EMISSIONS AND EMISSION CONTROLS
AT A
SECONDARY LEAD SMELTER

13

Prepared by:

Klaus Schwitzgebel

and

Robert Vandervort

RADIAN CORPORATION
8500 Shoal Creek Boulevard
Austin, Texas 78766

EPA Contract Number 68-03-2807

Project Officer:

Alfred B. Craig, Jr.
Metals and Inorganic Chemistry Branch
Industrial Environmental Research Laboratory
Office of Research and Development
U. S. ENVIRONMENTAL PROTECTION AGENCY
Cincinnati, Ohio 45268

9 January 1981

DISCLAIMER

FOREWARD

When energy and material resources are extracted, processed, converted and used, the impacts on our environment and our health often require that new and increasingly more efficient control methods be used. The Industrial Environmental Research Laboratory, Cincinnati, (IERL-Ci), of EPA and the Division of Physical Science and Engineering of NIOSH assist in developing and demonstrating new and improved methodology that will meet these needs both efficiently and economically.

This report presents the findings of an investigation performed to obtain data concerning environmental and workplace emissions from secondary lead smelting. The results are being used within both EPA and NIOSH as part of a larger effort to define the potential environmental/workplace impact of emissions from this industry segment and the need for improved controls. The findings will also be useful to other agencies and the industry in dealing with control problems. Either the Metals and Inorganic Chemical Branch of EPA or the Division of Physical Science and Engineering of NIOSH should be contacted for any additional information desired concerning this program.

Director - Industrial Environmental
Research Laboratory, EPA, Cincinnati

Director - Division of Physical
Science and Engineering, NIOSH,
Cincinnati

ABSTRACT

This report presents the results of an interagency control technology demonstration and research study conducted at a domestic secondary lead smelter. Included are data describing conditions at the smelter before and after the implementation of a major environmental and workplace clean-up program. This program included installation of the Bergsøe flash agglomeration furnace, an upgraded local exhaust system for smelting operations, yard paving and other housekeeping measures.

The agglomeration furnace failed to perform satisfactorily due to poor agglomerating properties of the smelter's flue dust. Insufficient chlorine content (below ~8 percent) was determined to be the primary cause. The chlorine sources are PVC battery plate separators. PVC is contained in an estimated 30 percent of European car batteries; this compares to only 3 percent in the United States.

Emissions captured by local exhaust ventilation complete with particle sizing analysis were determined for several smelting operations. A preponderance of small particles (<2.5μ) was found. Lead emission rates for specific operations were:

- Blast furnace charging ~85,000 g/hr; ~80 tons/day capacity.
- Blast furnace slag tapping ~900 g/hr; ~13 tons/day capacity.
- Blast furnace metal tapping ~340 g/hr; ~50 tons/day capacity.
- Refining kettle ~13 g/hr; ~25 tons/day capacity.
- Ingot casting ~14 g/hr; ~50 tons/day capacity.
- Flue dust agglomeration ~50,000 g/hr; ~4 tons/day capacity.

Control efficiencies for three baghouse dust collectors were determined as a function of particle size and lead content. Efficiencies below 99 percent were found and can be attributed to the high percentage of small particles <2.5μ. Lead emission rates and baghouse efficiencies based on total particulate are:

- Slag tap baghouse, 10 g/hr, 97.6 to 97.9 percent.
- Process baghouse, 195 g/hr, 99.2 to 99.9 percent.
- Sanitary baghouse, 34 g/hr, 97.2 to 99.9 percent.

Upwind-downwind ambient monitoring and particle sizing were conducted over a short period of time. Upwind, off-site concentrations ranged from 0.1 to 0.6 µg/m³. Downwind measurements at a distance of 200 meters (~700 feet) and 370 meters (~1,200 feet) ranged from 0.7 to 11.4 µg/m³ Pb. Modeling indicated that only a small part of the ambient downwind concentration was attributable to point sources of emission. This compares to a range of 30 to 60 µg/m³ at the access road 10 meters (~30 feet) downwind of the flue dust pile and adjacent to the baghouse/agglomerator building.

Employee exposures, workplace controls, work practices and biological monitoring data were analyzed. Retrofitted control improvements, consisting primarily of improved enclosure and local exhaust ventilation of emission sources, reduced employee exposures to airborne lead. Exposure levels were reduced from well in excess of 200 µg/m³ to near or below 200 µg/m³ on an eight-hour time-weighted average basis. Exposures to lead associated with battery breaking using a slow moving shear were reduced to below 50 µg/m³. Employee exposures to antimony, arsenic and sulfuric acid mist and workplace concentrations of carbon monoxide were found to be well within permissible occupational exposure limits. Lead in blood concentrations for all smelter workers and a select group of veteran workers showed gradual reduction over a period of more than three years. Personal protective clothing and equipment utilization, personal hygiene and housekeeping all improved from the initial to final evaluations. Conveying, handling and storage of flue dust and other leady materials remains a significant source of employee exposure to lead.

Cost information related to improved workplace and environmental controls is provided. Local exhaust ventilation was fabricated and installed at a cost of $11/scfm.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CONVERSION CHART

To convert from	To	Multiply by	
British thermal unit (Btu, International Table)	joule(J)	1.0550559	E + 03
Btu/hour	watt(W)	2.9307107	E - 01
Btu/second	watt(W)	1.0550559	E + 03
Btu/ft²-hr-deg F (heat transfer coefficient)	joule/meter²-second-kelvin(J/m²·s·K)	5.6782633	E + 00
Btu/ft²-hour (heat flux)	joule/meter²-second(J/m²·s)	3.1545907	E + 00
Btu/ft-hr-deg F (thermal conductivity)	joule/meter-second-kelvin(J/m·s·K)	1.7307347	E + 00
degree Fahrenheit (°F)	kelvin(K)	$t_K = (t_F + 459.67)/1.8$	
degree Rankine (°R)	kelvin(K)	$t_K = t_R/1.8$	
foot	meter(m)	3.0480000*	E - 01
foot²	meter²(m²)	9.2903040*	E - 02
foot/second²	meter/second²(m/s²)	3.0480000*	E - 01
foot²/hour	meter²/second(m²/s)	2.5806400*	E - 05
foot²/second	meter²/second(m²/s)	9.2903040*	E - 02
foot³	meter³(m³)	2.8316847	E - 02
gallon (U.S. liquid)	meter³(m³)	3.7854118	E - 03
horsepower (550 ft·lbf/s)	watt(W)	7.4569987	E + 02
inch	meter(m)	2.5400000*	E - 02
inch of mercury(60°F)	pascal(Pa)	3.37685	E + 03
inch of water(60°F)	pascal(Pa)	2.48843	E + 02
inch²	meter²(m²)	6.4516000*	E - 04
inch³	meter³(m³)	1.6387064*	E - 05
kilocalorie	joule(J)	4.1868000*	E + 03
kilogram-force(kgf)	newton(N)	9.8066500*	E + 00
psi	pascal(Pa)	6.8947573	E + 03
ton (short, 2000 lbm)	kilogram(kg)	9.0718474*	E + 02
watt-hour	joule(J)	3.6000000*	E + 03

ACKNOWLEDGMENT

The authors would like to thank the East Penn Manufacturing management and personnel who were most cooperative in this study.

We also would like to commend the members of the sampling and analytical team who helped perform this characterization study and contributed to the data evaluation and this report. Special thanks to:

Gary Beall
Jacqueline G. Beskid
Rebecca H. Burris
D. Jeff Burton
Richard T. Coleman, Jr.
Guy M. Crawford
Michael R. Fuchs
William C. Hawn
Lawrence J. Holcombe
Darrell B. Hunt
Patricia M. Jeans
Jeff L. Meling
Terry B. Parsons-Smith
Ann V. Simonson
Paul N. Williams

SECTION 1

INTRODUCTION

The Environmental Protection Agency (EPA) and the National Institute for Occupational Safety and Health (NIOSH) have sponsored a study of environmental and workplace controls at a domestic secondary lead smelter. The purpose of the study was to develop information regarding the reduction in environmental emissions and employee exposures which could be achieved by retrofitting controls to an existing secondary lead smelter.

Specifically, the study involved initial and follow-up evaluations at the East Penn Manufacturing smelter located in Lyons, Pennsylvania. Figure 1-1 shows a topographical map of the test site. The initial evaluation documented conditions at the smelter in January, 1979, before the implementation of a major environmental emission/employee exposure abatement program. The follow-up evaluation, conducted in August, 1980, served to document the design, operation and effectiveness of control systems installed by the smelter.

The control program designed and implemented by the smelter included:

- Purchase, installation and operation of a Bergsøe Agglomeration Furnace to treat leady flue dust.
- Design and installation of improved local exhaust ventilation systems for smelting operations.
- Major clean-up of smelter buildings and yard areas with paving of yard areas and access roads.
- Installation of a central vacuum system.
- Wetting of raw materials and work surfaces.
- Improving employee personal protective equipment and hygiene programs.

East Penn Manufacturing is the first US secondary lead smelter to apply the Bergsoe Agglomeration Furnace to flue dust handling problems. This furnace is intended to convert leady flue dust into a slag-like material which can be handled with less relative hazard. The flue dust agglomeration technique has been successfully applied in Denmark at the Paul Bergsoe and Sons A/S secondary lead smelter.

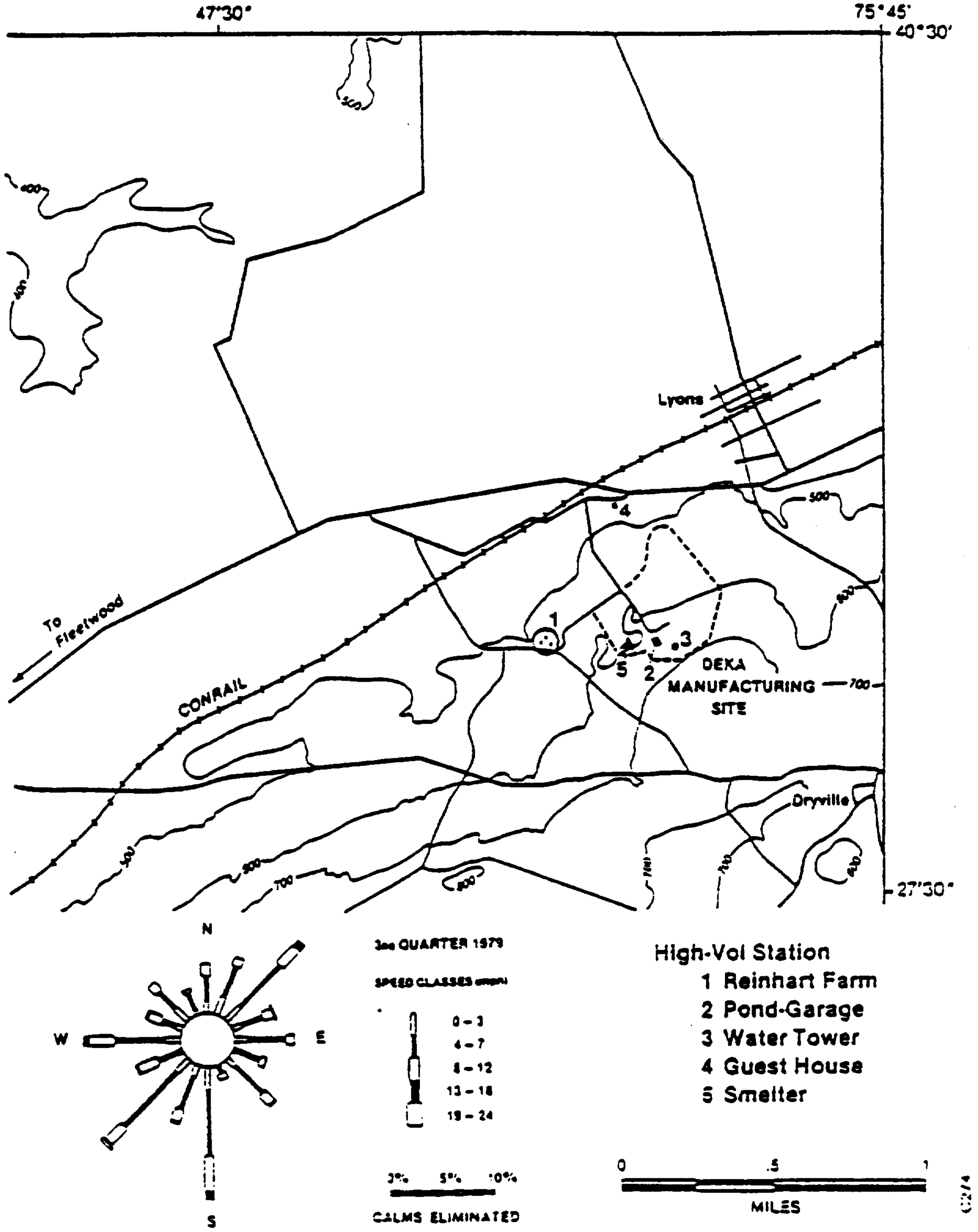


FIGURE 1-1. TOPOGRAPHICAL MAP OF THE EAST PENN (DEKA) MANUFACTURING SITE. WIND ROSE AND HI-VOL STATIONS ARE INCLUDED

To describe and document the applicability and effectiveness of individual control techniques, the following information development activities were conducted:

- Description of work processes, operation, controls and work practices.
- Measurement of employee exposures to airborne contaminants and work area contaminant concentrations.
- Measurement of process emissions collected by local exhaust ventilation enclosures (including particle size analyses).
- Measurement of exhaust ventilation control parameters (e.g., volumetric exhaust rate, face velocity).
- Measurement of baghouse collection efficiencies as function of particle size.
- Source testing of major point sources of emission including chemical and particle size analyses.
- Analysis of flue dust agglomerating properties.
- Description of agglomeration furnace operating parameters and experience.
- Measurements of fugitive emissions from yard access roads (including particle size analyses).
- Upwind-downwind ambient monitoring for total suspended particulates and lead.
- Ambient monitoring along the access road.
- Determination of dust cover at selected spots around the smelter.
- Lead concentration of soil around the smelter.
- Modeling of smelter point source and fugitive emission contributions to fence line, downwind ambient lead concentrations.
- Collection of cost data regarding control fabrication and installation.

The information collected by each of these activities is presented and discussed in the remaining sections of this report.

Section 2 presents a detailed description of the smelter, processes, equipment, controls and work practices as they were studied during the initial and follow-up evaluations. Section 3 describes the measurements made related to process and point source emissions, baghouse efficiencies, ambient monitoring and modeling. Section 4 presents the assessment of employee exposures and workplace exposure controls. Section 5 summarizes the control cost information provided by the smelter. Section 6 discusses the major findings of the study and Section 7 the references. Section 7 is followed by several appendices which contain detailed information regarding work summarized in Sections 3 and 4. Appendix A describes the investigations concerning dust agglomeration properties. Appendix B lists in detail the University of Washington Impactor results. Appendix C summarizes the workplace exposure control information provided to East Penn following the initial evaluation. In Appendix D additional information about point source particulate matter and total lead data is given. Lead content and size of ambient suspended particulate data are presented in Appendix E in greater detail.

SECTION 2

SMELTER DESCRIPTION

East Penn Manufacturing Company consists of battery and cable manufacturing facilities and a secondary lead smelter. Both automotive and industrial batteries are manufactured. Secondary lead is produced from scrap batteries and plant scrap by processing these materials through a blast furnace and refining kettles.

Between the initial and follow-up evaluations conducted at the smelter, a number of changes to the physical facilities and mode of smelter operation were made. These changes greatly complicate description of conditions during the two evaluation visits. This section describes the smelter, how it was operated and the control systems provided. The description begins with an overview of the plant property and facilities layout and then proceeds through the smelting activity from receipt of raw materials to final products and wastes.

OVERVIEW OF PLANT LOCATION AND FACILITIES

Referring to Figure 2-1, the plant is located on the north side of a rolling hill. The lead smelter is on the west end of the manufacturing complex very near the fence line. The smelter includes three point sources of lead emission: the process baghouse stack, the sanitary baghouse stack and the slag tapping baghouse stack. Many other point sources of lead emission are found on the plant property. They are associated with oxide, automotive and industrial battery manufacture. Fugitive emissions emanate from buildings, road surfaces, storage piles and other sources.

The zero point of the coordinate system used in the following description is the smelter process baghouse stack (see Figure 2-1). To the north of this point is an open, cultivated field. Also visible from this point are the automotive battery building and the light-duty vehicle road connecting the plant with Reinhart's farm. Kutztown, Pennsylvania, is approximately 6.4 kilometers (4 miles) north of the plant.

Most of the plant buildings are located along compass bearing 45°. As Figure 2-1 shows, these buildings are the industrial battery building, the cable building, the wastewater treatment plant (which includes the meteorological station) and the wire and warehouse building. To the east, along bearing 90°, are a pond and an access road leading to the dust storage area. The pond is about 90 meters (300 feet) long and lies in an east-west direction. Figure 2-2 is a photograph of the smelter as viewed from across the pond. The access road to the north of the pond and the dust

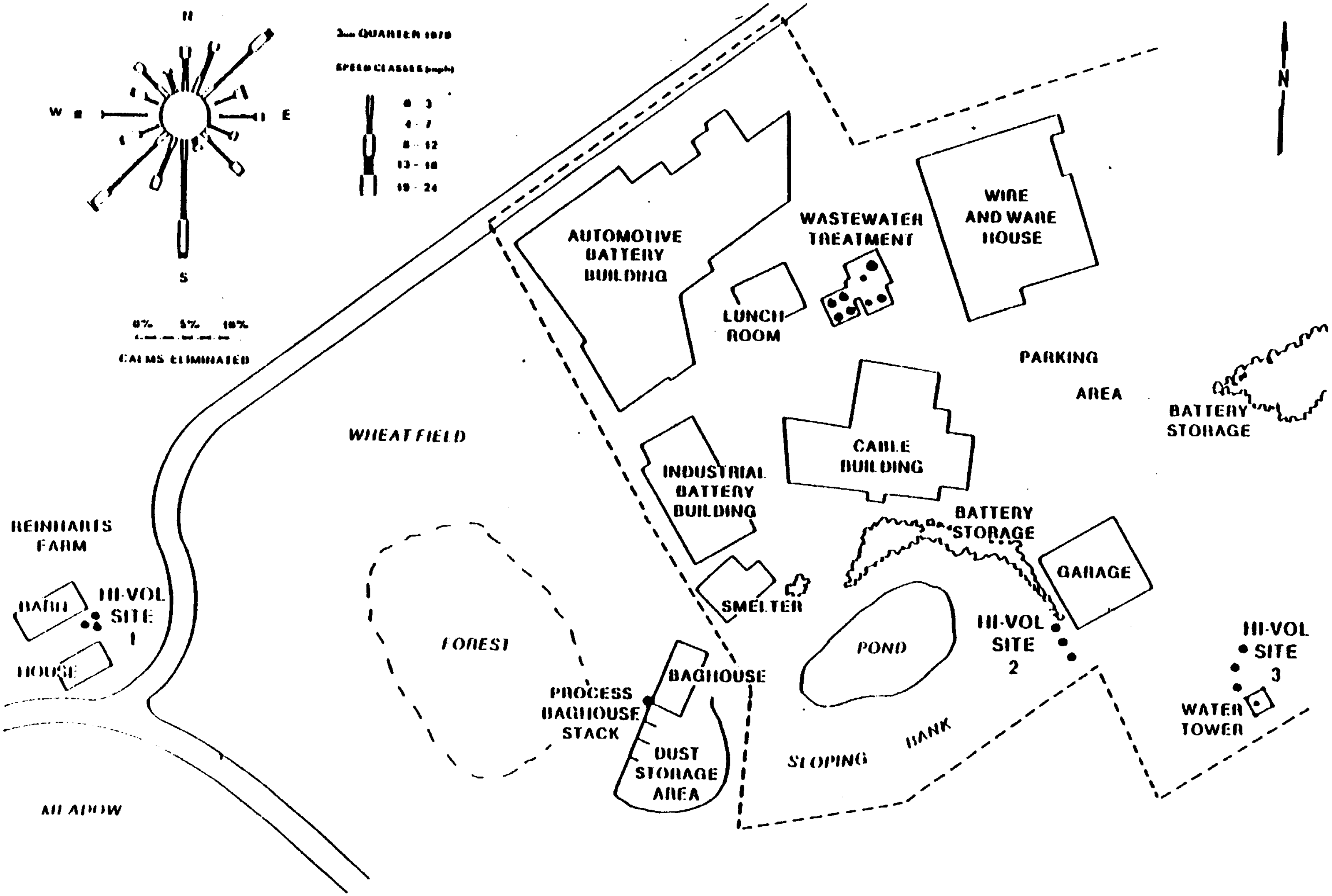


FIGURE 2-1. SMELTER SURROUNDINGS AND LOCATION OF HI-VOL STATIONS

FIGURE 2-2. VIEW OF SMELTER AND BAGHOUSE FROM EAST TO WEST

storage area were not paved at the time of the initial evaluation. During the interim, large quantities of lead-bearing earth and other material were removed and the access road and dust storage areas paved with asphalt. The pond is flanked on the south side by a 9 meter (30 foot) sloping bank. The bank is heavily wooded with trees 9 to 12 meters (30 to 40 feet) tall. Behind the trees are open fields and the water tower.

A space surrounded by vegetation lies to the south between the smelter, the forest and the pond. Although there are some low-walled, three-sided storage bins at the west side, this space is basically open. It is used for storage of nonagglomerated baghouse dust, agglomerated dust, tote boxes and slag. Battery casings line the circumference of the area. The soil is contaminated with lead dust.

To the southwest, the cultivated field extends to a low-traffic farm road. A dense forest grows further to the southwest. The west and northwest views are blocked by a forest, which forms an island in the cultivated field. It also blocks the view to Reinhart's farm at compass bearing 280° at a distance of 360 meters (1,200 feet). This location was used as a hi-vol station. The terrain slopes to the north and northwest and rises to the south and east. A wind rose summarizing prevailing wind direction and wind forces is shown in the upper left corner of Figure 2-1.

PROCESS OVERVIEW

At the test smelter, scrap batteries are broken using slow-moving shears. Battery plates, mud, plant scrap from an adjacent battery manufacturing facility, skims and a variety of other lead scrap are fed to a vertical shaft blast furnace. This blast furnace is charged using a skip hoist and traditional slag-tapping and metal-tapping equipment is employed.

The smelter employs approximately 12 people per shift. Much of the work is manual. Charging the furnace and handling of crude and refined lead in the smelting building involve simple materials handling equipment. A small Bobcat loader is utilized to handle charge materials within the smelting building.

An open-air building houses the blast furnace, refining kettles and other smelting equipment. Several of the walls are open to allow movement of fresh air in and out of the building. The floor of the building is paved but rough. It is contaminated with muds formed by water and paste from battery plates, as well as by other materials tracked in from the yard surrounding the smelting building. Housekeeping, at this particular smelter, is a difficult problem due to the rough surface of the floor and the lack of appropriate drains to flush accumulated lead-containing materials.

Local exhaust ventilation is provided for various points of emission associated with the blast furnace and other equipment and operations. Between the initial and follow-up evaluations, several important modifications were made. A new baghouse dust collection system was installed to control sources of workplace lead-in-air contamination. This system extended new or improved local exhaust ventilation service to several operations. A local exhaust ventilation system was installed to serve the battery breaking facility and a central vacuum cleaning system provided to serve smelting, refining and dust handling areas. A Bergsøe flash agglomeration furnace was installed to solidify lead-bearing dusts collected in baghouses, knockout chambers, etc.

The following paragraphs describe specific operations and controls at the smelter. A discussion of housekeeping and flue dust handling is also included together with a review of operating experience with the agglomeration furance.

SCRAP BATTERY DELIVERY AND STORAGE

Automotive and industrial batteries are delivered to the plant by large 20-ton trucks. Depending on the inventory of scrap batteries, arriving batteries may be unloaded directly into the battery breaking building, allowed to remain in closed truck trailers until needed or stored at the north and east banks of the pond, and between the east parking lot and garage (refer to Figure 2-3). The quantities of batteries processed are approximately 5 to 10 percent industrial and 90 to 95 percent automotive. This ratio remained relatively unchanged from the time of the initial evaluation to the follow-up evaluation. Two kinds of casings are used in the manufacture of automotive batteries: plastic and rubber. It was estimated from checking the storage piles that the ratio of plastic to rubber casings was approximately 1:1. The percentage of plastic-cased scrap automobile batteries received by the smelter has increased over the last several years.

The battery storage areas are open. Weather and sun radiation cause the casings to become brittle and crack. Thus, battery plates and oxide are exposed to the environment.

SLI BATTERY BREAKING

Scrap SLI (starting, lighting, ignition) batteries are delivered primarily by truck trailer to the battery breaking site. These batteries are broken in a small building adjacent to the main smelter. SLI battery breaking involves the following steps:

- Manually unloading batteries from truck trailers onto a roller conveyor.

- Manually moving the batteries along the roller conveyor to a position in front of a slow-moving hydraulic shear.

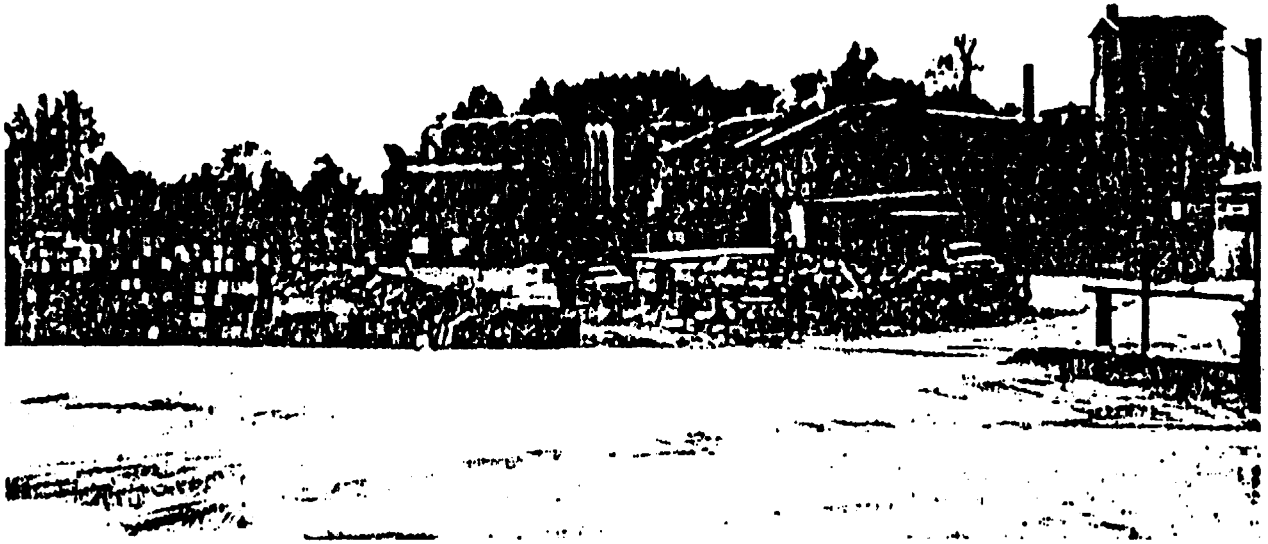


FIGURE 2-3. VIEW OF BATTERY STORAGE AREA ALONG ACCESS ROAD FROM EAST TO WEST

- Separating batteries with plastic casings from those with hard rubber casings.

- Manually positioning the batteries so that their tops face the shear.

- Activating the shear to cut off the battery tops, which fall onto an outside storage pile.

- Removing the battery plates from the hard rubber casings.

- Manually dumping the plates from the battery cases down a slide to an outside storage pile.

- Manually discarding rubber cases down a slide to a separate storage pile.

One person normally delivers truck trailers filled with scrap batteries to the yard and may also unload batteries onto the roller conveyor feeding the shear. Two persons operate and work near the shear. Figure 2-4 is a photograph of the interior of the battery breaking facility in use during the follow-up evaluation (August, 1980). Normally, SLI batteries are broken during the day shift, but occasionally this work is performed during other shifts.

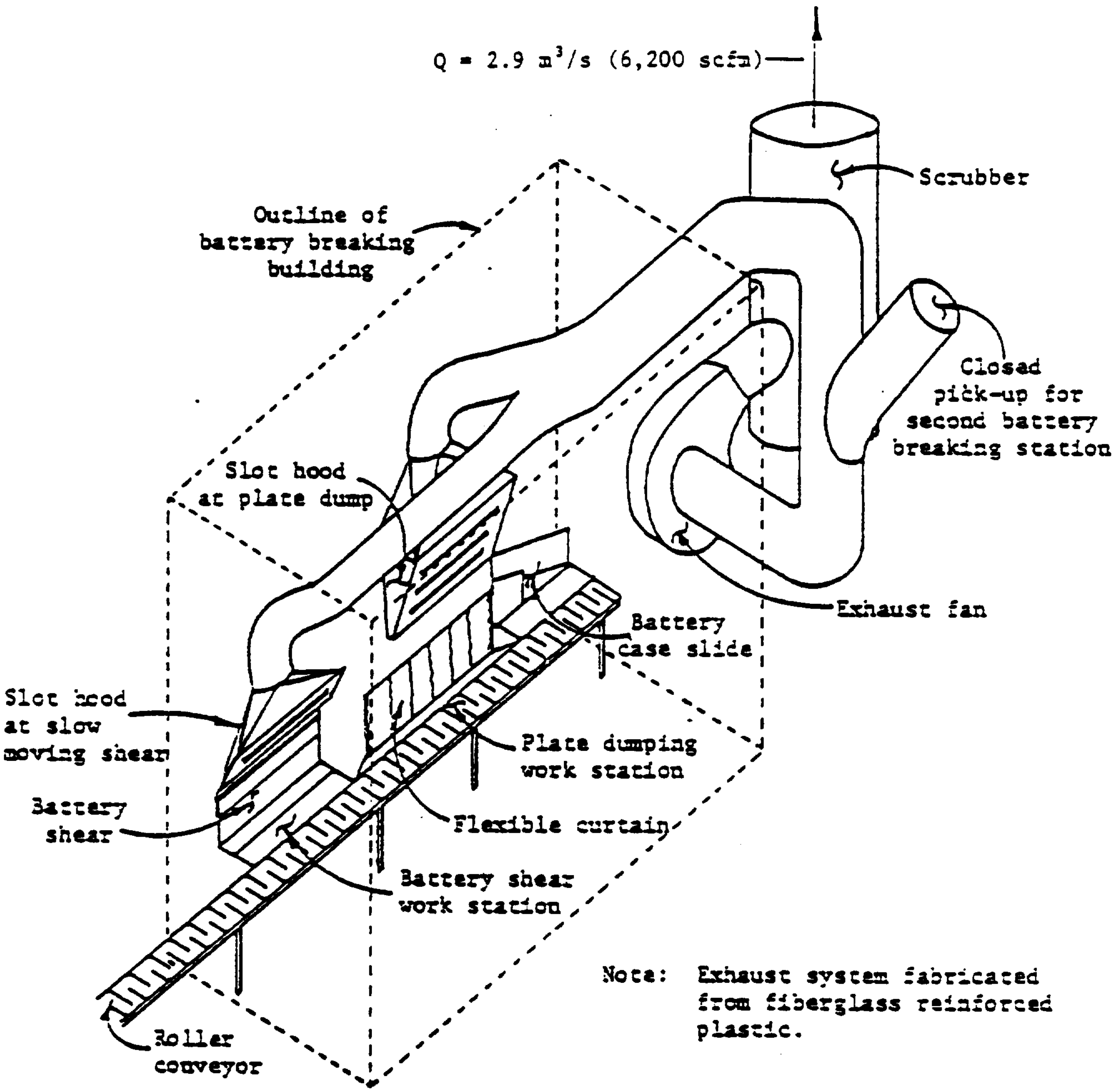
In addition to work shirts and trousers, the shear operator and helper wear rubber boots, aprons and gloves, plastic arm coverings and face shields, cloth head coverings and safety spectacles. During the initial evaluation no local exhaust ventilation was present to help control employee exposure to lead and sulfuric acid mist. An exhaust ventilation system was installed in 1980 to remove and scrub acid mist and lead particulate released during the breaking operation. Figure 2-5 presents a schematic view of the battery breaking station and its local exhaust ventilation system. This system was constructed of fiberglass reinforced plastic and consists of two slot hoods, an exhaust fan and scrubber. The measured total exhaust rate was 2.9 m^3/s (6,200 scfm).

