United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-78-205
October 1978

EPA

Balloon-borne Particulate Sampling for Monitoring Power Plant Emissions

Interagency Energy/Environment R&D Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

EPA-600/7-78-205

October 1978

Balloon-borne Particulate Sampling for Monitoring Power Plant Emissions

by

J.A. Armstrong, P.A. Russell, and R.E. Williams

Denver Research Institute
University of Denver
Denver, Colorado 80210

Grant No. R804829
Program Element No. EHE624

EPA Project Officer: Leslie E. Sparks

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

ABSTRACT

A lightweight remote controlled sampler which is carried aloft by a tethered balloon has been developed to collect particulates from the plumes of fossil fuel power plants at various downwind distances. The airborne sampler is controlled from the ground via a radio transmitter and receiver/servo system. A verification transmitter-receiver system allows monitoring of various commands to the sampler for correct operation.

The sampler utilizes a pump to draw air through a strip of nuclepore or other filter media. The sampler can be selectively actuated during flight to collect a number of discrete samples on the filter or to take a time-resolved streak sample across a length of the filter.

The sampling system has been field tested at both an urban and a rural power plant. The collected samples have been analyzed in terms of size, concentration, and composition using scanning electron microscopy/energy dispersive X-ray spectrometry.

This system has been specifically developed to quantify the impact of conditioning treatments on power plant emissions. In situ plume sampling should lead to a better understanding of how the addition of SO_3, H_2SO_4, lime, etc., can alter emissions. The balloon-borne sampling system can be used to monitor other point and non-point emitters, especially where the areas to be sampled have difficult accessibility.

This report was submitted in fulfillment of Grant No. 80492010 by the Denver Research Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from November 1, 1976, to July 31, 1978, and work was completed as of October 31, 1978.

CONTENTS

FIGURES

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the following personnel of the Public Service Company of Colorado: Dr. Robert Pearson and Mr. William Brines of the Main Office and Messrs. Harry McCormick, Edward Higgins, James Willy, Adam Wilchek, and Albert Imrie of the Arapahoe Station.

Likewise, the authors acknowledge the excellent cooperation received from the following personnel of the Colorado-Ute Electric Association: Messrs. Robert Bryant, Robert Wilbur, and Charles Means of the Main Office and Messrs. Wayne Butts and Robert Heard of the Hayden Station.

Finally, Messrs. Larry Brown and Robert Marchese of the Denver Research Institute are acknowledged for their efforts in the design, fabrication, and testing of the balloon-borne sampling system.

SECTION I

INTRODUCTION

The traditional methods of monitoring airborne particulates from point source emitters, such as fossil fuel power plants, have been based on ground based samplers, tower based samplers and/or samplers carried by aircraft. When monitoring a specific, well-defined source, a number of ground based samplers are usually positioned at considerable distances from the source. Dispersion modeling is normally required to analyze the distribution of particulates collected by the samplers in order to calculate the source strength. Considerable error is incurred when using this technique because of the simplicity of atmospheric dispersion models. In addition, there is considerable uncertainty that the fine particulates will be representatively sampled. The use of towers allows for better vertical resolution in terms of sampling source emissions, but towers are limited by the practical height they can sample and by their obvious lack of mobility. Monitoring of source emissions using aircraft is not feasible at low flying altitudes and in the proximity to the source because of the poor time and spatial resolution, due to the necessary speed of aircraft, and for safety reasons. While all of the above techniques are useful for monitoring source emissions under certain conditions, an additional sampling system is needed which has vertical and horizontal mobility and is capable of relatively long sampling times. With this need in mind, the Denver Research Institute (DRI) of the University of Denver has developed and field tested a lightweight, remote controlled particulate sampler which is carried aloft by a tethered balloon. This system is capable of sampling to altitudes of one kilometer in relative height. In addition, it is readily transportable so that sampling at selected downwind distances from the emitting source is accomplished.

This sampling system has been developed and demonstrated specifically for the investigation of particulate emissions from fossil fuel power plants which use flue gas conditioning treatments. The sampling system should also prove useful in monitoring other point and non-point source emitters where sampling from the ground, from towers, or by aircraft is impractical.

SECTION 2

CONCLUSIONS

The results of this program have demonstrated that the basic concept of *in situ* sampling of particulates from the plumes of point sources (in this case, fossil fuel power plants) is feasible using a remote controlled balloon-borne sampler. In particular, it has been shown that:

1. A versatile and inexpensive airborne particulate sampler which is controllable from the ground via a telemetry link and yet is light enough to be carried by a tethered balloon designed to operate without FAA waivers to FAR, Part 101, can be designed and fabricated.

2. It is definitely possible to position the sampling system in the visible plume of a fossil fuel power plant at desired downwind distances from the stack.

3. With the sampling system properly placed in a visible plume, adequate filter loading for energy dispersive X-ray fluorescence, scanning electron microscopy and transmission electron microscopy are readily attainable.

4. The sampling system can be safely operated up to wind velocities of 10 meters per second.

5. The sampling system is capable of operating at ambient temperatures down to at least -13° Celsius.

SECTION 3

RECOMMENDATIONS

It is recommended that the balloon-borne particulate sampling system be used to investigate the impact of flue gas conditioning on emissions from fossil fuel power plants. Field tests should be conducted at several power plants which use different coal and/or conditioning treatments. The tests should be run while these plants are operating both with and without conditioning. This is necessary in order to establish a broad data base for evaluating the effects of conditioning treatments and control strategies on power plant emissions.

Analytical investigations of the collected particulates should be directed at (1) the detection, identification, and quantification of specific byproducts of additives used to improve precipitator efficiency, (2) detection and quantification of trace elements associated with flyash and changes possibly caused by the addition of these conditioning agents and (3) shifts in mass or particle size distributions caused by conditioning agents. Such analyses will require utilizing quantitative energy dispersive X-ray fluorescence, scanning electron microscopy, and transmission electron microscopy.

The sampling system should also be used to investigate fugitive emissions, and their subsequent transportation, from point and non-point sources. Such sources include: mining sites; certain operations at mills, smelters, and refineries; materials handling operations; storage piles, etc. Specific point and non-point sources of fugitive emissions can be identified by monitoring airborne particulates directly up and downwind of suspected sources. The above analytical techniques can be used to quantify the collected particulates.

SECTION 4

DESIGN CRITERIA FOR THE BALLOON-BORNE PARTICULATE SAMPLING SYSTEM

DESIGN GOALS

General design goals for the tethered balloon particulate sampling system were to develop a system that is readily transportable in the field, thus having horizontal mobility, and that is capable of operating to reasonably high selected altitudes, thus giving the system vertical mobility. Specific design goals for the balloon-borne sampling package included that it be capable of long sampling times, that it be controllable from the ground, that it be simple to operate, that it be versatile in terms of being able to collect time resolved "streak" samples or a number of discrete samples and also be able to collect samples on various types of filter media. Finally, the sampling system should be relatively inexpensive.

DESIGN CONSTRAINTS

The major design constraint involved developing a sampling package which has the above features but is still light enough in weight so that it can be carried aloft by a tethered balloon whose size does not require Federal Aviation Administration waivers to Federal Aviation Regulations, Part 101. These regulations entitled "Moored Balloons, Kites, Unmanned Rockets and Unmanned Free Balloons", state the following restrictions for tethered balloons over six feet in diameter (1.83 meters) or having a buoyant gas capacity of more than 115 cubic feet (3.25 cubic meters):

Operation is forbidden within 500 feet (152 meters) of the base of a cloud.

Operation is forbidden more than 500 feet (152 meters) above the ground.

Operation is forbidden from an area where ground visibility is less than three miles (4.8 kilometers).

Operation is forbidden within five miles (8.0 kilometers) of the boundary of any airport.

Other regulations require lights for night operation and a rapid deflation device to spill buoyant gases if the balloon escapes its mooring. It is therefore apparent that the operation of a captive balloon system is greatly simplified if the size of the balloon is kept below the above FAA restrictions. It should be noted that the balloons having a gas capacity up to 3.25 cubic meters are placed in the same aviation hazard category as standard meteorological radiosonde balloons.

A second consideration concerning the use of a balloon for the airborne platform of the particulate sampler involves the balloon's shape. Basically, a choice can be made between using a spherical balloon whose cost is generally less than one hundred dollars versus an aerodynamic (blimp shaped) balloon whose cost is on the order of three hundred dollars. Both types have the same life, that is, about ten inflations and deflations. By attaching the tetherline to appropriate points on the balloon, an aerodynamic balloon has the added advantage of always being orientated into the wind during flight operations. This is a desirable feature when sampling particulates from a point source emitter in that the orientation of the sampling package relative to the source can be controlled. A final advantage of aerodynamic balloons is that they are more stable than spherical balloons in moderately strong winds.

SECTION 5

DESCRIPTION OF THE BALLOON-BORNE PARTICULATE SAMPLING SYSTEM

BALLOON SYSTEM

Based upon the above considerations, an aerodynamic 3.25 m^3 balloon and battery powered winch were purchased for this program from the A.I.R. Company of Boulder, Colorado. The size of the balloon is 4.9 x 1.39 meters, and it has a static lift at sea level of 1.9 kilograms when inflated with helium. The balloon is constructed of plastic and for observation and safety reasons is bright red in color. The dimensions of the portable winch are 40 x 23 x 25 centimeters. The weight of the winch is 27 kilograms. The winch contains a 12 volt battery to power a forward-reverse, variable speed motor which drives the tetherline spool. The extremely lightweight tetherline has a breaking strength of 535 newtons (120 pounds) and a mass per length ratio of 0.4 kilograms per kilometer. It consists of a bundle of small straight fibers bound together in a plastic matrix.

This balloon system is capable of lifting a package weighing 1,200 grams to altitudes of 800-1000 meters in winds up to 10 meters per second and of surviving winds of 20 meters per second.

In addition to the balloon and winch, a battery powered transmitting meteorological package, designed to be carried by the above balloon, and a battery powered receiving ground station were also purchased from the A.I.R. Co. This complete package is called the TS-1A-1 Tethersonde System. This entire system was purchased so that atmospheric soundings could also be made through plumes of power plants being sampled for particulate emissions. The meteorological package measures dry and wet bulb temperatures, pressure, wind velocity, and direction. The weight of this package is 1175 grams.

PARTICULATE SAMPLING PACKAGE

The balloon-borne particulate sampler developed during this program has all of the above design goals incorporated into it. The total weight of the sampling package has been held to 1170 grams so that, as stated above, it is possible to fly and operate the package to heights of one kilometer using the 3.25 m^3 aerodynamic balloon system.

Basically, the sampler, which is battery powered, consists of a movable sampling head connected via flexible tubing to a pump and a flow adjust needle valve loop followed by a flow meter. The sampling head translates along a filter strip which is used to collect airborne particulates when air is sucked through it. The sampling head is translated by means of a guide mechanism consisting of a guide rod and a motor driven leadscrew. The sampler contains a radio receiver-servo system used to selectively control, from the ground, the suction pump and the translate mechanism motor as well as a flight termination system which deflates the balloon in case of a tetherline failure. The sampler also contains a radio transmitter system used to verify that the sampler is operating correctly.

<u>Mechanical System</u>

A sketch showing the front perspective view of the particulate sampling package is presented in Figure 1. The overall dimensions of the package are 43 x 11.4 x 8.9 centimeters. The sampler housing consists of a rectangular box which has been fabricated using thin aluminum sheeting. The vertical wall opposite the front surface shown in Figure 1 is removable to allow access to the various sampler components. Aluminum, plastic, and nylon have been used extensively throughout the package in order to minimize its weight. The means of suspending the package to the balloon is also shown in the figure. The two lines that attach to the balloon do so on opposite sides of the balloon body. This method of attachment allows the package to be orientated so that the filter collecting the particulates is either pointing into or away from the wind and, thus, the emitting source.

The exploded portion of Figure 1 shows a rectangular aperture in the front wall of the housing. Into this aperture fits a thin slotted aluminum plate onto which a linear filter strip, 15.8 centimeters long by 1.5 centimeters wide, has been mounted by means of an adhesive to the plate's back surface. A framing plate attached to the inside of the housing wall holds the filter plate flush to the housing surface. To date, a 0.4 micrometer nuclepore substrate has been used as the filter. Other filter media, such as millipore or glass fiber, are also compatible with this sampler.

A filter cover plate having a port in registry with the nozzle of the movable sampling head is employed to insure that only the portion of the filter on which particulates are being collected is exposed so that the remainder of the filter strip is protected from the outside atmosphere. This cover is held in position by means of a grooved guide rigidly fixed to the front housing located above the filter plate aperture and by attachment to a translate plate connected to the movable sampling head. This plate passes through a lengthwise slot in the housing wall which, as seen in Figure 1, is located just under the filter plate aperture.

Figure 1 also shows a set of wire leads that connects to a flight termination device which is taped to the skin of the balloon. This device consists of two flashbulbs housed in an aluminum cannister. The bulbs in the cannister lie flat against the balloon surface. In case of an accidental release of the balloon from its winch and tetherline assembly, the flashbulbs are electrically actuated by a destruct servo within the sampler which is remotely controlled by the ground operator. This is discussed in detail later. Once the bulbs ignite, a hole is melted through the balloon skin. This allows the helium to escape and causes the balloon to lose lift and descend, thus averting the loss of the sampler package.

Internal components of the sampling package are shown in detail in Figures 2 and 3. Figure 2 is a top plane view of the package with the top of the housing removed. Figure 3 is a cross-sectional view of the sampling head taken along the plane A-A in Figure 2.

The sampling head is comprised of a nylon block having a threaded hole through which a leadscrew passes and a smooth hole through which a guide rod passes. The leadscrew has a diameter of 0.953 centimeters (0.375 inches) and has a coarse thread (16 threads per inch). In addition, the sampling head has a third hole whose direction is perpendicular to the above mentioned holes. A thin walled metal tube passes completely through this third hole. A teflon nozzle attaches to the tube segment which faces the filter. The other end of the metal tube forms a nipple which projects from the back of the block as shown. This nipple is connected to a length of flexible latex tubing. Latex tubing is used to connect all flow components. The tubing from the nipple connects to a tee which in turn connects to the inlet of the sampling pump and to the outlet of a flow adjust needle valve. Flexible tubing from the pump outlet again connects to a tee which in turn connects to the inlet of the flow adjust valve and to a miniature ball-type flowmeter. The flowmeter measures the amount of air drawn through the sampling head nozzle by the pump. The pump is a Bendix Model 3900-300 piston type suction pump. The sampling area of the sampling head nozzle that comes in contact with the filter is 0.7 cm^2. Using 0.4 micrometer nuclepore filter material and the above pump, the maximum sampling rate through this sampling area is approximately 1.5 liters/minute.

The leadscrew used to translate the sampling head and the guide rod are parallel to each other. The guide rod serves both to guide the nozzle of the sampling head across a lengthwise portion of the filter strip and to prevent the sampling head from rotating along with the leadscrew when this screw is turned by the electric motor shown in Figure 2. The motor, which is directly coupled to the leadscrew, turns the screw at a rate of 10.9 revolutions per minute.

Mounted on the sampling head are a pair of microswitches which ride on an index track parallel to the axis of the leadscrew. The track has ten notches machined in it which correspond to a start or launch position, eight discrete sampling positions, and the end position. The entire filter strip is covered in the start and end positions. The microswitches are used in the control of the translate motor and in verifying the translate operation. This is discussed in detail below.

<u>Electronic System</u>

The electronic system of the sampling package is illustrated by Figures 2 and 4. Figure 4 is an electronic block diagram of the radio operated, remote control system. The package contains a radio receiver for receiving command signals transmitted by the sampler operator via a Futaba FP-T3F radio transmitter which operates at 72.4 MHz. The receiver is electronically connected to a flight termination servo circuit, a translate servo circuit, and a pump servo circuit as shown. The receiver is a Futaba FP-R3F three channel receiver, and each of the three servo circuits is a Futaba FP-S61C servo, each of which responds to one of the three channels of the receiver.

The battery pack used to supply power to the electronics, translate motor, and pump motor of the airborne sampler is a system of three Yardney silver cells, Model LR1-5. The battery pack is a large capacity source that is compact, lightweight, and has a high current drain capability. The battery pack weight is 156 grams. This will operate the system for eight hours. This type of rechargeable battery discharges at a constant voltage until the charge is almost totally depleted.

The flight termination servo circuit connects to the termination device discussed above by way of wire leads. This circuit serves to ignite the flashbulbs of the termination device upon command by supplying power from the battery pack to the bulbs.

