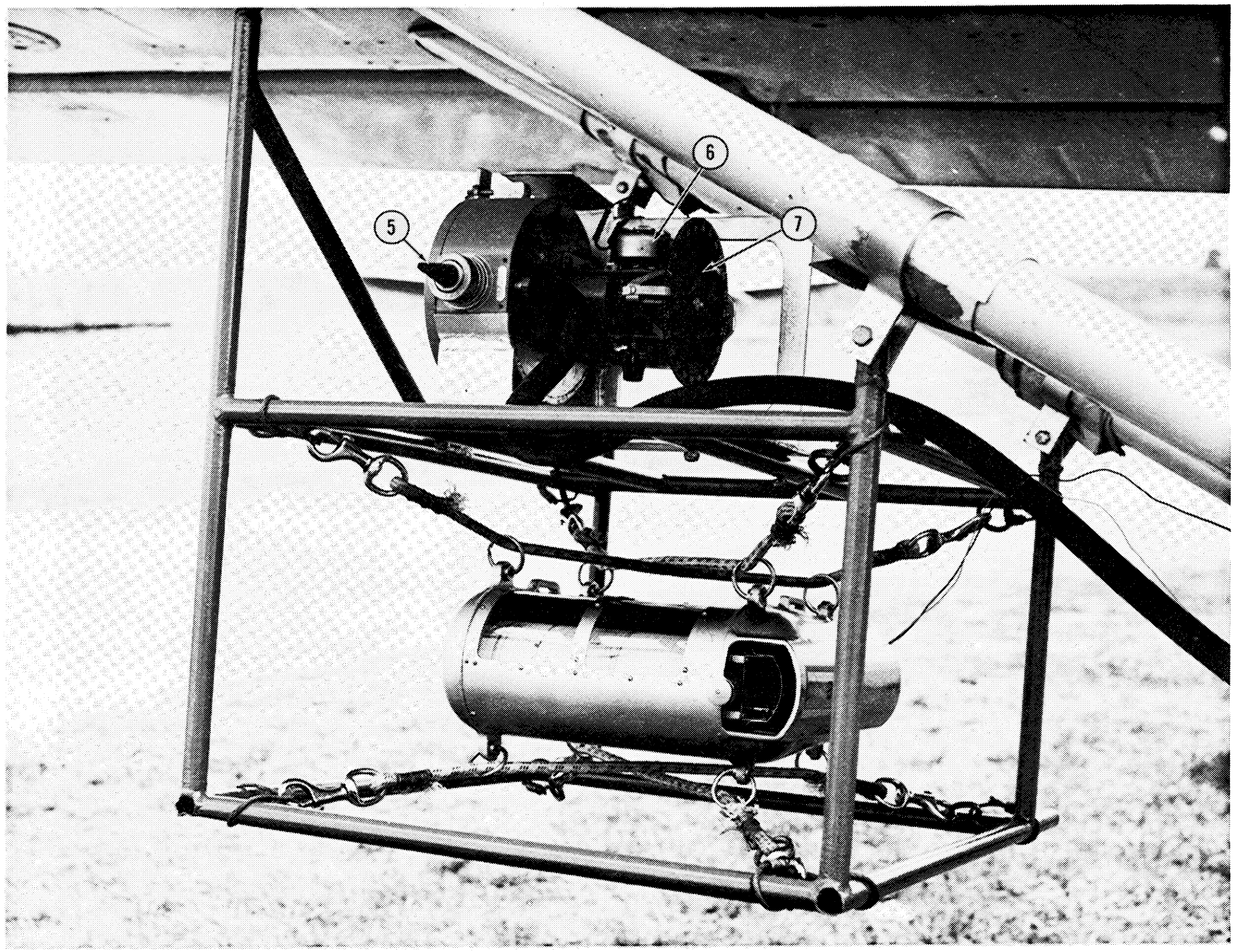

Fig. 3. Closeup of sampler and aerometeorograph: (5) isokinetic cone, (6) rotary solenoid, (7) dial plate corresponding to sample number.

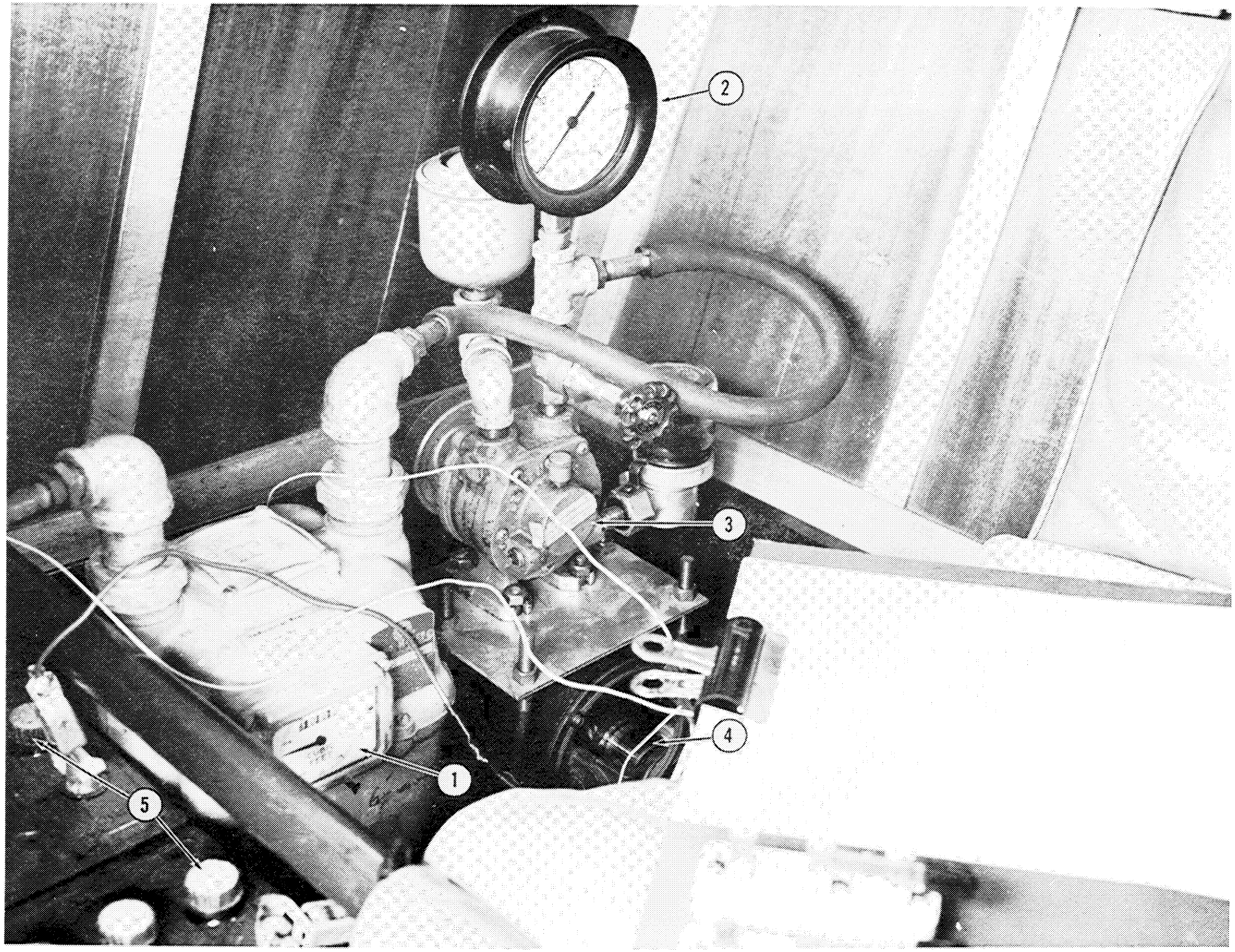

Fig. 4. Vacuum source mounted in rear of plane: (1) gas meter, (2) vacuum gage, (3) vacuum pump, (4) 24V DC motor, (5) two 12V storage batteries.

meant that each sample covered an arc of approximately 17°. Switching from sample to sample was done automatically by one of the three timer cams closing the electric circuit to the rotary solenoid (6) and instantly advancing the drum 3°. Thus for 360° rotation of the drum it is possible to take 120 samples. In practice one sample is lost whenever changing levels or changing arcs. Thus the number of useable samples is generally reduced to 90 - 100 per drum. This usually is adequate for about 3 hours of flying time -- which also is the fuel capacity of the airplane.

Two 12-volt, 70-ampere hour capacity lead storage batteries, (5) of Fig. 4, powered the 24-volt D.C. motor. Fully charged batteries would operate the vacuum pump under normal operating conditions of 16" Hg. vacuum for somewhat over two hours of continuous use -- adequate for most of our requirements.

4. COUNTING EQUIPMENT

As mentioned earlier the samples on the drum are examined through a 100 X microscope that is illuminated by a G. E. 100 watt, model BH-4 mercury arc lamp fitted with a filter. This equipment is shown installed in the airplane in Fig. 5, but in normal useage it is used in a photographic dark room well away from possible sources of FP material.

The microscope is equipped with a micrometer type carriage so that the microscope can be moved steadily, and at will, parallel to the axis of the exposed drum. Since 90 percent of the FP material is normally deposited on a strip 0.7 x 6.1 mm on the tape, it is normal practice to count the number of particles for a given test by a single transit of the microscope from one end of the sample to the other. All of the samples on a drum can usually be counted in 3 to 6 hr by the average technician.

The Atmospheric Physics Group at the Hanford Atomic Products Operation at Richland, Washington have developed a device which gives a count in specified time (say 30 sec) proportional to the mass of FP material deposited on a millipore filter. Since this unit costs nearly $2000, and since a relatively limited number of hours of counting would be needed for this complete project, the expense of purchasing such equipment has not been warranted.

Fig. 5. Fluorescent particle counting equipment: (1) 100 X microscope, (2) ultraviolet light (shielded), (3) sampler drum with greased aluminum foil coating being inspected.

V. TECHNICAL DETAILS OF ENRICO FERMI INSTALLATION

1. DISPENSING THE FLUORESCENT PARTICLE TRACER

In the event of an accidental leak of radioactive material from the nuclear reactor this leak would most likely occur at some height below the top of the reactor, that is, some height below an elevation of 70 ft. It was desired to release the tracer material at a corresponding height, and in the plant site area. Since all meteorological, radar and aircraft observations would be centered about the meteorological tower, and since wind and temperature measurements were being made at the 56 ft level on the tower, (4) of Fig. 6 it was decided to locate the FP dispenser approximately at this level on a suitable platform projecting from the tower (5) of Fig. 6.

Weighing out of FP material was carried out in the permanent heated Instrument Hut (not visible in photographs) located about 80 ft north of the tower. The FP material was dispensed at a uniform rate for periods up to 3 hours, starting at an appropriate time before the airplane sampling started and continuing to an appropriate time just prior to termination of sampling.

2. AIRCRAFT SAMPLING

A single engined high wing monoplane (Stinson Flying Station Wagon) is being used for the study. When throttled back it has a safe cruising speed of 90 mph, and this speed is maintained for the operation. Fuel capacity is such as to maintain the airplane in the air about 3 1/2 hours at this speed. This is adequate for normal needs.

A full description of the FP sampler and its associated equipment as they are installed in the airplane (Fig. 2, 3) are given in the preceding chapter.

For the main meteorological measurements (air temperature, pressure, relative humidity) to be made aloft, a Bendix Friez Aerometeorograph was installed in the frame below the drum sampler (3) of Fig. 2. The instrument is insulated from aircraft vibration by means of rubber shock cords (not exactly as shown in the photograph). Just prior to the ascent the clock is wound and the pens lowered on the chart drum to draw individual inked traces of temperature pressure and relative humidity versus time. The drum makes one revolution per two hours. A solenoid operated marking pen at the edge of the drum connects by duplex wire to the observer in the aircraft so that the time corresponding to the start of the 2 km sampling,

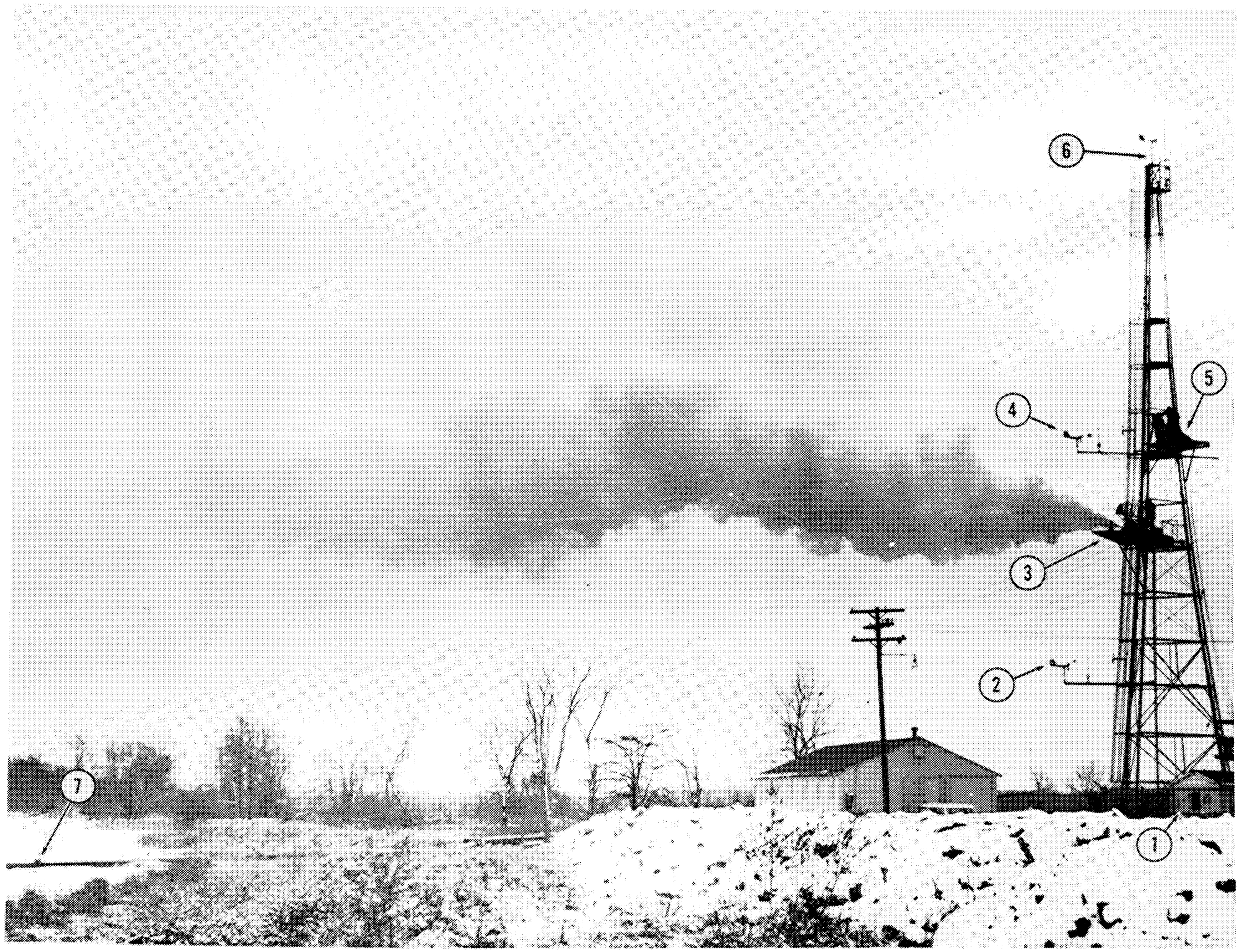

Fig. 6. View of meteorological installation looking south: (1) communications shack, (2) 25 ft aerovane and bivane, (3) oil-fog generator and radar antenna at 45 ft level, (4) 56 ft aerovane and bivane, (5) FP dispenser and theodolite, (6) 102 ft aerovane and radio antennae, (7) edge of Lake Erie.

or other times, may be marked on the drum and later correlated with the meteorological record.