Since the follow-up evaluation conducted in August, 1980, the shear has been replaced with a slow-moving saw. The company plans to shred the broken batteries in the future. A sink float technique will then be used to separate plastic, rubber, lead oxide and lead; this will help to improve control of the blast furnace charge make-up.

INDUSTRIAL BATTERY BREAKING

The smelter receives various types and sizes of industrial batteries. Some are cased in steel; others resemble SLI batteries, but are generally larger. Industrial batteries are broken in an open air work area located adjacent to the smelter building. Acid released by the industrial battery breaking operation drains toward a retention pond.

FIGURE 2-4. INTERIOR OF THE BATTERY BREAKING FACILITY



Note: Exhaust system fabricated from fiberglass reinforced plastic.

	Exhaust Air Flow, Q m^3/s(scfm)	Hood Entry Coefficient C_e	Slot Velocity m/s(fpm)	Control Velocity m/s(fpm)
Shear Hood	1.4(3000)	0.57	13(2600)	0.61(120)
Plate Dumping Hood	1.5(3200)	0.34	7.1(1400)	0.66(130)

FIGURE 2-5. LOCAL EXHAUST VENTILATION FOR THE SLI BATTERY BREAKING OPERATION

The following activities are involved in breaking these batteries:

- A forklift delivers batteries to the breaking station.
- An oxygen-acetylene torch is used to cut open the metal boxes housing the battery cells.
- Battery cells are manually removed from the metal housings using metal rods with hooked ends.
- Axes are used to chop battery sections into individual cells or to break up hard rubber batteries.
- Battery cells, plates, etc., are manually loaded into the bucket of a Bobcat or mechanically scooped up. (There is also some shoveling of battery mud).
- The Bobcat delivers the broken battery pieces to the raw materials storage area in the smelter building.

Industrial battery breaking is normally performed by one individual. He may be assisted by other smelter workers as the need arises. This workman wears a respirator, face shield and hard hat in addition to safety-toed rubber boots and other work clothing. A water hose is used to flush the industrial battery breaking area. Wash water flows toward the retention pond.

BLAST FURNACE

The blast furnace itself remained basically unchanged from the initial to follow-up evaluations. The furnace is 1 meter (40 inches) in diameter. It is constructed of steel, water jacketed and lined with refractory. Blast air is introduced through tuyeres near the base of the furnace. Feed materials, furnace workroom emission controls and furnace operating practices underwent significant changes between the two evaluations. The upcoming subsections describe various facets of blast furnace charging, tapping and operation.

Charge Materials Handling

The following operations are involved with charge materials handling:

- Broken battery tops, plates and cases are moved into the smelter building using a large rubber-tired bucket loader.
- Plant scrap is delivered to the smelter building in tote boxes transported by forklift trucks.
- Tote boxes of plant scrap are dumped and returned for refilling.

- The Bobcat loader is used to deliver broken industrial batteries, recycle slag, flue dust, limestone, etc.

- Coke is manually transported from its storage area within the smelter building using a wheelbarrow. The Bobcat is also used for this purpose.

During both the initial and follow-up evaluation, one smelter worker operated the large rubber-tired bucket loader for the entire shift. Three other jobs are associated with charge materials handling: payloader (Bobcat) operator, hoist operator and cokeman. During the initial evaluation, employees performing these three jobs changed job assignments at midshift. During the follow-up evaluation, employees did not rotate between job assignments. Employees wear respirators at all times when working in the charge materials handling area.

Between the initial and follow-up evaluations, a practice of frequently wetting the materials handling area inside the smelter building was implemented. Also, partial enclosures at each side of the skip hoist feeding the blast furnace were provided to better segregate and contain various charge materials.

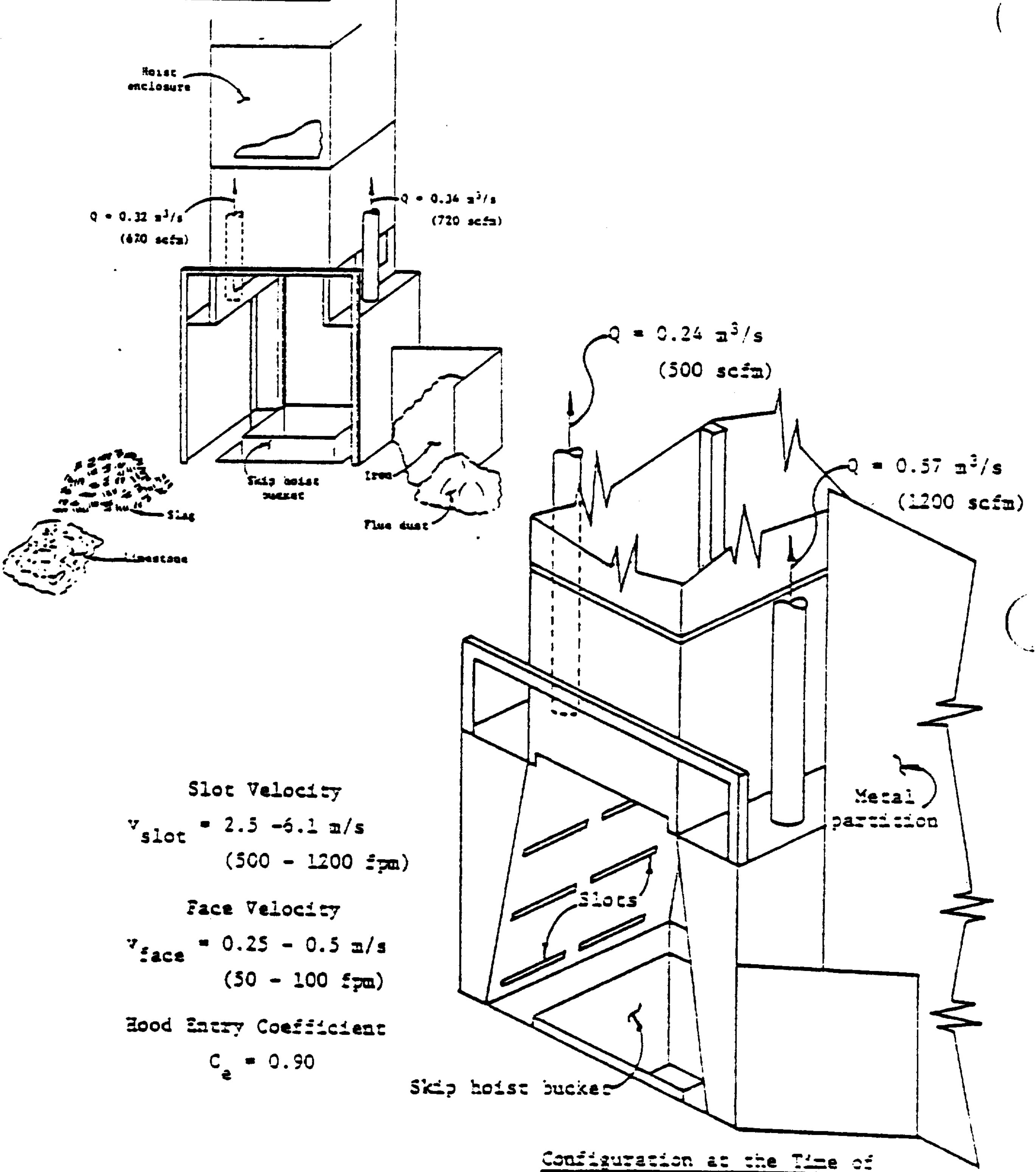
Furnace Charging

Figure 2-6 shows the base of the skip hoist used to charge the blast furnace. Although the hoist remained unchanged between the initial and follow-up evaluations, the local exhaust ventilation at the skip hoist bucket loading station was modified as indicated in Figure 2-6.

The skip hoist bucket is loaded using the Bobcat and by manual shoveling or wheelbarrow dumping. Occasionally the area directly beneath the skip hoist bucket must be shoveled out to allow the bucket to descend to its proper filling elevation. Furnace charging is almost a continuous operation. The charge is neither premixed nor weighed. The portions of each feed material charged to the furnace are based on operating experience. Between 300 to 400 hoist loads, each weighing about 250 kg (550 pounds), are fed to the furnace each day. Four hoist loads constitute one charge.

Figure 2-7 shows the exhaust ventilation enclosures provided at the top of the skip hoist and blast furnace. The slot hood over the furnace access doors was added following the initial evaluation. Exhaust air volumes were markedly increased for these enclosures when the new sanitary baghouse became operational.

The feed composition varies. Table 2-1 shows a comparison of furnace feed characteristics between the initial and follow-up evaluations.



Configuration at the Time of the Initial Evaluation

Slot Velocity

$v_{slot} = 2.5 - 6.1$ m/s

(500 - 1200 fpm)

Face Velocity

$v_{face} = 0.25 - 0.5$ m/s

(50 - 100 fpm)

Hood Entry Coefficient

$C_e = 0.90$

Configuration at the Time of the Follow-up Evaluation

FIGURE 2-6. BLAST FURNACE SKIP HOIST EXHAUST HOOD

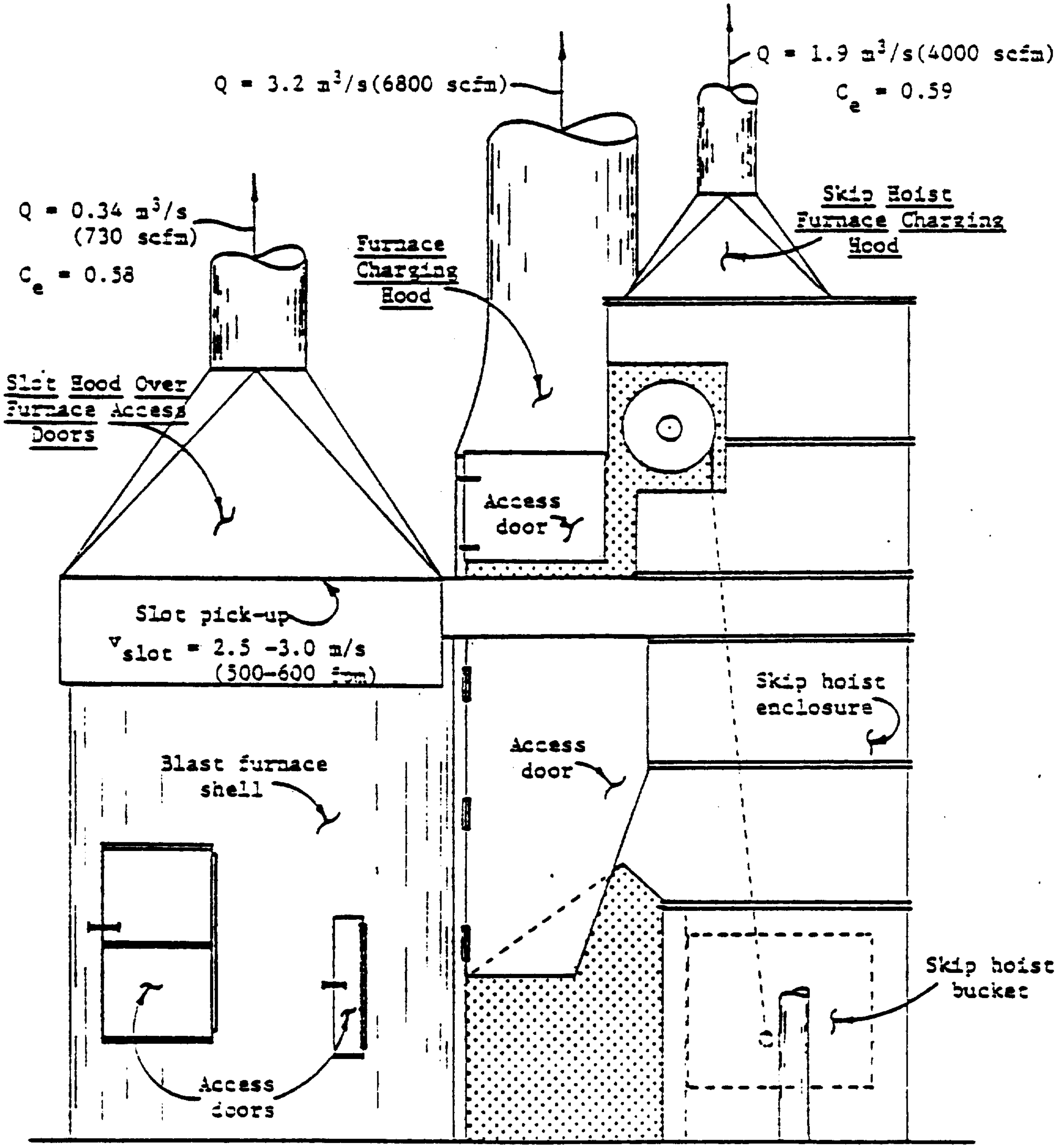


FIGURE 2-7. EXHAUST HOODS AT THE BLAST FURNACE CHARGING LEVEL DURING THE FOLLOW-UP EVALUATION

TABLE 2-1. COMPARISON OF BLAST FURNACE FEED CHARACTERISTICS BETWEEN THE INITIAL AND FINAL EVALUATIONS

	Percent by Weight of Charge	
Feed Material	January, 1979	August, 1980
Battery and lead scrap	66	84 - 88
Return slag	19	5 - 0
Return dust	1	0 - 0
Coke	9	7 - 6
Iron	2	2
Limestone	-	1
Silica	3	1 - 2
Agglomerated dust	-	0 - 1
	100	100

The target feed composition during the follow-up evaluation effort between August 4 and August 16, 1980, is summarized in Table 2-2. The main changes were as follows:

- Oxygen was increased from 0 to 2 percent on August 7, 1980.
- Feeding return slag was stopped on August 7, 1980.
- Oxygen was reduced to 1 percent on August 8, 1980.
- Agglomerated flue dust was recycled starting August 8, 1980.
- The lime and silica feed was changed starting August 8, 1980.
- PVC material was fed to the system starting August 11, 1980.
- Feed of iron scrap was increased starting August 11, 1980.

Unlike the relatively shorter observation period during the initial evaluation, the mix of charge materials changed substantially during the follow-up evaluation as smelter management personnel attempted to improve crude lead and slag characteristics.

According to the smelter, an optimum slag contains 32 percent SiO_2, 30 percent FeO, and 15 percent CaO. This combination forms an eutectic mixture at 1,130°C (2,066°F). Potassium and sodium compounds lower the melting temperature even further and are considered beneficial.

<u>Blast Furnace Production</u>

Table 2-3 compares furnace production during the initial and follow-up evaluations. The furnace is one meter (40 inches) in diameter.

The crude lead production rates of 41 and 51 metric tons/day correspond respectively to specific smelting rates of 52 and 64 metric tons per square meter of furnace cross sectional area. This smelting rate compares to 29.5 and 17.6 metric tons of metal per day per square meter of hearth area for another 1 meter furnace and the Paul Bergsøe and Sons A/S SB smelting furnace.[1]

High furnace temperatures are one reason for the high production rate in this furnace compared to the other two previously mentioned. The furnace top temperature averaged between 400 and 450°C (750 and 850°F) during the initial evaluation. Even higher furnace top temperatures 370 to 800°C (700 to 1,470°F) were found during the follow-up evaluation. The other one meter furnace mentioned averages 260°C (500°F) at the furnace top compared to between 100 and 125°C (212 and 260°F) for the SB furnace. High furnace temperatures do give greater smelting rates. However, high temperature also causes faster refractory wear and increases the likelihood of water jacket failure and furnace burnthrough.

TABLE 2-2. SMELTER OPERATION DURING THE FOLLOW-UP EVALUATION - AUGUST, 1980

		8/5	8/6	8/7	8/8	8/9	8/10	8/11	8/12	8/13	8/14	8/15	8/16
Battery Scrap	kg/charge	880											→
Coke	"	70		→ 60									→
Iron	"	18						→ 25					→
Silica	"	14			→ 20								→
Limestone	"	15			→ 8								→
Return Slag	"	54		→ 0									→
Agglomerated Dust	"	0			→ 11								→
# of charges		330	354	416	414	386	300	298	300	12	108	376	420
# of lead ingots*		57	60	65	68	51	43	46	50	3	20	62	59
# of slag plugs**		16	21	20	20	23	19	18	24	1	6	22	23
Air flow m³/min		45	45	34	34	34	34	34	34	34	34	34	34
Oxygen percent		0	0	2	1	1	1	1	1	1	1	1	1

* 820 kg each

** 590 kg each

TABLE 2-3. COMPARISON OF BLAST FURNACE PRODUCTION RATES BETWEEN THE INITIAL AND FOLLOW-UP EVALUATIONS

Product	Production Rate (metric tons/day)	
	January, 1979	August, 1980
Crude lead (~3% Sb)	41	50
Slag and matte	15	20
Flue dust	not available	8

The high furnace top temperatures also help combust most of the organic material and carbon monoxide in the blast furnace gases. The afterburner normally operates on standby. If the gas temperature entering the afterburner falls below 260°C (500°F), the afterburner switches on to insure complete combustion.

The temperature at the top of the furnace is high enough to vaporize lead compounds. Significant amounts of lead metal accumulate in the process gas duct and particulate dropout chamber prior to the afterburner. These accumulations are removed during normal maintenance periods.

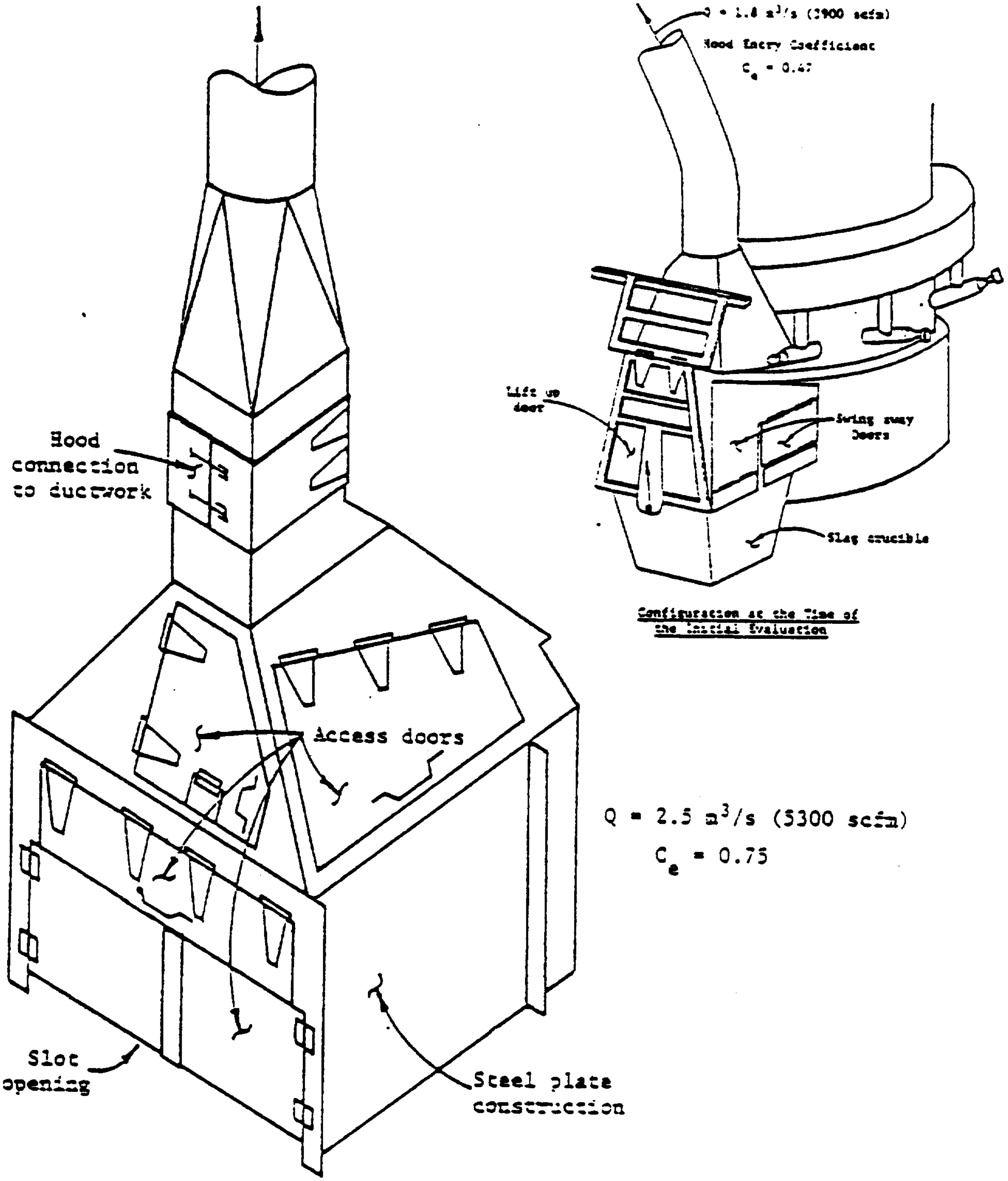
Slag Tapping

As dictated by the slag elevation in the furnace viewed through the tuyeres, slag is tapped every 30 to 60 minutes. The slag has a temperature of approximately 1,150°C (2,100°F) when leaving the blast furnace. It is tapped into a block mold of approximately 590 kg (1,300 pounds).

A separate baghouse exhaust ventilation system is provided to control emissions from slag tapping. Between the initial and follow-up evaluations, an improved local exhaust enclosure was provided for the slag tapping operation. Figure 2-8 shows the configuration of the old and new slag tapping hood.

During the tapping of slag, several smelter employees work together to perform the following tasks:

- The fire clay plug in the tap hole is chipped away until a glowing core shows. This chipping is accomplished using a steel bar and sledge hammer.
- A metal rod is used to open the slag tap hole. Initially, slag is allowed to flow while blast air is at normal pressure.
- An air lance is used to burn out the slag port when accretions build up.
- As slag empties, tuyere blast air is bypassed.
- While blast air is bypassed, tuyere covers are removed and the tuyeres are punched using metal rods.
- Fire clay is sprinkled on the slag launder and a fire clay plug is placed in the slag tap hole by hand and tamped into place using a metal rod.
- Blast air is restored to the furnace.



Configuration at the Time of the Follow-up Evaluation

Configuration at the Time of the Initial Evaluation

FIGURE 2-8. BLAST FURNACE SLAG TAPPING HOOD

- The filled slag ladle sometimes remains under the slag tapping hood until hardened and cool.

- A forklift is used to remove slag to an outdoor storage pile.

Employees are provided with plastic face shields during slag tapping. Although a substantial hazard was present from flying molten particles during the initial evaluation, face shields were not always utilized. Figure 2-9 is a photograph of the new slag tapping hood while slag tapping is in progress.

During the initial evaluation, a substantial amount of slag was recycled to the blast furnace. At the time of the follow-up evaluation a much smaller quantity of slag was being recycled . The balance is disposed of in a landfill.

Crude Metal Tapping

Crude metal is continuously tapped from the blast furnace. Molten metal flows from the tapping hole through a lead well, down a launder to water cooled molds. Local exhaust ventilation is provided from the tap hole to mold pouring. Figures 2-10, 2-11 and 2-12 illustrate the changes which were made in the local exhaust ventilation control at the lead well, molten metal launder and block casting station. Each exhaust enclosure features movable panels or doors to facilitate material removal, cleaning, observation and maintenance.

Figure 2-13 is a side view photograph of primarily the launder hood. Figure 2-14 is a photograph of the block casting hood presently in use.

Crude metal tapping and casting involves the following steps:

- The crude metal launder is manually positioned so that molten metal flows to an empty mold.

- A metal rod is used to clear the molten metal stream along the launder.

- When a mold has been filled, the launder is moved to fill another mold.

- A steel lifting handle is inserted into each poured block before the metal freezes.

- When the metal in the mold has frozen, an overhead monorail hoist is used to lift the lead block from the mold.

- Crude lead blocks are stockpiled near the blast furnace until they are placed in the refining kettles.

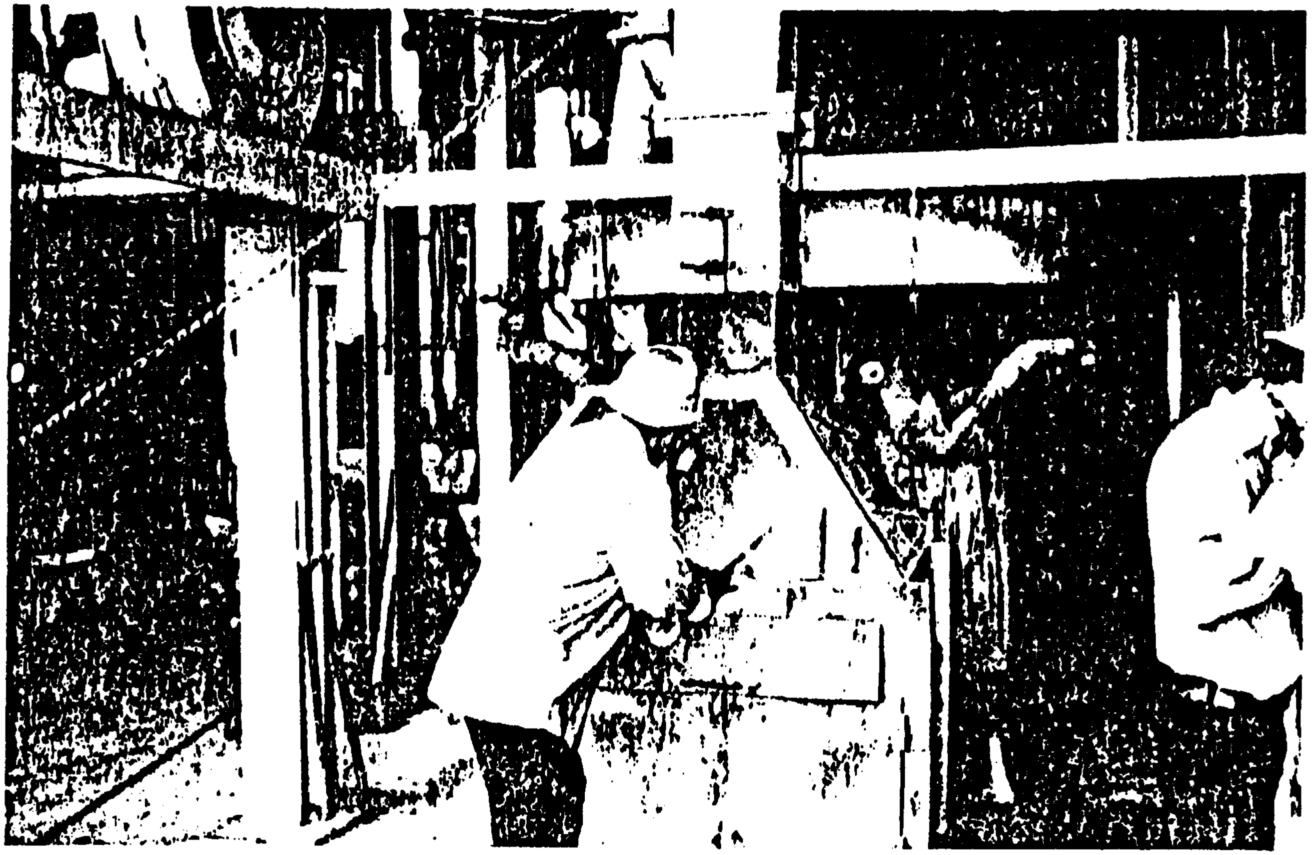
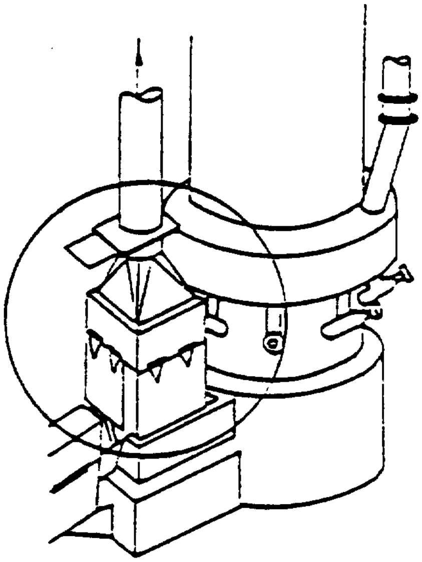
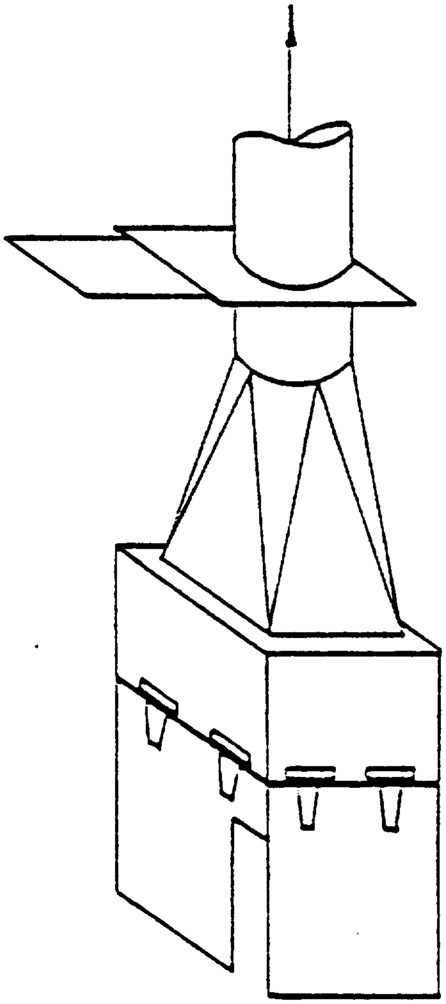


FIGURE 2-9. SLAG TAPPING HOOD - TAPPING IN PROGRESS





	Initial Evaluation	Follow-up Evaluation
Exhaust Rate Q, m^3/s (scfm)	0.66(1400)	2.2(4700)
Hood Entry Coefficient, C_e	0.71*	0.89
Face Velocity v_f, m/s(fpm)	0.5 - 1.0 (100-200)	2.5 - 4.1 (500-800)

*Blast gate partially closed.