The translate servo circuit is connected to the leadscrew motor and controls the actuation of the motor. With the leadscrew motor actuated, once the sampling nozzle reaches a new sampling position, which corresponds to one of the detents or notches on the index track discussed above, the microswitches mounted on the sampling head enter the detent. This causes one of the microswitches to deactuate the leadscrew motor while the other keys a verify and battery alarm circuit. This circuit generates a signal to a 27 MHz transmitter located within the housing of the sampler, which broadcasts a signal down to a verify receiver located with the ground operator. The receiver is a Realistic TRC-74 citizen's band transceiver. By this means, the operator is informed that the sampling head has in fact been translated to a new sampling position in accordance with the radio command signal transmitted by the ground transmitter.

The pump servo circuit is connected to the sampling pump which in turn is connected to the verify and battery alarm circuit. When the pump servo circuit actuates the pump in response to servo control signals received from the radio receiver, the verify and battery alarm circuit senses that the pump has been actuated and transmits a pump actuation verification signal to the package transmitter. The transmitter in turn broadcasts a signal down to the verify receiver in order to alert the ground operator that the pump is operating.

The verify and alarm circuit also constantly monitors the power output of the battery pack. If the battery power drops below a set value, this circuit generates a "weak battery" signal which in turn is transmitted via the package transmitter to the operator, thus informing the operator that the battery power is inadequate for further sampler operations.

Operation of the Sampling System

First, the operator of the sampler guides the balloon system to a desired airborne sampling position by moving the winch to a proper ground location and by releasing the necessary length of tetherline from the winch spool.

The proper placement of the balloon-borne package is of course dependent upon the atmospheric wind conditions. Once the sampler is in the proper position, the operator actuates the translate function of the ground transmitter, and the leadscrew motor of the sampling package is energized via the translate servo. This causes the sampling head to move from the covered "start" position to the first sample position. As discussed above, the leadscrew motor automatically stops at the first sampling position. A signal is transmitted to the operator verifying the arrival of the sampling head to the first sample position. The operator then actuates the pump command of the ground transmitter, and the airborne pump servo circuit actuates the pump motor so that the sampling commences. A verification signal is again transmitted to the operator. When sufficient sampling time has elapsed for the first sample position, the operator transmits a signal to the pump servo which turns off the pump. The balloon carrying the sampler is then repositioned to the next desired sampling location. The operator then activates the translate function of the ground transmitter again, and the sampling head moves to the second sampling position, and the process is repeated until eight separate samples have been taken. The sampling head is then translated to the covered end position so that the cover plate again covers all of the filter strip, protecting it from further exposure to the atmospheric environment. The balloon is then retrieved, and the filter strip is removed for analysis.

The preceding description assumes that the sampler is operated in the "discrete sample" mode. When a "continuous streak" sample is desired, the ground operator first actuates the sampling pump and then continuously holds the translate control lever of the radio transmitter to the command position. This causes the sampling head to continuously translate across the filter strip as the nozzle draws air. This allows for a single sample streak to be taken across a portion of the filter strip. The "streak sample" mode may be employed when the operator wishes to take a continuous air sample in one location over a selected period of time in order to obtain a time-resolved sample.

The sampling head of the present package translates at a rate of 1.73 centimeters/minute. Since the filter is 15.8 centimeters long, a continuous 9.1 minute streak sample can currently be taken. This sampling rate is too fast for most particulate sampling situations. The translation speed of the sampling head can be easily varied, however, by use of an appropriate gear train between the translate motor and leadscrew.

A photograph of the complete balloon-borne particulate sampler is shown in Figure 5.

SECTION 6

FIELD OPERATIONS

ARAPAHOE TEST PROGRAM

The first power plant checkout flights of the balloon-borne particulate sampling system were made on July 6 and 12, 1977, at the Arapahoe Steam Electric Generating Station of the Public Service Company of Colorado. This plant is located in the city of Denver at an approximate distance of 7.7 kilometers (4.8 miles) south-southwest of the State Capitol Building. The flights took place during the early morning hours when surface radiational inversions commonly are observed. The flights were conducted to determine the operating characteristics of the sampling system, effective sampling times, and to establish sampling procedures and positioning of the balloon in power plant plumes.

Flight Operations

On July 6, 1977, the east stack plume of the Arapahoe Station was sampled between 0630 hrs. and 0800 hrs. MDT while the west stack plume was sampled between 0830 hrs. and 1000 hrs. The east stack is fed by the steam generators of Unit #1 (full load capacity of 46 megawatts) and Unit #2 (47 megawatts). The west stack is fed by the steam generator of Unit #3 (47 megawatts) and Unit #4 (113 megawatts). All of the steam generators are equipped with electrostatic precipitators preceded by conditioning systems which inject SO_3 into the flue gas. In addition, Unit #4 is equipped with a wet scrubber. The four Arapahoe units are capable of burning coal or natural gas. Properties of the coal burned at the Arapahoe Station are reported in Appendix A. Operating loads of the four units during July 6 and July 12 tests are given in Appendix B. On July 6 the flue gas conditioning equipment on Units #2, #3, and #4 were not operating. On this day, Units #1, #2, and #3 were burning coal, and Unit #4 was burning coal plus natural gas.

The launch locations for these tests were the coal piles just north of the plant. The balloon winch was positioned directly below the plume to be sampled. Vertical positioning of the balloon in a plume was accomplished by watching the balloon behavior from the launch position. During ascents, the horizontal motion of the balloon was minimal until the balloon entered the plume. Once there, the horizontal tracking motion of the balloon matched the visible smoke motion of the plume passing by the balloon. Also, when the balloon was in the plume, a portion of the plume smoke could be seen below the balloon. In addition to observations made from the Arapahoe launch site, the location of the balloon relative to the plant stacks was established by an observer stationed on the fourth floor of a Denver University building located 3.4 kilometers (2.1 miles) due east of the Arapahoe Station. The observer, using a 35 mm camera equipped with a 400 mm telephoto lens, took slides of the flight operations. Since the wind on the morning of July 6 was from the south, reasonably accurate measurements of the horizontal and vertical distances of the balloon downwind from the top of the stacks have been determined from the photographic slides. During the tests, the horizontal distance varied between 92 and 99 meters while the vertical distance above the 76.2 meter high stacks varied between 47 and 52 meters.

Sample times for collecting material from the east stack plume were purposely varied and ranged from 15 minutes to 10 seconds. Due to a malfunction of the airborne sampler, the planned 15 minute sample of the west stack plume was collected over a longer period (16 - 20 minutes).

After these tests, a quarter wavelength antenna was designed, fabricated, and installed on the sampling package, resulting in an improved telemetry link between the ground transmitter and the sampler receiver, and thus an elimination of servo noise. Once during the July 6 tests servo noise caused spurious actuation of the flight termination circuit.

On July 12, 1977, Units #1, #2, and #3 were burning coal, and Unit #4 was again burning coal plus natural gas (see Appendix B). The flue gas conditioning equipment on all units was in operation. Samples were again collected from both the east and west stack plumes, with sampling times ranging between 15 minutes and 15 seconds. In addition, an atmospheric sounding through the east plume was taken, using the balloon-borne meteorological package. The wind direction during the tests was again from the south. The vertical height of the plume increased during the testing period. The east plume was sampled between 0620 hrs. and 0730 hrs. On this particular day, the plume from the east stack separated into two distinct portions (see Figure 6). Particulates from both the east and west portions of the east plume were sampled.

The atmospheric sounding of the east plume was taken between 0750 hrs. and 0830 hrs. The results of the sounding are reported later.

The west plume was sampled between 0900 hrs. and 0950 hrs. During this portion of the test, the balloon position relative to the stacks was again determined from photographic slides taken from the university building. The horizontal distance of the balloon downwind of the stacks varied between 117 and 128 meters while the height above the stacks varied between 58 and 76 meters.

Figures 6, 7, and 8 are photographs showing flight operations at the Arapahoe site during the July 12 tests.

Particulate Analysis--

Particulates collected during the Arapahoe checkout flights were examined with the DRI AMR 900 scanning electron microscope which includes a KEVEX energy dispersive X-ray analyzer. This was a cursory examination to ascertain "typical" particle size, concentration, and composition. Sections of nuclepore substrates containing material collected by the balloon sampler during the July 6 tests were attached to aluminum SEM stubs which had previously been coated with parlodion. Substrates used during the July 12 tests were cut in half and fastened to standard glass slides using double-sided adhesive tape. In terms of ease of mounting, the second technique is preferred. Both types of mounted samples were then vacuum coated with approximately 100 Å of carbon and examined by scanning electron microscopy/energy dispersive X-ray spectrometry. The samples prepared by the above techniques are also suitable for bulk sample X-ray analysis using X-ray excitation. For the present investigation, this analysis was not conducted.

July 6 Test Results--

For the "stacks to balloon" separation distance reported above, 30 second samples proved to be adequate for SEM work, and 15 minute samples are believed to be adequate for X-ray excitation analysis. Sampling at greater distances downwind from the stacks of the Arapahoe Station, although possible, was not conducted at this time because of potential analytical problems caused by the power plant plume mixing with Denver's air pollution.

The 15 minute sample from the east stack (3-4)* and the longer time sample from the west stack (3-8) were examined in some detail using scanning electron microscopy.

East Stack Samples--SEM photographs showing typical particle size and concentration and X-ray traces showing the composition of selected areas of material from the east stack plume are presented in Figures 9, 10, and 11 (X-ray traces taken at the arrow locations). Most of the flyash was mainly composed of silicon and aluminum with small amounts of iron (Figure 9). The next most predominant species in terms of number were relatively rich in calcium. A number of large particle agglomerates rich in sulfur were observed in the east stack sample (Figure 10). In addition, a number of small particles with relatively high sulfur concentrations were observed adhering to the surface of relatively large flyash particles (Figure 11). A few particles rich in phosphorus were also noted in the east stack sample (an X-ray trace of this is not shown).

West Stack Samples--The basic flyash from the west plume (Figure 12) was generally the same in terms of size, concentration, and composition as that from the east plume (see Figure 9). Carbon particles, however, were obvious in material collected from the west plume (Figure 13) while carbon was almost totally absent in the east plume samples. The carbon material generally contained trace amounts of sulfur (Figure 13) or phosphorous (Figure 14).

*The first number designates the nuclepore strips used on a particular sampling day, while the second number designates the sampling station on each strip on which particles were collected.

July 12 Test Results--

East Stack Samples--Material from both the east and west portions of the east stack plume were similar (Figures 15 and 16). Flyash diameters ranged from 5 µm in average diameter to less than 0.5 µm. The composition of the flyash was similar to that collected on July 6. Sulfur was observed to be associated with fine particles on the surface of flyash (Figure 17) or fine particle agglomerates associated with the flyash (Figure 18). Individual particles rich in sulfur were not observed.

West Stack Samples--This plume contained flyash similar in basic composition to that collected from the east stack, but in a much lower size range and concentration (the 15 minute sample was just adequate for electron microscopy). The largest flyash particle observed was only 2.25 µm in diameter, and the majority (by number) were less than 1.0 µm. Many of these particles contained relatively high levels of sulfur on their surfaces, not associated with small particles attached to their surfaces (Figure 19). Also observed were a number of somewhat spherical particles < 0.5 µm which were probably carbon (Figure 20). These particles characteristically contained traces of sulfur, silicon, and calcium.

Atmospheric Sounding Analysis

An atmospheric sounding was taken through the east stack plume on July 12, 1977. The sounding consisted of measuring the wind speed and direction, dry and wet bulb temperatures, and pressure versus height. The height is determined from the pressure measurements. The wind speed varied from 0.7 meters per second at the ground to 5 meters per second at the vertical center of the plume (which at 0810 hrs. was at an altitude of 115 meters from the ground) to a maximum of 6.4 meters per second at an altitude of 231 meters. Figure 21 is a plot of the dry and wet bulb temperatures and the calculated relative humidity versus height. A definite "signature" of the power plant plume was found to exist at a horizontal distance of approximately 100 meters downwind from the stack. In future flights it will be interesting to determine how far downwind from the stack a recognizable signature can be observed.

HAYDEN TEST PROGRAM

The first field measurements of particlates from the plume of a rural fossil fuel power plant were made at the Hayden Station of the Colorado-Ute Electrical Association, Inc. The tests were conducted from November 29 to December 1, 1977. The location of this plant allows for the plume sampling to be conducted at various distances downwind from the stacks until the definitive shapes of the plumes are lost. The objectives of this field program were to establish effective sampling times for selected downwind distances and to verify that the sampling system is capable of being operated in a cold ambient environment.

The Hayden Station is located in Routt County, Colorado, at the end of a mountain valley 4.8 kilometers east of the town of Hayden, on U.S. Highway 40. A mountain range is situated approximately 2.4 kilometers east of the plant. This is a fairly remote and pristine area of the state so that background pollutants associated with urban activity are eliminated. A topographic map of the Hayden Station area is shown in Figure 22.

Flight Operations

The power plant consists of two coal-fired steam electric generating units: Unit #1 having a full load capacity of 190 megawatts and Unit #2 having a full load capacity of 282 megawatts. The flue gas of Unit #1 is fed to a 72.6 meter (250 foot) stack while that of Unit #2 is fed to a 122 meter (399 foot) stack. The station normally operates with both units at full load capacity using low sulfur coal from the nearby Hayden Plant Reserves. Coal from the Wadge Seam of the reserves or that of "substantially the same characteristics and quality" is supplied under contract to Colorado-Ute.[1] Average properties of the coal burned at the Hayden Station during November 1977 are reported in Appendix C.

Both generating units utilize electrostatic hot-side precipitators to collect flyash particulates from the gas streams before they enter the stacks. In order to comply with state and federal regulations concerning particulate emissions, Colorado-Ute has found it necessary to inject the Appollo Chemical Company conditioning agent LPA-40 into the flue gas of Unit #2 upstream of the electrostatic precipitator.[1] This agent is normally injected at a rate of 12 to 15 gallons per hour. As discussed below, only the plume of Unit #2 was sampled during the three day field program. Operating loads of Unit #2 during this test period are given in Appendix D as well as in-stack opacity measurements.

The local weather during the flight operations of the tethered balloon sampling system was less than ideal in terms of the cloud cover and atmospheric stability. In the absence of weather fronts, morning temperature inversions normally occur at the Hayden site during this time of year in which the wind is from the east (downslope conditions). Only on the first test day, November 29, was there a weak morning inversion with the wind from the east to northeast. On this day the plume from the 122 meter stack was sampled from 0845 hrs. to 1023 hrs. MST for various sampling times ranging from 2 to 15 minutes. The horizontal sampling distance was estimated to be 150 meters from the stack. (As in the Arapahoe tests, linear 0.4 micrometer nuclepore substrates were used in the airborne sampling package. The flow rate through the substrates was 1.5 liters/minute.) A plot plan of the Hayden Station is shown in Figure 23 on which the launch and balloon sampling locations for the test periods are identified.

The ambient temperature, measured by a meteorological station situated on a 9.1 meter (30 foot) tower which is permanently located on the plant property, varied from -13°C (8°F) at 0800 hrs. to -9°C (15°F) at 1000 hrs. on November 29. (A weather summary for the test periods is given in Appendix E.)

During the evening of November 29 a boiler tube in Unit #1 failed causing this unit to be off line for the second and third test days. Consequently, a comparison between the particulates from the plumes of the two stacks could not be made as was done during the Arapahoe tests.

On the second and third test days, November 30 and December 1, the wind was from the west so that upslope conditions persisted. Fortunately, on these days, the winds in the mornings and early afternoons were of sufficiently low velocity so that plume sampling could be safely conducted. The weather during this period was dominated by fast moving fronts in the evenings with snow showers occurring nightly. With the exception of several hours during the second test day, stratocumulus and/or cirrus cloud covers persisted during the entire test period making ground observations of the power plant plumes difficult.

Due to the plant layout, shown in Figure 23, it was not possible to sample in close to the plant with the wind coming from the west. On the second and third test days, the balloon was launched from a north-south service road located approximately 675 meters due east of the 122 meter stack. On November 30 the plume from this stack was sampled from 0918 hrs. to 1253 hrs. for sampling periods ranging from 5 minutes to 45 minutes. On December 1 the same plume was sampled from 0950 hrs. to 1410 hrs. for sampling periods ranging from 20 minutes to 120 minutes (a summary of the plume sampling is reported in Appendix F). The downwind distances of the balloon-borne sampler from the stack during flight operations on the second and third test days have been estimated to be between 900 and 1000 meters which are distances of seven to eight times greater than the maximum sampling distance of the Arapahoe tests. Attempts to monitor the plume at greater "stack to balloon" distances were not made on these days because the atmospheric instability caused the plume to become somewhat undefined at further distances.

