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June 25, 2002

A Portable Aerosol Sampling System (PASS) for Remote Sampling

July 23, 2002

A PORTABLE AEROSOL SAMPLING SYSTEM (PASS) FOR REMOTE ENVIRONMENTAL SAMPLING

Robert Leifer

Environmental Measurements Laboratory
Ofice of Environmental Management, OST
U.S. Department of Energy
201 Varick Street, 5th Floor
New York, NY 10014-4811

Abstract

A portable aerosol sampling system (PASS) has been developed by the Environmental Measurements Laboratory (EML) using an EML drum impactor and a PM10 EPA certified inlet. PASS is powered by either AC power or fuel and solar cells technology to collect sufficient atmospheric aerosol mass during a one month sampling period (time resolution up to 2 hours) for trace elemental or radionuclide analyses. PASS consists of a dual two 2-stage rotating drum parallel impactor that collects particles in two size ranges, 0.4 µm to 2.5 µm and 2.5 µm to 10 µm. The impactor drums are rotated by a single stepping motor that is controlled by the system's computer (Tattletale® computer), which also provides datalogging and system supervision. The mechanical design of the system allows for a rapid change of the impactor drums every 28 days. The sampling system is powered by a solid-state proton exchange membrane fuel cell operating on clean hydrogen fuel and oxygen from ambient air. The fuel cell is rated at 50 watts and can last for approximately 2 weeks before gas refill is needed. With an additional solar panel and rechargeable battery, as a storage device, the operating time of the sampling system is greatly extended. This document provides information on why the PASS is an exciting new aerosol sampler, and gives examples of the many programs in which EML used a drum impactor.

Contacts

Technical

Robert Z. Leifer: Principal Investigator
Environmental Measurements Laboratory
201 Varick Street, 5th floor
New York, NY 10014-4811
Phone: 212-620-3626
Email address: rleifer@eml.doe.gov

Management

Mitchell D. Erickson: Director, Environmental Measurements Laboratory
Phone: 212-620-3619
Email: erickson@eml.doe.gov

Acknowledgement

I would like to thank the following people who have contributed to the development of the PASS.

Brian J. Albert
Stanley Borenstein
Cecilia M. Breheny
Norman C. Chiu
William Cunningham
Frederick Guggenheim
Ethyl Jacob
John W. Kivlehan
Norman Latner
Rienzie D. Perera
Michael D. Polito
Peter Roiz
William Van Steveninick

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Purpose of this document

This document is designed to provide potential users with the information they need to quickly determine whether this technology would apply to a particular management or scientific problem. This document is also designed for readers who may recommend that this technology be considered for prospective users.

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Summary

Present Market

There are many aerosol samplers on the market developed for filter sampling. They usually collect air for 24-hour sampling periods, requiring hundreds of watts of AC power. Some companies have incorporated aerosol size separation capability into their samplers requiring even greater amounts of AC power. Recently, many companies designed battery or solar powered units, but only for filter samplers, and usually sampling no more than 24 hours. These samplers are designed to provide integrated samples over a 24 hour sampling period. Obtaining samples for shorter time periods requires someone to be physically present to change the filter. What is lacking in these filter samplers is the ability to be operationally flexible, provide a time history of atmospheric aerosols using low power, and operate unattended in remote areas for long periods of time. EML has developed such an instrument, called PASS, which is based on the drum impactor design. PASS meets all of the requirements mentioned above and will be discussed in detail in this report.

Figure 1. *EML's Portable Aerosol Sampling System (PASS).*

EML PASS

At EML we have been involved in aerosol sampling for decades. We have designed many different aerosol collection systems for different applications. From the experience we gained from our earlier designs, evolved a new portable, low powered, multipurpose, aerosol sampling system (PASS) for environmental sampling. PASS can operate on less than 40 watts of DC power for periods lasting 30 days, and can provide filter samples or size separated aerosol samples for chemical analysis by proton induced x-ray emission (PIXE), scanning electron microscopy (SEM), or inductively coupled plasma/ mass spectrometry (ICP/MS).

Uniqueness

The uniqueness of this instrument is in its ability to provide a "time history" of atmospheric aerosol concentrations . There is no other commercially available instrument on the market that is as versatile as PASS for automated sampling in urban, rural or remote environmental regions.

Figure 2. *Photograph of 1 month deposit of collected aerosol in two size ranges: (A) coarse particles, 2.5 µm to 10 µm; and (B) fine particles, 0.3 µm to 2.5 µm.*

Demonstrations

The drum impactor used in PASS has been demonstrated in programs involving aircraft, balloons, and ground samplers. The impactor was used for the collection of atmospheric aerosols for climate studies on balloons, boundary layer aerosol studies on aircraft, and, more recently for surface radionuclide sampling for population dose calculations.

This report provides information on the development and use of an EML designed drum impactor for atmospheric aerosol sampling.