In addition to the automatic aerometeorograph readings of meteorological conditions, the technician in the aircraft records air temperatures (mercury thermometer in the air stream); the altimeter reading (which may be converted to pressures); the plane's position (over land or over water); and the sky conditions.

3. OIL FOG GENERATOR

In order to provide a visible plume to assist the airplane technician as to when sampling should be started and stopped, an oil fog generator is used. At first it was intended to operate the generator for one half minute intervals every five minutes, that is, putting out a series of longitudinal "puffs." Under fair diffusion conditions this frequency and duration of "puffs" was entirely inadequate, so under such conditions the generator is operated for a one half minute period every two minutes.

The generator is classified as follows: "Mechanical Smoke Generator, Type M2, (50-gallon)." It is seen in operation in Fig. 6, and being serviced in (2) of Fig. 7. In operation, Atlantic Industrial oil No. 25, and water are forced through a coil heated to about 950°F.; are vaporized and ejected to the outside at a pressure of about 50 p.s.i., where the oil condenses into very fine fog droplets. The dense white cloud produced travels with the wind, and is dispersed by the eddies. Under poor diffusion conditions the oil fog may be followed for distances of 4 km or more.

Oil consumption is at a rate of 50 gallons per hr, and water at a rate of 5 gallons per hr.

4. RADAR TRACKING

For the guidance of the pilot and the meteorological observer a surface map of the Monroe area was prepared with circles drawn on it corresponding to distances of 2, 4, 8, and 16 km from the plant site. Radial lines at 10° intervals corresponding to the various azimuth positions from 0° to 360° were drawn. Thus over land the pilot could specify the location of each sample taken by listing the elevation above lake, the radius of arc, and the azimuth reading at the start and at the finish of each sample. Well out over the lake the pilot could advise his elevation as accurately as before but his reported distance from the plant site might be in error by ± 20 percent, and his azimuth position be in error by ± 10°.

In order to markedly improve the accuracy of where these samples were taken, especially over the water, and, in case of an accident to be able to

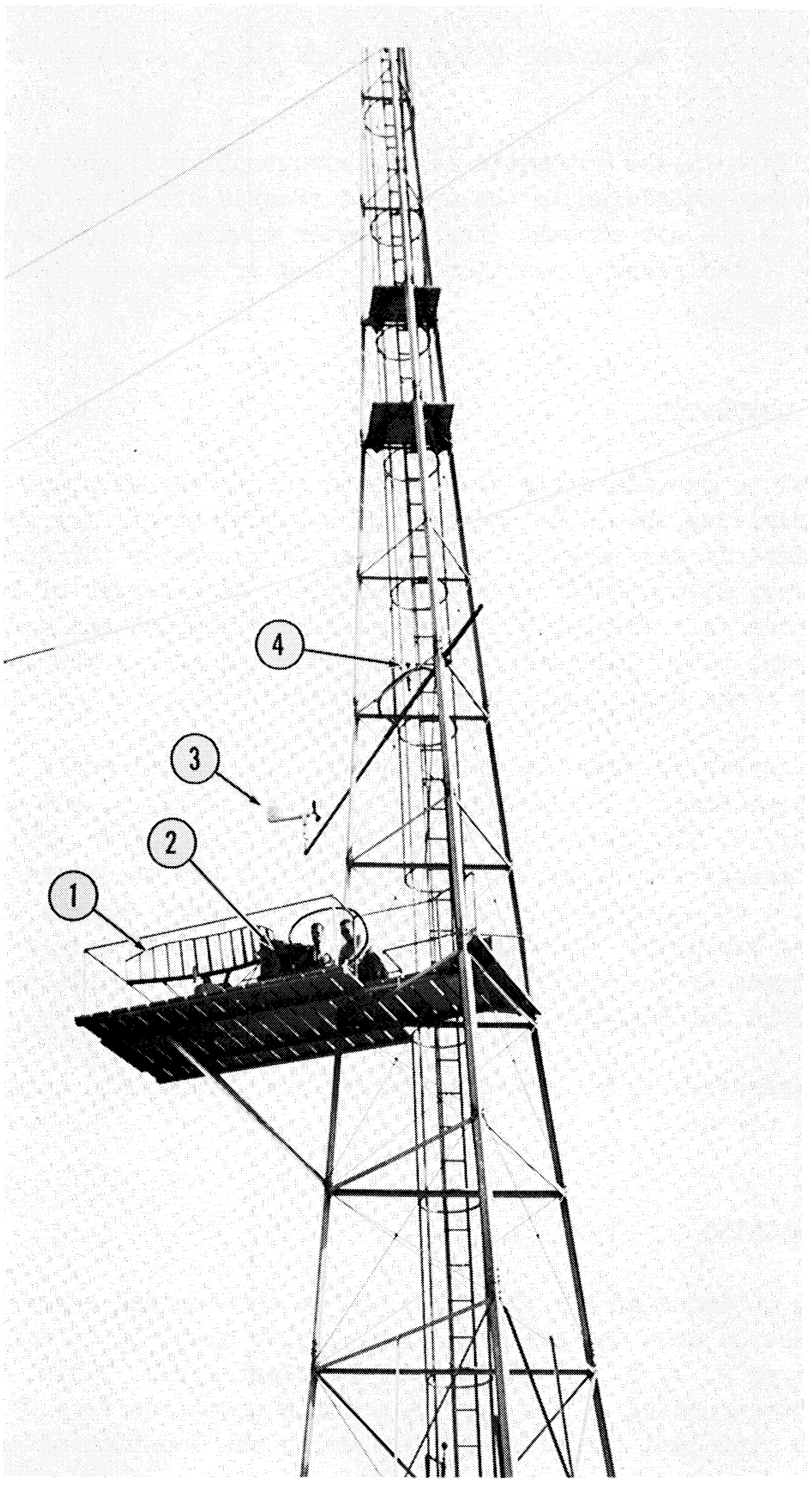

Fig. 7. View of central section of meteorological tower: (1) radar antenna, (2) oil-fog generator, (3) 56 ft aerovane, (4) 56 ft aspirated thermocouple unit.

provide rescue aircraft the exact position the airplane was last sited, it was decided to try to obtain a suitable radar unit either on loan or as a gift. The Department of Naval Architecture and Marine Engineering loaned the Department of Civil Engineering a radar set (Raytheon Mariners Pathfinder Junior) formerly used on a lake freighter. After some months of putting this equipment into good working condition, it proved to be incapable of following small fabric covered airplanes for more than 1 to 2 km. Through the courtesy of Mr. A. R. Wolfe of the Raytheon Company in Cleveland, the meteorologists were put in contact with the M. A. Hanna Company of Cleveland who were removing much later models of radar units from some of their lake freighters, one of which was well suited to our needs. Through the courtesy of Mr. Stewart Sexsmith, General Manager of this company the unit was given to The University of Michigan for research work. This unit was installed at the tower site, and its rotating antenna may be seen on the platform 45 ft above ground, (1) of Fig. 7. In Fig. 8 the radio-radar operator is seen viewing the radar screen and talking by telephone to the theodolite operator at the 56 ft level on the tower. This radar set has been very useful but, generally speaking, small aircraft cannot be followed for more than 10 km from the plant site. This has not been a serious limitation to date as we have not attempted FP sampling beyond the 8 km arc.

Brief specifications of this radar unit are as follows:

Mfr.: Raytheon Mfg. Co., Waltham, Massachusetts
Model: Mariners Pathfinder Radar, cat. No. CX1128, 3 cm - X band
Frequency: 9330 to 9420 Mc
Peak R. F. power output: 40 Kw
Range scales: 1, 2, 4, 8, 20, and 40 miles
Range accuracy: 1° or better.

5. THEODOLITE TRACKING

A theodolite (special transit) was mounted on a tripod at the 56 ft level on the tower. This permitted accurate visible reporting of the azimuth position of both sides of the smoke plume, and accurate tower reporting of the azimuth position of the airplane. Visual reports on the behavior of the smoke plume and on the general meteorological situation are made at this location and telephoned to the radar-radio operator in the radio hut below.

6. COMMUNICATIONS

a. Radio -- two-way. Communication between the tower site and the airplane is maintained at all times that the plane is flying. In this way good coordination is possible between the two locations and the observer in the airplane can be directed on the spot when to start sampling and when to cease.

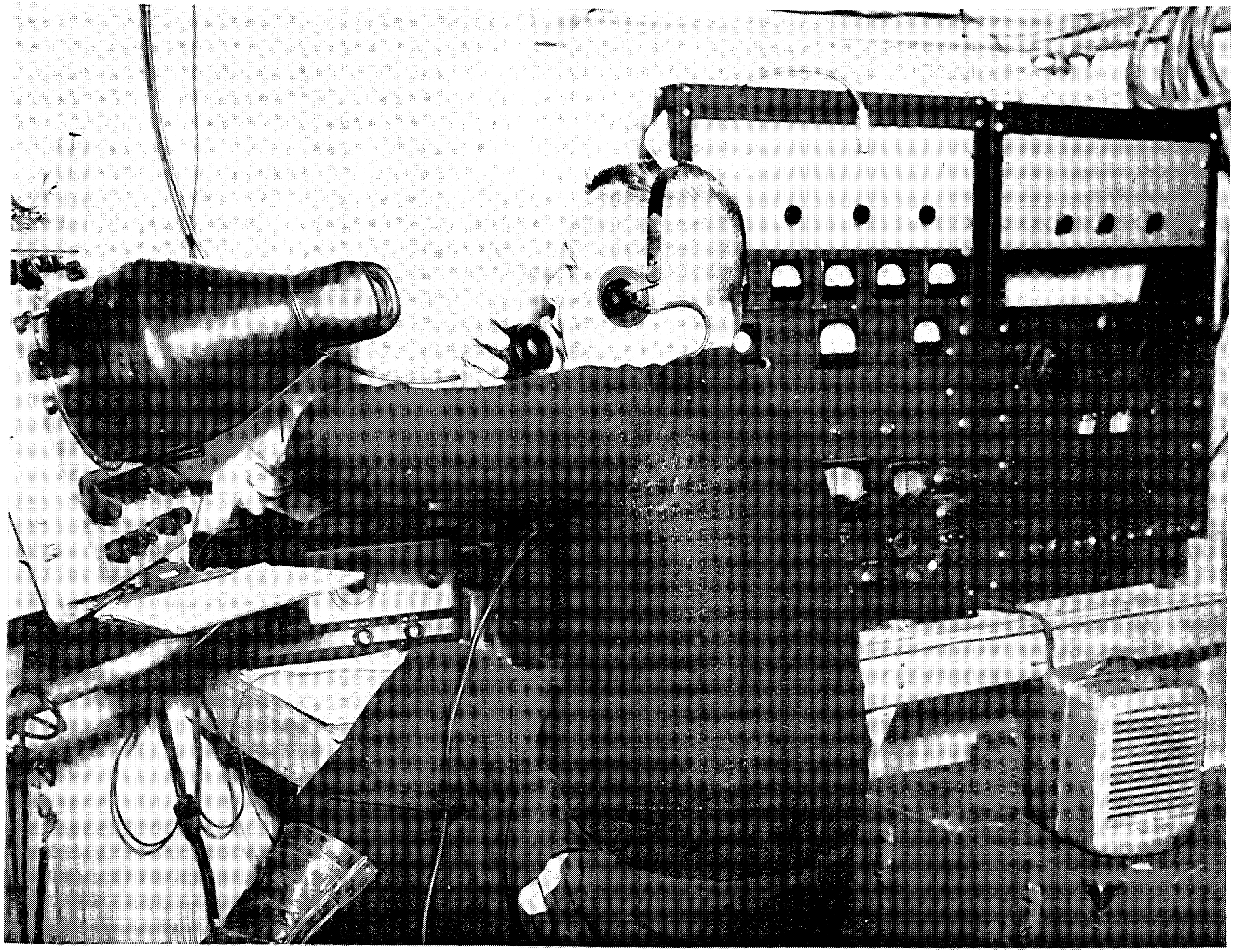

Fig. 8. View of communications center: radio transmitter and receiver on right, radar PPI scope on left, sound powered telephones on operator.

The tower based transmitter is an amateur band transmitter of 100 watt peak power which has been purchased by the project. The receiver being used is a Hallicrafters, Model S-106. Both of these units may be seen in the background of Fig. 8. In the aircraft a Gonset "Communicator III" transmitter-receiver is used. Both ground based and airborne transmitters are operated on 49.50 megacycles. Ground to air communication by these two units has been excellent.

b. Telephones -- sound powered. Telephones permit the theodolite operator to advise the radio-radar operator the instant the plane passes successive 10 degree azimuth positions; the times when sampling should start and should cease; the azimuth limits of the plume; and to report changing meteorological conditions or report any other pertinent information.

c. Tape recorder. With the rapidity with which samples are taken on the inner arcs and with the problems of two-way radio communication, it is practically impossible for either the radio radar operator or the technician in the aircraft to record as much data as he should. A tape recorder installed in the radio hut with the microphone near the radio-radar operator and adjacent to the ground receiver permits automatic recording of all conversations between ground and air, and between the radio-radar operator and the theodolite operator. Other pertinent information on the operation is similarly recorded, such as the time the FP dispenser is turned on; the time the wind shifts occurred; the cloud conditions; etc. The use of the tape recorder has been found to be more valuable than an extra man.