FIGURE 2-10. BLAST FURNACE TAPPING HOOD

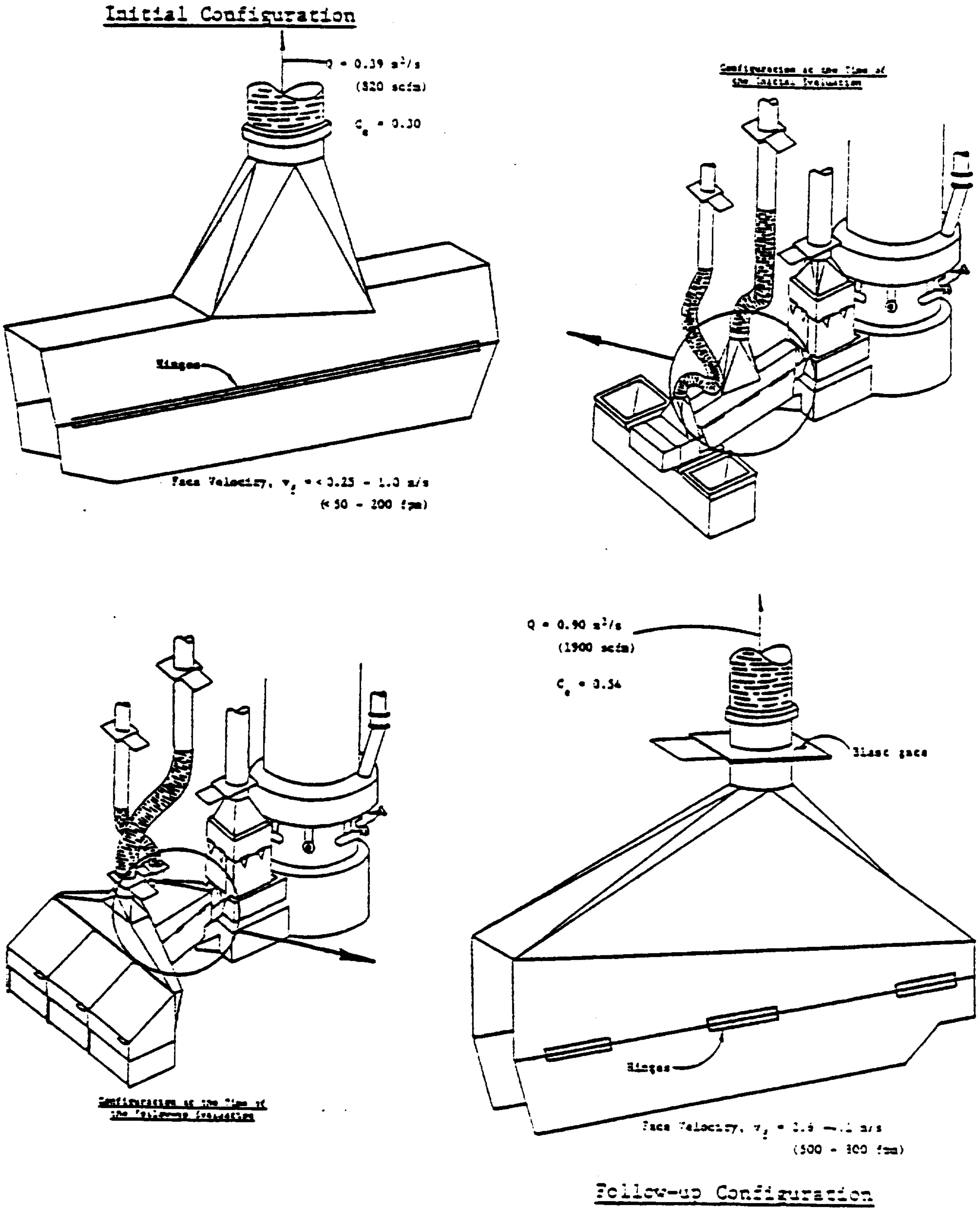


FIGURE 2-11. BLAST FURNACE LAUNDER HOOD

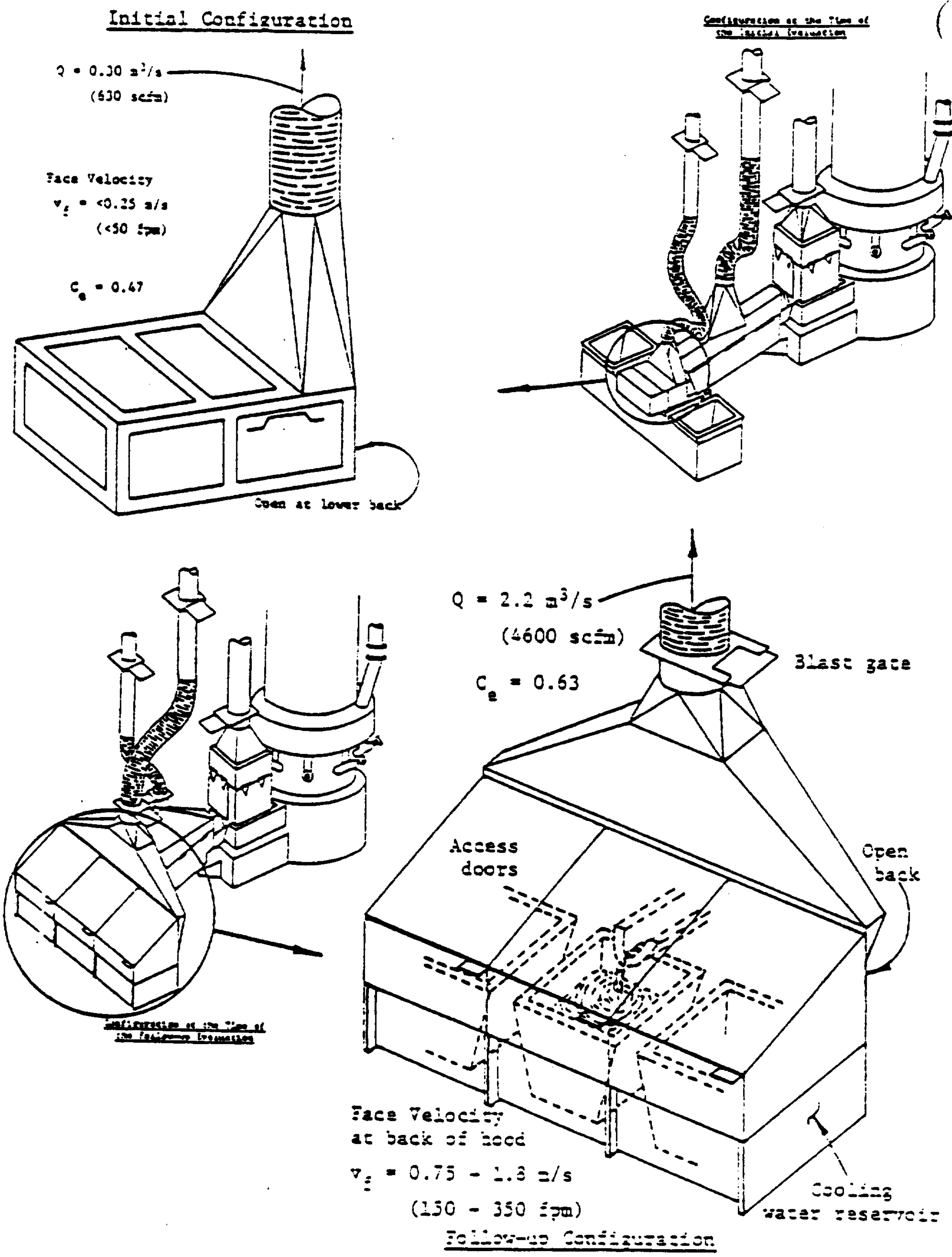


FIGURE 2-12. BLAST FURNACE BLOCK CASTING HOOD

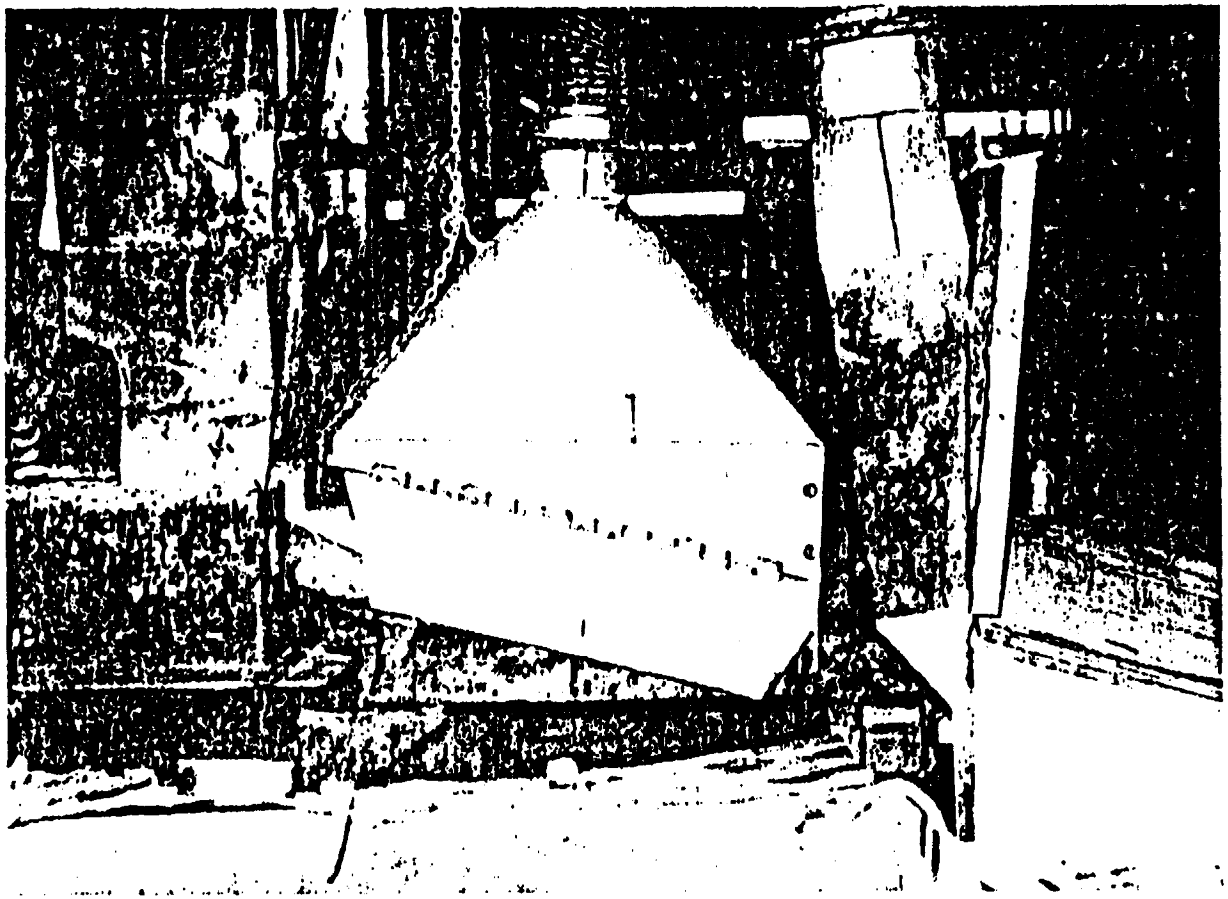


FIGURE 2-13. SIDE VIEW OF BLAST FURNACE LAUNDER HOOD

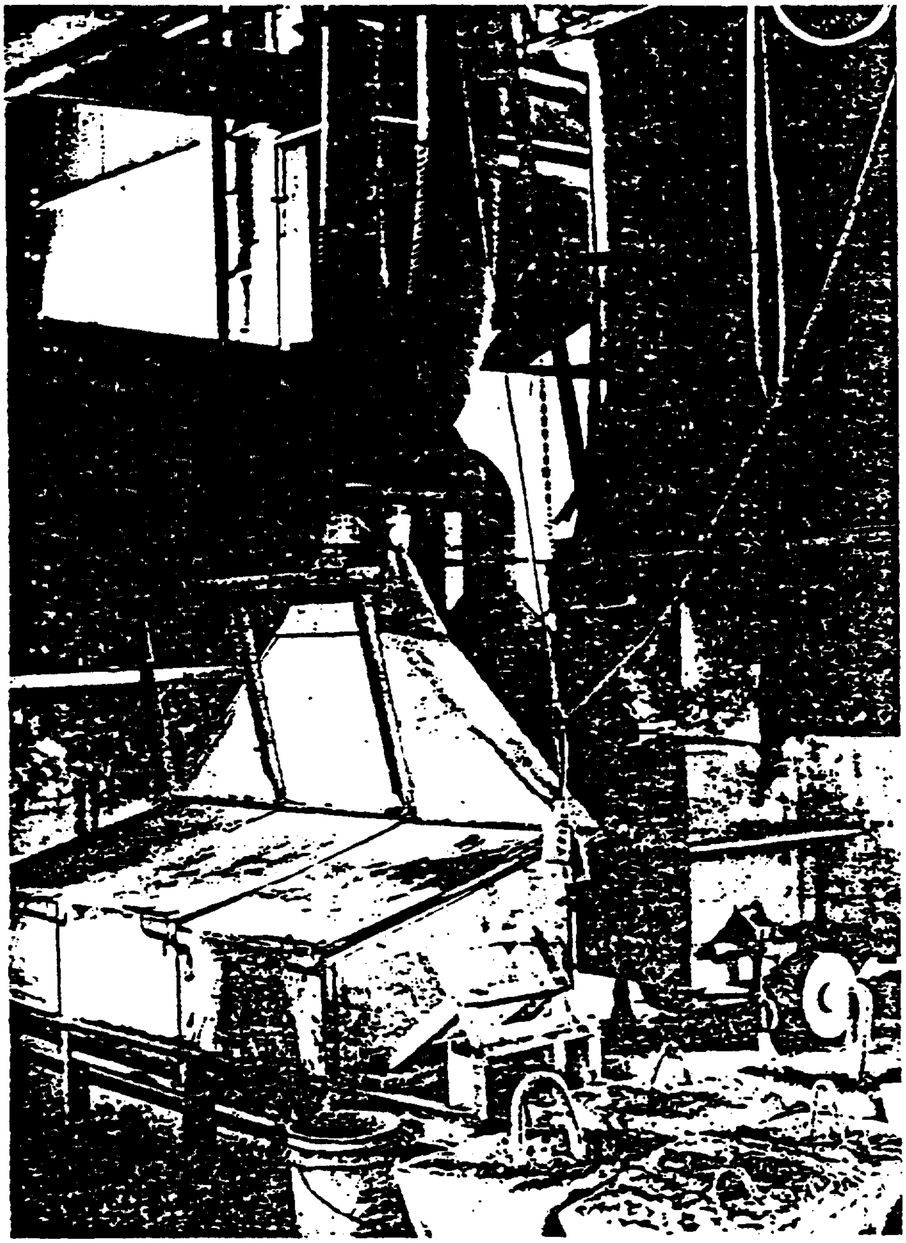


FIGURE 2-14. BLAST FURNACE BLOCK CASTING HOOD

Employees who operate the furnace and tend the refining kettles routinely look after crude metal tapping and block removal.

KETTLE REFINING

This smelter has two refining kettles which operate on staggered schedules. Kettle refining involves the following activities:

- Crude lead blocks are placed in the refining kettles using the overhead monorail hoist.
- Lead blocks are melted and samples of molten crude metal are obtained to determine what refining techniques are necessary.
- Once the melt is sufficiently fluid, the mechanical stirring device is lowered into the molten metal.
- Refining agents are added manually and stirred into the melt.
- Skimmings are manually removed using a flat point shovel while the mechanical stirrer slowly turns.
- Skimmings are deposited in "pies" on a steel pallet. Approximately eight pallets of pies are made each time a kettle is skimmed.
- Pallets containing pies are moved away using a forklift.
- After skimming, another metal sample is collected and analyzed. Alloying agents may then be added to the melt depending on the composition desired.
- Once the desired refining has been completed, the molten metal is held and allowed to cool until pumped to the pigging machine.

Kettle refining is routinely performed by the potman. From time to time he is assisted by other smelter employees including the foreman. As necessary, the potman sometimes assists in operation of the blast furnace.

The capacity of each kettle is approximately 25 crude lead blocks or 20 metric tons. Block melting, drossing, alloying and refining span over 12 to 16 hours for each full kettle charge. At the time of the initial evaluation, both hard and some near soft lead were produced. Recently, the smelter has produced only hard lead in the following composition ranges: antimony 2 to 6 percent, arsenic 0 to 0.25 percent, copper 0 to 0.1 percent, tin 0 to 0.4 percent and sulfur 0 to 0.01 percent.

During the initial evaluation only Kettle No. 1 was equipped with local exhaust ventilation. Figure 2-15 shows the configuration and performance data for this exhaust ventilation as measured during the initial evaluation.

In the interim between the initial and follow-up evaluations, improved exhaust enclosures for both kettles were designed and installed. Figure 2-16 shows the new hood provided for Kettle No. 1; Figure 2-17 is a photograph providing another perspective of the hood for Kettle No. 1. This hood was originally equipped with curtains to cover the open face of the hood. These curtains proved impractical and were subsequently removed.

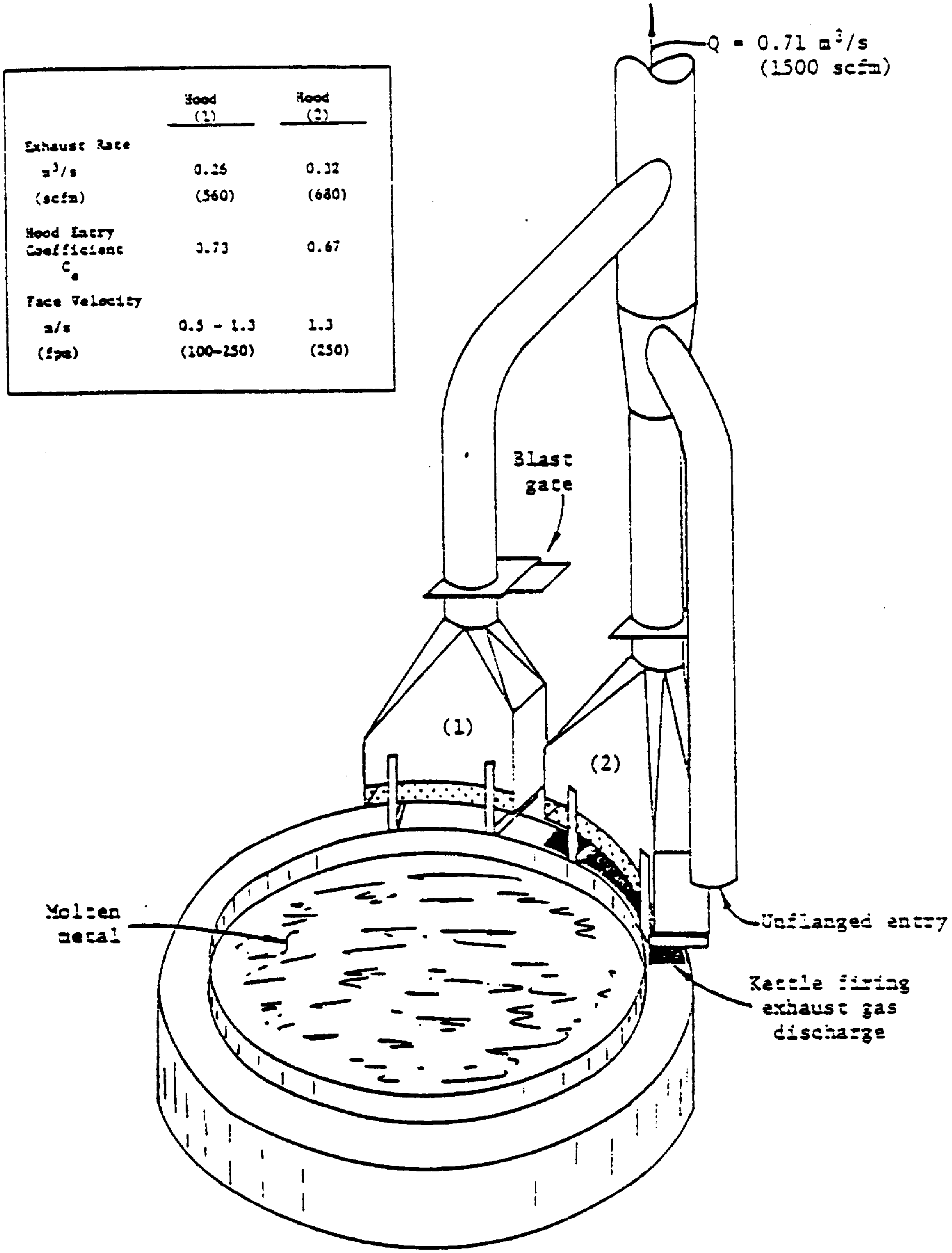
The new hood for Kettle No. 2 shown in Figure 2-18 reflects improvements based on plant experience with the new hood for Kettle No. 1. This hood features metal access doors to allow passage of the monorail hoist, molten metal pump, etc. Figure 2-19 shows another perspective of the hood for Kettle No. 2.

INGOT CASTING (PIGGING)

Ingots or pigs are cast in a mobile machine which moves back and forth on tracks between two refining kettles. The pigging machine is operated by the potman. The potman is assisted by the foreman and other smelter workers as necessary. Pigging involves the following steps:

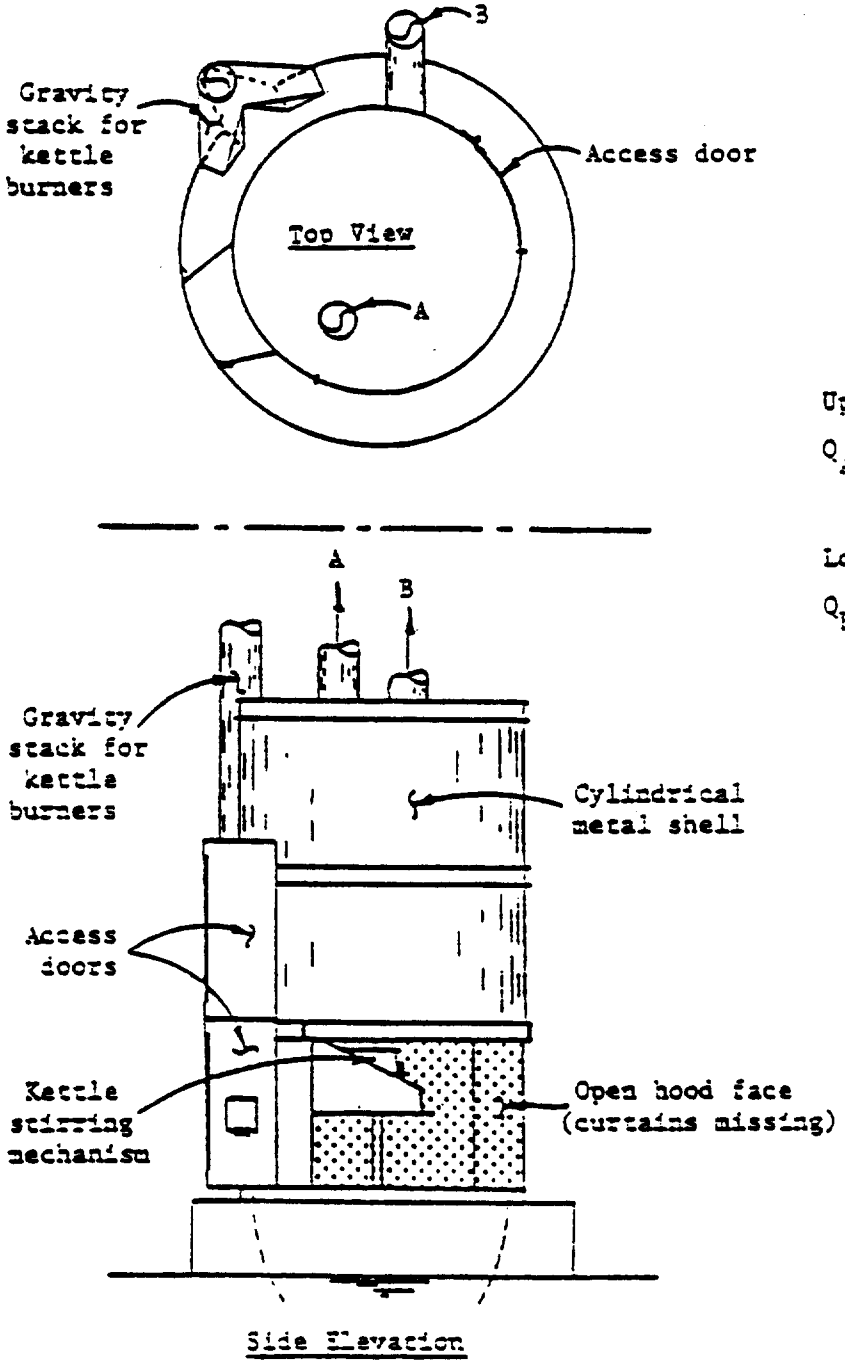
- The molten metal pump and pigging machine reservoir, molds, etc., are preheated using gas torches.
- Molten lead is pumped from the refining kettle to the reservoir on the pigging machine.
- Molten lead is poured from the reservoir into molds which are mechanically advanced.
- Ingots are dumped out of the molds and manually stacked.
- A forklift is used to move stacks of ingots.

During the initial evaluation, no local exhaust evaluation was provided for the pigging machine. Figure 2-20 shows the enclosing canopy hood which was installed on the pigging machine prior to the follow-up evaluation. This hood is connected to the new sanitary baghouse exhaust system through use of a flexible duct. Since the pigging machine travels back and forth between the two refining kettles, two exhaust connections with blast gates are provided for the attachment of the flexible duct. Figure 2-21 is a photograph of the pigging machine and emission control hood.



	Hood (1)	Hood (2)
Exhaust Rate		
m^3/s	0.26	0.32
(scfm)	(560)	(680)
Hood Entry Coefficient C_e	0.73	0.67
Face Velocity		
m/s	0.5 - 1.3	1.3
(fpm)	(100-250)	(250)

FIGURE 2-15. OLD EXHAUST VENTILATION FOR REFINING KETTLE NO. 1



Upper Exhaust Take-off, A

Q_A = 0.85 m^3/s (1800 scfm)

Lower Exhaust Take-off, B

Q_B = 0.20 m^3/s (430 scfm)

FIGURE 2-16. NEW EXHAUST HOOD FOR REFINING KETTLE NO. 1

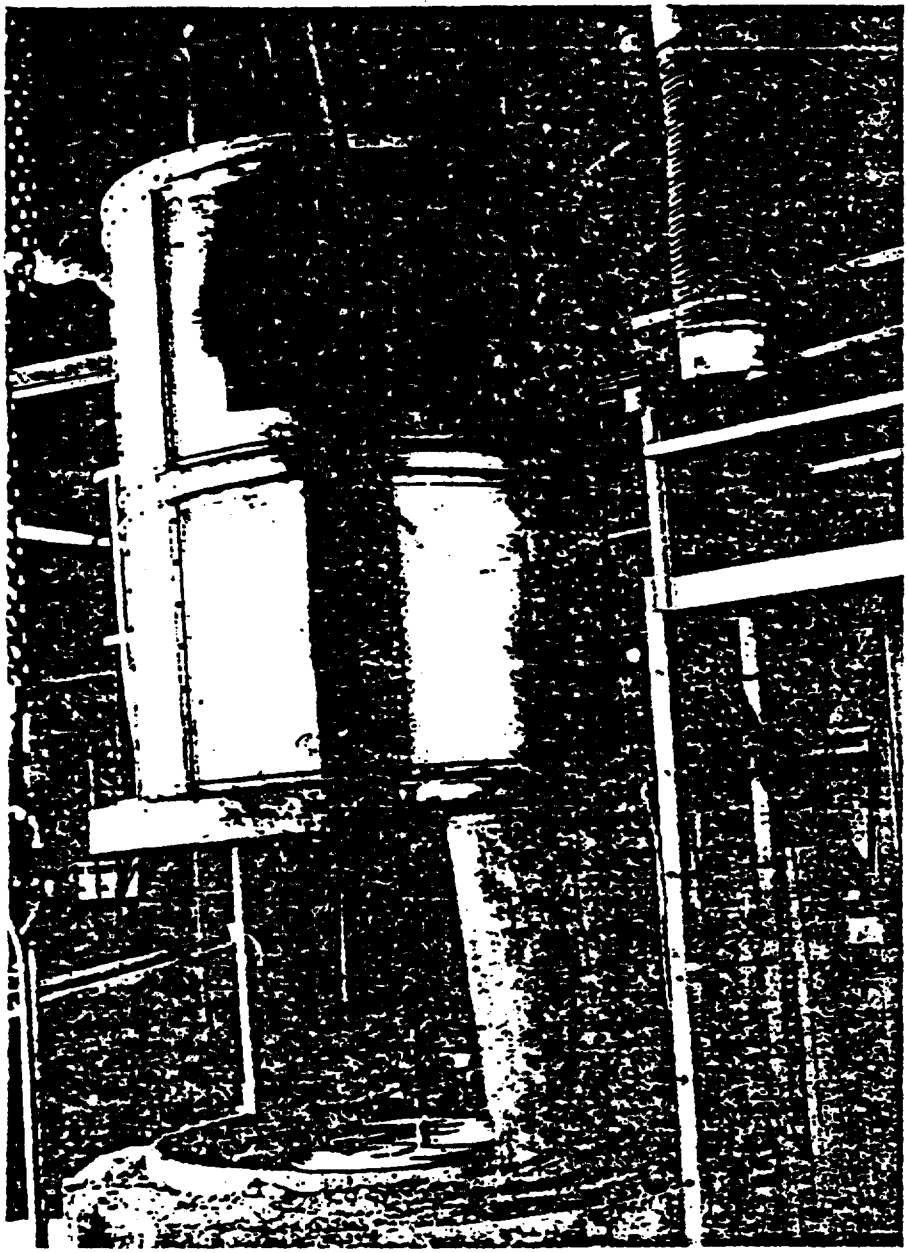
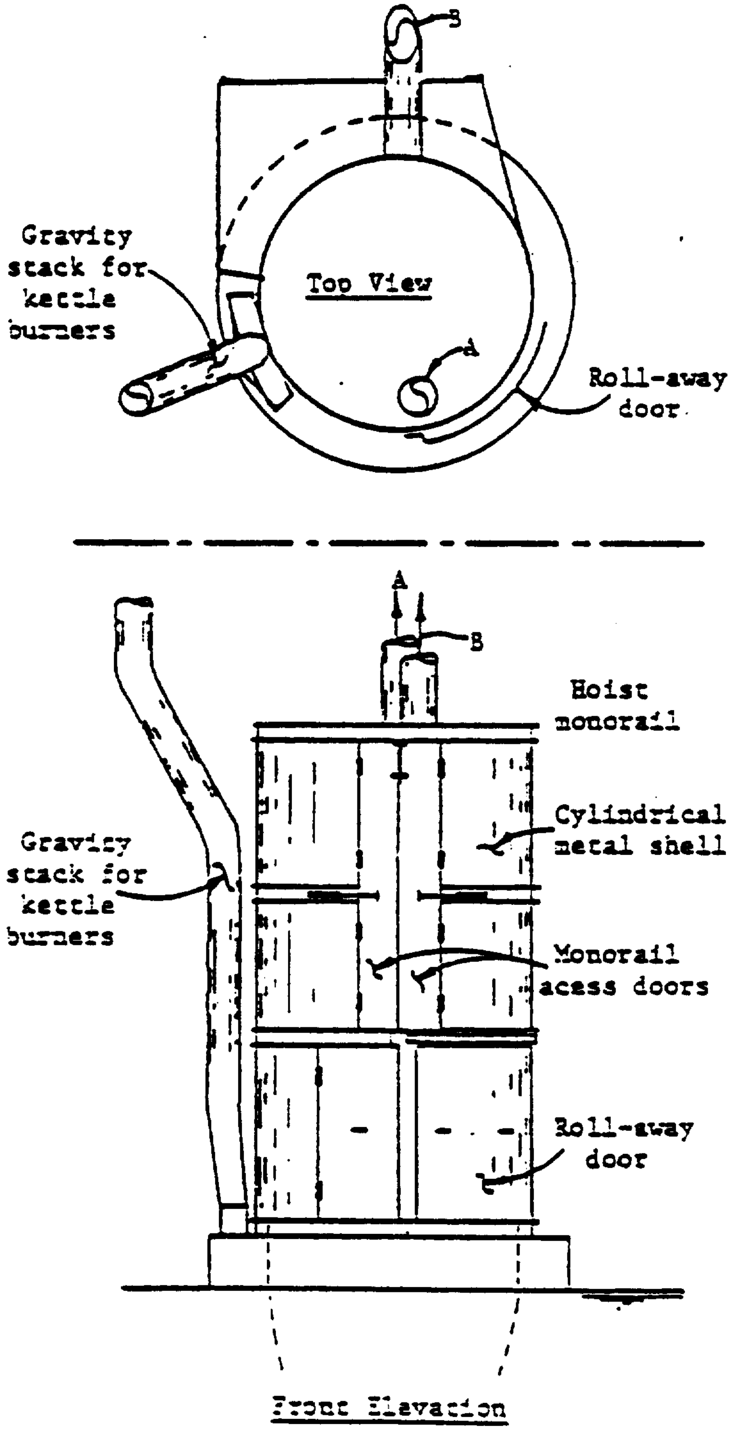


