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Industrial Environmental Research
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Research Triangle Park NC 27711

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Research and Development

Particulate Sampling and Support: Final Report, Executive Summary

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EPA REVIEW NOTICE

EPA-600/2-79-114a

November 1979

Particulate Sampling and Support: Final Report, Executive Summary

by

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Contract No. 68-02-2131
Program Element No. INE623

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

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INTRODUCTION

The scope of the research, development, and support performed for the Environmental Protection Agency under Contract 68-02-2131 (November 20, 1975-November 19, 1978) by Southern Research Institute covered many aspects of particulate sampling in gaseous process and effluent streams. Specific objectives which were identified and given priority during this contract were to:

1. Identify current and future requirements for particulate sampling - the nature of the particles (shape, volatility, concentration, size distribution, charge, etc.), the sampling conditions (temperature, pressure, entrained fluids, etc.), and the goals of the sampling programs (control device evaluation, health effects, etc.).

2. Continue research on the nonideal or unmodelled behavior of cascade impactors. Investigate problems in using impactors on nonroutine process streams (wet, high temperature, high pressure). Design cascade impactors which incorporate all that we have learned about their fundamental behavior and operational problems.

3. Design, fabricate, and test cyclone systems for particle sizing. Evaluate existing cyclone systems for particle sizing effectiveness. Consider alternatives to back up filters in high flow rate applications.

4. Study alternatives to impactors and cyclones for particle sizing such as optical, electrical, or hybrid systems. Concentrate on devices which offer the possibility of real time, automatic, sampling and analysis.

5. Study methods of Quality Assurance in sampling and calibration programs.

6. Generate and review documents on particulate sampling and continually update our bibliography and literature survey.

7. Continue to study and evaluate new techniques, ideas, and instruments for particulate sampling.

8. Attend and organize meetings and symposia on particulate sampling.

9. Provide consulting and research and development support to EPA programs.

In this Executive Summary of the work performed under this contract, a short description of each of the thirty-three Technical Directives issued during the three year period (11/75 - 11/78) is presented. Information includes the task description and task summary and/or published document(s) and abstract(s), hardware fabricated (if any), oral presentation of results and expenditures in dollars and manhours.

Complete descriptions of the technical directives that did not result in published documents can be found in the annual report for 1977 and the final report. These documents are entitled:

Particulate Sampling Support: 1977 Annual Report
EPA-600/7-78-009, January 1978 NTIS PB (239-170/AS)

Particulate Sampling and Support: Final Report
EPA-600/2-79-114, May 1979

Technical Directive Number 10101

Cascade Impactor Computer Data Reduction

Published Documents and Abstracts

A Computer-Based Cascade Impactor Data Reduction System
Jean W. Johnson, George I. Clinard, Larry G. Felix,
Joseph D. McCain
EPA-600/7-78-042, March 1978, NTIS (PB 285 433/AS)

This document describes a cascade impactor data reduction system written in the FORTRAN IV language. The overall system incorporates six programs: MPPROG, SPLINI, GRAPH, STATIS, PENTRA, and PENLOG. Impactor design, particulate catch information, and sampling conditions from single impactor runs are used to calculate particle size distributions. MPPROG and SPLINI perform data analysis and make curve fits, while GRAPH is totally devoted to various forms of graphical presentation of the calculated distributions. The particle size distributions can be output in several forms. STATIS averages data from multiple impactor runs under a common condition and PENTRA or PENLOG calculate the control device penetration and/or efficiency. The plotting routines have been written for a PDP15/76 computer and are not compatible with other computing systems without modification.

A Data Reduction System for Cascade Impactors
Joseph D. McCain, George I. Clinard, Larry G. Felix, Jean W. Johnson
EPA-600/7-78-132a, July 1978 NTIS PB (283-173/AS)

A computer based data reduction system for cascade impactors has been developed. The system utilizes impactor specific calibration information together with operating conditions and other pertinent information such as stage weights, sampling duration, etc., to determine particle size distributions in several forms for individual runs. A spline technique is applied to fit a curve to the cumulative size distribution obtained from each individual impactor run. These fitted curves have forced continuity in co-ordinates and slopes. Averages of size distributions for multiple runs are made using the fitted curves to provide interpolation values at a consistent set of particle diameters, irrespective of the diameters at which the data points fall in the original individual run data sets. Statistical analysis are performed to locate and remove outliers from the data being averaged, following which averages, variances, standard deviations and confidence intervals are calculated. The averages and statistical information are available in tabular and graphical form in several size distribution formats (cumulative mass loading, cumulative percentage by mass, differential mass, differential number). The averaged data are stored in disk files for subsequent manipulation. Additional programs permit data sets from control device inlet and outlet measurements to be combined to determine fractional collection efficiencies and confidence limits of the calculated efficiencies.

These results are available in graphical form with a choice of log-probability or log-log presentations and as tabular output. The program is set up to handle all commercially available round jet cascade impactors, including common modifications, which are in current use in stack sampling. Other round jet impactors can be easily substituted and slot type impactors could be accommodated with slight program revision.

Presentation: The results of this work were presented at the First, Advances In Particle Sampling and Measurement Symposium, Asheville, NC, May, 1978. Authors of the paper were Joseph D. McCain, George I. Clinard, Larry G. Felix, and Jean W. Johnson. (See Technical Directive 21306)

Technical Directive Number 10201

HP-65/HP-25 Source Sampling Program Booklets

Published Documents and Abstracts

HP-65 Programmable Pocket Calculator Applied To Air Pollution Measurement Studies: Stationary Sources
James W. Ragland, Kenneth M. Cushing, Joseph D. McCain, Wallace B. Smith
EPA-600/8-76-002, October 1976, NTIS (PB 264 284/AS)

This report is intended to provide a useful tool to persons concerned with Air Pollution Measurement Studies of Stationary Industrial Sources. Detailed descriptions are given for twenty-two separate programs that have been written specificly for the Hewlett Packard Model HP-65 card programmable pocket calculator. Each program includes a general description, formulas used in the problem solution, numerical examples, user instructions, and program listings. Areas covered include the following: Methods 1 through 8 of the EPA Test Codes (Federal Register, December 23, 1971), calibration of a flame photometric detector by the permeation tube technique, determination of channel concentrations for a droplet measuring device, resistivity and electric field strength measurements, determination of stack velocity, nozzle diameter, and isokinetic delta H for a high volume stack sampler, and several programs for cascade impactors. Those for cascade impactors include: determination of impactor stage cut points, calculation of the square root of the Stokes number for round jet and for rectangular slot geometries, nozzle selection and determination of delta H for isokinetic sampling, determination of sampling time required to collect 50 mg total sample, determination of impactor flow rate, sample volume, and mass loading, and calculation of cumulative concentration curves and their differentials.