7. METEOROLOGICAL OBSERVATIONS AT PLANT SITE

a. Wind measurements

(i) Bendix Friez Aerovanes

Three Aerovane transmitters are located on the tower -- at heights of 24, 56, and 102 ft, ((2), (4), and (6) of Fig. 6). These transmit wind speed and wind direction measurements to corresponding recorders in the permanent instrument hut. Although these recorders normally record continuously at a chart speed of 3" per hr, during the diffusion experiments they are run at a chart speed of 3" per minute to permit detailed analysis of wind fluctuations. Through the use of these three instruments, data on the wind shear (change of speed and of direction with height) as well as the "n" factor in Sutton's diffusion equation may be obtained.

(ii) Gill All-Weather Bivanes

While two of the writers were at the MIT Round Hill Field Station, one of them developed the MIT bivane (10) (11). This bi-directional wind vane transmits elevation angle fluctuations of the wind as well as azimuth angle fluctuations. It is a fast response instrument with extremely little overshoot of the vane during rapid wind direction fluctuations. In the subsequent work at MIT (12) and in the diffusion study for the nuclear power plant for the Consolidated Edison Company near Peekskill on the Hudson River (13) these bivanes showed excellent correlation between wind direction fluctuations and the diffusion of tracer materials.

The MIT bivane was a fragile instrument useable only in light to medium winds during fair weather. To obtain detailed information on winds at the Enrico Fermi Plant during most kinds of weather Mr. Gill redesigned the instrument. Two of these instruments were constructed and one is shown in Fig. 9 (a) (b) (c).

The complete bivane, less recorder, is shown in Fig. 9 (a). Details of the head and of the base, with the rain shields removed are shown in the inserts (b) and (c). Azimuth angle fluctuations are transmitted by the vertical shaft through a pair of one-to-one gears to the precision potentiometer on the right of Fig. 9 (b). Elevation angle fluctuations are transmitted by the bead chain passing over the 1" diameter pulley in (c) to the pulley of the same diameter in (b) and thus to the second precision potentiometer. These two potentiometers transmit appropriate voltages to the twin channel recorder in the radio hut.

Owing to the very low ratio of mass to surface area for the vane section; the use of micro ball bearings; of low torque potentiometer and employing other design features, the instrument has exceptional dynamic characteristics. It will follow all gusts of wave length 20 ft or longer with an accuracy of 100 $\pm$ 5 percent, the error increasing to a peak of 30 percent for gusts of 15 ft in wave length. (For comparison, the aerovane resonates with gusts of 20 to 70 ft in wave length, with a peak error of over 150 percent for gusts of 40 ft in wave length.)

The two bivanes mounted adjacent to the two Aerovanes may be seen in Fig. 6. They have yielded very valuable data for the study and have satisfactorily withstood continuous exposure to all weather for over six months.

b. Vertical Temperature

In order to have a continuous record of the stability of the air at the

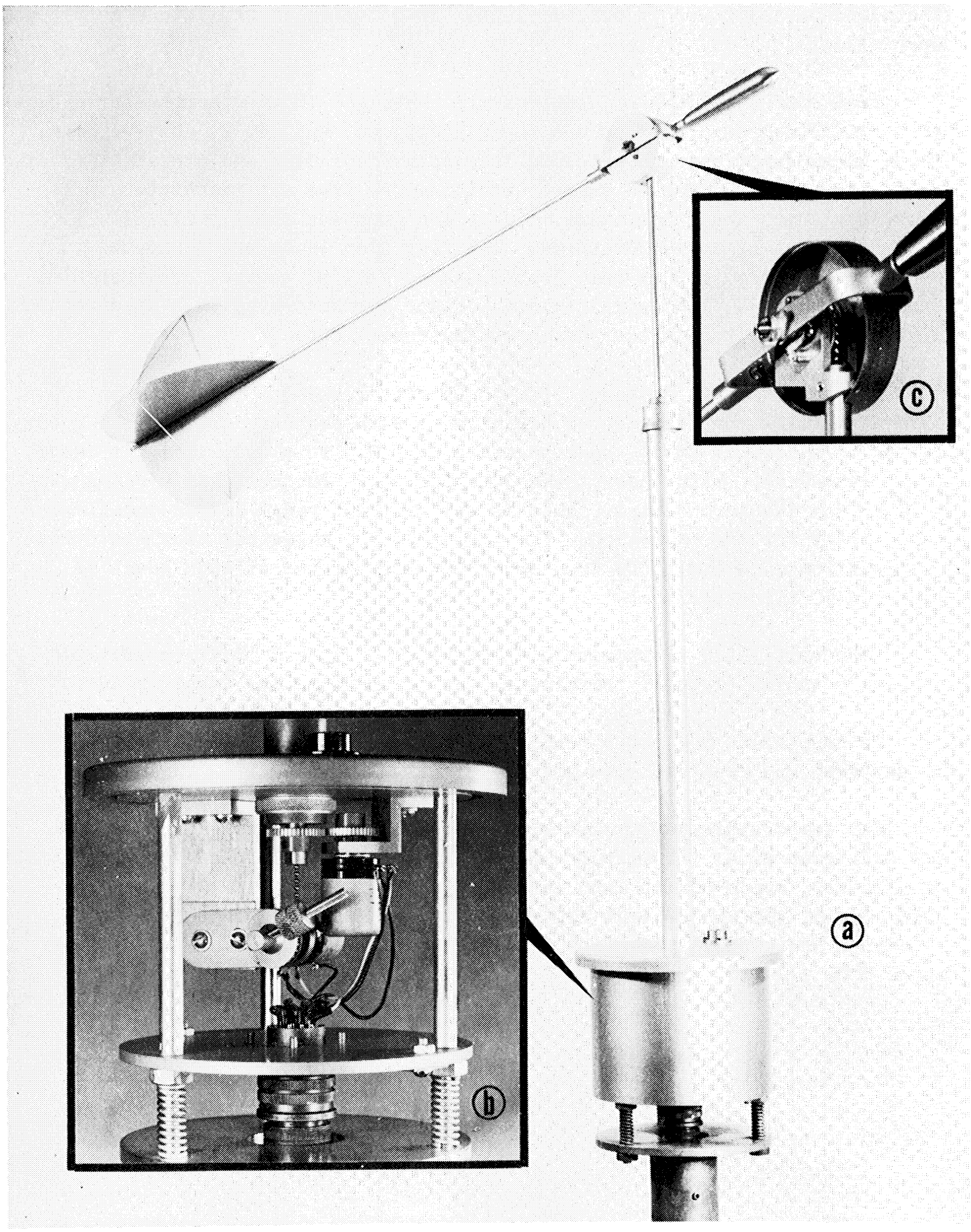

Fig. 9. (a) Gill all weather bivane, (b) enlargement of base showing potentiometer, rain shield removed, (c) enlargement of head with rain shield removed.

plant site, a thermocouple temperature difference measuring system was installed on the tower in October 1956. In has been in continuous service ever since.

Iron-constantan thermojunctions are installed in the thermometer shelter at 4 ft above ground; and on the tower at 25, 56, and 100 ft above ground. These thermojunctions are shielded from solar radiation and are artifically ventilated at all times to ensure obtaining the true air temperature. The four constantan leads terminate at a common junction about 3 ft below ground to avoid fluctuating temperatures. The four iron leads are connected to copper conductors in this same junction box, but, of course, are insulated from one another. The four insulated copper conductors go to a synchronously driven rotary switch in the permanent Instrument Hut.

The thermocouple voltages of 4 to 25 ft; or 4 to 56 ft; and 4 to 100 ft plus a shorting contact are fed one at a time in sequence through the rotary switch to a Bristol strip chart recorder of - 0.5 to + 0.5 millivolt range, (zero centered). With these thermojunctions this recorder has a range of ± 10°C from its zero center. This is an excellent range and an excellent sensitivity for the operation. The rotary switch makes one complete cycle of operation each 6 min, so the temperature difference at each level is recorded 10 times per hr.

(The ventilated thermocouple elements at 25 ft and 56 ft are visible in Fig. 6 to the right of the bivanes and adjacent to the tower ladder.)

To supplement the tower readings the lake water (or ice) temperature is observed and recorded once per day.

For temperature measurements above the tower during the periods of the diffusion study the airplane makes two temperature soundings at the start of each run, one over the land and one over the water. It makes similar soundings at the end of each run just prior to returning to the airport. Soundings are usually made from an elevation of 100 ft to an elevation of about 2000 ft above ground.

VI. EXPERIMENTAL RUNS

1. INTRODUCTION

Once the equipment had been placed on the tower and in the radio hut, several test runs were made using the airplane, radar, and radio equipment as well as the theodolites. It was thought necessary to make at least two such runs in order to familiarize the crew with their individual jobs and to properly test all the apparatus. Such preliminary testing was completed by mid-July of 1959.

2. EXPERIMENT OF 5 AUGUST 1959

a. Synoptic Situation -- At 0700 EST the surface weather map, Fig. 10 showed a weak wave with its peak located near Selingsgrove, Pennsylvania. The cold front from the wave ran southwestward through Elkins, West Virginia and then became diffuse near Charleston, West Virginia. The warm sector of the wave ran southeastward off the coast near Atlantic City, New Jersey.

Another small low pressure system was located near Quebec City, Quebec with a very weak cold front running westward to central Lake Superior.

Several other low pressure areas were located east of the Rockies, the major one being in north Central Manitoba. A cold front extended southwestward from this Manitoba low through Cody, Wyoming and then westward.

A very small high pressure area was located southeast of Charleston, South Carolina with a weak ridge extending northwestward as far as Covington, Kentucky.

The general synoptic pattern throughout the eastern United States was one of weak and diffuse frontal systems and a weak pressure gradient. Such conditions can be conducive to poor visibilities due to fog and haze. The 0700 EST surface map shows that situation throughout the central and northeastern United States.

b. Monroe Area Weather -- The Monroe area was under the influence of a weak northeasterly gradient as a result of both the Quebec and the Selingsgrove low pressure systems. As the lows moved eastward, the pressure gradient became weak enough for local effects such as the lake breeze to dominate the local weather pattern.

Figure 11 shows a copy of the hourly surface weather observations taken at the U. S. Naval Air Station located at Grosse Ile, Michigan. The map, Fig. 12 shows the location of Grosse Ile relative to the plant site. The air station as well as the plant site is influenced by a lake breeze under certain meteorological conditions. Thus, the observations from Grosse Ile may be viewed as an excellent indicator of the weather that occurred at the plant site.

Notice in Fig. 11 that at 0456 EST there was a light northerly wind with ground fog and smoke reducing the visibility to 1 1/2 miles. This condition persisted until after sunrise when the visibility began to improve, the wind speed to increase and the wind direction to change so as to be from the northeast. As the day went on the visibility increased to 10 miles with clear skies changing to scattered cloudiness. By 1057 the wind had veered to easterly and by 1256 it had become east-southeast. Thus Grosse Ile was beginning to feel the effects of the lake breeze. It is interesting to note that clouds began to form by 0958 indicating that the temperature lapse rate was changing from an inversion to a strong lapse rate condition. (This is verified by the tower data at the plant site.) When the lake breeze at the air station became fully developed as evidenced by the southerly wind at 1350, the temperature stopped rising and began to fall very slowly. At the same time, the dew point kept increasing, and thus indicating a rising atmospheric water content and increasing relative humidity.

c. Special Characteristics at Lagoona Beach -- Table I indicates that the wind direction at the plant site followed the same pattern as had been observed at Grosse Ile, although the wind speed was stronger at the plant site. This difference is easily explained since the aerovane at the air station is approximately 10 ft above the ground whereas the observations in Table I are from an aerovane at 102 ft above the ground. Although there were no official surface observations taken at the plant site while the experiment was being conducted, remarks were put into the field log book that verify the fact that the visibility and cloud cover at the plant site were indeed quite similar to what is shown in Fig. 11. There was so much low lying fog in the Monroe area and especially at the Custer Municipal Airport where the airplane used for sampling is based, that it was after 0900 before conditions were such as to permit the plane to fly under visual flight rules. Remarks in the log book indicate that at 0942 small cumulus clouds were noted forming to the northwest of the plant site. At 0958, Grosse Ile observed scattered cumulus at 3500 ft.

The inference has been made from looking at Fig. 11 that an inversion existed during the period around sunrise which had changed to a lapse condition by 1000 when clouds were noted in the Grosse Ile observations. Table I shows the lapse rates as measured at the plant site. Note the way in which the vertical temperature structure changed from inversion through weak lapse rate to a strong lapse rate. Another interesting and important fact to note is that the very strong lapse rate that existed by 1200 EST slowly changed into an inversion condition by 1600. Thus a condition of excellent diffusion became one of poor diffusion, at least at the plant site.

STATION U.S. NAVAL AIR STATION, GROSSE ILE, MICH. DATE AUG. 5, 1959

TYPE 1	TIME (LST) 2	SKY and CEILING (Hundreds of Feet) 3	VISIBILITY (Miles) 4	WEATHER and OBSTRUCTIONS TO VISION 5	SEA LEVEL PRESS. (mbs.) 6	TEMP (°F) 7	DEW PT. (°F) 8	WIND DIRECTION 9	WIND SPEED (knots) 10	WIND CHARACTER & SHIFTS 11	ALTIMETER SET. (ins.) 12	REMARKS AND SUPPLEMENTAL CODED DATA 13	14A	14B	OBSERVERS Initials 15
R	0058	○	3	GFK	138	68	66		C		995	312 81			STL
S1	0140	30⦶	2½	GFK		67	66		C		995	ACFT EMGCY			STL
R	0157	30⦶	2½	GFK	136	69	66	↘	3		995				STL
R	0357	○	2½	GFK	137	68	66	↓↘	3		995				STL
R	0358	30⦶	2½	GFK	135	68	66	↘	2		995	708 1500			STL
S2	0430	E30⦶	2	GFK				↓↘	4						STL
R	0456	E30⦶	1½	GFK	137	68	66	↓	5		995	BLDG CU SW			STL
R	0556	E35⦶/⦶	1½	GFK	140	68	66	↓	4		996				STL
RS3	0657	35⦶/⦶	1	GFK	143	70	66	↓	5		997	308 1501 67			STL
R	0759	35⦶	1½	GFK	146	72	66	↙	8		998				GWC
S4	0817	35⦶	4	GFK				↙	9						GWC
S5	0830	○	7					↙	8						[illegible]
R	0857	○	7		151	75	65	↙	7		999				GWC
R	0958	35⦶	10		155	76	66	↙	7		000	310 1500			GWC
R	1057	30⦶	10		157	80	66	←	8		001				GWC
R	1157	30⦶	7		156	80	66	←	7		000				GWC
R	1256	30⦶	7		153	81	65	←↖	6		000	808 1100 51			GWC
S6	1350	E30⦶	7					↑	9						GWC
R	1357	E30⦶	7		152	81	68	↑	11		999				GWC
S7	1435	35⦶	7					↑	10						GWC
R	1458	35⦶	7		149	80	69	↑	12		[illegible]				GWC
R	1558	40⦶/⦶	7		142	80	70	↑	10		996	810 1108			GWC
R	1658	40⦶/⦶	7		141	78	70	↑	10		996				LNB
R	1758	40⦶/⦶	7		141	78	69	↑	8		996				LNB
R	1858	40⦶/⦶	7		141	77	69	↑	7		996	608 1109 [illegible]			LNB
R	1957	150⦶	7		143	76	68	↑	4		997				LNB
R	2057	1⦶	10		146	75	68	↙	6		998				LNB
R	2156	1⦶	10		149	72	64	↙	9		999	308 1006			LNB

Fig. 11. Surface weather observations taken at U. S. Naval Air Station, Grosse Ile, Michigan on 5 August 1959.