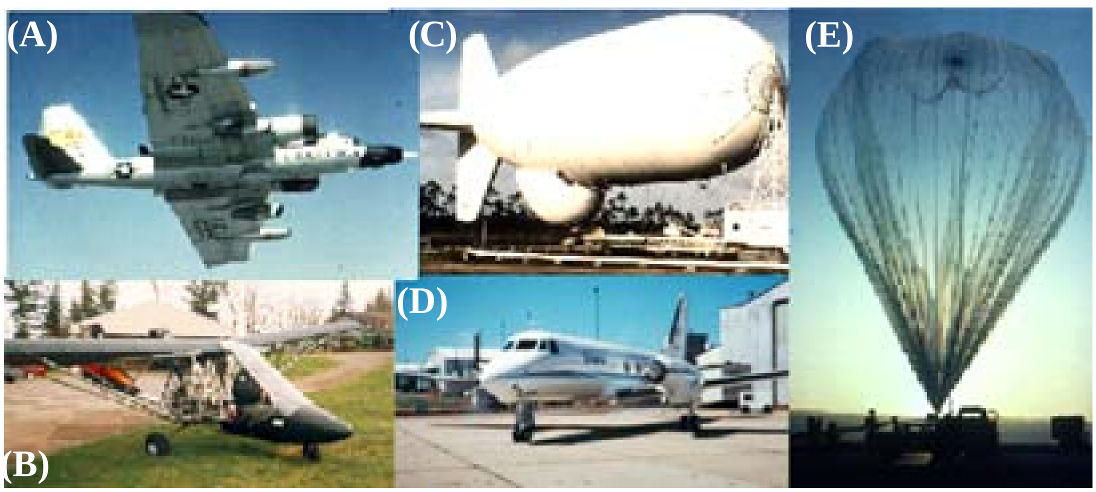

Figure 3. *Platforms where EML's impactors have been used: (A) DOE's Project Airstream; (B) University of Oregon Quick Silver rear prop aircraft; (C) EML's tethered aerostat sampling program; (D) DOE's Gulfstream 1 aircraft; and (E) DOE's Project ASHCAN.*

This report provides information on the development and use of an EML designed drum impactor for atmospheric sampling.

Introduction

History

High Altitude Sampling Program (HASP): Our first sampler, a rotating drum cascade impactor, separated and collected particulate samples in a number of size-segregated fractions for time-dependent sampling. This sampler was based on the design of the Lundgren impactor (Lundgren 1967) of the 1970's, and was successfully used in HASP to characterize the eruption from Mt. St. Helens in the upper troposphere and stratosphere (Leifer et al 1981a,b).

Tethered Aerostat Sampling Program (TASP): Our first surface sampler, a single drum impactor, was based on Dr. Thomas Cahill's jet impactor of 1978 (Raabe et al. 1988), and was tested on a tethered balloon (TASP) at altitudes up to 3 km (Kromidas and Leifer 1996, Leifer et al 1992). As program needs changed, we redesigned the impactor with additional stages for special applications.

Portable Aerosol Sampling System (PASS): From the experience we learned from our earlier designs, evolved a new portable, low powered multipurpose portable aerosol sampling system (PASS), for environmental sampling. PASS can operate on less than 40 watts of DC power for periods lasting 30 days, and can provide filter samples or size separated aerosol samples for chemical analyses.

The Heart of PASS

The heart of PASS is a rotating drum impactor originally developed by Dale Lundgren (1967) , modified by the University of California, Davis (Raabe 1988), and then completely redesigned by EML. In

PASS, the impactor is controlled by an onboard computer (Onset Corp., 199 Main St., P.O. Box 1030, North Falmouth, MA 02556-1030; Model 4A Tattletale Computer), providing system control and data logging capability. The present configuration has the first stage collecting particles between 10 µm and 2.5 µm. The second stage collects particles between 2.5 µm and 0.4 µm. A final filter collects particles less than 0.4 µm. The final filters provide time integrated samples and not time-dependent samples.

Figure 4. *Dual stage rotating drum impactor.*

PASS Description

Compact drums

The impactor samples are collected on a 6 cm diameter drum covered with an Apiezon coated Mylar foil or polyurethane foam.

Figure 5. *Shown is EML's impactor drum with a PUF (polyurethane foam) impaction collection surface.*

Controlled drum rotation

The computer can provide daily, weekly, monthly or stepping mode samples for analysis.

Adjustable sampling

The "stepping mode" allows the collection of hundreds of discrete samples for microscopic analysis.

Menu driven

The operation of the sampler is menu driven and a simple computer input changes the operating mode.

Samples are easily archived

Because of the physical size of the drums, the samples are easily archived for future analysis.

Direct insertion in SEM

The EML sample drums have been integrated into EML's SEM for "automated size and elemental analyses."

Very low power

PASS has been designed to operate on very low power.

Figure 6. *PASS drums, holding the collected aerosols are mounted on a SEM rotation stage control and placed, uncoated, directly in the SEM for analysis.*

Depending on the sampling configuration, PASS DC power requirements could be as little as 20 watts. Even under full configuration, PASS will draw less than 50 watts, easily achieved using 12 DC batteries recharged by solar panels or fuel cell technology.

PASS footprint

PASS has been designed to occupy little space (~0.06 m^3)

Versatile Instrument

PASS can be used in many different collection modes. It can act as a parallel dual impactor, single impactor with a second filter collection. The impactors can be replaced with high efficiency filters or each sampling line replaced by multi-headed filters. These different configurations are easily controlled with PASS.

PASS can provide two independent filter collections

Sampling with two filters or impactors allows for either multiple analyses on the two independent samples or saving one sample for either archival purposes or for QC (duplicate samples).