HP-25 Programmable Pocket Calculator Applied To Air Pollution Measurement Studies: Stationary Sources
James W. Ragland, Kenneth M. Cushing, Joseph D. McCain, Wallace B. Smith
EPA-600/7-77-058, June 1977, NTIS (PB 269 666/AS)

This report is intended to provide a useful tool to persons concerned with Air Pollution Measurement Studies of Stationary Industrial Sources. Detailed descriptions are given for twenty-two separate programs that have been written specifically for the Hewlett Packard Model HP-25 manually programmable pocket calculator. Each program includes a general description, formulas used in the problem solution, program listings, user instructions, and numerical examples. Areas covered include the following: Methods 1 through 8 of the EPA Test Codes (Federal Register, December 23, 1971), calibration of a flame photometric detector by the permeation tube technique, determination of channel concentrations for a droplet measuring device, resistivity and electric field strength measurements, determination of stack velocity, nozzle diameter, and isokinetic delta H for a high volume stack sampler, and several programs for cascade impactors. Those for cascade impactors include: determination of impactor stage cut points, calculation of the square root of the Stokes number for round jet and for rectangular slot geometries, nozzle selection and determination of delta H for isokinetic sampling, determination of sampling time required to collect 50 mg total sample, determination of impactor flow rate, sample volume, and mass loading, and calculation of cumulative concentration curves and their differentials.

Technical Directive Number 10301

Nonideal Cascade Impactor Behavior

Description of Task:

Particle size distributions of particulate emissions from industrial sources are frequently determined using cascade impactors. Errors in size distributions measured with impactors arise through the lack of sharp (step function) stage collection efficiencies with varying particle size and from particle bounce and carry over from stage to stage.

Computer models of particle collection by two widely used impactors (Brink and Andersen) were used to determine the extent of errors arising from the nonideal stage collection characteristics given above. The models were based on measurements of stage collection efficiencies, including effects of particle bounce, which were obtained in a previous study involving the complete stage by stage calibration of a number of commercially available cascade impactors.

Results of the study reveal: (1) systematic errors in measured mass median diameters and geometric standard deviations when aerosols having log-normal size distributions are sampled, (2) larger errors occur when sampling aerosols having small (1 μm) mass median diameters than for those having larger (10-20 μm) mass median diameters, (3) Particle bounce has very little effect on the weights of particulate caught on the various impactor stages but has a pronounced effect on the weight of material caught on back up filters. This results in substantial overestimates of the concentrations of very fine particles when sampling dry, hard particulates.

Presentation:

The results of this study were presented at the 70th Annual Meeting of the Air Pollution Control Association in Toronto, Canada, in June, 1977. Authors of Paper No. 77-35.3 were Joseph D. McCain and James E. McCormack.

Technical Directive Number 10401

Cascade Impactor Sampling of Charged Particles

Published Document and Abstract

Sampling Charged Particles With Cascade Impactors
William E. Farthing, David H. Hussey, Wallace B. Smith, Rufus Ray Wilson, Jr.
EPA-600/7-79-027, January 1979 NTIS PB 290 897/AS

In performing particle size distribution measurements at control devices operating on industrial process streams, investigators are usually aware that in some cases charged particles will be present in the gas stream. In order to assess the influence of particle charge, three different experiments were performed to determine whether or not cascade impactors sampling charged aerosols can yield erroneous particle size distribution measurements. The commercially available cascade impactors utilized in this study were the Andersen Mark III Stack Sampler, the Meteorology Research, Inc. Model 1502 Cascade Impactor, and the University of Washington Mark III Source Test Cascade Impactor. In general, the measured distributions indicated more large particles and fewer small particles than actually existed. The deviations from the true size distribution was found to be a function of the magnitude of charge. This deviation was smaller if glass fiber substrates were used as impactor collection surfaces instead of the metal collection plates alone. For charge levels representative of electrostatic precipitators operating at normal charging conditions (an electric field strength of 400,000 V/m and a current density of 3×10^{-4} A/m^2), the differences between the true and measured polydisperse size distributions with glass fiber substrates were small.

(This work was performed in conjunction with Technical Directive 11301).

Presentation: The results of this work were reported at the 72nd Annual Meeting of the Air Pollution Control Association in Cincinatti, Ohio on June 27, 1979. Authors of Paper No. 79-28.2 were W. E. Farthing, D. H. Hussey, W. B. Smith, and R. R. Wilson, Jr.

Technical Directive Number 10501

Cascade Impactor Substrate Study

Published Document and Abstract

Inertial Cascade Impactor Substrate Media For Flue Gas Sampling
Larry G. Felix, George I. Clinard, George E. Lacey, Joseph D. McCain
EPA-600/7-77-060, June 1977, NTIS (PB 276 583/AS)

This report summarizes Southern Research Institute's experience with greases and glass fiber filter material used as collection substrates in inertial cascade impactors.

Tests have been performed to ascertain which of the available greases and glass fiber filter media are most suitable for flue gas sampling. Greases are probably not useful for temperatures above 177°C (350°F). For higher temperatures glass fiber filter material can be used.