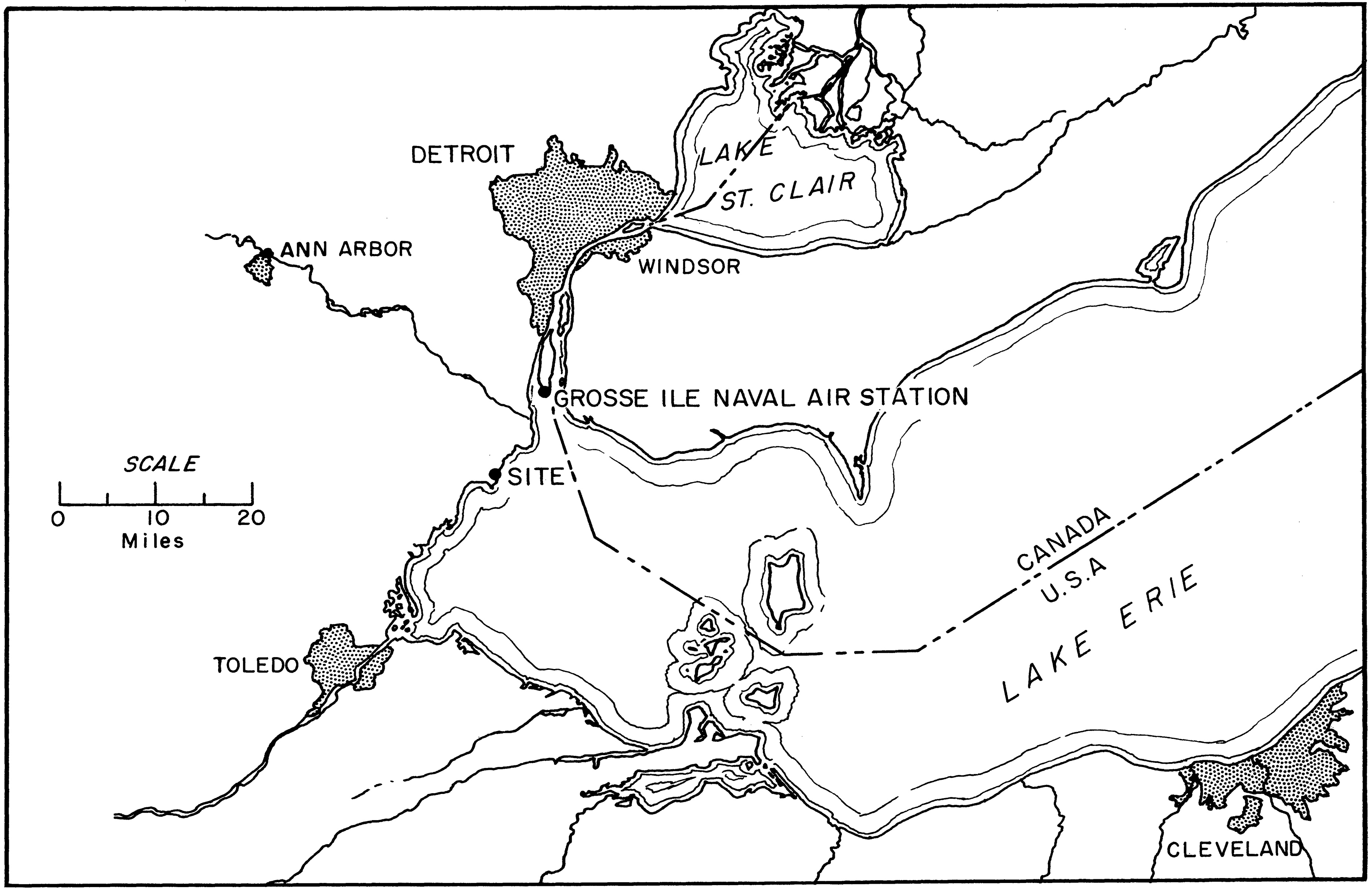

Fig. 12. Map of the local area in the vicinity of the Enrico Fermi plant site.

TABLE I.

HOURLY AVERAGE VALUES OF WIND DIRECTION, WIND SPEED, AND TEMPERATURE LAPSE RATE DATA FROM THE METEOROLOGICAL TOWER AT THE ENRICO FERMI SITE ON 5 AUGUST 1959

Hour Ending	Wind Direction	Wind Speed (mph)	Lapse Rate
0100	NW	9	I
0200	NW	10	I
0300	WNW	11	I
0400	NW	11	I
0500	NNW	9	I
0600	NNE	16	I
0700	NE	13	I
0800	NNE	10	W
0900	ENE	16	S
1000	ENE	15	S
1100	E	15	S
1200	E	15	S
1300	SSE	12	W
1400	SSE	10	W
1500	SSE	11	W
1600	SSE	13	I
1700	SE	11	I
1800	SSE	11	I
1900	SSE	11	W
2000	SSE	7	W
2100	S	5	I
2200	NE	18	I
2300	NE	20	S
2400	NE	16	S

The sampling was done between the hours of 0930 and 1100. Fig. 13 shows plots of the temperature distribution with height made by the airplane over both water and land at the beginning and ending of the sampling runs. These plots show that a strong lapse rate existed over both the water and the land.

d. Plume Characteristics -- Coincident with the plane sampling was the emission of an oil fog smoke from the tower. Between 1205 and 1255 an RF-84-F Thunderflash made several passes over the plant site photographing the smoke. Fig. 14 and 15 are some of the results of this run. It is evident in Fig. 14 that the wind is from the ESE and that a temperature lapse condition does exist. Fig. 15 shows the plume rising and diffusing as it travels to the WNW and away from the plant. Of course there is some effect of mechanical turbulence due to the smoke passing over the buildings, but even so, all the evidence points to the fact that diffusion was good at the time.

Approximately an hour and a half before the plane photographed the smoke plume, the theodolite operator at the plant site estimated the plume width as varying from 6°-15°. By the time the jet made its run, the convective activity was at a maximum. From Fig. 14 the plume width appears to be about 20° which is understandable since the vertical and horizontal mixing were at a peak.

e. Results of the Plane Sampling -- Fig. 16 gives the results of the samples as collected on the drum sampler. The numbers are the raw counts of the number of fluorescent particles that were collected. The counts are scattered somewhat so that the maximum count at all levels does not line up in the vertical, one exactly on top of the other. This is mainly due to lack of facility by the plane observer and the radio operator on the ground. At this time the only appropriate comment is that as far out radially as the plane went and as high as it went, a substantial number of particles were collected. This is a further indication that during the sampling period, diffusion was good, at least from a qualitative viewpoint.

f. Comments on the Diffusion Patterns -- Several points should be brought to light and emphasized at this time. The first and most important is that the diffusion was taking place at a fair rate when the sampling was done. The second is that this condition probably did not exist in the period immediately before and after sunrise due to the nocturnal inversion and probably did not exist by late afternoon due to the inversion caused by the lake breeze. Therefore, it is important to note that diffusion conditions can and do change rapidly at the plant site. Fortunately, these conditions may be forecast and they can be foretold by observation of the aerovane and temperature lapse rate records from the instrumentation located on the meteorological tower.

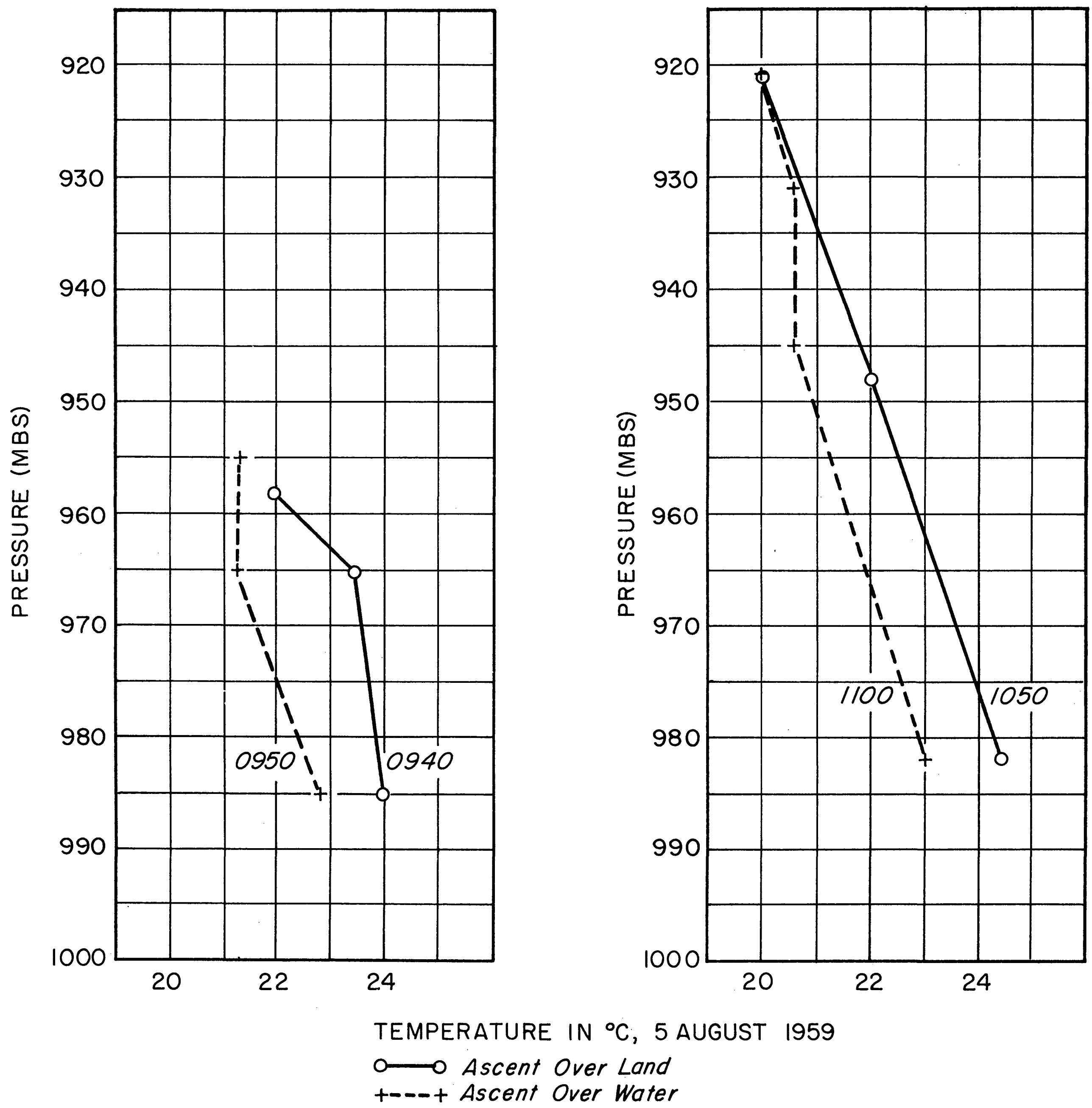

Fig. 13. Plots of the vertical temperature distribution as recorded by the aerometeorograph on 5 August 1959.

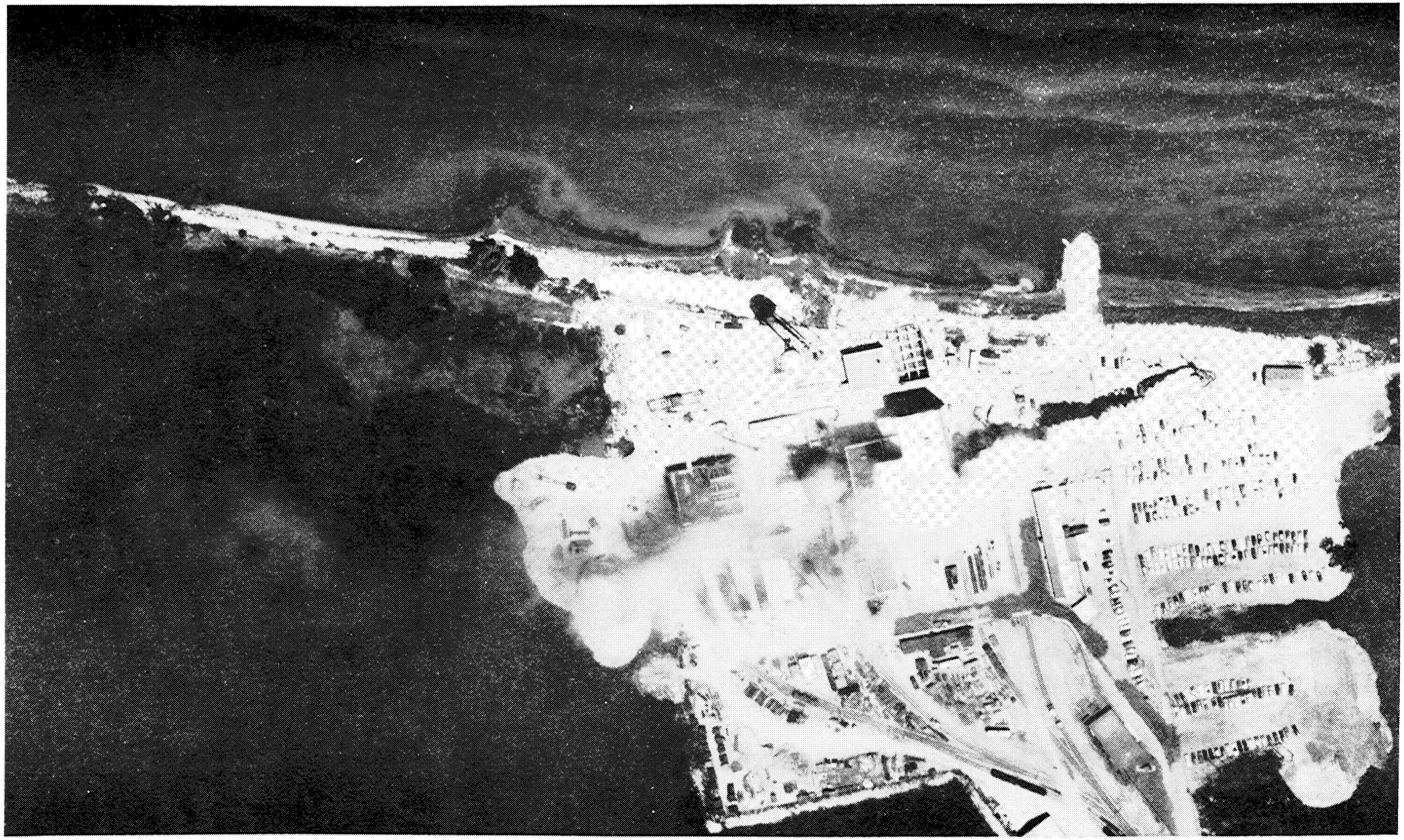

Fig. 14. Aerial view over the plant site showing the smoke plume coming from the ESE over the turbine building and diffusing upstream toward the WNW on 5 August 1959 at 1220 EST