Figure 7. *Two independent 47 mm filters are controlled by PASS.*

PASS can provide up to eight-sequential filter collections.

A 4 filter splitter has been designed for PASS allowing for sequential sampling by the Tattletale®. The Tattletale® constantly monitors the loading on the filter, and automatically switches to a new filter when the flow decreases by 5%. Since PASS has two independent control circuits, a second four-filter splitter can be incorporated into the total collection.

Figure 8. *Four separate filters are mounted on the 4-way splitter.*

Two independent impactor collections

EML's drum impactor can be configured in a number of different ways.

- Four single stage parallel impactors.
- Two dual stage parallel impactors.

The parallel impactors can be converted into a four-stage cascade impactor (additional jets would be designed for this configuration).

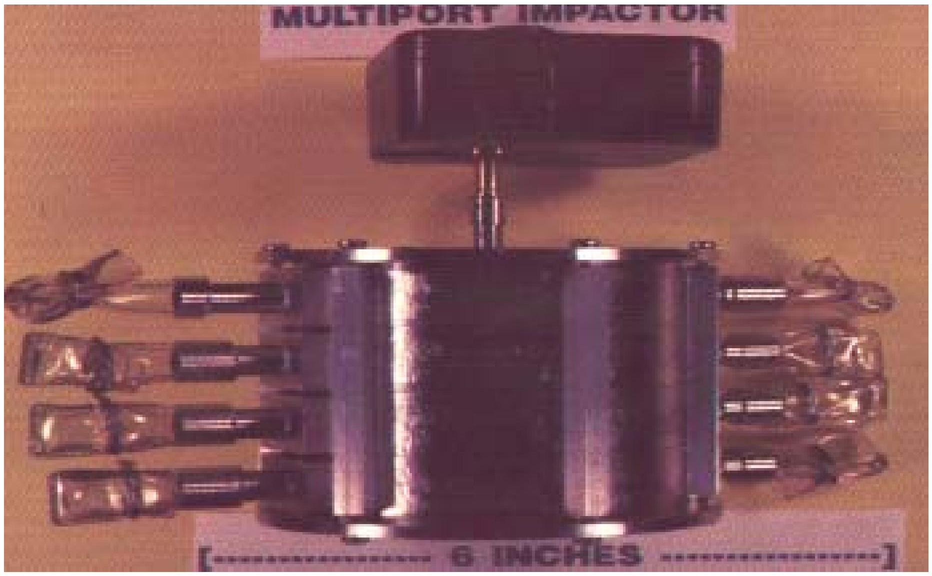

Figure 9. *Four single stage parallel impactors*

Figure 10. *Two parallel dual impactors.*

Operated in remote regions

PASS can operate where no AC power is available because of its low power requirements.

Completely automated and controlled by the Tattletale® computer.

- Algorithms have been built into the program to check that the system is operating properly.
- A flashing LED light provides direct verification of the operation of the instrument for anyone visiting the sampling station without the use of a computer.
- The data are also readily available for transmission, using either cell phone or satellite technology, to the home office.

PASS Design

PASS System Design

Shown below is a block diagram of PASS. Air is drawn through the PM10 inlet into a splitter where two identical airstreams are formed and flow through two independent impactors or filters. An onboard computer known as a Tattletale® maintains either a constant mass flow or constant volume flow through the samplers and provides data logging capability. The impactor can run undisturbed for 4 weeks and provides a "continuous" record of the ambient aerosols. The filters can be run for periods up to 2 weeks before being switched.