Of nineteen greases tested, by heating in the laboratory and by exposure to flue gas in the field, only Apiezon H grease was found to perform satisfactorily at temperatures above 149°C (300°F).

In experiments designed to evaluate the use of filter materials as impactor substrates it was found that mass increases occurred as a result of exposure to flue gas for all of the fiber media tested. Laboratory and field studies are described which were directed toward development of a method by which glass fiber filter material can be passivated to SO_x induced mass gains. These studies indicate that an H_2SO_4 wash followed by a thorough distilled water and isopropanol rinse, drying, and baking, augmented by in situ conditioning, offers the best hope for reduction of SO_x induced mass gains. Reeve Angel 934AH glass fiber filter material performed best among the media tested.

Presentation: Portions of this work were reported at the Workshop on Primary Sulfate Emissions From Conbustion Sources, EPA-600/9-78-020a, August, 1978. The paper, "Particulate Sampling in Process Streams in the Presence of Sulfur Oxides", was presented by Kenneth M. Cushing. Portions of this work were reported at the First Advances In Particle Sampling and Measurement, Asheville, NC, May, 1978. Authors for the paper "Substrate Collectors For Cascade Impactors-An Evaluation", were D. Bruce Harris, George Clinard, Larry G. Felix, George Lacey, and Joseph D. McCain. (See Technical Directive 21306)

Technical Directive Number 10602

Develop and Evaluate a Five Stage Series Cyclone System

Published Document and Abstract

Development and Laboratory Evaluation of a Five-Stage Cyclone System
Wallace B. Smith, Rufus Ray Wilson, Jr.
EPA-600/7-78-008, January 1978, NTIS (PB 279 084/AS)

This report describes the development and calibration of a Five-Stage Cyclone System for in situ sampling of process streams. Cyclones may be used to advantage for collecting large samples, and in sampling aerosols of high particulate concentration. The system was designed to operate instack at a sample flow rate of 28.3 ℓ/min and to have aerodynamic cut points between 0.1 and 10 μm. Dimensions were selected based on previous cyclone evaluations. The cyclone system was calibrated using a Vibrating Orifice Aerosol Generator to produce monodisperse organic dye and ammonium fluorescein spheres and a pressurized Collison nebulizer to disperse monodisperse latex spheres. At 25°C (77°F), 28.3 ℓ/min (1.0 ft^3/min) and for a particle density of 1.0 gm/cm^3, the D_{50} cut points of the cyclone system were 5.4 μm, 2.1 μm, 1.4 μm, 0.65 μm, and 0.32 μm for Cyclones I-V, respectively. Results from calibrating the cyclones at several conditions of flow rate (7.1, 14.2, 28.3 ℓ/min), temperature (25, 93, and 204°C), and particle density (1.05, 1.35, and 2.04 g/cm^3) suggest that the D_{50} cutpoints are proportional to the flow rate of the gas raised to a negative exponent which is between -0.63 and -1.11, linearly proportional to the viscosity of the gas, and proportional to the reciprocal of the square root of the particle density.

Presentation: This work was reported at the 72nd Annual Meeting of the Air Pollution Control Association in Cincinnati, Ohio on June 27, 1979. Authors of Paper No. 79-28.1 were Wallace B. Smith, Rufus R. Wilson, Jr. and D. Bruce Harris.

Hardware Fabricated: One aluminum prototype Five Stage Cyclone.

Technical Directive Number 10703

Develop an Electrostatic Precipitator Back-Up for Sampling Systems

Published Document and Abstract

An Electrostatic Precipitator Backup for Sampling Systems
P. Vann Bush, Wallace B. Smith
EPA-600/7-78-114, June 1978, NTIS (PB 283 660/AS)

This report describes the program carried out to design and evaluate the performance of an electrostatic collector to be used as an alternative to filters as a fine particle collector. Potential advantages of an ESP are low pressure drop and high capacity. Potential problems are unreliability and poor collection due to back corona or lack of particle adhesivity.

The electrostatic precipitator back-up filter was designed to be operated at a nominal sample flowrate of 6.5 ft^3/min., at a temperature of 205°C, and to achieve near 100% collection of submicron particles. Since it is possible that there would be a need to operate the collector in situ, a secondary requirement was that the collector pass through a 4 inch diameter port. Furthermore, the system was designed to be convenient to operate and clean, and to require a minimum of operator training or attention.

The prototype ESP collector is a highly efficient collector of submicron particles. When set to 200 µA on the corona disc electrde and 2 kV on the collector (both well below breakdown values), no further adjustments are necessary for proper operation. The power supply developed for the ESP collector facilitates correct operation. Since there is a potential for degraded performance due to back corona if the collected particles are of high resistivity, it is suggested that the collector be routinely used with a back-up filter following it in the sampling train. If experience has shown the system to operate reliably at a particular source, the filter can be eliminate.

After the sample is collected, the ESP is disassembled, immersed in a suitable liquid, and agitated ultrasonically. The wash can be filtered or evaporated to dryness, depending on the nature of the dust and the objectives of the test.

The electrostatic collector prototype developed and tested in this research effort fulfills the design criteria: near 100% collection of submicron particles when operated at a nominal sample flowrate of 6.5 ft^3/min and a temperature of 200°C, sized to fit through a 4 inch diameter port for in situ operation, convenient to operate, and clean.

Hardware Fabricated: One prototype stainless steel electrostatic precipitator back-up filter and power supply console.

Technical Directive Number 10804

Guidelines For Particulate Sampling, and Bibliography

Published Document and Abstract

Guidelines For Particulate Sampling In Gaseous Effluents From Industrial Processes
Rufus R. Wilson, Jr., Paul R. Cavanaugh, Kenneth Cushing, William E. Farthing, Wallace B. Smith
EPA-600/7-79-028, January, 1979 NTIS PB 290 899/AS

The guideline document written under this technical directive lists and describes briefly many of the instruments and techniques that are available for measuring the concentration and/or size distribution of particles suspended in process streams. The standard, or well established, methods are described as well as some experimental methods and prototype instruments.