Due to the difficulty of observing the plume because of the cloud cover, it was necessary for a member of the DRI field team to drive a vehicle to various locations both inside and outside the plant property in order to direct and/or confirm the vertical position of the balloon relative to the plume. Photographs were taken by the observer from the various vantage points in order to document the flight operations. Communications were always maintained between the observer and the personnel at the launch site through the use of two-way radios. Time lapse photography of the flight operations, at a rate of one frame per second, were also taken on the first and second test days. On November 29 a 16 mm movie camera equipped with a zoom lens and intervalometer was positioned 550 meters south of the plant at a perpendicular location to the plane passing through the 122 meter stack and the balloon. Since the sampling was conducted at a relatively short distance from the stack (~150 meters), both the stack and the balloon could be kept in the field of view of the camera. A battery operated clock was also positioned in the camera field of view to record the time. The camera locations on November 29 and November 30 are shown in Figure 22. On November 30 the distance between the camera and the stack was 1.3 kilometers. On this day the camera was located upwind of the plant at approximately 20 degrees south of the "stack to balloon" plane as measured from the stack. It was necessary to position the camera in such a manner in order to again have both the stack and balloon in the field of view. On December 1 the cloud cover was excessive such that time lapse photography was not employed. The resulting movies have proved to be useful in verifying the vertical positioning of the balloon in the plume and in showing the general atmospheric stability.

Although the ambient air temperature was cold during the test periods (see Appendix E), the airborne particulate sampling system performed well. Due to the ambient temperature, the batteries in the airborne package and the ground stations were changed daily.

Particulate Analysis

All sections of the substrates on which particles were collected were examined using scanning electron microscopy/energy dispersive X-ray spectrometry to determine the collection effectiveness of various sampling times for the "source to balloon" separation distances reported above. In addition, the samples were examined to determine the particle size range, particle morphology and selected particle elemental composition. Sample preparation involved mounting portions of the exposed sections of the substrates onto standard glass slides using double sided adhesive tape. The mounted samples were vacuum coated with approximately 100 Å of carbon and then analyzed.

Sampling Time--

For the November 29 test, in which the "source to balloon" separation distance was approximately 150 meters, the 5 minute sample was adequate for SEM work, and the 15 minute sample is believed to be adequate for X-ray excitation analysis. The samples from the November 30 and December 1 tests, with the balloon estimated to be 900 to 1000 meters from the stack, revealed that a 20 minute sampling time is reasonable for SEM analysis. As far as the suitability for X-ray induced X-ray analysis, most samples were too lightly loaded to permit sensitivities to assess trace elements; the longest sample (120 minutes) is believed, however, to contain an adequate coverage to permit trace elemental analysis using X-ray excitation.

Particle Size--The most predominant species observed were typically single spheres with a radius of 1.0 2.0 μm in diameter. Single spheres up to 9 μm in diameter were also observed (Figure 24). Single spheres < 1.0 μm were rare. Agglomerates of particulates were also prevalent and ranged up to 55 μm in effective diameter (Figure 25). These agglomerates often contained a relatively large number of particulates 0.5 - 1.0 μm in diameter as well as larger particles (see also Figures 26 and 27). In general, the Hayden Station during this test period was producing larger particulates than were observed at the Arapahoe Station and more agglomerates as well.

Particle Composition--Individual and agglomerated flyash spheres were usually composed of silicon and aluminum with some calcium, potassium, and iron, although flyash composed mainly of silicon and calcium were also observed. Sulfur rich material was usually observed with agglomerates (Figures 25, 26, and 27) and larger spheres of flyash (Figures 24 and 28). The sulfur rich material associated with flyash agglomerates usually appeared to form the matrix binding material. Whether it is from the coal itself or is a by-product of the LPA-40 conditioning agent, which is known to be an aqueous solution containing a large fraction of ammonium sulfate[1,2] cannot be determined from this brief test program. In order to address this question, it is hoped that in the future a more controlled test program of the Hayden Unit #2 plume can be conducted in which plume samples will be collected while the unit is operating both with and without the conditoning treatment.

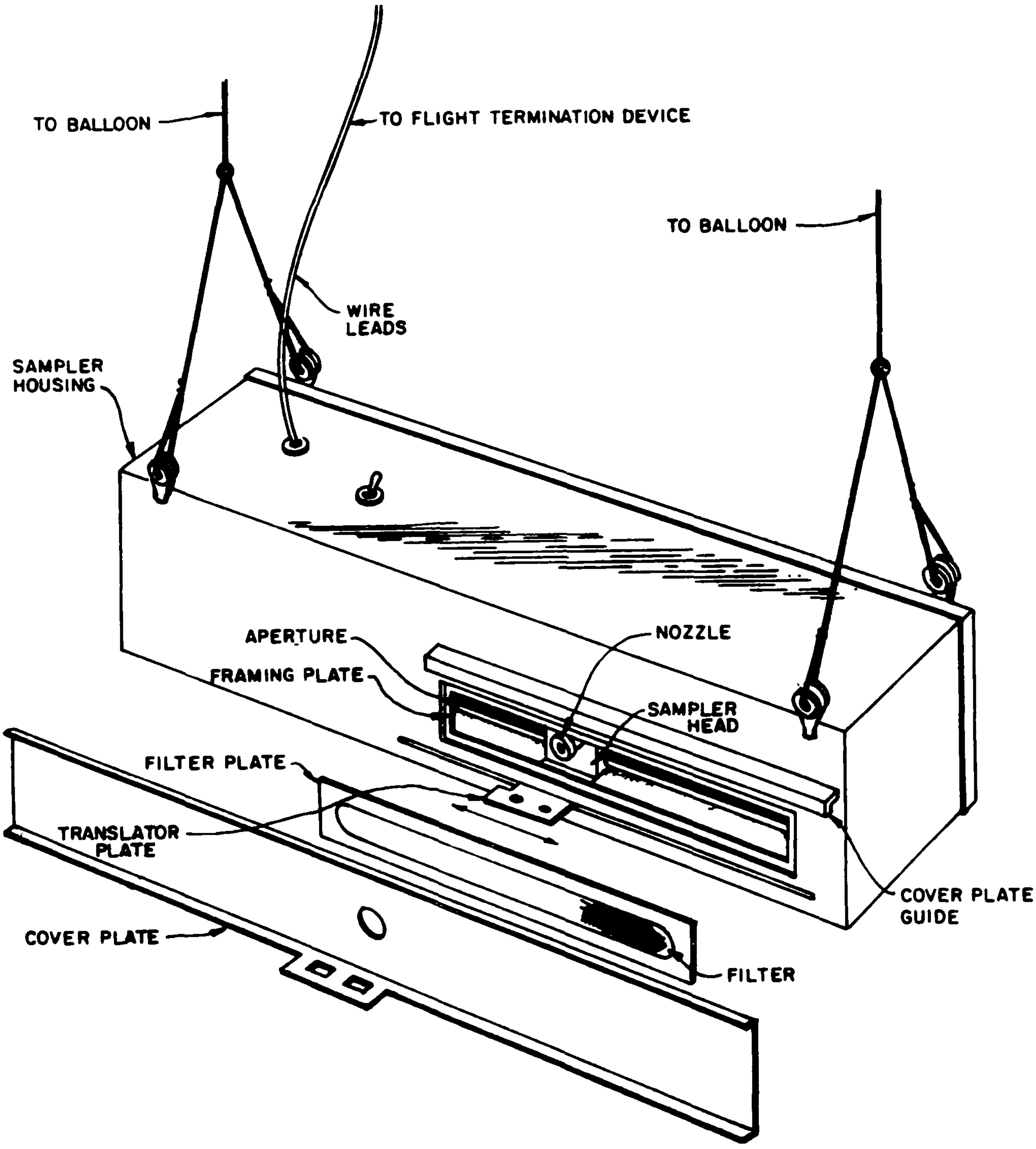


Figure 1. Front perspective view of particulate sampler.

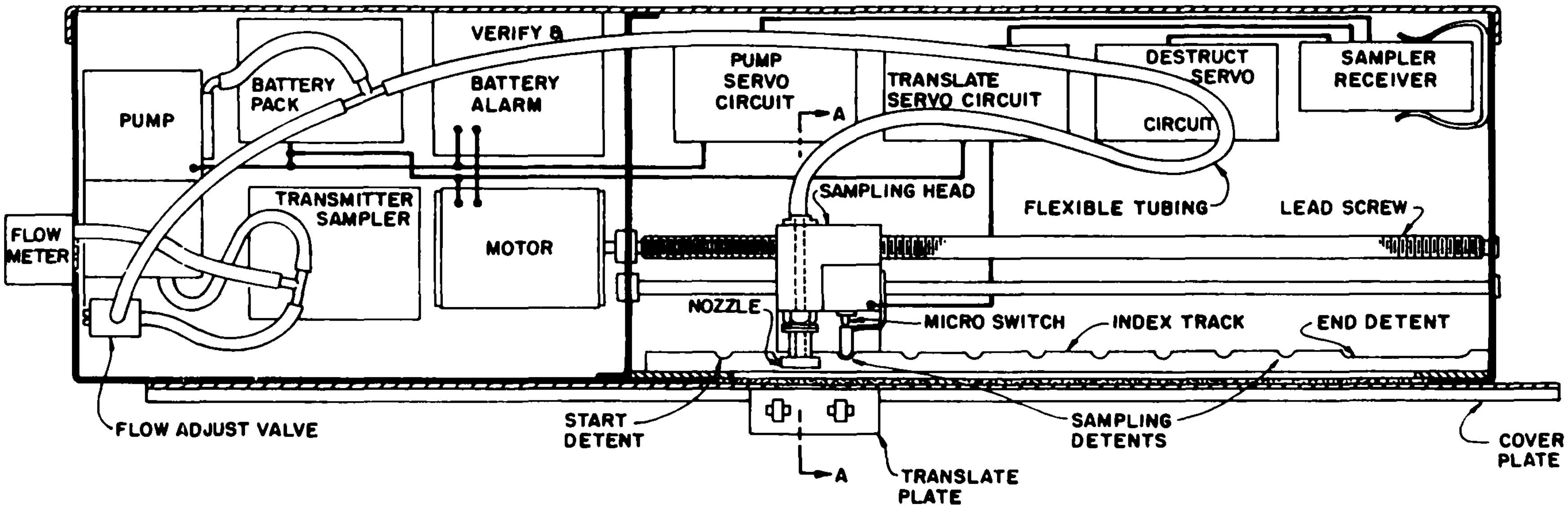
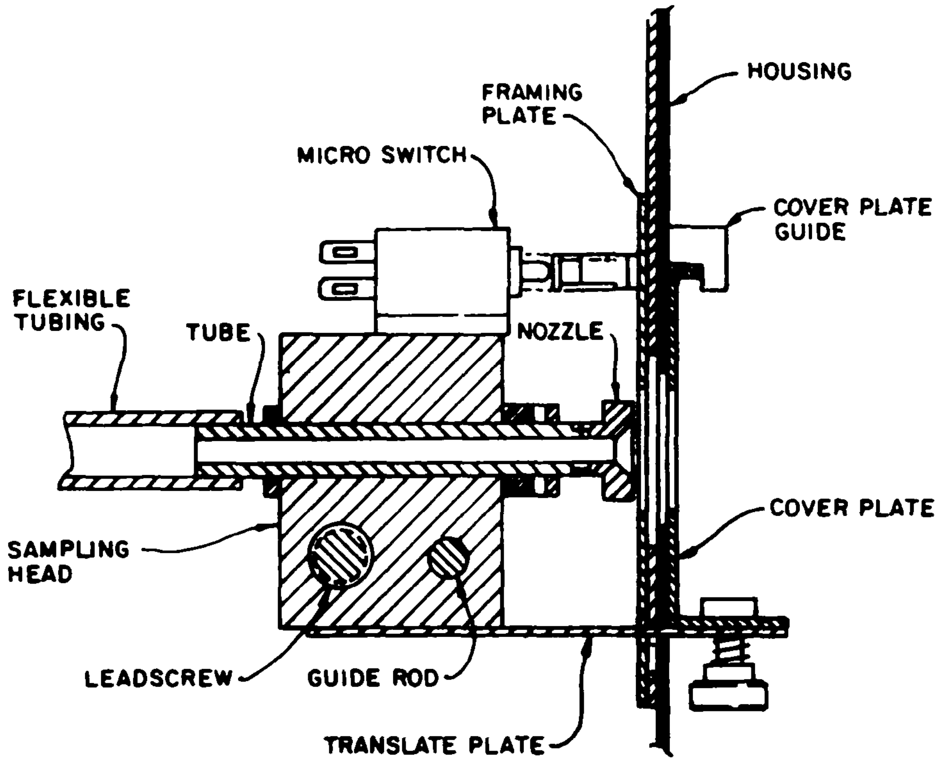


Figure 2. Top plane view of particulate sampler.



SECTION A-A

Figure 3. Cross-section view of sampling head.

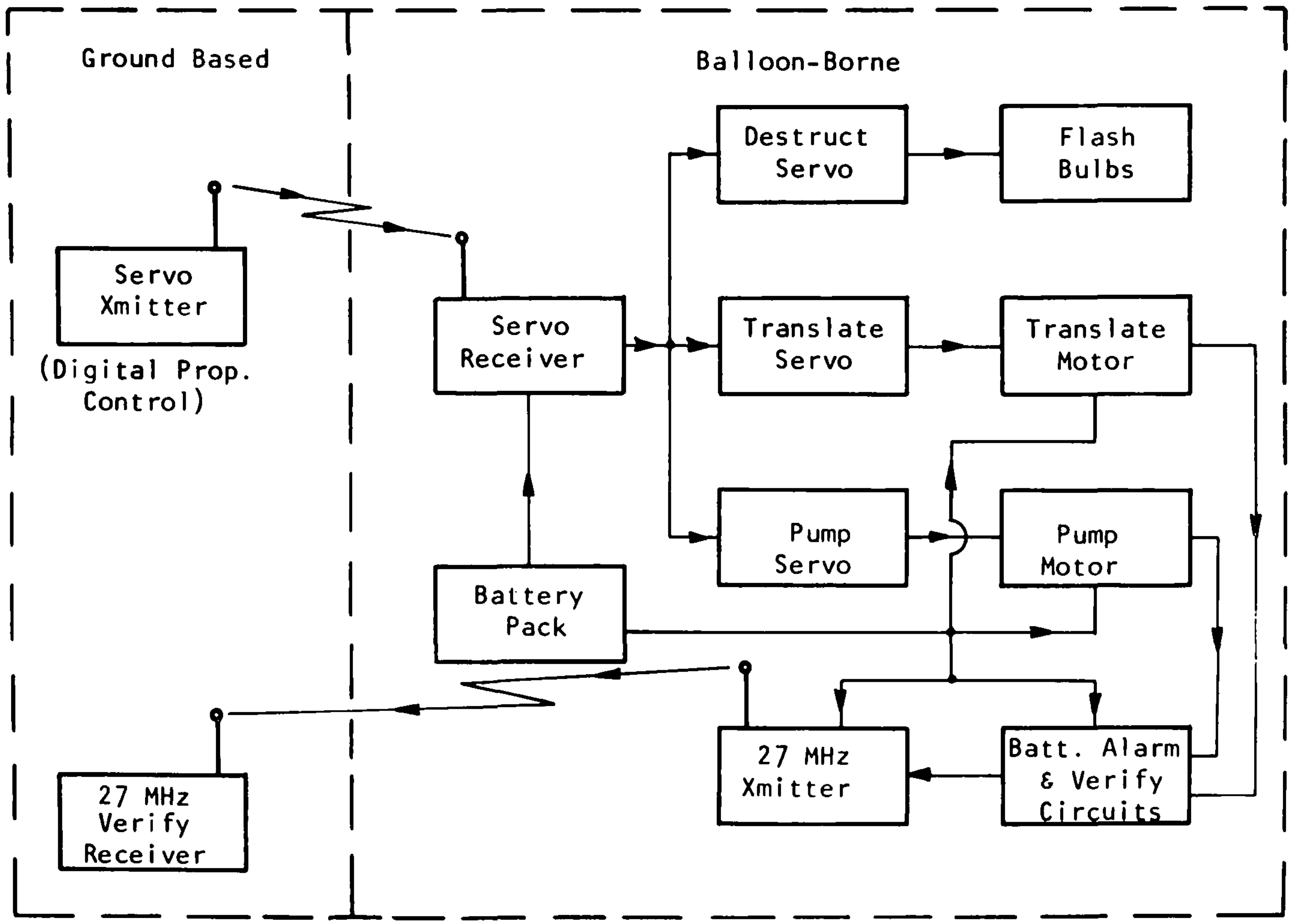


Figure 4. Electronic system block diagram of particulate sampler.