FIGURE 2-17. RIGHT SIDE VIEW OF THE EXHAUST HOOD FOR REFINING KETTLE NO. 1



Upper Exhaust Take-off, A

Q_A = 0.52 m^3/s (1000 scfm)

Lower Exhaust Take-off, B

Q_B = 1.1 m^3/s (2300 scfm)

FIGURE 2-18. NEW EXHAUST HOOD FOR REFINING KETTLE NO. 2

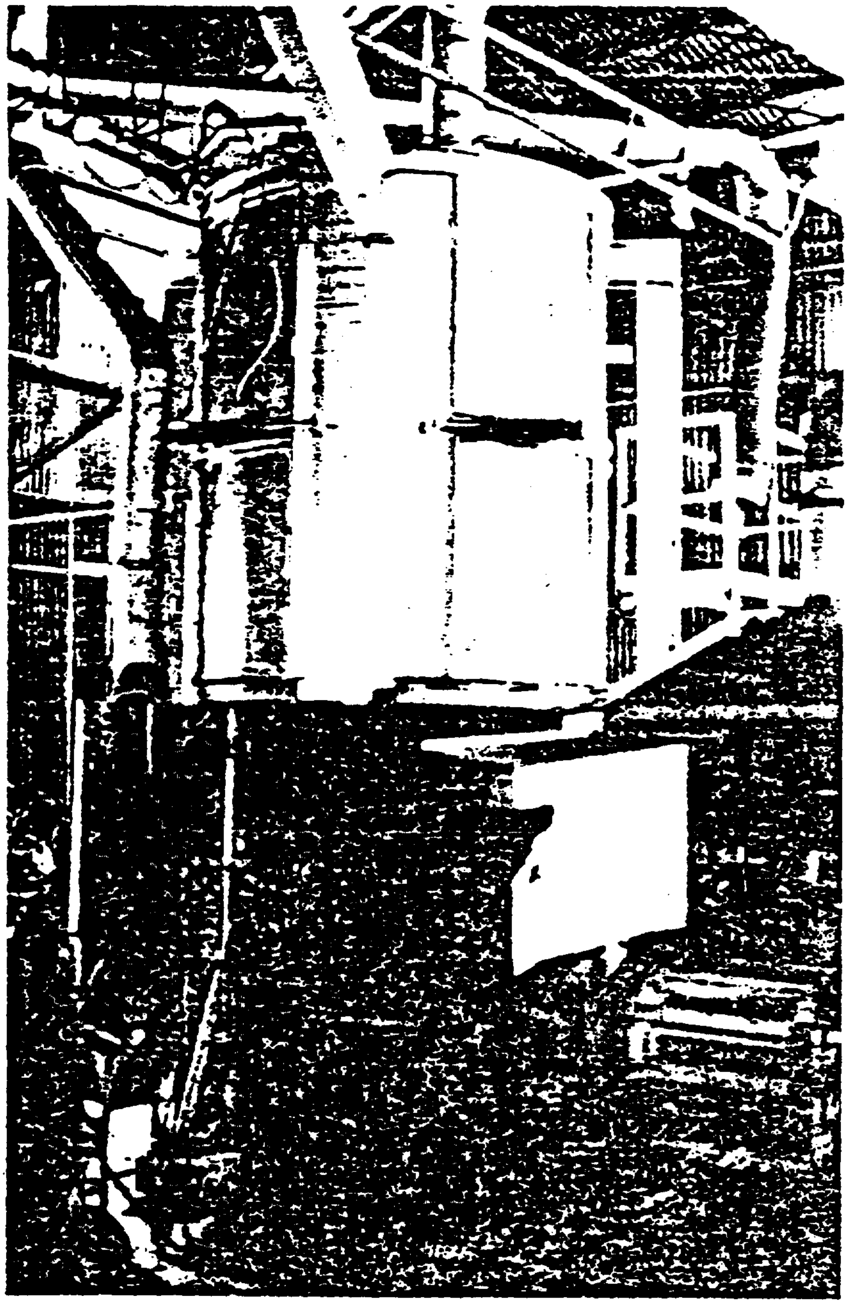


FIGURE 2-19. REFINING KETTLE NO. 2 EXHAUST HOOD WITH LOWER DOORS OPENED

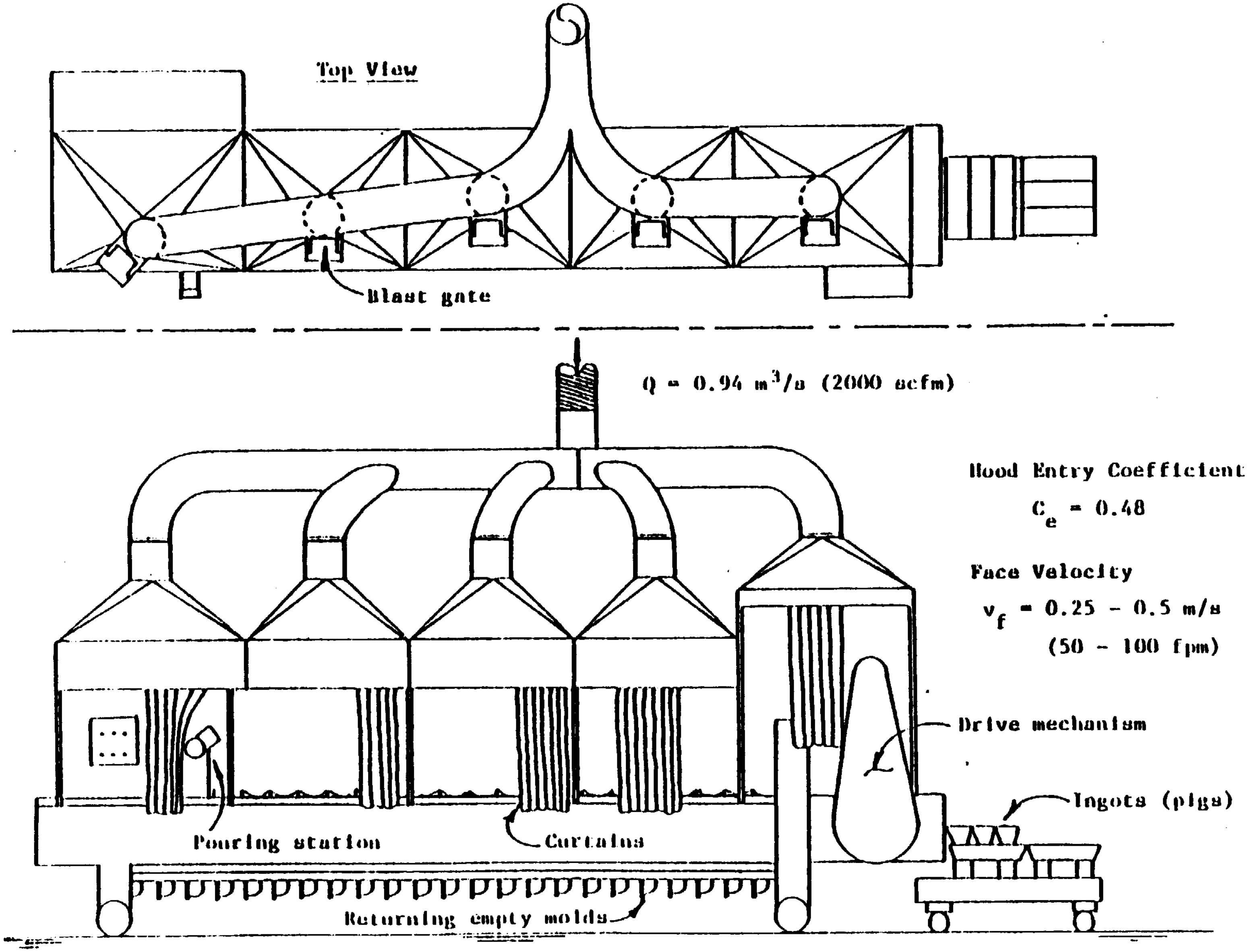


FIGURE 2-20. PIGGING MACHINE CANOPY HOOD

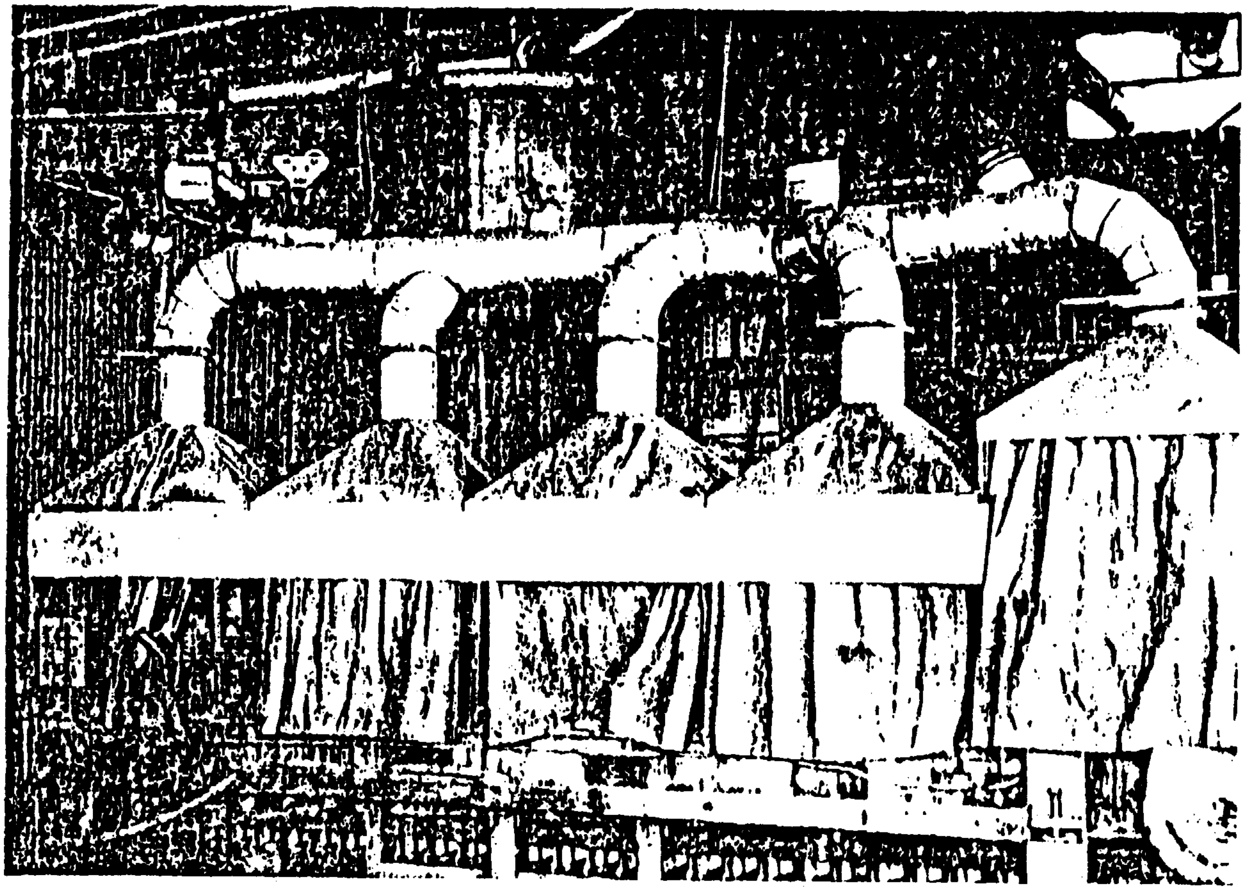


FIGURE 2-21. SIDE VIEW OF THE PIGGING MACHINE CANOPY HOOD

PROCESS EMISSION CONTROL SYSTEM

The emissions captured in the hoods described in previous sections are treated for particulate removal in three baghouse systems. The location of the slag tapping baghouse, the hygiene exhaust air baghouse (sanitary baghouse) and process baghouse systems are shown in Figure 2-22. All three baghouses are operated automatically and individually. Observed pressure differentials were up to 8" H_2O. Shaking cycles are approximately one hour. Orlon and dacron fabric was used as bag material.

Slag Tapping Baghouse

This is the smallest of the three systems. It controls only the emissions associated with the slag tapping operation, i.e., only the slag tapping hood is connected to it (refer to Figure 2-8).

The slag tapping baghouse has a design capacity of 2.4 m^3/s (5,000 scfm). The cloth area is 700 m^2 (7,500 ft^2). The air to cloth ratio is 1:0.7.

The dust collected is discharged to a tote box. The amount collected averages 1 bin/week or 265 kg/week. It is transported to the dust storage area.

Hygiene Exhaust Air Baghouse (Sanitary Baghouse)

The hygiene exhaust air system underwent dramatic change after the initial evaluation. At that time, emission sources other than the blast furnace slag tap and the blast furnace flue gas streams were treated for particulate removal by a baghouse of 4.7 m^3/s (10,000 scfm). This baghouse was located on the roof of the building housing the employee locker room and lunchroom. At the time of the initial survey this exhaust system did not serve the pigging machine, No. 2 refining kettle or the slot hood above the blast furnace access doors.

Following the initial evaluation, installation of a new hygiene exhaust air baghouse (sanitary baghouse) was completed. This system has a rated capacity of 20 m^3/s (42,400 scfm) and a cloth area of 3,000 m^2 (32,300 ft^2). The air to cloth ratio is 1:1.3.

As can be seen from Figure 2-22, the new hygiene system serves the:

- Upper and lower blast furnace skip hoist hoods.
- Blast furnace charging hood.
- Slot hood over the blast furnace access doors.

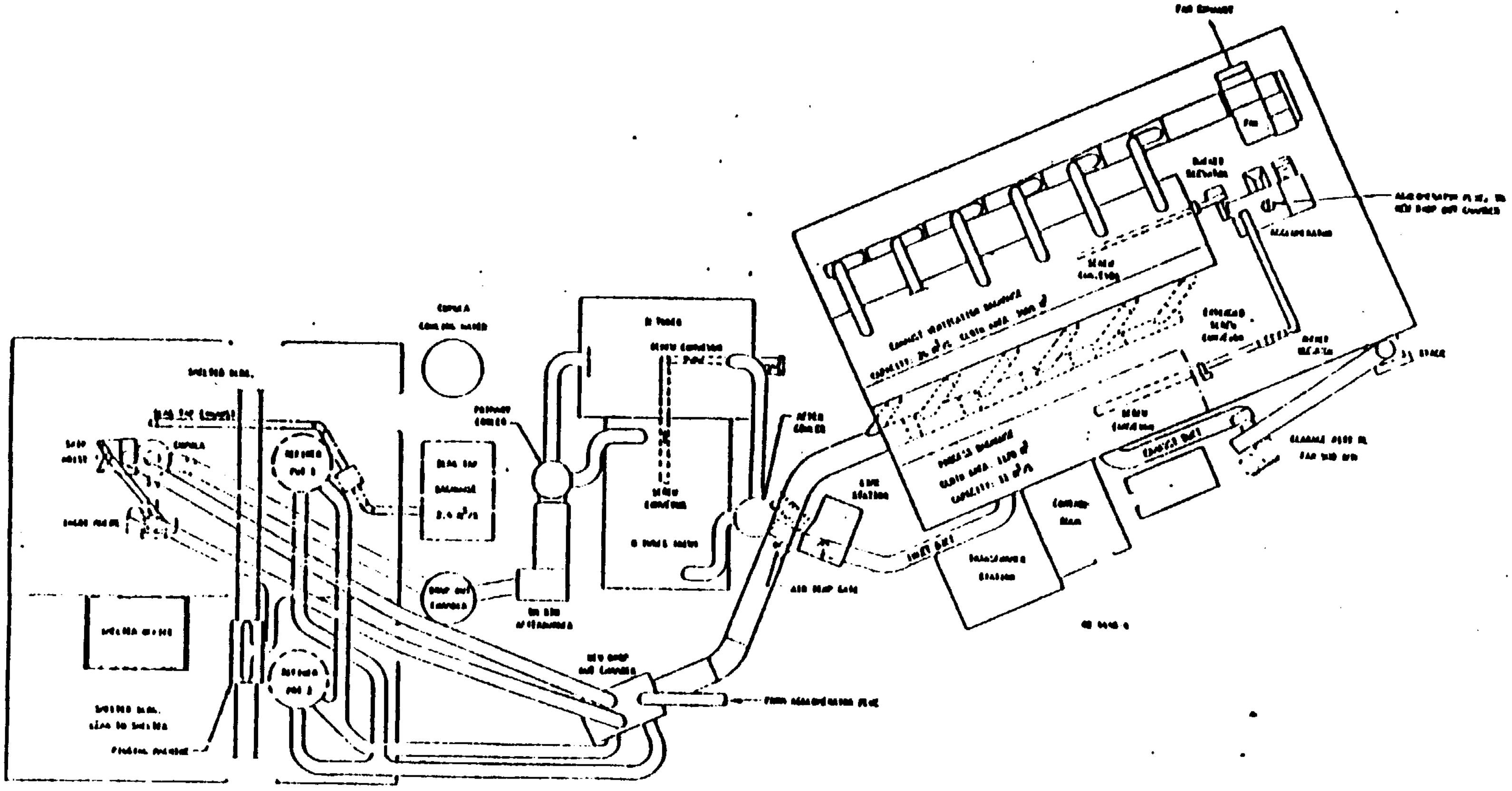


FIGURE 2-22. PLOT PLAN OF EMISSION CONTROL SYSTEM

- Blast furnace metal tapping, launder and block casting hoods.
- Exhaust hoods for refining kettles Nos. 1 and 2.
- Pigging machine canopy hoods.
- Flash agglomeration furnace.

Ductwork leading away from each exhaust hood is routed to a knockout chamber. The knockout chamber is then connected via a large duct to the baghouse. This system collects approximately 3 tote boxes of leady dust each day or 700 kg/day. The dust is either transported to the agglomeration furnace by a bucket elevator system or collected in tote boxes and stored outside near the dust storage pile.

Process Gas Treatment System

The description here follows the gas treatment path illustrated in Figure 2-22. Hot blast furnace off gas with a very high dust loading is drawn down a 122 cm (4 feet) diameter duct to a dropout chamber. The biggest particles settle here. An afterburner follows next. Its purpose is to combust organic pyrolysis products from battery casings and plate separators. The first cooling step occurs in a spray tower. The gas stream is split and flows through parallel banks of U-tube coolers. Exit gases from the U-tube coolers are combined in after coolers. Lime addition takes place in the lime station; four bags of hydrated lime are used per shift. The feed is intermittent and done manually. The hydrated lime acts as a fire retardant and as an acid neutralizer, in case of acid condensation. The process gas finally enters the process baghouse. This unit has a capacity of 11 m^3/s (23,300 scfm) and a cloth surface area of 1,170 m^2 (12,600 ft^2). The air to cloth ratio is 1:1.8.

The quantity of dust retained in the system amounts to the following:

• First dropout chamber	1 bin/day =	265 kg/day
• Spray tower	1 bin/day =	265 kg/day
• Air coolers	4 bins/day =	1,060 kg/day
• Process baghouse		7,000 kg/day

The dropout chamber and the spray tower are cleaned manually. Dust from the air coolers is transported to tote boxes by screw conveyors and discarded to the dust pile. Half of the material from the process baghouse is fed to the Bergsoe agglomeration furnace, the other half is put in bins and stored at the outside dust pile.

FLUE DUST AGGLOMERATION

As part of an overall plan to improve environmental and workplace lead emissions at the smelter, a Bergsøe flash agglomerator was purchased and installed. The intended purpose of the furnace was to change the physical form of flue dust generated and stockpiled at the smelter to a solid material which could be handled with less lead emission. In an agglomerated form the flue dust could be safely recharged to the blast furnace or transported to outside consumers. Until recycled or sold, the agglomerated material could be safely stored without contributing significantly to fugitive lead emissions.

At the time this study was conceived, East Penn Manufacturing Company was the first United States secondary lead smelter to attempt application of the Bergsøe agglomerating technology. Many questions were unanswered concerning the variables which would affect successful use of the furnace in this country. The potential benefits of the furnace were obvious, thus, both EPA and NIOSH were pleased to support a study to characterize the performance of the furnace.

It should be stated at the outset that the agglomeration furnace as installed and operated at East Penn Manufacturing differs markedly from those furnaces in use at the Paul Bergsøe and Sons, A/S smelter in Glostrup, Denmark. The furnace as designed was very similar; however, the mechanism used to feed the furnace, the composition of the flue dust feed and the operating temperature are distinct. The basis for these differences will be explained in later paragraphs.

Figure 2-23 shows a simplified sketch of the agglomeration furnace. The furnace is fed flue dust which falls to a sloping hearth. The hearth is directly heated by a burner flame which causes the lower melting point materials to become molten and run down the hearth and out a tapping port to a crucible mold. The material cools and solidifies in the crucible.

One person is assigned to tend the agglomeration furnace and baghouse building. During the follow-up evaluation, the smelter foreman also spent a large portion of his time in the agglomeration area.

Dust Feed Mechanism

At the Bergsøe smelter flue dust is screw conveyed from the baghouse directly to the agglomeration furnaces. This results in a reasonably constant feed rate and facilitates stable furnace operation.

At the East Penn smelter flue dust is collected in knockout chambers and baghouses which are physically separated from one another. No simple system of screw conveyors could be devised to collect dust from all collection points and feed it to the furnace. Also, this smelter feared that

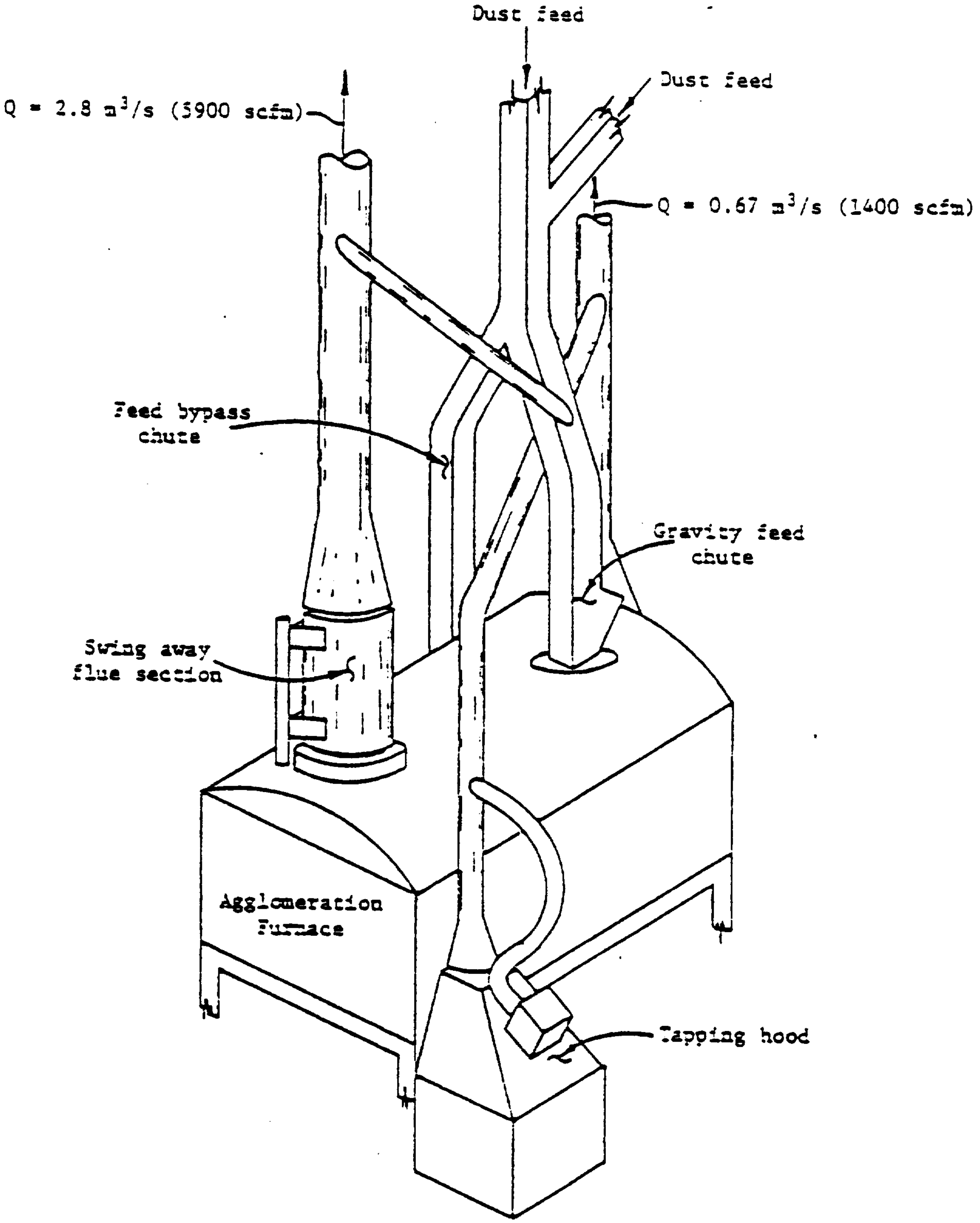


FIGURE 2-23. FLUE DUST FLASH AGGLOMERATION FURNACE

a screw conveyor connection to the furnace may significantly increase the chance of a baghouse fire.

A feed mechanism was devised which terminated in a gravity feed chute to the agglomeration furnace. This chute and its accompanying bypass are shown in Figure 2-23. The chute is fed by a system of bucket elevators and screw conveyors.

As shown in Figure 2-24, the dust feed to bucket elevators can be shunted to tote boxes in the event of a breakdown or other problem. Figure 2-24 also shows the tote box dumping station where material collected in tote boxes is introduced to the furnace feed mechanism.

Due to the inherent pulses caused by dumping of tote boxes and emptying of bucket elevator buckets, the resulting feeding of the furnace is not constant. This problem is aggravated by uneven dust drops during the shaking of bags in various baghouse compartments and the tendency of the dust to clog the gravity feed chute. Blockages in the feed chute required installation of a vibrator and manual rodding of the chute.

Uneven feeding of the furnace causes its operation to be unsteady. Rapid dust feeding occasionally overwhelmed the furnace requiring a cessation of the dust feed and high firing of the furnace to clear its charge.

Furnace Tapping

Material flows from the agglomeration furnace into a crucible which is placed inside an exhaust ventilated enclosure. This enclosure is shown in Figures 2-25 and 2-26.

A number of problems have been encountered in tapping the agglomeration furnace. Some are at least partially attributable to uneven feeding of the furnace and others relate more to the poor agglomerating properties of the flue dust at this smelter.

The tapping spout repeatedly becomes clogged with material which is not fluid. An auxilliary burner was installed to heat the tapping spout. Later, the tapping spout was enlarged as shown in Figure 2-25. These modifications did not solve furnace plugging problems.

Influence of Dust Composition on Agglomeration Properties

The pronounced differences in the agglomeration behavior of East Penn and Bergsoe flue dusts prompted an investigation to identify chemical and physical differences. Flue dust from the General Battery Corporation, Reading, Pennsylvania, was included in this study. Detailed results are presented in Appendix A, "Baghouse Dust Agglomeration in the Secondary Lead Industry." This study was undertaken well before the follow-up evaluation and the information provided to East Penn.