Descriptions of instruments and procedures for measuring mass concentration, opacity, and particle size distribution are given. Procedures for planning and implementing tests for control device evaluation are also included.

A bibliography at the end of the report contains 141 citations to articles pertaining to the topics discussed in the text. The topics are listed below:

- Mass Concentration
  - Filtration
    - EPA Test Method 5
    - EPA Test Method 17
    - ASTM - Test Method 17
    - ASME Performance Test Code 27
    - Advantages and Disadvantages
    - Filter Materials
  - Process Monitors
    - Beta Particle Attenuation Monitors
    - Piezoelectric Mass Monitors
    - Charge Transfer
    - Optical Methods
      - Conventional Transmissometers
      - Other Optical Methods
        - Multiple-wavelength transmissometers
        - Light scattering
    - Opacity
    - Particle Size Distributions
      - Established Techniques
        - Field Measurements
          - Aerodynamic Methods
            - Cascade impactors
            - Cyclones
          - Optical Particle Counters
          - Diffusion Batteries with Condensation Nuclei Counters
          - Electrical Mobility

Technical Directive Number 10904

Technical Manual on Particle Sampling

Published Document and Abstract

Technical Manual: A Survey of Equipment and Methods for Particulate Sampling in Industrial Process Streams
Wallace B. Smith, Paul R. Cavanaugh, Rufus Ray Wilson, Jr.
EPA-600/7-78-043, March 1978, NTIS (PB 282 501/AS)

This technical manual lists and describes the instruments and techniques that are available for measuring the concentration or size distribution of particles suspended in gaseous process streams. The standard, or well established methods are described as are some experimental methods and prototype instruments. To the extent that the information could be found, an evaluation of the performance of each instrument is included.

The manual describes instruments and procedures for measuring mass concentrations, opacity, and particle size distributions. It also includes procedures for planning and implementing tests for control device evaluation, a glossary, and an extensive bibliography containing 422 citations.

In order to briefly convey the scope of this document, a list of the topics discussed is presented below.

Process Cycles and Feedstock Variations
Long and Short Sampling Times
Planning a Field Test

Technical Directive Number 11007

Evaluation of the PILLS IV

Published Document and Abstract

Evaluation of the PILLS-IV
William E. Farthing, Wallace B. Smith
EPA-600/7-78-130, July 1978, NTIS (PB 283 173/AS)

The operating characteristics of the PILLS IV in situ particle sizing instrument have been investigated theoretically and experimentally. The results of both types of work show large errors in this instrument's ability to size particles. Attempts to correlate the experimental findings with qualitative theoretical explanations have been successful. This investigation established a sensitivity to particle refractive index and detector response that seems to account for the observed characteristics of the instrument. Further measurements would be required to test this explanation quantitatively.

The prototype device, an extension of the PILLS (Particulate Instrumentation by Laser Light Scattering) technology to fine particles, was designed to measure particle size using the ratio of intensities of light scattered from a particle at two small angles (14° and 7°) with respect to an incident laser beam. The intensity ratio was chosen as the sizing parameter because of its relative independence of particle refractive index. However, the magnitude of the scattered intensity at 14° is also used for several important decisions in the electronic processing logic, which, for this particular optical system, render it especially sensitive to refractive index and detector variations for determinations of particle size distribution. Possible solutions to these problems with only minor hardware changes are offered.

Technical Directive Number 11102

Investigation of Cyclone Performance and Theory

Description of Task:

1. Complete Five Stage Series Cyclone calibration begun under Technical Directive No. 10602.

2. Based on the experimental results of this calibration, investigate various cyclone theories for the determination of cyclone performance at conditions of temperature, sampling rate, and particle density other than those at calibration. If necessary, develop a new theory of cyclone performance.

3. Perform tests at a suitable site to compare the performance of these cyclones with cascade impactors.

Task Summary:

Subtask 1. Completed

Subtask 2. Partially complete; results reported under Technical Directive Number 10602.

Subtask 3. Not performed.

Technical Directive Number 11202

Cyclone For Fugitive Source Assessment Sampling System

Description of Task:

Investigate available cyclones for use as sizing devices for the Fugitive SASS. Donaldson Company and Sierra Instruments may have instruments which may be useful for this application. This cyclone should be able to fractionate the sample at approximately three micrometers and operate at a sampling rate of 180 CFM. It is likely that several cyclones in parallel will be necessary to meet the objectives.

Task Summary:

1. Design of 15 μm aerodynamic diameter D_{50} pre-separator impaction stage.

2. Design of 2.5 μm aerodynamic diameter D_{50} cyclone.

3. Laboratory calibration of impaction stage and cyclone.

4. Assisted in field testing of FAST system for TRC - The Research Corporation of New England.

Technical Directive Number 11301

Impactor Sampling of Charged Polydisperse Aerosols

Published Document and Abstract

Sampling Charged Particles With Cascade Impactors
William E. Farthing, David H. Hussey, Wallace B. Smith, Rufus Ray Wilson, Jr.
EPA-600/7-79-027, January 1979 NTIS PB (290-897/AS)

In performing particle size distribution measurements at control devices operating on industrial process streams, investigators are usually aware that in some cases charged particles will be present in the gas stream. In order to assess the influence of particle charge, three different experiments were performed to determine whether or not cascade impactors sampling charged aerosols can yield erroneous particle size distribution measurements. The commercially available cascade impactors utilized in this study were the Andersen Mark III Stack Sampler, the Meteorology Research, Inc. Model 1502 Cascade Impactor, and the University of Washington Mark III Source Test Cascade Impactor. In general, the measured distributions indicated more large particles and fewer small particles than actually existed. The deviations from the true size distribution was found to be a function of the magnitude of charge. This deviation was smaller if glass fiber substrates were used as impactor collection surfaces instead of the metal collection plates alone. For charge levels representative of electrostatic precipitators operating at normal charging conditions (an electric field strength of 400,000 V/m and a current density of 3×10^{-4} A/m^2), the differences between the true and measured polydisperse size distributions with glass fiber substrates were small.