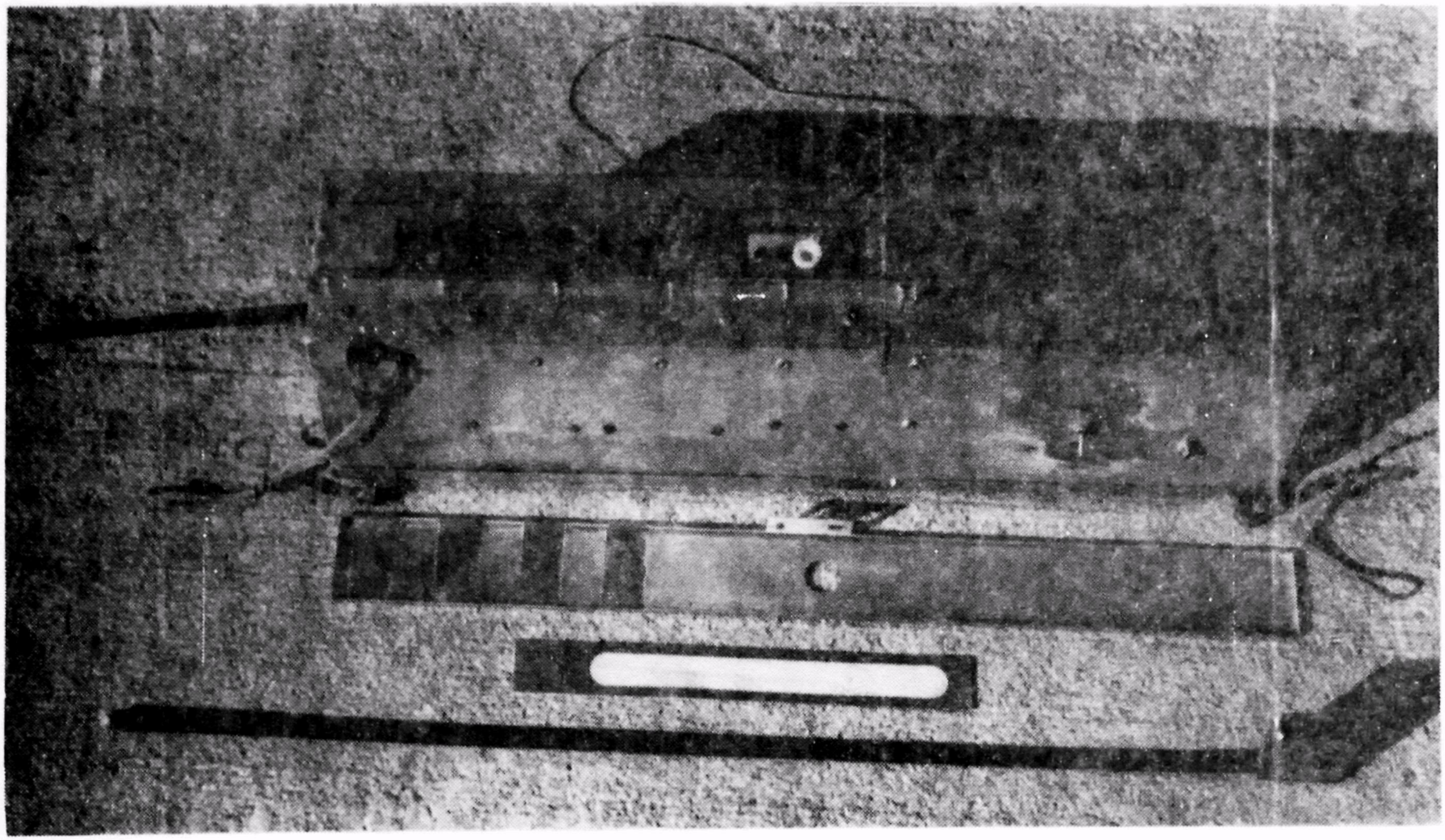


Figure 5. Balloon-borne particulate sampler.

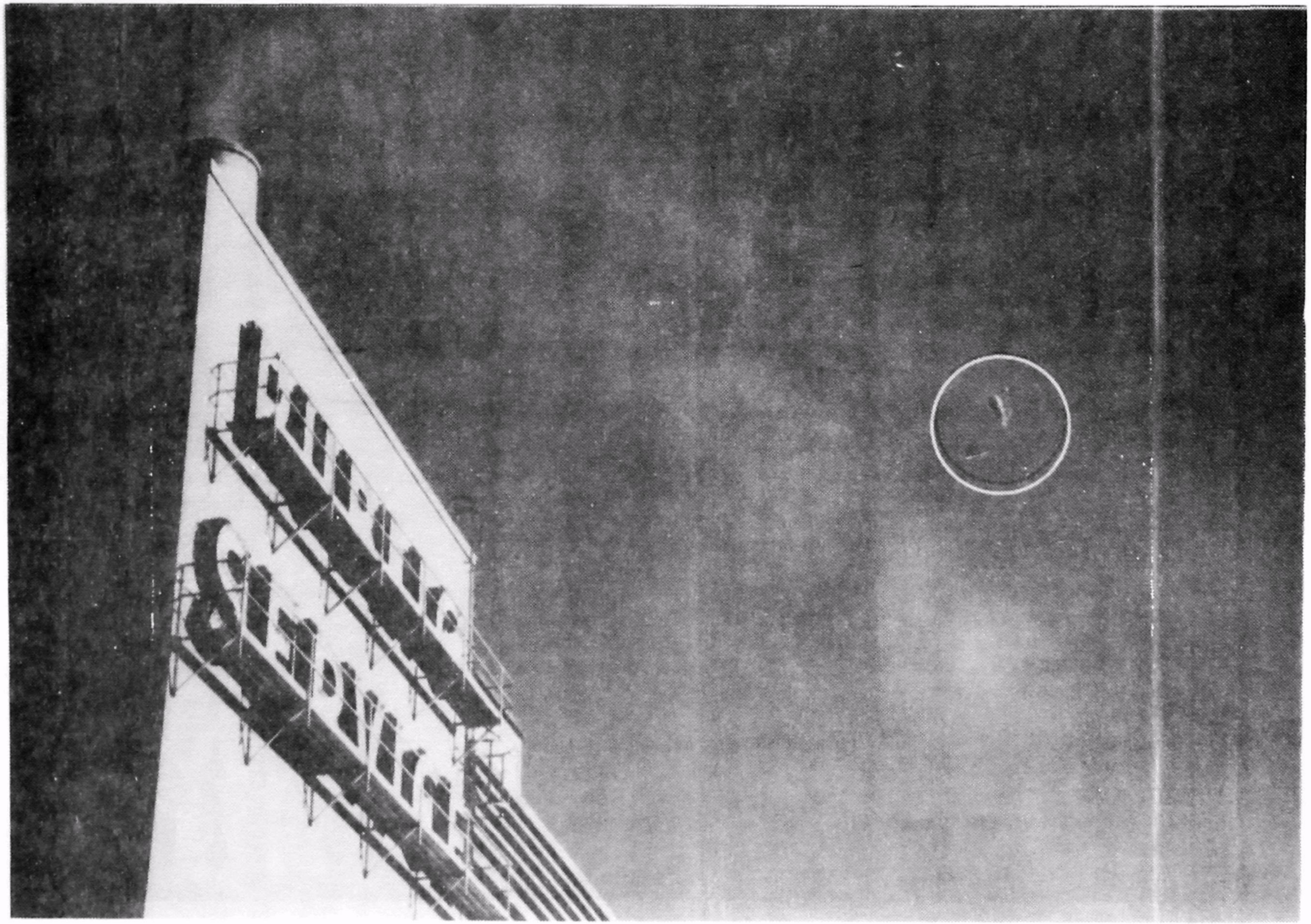


Figure 6. Sampling of east plume, Arapahoe Station, July 12, 1977 - photograph taken looking northwest.

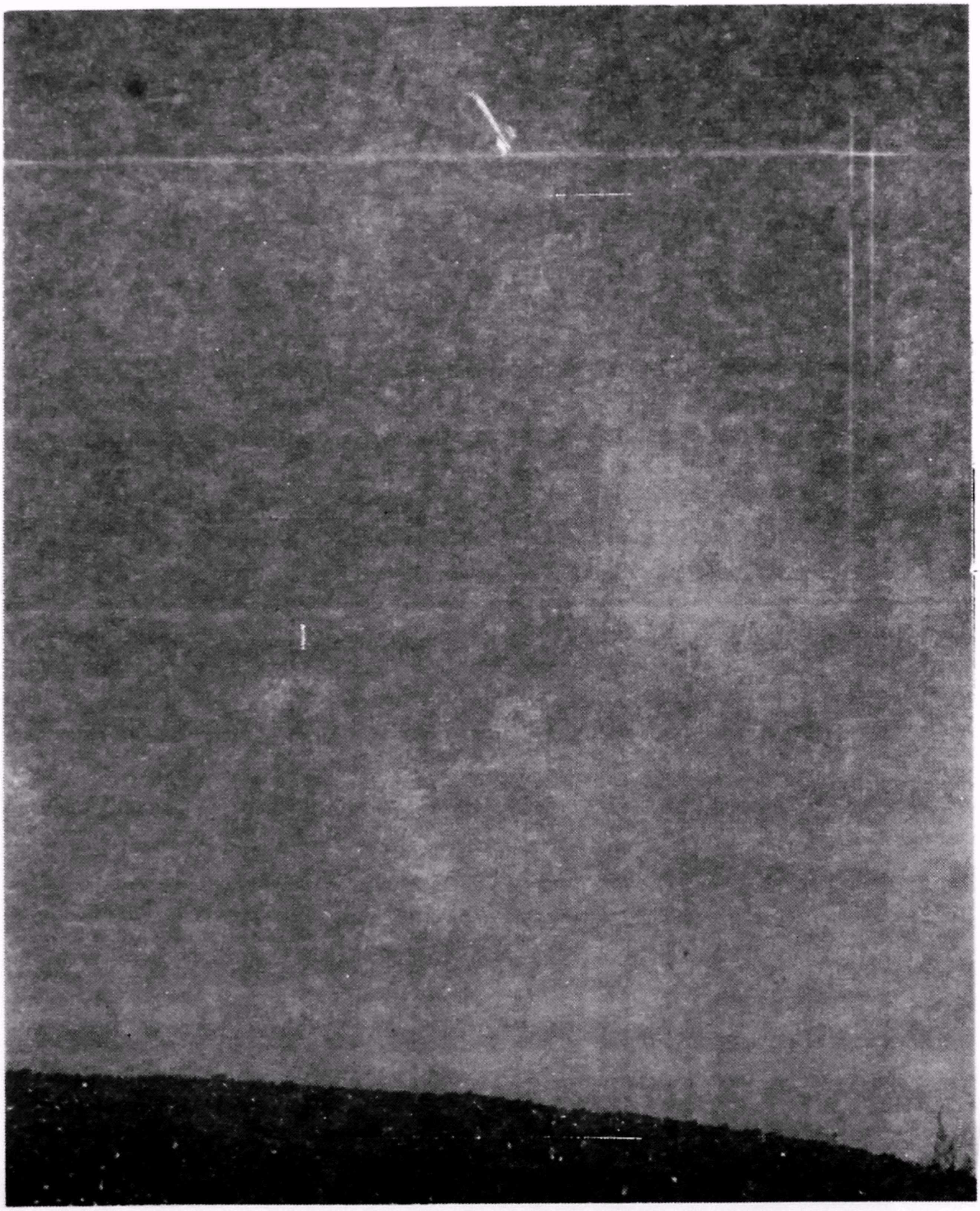


Figure 7. Sampling of east plume, Arapahoe Station, July 12, 1977 - photograph taken looking north.

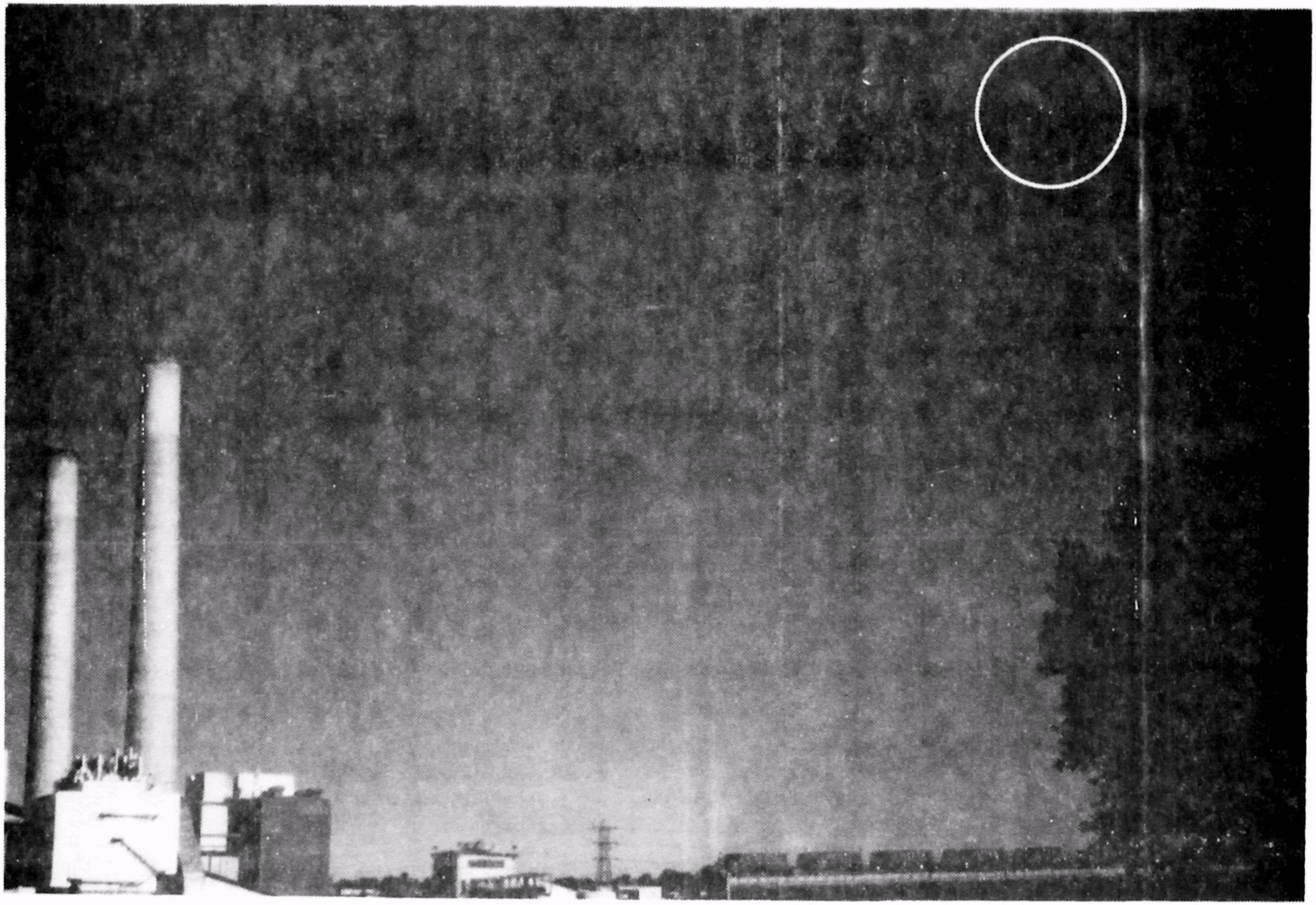


Figure 8. Sampling of east plume, Arapahoe Station, July 12, 1977 - photograph taken looking west-northwest.