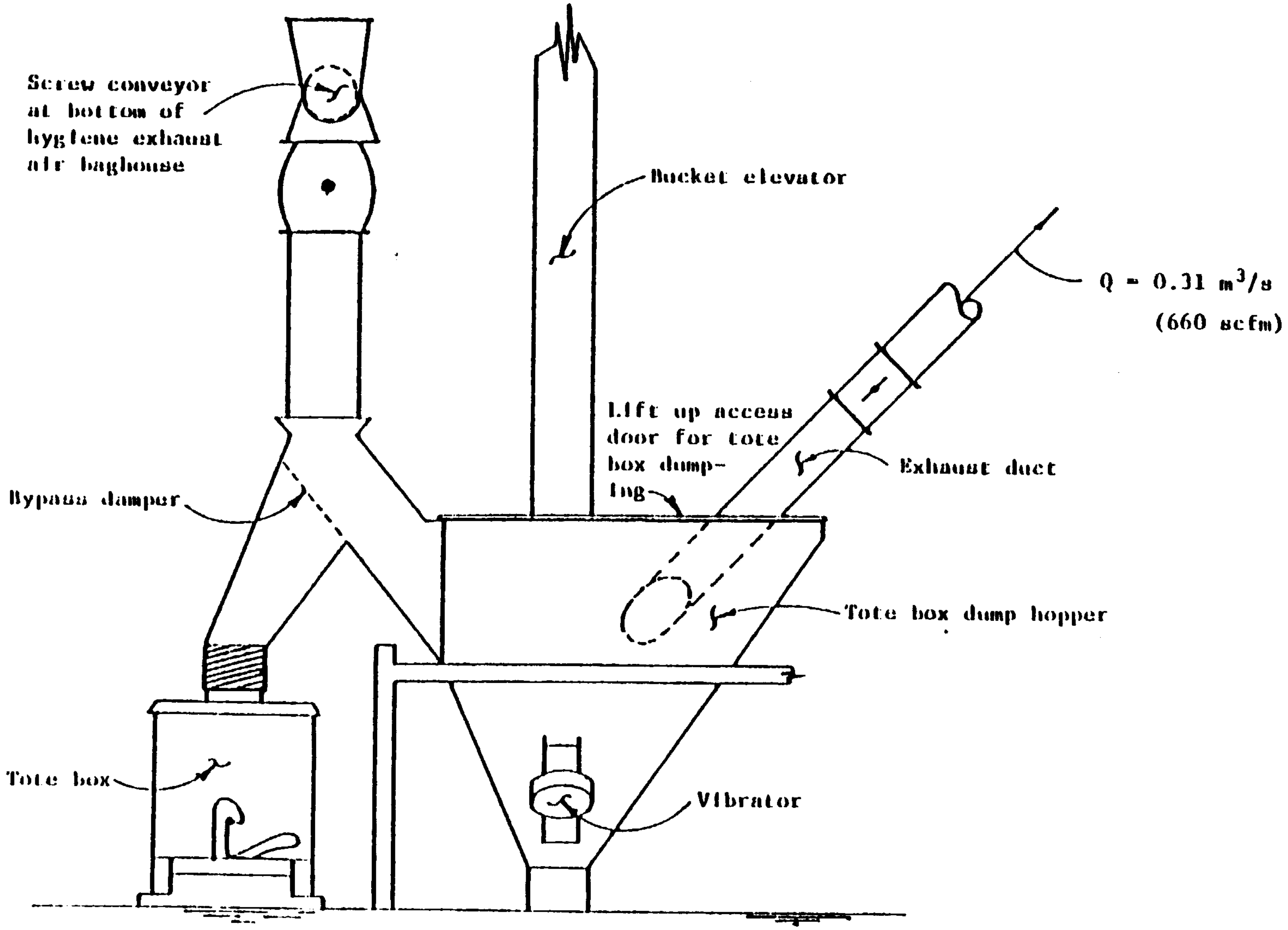


FIGURE 2-24. TOTE BOX DUMPING STATION AND SECTION OF THE AGGLOMERATION FURNACE DUST FEED MECHANISM

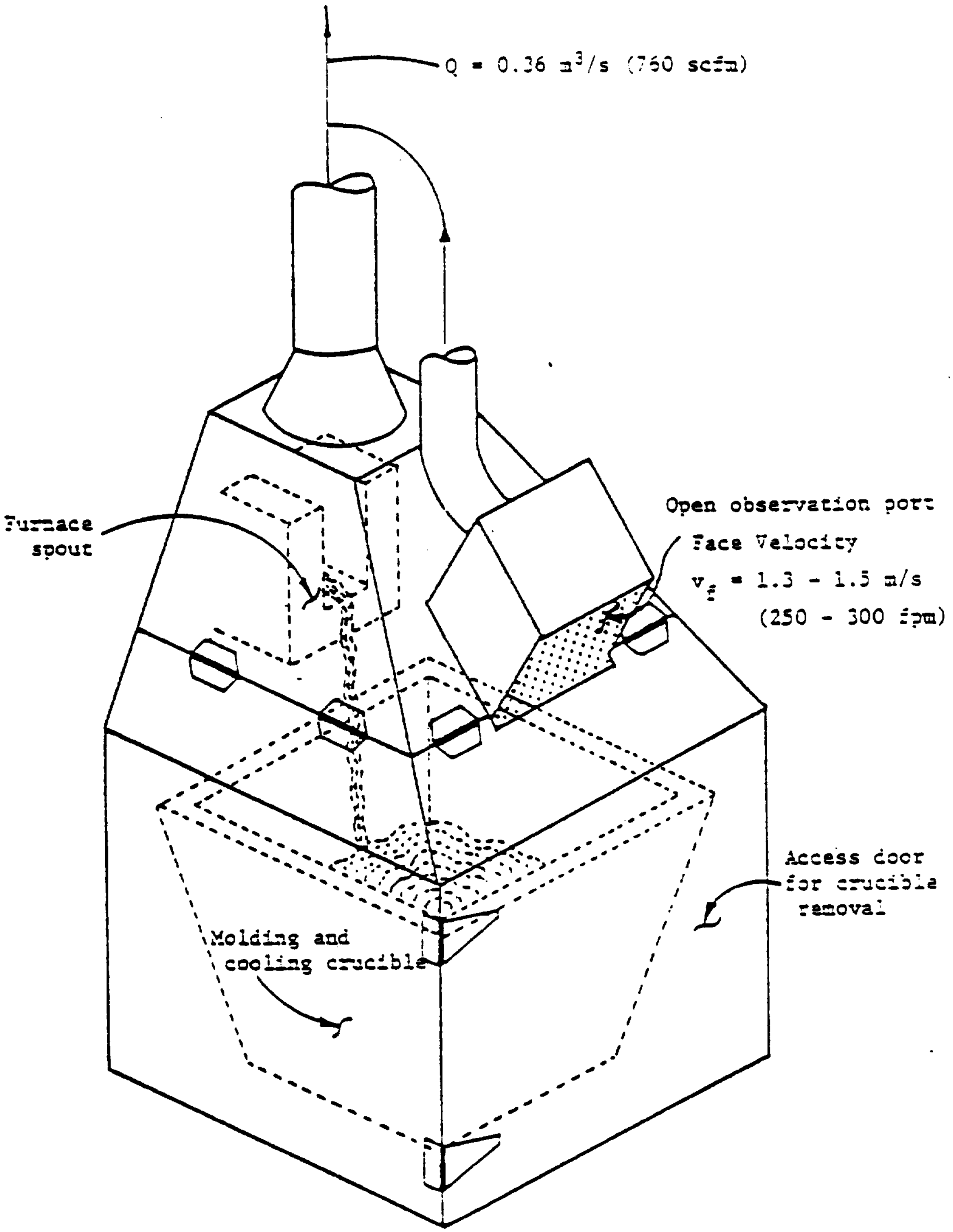


FIGURE 2-25. AGGLOMERATION FURNACE TAPPING HOOD

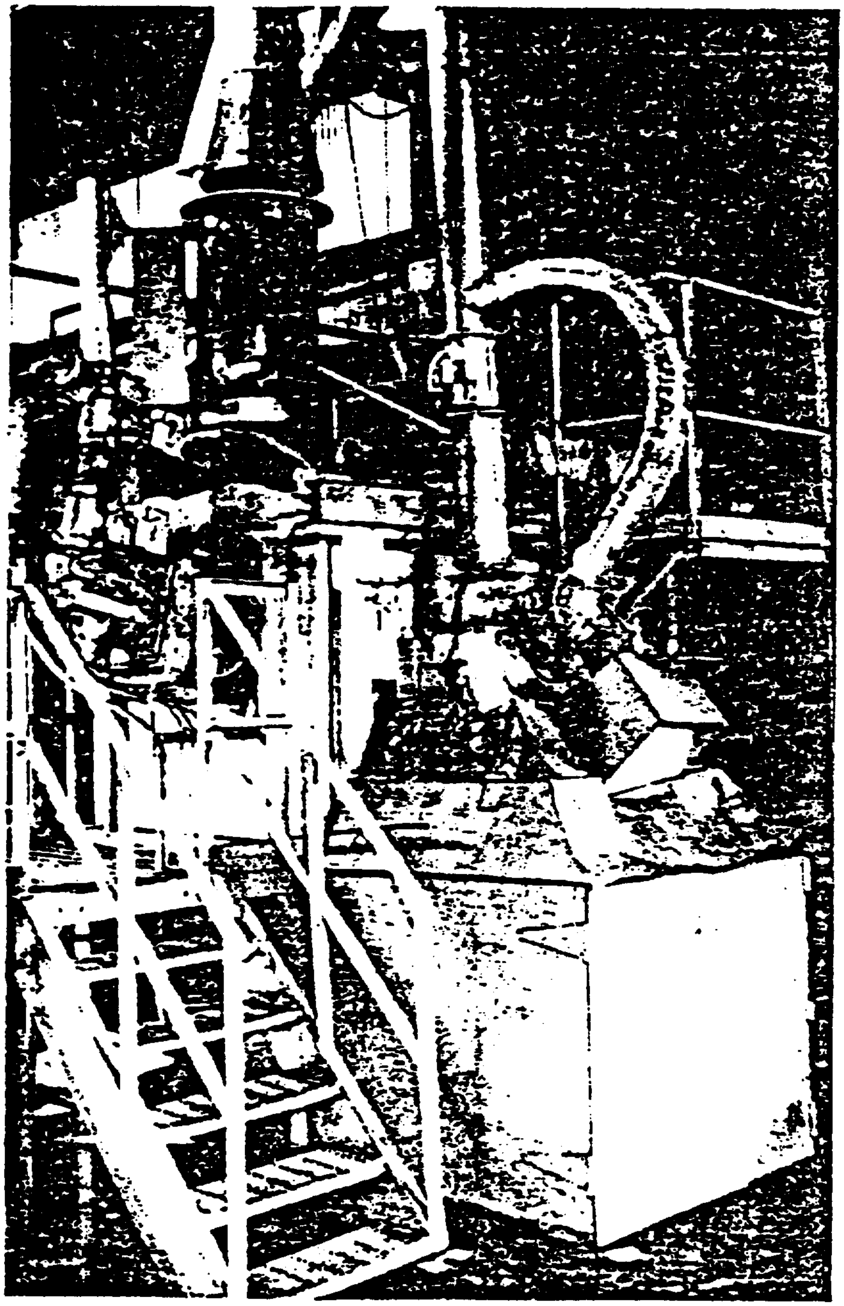


FIGURE 2-26. VIEW OF THE FIRING MECHANISM AND TAPPING HOOD FOR THE AGGLOMERATOR FURNACE

The main findings are listed below.

Chemical Composition

Elements found in high concentration besides lead, calcium and iron are chlorine and potassium. The concentration ranges of these elements are:

	Lead	Chlorine	Potassium
East Penn	64-99%	1-3%	0.3%
General Battery	53%	8.5%	1.3%
Bergsøe	60-65%	24-26%	3-4%

The high chlorine and increased potassium values in the General Battery and Bergsøe samples are noteworthy. Chlorine originates from chlorine containing polymers introduced with the battery casings and plate separators.

Crystalline Phases

The crystalline species present in the baghouse dust were investigated by X-ray diffraction. The findings are:

East Penn:	Pb, PbS, $PbSO_4$, PbO, $PbO \cdot PbSO_4$, Unidentified compounds
General Battery:	$PbSO_4$, $PbO \cdot PbSO_4$, $PbCl_2$, Unidentified compounds
Bergsøe:	PbS, KPb_2Cl_5, $PbCl_2$

Noteworthy is the presence of elemental lead in the East Penn sample, the presence of $PbCl_2$ (major constituent) in the General Battery sample and the presence of KPb_2Cl_5 (major constituent) and $PbCl_2$ (moderate concentration) in the Bergsøe samples.

Melting Points

The quantity and types of chloride compounds present in the dust have a pronounced influence on the agglomeration properties. This is evident from the low melting points of the chloride compounds summarized in the following table:

TABLE 2-4. MELTING POINTS OF COMPOUNDS IDENTIFIED OR POTENTIALLY PRESENT IN BAGHOUSE DUST

Lead	Pb	326°C
Potassium Lead Chloride	$KCl \cdot 2PbCl_2$	440°C
Lead Chloride	$PbCl_2$	496°C
Lead Oxychloride	$PbO \cdot PbCl_2$ $2PbO \cdot 3PbCl_2$	524°C 530°C
Potassium Lead Chloride	$2KCl \cdot PbCl_2$	540°C
Lead Oxychloride	$2PbO \cdot PbCl_2$ $4PbO \cdot PbCl_2$	693°C 711°C
Potassium Calcium Chloride	$CaCl_2 \cdot KCl$	755°C
Calcium Chloride	$CaCl_2$	774°C
Potassium Chloride	KCl	775°C
Lead Oxide	PbO	850°C
Lead Oxysulfate	$2PbO \cdot PbSO_4$	960°C
Lead Sulfide	PbS	1,114°C
Lead Sulfate	$PbSO_4$	1,170°C

The lead chloride melt readily wets higher melting lead compounds like PbO and PbS. This is not true for elemental lead. Elemental lead does not wet lead oxide and sulfide. This results in a two-phase system upon resolidification.

Thermal Analysis Results and Agglomeration Tests

Thermal analysis using Differential Scanning Calorimetry showed endotherms (melting phases) at the following temperatures (°C).

Bergsoe:	370, 385, 518, 565, 708 (Sample I) 362, 385, 568, 600, 635 (Sample II)
General Battery:	430, 610
East Penn:	Very broad endotherm between 500 - 580.

The endotherms of the Bergsoe samples were highest. The two peaks of the General Battery sample were far less pronounced, indicating a lower concentration of the melting constituents. The East Penn endotherm was flat and broad.

Good agglomeration of the three samples was achieved at the following agglomeration temperatures:

Bergsoe:	410°C
General Battery:	650°C
East Penn:	900°C

This is in agreement with the thermal analysis results.

Mechanism of Lead Chloride Built Up

Lead chloride shows a partial vapor pressure of:

- 1 mm at 547°C
- 10 mm at 648°C
- 100 mm at 784°C, and
- 760 mm at 954°C.

Lead chloride formed in the blast furnace will, therefore, evaporate at furnace temperatures and recondense upon cooling of the flue gas. The resolidified $PbCl_2$ helps to lower the agglomeration temperature considerably as indicated at Bergsoe.

Chlorine Source

Battery plates are separated by nonconductive materials, among them polyvinylchloride (PVC). It is estimated that in the US 50 percent of the industrial batteries, but only 3 percent of the car batteries contain PVC separators. This is in contrast to Europe where at least 25 to 30 percent of the car batteries contain PVC separators.

This has an important consequence. Much less chlorine is introduced into US secondary lead smelters than in Europe. This causes the different dust compositions and as a consequence, the different agglomeration properties observed at East Penn and Bergsøe.

As a result of this fact, European technology may not transfer to US operations without some alterations or development work.

$PbCl_2$ Removal Option

The lead chloride concentration can continuously build up if the agglomerated dust is recycled to the blast furnace. The rate of build up depends on the formation rate which is dependent on the chloride content in the feed materials. Ultimately, a slip stream of the baghouse dust may need to be treated for $PbCl_2$ removal.

One method is aqueous leaching. The solubility of $PbCl_2$ is 10 g/l at 20°C and 33 g/l at 100°C.

Implications for East Penn

This study of flue dust agglomerating properties indicates that East Penn will have to increase the chlorine content of its flue dust if improved agglomeration properties are to be achieved. This can be done by recycling flue dust to the blast furnace or adding a source of chlorine to the feed. Traditionally, East Penn has recycled only small amounts of flue dust and has sold the rest. Thus, the average chlorine content of this dust is low. Attempts to increase the chlorine content are described in Section 6.

HOUSEKEEPING PROCEDURES AND EQUIPMENT

According to smelter personnel, housekeeping has been a severe problem at this smelter throughout its operating history. Battery muds, drosses and flue dust all give rise to workplace contamination and fugitive emissions to the environment.

At the time of the initial evaluation much of the smelter grounds were not paved. Collected flue dust was stockpiled outside where wind and traffic spread the dust over the entire smelter area. Similarly, battery mud was tracked in and out of the buildings and heavy accumulations were present in yard areas. Dry sweeping techniques were utilized in many work areas.

Between the initial and follow-up evaluations, a major clean-up program was implemented. The yard was paved and large accumulations of flue dust and other leady materials were removed. Wet methods were developed for cleaning several areas of the smelter. A central vacuum system was installed. The following paragraphs describe current housekeeping procedures and equipment. Constant attention to housekeeping is necessary since handling of broken batteries, screw conveying of flue dust, etc., remain to be sources of lead contamination.

Central Vacuum System

A central vacuum system was installed to aid plant clean-up operations. The system has 14 inlet ports located in smelter buildings and yard areas. Workers assigned to clean-up duty connect a vacuum attachment to one of the inlet ports and use the vacuum to remove dust and dirt from floors and other plant surfaces. Vacuuming is a preferred method for clean-up because it removes settled particles without reintroducing them into the air (as would occur with dry sweeping methods).

System Description

The central vacuum system serves the yard area, the smelter building and the agglomeration building. The vacuum inlet ports are distributed as follows (see Figure 2-27 for details):

Plant Area	Location of Inlet Ports
Yard Area	Two ports; one located under the U-tube heat exchangers; one near the entrance to the changeroom.
Smelter Building	Five ports; four located on the main floor; one located on the second level.
Agglomeration Building	Seven ports; six located on the main floor; one located on the upper level on the furnace platform

The vacuum system uses a Spencer Vacuum Products Fan rated at 0.19 m^3/s (400 scfm) and 254 mm (10") Hg. The fan is driven by a US Electrical motor rated at 30 hp and 3,535 rpm. A series of two cyclone collectors remove large particles from the vacuum airstream and discharges them into two 50-gallon drums. Workers empty these drums as necessary. The second cyclone is followed by filters to remove fine particulate before the vacuum airstream is released to the atmosphere.

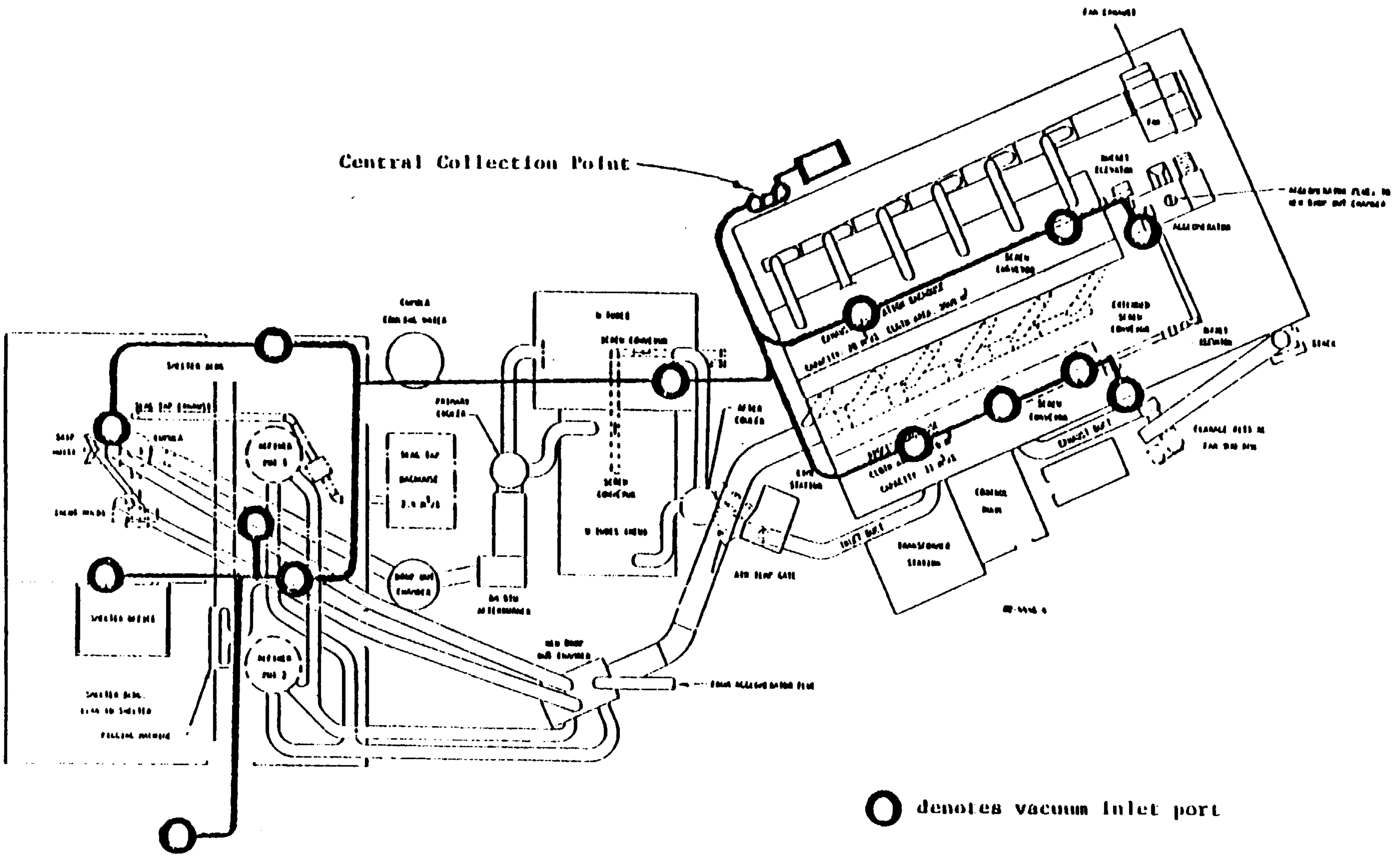


FIGURE 2-27. CENTRAL VACUUM SYSTEM LAYOUT

System Operation

The central vacuum system is used for routine daily clean-up of smelter buildings and two outside plant areas. Workers stated that they thought the system worked well and was easy to use. The central vacuum system reportedly picks up two tote boxes of dust per week or approximately 530 kg (1,200 pounds).

Mobile Sweeper/Vacuum

A Tennant brand mobile sweeper/vacuum is used for routine daily cleanup of paved roadways and yard areas. The Tennant sweeper is a mobile sweeper/vacuum unit that is operated by a single worker who rides on top of it. As the sweeper moves along, two brushes in the front loosen dirt accumulations which are picked up by a vacuum unit located behind the brushes. Plant areas not accessible to the sweeper are cleaned with the central vacuum system.

Workers use the sweeper a number of times during a single shift. Most frequently cleaned are the access road adjacent to the pond and the yard area near the outside storage area for flue dust, slag and agglomerated flue dust. The mobile sweeper/vacuum reportedly collects two tote boxes of dust per week or approximately 530 kg (1,200 pounds).

Wet Washing and Sweeping

The agglomerator building has a concrete floor with a floor drain. Workers used water hoses and push brooms to wash down the floor and keep it wet during the follow-up evaluation. The water - dust combination made the floor slippery. Reportedly, water is not routinely used to clean the floor or keep it wet. The central vacuum system is routinely used to clean up dust spills.

Water washing was also used extensively in the blast furnace charge preparation area, slag tapping area and refining area. Hoses were also used to wash down areas under the U-tube coolers and other outdoor surfaces.

SECTION 3

SMELTER CHARACTERIZATION

This section outlines the procedures and results of the sampling and analytical efforts used for characterizing emissions at the East Penn lead smelter. The source characterization effort entailed three major areas. They were:

- the determination of stack emission,
- the determination of smelting process emission factors for lead, and
- the determination of collection efficiencies across each of the three baghouses.

In addition, five hi-volume samplers were stationed around the plant perimeter for the determination of ambient lead levels. Additional samples were collected in conjunction with the industrial hygiene and source characterization efforts with emphasis on characterization of inhalable particles.

SAMPLING AND ANALYTICAL METHODS

The methodologies used in characterizing the smelter emissions are described in this section.

EPA Method 12

The EPA Method 12 sampling train pictured in Figure 3-1 was used to determine the following for process source sampling:

- average stack temperature and velocity,
- total lead and lead particle emissions, and
- total particle emissions.

The sampling train consisted of a stainless steel probe lined with a heat traced glass sample line. A stainless steel gooseneck nozzle was connected to the front of the sampling probe. Stack particles were collected isokinetically on a glass fiber filter heated to 121°C (250°F) in a thermostated oven. The impinger train consisted of two nitric acid impingers to catch vaporous lead followed by a dry impinger to knock-out moisture and finally a silica gel impinger as a dessicant.

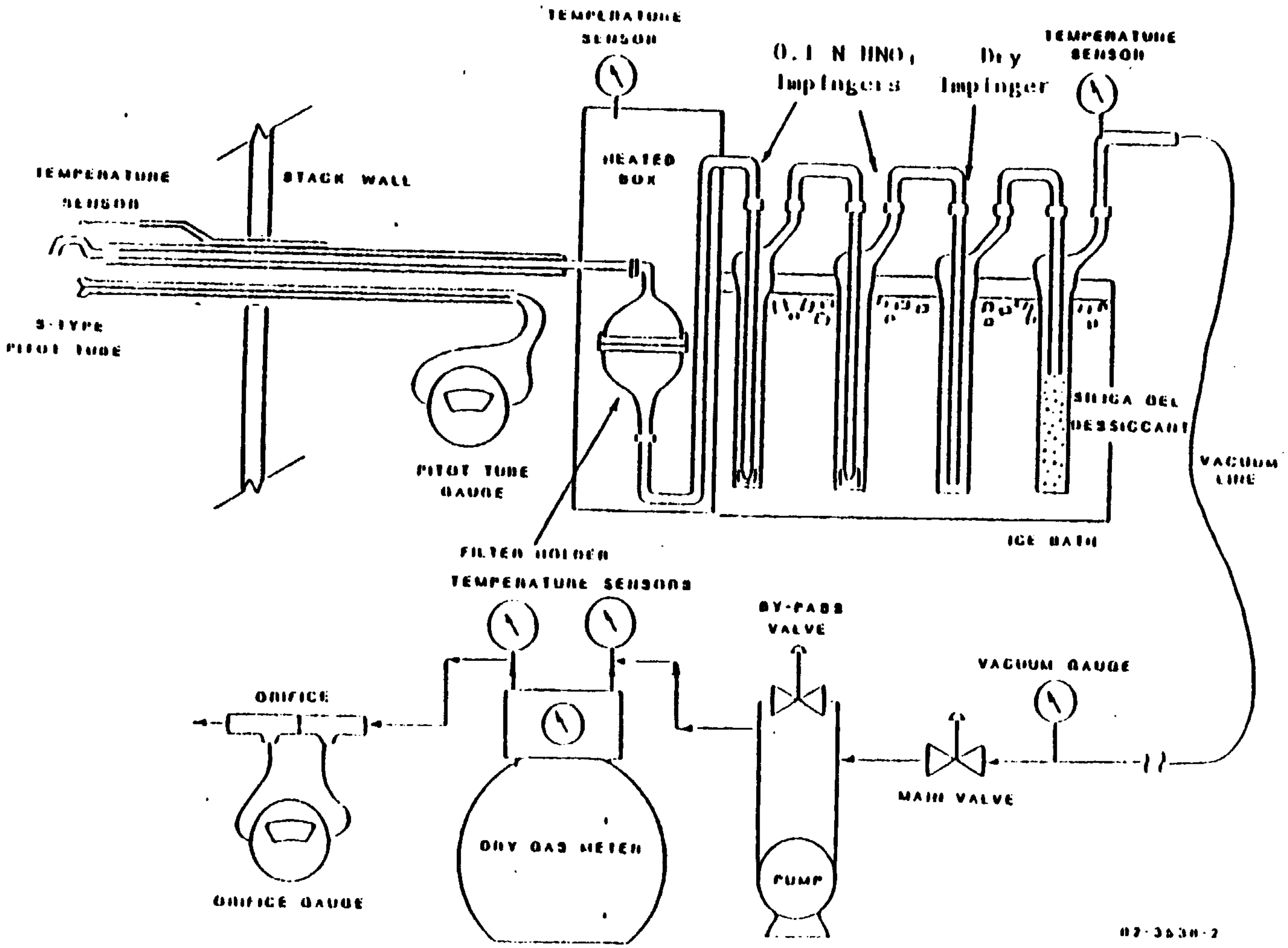


FIGURE 3-1. EPA METHOD 12 SAMPLING TRAIN

Particles deposited on the nozzle and probe interior were carefully removed by nitric acid washings into a clean storage container. The washings were evaporated to dryness and weighed. This weight, combined with the weight of the particles collected on the filter, was used to determine the total particle and lead particle loading in the stack. The lead captured in the impinger train was added to the lead particle loading to yield the total lead in the stack gas.

For sampling at the process baghouse inlet and outlet a modified EPA Method 12 was used. Two sodium hydroxide impingers were added behind the two nitric acid impingers in order to catch sulfur and chlorine species. The impinger train configuration for the modified EPA Method 12 runs is detailed in Table 3-1 below.

TABLE 3-1. MODIFIED EPA METHOD 12 IMPINGER TRAIN SUMMARY

Impinger	Contents	Catch
1	250 mls, 0.1N HNO_3	lead, antimony
2	250 mls, 0.1N HNO_3	lead, antimony
3	Empty	knockout
4	250 mls, 0.1N NaOH	sulfur, chlorine, lead, antimony
5	250 mls, 0.1N NaOH	sulfur, chlorine, lead, antimony
6	Empty	knockout
7	250 gms silica gel	H_2O

For the modified EPA Method 12 runs the filter and probe wash particulate matter were analyzed for lead, antimony, sulfur and chlorine. The exact methods of analysis are described in the section entitled Analytical Procedures.

Process Source Particle Sizing

Size classification of particulates was performed using a University of Washington Cascade Impactor illustrated in Figure 3-2. Particles present in the gas stream are classified with respect to their aerodynamic size and impacted on twelve collection surfaces (eleven impaction surfaces and one backup filter).

Glass fiber collection substrates were used to facilitate removal of the particles from the impaction stages and to enable lead analysis to be performed on selected size fractions. Prior to sampling, the substrates were dessicated for at least 24 hours, weighed and then loaded into the University of Washington body.

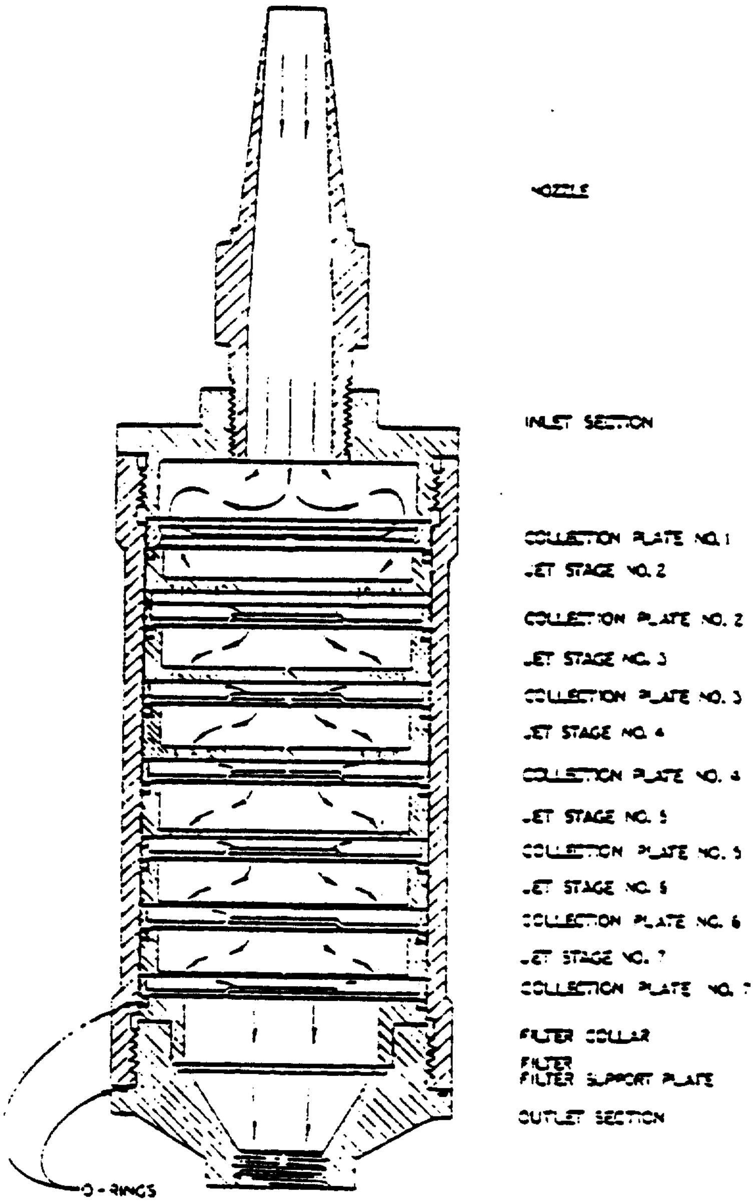


FIGURE 3-2. CROSS SECTION OF UNIVERSITY OF WASHINGTON CASCADE IMPACTOR

Impactor sampling was performed at a single point of average velocity. The isokinetic flow rates through the nozzle were precalculated based on velocity data previously obtained. After the sampling, the impactor was unloaded and the filters dessicated before reweighing. Filter weight gains were then used to calculate the particle size distribution.