(This work was performed in conjunction with Technical Directive 10401).

Presentation: The results of this work were reported at the 72nd Annual Meeting of the Air Pollution Control Association in Cincinatti, Ohio on June 27, 1979. Authors of Paper No. 79-28.2 were W. E. Farthing, D. H. Hussey, W. B. Smith, and R. R. Wilson, Jr.

Technical Directive Number 11401

Design, Construct, and Test Optimized Cascade Impactors

Description of Task:

DEFINITION OF OPTIMIZED CASCADE IMPACTOR -- A cascade impactor which is designed to operate in a laboratorv or field environment in such a way that the effects of; particle bounce, particle reentrainment, wall loss, and non step function collection efficiency curves, etc. are minimized. Mechanical reliability and ease of operation will also be included in the design of an optimized impactor.

1. Based on the current knowledge of impactor operation theory and the results of field and laboratory use of currently available commercial and prototype cascade impactors, design high and low flowrate cascade impactors which will attempt to meet the criteria for an optimized cascade impactor.

2. Fabricate the impactors.

3. Calibrate and field test the impactors.

Task Summary:

Subtask 1. Design parameters for 0.1, 0.5, and 2.0 ACFM Optimized Cascade Impactors calculated. Fabrication drawings for 0.5 ACFM Optimized Cascade Impactor completed.

Subtask 2. Not performed.

Subtask 3. Not performed.

Technical Directive Number 11506

Assorted 100 man-hour tasks (Research and Development)

Description of Task:

This technical directive will cover various small research and development tasks of less than 100 man-hours. These small tasks will be chosen by the Project Officer.

Task Summary: The majority of the manhours spent on this task were used in support of other research and development tasks under this contract.

Technical Directive Number 11601

Design a High Temperature Aerosol Test Facility

Description of Task:

Design toward fabrication of a High Temperature Aerosol Test Facility

Design Goals:
(a) Gas Flow to 1000 ACFM;
(b) Gas Temperatures to 1000°F;
(c) Gas Pressures ranging from 380 mm Hg to 760 mm Hg;
(d) Introduction of various aerosols.

Purpose: Provide a test environment for particle measurement instruments to simulate process streams.

Task Summary: A design for the Test Facility meeting the above requirements was completed.

Published Document:

Design a Particle Sampling Test Facility
Norman L. Francis, Kenneth M. Cushing
SORI-EAS-78-560, September 22, 1978

Technical Directive Number 11708

Develop and Test a High Volume Particle Sampler

Description of Task:

The Contractor shall design, fabricate, field evaluate, and deliver a system capable of obtaining large quantities of fine particulate for use in animal inhalation studies. In addition, the Contractor shall also study current technology for redispersing and diluting the collected particulate into the animal exposure chambers and shall make recommendations to improve this technology. More specifically, the program shall be conducted as follows:

Hardware Development

The High Volume Particulate Sampler (HVPS) shall be designed to meet the following criteria:

1. Sample flow rate 200 to 300 acfm

2. Sampling range shall be divided into two intervals; large particulate and fine particulate

3. Collected mass of fine particulate shall be a minimum of 750 grams

4. The HVPS shall be packaged such that it is shippable by commercial carriers

5. The HVPS shall be designed such that the length of sampling lines is a minimum

6. Two fine particle collection devices shall be supplied with the HVPS (1) a filter type collector, (2) an electrostatic precipitator type collector

7. The HVPS shall be designed to facilitate sample recovery

8. The HVPS shall be designed to minimize sample contamination.

    (1) The Project Officer shall approve the completed system design prior to fabrication. After approval by the Project Officer, the Contractor shall fabricate the HVPS.

    (2) The Contractor shall conduct a rigorous laboratory evaluation of the HVPS and shall determine:

    - The precise size cut

    - The percent of the total collected sample that can be recovered

- Set up and tear down time
- System changes that would improve operability
- Minimum field team needed to operate HVPS
- Operator time required to maintain system while sampling

Field Evaluation

The Contractor shall recommend a suitable field test site for the Project Officer's approval. Upon approval by the Project Officer, the Contractor shall make all arrangements necessary to evaluate the HVPS at an operating energy conversion process and shall conduct the field evaluation. The purpose of the field evaluation is two fold: (1) to demonstrate the HVPS and to identify potential problems and (2) to obtain a sample suitable for use in inhalation tests.

Particulate Delivery to Test Chamber

The Contractor shall evaluate the current state-of-the-art in redispersing and diluting the collected particulate into the inhalation chambers. Contact shall be made with the organizations performing these tests to determine existing problem areas. The Contractor shall submit his recommendations on the current state-of-the-art in redispersion and dilution and assess its adequacy.

Task Summary:

The Hardware Development portion of this task was completed under this contract. The field evaluation and particulate delivery to test chamber were not performed.

Technical Directive Number 20101

Calibration and Evaluation of Commercial Impactors

Published Document and Abstract:

Particulate Sizing Techniques For Control Device Evaluation: Cascade Impactor Calibrations
Kenneth M. Cushing, George E. Lacey, Joseph D. McCain, Wallace B. Smith
EPA-600/2-76-280, October 1976, NTIS (PB 262 849/AS)

(This document assigned to EPA Contract No. 68-02-0273).

A calibration study of five source-test cascade impactors has been conducted to determine sizing parameters and wall losses. A Vibrating Orifice Aerosol Generator was used to produce monodisperse ammonium fluorescein aerosol particles 18 micrometers to one micrometer in diameter. A Pressurized Collison Nebulizer System was used to disperse Polystyrene Latex (PSL) Spheres 2 micrometers to 0.46 micrometer in diameter. Results are reported showing stage collection efficiencies versus the square root of the inertial impaction parameter, Ψ, and impactor wall losses versus particle size. It has been determined that the values of the inertial impaction parameter for 50% collection efficiency are not generally the same for each impactor stage. Published theories do not successfully predict these $\sqrt{\Psi_{50}}$ values, so empirical calibration is required before these devices can be accurately used in the field or laboratory.