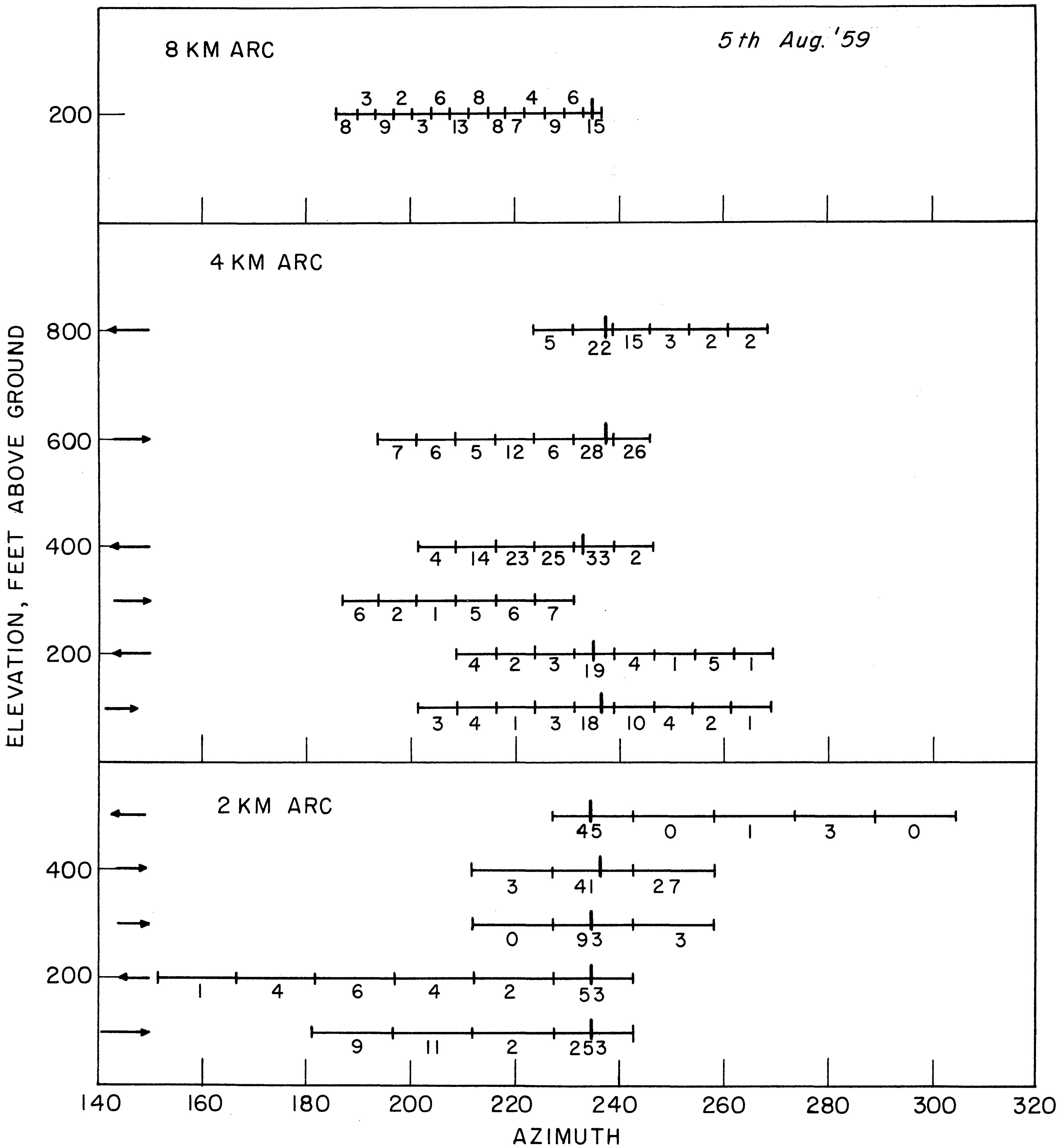

Fig. 16. Raw counts of FP material from 5 August 1959 plotted according to azimuth and height above the lake surface. Arrows on the left indicate direction of flight. Vertical dashes show the estimated centerline of the plane.

3. EXPERIMENT OF 6 AUGUST 1959

a. Synoptic Situation -- The low pressure center that had been centered near Selingsgrove, Pennsylvania 24 hours earlier had moved southeastward to a position about 300 miles east of Norfolk, Virginia by 0700 EST on 6 August. See Fig. 17. The Quebec low had filled and was no longer distinguishable on the map. The several low pressure areas that had been in the lee of the Rockies had not developed into any well defined system but rather a moderate cold front with unstable waves along it stretched from Hudson Bay southwestward through central Lake Superior to west central Kansas thence westward through southern Colorado.

A very weak high pressure area was centered over Parent, Quebec with a ridge extending as far southwestward as Knoxsville, Tennessee. Another small, weak high pressure cell was centered near Meridian, Mississippi. A large mass of cool air lay behind the cold front being centered near Regina, Saskatchewan.

Again the entire eastern United States lay in an area of extremely weak pressure gradient, a situation conducive to early morning fog and afternoon lake breezes.

b. Monroe Area Weather -- If the Monroe area could be characterized by saying that it was influenced by any one pressure system, then one must say that it was in the circulation from the Parent high. Fig. 18 shows the hourly surface observations from NAS, Grosse Ile. The pattern is quite similar to that of 5 August with two exceptions. The first is that the visibility never did improve above 6 miles because of haze and secondly there were high thin cirrus clouds throughout most of the morning and afternoon.

c. Special Characteristics at Lagoona Beach -- Since the observations at Grosse Ile tell the story of the local weather, there is no need to reiterate the conditions present during the experiment. Table II shows the hourly wind direction and speed measured by the 102 ft aerovane and the temperature lapse rate measurements. Again notice the fact that the nocturnal inversion broke up between 0700 and 0800 and a weak lapse rate was measured until 1500. Fig. 19 which shows the vertical temperature profile as measured by the aerometeorograph on the plane verifies this condition. The sounding over the land that began at 0804 showed a low level inversion, then strong lapse rate to 975 mbs above which was an inversion to 955 mbs and finally a weak lapse above to 924 mbs. The sounding over the water was essentially isothermal. By 1215 both soundings showed lapse conditions.

The lake breeze effect was felt both at Grosse Ile, as evidenced by southerly and south southeasterly winds, and at the plant site evidenced by the SSE winds and the inversion which began by 1500 EST.

The sampling took place between 0813 and 0930 and between 1115 and

STATION U.S. NAVAL AIR STATION, GROSSE ILE, MICH. DATE AUG. 6, 1959

TYPE 1	TIME (LST) 2	SKY and CEILING (Hundreds of Feet) 3	VISIBILITY (Miles) 4	WEATHER and OBSTRUCTIONS TO VISION 5	SEA LEVEL PRESS. (mbs.) 6	TEMP. (°F) 7	DEW PT. (°F) 8	WIND DIRECTION 9	WIND SPEED (knots) 10	WIND CHARACTER & SHIFTS 11	ALTIMETER SET. (ins.) 12	REMARKS AND SUPPLEMENTAL CODED DATA 13	14A	14B	OBSERVERS Initials 15
R	0556	120 ①	3	GF	158	65	62	↓	2		001	FEW Cu W			LNB
R	0657	50 ①	3	GF	159	65	63	↘	2		001	108 1100 63			LNB
RS1	0756	50 ①	5	H	157	71	64	← ↙	4		001				LNB
R	0857	O	5	H	155	74	67	↙	5		000				LNB
R	0958	1-⑪	6	H	152	78	65	← ↖	3		000	705 1006			ENB
R	1056	1-⑪	6	H	155	79	65	↙	7		000				STL
R	1159	1-⑪	6	H	149	81	65	← ↙	8		999				GWC
R	1257	1-⑪	6	H	145	81	64	← ↙	7		998	807 1006 63			GWC
R	1357	1-⑪	6	H	143	80	67	↑ ↖	10		997	FEW Cu E			LNB
R	1456	50① 1-⑪	6	H	140	80	68	↑	10		996				STL
R	1559	50① 1-⑪	6	H	137	90	68	↑	10		995	810 1106			STL
R	1658	50①	6	H	136	79	67	↑	11		995				ONG
R	1758	O	5	H	133	78	69	↑ ↖	10		994				ONG
R	1859	O	5	H	134	76	67	↑ ↖	8		994	703 1009 82			ONG
R	1959	1①	5	H	135	74	67	← ↖	7		994				ONG
R	2058	1①	5	H	138	73	68	← ↖	6		995				ONG
R	2158	O	5	H	137	72	67	← ↖	5		995	105			ONG

Fig. 18. Surface weather observations taken at U. S. Naval Air Station, Grosse Ile, Michigan on 6 August 1959.

TABLE II.

HOURLY AVERAGE VALUES OF WIND DIRECTION, WIND SPEED, AND TEMPERATURE LAPSE RATE DATA FROM THE METEOROLOGICAL TOWER AT THE ENRICO FERMI SITE ON 6 AUGUST 1959

Hour Ending	Wind Direction	Wind Speed (mph)	Lapse Rate
0100	NE	11	W
0200	NE	12	W
0300	NNE	10	I
0400	NNE	8	I
0500	NNE	8	I
0600	N	8	I
0700	NNE	7	I
0800	NE	8	W
0900	ENE	11	W
1000	ENE	6	W
1100	ENE	7	W
1200	ESE	6	W
1300	SSE	msg	W
1400	S	3	W
1500	S	5	I
1600	SSE	5	I
1700	SSE	5	I
1800	SSE	7	I
1900	SSE	8	W
2000	S	10	S
2100	SSW	12	S
2200	ESE	14	S
2300	SE	15	S
2400	SE	15	S

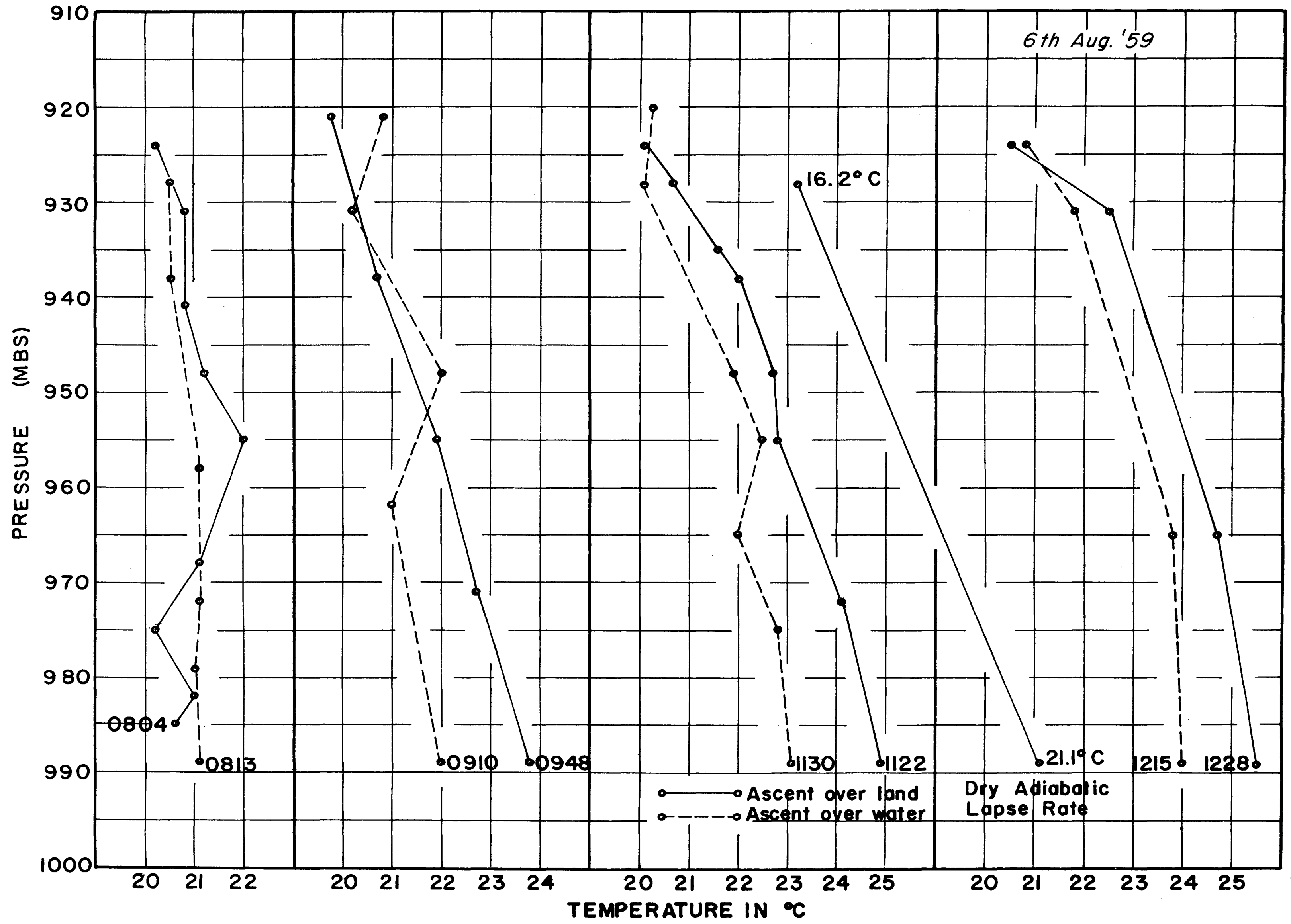

Fig. 19. Plots of the vertical temperature distribution as recorded by the aerometeorograph on 6 August 1959.