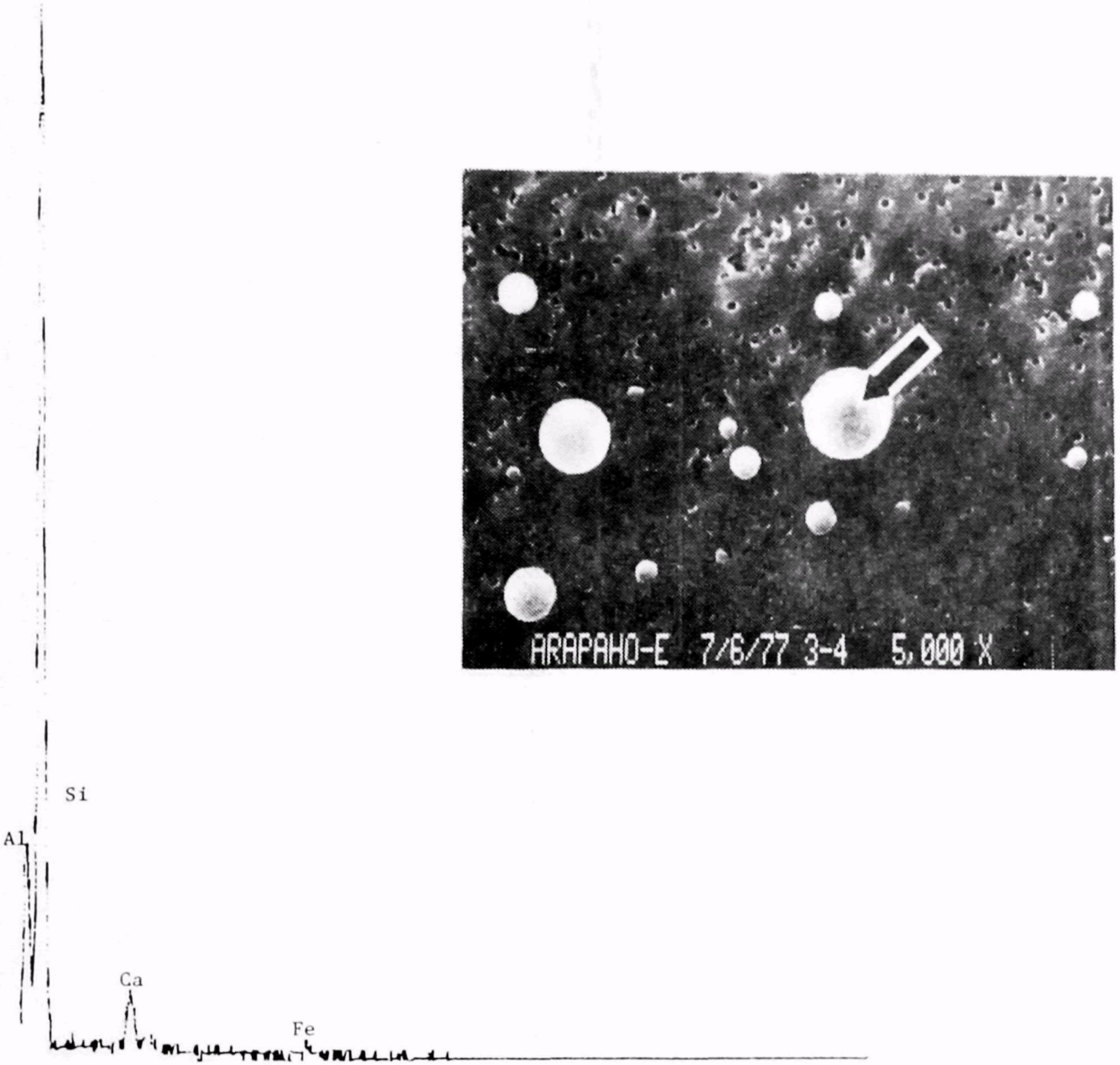


Figure 9. Typical flyash - east plume, Arapahoe Station, July 6, 1977

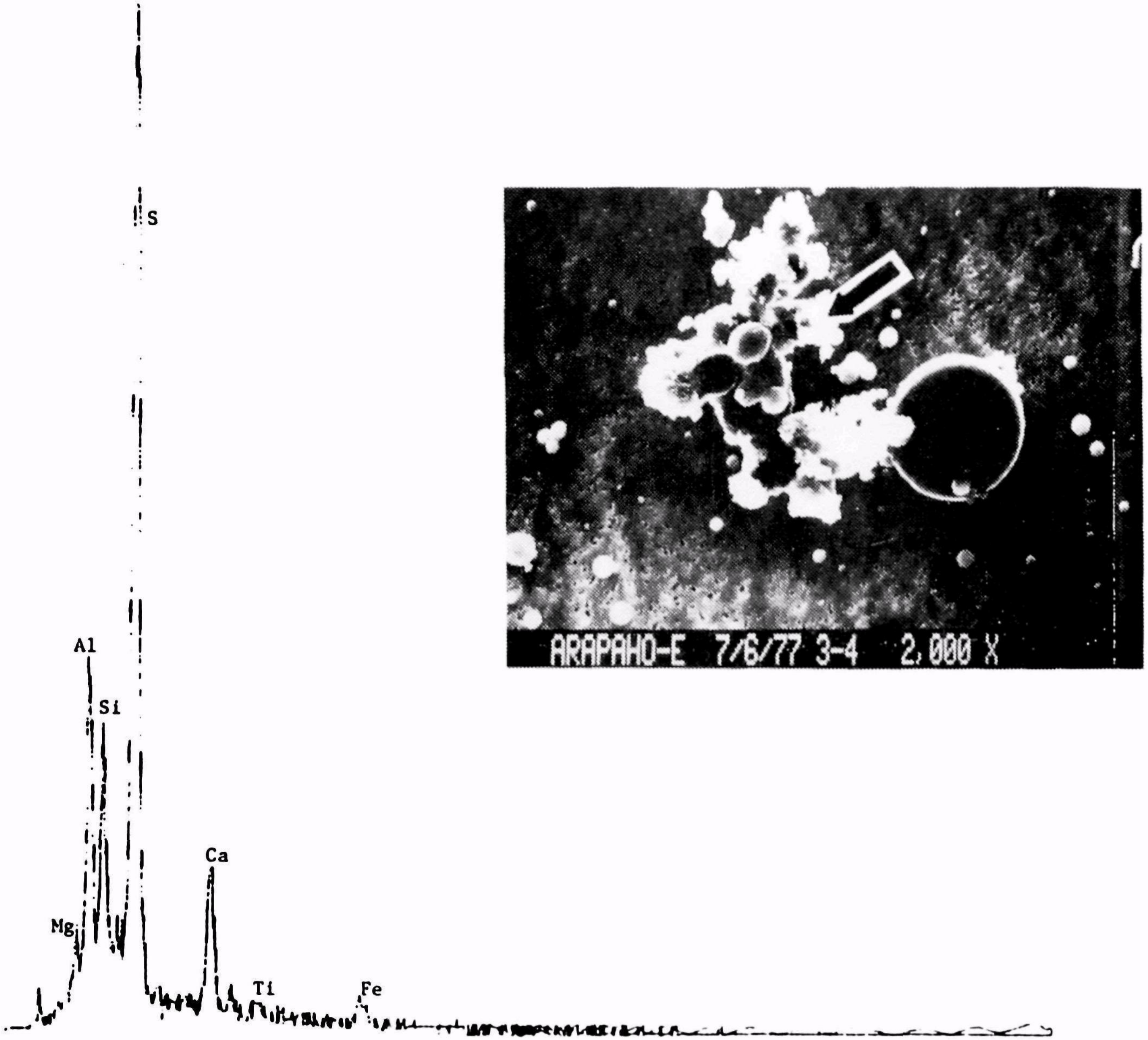


Figure 10. Large particle agglomerate rich in sulfur - east plume, Arapahoe Station, July 6, 1977

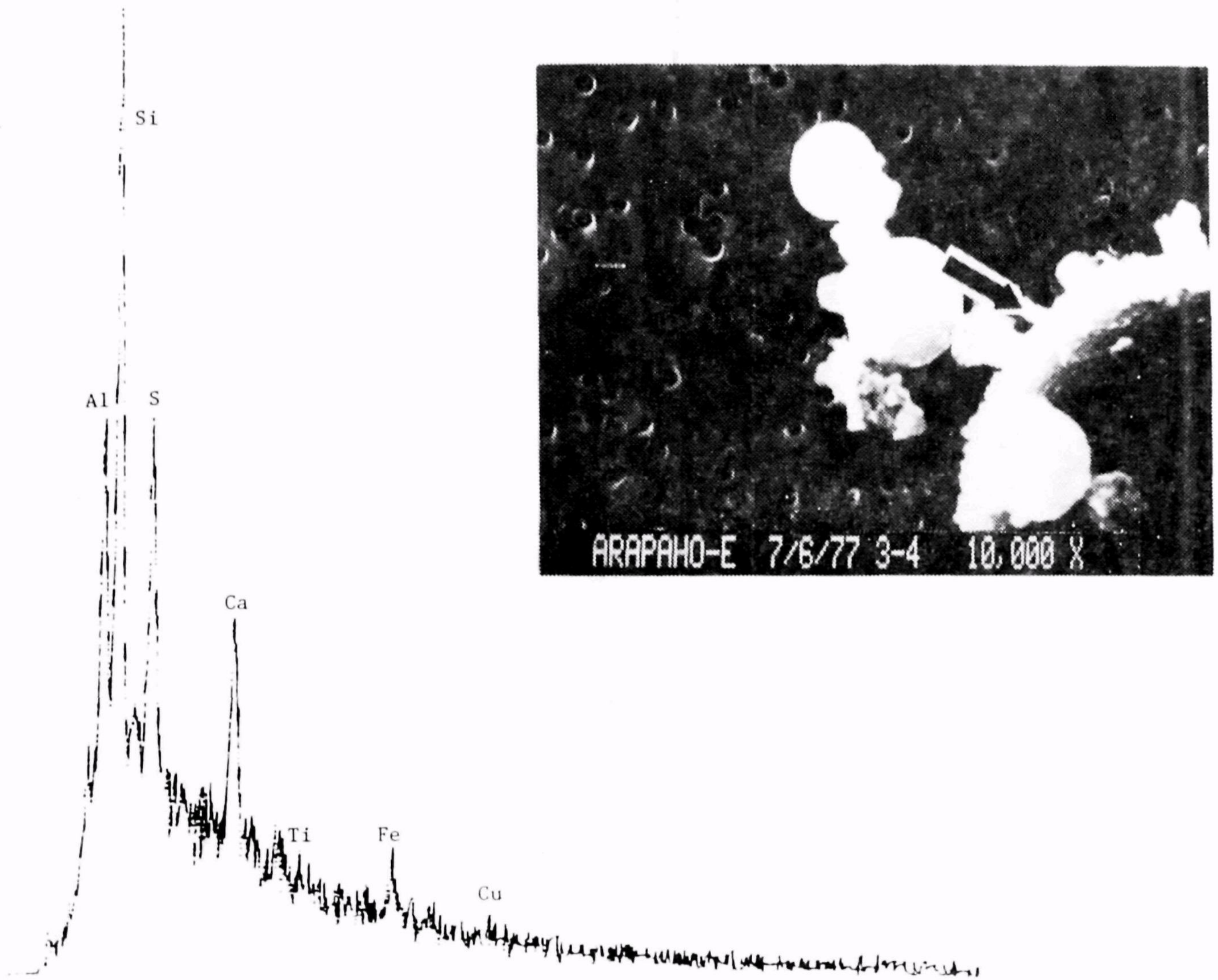


Figure 11. Small particles rich in sulfur attached to large flyash particle - east plume, Arapahoe Station, July 6, 1977

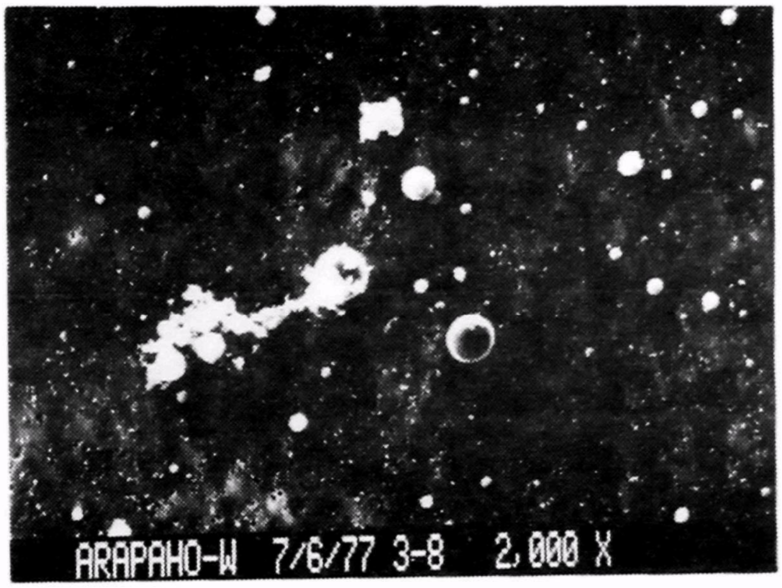


Figure 12. Typical flyash - west plume, Arapahoe Station, July 6, 1977.

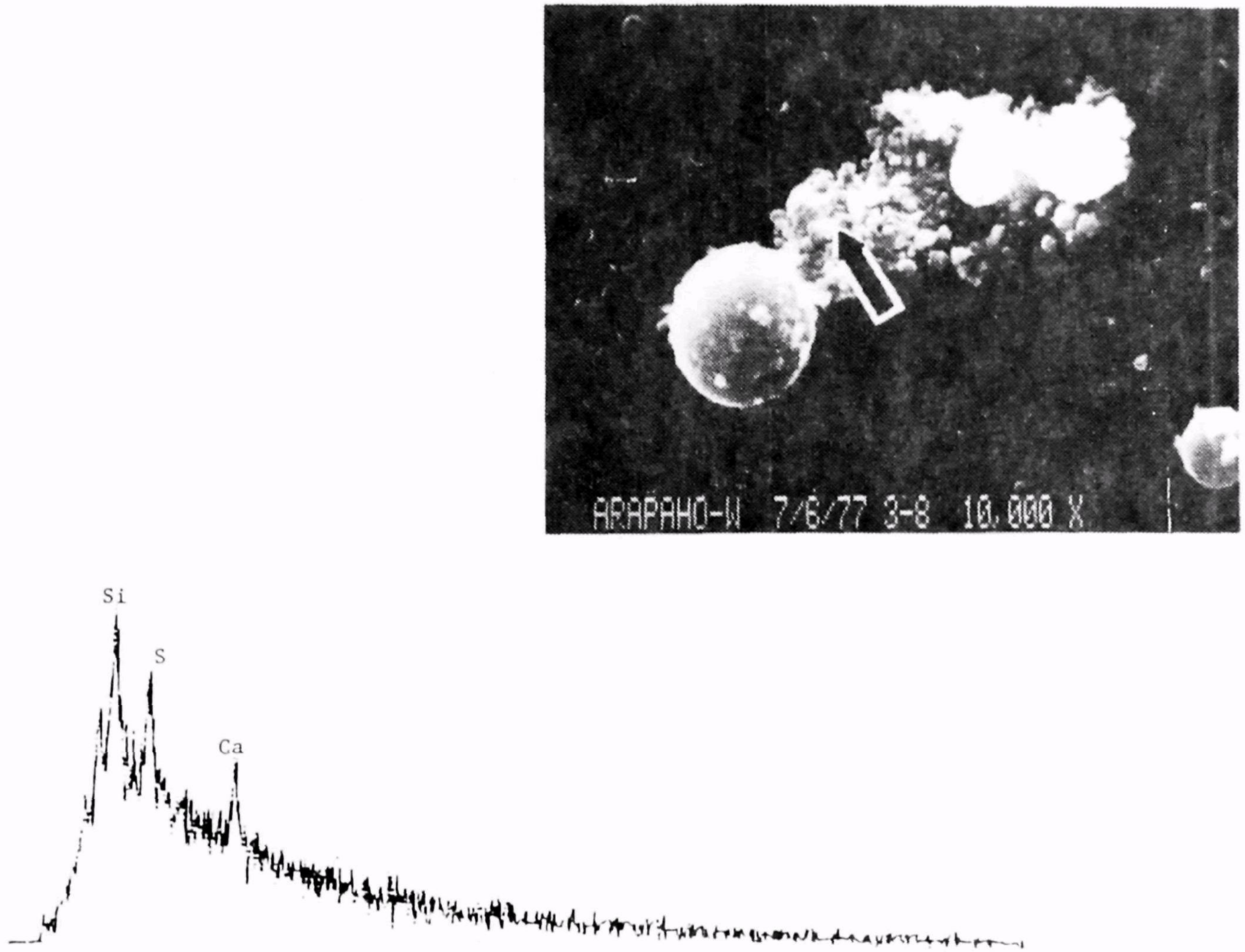


Figure 13. Carbonacious particle agglomerate - west plume, Arapahoe Station, July 6, 1977.