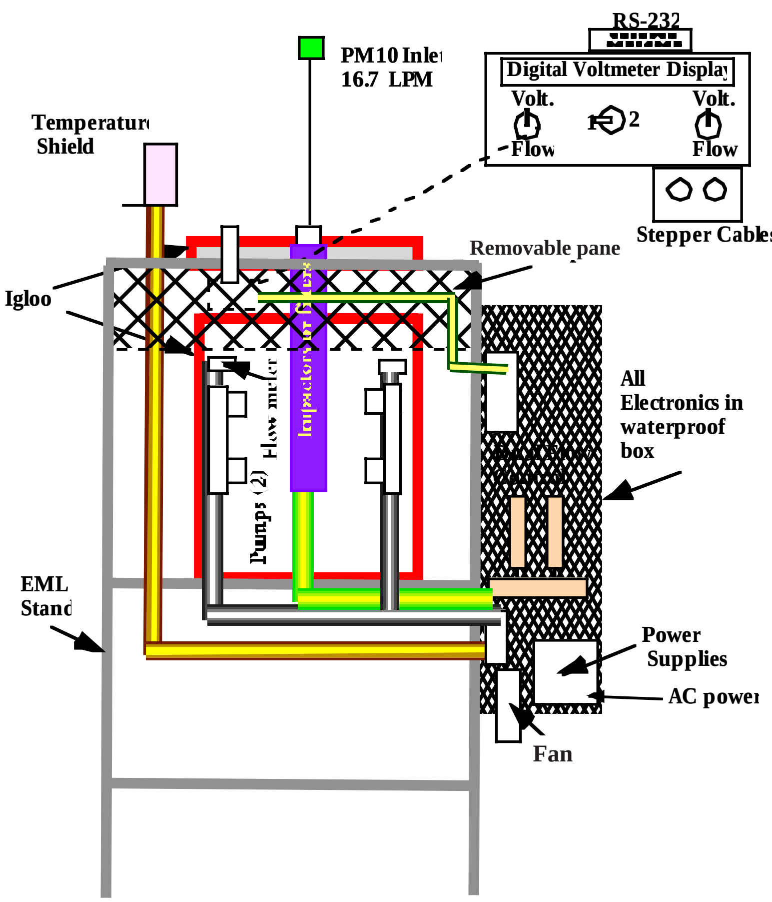

__Figure 11.__ PASS block diagram showing the components used in the sampler.

Flow circuit

The flow circuit module contains a PM10 inlet, a two way air splitter, two independent impactors or filters, flow sensors, vacuum pumps, air surge chambers, and flow control circuits.

PM10 inlet

The PM10 inlet, certified EPA approved, provides an inlet that restricts particles above 10 μm (50% aerodynamic diameter)

Vacuum pumps

- We are presently using two Sensidyne vacuum pumps, connected in parallel, to provide the necessary vacuum for the sampler for one of the flow lines.

- The vacuum pumps, the heart of the air moving circuit, move the air through the impactors at a nominal flow rate of 8.3 liters per minute (LPM).

- These vacuum pumps are operated at ***well below their rated voltage of 12 volts***. Should the final filter start to load up with time, the vacuum pumps, with increased operating voltage, have the additional capacity to over come the loading. See below for the discussion on the flow control circuit.

- When operating in the filter mode, ***only one vacuum pump is needed*** to maintain the 8.3 LPM. Should the vacuum pump not keep up with the filter loading, causing the flow to decrease, the Tattletale® automatically turns on the second pump. If towards the end of the sampling period the pumps again cannot keep up with the loading, the Tattletale® automatically switches to a new filter and shuts down one pump.

Surge tank

The surge tank is used to damp out the small oscillations in the flow developed by diaphragm type vacuum pumps.

Flow control circuit

PASS has a unique flow control circuit. Where other manufacturers use a variable orifice with a large vacuum pump to control the flow, we adjust the flow by adjusting the voltage on the pump with our onboard computer. This allows us to use much smaller vacuum pumps for control.

Computer control

We use small, battery-powered logger/controllers for use in air monitoring. The Tattletale® provides both analog, digital and serial channels to control all of the needs of PASS. The computer is programable using a specialized set of Tattletale® "Basic" commands. The computer programs written for PASS are user friendly and allow for rapid operation and change from impactor to filter sampling with a simple entry.

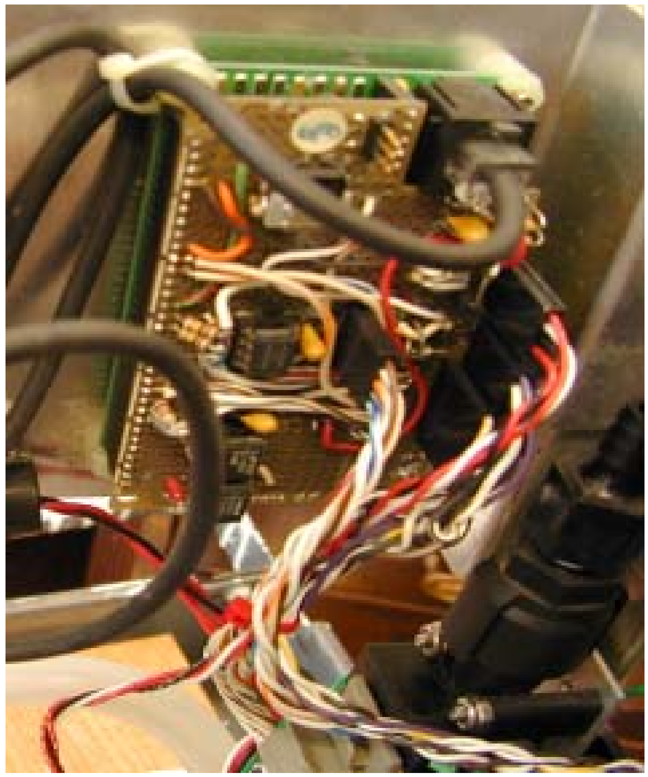

***Figure 12**. Photograph of the Tattletale® Computer used in PASS that measures 7 cm by 10 cm by 2 cm thick.*

Example of a PASS computer menu

SET TIME
CLEAR DATAFILE
READ DATAFILE
CHANGE SAMPLE PARAMETERS
RESTORE DEFAULT SAMPLE PARAMETERS
STEP THE IMPACTOR
START A NEW SAMPLE
CONTINUE SAMPLING
IDLE/FILTER MODE SAMPLING
END PROGRAM

Power operating requirements.

- **AC operation:** PASS has built into its circuitry AC to DC conversion using a regulated power supply. The power requirement for PASS is approximately 120 VAC at 0.3 amps.

- **Solar powered DC operation:** Depending on the latitude of sampling, a dual panel solar (Solarex panel model MSX-83-166W) system, including battery recharging circuitry, can operate PASS for a month. The following table gives examples of the output of a panel.