1228. Two separate runs were made mainly because the wind direction changed from ENE to ESE resulting in two different diffusion patterns. Table II indicates that the lapse rate at the tower was weak so diffusion would not be as rapid as on the previous day.

d. Plume Characteristics -- No aerial photographs were taken during these runs but a theodolite followed the smoke plume. During the first run the plume width averaged 15-20° with a range of from 10 to 35°. The average direction of the plume was toward 240°. On the second run the plume width averaged 19° while the average direction was towards 315°.

e. Results of the Plane Sampling -- Fig. 20 and 21 show the raw counts as gathered by the airplane sampler. Fig. 20 shows the meander of the plume as the plane went out further from the plant site. For example at the 200 ft level, the centerline of the plume at 2 km was estimated to be at 235°. At 4 km the centerline was at 266° while at 8 km it was estimated to be at 247°. There was probably a difference of one hour in time between the sampling at 2 km and at 8 km. Thus in such a period of time the plume does meander back and forth.

Run No. 2, Fig. 21 indicates that the wind direction had shifted to a wind from the SE. The 2 km data indicate that there was some basic locational error when the data were collected because all flights from N through W to S have the centerlines lined up fairly well, while those from S through W to N have their centerlines further south. This difference of approximately 40° could be caused by a wind factor on the plane or observational error. Such errors can not be entirely eliminated but they can be held constant by having all sampling done from right to left as the plane is viewed from the plant site so the pilot can better see the ground and, if there is an error due to wind, it will be the same at all sampling levels.

FP material was collected wherever samples were taken indicating that the system was operating properly.

f. Comments on the Diffusion Patterns -- As indicated above the diffusion probably was not as rapid on the 6th of August as it had been on the 5th. Later analysis will better indicate the veracity of such a statement. Again, poor diffusion conditions changed into fair and then back again to poor all in the same day. Such a situation must be watched if an emission is contemplated on such a day.

4. EXPERIMENT OF 27 NOVEMBER 1959

a. Synoptic Situation -- At 0700 the surface map had a small, weakening wave whose peak was located over Erie, Pennsylvania. See Fig. 22. The warm front of this wave ran eastward off the coast just north of Long Island. The cold front lay in a long narrow trough that ran south-southwestward through

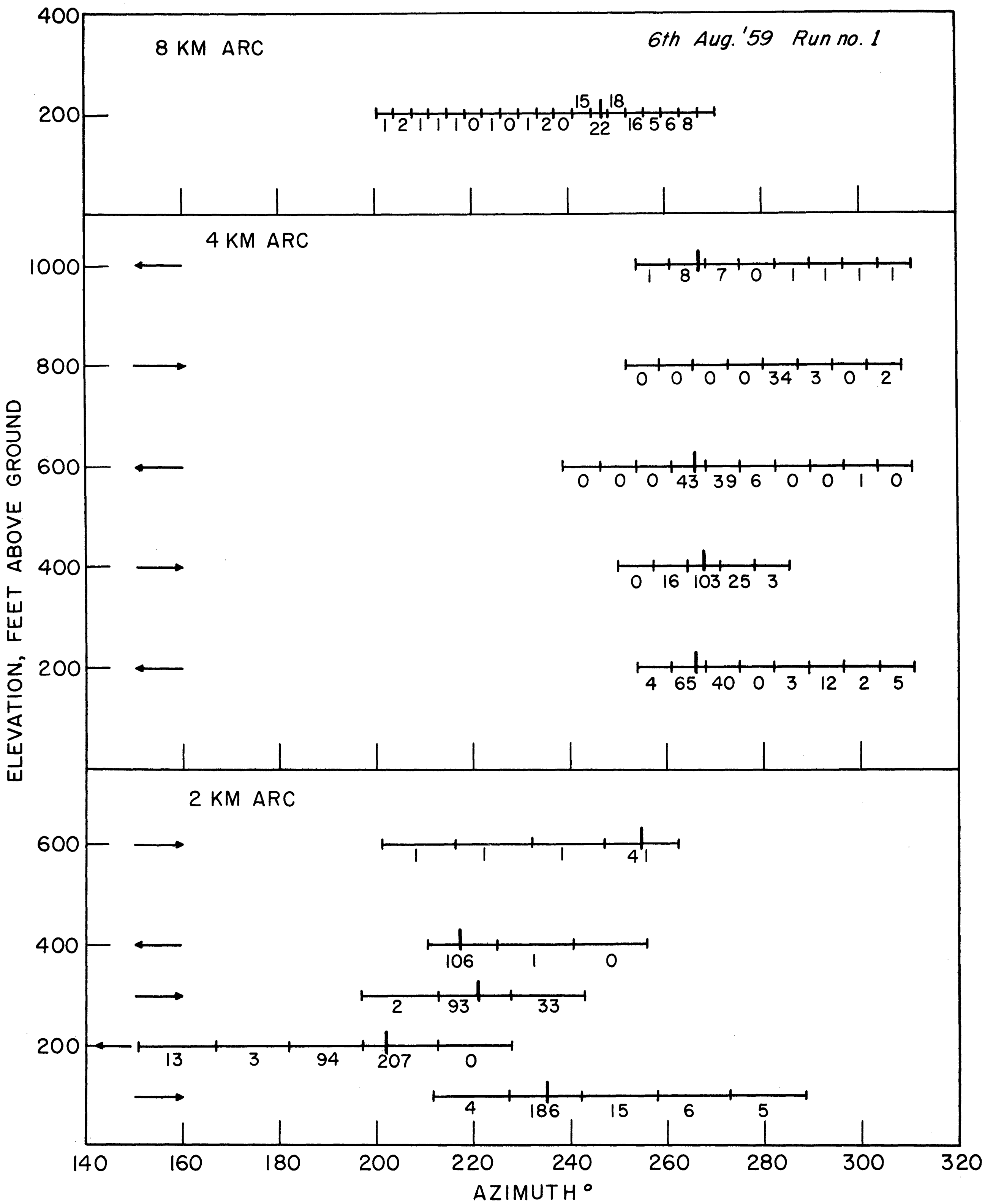

Fig. 20. Raw counts of FP material from Run No. 1. of 6 August 1959 plotted according to azimuth and height above the lake surface. Arrows on the left indicate direction of flight. Vertical dashes show the estimated centerline of the plume.

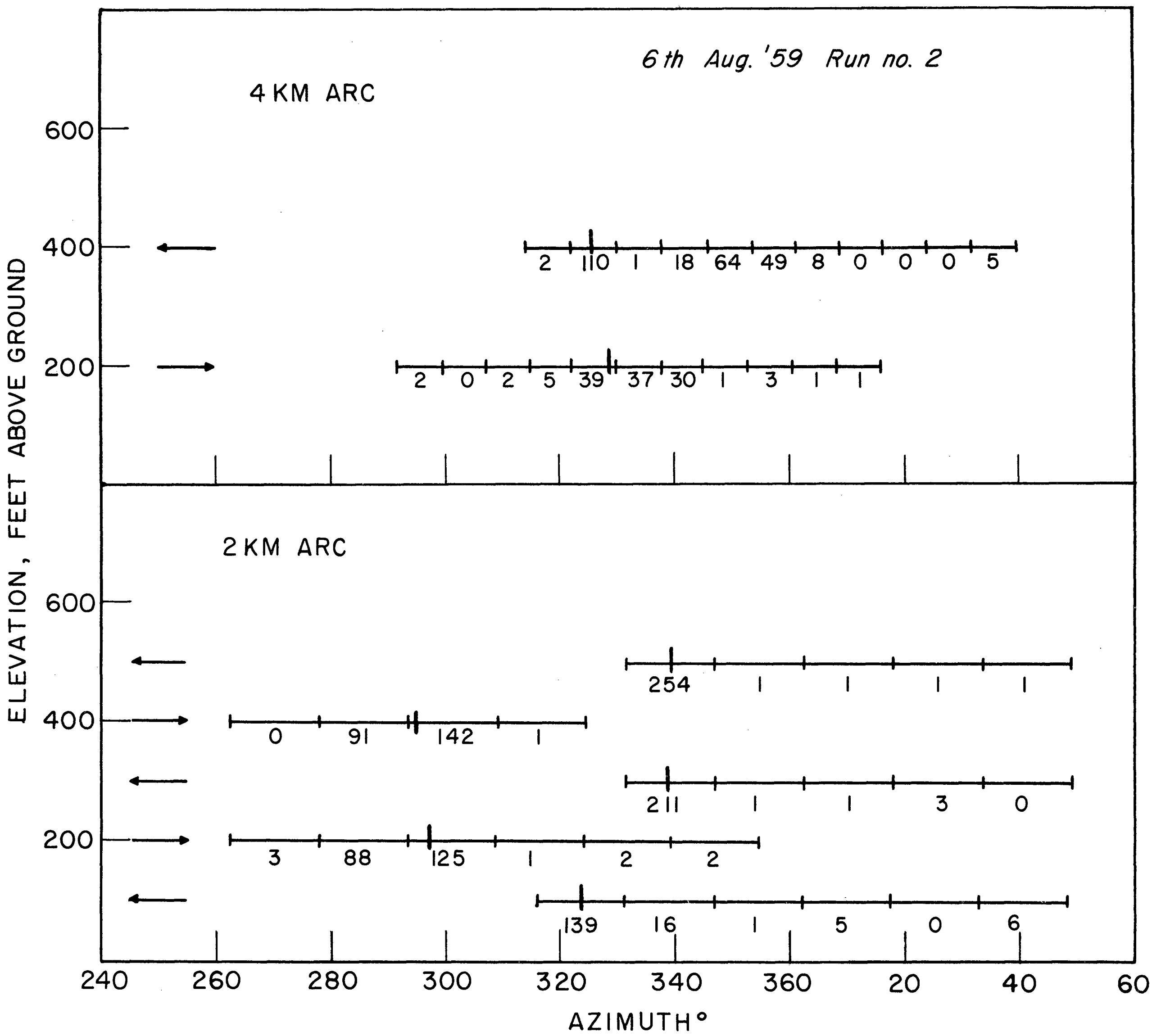

Fig. 21. Raw counts of FP material from Run No. 2. of 6 August 1959 plotted according to azimuth and height above the lake surface. Arrows on the left indicate direction of flight. Vertical dashes show the estimated centerline of the plume.

New Orleans, Louisiana and into the Gulf of Mexico. A small wave on the cold front was located north of Crossville, Tennessee.

The western United States was covered by a large ridge of high pressure with two main centers. The southern high center was located at Hobbs, Texas while the northern one was in east central Idaho.

A small insignificant low was centered near Kansas City, Missouri but was of no particular importance.

With a low center west of the Appalachians and a circulation as shown in the Ohio Valley and Great Lakes regions, that entire area had intermittent snow showers and a low, broken to overcast ceiling from 2500 to 3500 ft high. The cold air that was moving over the warmer ground caused the lapse rate to be quite strong. Such was the case on 27 November 1959.

b. Monroe Area Weather -- Monroe, of course, fell into the area and the general weather pattern described above. Fig. 23 is the hourly surface observational sheet from Grosse Ile NAS. At 0559 there were clouds at 700 ft and an overcast at 1200 ft with light snow showers taking place. The snow showers continued for several hours and then the overcast began to rise. By 1359 the lower overcast had broken, showing a high overcast layer above 20,000 ft. This condition persisted throughout the afternoon hours. All the time the wind was northerly to north-northeasterly at 3 to 6 mph. Visibility was reduced to 4 miles in mid day by haze.

With snow showers and the fact that the cold air was passing over warmer land and water, it would be supposed that the lapse rate would be strong. It is interesting to note that the air temperatures were near freezing during the day, reaching a maximum of 34°F while Lake Erie's temperature was in the neighborhood of 44°F. Thus a strong lapse rate certainly did exist.

c. Special Characteristics at Lagoona Beach -- Table III presents the hourly average values of wind direction and speed and the average value of the temperature lapse rate during the day. The wind direction patterns at Grosse Ile and the site were the same except again the 102 ft aerovane on the meteorological tower gave a slightly higher reading than the 10 ft one at NAS Grosse Ile.

As had been suspected above, the lapse rate was strong throughout the daylight hours except at 1400 when it was observed as being weak. The vertical temperature measurements made with the aerometeorograph also verify this lapse condition. See Fig. 24 where both the over water and over land trajectories were lapse conditions. Sampling was done between 1200 and 1400 when the lapse rate was strong so diffusion should be good.

d. Plume Characteristics -- No aerial photographs were taken during

STATION U.S. NAVAL AIR STATION, GROSSE ILE, MICH. DATE 27 NOV 1959

TYPE 1	TIME (LST) 2	SKY and CEILING (Hundreds of Feet) 3	VISIBILITY (Miles) 4	WEATHER and OBSTRUCTIONS TO VISION 5	SEA LEVEL PRESS. (mbs.) 6	TEMP. (°F) 7	DEW PT. (°F) 8	WIND DIRECTION 9	WIND SPEED (knots) 10	WIND CHARACTER & SHIFTS 11	ALTIMETER SET. (ins.) 12	REMARKS AND SUPPLEMENTAL CODED DATA 13	14A	14B	OBSERVERS Initials 15
R	0559	E 7①/12⊕	5	SW-	182	30	28	↓	6		002				STL
RS1	0658	E 16⊕	6	SW--	187	30	27	↓↘	4		004	31015 15XX 90203 90403			STL
R	0757	E 18⊕	7	SW--	193	29	27	↓↘	6		006				EPC
RS2	0859	E 23⊕	7		199	29	28	↓↘	5		008	SE10			STL
RS3	0958	E 25⊕	4	H	209	30	28	↓↘	3		010	320 15XX			EPC
R	1056	E 25①40⊕	4	H	213	31	28	↓↘	4		011				STL
R	1159	E 40⊕	4	H	212	32	28	↘	5		011	THN SPOTS INOVC OVHD			STL
RS4	1258	E 45⊕	6	H	215	33	27	↓↘	4		012	10700 15XX 29			STL
RS5	1359	E 70①/⊕	6	H	216	33	27	↘	5		013				STL
R	1458	E 70①/⊕	8		218	34	27	→↘	3		013				EPC
R	1559	70①/⊕	10		223	33	27	→↘	4		014	308 1077			EPC
R	1659	70①150①/①	10		230	33	28	→↘	5		017				LNB
R	1759	150①/⊕	10		233	33	26	↓	4		017				LNB
S6	1830	E 70①/⊕	10					↓	3						LNB
R	1858	E 70①/⊕	10		235	33	26	↓	1		018	11076 1076 34			LNB
R	1957	E 65⊕	10		234	31	27		C		018				LNB
R	2059	E 65⊕	10		227	31	25	↓	5		016				LNB
R	2158	E 65①/⊕	10		221	31	25	↓	5		014	814 1506			LNB

Fig. 23. Surface weather observations taken at U. S. Naval Air Station, Grosse Ile, Michigan on 27 November 1959.