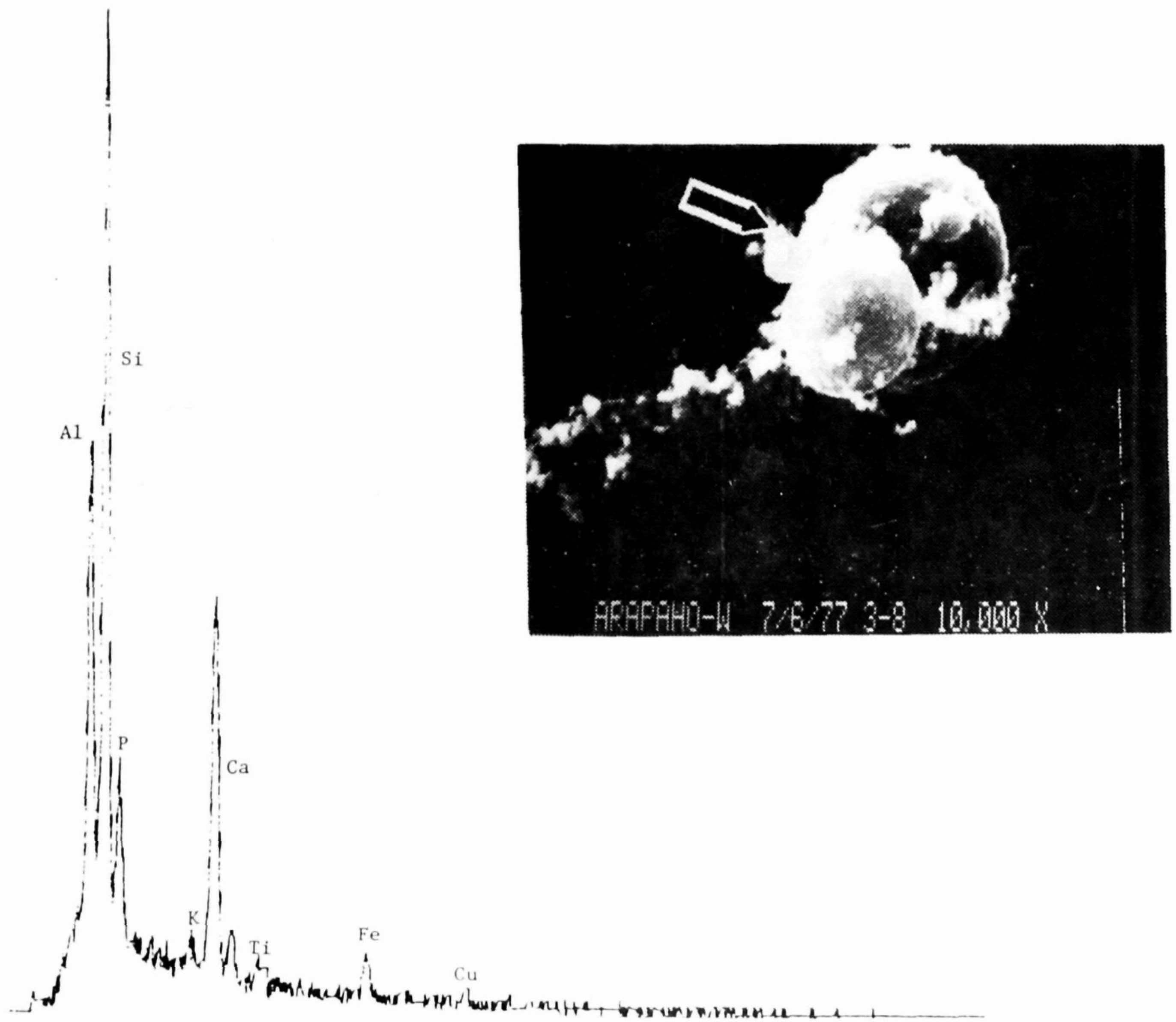


Figure 14. Small particle rich in phosphorous attached to flyash - west plume, Arapahoe Station, July 6, 1977.

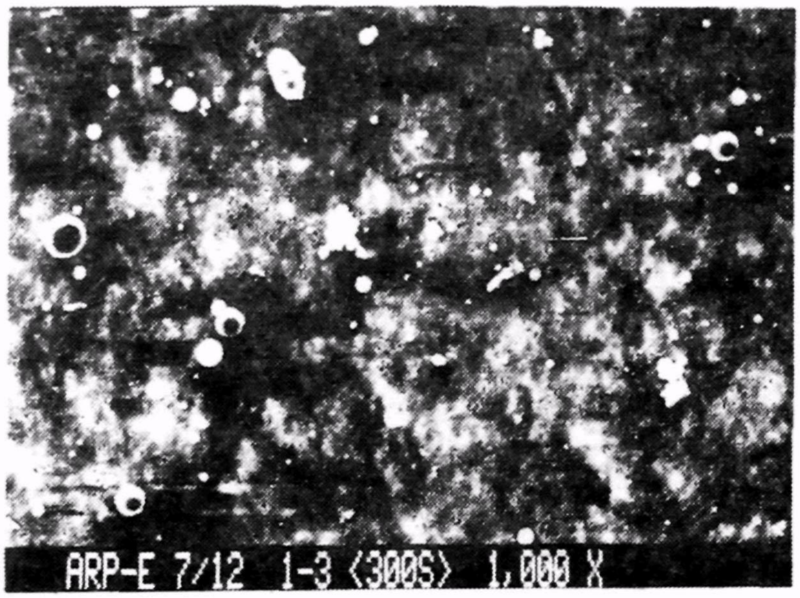


Figure 15. Typical flyash from east portion of east plume, Arapahoe Station, July 12, 1977.

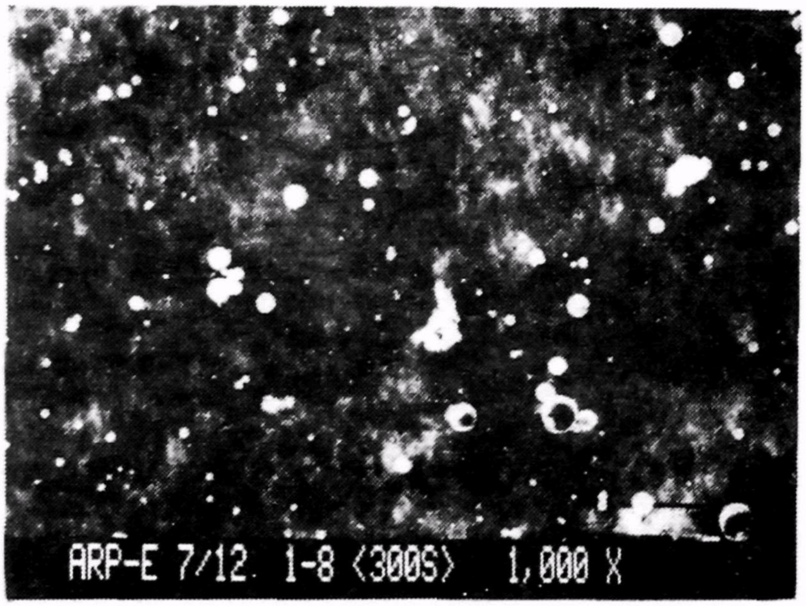


Figure 16. Typical flyash from west portion of east plume, Arapahoe Station, July 12, 1977

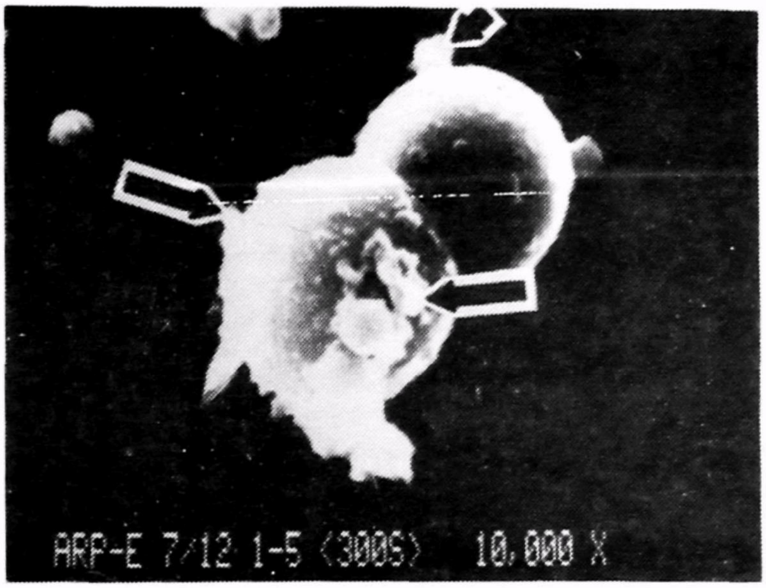


Figure 17. Fine particles rich in sulfur (arrows) attached to surface of flyash - east plume, Arapahoe Station, July 12, 1977.

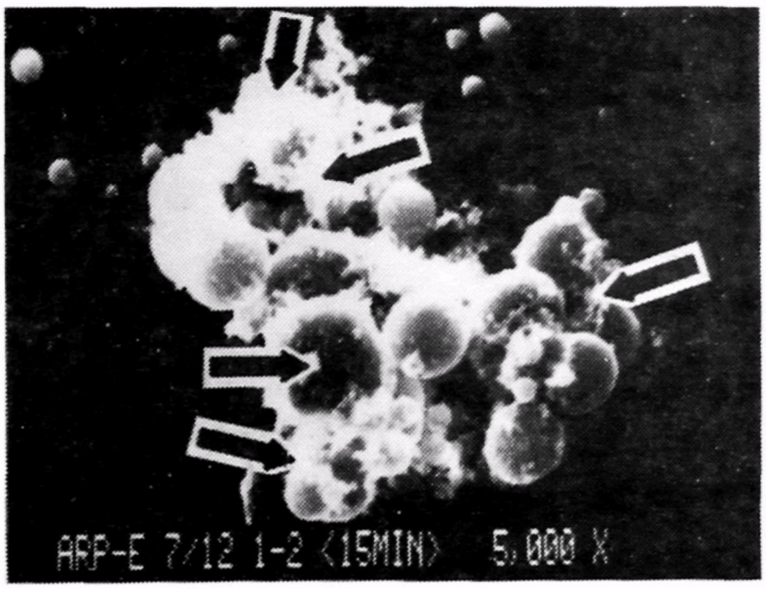


Figure 18. Fine particle agglomerates rich in sulfur (arrows) associated with flyash - east plume, Arapahoe Station, July 12, 1977.

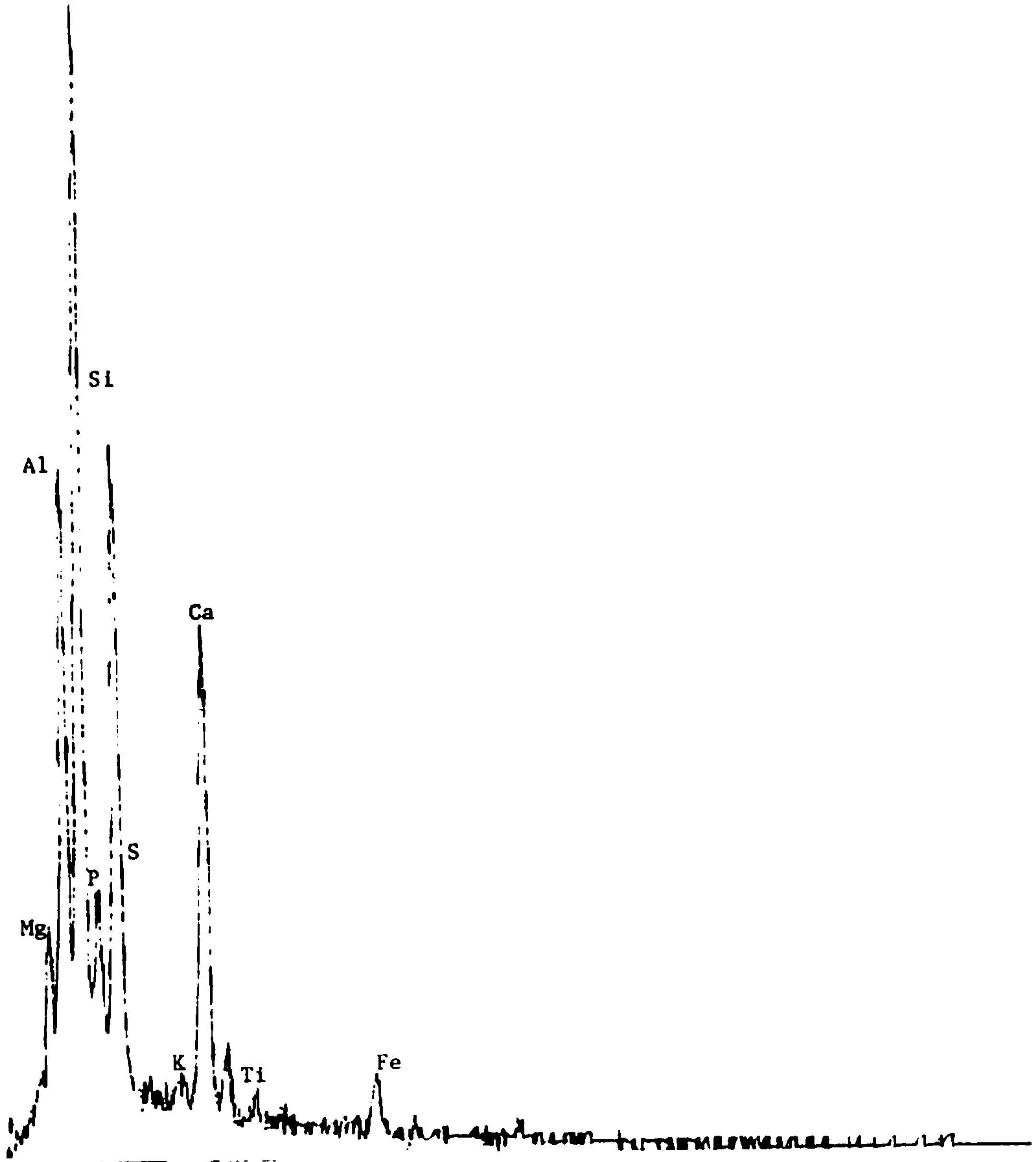


Figure 19. X-ray trace of sulfur-rich flyash surface - west plume, Arapahoe Station, July 12, 1977.

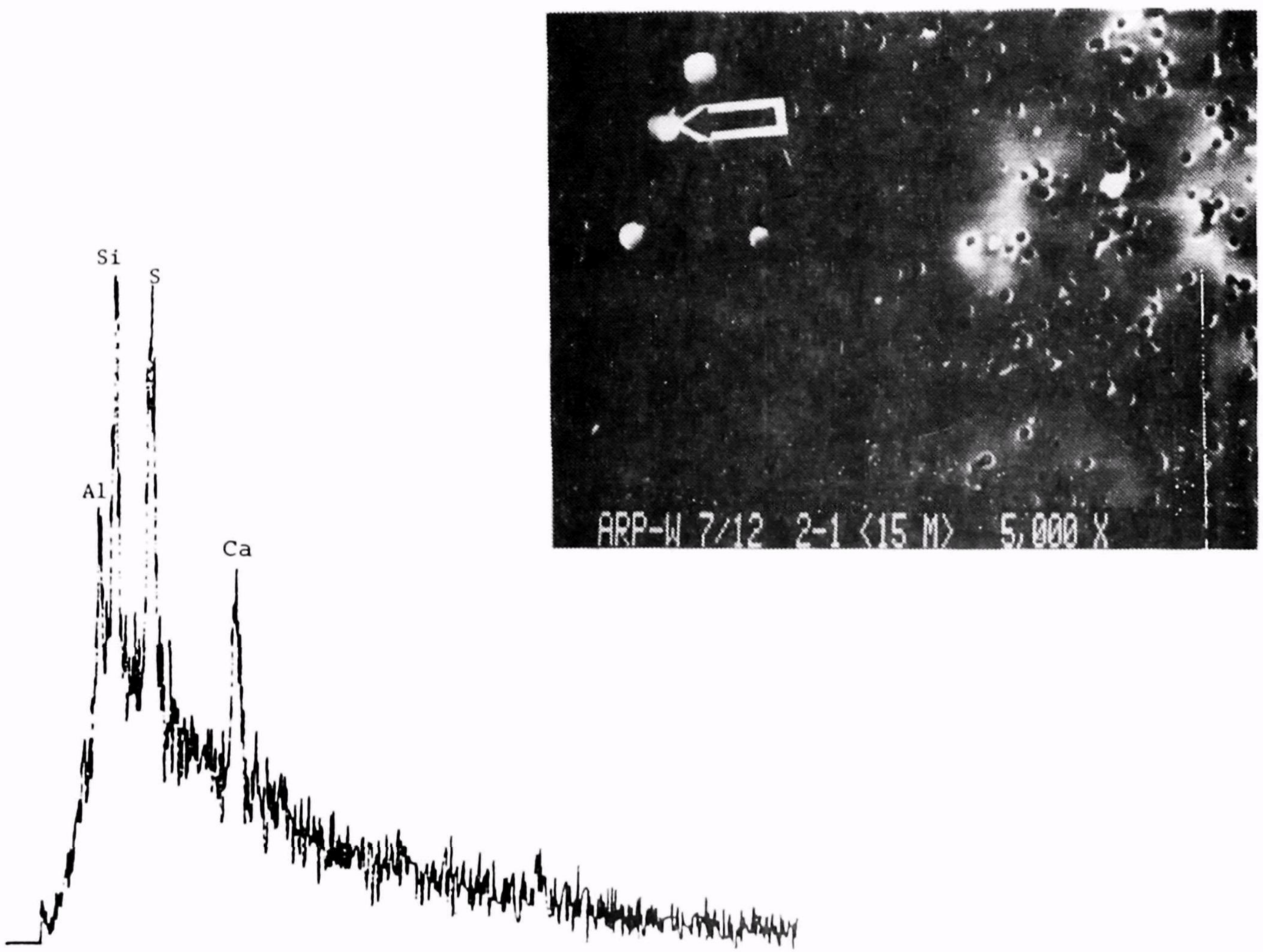


Figure 20. Spherical particles less than 1.0 μm - west plume, Arapahoe Station, July 12, 1977.