Power use analysis for EML PASS system

(A)	(B)	(C)	(D)	(E)	(F)
Phoenix	January	913	38	0	-
	April	1145	47	0	-
	December	880	37	0	-
Cleveland	January	415	17	7	104
	July	813	34	0	0
	December	332	14	10	69
Seattle	August	813	34	0	-
	December	232	10	14	49

(A) City.
(B) Date.
(C) Watts generated using two panels.
(D) Supply hours provided by two panels.
(E) Shortfall made up by fuel cell in hours.
(F) Length of time in days fuel cell will last under 50 watt load.

As can be seen from this table the fuel cell is needed in only three cases and would last for at least one month using a # 4A hydrogen storage cylinder.

Solar powered/fuel cell combination

The deficit energy for some latitudes, seen in the above table, can easily be made up with a fuel cell. We have been working with H-power's fuel cell model PEM 50, a 50 W, 12 VDC power source.

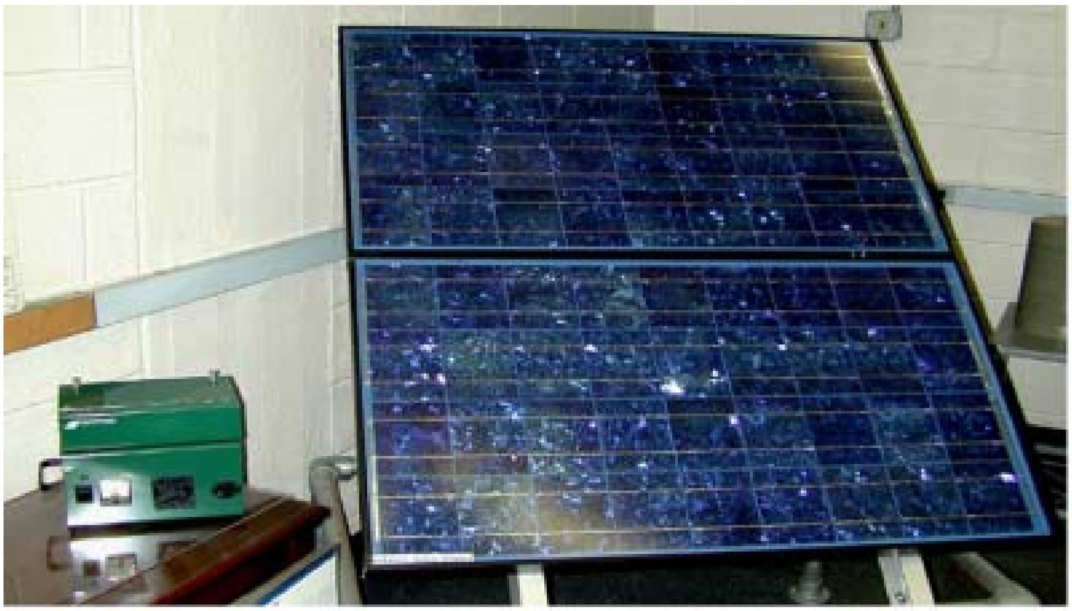

Figure 13. *Dual solar panel (1.3 m by 1.2 m) along side a 50 watt fuel cell.*

Conclusions

In these few pages we have tried to present a brief description of the PASS system for characterizing atmospheric aerosols. The heart of PASS is the drum impactor, which can provide a time history of atmospheric trace elements and radionuclides (thorium and uranium, as well as plutonium isotopes).

Because of the design of PASS, samples can be easily collected using impactors, filters or any combination of both.

In conclusion, a summary of PASS's unique features as outlined in this report follow.

- **PASS can provide a time history of atmospheric aerosols using a drum impactor.**
- **Duplicate samples can be easily obtained for alternate analysis or to provide quality assurance samples because of the design of EML's impactors.**
- **PASS is easily switched from impactor to filter sampling.**
- **PASS can be powered from many different sources, alternating current, solar cells, and fuel cell because of its low power consumption.**
- **PASS is portable and can operate far from power lines.**
- **PASS is ideal for collecting samples for SEM.**
- **PASS can operate unintended for many weeks because of its internal computer.**
- **PASS can automatically initiate a sampling session based on input from an independent sampling instrument, such as a gamma spectrometer. The sampler can provide a few hundred discrete samples for SEM analysis in the SEM mode .**
- **The drum impactor, used in PASS, has been sucessfully demonstrated at various sites throughout the world (see appendix for details).**

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Appendix

Drum Impactor Examples

In this appendix we provide examples of the use of the drum impactor, presently used in PASS, to demonstrate the applications of the unique impactor design used in EML's research over the years.

Global climate - TASP

An environmental sampler was installed on a U.S. Coastguard TASP in the Grand Bahama Island. The TASP provided the unique opportunity to make measurements at sufficient distances from the surface (up to 3 km), and, therefore away from the influence of local sources. We mounted our instrument package in the forward part of the aerostat where sampling would be carried out in the free airstream. Initial measurements were made for the purpose of chemical and physical characterization of atmospheric aerosols. These instruments provided samples for trace element, ion chromatographic and SEM analyses, and they gave a detailed picture of the elemental, ionic and size distribution of the collected aerosol over a long-time period.