High-Volume Sampling

High volume air samplers were used to collect suspended particulate matter on large 20.3 cm x 25.4 cm (8 inches by 10 inches) glass fiber filters. The samplers were operated over several 24 hour periods at the locations described in the Ambient Particulate and Lead Levels section. Wind velocity and direction data were collected during the hi-vol sampling. Samples collected on days during which the wind speed and direction were favorable for collecting the desired emissions were analyzed for total particle loading and lead particle loading.

All of the hi-vols were calibrated for flow rates before sampling using an NBS traceable standard orifice. The filters were dessicated for at least 24 hours and then weighed before and after sampling. The weight difference was recorded as the mass of particles collected. Sampling time, sampling flow rate and the particulate mass collected were used to calculate the total suspended particles (in micrograms per cubic meter). Suspended particulate lead in the air was determined on the same filters by chemically analyzing the filters for lead. The analytical method is described in the section entitled Analytical Procedures.

High-Volume Particle Sizing

Six high-volume samplers equipped with particle sizing devices were used in the upwind-downwind sampling and in characterizing fugitive emissions. Three of the hi-vols were modified to include a size-selective inlet to remove particulate matter larger than 15 micrometers from the sample stream. The other three hi-vols were equipped with five-stage cascade impactors to provide particle size data in the range of 10 to 0.5 micrometers.

The size selective inlet and the five-stage impactor both fractionate particles according to their aerodynamic size. This is important since the aerodynamic size determines the penetration of particles in the human lung, the particle collection efficiency in pollution control equipment and the transport of particles through the air. As with the standard hi-vols, wind velocity and direction data were used to select the hi-vol filters to be used for lead analysis.

ANALYTICAL PROCEDURES

This section describes the procedures used for treating and analyzing samples collected at East Penn Manufacturing. The samples are associated with EPA Method 12 tests, process source particle sizing, high volume sampling, high volume particle sizing and with grab sampling methods. The last paragraphs of this section describe the sample preparation and chemical analysis techniques used for these samples.

EPA Method 12

The EPA Method 12, as previously described, was used for determining the inorganic lead emission from the process sources. Each Method 12 test provided the following samples for analysis: filter, nitric acid probe wash, cyclone solids (if collected), two nitric acid impinger solutions and probe solids (when available as separate from the probe wash). In using the modified Method 12, two additional samples were collected: dilute sodium hydroxide solutions from two impingers connected in series.

The analytical matrices used for the Method 12 and modified Method 12 samples are presented in Figures 3-3 and 3-4 respectively.

Process Source Particle Sizing

Each in-stack cascade impactor test provided eleven glass fiber substrates and one back-up filter on which were collected several size fractions of particulate matter. The analytical matrix used for process emission particle sizing is presented in Figure 3-5.

High-Volume Sampling

High volume air samples were used to collect samples for the determination of total suspended particles less than 15u, and particle size distribution between approximately 0.5 and 10u. The analytical scheme for the three types of high volume samples is depicted in Figure 3-6. Selected hi-vol runs were chosen for lead analysis in order to determine total suspended lead and particulate lead size distribution. The runs were chosen based on favorable wind and weather conditions.

Grab Samples

Figure 3-7 presents the matrix for baghouse dust and agglomerator dust analysis. These samples were collected to supplement the stack and ambient air analysis. Dust from each of the three baghouses was analyzed for ash content and lead. Process baghouse dust was also analyzed for antimony, chlorine and sulfur. Agglomerator dust samples were analyzed for lead, antimony, chlorine and sulfur.

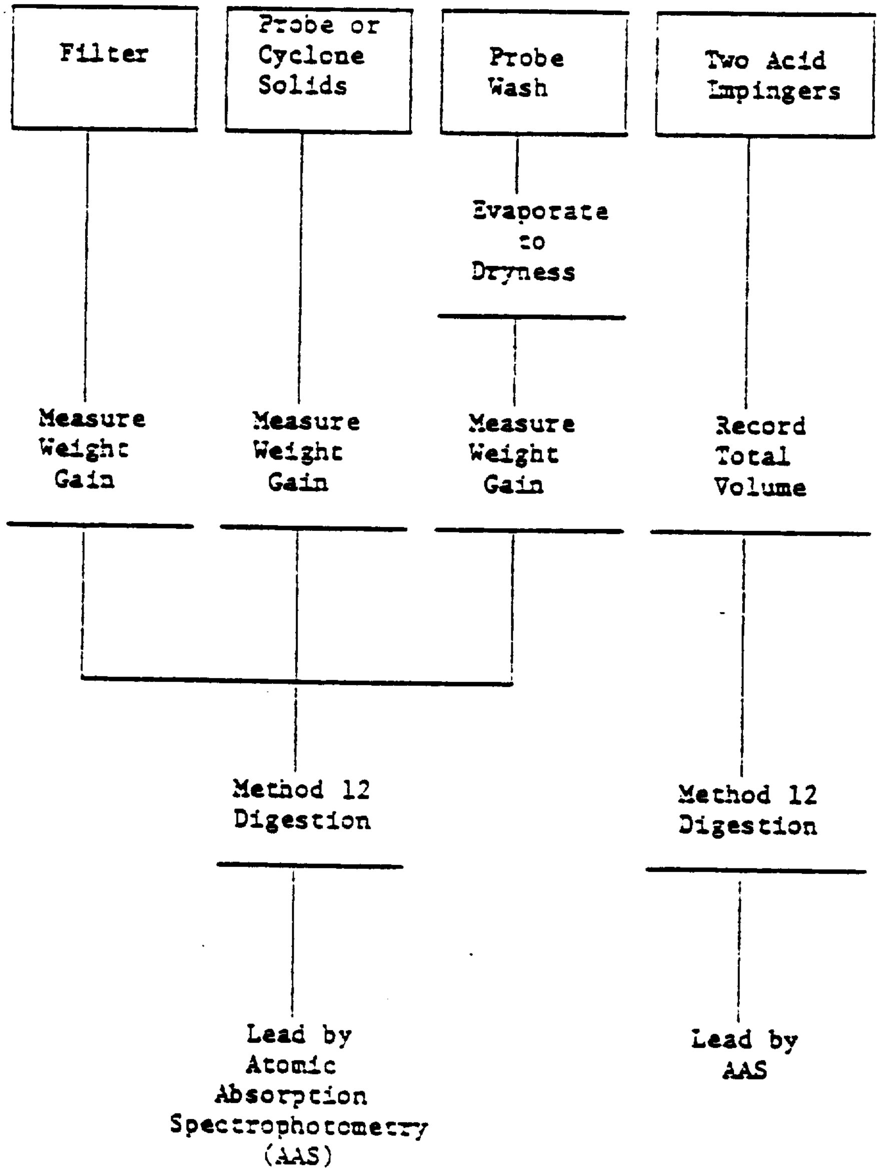


FIGURE 3-3. METHOD 12 ANALYTICAL MATRIX

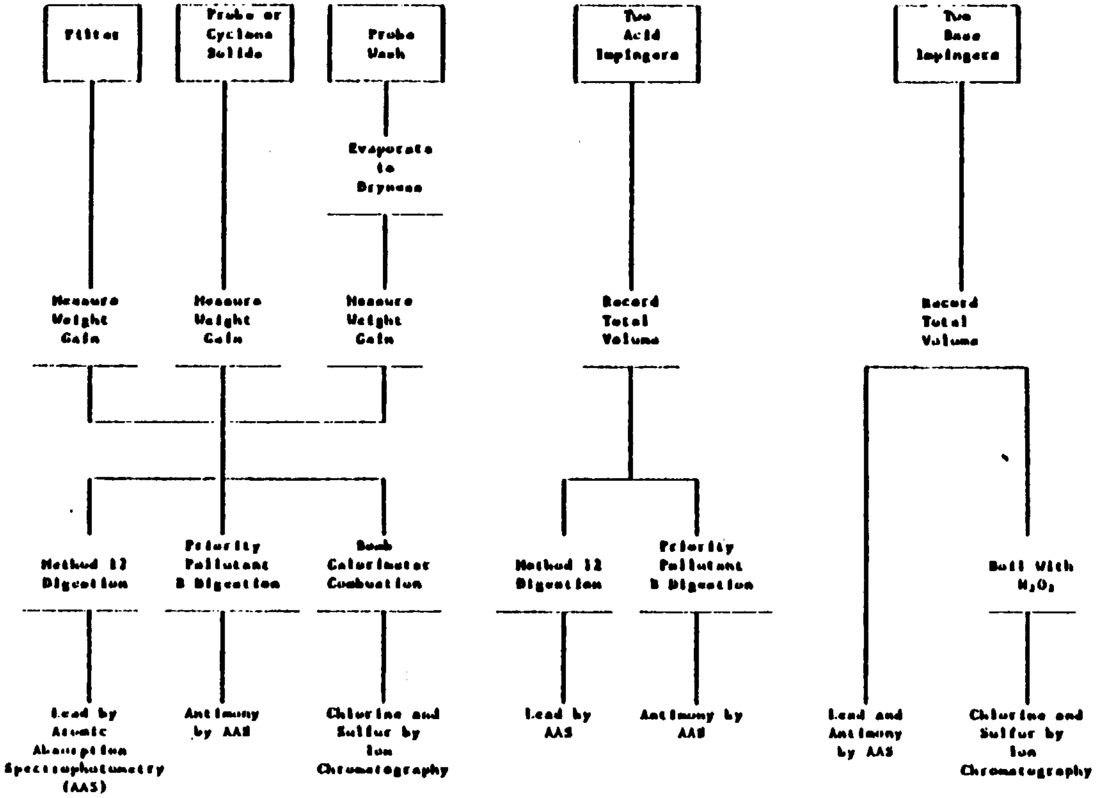


FIGURE 3-4. MODIFIED METHOD 12 ANALYTICAL MATRIX

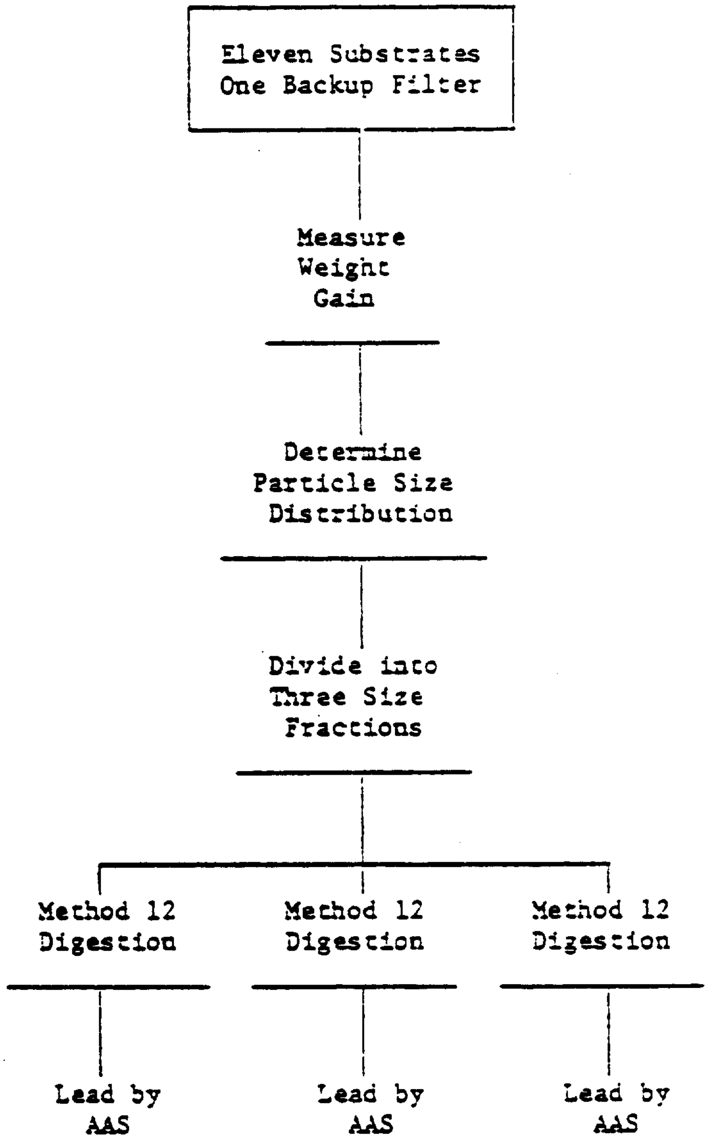


FIGURE 3-5. PROCESS SOURCE PARTICLE SIZING ANALYTICAL SCHEME

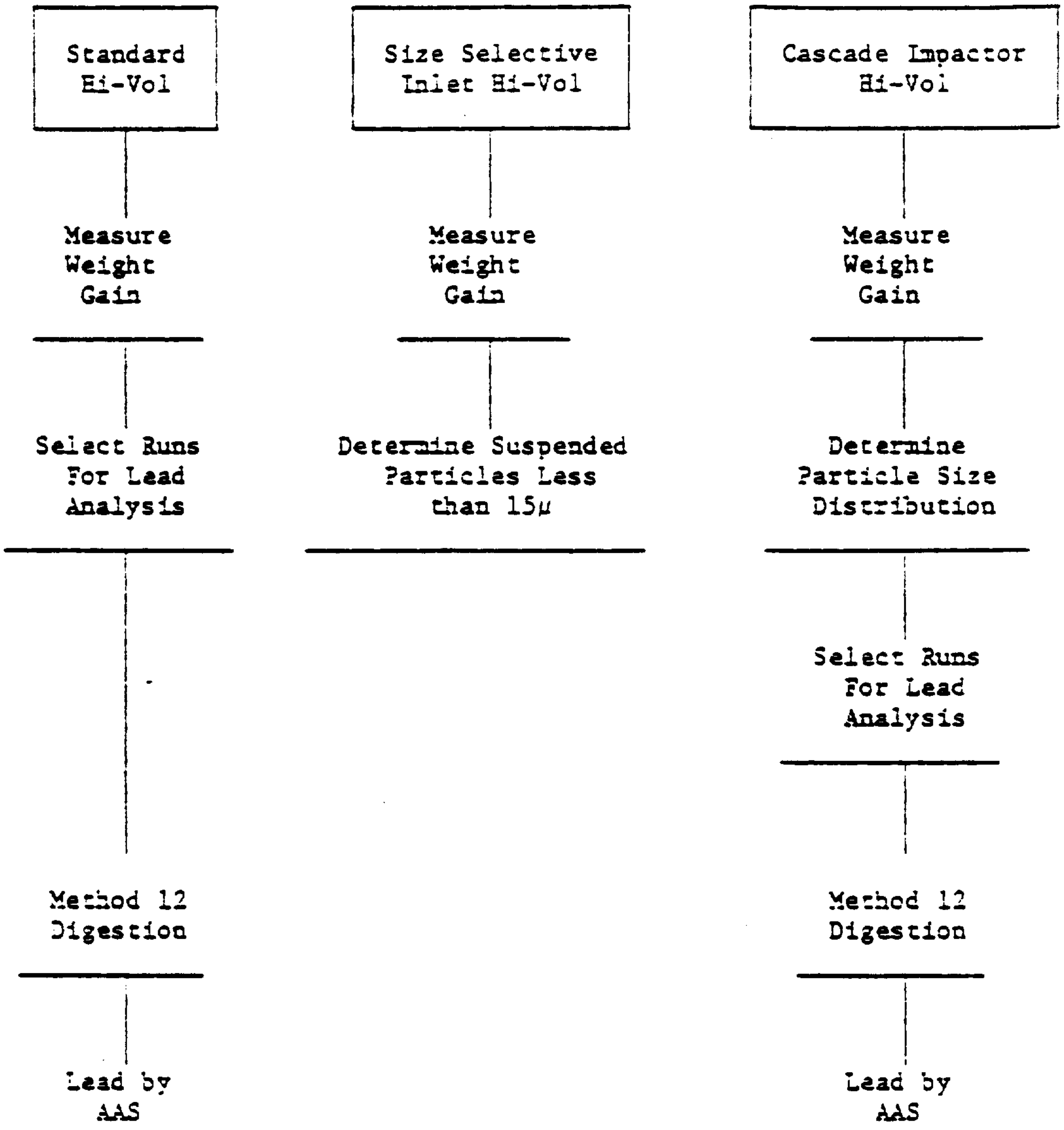


FIGURE 3-6. HIGH VOLUME SAMPLING ANALYTICAL SCHEME

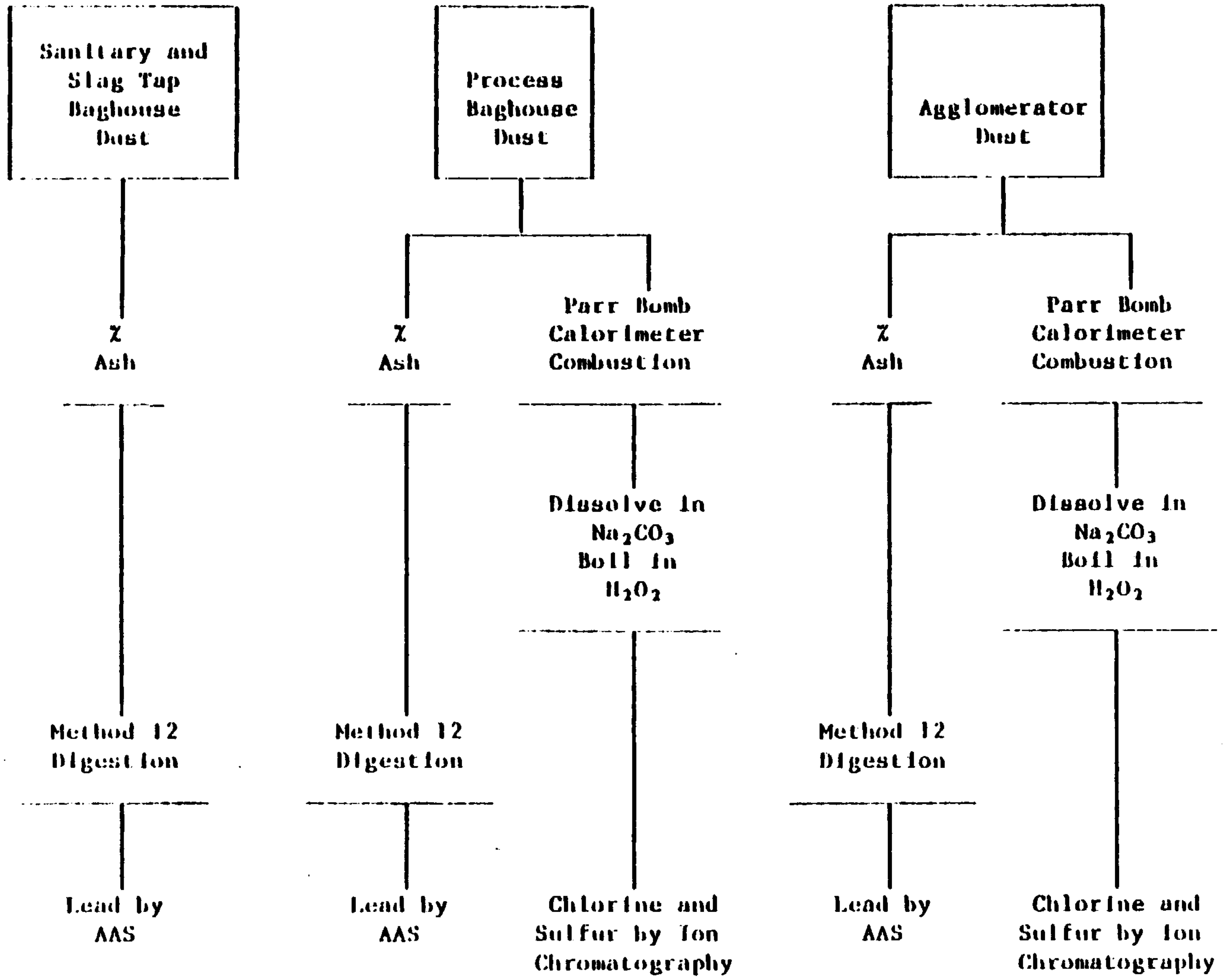


FIGURE 3-7. GRAB SAMPLING ANALYTICAL SCHEME

SAMPLE PREPARATION AND ANALYTICAL METHODS

The samples discussed in this section required several methods of preparation, digestion and analysis.

Calculation of grain loading and particle size distribution required the measurement of filter weight gain, the weight of the probe or cyclone solids and the weight of the probe wash after evaporation just below the boiling point.

The Method 12 Digestion is described in EPA Method 12, (Federal Register, Vol. 45, Number 9, Appendix A). This method uses nitric acid and hydrogen peroxide to extract inorganic lead. The Priority Pollutant B Digestion (Sampling and Analysis Procedures for Screening of Industrial Effluents for Priority Pollutants, U.S. EPA) is an aqua regia digestion suitable for analysis of antimony.

Solid samples for total chlorine and sulfur determinations were combusted in a bomb calorimeter. The combustion products were absorbed in a sodium carbonate solution. This solution was then boiled with hydrogen peroxide to oxidize the sulfur species to sulfate.

Baghouse dusts were ashed in a muffle furnace. After ash content was determined, further digestions were performed as required.

Two proven analytical techniques were used for all chemical analyses. Atomic Absorption Spectrophotometry (AAS) using an air-acetylene flame was used to analyze for lead and antimony. Total chlorine and sulfur content was determined using ion chromatography for chloride and sulfate. The low metal concentrations in the impinger solutions required AAS analysis by heated graphite analyzer.

Quality Assurance

Sampling quality was assured by sampling each point in duplicate. In addition, any runs which appeared anomalous (plugged nozzle, leak in sampling train, non-isokinetic run, etc.) were repeated while on-site.

Sample handling quality assurance was straightforward. Standard reference materials available from the National Bureau of Standards were simultaneously digested with the samples. Digestion blanks were also prepared to check for possible contamination during the procedure. Each sample was digested in duplicate.

Analytical quality assurance concentrated on repeatability and accuracy assessment. Instrument response was calibrated using commercially available reference solutions. Sample analysis proceeded only upon verification that : (1) the standards were internally consistent, and (2) analyte concentrations measured in standard reference materials were accurate. The method of standard additions in AAS was used to eliminate matrix interferences. Each analysis was performed in duplicate.

PROCESS EMISSION MEASUREMENTS

Emission factors for specific lead smelting and refining operations were determined on sources hooded for emission control by the sanitary baghouse. Table 3-2 presents for each of the process sources the sampling scheme used, including sampling location, sampling date and sampling methodology.

The hooded sources were sampled for total lead, total particle loading and particle size distribution using the techniques described in the Sampling and Analytical Methods section. Samples were collected in the transfer lines between the hood and the point at which the stream fed into the total feed to the sanitary baghouse. This data allowed for an assessment of the value of controlling the emissions of these sources. Process sources which were hooded and sampled were:

- Blast Furnace Slag Tapping. Although slag was tapped intermittently, the exhaust system operated continuously. Sampling was conducted continuously and the number of slag taps made during a sampling run were recorded.
- Blast Furnace Metal Tapping. This included a composite of the metal tapping hood, launder hood and block casting hood.
- Blast Furnace Charging. Sanitary gases sampled here included one of two ground level hoods of the skip hoist, the charging hood and the slot hood over the furnace access doors.
- Agglomeration flue. The gases of the dust agglomeration furnace, including flue and external hoods, were sampled before the knock-out chamber.
- Refining Kettle No. 2. The two ducts carrying the refining kettle No. 2 off-gases were sampled for total lead and total particle emissions over approximately a three-hour period. The sampling periods encompassed the refining processes of melting, stirring, drossing, chemical addition and refining. Particle size fractionation was not determined because of the low grain loading.

TABLE 3-2. PROCESS SOURCE SAMPLING SCHEME

Process Source	Sampling Location	Sampling Date	Sample Taken EPA Method 12	Sample Taken University of Washington Cascade Impactor
Blast furnace slag tapping	Horizontal transfer line inside smelter building. (0.38 m duct diameter).	8-05-80	X	X
		8-06-80	X	X
Blast furnace metal tapping	Vertical transfer line on roof of smelter building (0.48 m duct diameter).	8-12-80	X	X
		8-15-80	X	X
Blast furnace charging	Transfer line on roof of smelter building (0.72 m duct diameter).	8-12-80	X	X
		8-15-80		X
Agglomeration flue	Horizontal transfer line before knock-out chamber, along catwalk (0.34 m duct diameter).	8-13-80	X	X
		8-14-80	X	X
Refining kettle	Two vertical ducts directly over kettle hoods (each 0.23 m diameter).	8-15-80	X	
		8-15,16-80	X	
Pigging machine	Horizontal transfer line in smelter building (0.23 m duct diameter).	8-15-80	X	
		8-16-80	X	

- Pigging Machine. The total lead and total particulate emissions generated by the pigging operation were measured in the pigging hood transfer line. Sampling was performed only when the pigging machine was operating. The low grain loading precluded the measurement of particle size fractionation.

The process source emission rates for total particulate matter and total lead are presented in Table 3-3. These data are from the EPA Method 12 runs. For two runs on each of the six process sources the following data are presented:

- Sampling date.
- Stream flow rate - the flow rate of gas through the particular ventilation system.
- Volume sampled - the volume of gas sampled during an EPA Method 12 run.
- Emission rates - the concentrations in the stack gas (mg/m^3) and the emission rates (g/hr) are reported for both total particles and total lead. English units have not been included for reasons of reporting clarity.

Blast furnace charging had the highest emission rate for both total particulate matter and total lead. Close behind were the emission rates of the agglomerator furnace. Total particles emitted by the slag tapping process (1,300 and 1,800 g/hr) are well below charging and agglomeration processes. A lead emission rate could not be calculated for the slag tapping process. The probe wash dust was lost during the digestion step used to determine lead content. However, a reasonable estimate of the lead content in the particulate matter based on the lead found in the dust collected on the Method 12 filter would be around 60 percent lead. This would give a lead emission rate for the slag tap on the fifth and sixth of August of 740 and 1,100 g/hr respectively. Slag was tapped four times during each of the two sampling runs. Lead emissions from the metal tapping fall close behind at 340 g/hr. The metal tapping ventilation system had a relatively large air draw and the dust had a high lead content (60 percent).

The pigging machine and the refining kettle had the lowest emission rates of the six processes. Note that the concentration of lead in the pigging ventilation gas (average of 7 mg/m^3) was higher than the lead concentration in the refining off-gas (average 3.6 mg/m^3). The higher lead in the pigging ventilation could be a result of the lower stream flow rate in the pigging hood than the refining hood.

TABLE 3-3. PROCESS SOURCE SAMPLING - EMISSION RATES

Process Source	Sampling Date	Stream Volumetric Flow Rates m^3/hr*	Volume Sampled m^3*	Emission Rates*			
				Total Particles		Lead	
				mg/m^3	g/hr	mg/m^3	g/hr
Blast furnace slag tap	8-05-80	7,000	1.3	190	1,300	108†	740†
	8-06-80	6,800	1.2	270	1,800	160†	1,100†
Blast furnace metal tapping	8-12-80	18,000	2.9	31	570	19	340
	8-15-80	18,000	2.8	53	950	-	-
Blast furnace charging	8-12-80	11,000	1.5	7,700	86,000	6,100	67,000
	8-15-80	9,100	0.56	17,500	160,000	11,000	100,000
Agglomerator flue	8-13-80	9,100	0.64	7,900	72,000	5,400	49,000
	8-14-80	8,000	0.34	10,500	84,000	6,800	55,000
Refining kettle	8-15-80	3,600	4.1	12	43	3.0	11
	8-15,16-80	3,300	4.0	7.8	26	4.3	14
Pigging machine	8-15-80	2,000	0.41	27	53	5.4	11
	8-16-80	2,000	0.35	17	33	8.9	17

* At 760 mm and 20°C

† Value based on lead content of EPA Method 12 filter solids extrapolated to total particulate matter collected in probe wash and filter.
Calculated from EPA Method 12 runs.

Table 3-4 presents a summary of the in-stack particle size determinations for the six process sources. A more detailed presentation of the particle size data is presented in Appendix B.

The total particulate matter and lead particles are grouped into three size ranges; less than 2.5 microns for the proposed inhalable size class, between 2.5 and 15 microns for the respirable range and greater than 15 microns. The distribution of particles into these three size ranges was extrapolated from the cascade impactor runs normalizing all particles to their aerodynamic size. Aerodynamic sizing assumes a density of 1 g/cm^3 for all particles. The actual density of most of the dust samples was closer to 5 g/cm^3. This normalization to 1 g/cm^3 is necessary since it is the aerodynamic size which determines the penetration of particles in the human lung and particle collection efficiency in pollution control equipment.

In general, the size distributions of the lead particulate matter closely followed the total particle size distributions except in the slag tap stream, where the lead particles were more strongly distributed to the smaller size fractions. The blast furnace metal tapping and agglomerator furnace emissions had a preponderance of particles less than 2.5 microns in diameter. The particles emitted by the slag tapping were slightly coarser (average of 66 percent <15 microns) and the charging area emissions were coarser still (average of 29 percent <15 microns). Particle size distributions were not determined on the pigging machine and the refining kettle due to their very low grain loadings.

BAGHOUSE EFFICIENCY

Collection efficiencies of the slag tap baghouse, process baghouse and sanitary baghouse were determined. Total particulate matter and particulate lead measured simultaneously on the inlet and outlet streams of each baghouse were used to determine collection efficiencies. Collection efficiencies as a function of particle size were determined from particle size distribution measurements and lead analyses of cascade impactor runs made on the inlet and outlet streams.

Table 3-5 presents the sampling scheme used for determining baghouse collection efficiencies. The procedures used for sampling are delineated in the Sampling and Analytical Methods section. Situational factors encountered at each sampling point and the results are described below.