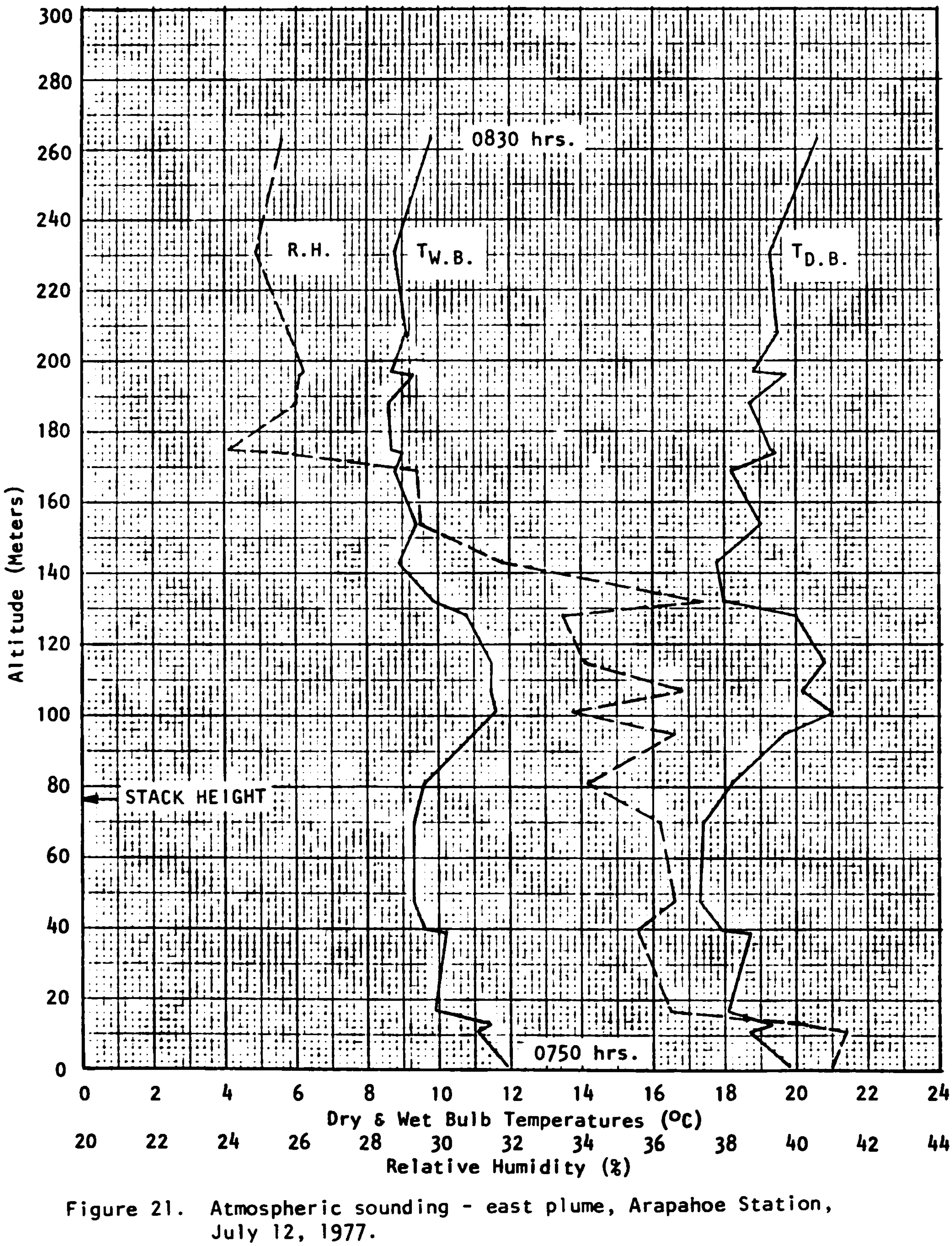


Figure 21. Atmospheric sounding - east plume, Arapahoe Station, July 12, 1977.

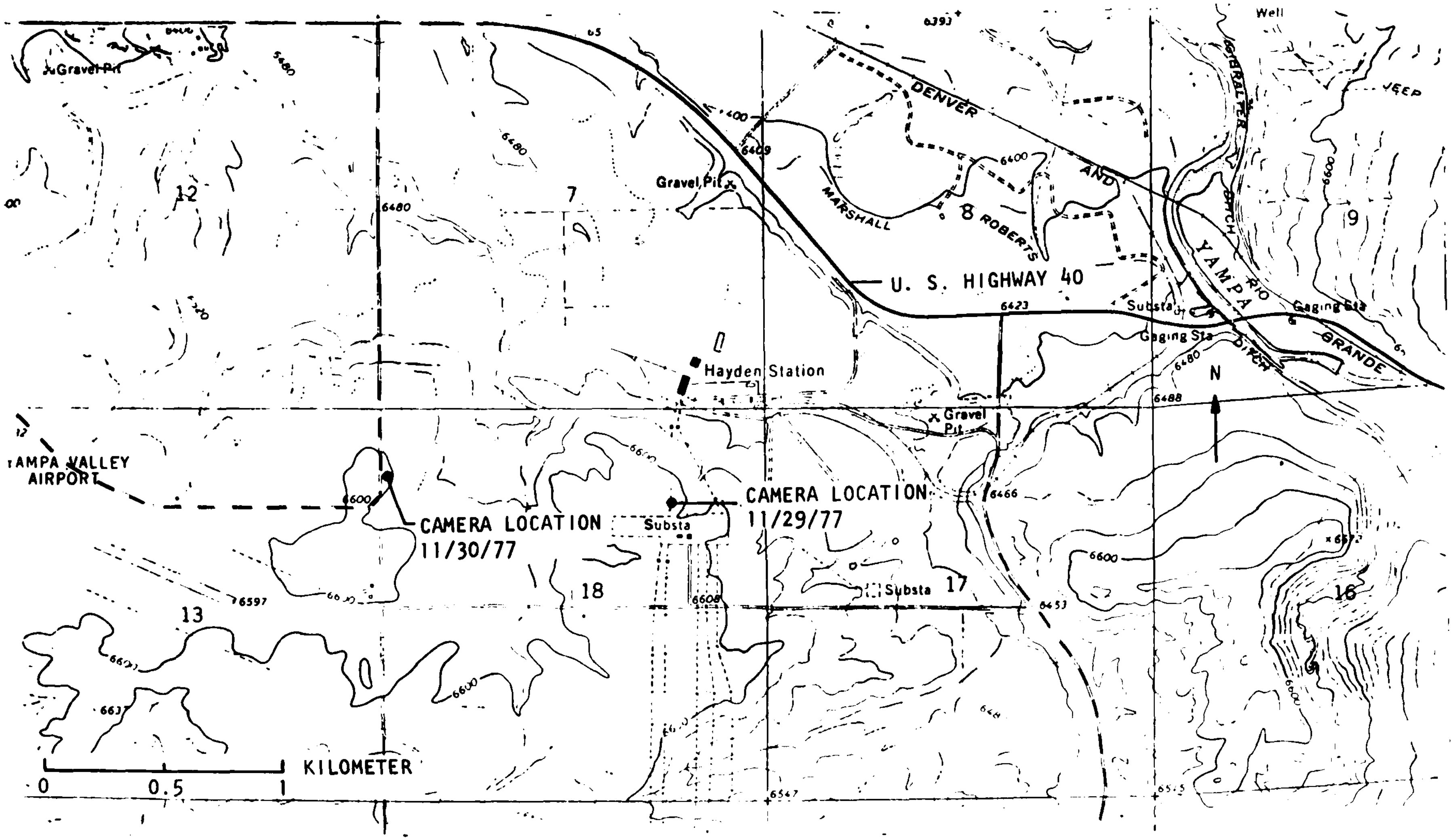


Figure 22. Topographic map of the Hayden Station area.

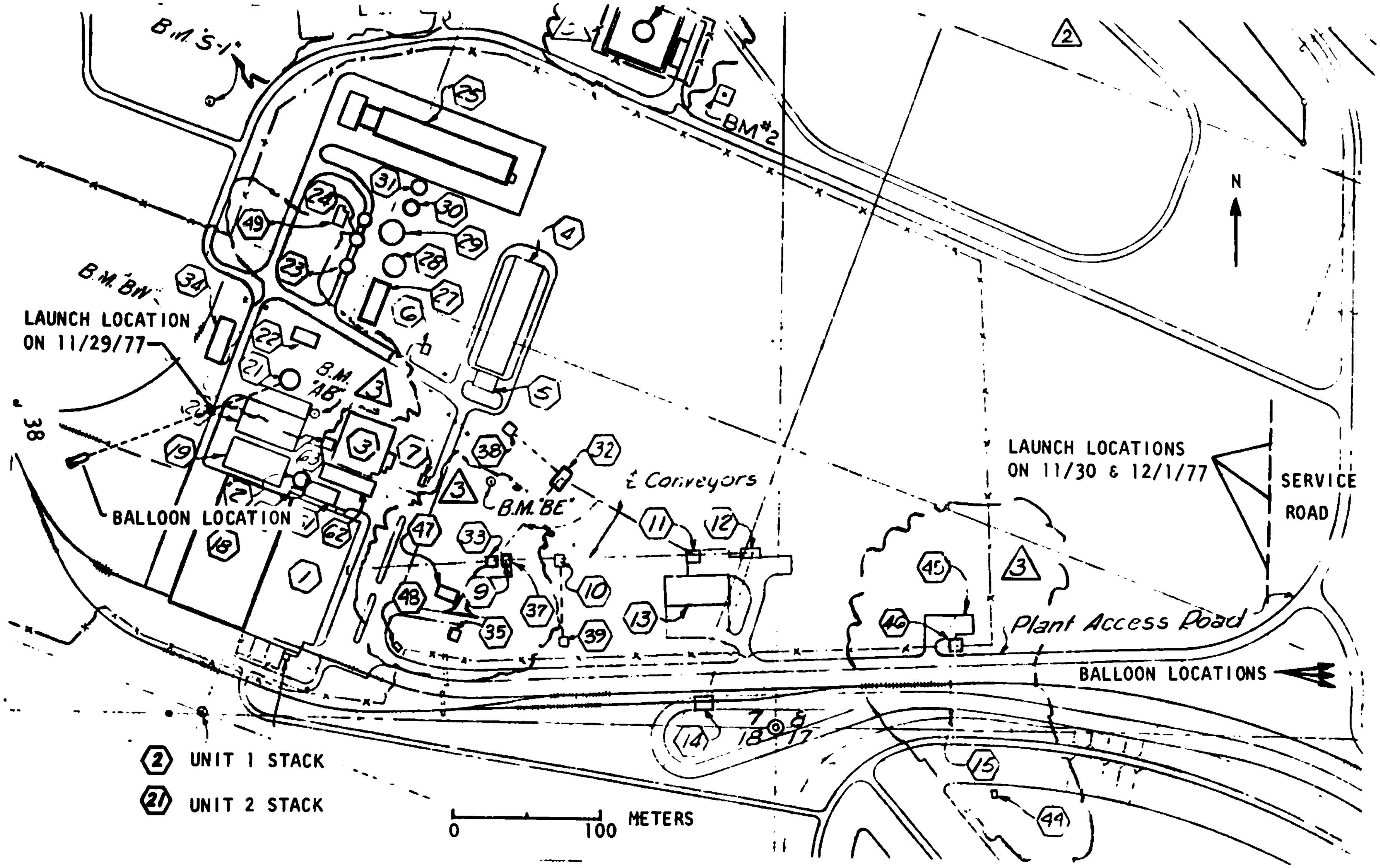


Figure 23. Plot plan of the Hayden Station

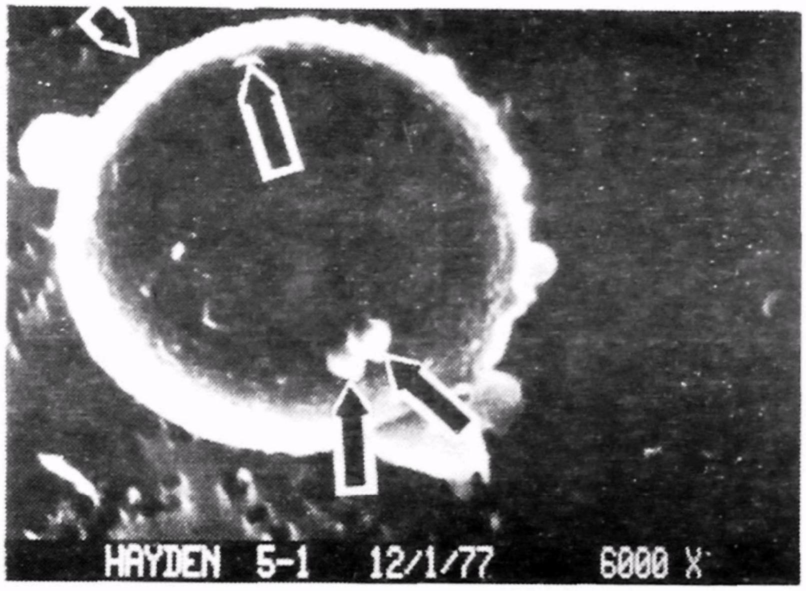


Figure 24. Sulfur rich areas (arrows) on large flyash particle - Unit #2 plume, Hayden Station, December 1, 1977.