These analyses were used to:

- **develop an understanding of atmospheric transport processes from continental and maritime regions,**
- **determine the importance and rate of input to the Atlantic Ocean of specific natural and anthropogenic substances,**
- **understand the cycling of sulfur on the east coast of the United States. These measurements are also combined with meteorological modeling to provide insight into the transport and transformation of short-lived species.**

TASP Examples

EML's TASP impactor continuously collects air samples for periods lasting up to 1 month. The collected samples are analyzed using proton induced x-ray emission (PIXE). PIXE provides elemental analysis (sodium to lead) with a time resolution of approximately 8 hours. The following are examples of the kinds of data one can obtain from EML's impactor.

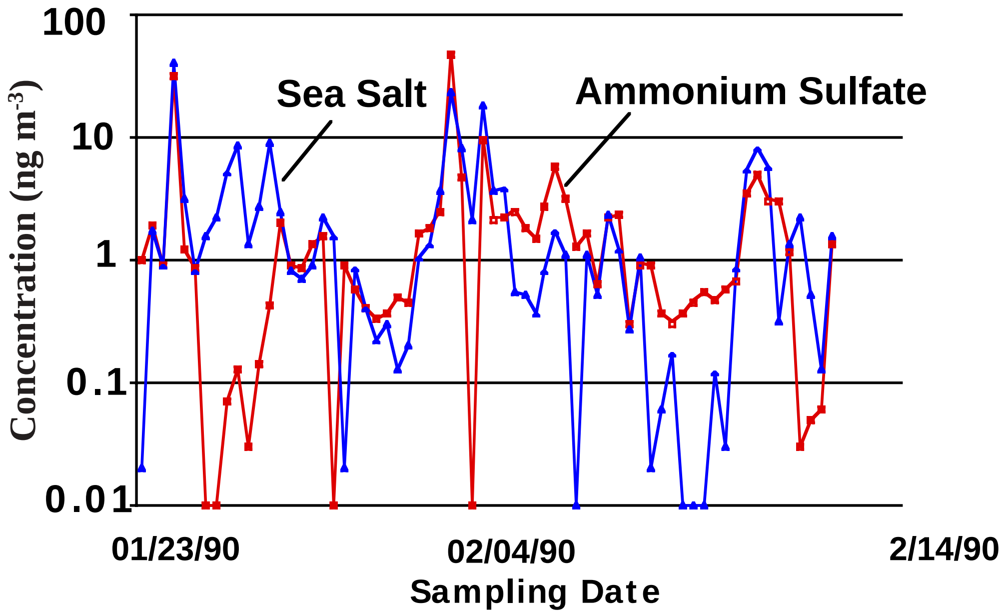

Figure 14. *Time series of air concentrations of ammonium sulfate and sea salt collected at 1-3 km over the Grand Bahama Island.*

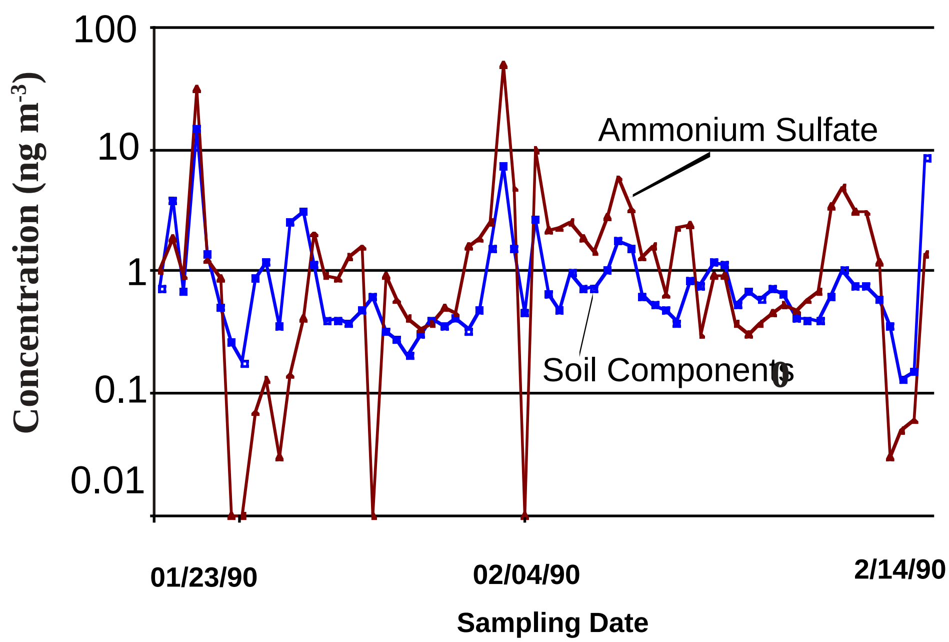

Figure 15. *Time series of air concentrations of ammonium sulfate and soil aerosols collected at 1-3 km over the Grand Bahama Island.*

Marine Boundary Layer

Problem

Acid reactions with sea-salt aerosols are the major source of inorganic chlorine in the marine boundary layer (MBL). A detailed knowledge of the chemical composition of the sea-salt aerosols can provide insite into the changes of chlorine in the MBL.

Approach

- Develop and operate an automated aerosol system for the characterization of the aerosols collected during the flights of the G-1 in the MBL.

- Quantify the change in the sodium/chlorine ratio on collected marine aerosols during the flights of the G1.