Technical Directive Number 20201

Soviet Impactor - Cyclone Calibration

Description of Task:

Calibrate and evaluate three Soviet impactor/cyclone devices.
The upper stages are to be calibrated using a Vibrating Orifice Aerosol Generator.
The lower stages are to be calibrated usine a PSL aerosol generator.

Task Summary:

Under this task three Soviet cascade impactors and one Soviet impactor/cyclone were calibrated. The three cascade impactors included one twelve stage device and two fourteen stage impactors. The three stage impactor/cyclone had a single impaction stage followed by two cyclonic stages. All four devices had an integral back-up filter holder which used a plug of glass wool fibers.

The upper stages of these sizing devices were calibrated using ammonium fluorescein aerosols (20 µm to 2 µm) dispersed by a Vibrating Orifice Aerosol Generator. The lower stages were calibrated using monodisperse polystyrene latex or Polyvinyltoluene latex spheres (2.02 µm to 0.46 µm) dispersed by a Pressurized Collison Nebulizer System.

Technical Directive Number 20302

Calibration of Source Assessment Sampling System (SASS) Cyclones

Description of Task:

The contractor shall calibrate the SASS cyclones using latex spheres and the Vibrating Orifice Particle Generator. The calibration shall be of sufficient accuracy to characterize the D_{50} of the 3μm cyclone to ± 0.5 μm.

Task Summary:

The calibrations of the Large (10 μm) and Middle (3 μm) Cyclones were performed using ammonium fluorescein aerosols generated with Southern Research Institute's Vibrating Orifice Aerosol Generator (VOAG). Monodisperse ammonium fluorescein aerosols with diameters of 2, 3, 4, 5, 7.5, 10.5, and 14.5 micrometers were sampled at flow rates of 4 ACFM and 3 ACFM.

The Small Cyclone was calibrated using Dow Corning polystyrene latex (PSL) and polyvinyltoluene latex (PVTL) spheres dispersed with the Institute's Pressurized Collison Nebulizer System. Using an auxiliary pump, aerosols were pulled through the Small Cyclone at two flowrates, 3.1 ACFM and 1.8 ACFM. The calibration at 75°F and 4 ACFM gave approximately 0.86 μm, 3.5 μm, and 11.0 μm D_{50}'s for the Small, Middle, and Large Cyclones, respectively.

Technical Directive Number 20402

SASS Cyclone Calibration - 45CFM

Description of Task:

The SASS cyclones are to be recalibrated at a flowrate of 4 SCFM and an operating temperature of 400°F. There are two objectives of the test: (1) To establish the cut points of the cyclones as they presently exist and (2) To determine what modifications and design parameters are required to achieve cut points of 10, 3, and 1 µm at 4 SCFM and 400°F.

Task Summary:

The calibration of the Large and Middle Cyclones was performed using ammonium fluorescein aerosols generated with Southern Research Institute's Vibrating Orifice Aerosol Generator (VOAG). With the cyclones placed in a heated oven and using a heated inlet line, the temperature of the gas stream at the inlet to the Large Cyclone was maintained at 400°F. Particle integrity of the ammonium fluorescein at high temperature was a major problem.

The Large Cyclone was modified to try to obtain a D_{50} closer to the desired 10 micrometers. This modification involved the removal of the vortex buster from the Large Cyclone outlet.

The Middle Cyclone was also modified in an attempt to obtain a D_{50} closer to the desired 3 micrometers. This was done by reducing the Middle Cyclone inlet diameter from 0.62 inches to 0.53 inches.

As a result of this laboratory calibration, the approximate D_{50}'s for the Large and Middle Cyclones at 400°F and 4 SCFM are 15 micrometers and 4.4 micrometers, respectively.

It was decided that the results of this study were not sufficiently conclusive to recommend changes in the cyclone construction to obtain the desired cut points of 10, 3, and 1 micrometer at operating conditions of 400°F and 4 SCFM.

Technical Directive Number 20502

High Temperature Recalibration and Modification of SASS Cyclones

Description of Task:

Use Vibrating Orifice Aerosol Generator with suitable compound soluble in water. This aerosol must have a high melting point.

Generate approximately 10 to 12 sizes of aerosol. Sample and make necessary modifications and retest.

Concentrate on Middle Cyclone.

Test at 75°F, 200°F, 350°F.

Extrapolate data to 400°F.

Task Summary:

Because previous tests have indicated ammonium fluorescein was unstable at 400°F, a search was initiated for an aerosol with some or all of the following characteristics:

- Non-toxic
- Stable at temperatures up to 500°F or above
- Soluble in water or other non-toxic, non-residue forming solvent
- Amorphous - dries to form solid, homogeneous spheres when dispersed in solution from a VOAG
- Known or easily measured density
- Has a definite, distinct absorption spectrum peak for absorption spectroscopy measurement between 400 NM and 900 NM.

Of several samples from three chemical companies, du Pont's "Pontamine" Fast Turquoise 8 GLP dye was the first found to satisfactorily meet the requirements listed above.

The calibration of the SASS train cyclones was performed using the Institute's Vibrating Orifice Aerosol Generator (VOAG). The VOAG generated monodisperse ammonium fluorescein particles and turquoise dye particles with diameters from 2 micrometers to 7 micrometers.

The SASS Middle Cyclone calibration at 70°F, 200°F, and 350°F were 2.8, 3.5, and 4.2 micrometers aerodynamic diameter, respectively.