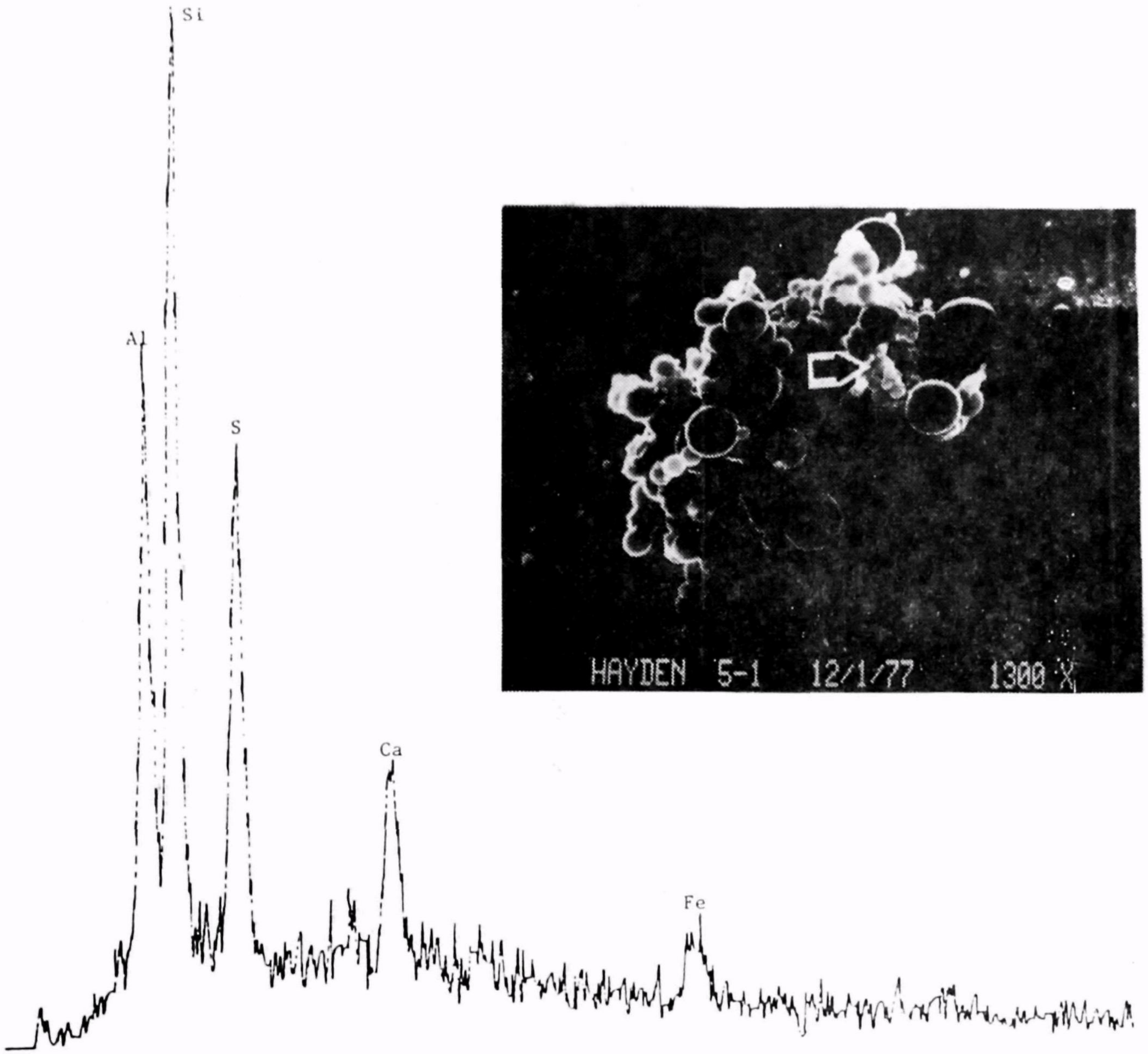


Figure 25. Large flyash agglomerate - Unit #2 plume, Hayden Station, December 1, 1977.

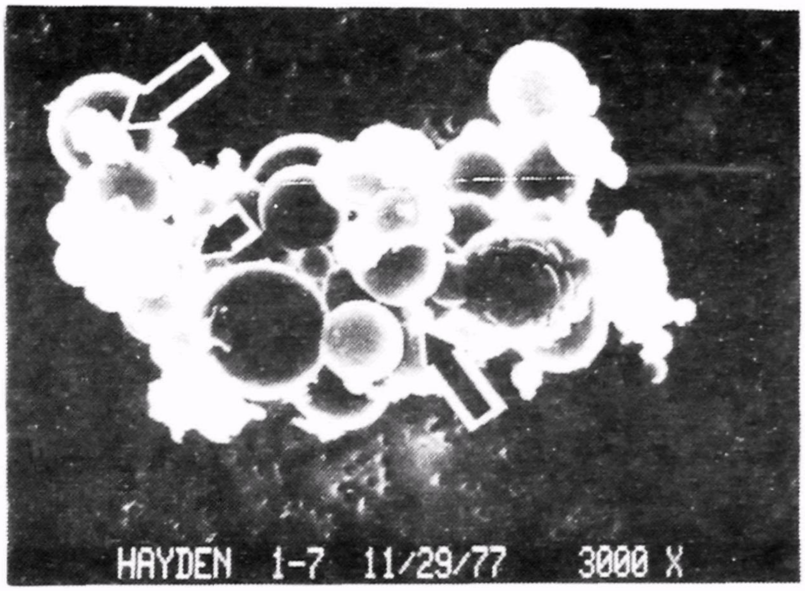


Figure 26. Sulfur rich areas (arrows) of flyash agglomerate - Unit #2 plume, Hayden Station, December 1, 1977.

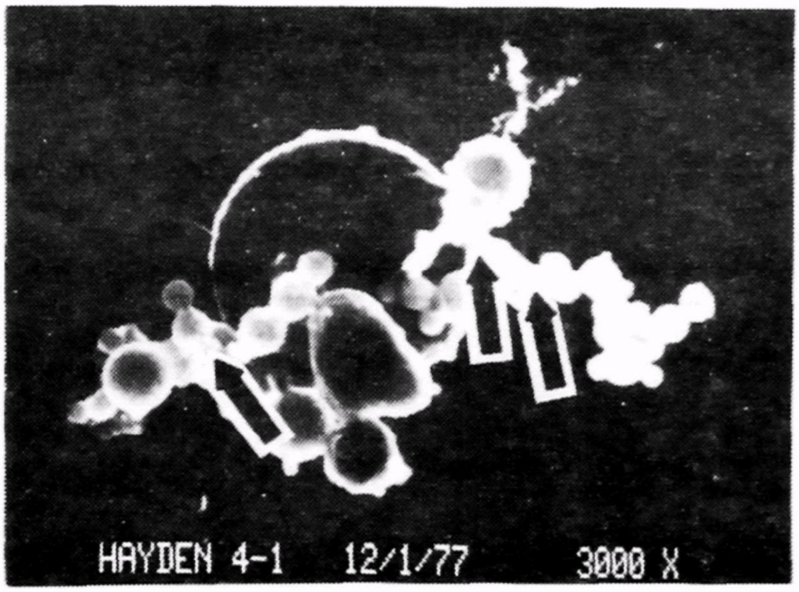


Figure 27. Sulfur rich areas (arrows) of flyash agglomerate - Unit #2 plume, Hayden Station, December 1, 1977.

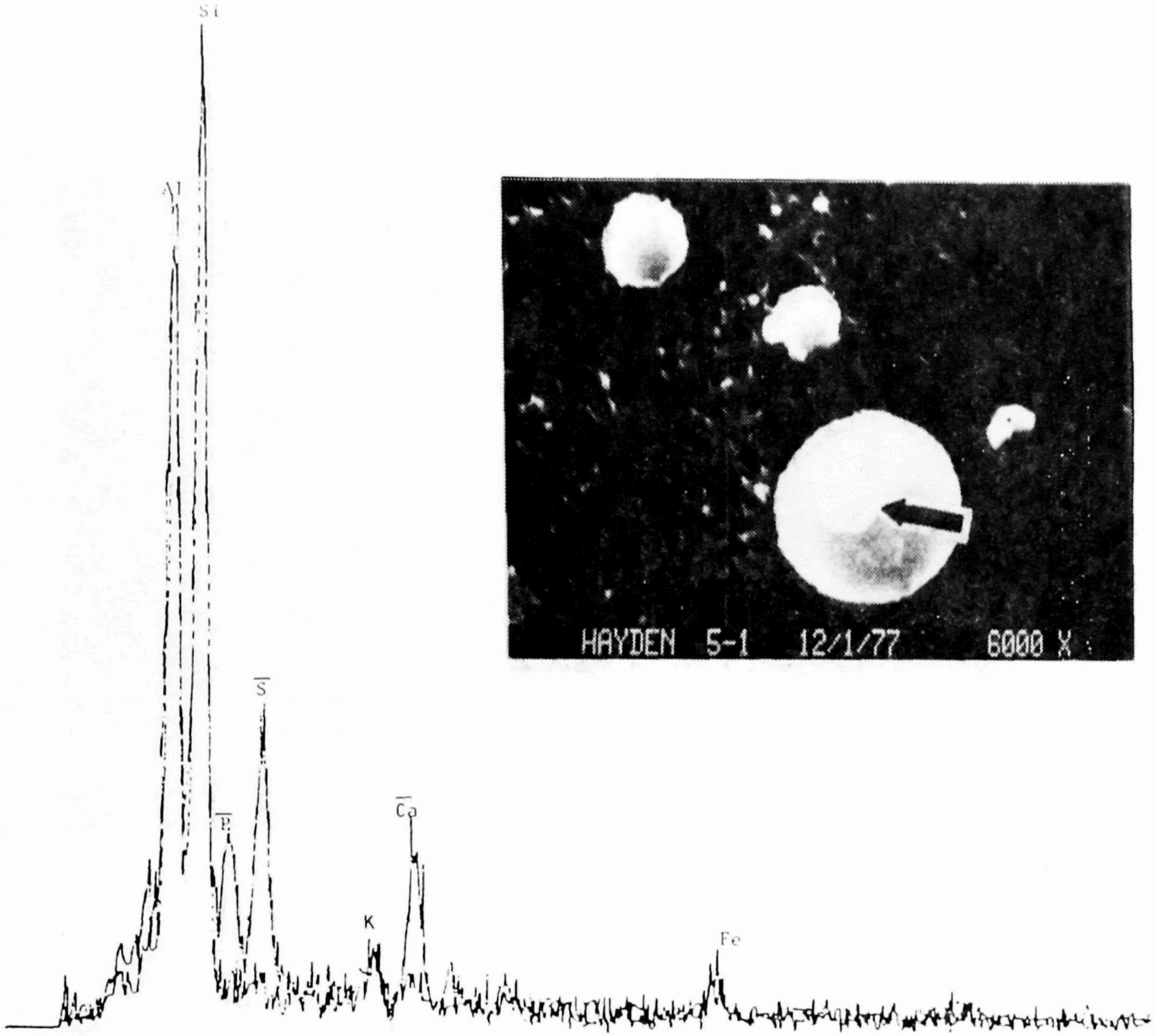


Figure 28. Sulfur rich particle associated with flyash (arrow). Spectrum shows increased concentrations of sulfur, phosphorous, and calcium - Unit #2 plume, Hayden Station, December 1, 1977.

REFERENCES

1. Bryant, R. W., L. Michael, and J. R. McNamara. In: Prepared Testimony before the Air Pollution Control Commission of the State of Colorado. Colorado-Ute Electric Association, Inc. November 14-15, 1977.

2. Pressey, R. E., et al. Four Corners Unit 4 Gas Conditioning. Denver Research Institute Report No. 5584. September 1977.

Appendix A

Typical Properties of the Coal Burned at the Arapahoe Station

I. Coal Test Results (Approximate Analysis)

Location: Arapahoe 4
Date sampled: 5/20/77
Sample I.D.: 5/24/77

% Moisture = 10.01
% Ash = 10.66
% Volatile Matter = 0
% Fixed Carbon = 0
% Sulfur = 0.62

Btu (Corrected) = 10595.43
Btu (Moisture - Ash Free) = 13355.29

II. Ultimate Analysis - "Energy Coal" Mine, Route County, Colorado

% Carbon = 58.00
% Hydrogen = 4.26
% Oxygen = 12.13
% Sulfur = 0.65
% Moisture = 11.25
% Nitrogen = 1.19
% Ash = 12.52

NOTE: Information supplied by the Public Service Company of Colorado.

Appendix B

Arapahoe Station Operating Log

Date	Unit	Unit Load (MW) Time (Hours-MDT) 0600	0700	0800	0900	1000	Full Load Capacity (MW)	F.L. Coal Consumption (lbs./hr.)
7/6/77	1	28	28	37	42	44	46	43,000
	2	47	47	46	46	46	47	43,000
	3	27	27	38	46	47	47	43,000
	4	109	110	109	109	109	113	50,000*
7/12/77	1	26	26	40	45	45	46	43,000
	2	46	46	46	43	46	47	43,000
	3	27	27	46	46	46	47	43,000
	4	50	108	109	110	110	113	30,000*

*Normally the full load coal consumption of Unit #4 is 100,00 lbs./hr. Due to inefficient operation of the wet scrubber, the coal consumption was 50,000 lbs./hr. on July 6, 1977, and 30,000 lbs./hr. on July 12, 1977. Natural gas was burned in Unit #4 on both days to supply the remainder of the thermal energy required. Units #1, #2, and #3 burned only coal on those days.

NOTE: Information supplied by the Public Service Company of Colorado.

Appendix C

Hayden Fuel Analysis - Average Coal Properties

November 1977

As Received:

% Moisture	=	10.34
% Ash	=	12.08
% Sulfur	=	0.46
BTU	=	10,607

Dry Basis:

% Ash	=	13.46
% Sulfur	=	0.51
BTU	=	11,832

BTU (Moisture - Ash Free) = 13,672

NOTE: Information supplied by Colorado-Ute Electric Association, Inc.

Appendix D

Log of Operating Loads and In-Stack Opacity Measurements

Unit #2, Hayden Station

Date	Time (hours-MST)	Unit Load (MW)	Stack Opacity (%)
11/29/77	0800	281	14
	0900	281	17
	1000	281	20
	1100	281	20
	1200	281	20
11/30/77	0900	280	15
	1000	280	19
	1100	280	17
	1200	280	15
	1300	280	16
12/1/77	0900	280	18
	1000	280	17
	1100	280	16
	1200	280	16
	1300	280	16
	1400	280	16
	1500	280	17

NOTE: Information supplied by Colorado-Ute Electric Association, Inc.

Appendix E

Hayden Station Weather Conditions

Date	Hour (MST)	Wind Direction (degrees)	Wind Speed (MPH)	Ambient Air Temperature (°F)	Relative Humidity (%)
11/29/77	0800	-	-	8	87
	0900	-	-	13	82
	1000	-	-	15	78
	1100	-	-		-
11/30/77	0900	250	6	16	62
	1000	260	9	18	61
	1100	285	8	19	59
	1200	275	6	21	51
	1300	265	10	24	48
12/1/77	0900	285	8	8	72
	1000	280	10	10	68
	1100	280	13	12	65
	1200	270	10	16	58
	1300	285	11	17	52
	1400	260	14	19	52
	1500	270	17	19	48

NOTES: 1) Hour readings are obtained by averaging continuous data traces from 30 minutes before the hour to 30 minutes after.

2) Wind information from 0800 to 1100 MST and ambient air temperature and relative humidity information from 1000 to 1100 MST on November 29, 1977, missing.

3) Weather information supplied by Stearns-Roger, Inc., who, under contract to Colorado-Ute, maintains the meteorological station at the Hayden facility.

Appendix F

Hayden Station Sampling Log

Date	Filter	Strip Location	Time Sample Started (hours-MST)	Total Sample Time (minutes)	Estimated Balloon Altitude (meters)
11/29/77	1	4	0845	15	170
		5	0900	5	170
		6	0908	2	170
		7	0912	15	170
		8	1008	15	190
11/30/77	2	1	0918	45	200
		2	1007	45	215
	3	2	1150	15	-
		3	1207	30	260
		4	1248	5	180
12/1/77	4	1	0950	20	185
		2	1012	20	200
		3	1037	20	170
		4	1105	20	185
	5	1	1148	120	185
		2	1350	20	185

NOTES:

1) The plume from 122 meter stack (Unit #2) sampled at all times.

2) The balloon altitude was estimated from photographic documentation.

3) The estimated horizontal downwind distance of the balloon from the stack was 150 meters on 11/29/77 and between 900 to 1000 meters on 11/30/77 and 12/1/77.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-78-205	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Balloon-borne Particulate Sampling for Monitoring Power Plant Emissions		5. REPORT DATE October 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J.A. Armstrong, P.A. Russell, and R.E. Williams		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Denver Research Institute, University of Denver, Denver, Colorado 80210		10. PROGRAM ELEMENT NO. EHE624
		11. CONTRACT/GRANT NO. Grant R804829
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 11/76 - 7/78
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Leslie E. Sparks, Mail Drop 61, 919/541-2925.

16. ABSTRACT The report describes a lightweight remote-controlled sampler, carried aloft by a tethered balloon, that has been developed to collect particulates from the plumes of fossil-fueled power plants at various downwind distances. The airborne sampler is controlled from the ground by a radio transmitter and receiver/servo system. A verification transmitter/receiver system allows monitoring of various commands to the sampler for correct operation. The sampler utilizes a pump to draw air through a strip of Nuclepore or other filter media. The sampler can be selectively actuated in flight to collect a number of discrete samples on the filter or to take a time-resolved streak sample across a length of the filter. The sampling system was field tested at two sites burning low-sulfur coal, an urban and a rural power plant. The collected samples were analyzed in terms of size, concentration, and composition using scanning electron microscopy/energy dispersive X-ray spectrometry. In general, the particles were spheres with diameters <5 micrometers. Some agglomerates were found. Most of the fly ash was composed of Si and Al, with small amounts of Fe.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution, Dust, Sampling, Airborne Equipment, Balloons, Monitors, Remote Control, Electric Power Plants, Coal, Fly Ash	Air Pollution Control, Stationary Sources, Particulate	13B 10B, 11G 21D, 14B 21B, 15E, 01C

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 56
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)