Design

To characterize the marine boundary aerosol, a new aerosol sampling system was designed, built and tested during the summer 1995 for the Long Island ACP ocean chlorine study. The equipment was mounted in an aircraft rack used on the Gulfstream 1 (G-1) aircraft. Our special aerosol probe was mounted in one of the aircraft windows adjacent to the aerosol sampling rack. The system consisted of a:

- four-parallel-impactor or (4PI)
- six channel optical particle counter (OPC)
- integrating nephelometer,
- computer data logger and controller, vacuum pumps and mass flow controllers

Automation

The system was fully automated and programmed for aerosol sampling throughout each flight. The 4PI has the capability of collecting four simultaneous aerosol samples. Controlled by a small computer, the impactor can sequentially collect more than 100 samples on a single drum for SEM analysis. Two sizes (0.18 µm and 1.0 µm aerodynamic diameter) were choosen for the study to coincide with the accumulation and giant aerosol size modes.

Analysis

The most difficult part of aerosol collection for SEM/x-ray examination is depositing sufficient particles on the substrate without particle overlap. Because the 4PI is computer controlled, we can set the sample time based on counts from the OPC for collections at specific times. In addition, sampling can be triggered by an independent instrument, such as a pressure transducer (altitude) or relative humidity for in and out of the marine boundary layer sampling, or a real-time analyzer (O_3, SO_2, etc.)

when signals exceed a preset threshold. The individual jets of the 4PI are replaceable and allow the selection of different cut sizes (0.18 µm and 1.0 µm were choosen for the Long Island study) for special studies. Using our onboard computer we can extend the sampling times for the 1.0 µm impactor. The longer sampling time allows us to collect sufficient giant sea salt particles, which are few in number relative to the fine aerosol, for SEM/x-ray analysis.

Microscopic Examination

The aerosols are pulled through a circular jet and impact onto a 5 cm diameter cylinder constructed of aluminum and covered with a foil coated with grease. A small DC operated vacuum pump maintains a flow of 1.0 L min^{-1} through the impactor. At this flow rate, and at STP one parallel stage of the 4PI has a calculated 50% cut diameter of 0.18 µm. The collection cylinder from this impactor is easily removed and can be placed directly in the scanning electron microscope chamber, coated or uncoated for observation and chemical analysis.

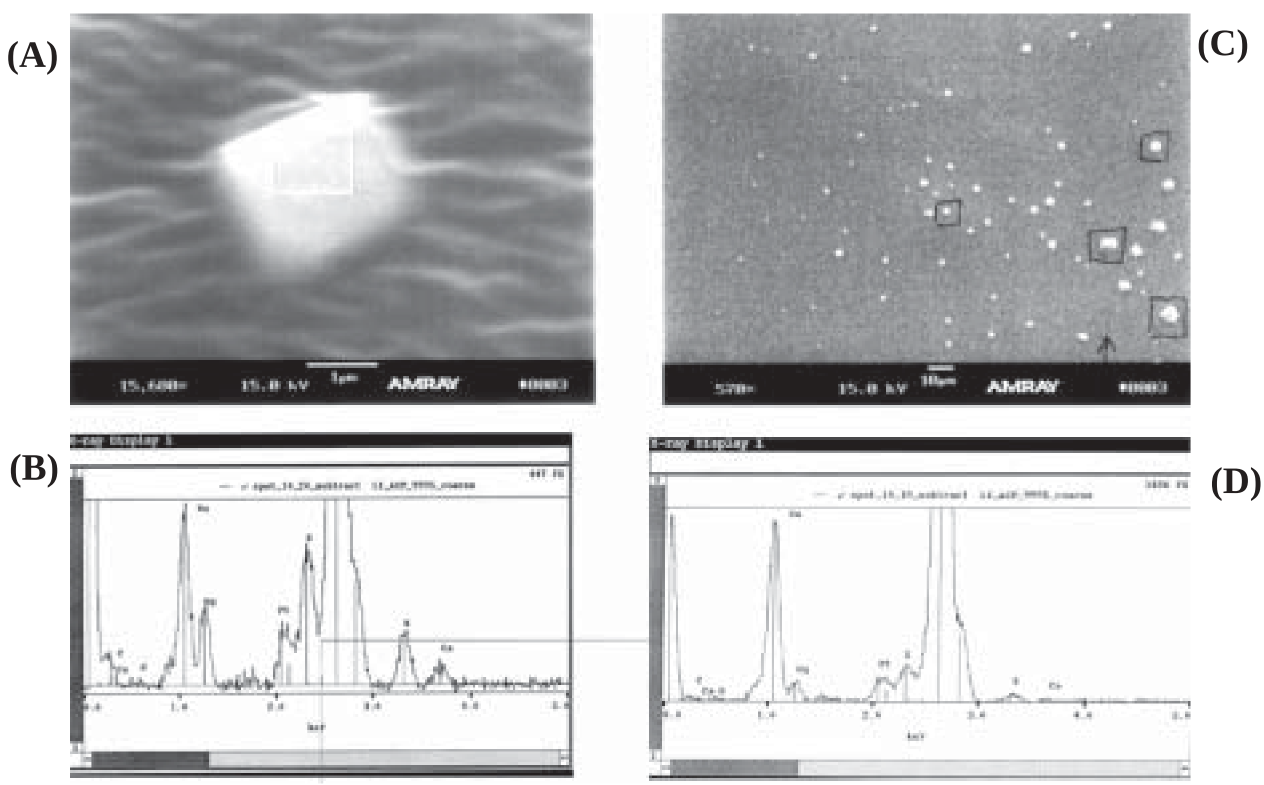

Figure 16. *Examples from coarse drum impactor stage collections in the marine environment: (A) salt particle magnification 15,600x. Square in center is the x-ray beam area; (B) X-ray analysis of salt particle showing elemental composition; (C) Coarse impaction area showing large number of particles; and (D) X-ray analysis of a different salt particle showing a completely different composition.*