TABLE III

HOURLY AVERAGE VALUES OF WIND DIRECTION, WIND SPEED, AND TEMPERATURE LAPSE RATE DATA FROM THE METEOROLOGICAL TOWER AT THE ENRICO FERMI SITE ON 27 NOVEMBER 1959

Hour Ending	Wind Direction	Wind Speed (mph)	Lapse Rate
0100	NE	14	S
0200	NE	13	S
0300	NNE	10	S
0400	N	7	S
0500	N	4	S
0600	N	4	S
0700	NNW	9	S
0800	NNW	11	S
0900	NW	11	S
1000	NNW	6	S
1100	msg	msg	S
1200	msg	msg	S
1300	NW	8	S
1400	NW	8	W
1500	NW	6	S
1600	NW	6	S
1700	NW	6	S
1800	NW	6	S
1900	NNW	6	W
2000	NNW	6	W
2100	NNW	6	W
2200	NNW	9	W
2300	NNW	7	W
2400	NNW	11	S

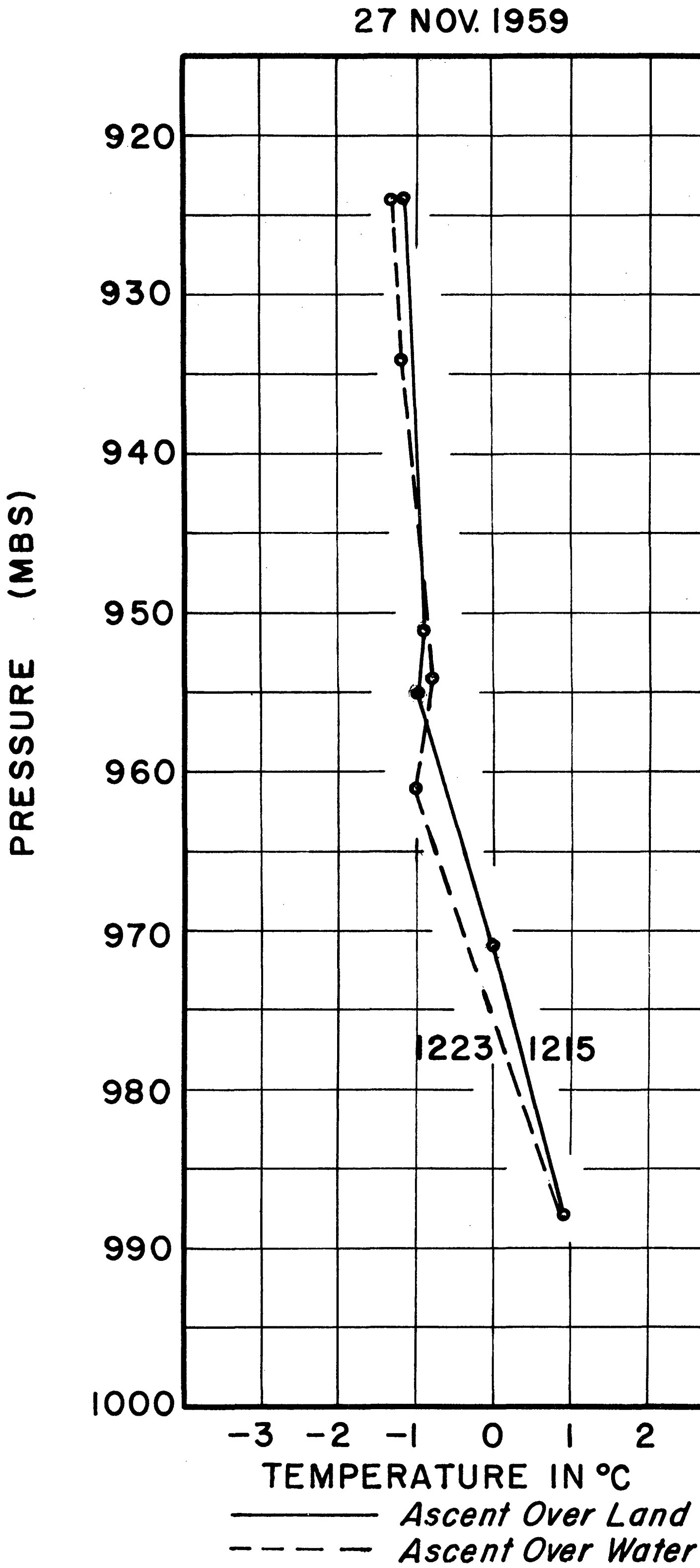

Fig. 24. Plot of the vertical temperature distribution as recorded by the aerometeorograph on 27 November 1959.

this series of tests because of the low ceilings and snow showers, both of which are not conducive to aerial reconnaissance by jet aircraft. A theodolite was set up on the 56 ft level of the tower and used to locate the plane. Unfortunately with a white airplane against a hazy, cloudy sky and with puffs of oil-fog dispersed between the tower and the plane, the theodolite operator could not track the plane too well. However, the comments from the tape recorder indicate that the plume left the 56 ft level of the tower and then went out over the lake, often times lowering down to the lake surface. With the strong lapse rate conditions that existed, it was not long until the plume of oil-fog was well dispersed. The plume width was about 25° wide and moved away from the tower toward the direction of 110°.

e. Results of Plane Sampling -- Fig. 25 shows the raw counts of the FP material as gathered by the sampler on the plane. In this experiment the direction of flight was always from right to left as you view the plane from the tower. Thus any wind error on the plane was held constant. Even so, the maximum concentrations do not align themselves vertically in a straight line. This of course would indicate that there was a great deal of horizontal diffusion taking place. Vertical diffusion looks good too, since there were moderate counts at 600 and 800 ft on the 2 and 4 km arcs.

f. Comments on the Diffusion Patterns -- Certainly diffusion on this day was good. The only possibility of difficulty that might arise would be when a snow shower comes along. Such a snow shower could possibly washout some contaminants that might be in the air.

5. EXPERIMENT OF 28 NOVEMBER 1959

a. Synoptic Situation -- The wave that had been centered near Erie, 24 hours previously, was now centered over Glen Falls, New York at 0700 EST. Fig. 26 shows that the warm front from this wave ran eastward through Lebanon, New Hampshire, then northeastward generally following the coast line. The cold front lay through eastern Pennsylvania, central Virginia, South Carolina, east of Jacksonville, Florida, and finally across central Florida and into the Gulf of Mexico north of Fort Meyers, Florida.

The central and most of the western United States was dominated by a large ridge of high pressure emanating from a center near Brownsville, Texas. This ridge extended as far north as southern Hudson Bay.

Again, then, most of the eastern United States was in northerly to northwesterly flow which would cause snow showers in the Great Lakes region. Strong lapse rates also would be expected again during the daylight hours.

b. Monroe Area Weather -- Fig. 27 shows the Grosse Ile NAS hourly observations. It can be seen immediately that the wind was generally light and that the direction ranged from the north-northeast through north to

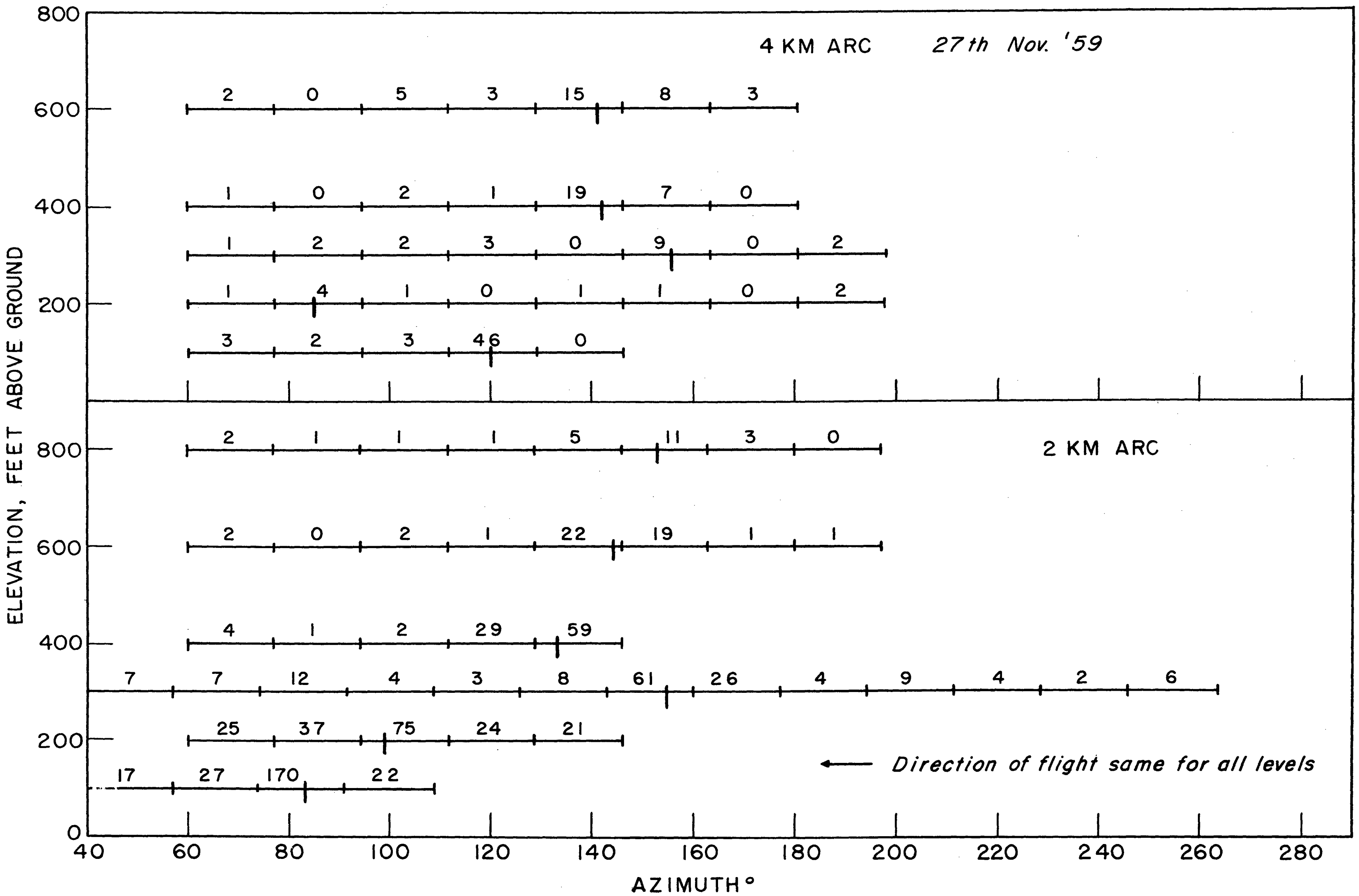

Fig. 25. Raw counts of FP material from 27 November 1959 plotted according to azimuth and height above the lake surface. Vertical dashes show the estimated centerline of the plume.

STATION U.S. NAVAL AIR STATION, GROSSE ILE, MICH. DATE 28 Nov 1959

TYPE 1	TIME (LST) 2	SKY and CEILING (Hundreds of Feet) 3	VISIBILITY (Miles) 4	WEATHER and OBSTRUCTIONS TO VISION 5	SEA LEVEL PRESS. (mbs.) 6	TEMP. (°F) 7	DEW PT. (°F) 8	WIND DIRECTION 9	WIND SPEED (knots) 10	WIND CHARACTER & SHIFTS 11	ALTIMETER SET. (ins.) 12	REMARKS AND SUPPLEMENTAL CODED DATA 13	14A	14B	OBSERVERS Initials 15
R	0559	M5⦷20⊕	3	S-	199	30	30	↓↘	4		008				LNB
R	0659	M8⦷20⊕	3	S-	204	30	30	↓	1		009	30205 12XX 29			LNB
S_1	0736	E6⊕	2 1/2	S-					C						LNB
R	0758	E6⊕	2	S-	209	30	29		C		010				LNB
R	0859	P6X	1	S-	208	30	29	↙	1		010				ONG
S_2	0945	P6X	3/4	S-FK				↓↙	2						ONG
R	0959	P6X	3/4	S-FK	209	31	28	↓	2		011	105 1XXX			LNB
R	1057	P6X	3/4	S-FK	208	30	29	↓↙	3		010				ONG
S_3	1132	E8⦷30⦷	1 1/2	S--FK				↙	3						ONG
R	1156	E9⦷30⦷/⦷	2 1/2	S--FK	204	31	28	↙	2		009				ONG
S_4	1203	E9⦷30⦷/⦷	4	FK				↓	2						LNB
S_5	1235	20⦶/⦷	4	FK				↘	3						LNB
S_6	1250	E9⦷/⦷	4	HK				↓↘	3						ONG
R	1257	E9⦷/⦷	3	S--HK	200	32	28	↓↘	4		008	SE00B55 81005 1606 29			ONG
S_7	1306	P8X	1 1/2	S-HK				↓↘	3						ONG
RS_8	1352	E9⦷/⦷	4	S--HK	198	32	30	↓	1		007				LNB
S_9	1403	P5X	1 1/2	S-HK				↘	4						LNB
S_{10}	1409	P5X	3/8	S-HK				↓↘	5						LNB
S_{11}	1440	P2X	3/4	S-HK				↘	2						ONG
S_{12}	1443	E9⦷50⦷	4	S--HK				↘	2						ONG
R	1456	E9⦷50⦷	4	HK	198	32	27	↘	2		007	SE52			LNB
S_{13}	1515	E9⦷50⊕	2	S-HK				↘	2						ONG
S_{14}	1528	E9⦷50⊕	4	S--HK				↓↘	2						ONG
R	1555	E9⦷50⊕	3	S-HK	199	31	27	↘	5						ONG
S_{15}	1605	P8X	3/4	S-HK				↓↘	4						ONG
S_{16}	1610	P5X	1/2V	S-HK				↘	4			VSBY 1/4V3/4			ONG
RS_{17}	1658	-XE40⊕	2 1/2	S-FK	200	30	27		C		008	56 CNDS XTRMLY VRBL			STL
S_{18}	1714	P3X	1/4V	S-FK				↓↘	5			VSBY 1/4V3/8			STL
R	1756	P3X	1	S-FK	207	29	28		C		010				STL
RS_{19}	1858	E20⊕	5	S--K	213			↙	5		011	31207 15XX 95404 32			STL
R	1956	20⦶E45⊕	10		215	28	23	↓↙	3		012	SE12			STL
RS_{20}	2057	40⦶	15+		217	28	21	↓↙	4		012				STL
R	2159	/⦷	15+		217	27	19	↓↙	3		013	105 1008			STL

Fig. 27. Surface weather observations taken at U. S. Naval Air Station, Grosse Ile, Michigan on 28 November 1959.

northwest. Visibility was marginal all day, ranging from 3/4 of a mile to 4 miles in light snow, fog, smoke, and haze. The ceiling ranged from obscured during snow flurries to broken cloudiness at 900 ft.