Technical Directive Number 20604

Procedures Manual for ESP Evaluation

Published Document and Abstract

Procedures Manual for Electrostatic Precipitator Evaluation
Wallace B. Smith, Kenneth M. Cushing, Joseph D. McCain
EPA-600/7-77-059, June 1977, NTIS (PB 269 698/AS)

The purpose of this procedures manual is to describe methods to be used in characterizing the performance of electrostatic precipitators for air pollution control. A detailed description of the mechanical and electrical characteristics of precipitators is given. Procedures are described for measuring the particle size distribution, the mass concentration of particulate matter, and the concentrations of major gaseous components of the flue gas-aerosol mixture. Procedures are also given for measuring the electrical resistivity of the dust. A concise discussion and outline is presented which describes the development of a test plan for the evaluation of an industrial precipitator. Several appendixes contain detailed information on testing methods as well as a listing of the Federal Stationary Source Performance Standards and Federal Source Testing Reference Methods.

To give a better idea of the scope of this document, the contents listing is reproduced below.

Technical Directive Number 20705

Review EPA Documents

Description of Task:

Critically review the following documents. Submit a list of corrections and suggestions to the project officer.

1. Cascade Impactor Guidelines - EPA

2. Sampling Protocol to Minimize Errors Due to Source Fluctuations - GCA

3. Level 1 Assessment - TRW

Task Summary:

All subtasks were performed as required.

Technical Directive Number 20806

Soviet - USA Information Exchange Program

Description of Task:

Participate as consultants on particle sizing in the Soviet-USA information exchange.

1. Prepare and ship equipment to the U.S.S.R. for field testing.

2. Send an expert (Joe McCain) to supervise the tests.

3. Prepare reports and papers as required to discuss the results of the tests and provide information exchange.

Task Summary:

Under this task Southern Research Institute personnel participated as consultants on particle sizing in a program of technical information exchange with scientists in the Soviet Union. During July, 1976 particle sizing equipment was prepared and shipped to the Soviet Union for a field testing program at a scrubber installed on a metallurgical plant. Mr. J. D. McCain of the Southern Research Institute staff accompanied several EPA staff scientists to the test site. The actual field test took place during August, 1976. No results have been published as of this date.

Technical Directive Number 20906

Coordinate Arrangements For The EPA-IERL 1977 APCA Exhibit Booth

Description of Task:

Coordinate the development of the EPA-IERL exhibit at the 1977 APCA Meeting in Toronto, Canada during June, 1977. This exhibit booth will display the research and development efforts of the IERL Task Level of Effort contractors. Certain pieces of hardware and software from these contractors will be displayed.

Task Summary:

On June 21, 22, 23, 1977, the Process Measurements Branch of IERL/RTP supported an exhibit booth at the 70th Annual Air Pollution Control Association Meeting in Toronto, Ontario, Canada. This 10' x 20' booth used a color scheme of dark blue back and side walls, light blue carpet, and green draped tables. Three tables along the back wall were used for document display. Two tables, one on each side, were used to display hardware. On the white 1' x 20' header board in black letters was printed the following title:

United States Environmental Protection Agency
Industrial Environmental Research Laboratory - RTP
Process Measurements Branch

On either side of the title was an EPA LOGO in color.

On the back wall were hung six 3' diameter discs which briefly described the research and development efforts of the six 1977 Task Level of Effort contractors for the PMB. These six contractors were Acurex/Aerotherm, Arthur D. Little, Inc., Research Triangle Institute, Southern Research Institute, The Research Corporation of New England, and TRW, Inc. Representatives from each of the contractors were at the booth on a rotating basis to answer technical questions.

The hardware on display included a complete Source Assessment Sampling System, a KLD Droplet Analyser, and a Five Stage Series Cyclone and IERL/PMB Advanced Sampling System.

Approximately 200 copies each of twenty-one EPA Research and Development Reports were distributed on a first-come, first served basis to the 4200 registrants at the meeting.

Technical Directive Number 21002

Calibration of SASS Cyclones For HERL

Description of Task:

The contractor shall calibrate the SASS cyclones used to collect the large volume particulate sample collected for use by the Health Effects Research Laboratory. The cyclones must be calibrated at the actual run conditions as operated by test personnel from Exxon Research and Engineering.

Task Summary:

Exxon Research and Engineering Corporation used a Source Assessment Sampling System at a coal-fired power plant in Padicah, Kentucky early in 1977. This work was performed for the Health Effects Research Laboratory of the National Environmental Research Center/RTP. The SASS was used to size and sample the particulate effluent. In order to determine the actual Middle Cyclone D_{50} as run, Southern Research Institute was requested to calibrate the actual SASS Middle Cyclone used by Exxon at the actual sampling conditions.

Exxon used the following sampling conditions.

- 600°F inlet gas temperature to the oven
- Oven temperature 375°F
- No filter element in the filter housing in the heated oven
- Pump flow wide open with filter on pump inlet and muffler on pump outlet
- Vacuum measured ahead of pump filter - 14 inches H_2O vacuum under sampling conditions
- Stack moisture 8%
- Gas temperature in middle cyclone unknown
- Vortex busters in the collection cups of the Large and Middle cyclones

These conditions and those of the calibration system were not completely compatible. The inlet gas temperature was 450°F, the constraint being the temperature limit of the calibration aerosol. The oven temperature was 375°F. The humidity of the air was not measured.

For a temperature of 450°F, a flow of 13 cfm, and a particle density of 2.04 gm/cm^3, the D_{50} cut points of the large and middle cyclones were 7.6 μm and 2.13 μm, respectively. For a particle density of 1.00 gm/cm^3 and the same conditions, the D_{50} cut point of the large and middle cyclones would be 11 μm and 3.0 μm, respectively.

The D_{50} cut points of the small cyclone for a flow of 13 ACFM were estimated to be 0.49 μm for a temperature of 375°F and 0.63 μm for a temperature of 600°F.

Technical Directive Number 21104

Procedures Manual For Fabric Filter Evaluation

Published Document and Abstract

Procedures Manual For Fabric Filter Evaluation
Kenneth M. Cushing, Wallace B. Smith
EPA-600/7-78-113, June 1978, NTIS (PB 283 389/AS)

The purpose of this procedures manual was to describe methods to be used in experimentally characterizing the performance of fabric filters for pollution control. A detailed description of the mechanical characteristics of fabric filters is presented. Procedures are described for measuring the particle size distribution, the mass concentration of particulate matter, and the concentration of major gaseous components of the flue gas-particle mixture. A concise discussion and outline is presented which describes the development of a test plan for the evaluation of a fabric filter installation. By following this outline useful tests may be performed which range in complexity from qualitative and relatively inexpensive to rather elaborate research programs.