Radioactivity

• Experimental design

The U. S. Department of Energy's (DOE) Fernald Environmental Management Project (FEMP), located 18 miles northwest of Cincinnati, OH, was constructed in the early 1950's to produce uranium metal products for use by the government. Activities at the site, formerly called the "Feed Materials Production Center," were suspended in July 1989. As part of the national environmental restoration program, the FEMP site managers needed to implement an environmental monitoring plan to characterize the radionuclide emissions at the site and how they impact the surrounding population (DOE 1988). The National Emissions Standard for Hazardous Air Pollutants (NESHAP 1979) requires an annual assessment of the individual dose to offsite receptors due to radionuclide emissions. The maximum allowable dose from airborne emissions, excluding radon, cannot exceed 10 mrem y^{-1} (NESHAP 1979). There are additional guidelines for detection limits, and site/facility boundary definitions, and more than 10 additional regulatory drivers having air monitoring implications (FEMP 1996).

• DRUM Impactor

To help the site managers better understand the dose to the offsite individuals, EML set up a Davis Rotating Universal Size-cut Monitoring Sampler (DRUM; a cascade impactor, Dr. Thomas Cahill, University of California, Davis) to characterize the size distribution of the atmospheric aerosols at one of the FEMP fence line stations. The Davis impactor contains eight stages with 50% aerodynamic cut diameters of 8.54 µm, 4.26 µm, 2.12 µm, 1.15 µm, 0.56 µm, 0.34 µm, 0.24 µm, and 0.069 µm, respectively. The inlet rain hat removes particles above 15 µm. The impactor was operated at 1.1 L min^{-1}. Ambient pressure and temperatures were available from a meteorological tower at the Fernald site.

• Results

Data on the size distribution of uranium bearing atmospheric aerosols from 0.065 µm to 100 µm in diameter were obtained and used to compute inhalation dose using several different models (Leifer et al. 2000). Because of our ability to measure the aerosol size distribution, we were able show that Fernald overestimated the inhalation dose to offsite individuals by as much as a factor of seven relative to values derived using the latest ICRP 66 lung model with more appropriate particle sizes.

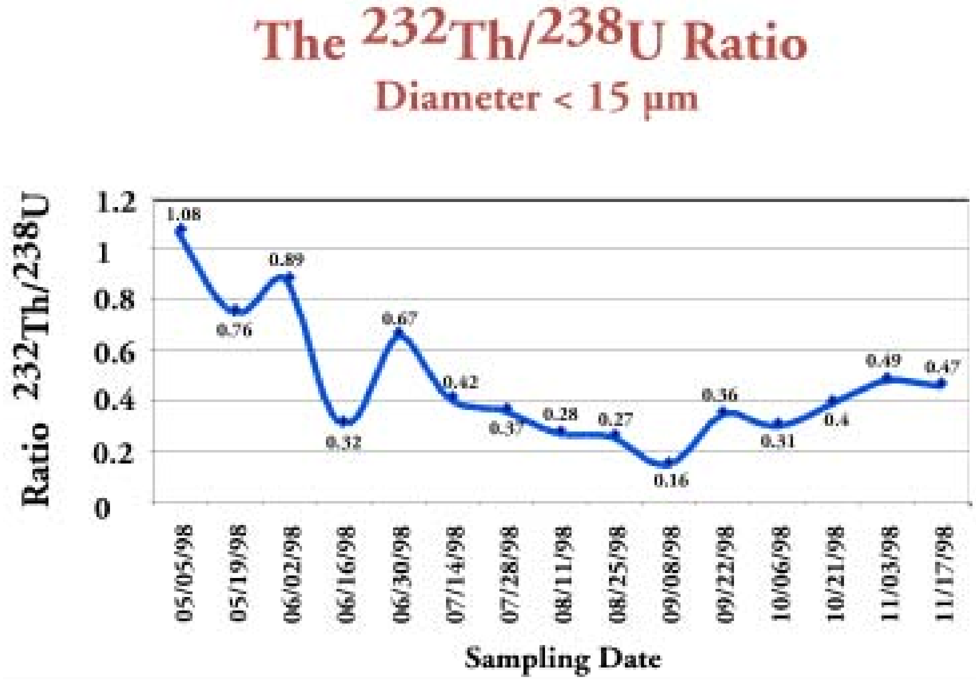

Figure 17. The ratio of ^{238}U to ^{232}Th measured with a DRUM impactor at Fernald. Analysis was carried out using ICP/MS.

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U.S. Department of Energy
New York, NY 10014-4811
http://www.eml.doe.gov