With all the snow falling, it can be assumed that the temperature lapse rate was strong. The air temperature reached a maximum of 32°F while the temperature of Lake Erie was about 44°F. With such a gradient, there might even have been a superadiabatic lapse rate in the lowest layer of the atmosphere.

With the snow, it is important to note that the dew point and the dry bulb temperatures were very close to each other, indicating that the air was nearly saturated with water vapor. This, of course, would be expected. The trend however, was a drying one. Note that at 0559 the air was saturated, the relative humidity being 100% while at 2159, the relative humidity had dropped to 70%. The skies were also clear by this time.

c. Special Characteristics at Lagoona Beach -- There are times when it is possible that Grosse Ile's visibility might be worse than that at the plant site due to the smoke from the industrial area to the northwest and west of the air station. The visibility at the plant site was marginal but not as poor as that at Grosse Ile.

The wind direction regime at both stations was the same. See Table IV. Again, the speed is higher at the plant site for the reason explained previously.

The lapse rate was generally strong except near sunrise, 0500 and 0600, when the lapse rate was recorded as being weak. The sampling was done in the early afternoon from 1345 to about 1530 EST. During this period, the temperature lapse rate was strong and became weak indicating the diffusion was probably good.

The plotted vertical temperature profile from the aerometeorograph, Fig. 28, shows that both the temperature lapse rates, that over the land and over the water, were strong.

d. Plume Characteristics -- Since the weather was so poor, there were no jet reconnaissance flights. Although the theodolite was in position on the tower, visual contact with the plane was not continuous due to intermittent snow flurries and hazy conditions.

The smoke plume became a part of the generally hazy condition soon after leaving the smoke generator, so few observations of the plume exist. Those that do, indicate the plume width to be 25-35°. It moved toward the direction of 110° initially and then more toward 150°.

e. Results of Plane Sampling -- Although the weather was poor, the

TABLE IV

HOURLY AVERAGE VALUES OF WIND DIRECTION, WIND SPEED, AND TEMPERATURE LAPSE RATE DATA FROM THE METEOROLOGICAL TOWER AT THE ENRICO FERMI SITE ON 28 NOVEMBER 1959

Hour Ending	Wind Direction	Wind Speed (mph)	Lapse Rate
0100	N	6	S
0200	NNW	11	S
0300	NW	15	S
0400	NW	15	S
0500	NW	14	W
0600	NW	12	W
0700	NW	11	S
0800	NW	9	S
0900	NW	5	S
1000	NNW	4	S
1100	NNE	8	S
1200	N	6	S
1300	N	4	S
1400	NW	9	S
1500	WNW	13	W
1600	NNW	9	W
1700	msg	msg	S
1800	msg	msg	S
1900	NE	6	S
2000	NNE	8	S
2100	NNE	8	W
2200	N	5	I
2300	NNW	5	I
2400	NW	7	I

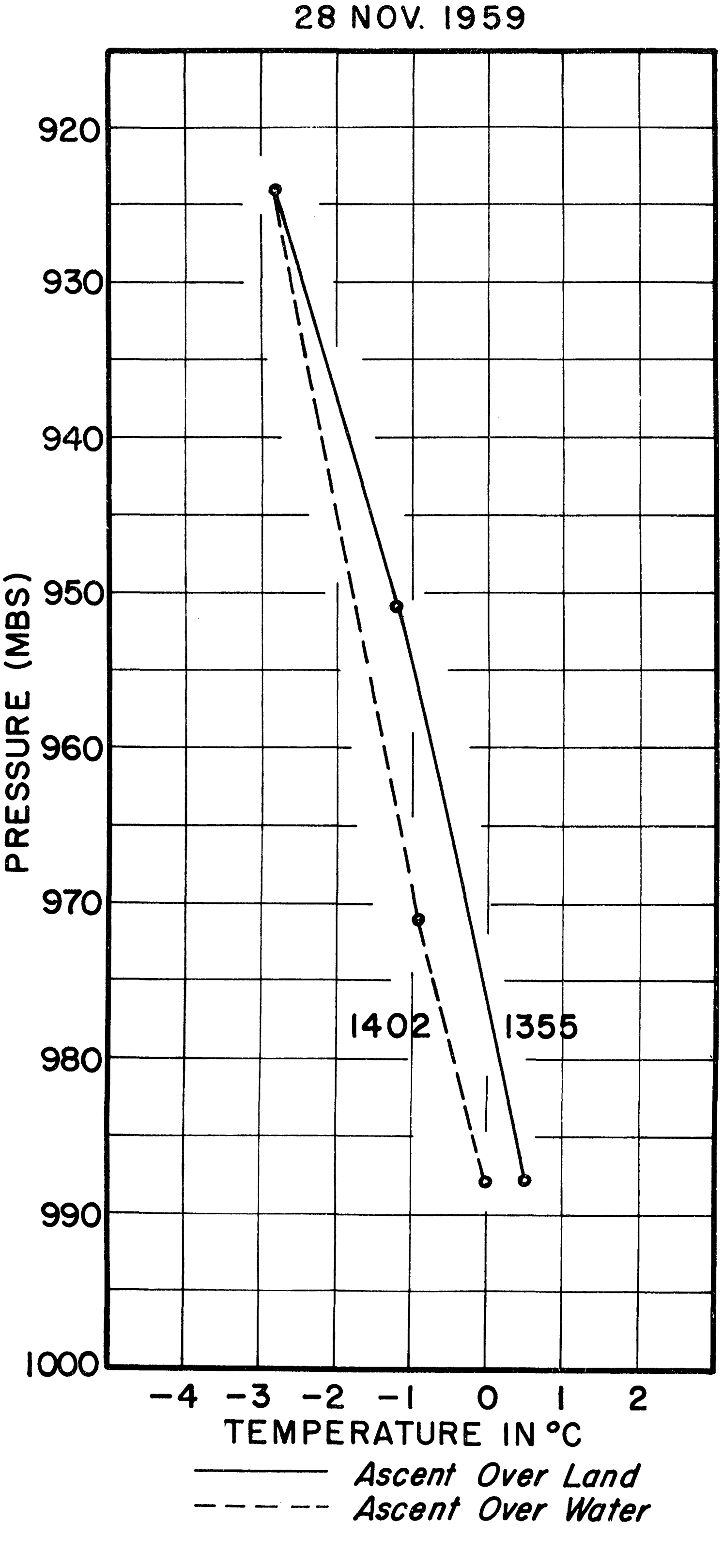

Fig. 28. Plot of the vertical temperature distribution as recorded by the aerometeorograph on 28 November 1959.

results of the collection on the drum sampler were the best of all the experiments. The output of the FP generator was increased and this increase shows markedly in the sampling. Fig. 29 shows the plots of the raw counts. A good run was made on the 8 km arc, which had not been done previously.

At 200' on the 2 km arc, the centerline of the plume was probably missed because the wasted sample had more FP material on it than the first sample of the 200 ft run. The meander of the plume could cause such difficulties.

Generally it looks as though diffusion was good both in the horizontal and in the vertical since there was a wide spread to the plume and there were high counts at 800 ft.

f. Comments on the Diffusion Patterns -- This experiment was another that indicated good diffusion conditions. Again, it should be reiterated that the falling of precipitation in any form might cause washout.

6. SUMMARY

All four of the experiments reported on in this report are under moderate to good diffusion conditions. Even though poor diffusion conditions were wanted, these four experiments are indicative of several different regimes. The weather situations are ones that reoccur time and time again. In other words they are not unusual conditions.

The experiments on the 5th and 6th of August were made before the lake breeze began. If they had been made several hours after the lake breeze had started, diffusion would probably have been quite poor, at least in the area of the plant. Just how far inland this effect is felt, is not known.

The fall experiments in late November had good diffusion. This good diffusion pattern should remain out over the lake and over the land as long as the air is colder than the land or water over which it is traveling. At night when there is cloud cover, the lapse rate will remain strong so diffusion should be good, but when there are no clouds, a low level inversion could form inhibiting diffusion. The only potential problem in such a situation is from the snow showers which could cause washout of material.

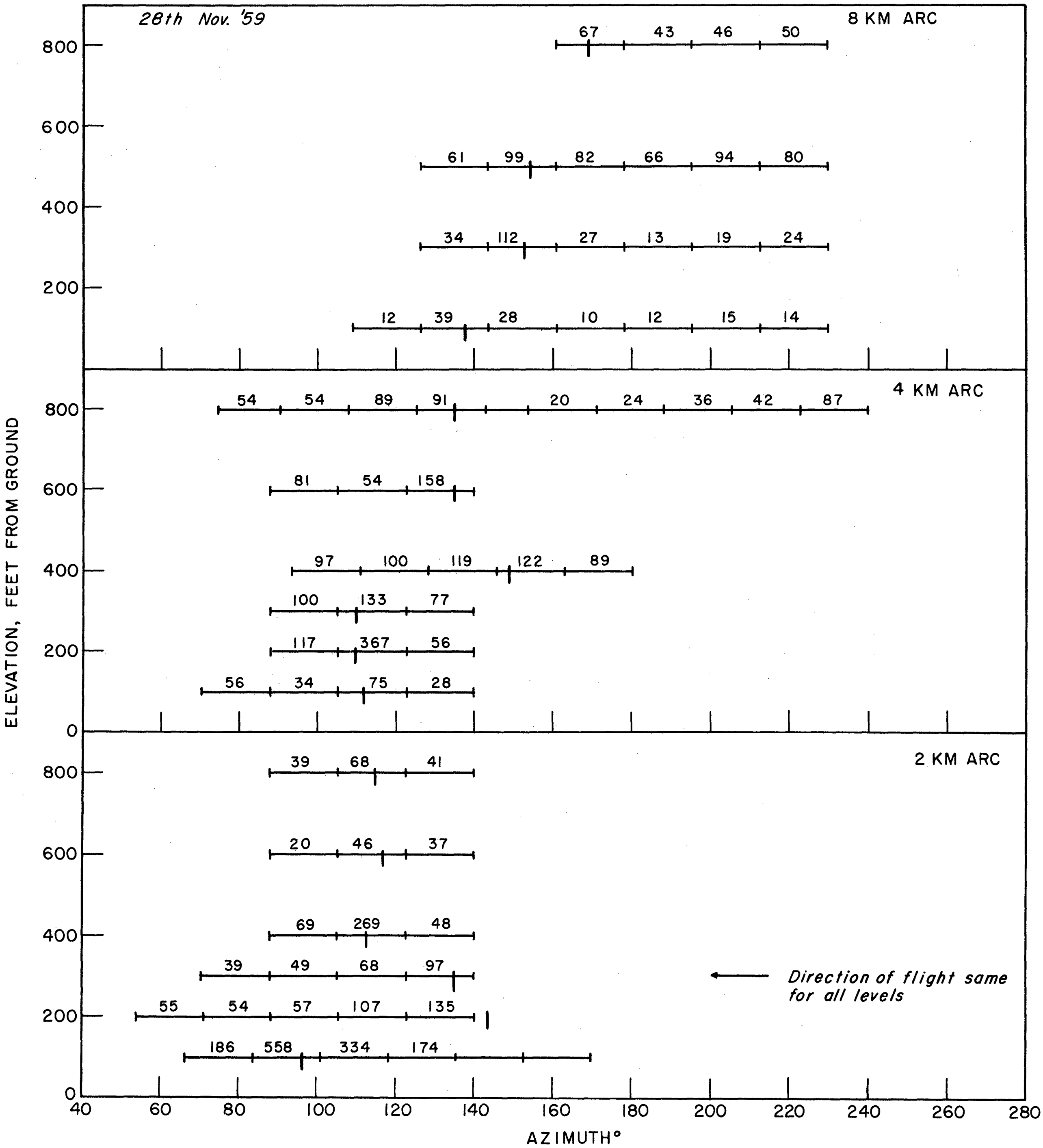

Fig. 29. Raw counts of FP material from 28 November 1959 plotted according to azimuth and height above the lake surface. Vertical dashes show the estimated centerline of the plume.

VIII. FUTURE WORK AND ANALYSIS

At the time of writing the third diffusion experiment, that of the winter season has already been conducted. On February 4 exceptionally poor diffusion conditions persisted, fluorescent particle samples were taken, and aerial photographs obtained. These data are being analyzed and will be discussed in the next report.

A spring experiment is scheduled to be held sometime during the period 26 March to 4 April 1960. This experiment will complete the seasonal series and hence the experiments to be performed on this project.

It is planned to report on the winter and spring experiments as well as to give full analyses and quantitative estimations from all four experiments in the final report. Such quantitative estimations will come from using formulae developed by G. R. Hilst (8) (9), F. A. Gifford (14), and O. G. Sutton (15).

The formulae of Sutton are well known and widely used in diffusion work. However, to obtain proper values for the diffusion coefficients is a difficult procedure: in fact, there is evidence which suggests that under inversion conditions an equation of the Sutton type is inadequate to represent the diffusion at considerable distances from the source. These factors will be discussed in a subsequent report.

Hilst has specialized in diffusion under stable atmospheric conditions or the well-known inversion dondition. His formulae were developed for observations over open land near Richland, Washington.

Gifford's model seems more reasonable for the long travel distances that are involved in the present experiments. His model takes into account both the small scale diffusion, or spreading, plus the large scale meander of the plume. All the information necessary for a testing of the model may not be available, however.

It is known that spectral analysis of the bivane data will show how the energy of the atmosphere is distributed, but it is not known how this energy distribution changes with lapse rate conditions and with wind direction. It seems plausible that the spectrum for an on-shore wind will be different than that for an off-shore wind under similar lapse rate and wind speed conditions. With the availability of an IBM-704 electronic computer on the campus such an analysis will be undertaken.

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