Slag Tap Baghouse

The inlet and outlet to the small slag tap baghouse were sampled simultaneously on the fifth and sixth of August, 1980. Both locations were sampled on two perpendicular traverses for total grain loading. The cascade impactor samples were taken isokinetically at a single point in the ducts where the gas velocity was closest to the average overall flue gas velocity.

TABLE 3-4. PROCESS SOURCE SAMPLING - PARTICLE SIZE DISTRIBUTION

Process Source	Sampling Date	Total Particle Size Distribution (weight %)			Lead Particle Size Distribution (weight %)		
		<2.5μ	2.5-15μ	>15μ	<2.5μ	2.5-15μ	>15μ
Blast furnace slag tap	8-05-80	32	33	35	82	11	7
	8-06-80	53	15	32	74	10	16
Blast furnace metal tapping	8-12-80	83	8	9	83	5	11
	8-15-80	-	-	-	-	-	-
Blast furnace charging	8-12-80	17	1	82	25	9	66
	8-15-80	29	11	60	39	6	55
Agglomerator flue	8-13-80	78	19	3	73	25	2
	8-14-80	69	19	12	70	19	11

Calculated from University of Washington Cascade Impactor runs.

TABLE 3-5. BAGHOUSE EFFICIENCY SAMPLING SCHEME

Baghouse	Sampling Location	Sampling Date	Samples Taken	
			EPA Method 12	University of Washington Cascade Impactor
Slag tap				
Inlet	Horizontal duct, 0.38 m diameter	8-05-80	X	X
		8-06-80	X	X
Outlet	Stack, 0.39 m diameter	8-05-80	X	X
		8-06-80	X	X
Process				
Inlet	Refractory lined duct before knock-out 0.57 m diameter	8-07-80	X	
		8-08-80	X	
Outlet	Pre-stack, 0.71 x 0.81 m duct	8-07-80	X	X
		8-08-80	X	X
Sanitary				
Inlet	Duct following knock-out, 1.22 m diameter	8-09-80	X	X
		8-11-80	X	X
Outlet	Pre-stack, 1.22 m diameter	8-09-80	X	X
		8-11-80	X	X

The fan for the slag tap hood was run continuously during sampling. Slag was tapped about once every thirty minutes. Slag was tapped four times during each of the two sampling runs.

The results of the baghouse efficiency emission rates are presented for all three baghouses in Table 3-6. The efficiency of the slag tap baghouse in removing particulate matter averaged about 98 percent for the two sampling periods. Lead particle collection efficiency averaged 99 percent. This resulted in an average lead emission rate from the stack of 9.8 gram/hour.

Particle size distributions in the inlet and outlet streams of the three baghouses are presented in Table 3-7. As expected, the slag tap baghouse was more efficient in collecting larger particles than particles less than 2.5 microns in diameter. The inlet averaged 42 percent of all particles less than 2.5 microns and the outlet averaged 62 percent less than 2.5 microns. The lead particle size distributions at the inlet and outlet were very similar.

Process Gas Baghouse

The process gas was sampled immediately after it left the blast furnace in a refractory-lined duct. The temperature (450°C[850°F]) and composition of the furnace off-gas prevented the use of cascade impactors in this stream. The vaporized metals in the stream would have condensed in the impactor resulting in anomalously high loading values at the front of the impactor.

Duplicate EPA Method 12 runs were made simultaneously at the inlet and outlet locations. The outlet from the process baghouse was sampled in an inclined rectangular duct immediately before the stack. Sampling traverses were made in three horizontal ports at the outlet.

The collection efficiency determined from the process gas sampling represents the combined collection efficiencies of the following devices listed in sequential order:

- knock-out chamber immediately after the inlet sampling location,
- afterburner for combustion of organics,
- second knock-out chamber,
- cooling tubes
- dry lime injection immediately before the process baghouse, and
- process baghouse.

TABLE 3-6. BAGHOUSE EFFICIENCY SAMPLING - EMISSION RATES

Baghouse	Sampling Date	Stream Flow Rates m³/hr*	Volume Sampled m³*	Total Particles mg/m³	Total Particles g/hr	Lead mg/m³	Lead g/hr	Antimony mg/m³	Antimony g/hr	Sulfur mg/m³	Sulfur g/hr	Chlorine mg/m³	Chlorine g/hr
								Pb/Part					
Slag Tap													
Inlet	8-05-50	7,000	1.3	190	1,300	-	240†	52.9					
	8-06-80	6,000	1.2	270	1,800	-	1,100†	61.1					
Outlet	8-05-80	8,700	1.7	3.6	31	1.0	0.6	27.7					
	8-06-80	8,000	1.5	4.9	39	1.4	11	28.2					
Process													
Inlet	8-07-80	4,300	.28	24,000	106,000	18,000	79,000				1,200	68	300
	8-08-80	4,500	.11	130,000	570,000	110,000	430,000				22,000	430	1,700
Outlet	8-07-80	33,000	2.8	25	830	7.4	240	28.9			66	0.21	6.9
	8-08-80	33,000	2.6	8.0	260	4.5	150	57.6			<13	0.038	1.2
Sanitary													
Inlet	8-09-80	62,000	1.4	800	50,000	580	36,000						
	8-11-80	62,000	1.4	3,200	200,000	2,500	150,000						
Outlet	8-09-80	59,000	2.3	24	1,400	-	-						
	8-11-80	56,000	2.3	4.5	250	1.5	84	33.6					

* At 760 mm and 20°C.
† Value based on lead content of EPA Method 12 filter solids extrapolated to total parti be wash and filter.
Calculated from EPA Method 12 runs.

Average
controlled
35.6

1 lb
453 gm

TABLE 3-7. BAGHOUSE EFFICIENCY SAMPLING - PARTICLE SIZE DISTRIBUTIONS

Baghouse	Sampling Date	Total Particle Size Distribution (weight %) <2.5μ	Total Particle Size Distribution (weight %) 2.5-15μ	Total Particle Size Distribution (weight %) >15μ	Lead Particle Size Distribution (weight %) <2.5μ	Lead Particle Size Distribution (weight %) 2.5-15μ	Lead Particle Size Distribution (weight %) >15μ
Slag Tap							
Inlet	8-05-80	32	33	35	82	11	7
	8-06-80	53	15	32	74	10	16
Outlet	8-05-80	60	18	22	78	19	3
	8-06-80	64	36	0	69	28	3
Process							
Inlet	8-07-80	-	-	-	-	-	-
	8-08-80	-	-	-	-	-	-
Outlet	8-07-80	73	20	7	76	20	4
	8-08-80	66	24	10	70	16	4
Sanitary							
Inlet	8-09-80	22	2	76	34	7	59
	8-11-80	34	4	62	36	12	52
Outlet	8-09-80	59	27	14	84	15	1
	8-11-80	71	25	4	52	29	19

Calculated from University of Washington Cascade Impactor runs.

Each of the above devices contributed to the removal of particles from the process gas stream and are included in the final collection efficiency determination.

The results presented in Table 3-6 show an average collection efficiency of 99.8 percent for the two sampling periods. Lead collection efficiency averaged 99.9 percent. Also shown in Table 3-6 are the emission rates from the process baghouse stack for total particles, total lead, chlorine and sulfur.

The particle size distribution in the process baghouse outlet were skewed to the smaller size range. Total particles were 70 percent less than 2.5 microns and lead particles were 73 percent less than 2.5 microns.

Sanitary Baghouse

The inlet to the sanitary baghouse was sampled after the sanitary gas knock-out chamber and after all of the following ventilation systems were mixed:

- blast furnace charging,
- blast furnace metal tapping,
- refining kettles,
- pigging machine, and
- agglomerator flue.

Two perpendicular traverses were sampled on both the inlet and outlet. The baghouse outlet was sampled immediately before the stack and the fan. Some turbulence in the flue gas stream may have arisen from the close proximity of the fan to the sampling location. However, the readings showed a fairly constant velocity profile across the duct. The simultaneous sampling at the inlet and outlet resulted in a collection efficiency for the sanitary baghouse.

Sanitary baghouse collection efficiencies for total particulate matter averaged 99.3 percent for the two sampling runs. The collection efficiency on the eleventh was 99.9 percent and on the ninth 97.2 percent.

AMBIENT PARTICULATE AND LEAD LEVELS

High-volume samples (hi-vols) were operated at several locations during the period 1979 to 1980 and during the main sampling effort in August. Impactor hi-vols and hi-vols with size-selective precutters (<15μ) were used in August.

Table 3-8 summarizes the collected samples and indicates the locations. The cylindrical coordinates of the receiver and the three point emission sources are shown in Table 3-9.

Detailed descriptions of the individual sampling stations are given below. They are also marked in Figure 2-1, showing the surroundings of the smelter.

Reinhart Farm Location (Station 1, Figure 3-8)

The coordinates of Reinhart's farm with respect to the baghouse stack are: bearing 280°, at a distance of 360 meters (1,200 feet). The elevation is 160 meters (520 feet) above sea level. One regular hi-vol was stationed here during the 1979 to 1980 period. A <15u precutter and a cascade impactor were also operated during the August, 1980, sampling period. The samplers were positioned on top of a rock wall, which was 1.2 meters (4 feet) high. Eighteen meters (60 feet) to the north of the wall was a large barn about 7 meters (24 feet) high and a storage silo of the same height. Eighteen meters (60 feet) to the south of the sampling location was a two-story farmhouse, a stucco-like structure about 6 to 9 meters (20 to 30 feet) high. Small outbuildings were located at the eastern end of the house.

The rock wall on which the samplers were located was surrounded by a field of closely cropped grass. To the west of the sampling location was a corn crib and a large cornfield. Thirty meters (100 feet) downwind was a fence, a tree line and a paved road that has a low traffic count. The traffic estimate was a maximum of 100 cars per day, mainly those of plant workers. Beyond the road was the harvested wheat field. A forest island separated most of the smelting activities from this upwind location.

Pond - Garage Hi-Vols (Station 2, Figure 3-9)

This site was located at compass bearing 90° at a distance of 210 meters (700 feet) from the process baghouse stack at an elevation of 190 meters (624 feet).

The samplers were located on top of the east bank of the pond. The bank is about 9 meters (30 feet) high. The elevation of the samplers was estimated to be the same as the level of the agglomerator building, which is approximately 7 meters (24 feet) above the level of the access road. The surrounding ground was composed of coarse gravel and rock. (The rock was a kind of sandstone mixed with crushed granite). There was a sparse covering of grass and weeds.

TABLE 3-8. SUMMARY OF HI-VOL, IMPACTOR AND INHALABLE PARTICULATE SAMPLES COLLECTED

Location	Sampler Type	Date of Operation	Operator
Reinhart's Farm	Hi-Vol Impactor <15μ	August 6, 7, 8, 9, 11, 12, 1980	Radian
	Hi-Vol	Intermittently - 1979 to 1980	Radian
Pond-Garage	Hi-Vol Impactor <15μ	August 6, 7, 8, 9, 11, 12, 1980	Radian
	Hi-Vol	Intermittently - 1979 to 1980	Radian
	Hi-Vol	August, 1980	Deka
Water Tower	Hi-Vol Impactor <15μ	August 6, 7, 8, 9, 11, 12, 1980	Radian
	Hi-Vol	Intermittently - 1979 to 1980	Radian
	Hi-Vol	August, 1980	Deka
Southwest of Dust Storage Area	Hi-Vol	Intermittently - 1979 to 1980	Radian
Smelter Slag Pile	Hi-Vol	Intermittently - 1979 to 1980	Radian
Guest House (Near Farm House)	Hi-Vol	Intermittently - 1979 to 1980	Radian
Smelter	Hi-Vol	August 11, 12, 13, 14, 1980	Radian
	Impactor	August 13, 14, 1980	Radian
	<15μ	August 11, 12, 1980	Radian
Dust Pile (Baghouse)	Hi-Vol	August 11, 12, 13, 14, 1980	Radian
	Impactor	August 11, 12, 1980	Radian
	<15μ	August 13, 14, 1980	Radian
Smelter-Dust Pile	Hi-Vol	August, 1980	Deka
Automotive Battery Plant	Hi-Vol	August, 1980	Deka

TABLE 1-9. CYLINDRICAL COORDINATES OF POINT EMISSION SOURCES AND HI-VOL RECEIVERS

	Bearing (d°)	Distance (meters)	Elevation (meters)	Stack Diameter	Exit Velocity m/s	Exit Volume Nm³/h*	Exit Temperature (°C)
Point Emission Source							
Process Baghouse Stack	0	0	200	1.22 m circular, Vertical exhaust	8	33,000	75
Slag Tapping Baghouse Stack	49	43	190	0.46 m circular, 30° down, SW direction	14	8,300	48
Sanitary Baghouse Stack	117	15	190	Rectangular 1.22 x 1.22 m 30° down SW direction	11	58,000	50
Receivers							
Reinhart Farm Hi-Vols	280	370	160				
Pond-Garage Hi-Vols	90	210	190				
Water Tower Hi-Vols	99	370	200				
Guest House (Near Farm House) Hi-Vol	0	790	150				
Automotive Battery Plant Hi-Vol	353	165	180				
Smelter Slag Pile Hi-Vol	23	41	180				

* 20°C, 760 mm, dry.

TABLE 3-7. BAGHOUSE EFFICIENCY SAMPLING - PARTICLE SIZE DISTRIBUTIONS

		Total Particle Size Distribution (weight %)			Lead Particle Size Distribution (weight %)		
Baghouse	Sampling Date	<2.5μ	2.5-15μ	>15μ	<2.5μ	2.5-15μ	>15μ
Slag Tap							
Inlet	8-05-80	32	33	35	82	11	7
	8-06-80	53	15	32	74	10	16
Outlet	8-05-80	60	18	22	78	19	3
	8-06-80	64	36	0	69	28	3
Process							
Inlet	8-07-80	-	-	-	-	-	-
	8-08-80	-	-	-	-	-	-
Outlet	8-07-80	73	20	7	76	20	4
	8-08-80	66	24	10	70	26	4
Sanitary							
Inlet	8-09-80	22	2	76	34	7	59
	8-11-80	34	4	62	36	12	52
Outlet	8-09-80	59	27	14	84	15	1
	8-11-80	71	25	4	52	29	19

Calculated from University of Washington Cascade Impactor runs.

Each of the above devices contributed to the removal of particles from the process gas stream and are included in the final collection efficiency determination.

The results presented in Table 3-6 show an average collection efficiency of 99.8 percent for the two sampling periods. Lead collection efficiency averaged 99.9 percent. Also shown in Table 3-6 are the emission rates from the process baghouse stack for total particles, total lead, chlorine and sulfur.

The particle size distribution in the process baghouse outlet were skewed to the smaller size range. Total particles were 70 percent less than 2.5 microns and lead particles were 73 percent less than 2.5 microns.

Sanitary Baghouse

The inlet to the sanitary baghouse was sampled after the sanitary gas knock-out chamber and after all of the following ventilation systems were mixed:

- blast furnace charging,
- blast furnace metal tapping,
- refining kettles,
- pigging machine, and
- agglomerator flue.

Two perpendicular traverses were sampled on both the inlet and outlet. The baghouse outlet was sampled immediately before the stack and the fan. Some turbulence in the flue gas stream may have arisen from the close proximity of the fan to the sampling location. However, the readings showed a fairly constant velocity profile across the duct. The simultaneous sampling at the inlet and outlet resulted in a collection efficiency for the sanitary baghouse.

Sanitary baghouse collection efficiencies for total particulate matter averaged 99.3 percent for the two sampling runs. The collection efficiency on the eleventh was 99.9 percent and on the ninth 97.2 percent.

AMBIENT PARTICULATE AND LEAD LEVELS

High-volume samples (hi-vols) were operated at several locations during the period 1979 to 1980 and during the main sampling effort in August. Impactor hi-vols and hi-vols with size-selective precutters (<15μ) were used in August.

Table 3-8 summarizes the collected samples and indicates the locations. The cylindrical coordinates of the receiver and the three point emission sources are shown in Table 3-9.

Detailed descriptions of the individual sampling stations are given below. They are also marked in Figure 2-1, showing the surroundings of the smelter.

Reinhart Farm Location (Station 1, Figure 3-8)

The coordinates of Reinhart's farm with respect to the baghouse stack are: bearing 280°, at a distance of 360 meters (1,200 feet). The elevation is 160 meters (520 feet) above sea level. One regular hi-vol was stationed here during the 1979 to 1980 period. A <15μ precutter and a cascade impactor were also operated during the August, 1980, sampling period. The samplers were positioned on top of a rock wall, which was 1.2 meters (4 feet) high. Eighteen meters (60 feet) to the north of the wall was a large barn about 7 meters (24 feet) high and a storage silo of the same height. Eighteen meters (60 feet) to the south of the sampling location was a two-story farmhouse, a stucco-like structure about 6 to 9 meters (20 to 30 feet) high. Small outbuildings were located at the eastern end of the house.

The rock wall on which the samplers were located was surrounded by a field of closely cropped grass. To the west of the sampling location was a corn crib and a large cornfield. Thirty meters (100 feet) downwind was a fence, a tree line and a paved road that has a low traffic count. The traffic estimate was a maximum of 100 cars per day, mainly those of plant workers. Beyond the road was the harvested wheat field. A forest island separated most of the smelting activities from this upwind location.

Pond - Garage Hi-Vols (Station 2, Figure 3-9)

This site was located at compass bearing 90° at a distance of 210 meters (700 feet) from the process baghouse stack at an elevation of 190 meters (624 feet).

The samplers were located on top of the east bank of the pond. The bank is about 9 meters (30 feet) high. The elevation of the samplers was estimated to be the same as the level of the agglomerator building, which is approximately 7 meters (24 feet) above the level of the access road. The surrounding ground was composed of coarse gravel and rock. (The rock was a kind of sandstone mixed with crushed granite). There was a sparse covering of grass and weeds.

TABLE 3-8. SUMMARY OF HI-VOL, IMPACTOR AND INHALABLE PARTICULATE SAMPLES COLLECTED

Location	Sampler Type	Date of Operation	Operator
Reinhart's Farm	Hi-Vol Impactor <15μ	August 6, 7, 8, 9, 11, 12, 1980	Radian
	Hi-Vol	Intermittently - 1979 to 1980	Radian
Pond-Garage	Hi-Vol Impactor <15μ	August 6, 7, 8, 9, 11, 12, 1980	Radian
	Hi-Vol	Intermittently - 1979 to 1980	Radian
	Hi-Vol	August, 1980	Deka
Water Tower	Hi-Vol Impactor <15μ	August 6, 7, 8, 9, 11, 12, 1980	Radian
	Hi-Vol	Intermittently - 1979 to 1980	Radian
	Hi-Vol	August, 1980	Deka
Southwest of Dust Storage Area	Hi-Vol	Intermittently - 1979 to 1980	Radian
Smelter Slag Pile	Hi-Vol	Intermittently - 1979 to 1980	Radian
Guest House (Near Farm House)	Hi-Vol	Intermittently - 1979 to 1980	Radian
Smelter	Hi-Vol	August 11, 12, 13, 14, 1980	Radian
	Impactor	August 13, 14, 1980	Radian
	<15μ	August 11, 12, 1980	Radian
Dust Pile (Baghouse)	Hi-Vol	August 11, 12, 13, 14, 1980	Radian
	Impactor	August 11, 12, 1980	Radian
	<15μ	August 13, 14, 1980	Radian
Smelter-Dust Pile	Hi-Vol	August, 1980	Deka
Automotive Battery Plant	Hi-Vol	August, 1980	Deka

TABLE 3-9. CYLINDRICAL COORDINATES OF POINT EMISSION SOURCES AND HI-VOL RECEIVERS

	Bearing (d°)	Distance (meters)	Elevation (meters)	Stack Diameter	Exit Velocity m/s	Exit Volume Nm^3/h^a	Exit Temperature (°C)
Point Emission Source							
Process Baghouse Stack	0	0	200	1.22 m circular, Vertical exhaust	8	33,000	75
Slag Tapping Baghouse Stack	49	43	190	0.46 m circular, 30° down, SW direction	14	8,300	48
Sanitary Baghouse Stack	117	15	190	Rectangular 1.22 x 1.22 m 30° down SW direction	11	58,000	50
Receivers							
Reinhart Farm Hi-Vols	280	370	160				
Pond-Garage Hi-Vols	90	210	190				
Water Tower Hi-Vols	99	370	200				
Guest House (Near Farm House) Hi-Vol	0	790	150				
Automotive Battery Plant Hi-Vol	353	165	180				
Smelter Slag Pile Hi-Vol	23	41	180				

[a] 20°C, 760 mm, dry.

FIGURE 3-8. HI-VOL STATION - REINHART FARM - UPWIND STATION

FIGURE 3-9. HI-VOL STATION - POND GARAGE

About 3 meters (10 feet) behind the first (most southern) sampler, which was a normal hi-vol sampler, there was a 2 meter (6 feet) tall stack of rubber battery cases. The second sampler was located about 9 meters (30 feet) north of the first; it was a standard hi-vol with a <15μ precutter. A third sampler, a standard hi-vol fitted with a cascade impactor, was located another 6 meters (20 feet) farther north, still on the bank of the pond. A battery storage area started about 1.5 meters (5 feet) behind this hi-vol. Scrap batteries were stored 1 meter (3 feet) deep in irregular stacks. Many of the cases were cracked or open, exposing the lead and lead oxide grids.

This location for the three hi-vols was by no means ideal. However, it was the only one possible for the first downwind location. If the prevailing wind direction was from the east, the samplers could have been affected by air-entrained dust from the storage area. If winds were from the west, a wake effect might have been created by the bank of the pond. This location was also necessitated by the source of electric power available at the garage.

Water Tower (Station 3, Figure 3-10)

The furthest downwind sampling location was near the Deka water tower. The coordinates were bearing 99°, distance 370 meters (1,200 feet), at an elevation of 200 meters (~650 feet).

Four hi-vol samplers were placed on the ground at this location. The ground elevation was at about the same level as the tip of the process baghouse stack. The four hi-vols included a total particulate hi-vol, an impactor hi-vol, a hi-vol with a size selective inlet for collecting particulates smaller than 15μ and a total particulate hi-vol operated by East Penn Manufacturing. There was no obstruction between the hi-vol samplers and the battery breaking and smelting building. However, trees on the east bank of the pond obstructed the view between the agglomerator furnace building and this location.

Between the smelter building and this location lies the pond and the garage. Both are at a lower level. The distance is approximately 300 meters (1,000 feet) to the battery breaking area.

The samplers were located in a field of wildflowers, grass and weeds. The area appeared to have about 50 percent vegetation cover. There were many areas in which a sandy soil was exposed.

Electricity was available from the water tower. Sites farther to the east were less advantageous.

FIGURE 3-10. HI-VOL STATION - WATER TOWER

Guest House Hi-Vol (Near Farmhouse Hi-Vol)

This standard hi-vol was in use during 1979 and 1980; it was removed at the beginning of the August, 1980, sampling effort. Its location was bearing 0°, distance 790 meters (2,600 feet), and elevation 150 meters (480 feet). It was situated on the edge of the paved parking lot of the guest house, which was about 30 meters (100 feet) from the access road to the plant. This area was north of the plant. Between this sampling location and the plant were a large corn field, some outbuildings and a stand of trees. All of the area was densely vegetated.

The paved road that runs south toward the plant next to this sampling site is heavily traveled. Nearly all the plant employees enter the plant on this side. Deka has 960 employees; that means about 1,920 vehicles (not counting service vehicles and trucks) pass this point each day. Farther to the north runs a medium-duty road, which connects Lyons and Fleetwood, the next village to the west. A small cornfield separates the hi-vol location and the medium-duty road. All of the area surrounding the sampling location was covered with vegetation and it appears that the only active source of particulates was the roadway.

Fence Line - Automotive Battery Plant

Deka operated a hi-vol at the fence line separating the automotive battery building and Reinhart's wheat field located to the north of the process baghouse stack. The coordinates of this hi-vol were: bearing 353°, distance 165 meters (540 feet), and elevation 180 meters (580 feet).

This sampler was located in a grassy area about 6 meters (20 feet) from the fence at the bottom of a steep bank next to the automotive battery building. Directly downwind from the sampler was the large automotive battery building; on top of this building there were two banks of baghouses and the baghouse exhaust area. There were possible building wake effects. About 0.6 meters (2 feet) behind the sampler was a small, deep drainage ditch. The bank of the ditch rose steeply to a fence; behind the fence was a gravel path about 0.9 meters (3 feet) wide. Slightly to the south of the sampler was a large area of the field not covered by grass or wheat. This area could have generated wind-blown dust.

Smelter Slag Pile

This sampler was located bewteen the smelter and the baghouse building north of the gas cooling section. Its cylindrical coordinates were bearing 23°, distance 46 meters (150 feet), and elevation 180 meters (600 feet).

It was operated during 1979 to 1980, but was dismantled before the August sampling campaign for use at other locations. This regular hi-vol was located too close to the smelter to be of use for modeling purposes. However, it indicated the lead-in-air level at the fence line of the smelter and Reinhart's wheat field. Formerly, slags were temporarily dumped in this area.

Smelter Access Road (Figure 3-11)

The final hi-vol sampling locations were on the access road to the dust storage area. The road is paved and is approximately 11 meters (36 feet) wide. It was covered with a fine coating of lead dust which was tracked or disturbed by the wheels of the forklift and other light-duty vehicles and large trucks that went down the road. Five samplers were located about 9 meters (30 feet) apart along the edge of the road.

The first sampler was a standard unit located near the dust storage area. The next one had a size selective inlet. The third hi-vol was a standard unit operated by East Penn; it was located opposite the agglomeration furnace. To the south of East Penn's hi-vol was an unpaved storage area for used industrial batteries, which are broken and have exposed parts. This storage area was covered with a heavy coating of baghouse dust. The pond was about 6 meters (20 feet) away.

The fourth hi-vol, which had a cascade impactor, was located directly across from the central vacuum system. The agglomerator building was closed at this point. Directly above, on top of the agglomerator building, were the baghouses. The pond was about 3 meters (10 feet) to the south. The space between the pond and the paved road was covered with large, heavy granite gravel and some slag.

The fifth sampler was a standard hi-vol located directly opposite the end of the agglomerator building. In back of the hi-vol was about 0.5 meters (2 feet) of unpaved area covered with lead dust and large rocks. The bank to the pond then sloped down fairly steeply; it was covered with empty battery casings.

The estimated traffic on the paved road was as follows:

●	Forklifts carrying slag molds	40 per day
●	Forklifts carrying flue dust	30 per day
●	Trucks removing slag	2 per day
●	Trucks removing dust	14 per month
●	Sweeper	36 per day
●	Other vehicles	5 per day

FIGURE 3-11. HI-VOL STATION - SMELTER ACCESS ROAD

AMBIENT PARTICULATE AND LEAD LEVEL RESULTS

Upwind-downwind sampling was conducted intermittently throughout 1979 to 1980 and also during the two week sampling period in August of 1980. The results of selected hi-vol runs are presented in Table 3-10. These runs were chosen because of the favorable wind conditions on these days.

In each case the farm location (Station 1) is upwind of the smelter. The hi-vol located at the guest house was normal to the wind vector through the smelter on the days shown and, therefore, can also be considered as a background monitor. The pond hi-vol is immediately downwind of the smelter and the water tower location is further downwind. The location marked battery plant is north of the smelter, normal to the smelter wind vector.

The results show high suspended lead particulate levels immediately downwind of the smelter at the pond. The total suspended particulate levels vary slightly from the upwind to the downwind positions; but the lead levels increase ten-fold going through the smelter. Further downwind at the water tower, the suspended lead particle levels drop off slightly; however, they are still higher than the upwind levels.

The size distribution of the suspended particles up and downwind of the plant are presented in Table 3-11. The total suspended particulate matter and suspended lead particles are grouped into three size ranges: less than 2.5 microns, between 2.5 and 15 microns and greater than 15 microns. The distribution of particles into these size ranges were extrapolated from the cascade impactor hi-vol runs and the size selective inlet (less than 15 microns) hi-vol runs. All particles were normalized to their aerodynamic size.

In general, the majority of suspended particles (approximately 70 percent) were in the inhalable or less than 2.5 micron size range. For suspended lead an even greater percentage (approximately 80 percent) of particles had an aerodynamic size less than 2.5 microns.

Area air quality measurements were made during August of 1980 at the access road and dust storage area on the east side of the smelter and baghouse buildings. The results of these measurements are presented in Table 3-12. Hi-vols were placed near the dust storage area immediately south of the baghouse building. The access road terminates at this point. Hi-vols were also placed along the east side of the access road. This location was directly east of the baghouse and smelter buildings. Data from these hi-vols are reported in Table 3-12 on two days when the wind was from the west, thus blowing dust and suspended particles across the road towards the hi-vols. The suspended lead in this area (approximately 30 $\mu g/m^3$) is several times greater than the suspended lead at the pond location, approximately 180 meters (600 feet) downwind.

TABLE 3-10. AMBIENT LEAD AND TOTAL PARTICULATE LEVELS AT UP AND DOWNWIND HI-VOL LOCATIONS AS FUNCTION OF SMELTER CONTROL IMPROVEMENT

Date	Location	Suspended Particulate (μg/SM^3)[1]	Pb Particulate (μg/SM^3)	mgPb/g Particulate	Wind Direction	Wind Speed (km/hr)	
10-24/10-25-79	Pond	64	19	290	260° (WSW-W)	16	Pre-control
	Water Tower	42	6.8	160			
	Farm	32	0.11	4			
	Slag Pile	26	0.36	14			
12-29/12-30-79	Pond	57	2.6	46	260° (WSW-W)	21	
	Water Tower	50	2.0	40			
	Farm	41	0.15	4			
	Slag Pile	41	1.4	34			
	Near Farm House	41	0.19	5			
04-05/04-06-80	Pond	23	0.37	16	260° (WSW-W)	30	
	Water Tower	23	0.13	6			
	Farm	27	0.10	4			
	Slag Pile	33	5.1	150			
	Near Farm House	23	0.10	4			
08-07/08-08-80	Pond	83	2.1	25	245° (WSW)	6	Post-control
	Water Tower	79	0.68	9			
	Farm	96	0.31	3			
08-08/08-09-80	Pond	89	7.0	79	225° (SW)	13	
	Water Tower	72	1.4	19			
	Farm	110	0.44	4			
08-09/08-10-80	Pond	71	11	160	315° (NW)	8	
	Water Tower	59	3.5	60			
	Farm	52	0.61	12			

[1] STP = 25°C, 760 mm Hg

TABLE 3-11. SIZE DISTRIBUTION OF SUSPENDED PARTICLES UP AND DOWNWIND OF SMELTER[1,2]

		Total Particle Size Distribution (weight %)			Lead Particle Size Distribution (weight %)		
Date	Location	<2.5μ	2.5-15μ	>15μ	<2.5μ	2.5-15μ	>15μ
08-07/08-08-80	Pond	75	25	0	84	14	2
	Water Tower	73	22	5	85	15	0
	Farm	73	20	7	90	3	7
08-08/08-09-80	Pond	74	24	2	72	28	0
	Water Tower	76	24	0	82	17	1
	Farm	76	15	9	98	2	0
08-09/08-10-80	Pond	57	31	12	81	19	0
	Water Tower	60	28	12	81	19	0
	Farm	74	22	4	93	7	0

[1] Particle size distributions for these size ranges were extrapolated from cascade impactor hi-vol runs and the <15μ size selective inlet hi-vol runs.