In order to detail the scope of this document, the Table of Contents is reproduced below.

Technical Directive Number 21207

Comparative Evaluation of Commercial and Prototype Mass Monitors

Description of Task:

1. Contact mass monitor manufacturers and obtain instruments.

2. Set up, check out, and learn to operate mass monitors. Pre-test on SRI dry wall ESP, if necessary.

3. Develop test plan for evaluation at IERL wind tunnel, or an alternate test site.

4. Ship instruments to test site.

5. Conduct tests. Variables may include particle size distributions, dust loadings, particle density, and duct gas velocity.

6. Write final report on test results.

Task Summary:

This task was not performed.

Technical Directive Number 21306

1978 Particulate Sampling Technology Symposium

Description of Task:

Coordinate the arrangements for the 1978 Particulate Sampling Technology Symposium sponsored by the Process Measurements Branch of IERL/RTP. This will include choosing a meeting site, organizing the program, choosing speakers, etc. Southern Research will be responsible for reserving the hotel accommodations, meeting rooms, any food services which are to be provided, and organizing any recreational activities.
Upon completion of this symposium, the proceedings will be published.

Task Summary:

Southern Research Institute coordinated a symposium for the Process Measurements Branch/IERL-RTP on May 15-17, 1978 at the Grove Park Inn and Country Club, Asheville, North Carolina. The number of attendees was 176. There were five sessions with a total of seventeen speakers. The symposium had morning and evening sessions with the afternoons free for recreation. A proceedings from this technical meeting has been published.

Published Document:

Proceedings: Advances in Particle Sampling and Measurement
(Asheville, North Carolina, May, 1978)
Wallace B. Smith, Compiler
EPA-600/7-79-065, February 1979 NTIS PB 293 363/AS

Technical Directive Number 21406

Assorted 100 man-hour tasks (Support Services)

Description of Task:

This technical directive will cover various small support service tasks of less than 100 man-hours. These small tasks will be chosen by the Project Officer.

Task Summary:

The majority of the hours spent under this task were in support of other contract support tasks.

Technical Directive Number 21506

Presentation To Federal Republic of Germany

Description of Task:

A paper on manual particulate mass and size measurements will be presented to the Federal Republic of Germany March 16 and 17, 1978. Preparation of the paper is estimated to consume approximately three manweeks, and illustrations will consume approximately three days. Travel expenses for six days per diem at $75/day and round-trip airfare for one person are included in this technical directive.

Task Summary:

Under this technical directive Mr. J. D. McCain of Southern Research Institute wrote and presented a paper on manual particulate mass and size measurements at a workshop held in Julich, Federal Republic of Germany on March 16 and 17, 1978.

Technical Directive Number 21608

Particulate Sizing Instrument Evaluation

Description of Task:

The contractor shall develop criteria for the evaluation of the real time particle sizing instruments currently being developed for IERL. These instruments are:

1. a light scattering instrument - Particle Measuring Systems, Inc. Boulder, CO

2. a light sensing virtual impactor - Meteorology Research Inc., Altadena, CA

3. an acoustic instrument - KLD Assoc., Huntington Station, NY

The evaluation shall consider the operational characteristics of each instrument and shall assess the instruments' performance based on its principle of operation. Additionally, evaluation criteria shall be developed which will allow all three instruments to be compared. These second criteria shall be based on measured parameters that are of greatest interest to IERL. For example, the evaluation of the PMS instrument might include an assessment of its sizing capability of particles with varying indices of refraction. The sampling volume of the instrument could also be verified. Likewise, the second evaluation might compare the response of the instrument to the aerodynamic diameter.

In developing these criteria, the contractor shall consider the field evaluation task that will be conducted by each instrument development contractor. The criteria developed under this technical directive shall seek to maximize the information gained during the instrument development contractor's field evaluation. A copy of the field evaluation scope of work is included as an attachment.

Task Summary:

Criteria were developed for the evaluation of three real-time particle sizing instruments. The instruments are:

1. a light scattering instrument--Particle Measuring Systems, Inc., Boulder, CO
2. a light sensing virtual impactor--Meteorology Research, Inc., Altadena, CA
3. an acoustic instrument--KLD Associates, Huntington Station, NY

The suggested evaluation program is based on the operational principle of each instrument. The evaluation criteria based on measurable parameters that are of greatest interest to EPA/IERL/RTP have been developed to allow comparisons of the three instruments.

Published Document:

Particulate Sizing Instrument Evaluation
William E. Farthing
SORI-EAS-78-595, October 6, 1978

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

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15. SUPPLEMENTARY NOTES IERL-RTP project officer is D. Bruce Harris, Mail Drop 62, 919/541-2557. EPA-600/2-79-114 is the final report.

16. ABSTRACT The report summarizes results of research, development, and support tasks performed during the 3-year period of the contract (11/75-11/78). The tasks encompassed many aspects of particulate sampling and measurement in industrial gaseous process and effluent streams. Under this contract: cascade impactors were calibrated and evaluated; novel particle sampling cyclones were designed and evaluated; technical and procedures manuals were prepared for control device evaluation and particle sampling methods; an electrostatic precipitator backup was designed for high flow rate systems; and advanced concepts in monitoring particle mass and size, using optical systems, were evaluated. A detailed examination of the results of this contract is contained in the basic report, EPA-600/2-79-114.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Impactors	Pollution Control	13B	13I
Dust	Cyclone Separators	Stationary Sources	11G	07A
Sampling	Electrostatic	Particulate	14B	
Measurement	Precipitators	Cascade Impactors		
Optical Measurement				
Industrial Processes			13H	

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