[2] Intermediate particle size data are reported in Appendix B.

TABLE 3-12. AMBIENT LEAD AND TOTAL PARTICULATE LEVELS AT SMELTER ACCESS ROAD AND DUST STORAGE AREA*

Date	Location	Suspended Particulate (µg/m^3)[1]	Pb Particulate (µg/m^3)[1]	Wind Direction	Wind Speed (km/hr)
8-12/8-13-80	Dust Storage	120	60	245° (WSW)	3
	Access Road	94	29		
8-14/8-15-80	Dust Storage	160	36	225° (SW)	5
	Access Road	140	34		

[1] STP = 25°C, 760 mm Hg

* See Table 3-12 for particle size distribution.

The size distribution of suspended particles along the access road and near the dust storage area are presented in Table 3-13. Once again, the suspended lead particles are skewed toward the smaller aerodynamic size in comparison to the total suspended particulate matter. The lead particles at the access road and dust pile are slightly coarser than the suspended lead particles downwind at the pond and water tower. Approximately 75 percent of the suspended lead near the access road is less than 2.5 microns while the suspended lead downwind averages 80 percent less than 2.5 microns. Given the actual values comprising these averages, this difference appears to be significant.

SOIL AND DUST ANALYSIS

Several grab samples of baghouse dust, agglomerator dust, road surface dust and soils from around the plant were analyzed for lead content. In addition, the agglomerator dust samples were analyzed for antimony, sulfur and chlorine.

The results of the analysis of the baghouse and agglomerator dust samples are presented in Table 3-14. In comparing the lead composition of the baghouse dust with that of the particulate matter collected isokinetically at the inlets and outlets to the baghouses, the following conclusions can be made:

- The lead content of the baghouse dust grab samples is the same as the lead content of the particulate matter collected at the inlets to the baghouses using EPA Method 12.
- The lead content of the particulate matter collected at the baghouse outlets is much lower (approximately one half) than the inlet particulate matter lead content.

Also, the slag tap baghouse dust has a lower lead content than the process or sanitary baghouse dust (57 percent compared to 88 percent).

Table 3-15 presents the road surface dust characterization performed around the smelter area. The locations where the samples were taken are illustrated in Figure 3-12. The results show that the dust loading on the road surface and the total amount of lead per road surface area was highest nearer to the smelter building. The lead content of the dust around the smelter and baghouse buildings ranged from 32 to 53 percent by weight.

Lead content in the soils of a wheat field adjacent to the smelter are presented in Table 3-16. The sampling locations for the soil samples are displayed in Figure 3-13. As expected, the soils nearest the smelter (points 1 and 4) have the highest lead content.

TABLE 3-13. SIZE DISTRIBUTION OF SUSPENDED PARTICLES NEAR SMELTER ACCESS ROAD AND DUST STORAGE AREA[1]

		Total Particle Size Distribution (weight %)			Lead Particle Size Distribution (weight %)		
Date	Location	<2.5µ	2.5-15µ	>15µ	<2.5µ	2.5-15µ	>15µ
08-12/08-13-80	Dust Storage	57	36	7	76	20	4
08-14/08-15-80	Access Road	65	25	10	73	17	10

[1] Particle size distributions for these size ranges were extrapolated from cascade impactor hi-vol runs and the <15µ size selective inlet hi-vol runs.

TABLE 3-14. BAGHOUSE AND AGGLOMERATOR DUST GRAB SAMPLE CHARACTERIZATIONS AT EAST PENN LEAD SMELTER

Sample	Lead %	Antimony mg/g	Sulfate (SO_4) mg/g	Chlorine mg/g
Process Baghouse	88	-	-	-
Slag Tap Baghouse	57	-	-	-
Sanitary Baghouse	88	-	-	-
Agglomerator, Collected 08-08-80	88	8.5	19	<DL
Agglomerator, Collected 08-13-80	53	12	6.0	<DL
Agglomerator, Collected 08-14-80	95	8.4	23	<DL
Agglomerator, Collected 08-16-80	79	9.6	24	6.8

DL = detection limit

TABLE 3-15. ROAD SURFACE DUST CHARACTERIZATION AT EAST PENN LEAD SMELTER

	Sample Location[1]	Total Particulate (grams)	gPb/g Particulate	Total Pb (grams)
1	End of Agglomerator Building Nearest to Smelter	1.2	0.53	0.64
2	Near Agglomerator Building Personnel Door	2.4	0.43	1.0
3	Between Smelter and Industrial Battery Building	17	0.50	8.5
4	Between Ore Pit and Smelter Building Door	18	0.32	5.8

---

[1] Samples are the sweepings collected from 2' x 2' areas on 8-16-80.

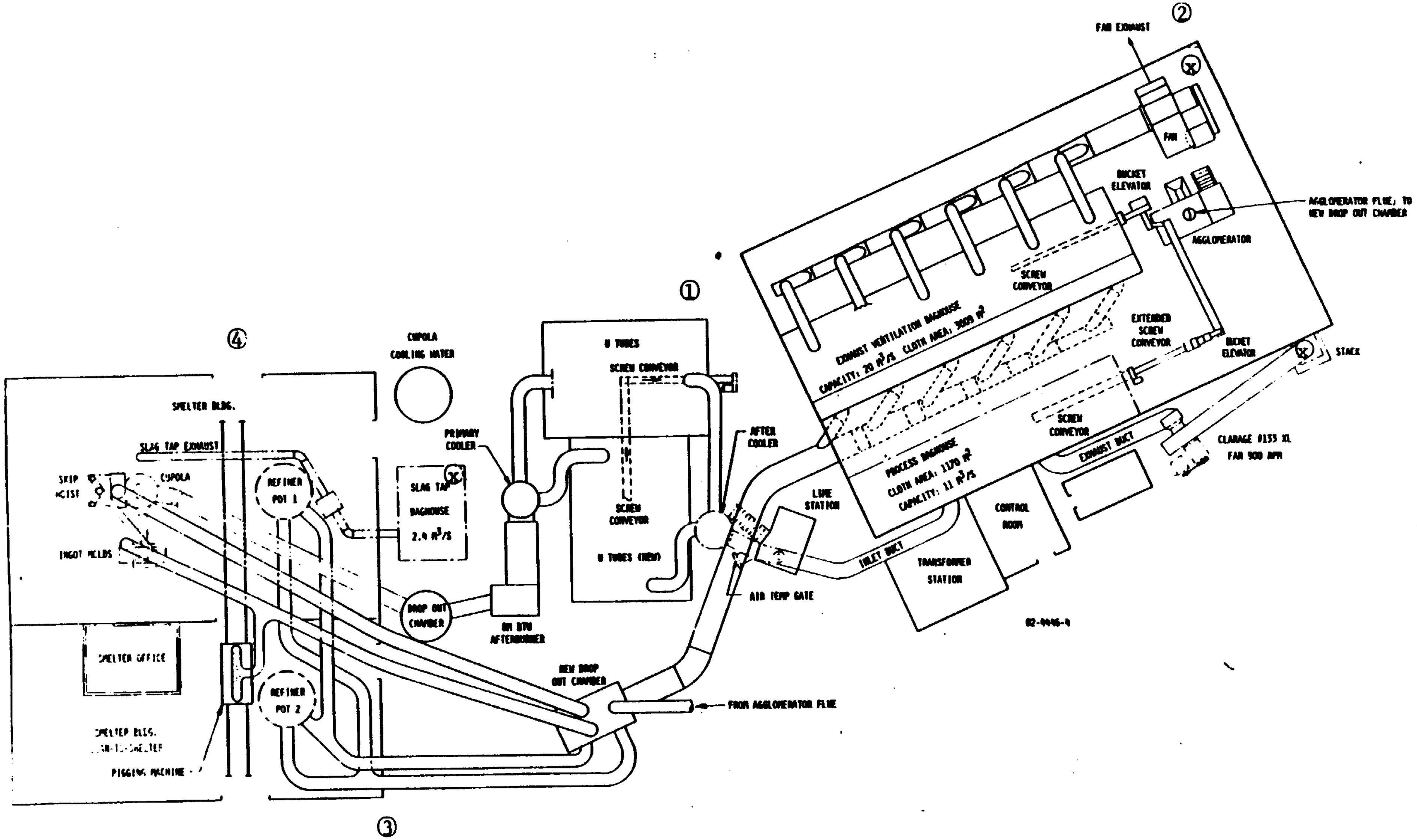


FIGURE 3-12. LOCATION OF ROAD SURFACE DUST SAMPLING POINTS

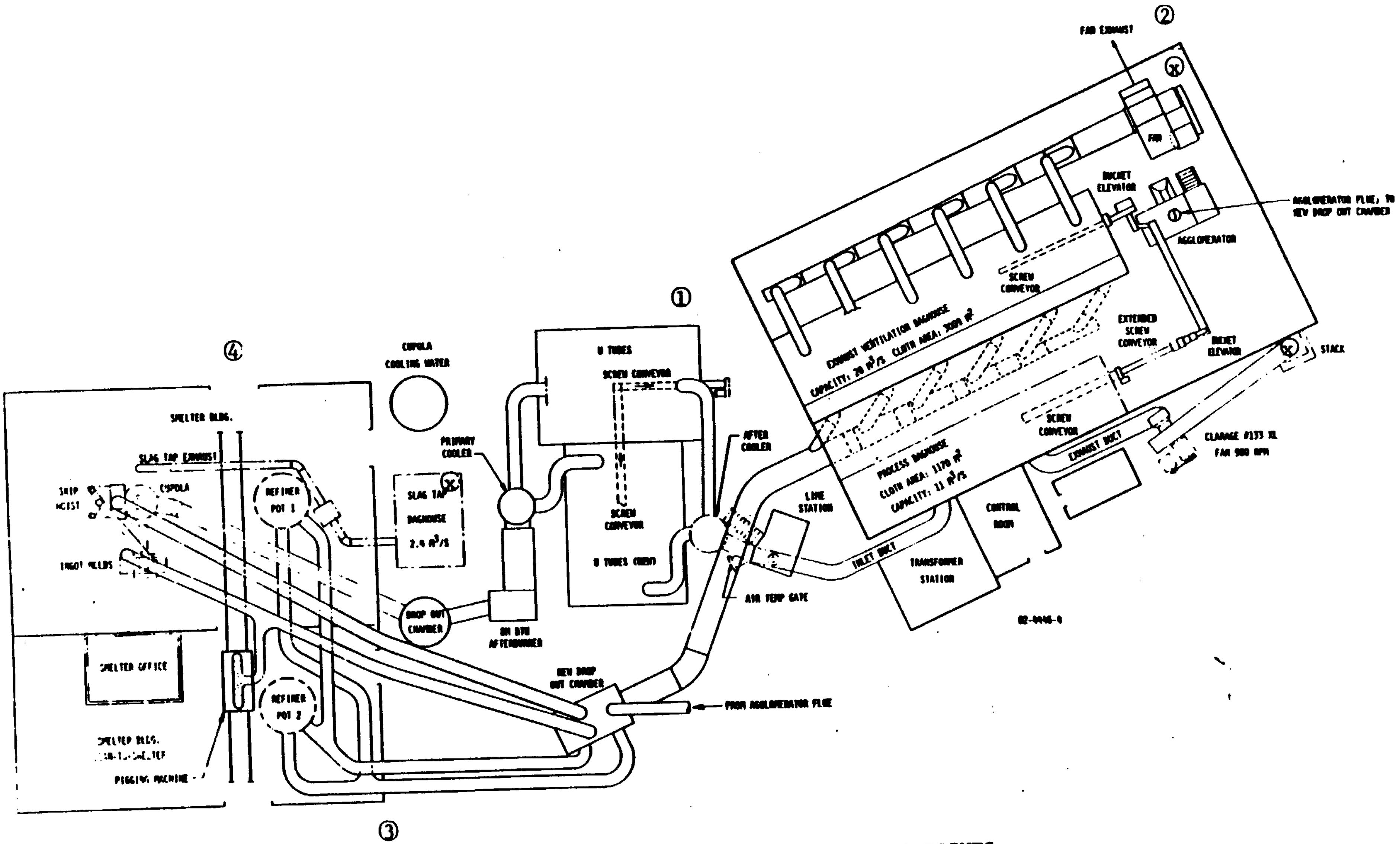


FIGURE 3-12. LOCATION OF ROAD SURFACE DUST SAMPLING POINTS

TABLE 3-16. LEAD CONTENT IN EAST PENN FIELD SOIL SAMPLES

Sample Location Number	Lead (mg/g)
1	3.2
2	1.5
3	1.5
4	3.5
5	0.57
6	0.79

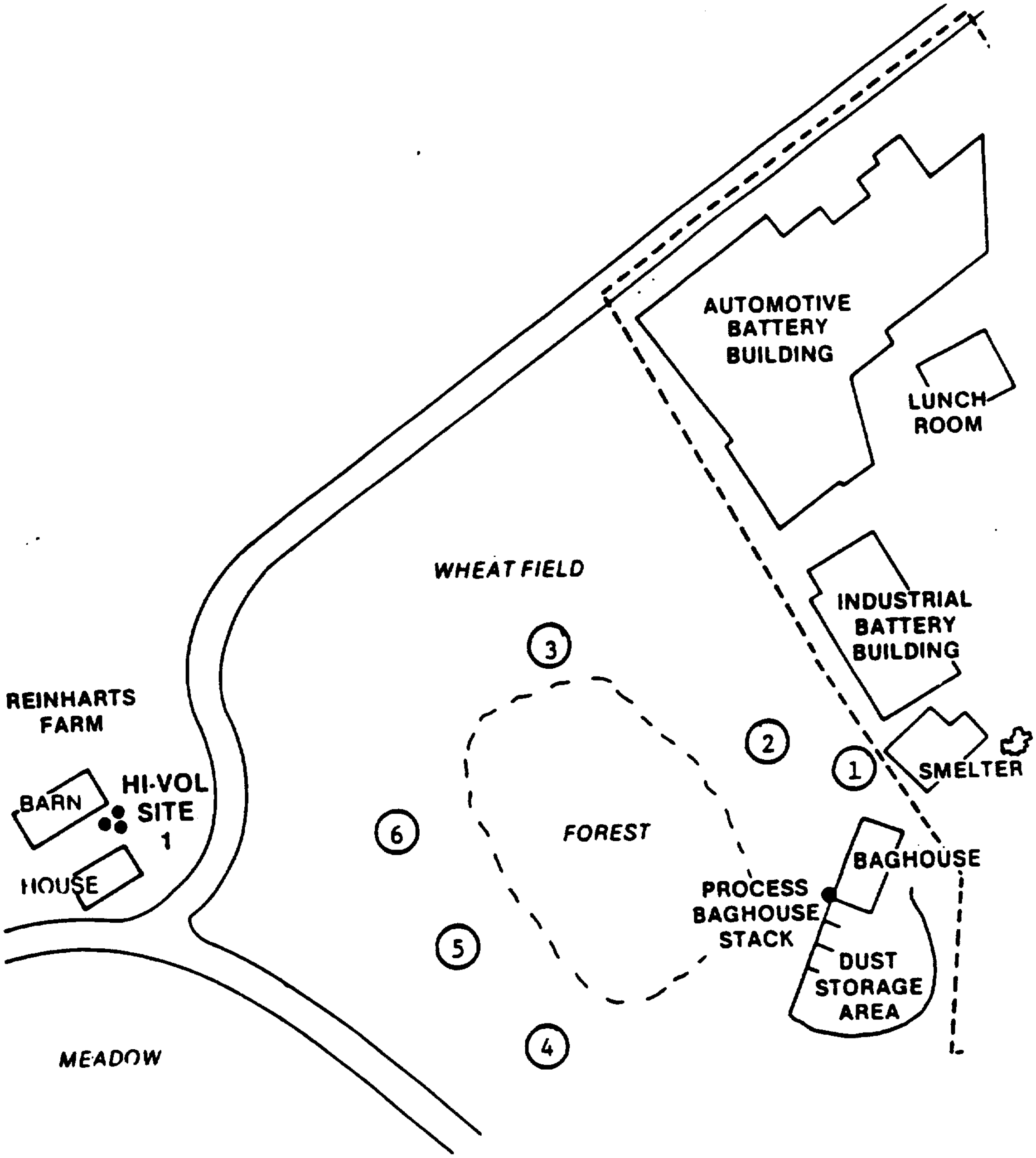


FIGURE 3-13. LOCATION OF EAST PENN FIELD SOIL SAMPLES

SECTION 4

ASSESSMENT OF EMPLOYEE EXPOSURE CONTROL

A basic objective of the initial and follow-up evaluations was to assess the effectiveness of the smelter's employee lead exposure control program. Of specific interest was the characterization of reduced employee exposure associated with improved: engineering controls, use of protective clothing and equipment, housekeeping and personal hygiene. Four general types of information were gathered during each visit to aid the assessment. These types of information included:

- Air sampling for workroom contaminants.
- Observation of work practices, use of protective clothing and equipment, housekeeping and personal hygiene.
- Biological monitoring data.
- Engineering measurements and observations relative to performance and design of engineered exposure controls.

The development of exposure control assessment information is presented in the remainder of this section.

Following the performance of the initial evaluation, a report was prepared to convey important information to the smelter, EPA and NIOSH. This report included an inventory of sources contributing to employee lead exposure and a number of recommendations related to improving exposure control. The lead exposure source inventory and exposure control recommendations are included in Appendix C. It should be understood that the smelter was not obligated to implement these recommendations. Rather, they were offered along with other information for consideration by smelter management in their development of an improved exposure control program. As will be apparent from later discussions, many of the recommendations contained in the initial evaluation report were implemented by the smelter.

WORKPLACE AIR CONTAMINATION AND EMPLOYEE EXPOSURES

Background Information Related to Workroom Air Contaminant Monitoring

The test smelter has monitored workplace lead-in-air contamination for a number of years. To assist this study, monitoring data covering a period from December, 1976, through August, 1980, were submitted for review and evaluation. These data are discussed in a later section. Basically, the monitoring data provided by the smelter indicate that severe lead-in-air exposures have accompanied operation of this smelting complex. Employee exposures have varied over a wide range which cannot be simply correlated with climatological factors.

As part of the initial evaluation of this smelter, a limited amount of breathing zone and work area air sampling was conducted. The purpose of this sampling was to corroborate the sampling performed previously by the smelter and define employee exposures during a known set of smelter operating and ambient weather conditions.

Study resource limitations confined air sampling to two consecutive operating days during the initial evaluation. The selection of an optimum time for sampling was constrained by the fact that the smelter was actively engaged in a major modification program. To obtain air contaminant information before the agglomeration furnace and other controls were operational required sampling at the site during mid-winter.

Breathing zone and work area sampling for lead and antimony were performed on January 23 and 24, 1979. January 23, 1979, was a relatively normal operating day at the smelting complex. The weather was sunny and cold with light winds blowing from several compass directions. Employees at the smelter performed normal tasks and rotated jobs at the halfway point in the work shift. January 24, 1979, was a relatively unusual day at the smelter complex. Heavy rains and strong winds were present throughout the period monitored. The strong gusty winds caused vigorous drafts through the smelting building which disturbed the control characterisitics of local exhaust ventilation hoods and resulted in the introduction of dust into the atmosphere from building surfaces. By the afternoon of January 24, large volumes of runoff water were entering the smelting complex and leaving on the downhill side. The smelting building itself was very wet with pools of water in most of the work areas. Several of the employees did not show up for work on this day due to flooded roads in the countryside.

During the follow-up evaluation, air contaminant measurements were made during three consecutive workdays. Employee exposures to lead were measured on August 5 and 7, 1980. Work area monitoring for lead and other monitoring was performed during August 5, 6 and 7, 1980.

With respect to weather, the monitored days were similar with warm summer temperatures and relatively light winds.

Just prior to the follow-up evaluation, the smelter had completed a major maintenance shutdown and clean-up. Many of the operations had very recently been restarted or were restarted during the period monitored.

Ideally, it would have been informative to continue workplace monitoring for a longer period to at least partially evaluate the success of housekeeping and other exposure controls during extended operation of the smelter.

Employee Exposures to Lead and Antimony During the Initial and Follow-Up Evaluations

Personal exposure monitoring for lead and antimony was conducted during the initial evaluation. Due to the insignificant exposures to antimony found during the initial evaluation, only limited breathing zone and work area measurements for antimony were made during the follow-up evaluation.

Personal exposure monitoring was conducted in accordance with NIOSH and OSHA procedures. Airborne lead was collected in the breathing zones of workers using 0.8µ pore size cellulose ester membrane filters held in closed face plastic cassettes. Air sampling rates between 1.5 and 2.0 liters per minute were provided by personal sampling pumps. Flow rates were monitored by a precision rotameter calibrated against a bubblemeter at a location near the smelter before and after each days sampling.

Samples were analyzed by atomic absorption spectrophotometry in basic accordance with NIOSH Method No. P & CAM 173. Some of the samples were wet washed with the addition of perchloric acid to the routine nitric acid ashing solution. During the follow-up evaluation, the use of perchloric acid was shown to have no beneficial effect in this sampling and analysis situation.

Table 4-1 presents the results of personal exposure measurements made during the initial evaluation. The exposure data are organized so that exposures associated with specific jobs can be compared. During this evaluation, employees changed job assignments at the midpoint of the workshift. Thus, in many cases two sets of employee initials are associated with each job. This approach to exposure evaluation does not reflect the actual eight-hour time-weighted average exposure of employees, but does approximate the exposure ("shift concentration") which would have been received by a single worker performing the indicated job. This approach also permits comparison of exposures by job to the sampling data collected during the follow-up evaluation when employees did not rotate jobs during the shift.

As can be seen from Table 4-1, employee exposures to antimony were insignificant when compared to the present permissible exposure limit of 0.5 mg/m^3 (500 $\mu g/m^3$) prescribed in 29 CFR 1910.1000. This same exposure limit is also recommended in the NIOSH criteria document for antimony.

TABLE 4-1. RESULTS OF BREATHING ZONE SAMPLING FOR LEAD AND ANTIMONY DURING THE INITIAL EVALUATION (JANUARY, 1979)

	1-23-79					1-24-79				
Job Description	Employee	Sample Interval	Interval Conc. (μg Pb/m³)*	Shift Conc. (μg Pb/m³)**	Interval Conc. (μg Sb/m³)*	Employee	Sample Interval	Interval Conc. (μg Pb/m³)*	Shift Conc. (μg Pb/m³)**	Interval Conc. (μg Sb/m³)*
Furnace Operator	LW	0758-1232	510	460	51	DH	0803-1212	620	760	ND
	NH	1300-1547	380		ND	LW	1234-1559	870		47
Hoist Operator	DH	0803-1205	370	300	ND	LW	0801-1233	870	3,800	ND
	RH	1300-1547	200			JM	1238-1558	7,800		ND
Payloader Operator	NH	0807-1300	780	670	ND	RH	0807-1300	1,200	1,100	ND
	LW	1258-1547	480		ND	NH	1343-1557	830		ND
Cokeman	RH	0828-1233	180	210	ND	NH	0818-1342	660	660	ND
	DH	1205-1547	250		ND					
Potman	WE	0807-1206	210	260	ND					
	WE	1206-1425	370		ND					
Foreman	CS	0825-1207	270	280	ND	CS	0821-1205	660	910	ND
	CS	1207-1547	280		37	DH	1214-1603	1,200		ND
Industrial Battery Breaker	JM	0805-1300	430	390	ND	JM	0815-1237	730	730	ND
	JM	1300-1615	350		ND					
Clean-Up (General)	DS	0817-1235	690		ND					
	DS	1235-1615	250	400	ND					
	RM	0818-1236	370							
	RM	1236-1615	230							
Battery Breaking	KA	0833-1209	2,500		ND	KA	0823-1200	260	232	ND
	WD	0826-1211	3,500	2,200	ND	WD	1203-1520	200		ND
	KA	1210-1515	180		ND					

* Time-weighted average contaminant concentration for the period sampled.

** Time-weighted average lead-in-air concentration for the total time sampled during the shift. No adjustments for periods not sampled.

Samples were analyzed for lead and antimony following NIOSH Method No. P & CAM 173 with addition of perchloric acid to complete the wet ashing of filters. The limits of detection for lead and antimony were 5 and 10 μg/filter respectively.

ND None detected.

Nearly all exposures to lead-in-air were high by comparison to the old permissible exposure limit of 0.2 mg/m^3 (200 µg/m^3) applicable at the time of the initial evaluation. Airborne lead levels were generally higher on January 24, 1979, than on January 23, 1979. This result is possibly due to the strong air currents which entrained contaminants from the capture zone of the local exhaust ventilation hoods. As stated earlier, the smelting work area was very wet, however, the production of fume from lead tapping, molten metal transfer, block molding, refining and pigging was still present. Several employees (potman and clean-up personnel) did not show up for work on January 24, 1979, due to local flooding.

Several employees were found to have very high exposures (>500 µg Pb/m^3) during portions of work shifts on each day sampled. Battery breakers on the first day sampled showed high exposures to lead and the hoist operator encountered very high lead exposure during the afternoon of the second day sampled. It is possible that relatively large particles of lead entered the filter monitoring cassette during the sampling period in each of these operations. In the case of battery breaking, a splash of lead laden solution may have caused excessive contamination. In the case of the hoist operator, the handling of flue dust as it is charged to the hoist could have caused the deposition of a lead particle onto the filter. However, in each of these cases, the measured exposure may not have been adversely influenced by artifact particulate and may represent the actual lead exposure.

Referring to Table 4-1, the furnace operator, hoist operator, payloader operator, cokeman, potman and foreman all perform their jobs in the main smelter building. Industrial battery breaking is performed in a covered area adjacent to the main smelter building. Automotive (SLI) battery breaking is performed in a separate building. Clean-up personnel work at various locations within the smelter building and in yard areas depending on need.

Table 4-2 presents the results of employee exposure monitoring for lead during the follow-up evaluation. The numbers in parentheses are values determined by East Penn Manufacturing in parallel (opposite shoulder) sampling. The two sets of exposure measurements agree very well and indicate that the exposures of many workers were below 200 µg/m^3 on an eight-hour time-weighted average basis.

During August 5, 1980, the two battery breaking employees manually dismantled industrial batteries. Both of these workers decased auto batteries in the new battery breaking facility on August 7, 1980.

The foreman spent a significant portion of each day monitored assisting the agglomeration furnace operator in the baghouse and agglomerator building. The agglomeration furnace operator and clean-up man assigned to the agglomerator area were exposed to visible emissions of flue dust from the furnace feeding mechanisms. Additional exposures resulted from tote box handling and dumping.

TABLE 4-2. RESULTS OF BREATHING ZONE SAMPLING FOR LEAD DURING THE FOLLOW-UP EVALUATION (AUGUST, 1979)

	8-5-80					8-7-80				
Job Description	Employee	Sample Interval	Interval Conc. (µg Pb/m^3)*	8-hour TWA Conc. (µg Pb/m^3)**	Note	Employee	Sample Interval	Interval Conc. (µg Pb/m^3)*	8-hour TWA Conc. (µg Pb/m^3)**	Note
Furnace Operator	CF	0807-1229	93(89)			DF	0800-1256	220(269)		
	CF	1229-1553	130(85)	110(87)		DF	1256-1551	(255)	--(260)	(2)
Hoist Operator	DD	0804-1231	73(74)			RH	0802-1255	190(204)		
	DD	1231-1549	53(95)	64(83)		RH	1255-1550	220(223)	200(211)	
Payloader Operator	DF	0800-1227	110(102)			CF	0801-1252	190(177)		
	DF	1227-1548	150(173)	120(135)		CF	1252-1549	180(218)	180(195)	
Cokeman	RH	0805-1240	150(131)							
	RH	1240-1544	35(31)	100(90)						
Potman	WE	0742-1244	66(108)			WE	0807-1228	82(132)		
	WE	1244-1544	99(44)	78(82)		WE	1228-1547	83(81)	80(110)	
Lead Pot Helper						DD	0803-1229	160(141)		
						DD	1229-1550	270(409)	210(330)	(3)
Foreman	CS	0750-1257	170(220)			CS	0814-1241	120(126)		
	CS	1257-1551	57(62)	130(153)		CS	1241-1553	286(381)	180	
Battery Breaker (Industrial/Auto)	KA	0822-1225	82(146)		(1), (5)	KA	0740-1231	55(14)		(4)
	KA	1225-1452	68(82)	77(121)		KA	1232-1503	700(46)	--(27)	
	WD	0822-1226	150(181)		(1), (5)	WD	0741-1237	18(10)		
	WD	1226-1448	56(117)	120(156)		WD	1237-1503	38(14)	25(12)	(1)
Clean-Up	DS	0803-1223	63(49)			DS	0805-1310	300(397)		
	DS	1223-1544	42(43)	53(46)		DS	1310-1548	180(253)	250(237)	
	JS	0806-1247	80(79)							
	JS	1247-1549	190(246)	120(152)						
Agglomerator Operator	DW	0803-1235	300(356)			DW	0810-1258	670(919)		
	DW	1235-1549	150(---)	240(---)		DW	1258-1550	410(586)	540(775)	
Clean-Up (Agglomerator)	KB	0801-1246	140(115)			KB	0806-1306	130(142)		
	KB	1246-1545	180(108)	150(112)		KB	1306-1552	160(267)	140(195)	

* Time-weighted average lead-in-air concentration for the period sampled.

** Time-weighted average lead-in-air concentration for an 8-hour work shift. The period not sampled is counted at an exposure level of 16 µg/m^3 or 0.07 µg Pb/min which corresponds to the lockerroom concentration.

(1) Eight-hour time-weighted average concentration estimated as average concentration for total time sampled.

(2) Sample for interval 1256-1551 invalid.

(3) Worked in battery breaker for part of shift.

(4) Afternoon sample contaminated by splash of lead laden solution. No 8-hr. TWA calculated.

(5) Employee performed manual breaking of industrial batteries on this day.

Samples were analyzed for lead following NIOSH Method No. P & CAM 173.

Table 4-3 presents a comparison of lead exposures for specific jobs between the initial and follow-up evaluations. The exposure values presented are time-weighted average concentrations for all job time sampled during the initial and follow-up evaluation. As can be seen from the table, lead-in-air concentrations were much lower at the time of the follow-up evaluation. The agglomerator operator was the only job involving exposure above 200 $\mu g/m^3$ during the follow-up evaluation.

Table 4-4 presents the results of employee exposure monitoring for antimony during the follow-up evaluation. Only three persons were monitored since previous measurements had indicated very low exposure levels to antimony. Only the cokeman was found to have a measurable, but very low level, exposure to antimony.

Historical Employee Lead Exposure Data Provided by East Penn Manufacturing

The employee exposure monitoring data developed by this study during two visits to East Penn Manufacturing profiled employee exposures by job at two points in time. In order to validate these data as truly representative, it is of interest to see if they are consistent with long-term employee exposure monitoring conducted at the smelter.

East Penn provided this study with copies of employee exposure monitoring data that were collected from December, 1976, to August, 1980. It was hoped that these data could be analyzed so as to establish exposure trends through time for each job category. However, because job categories did not remain constant through time, this type of analysis was not possible. Worker rotation was used extensively in 1977 and 1978 to reduce individual exposures. The introduction of the agglomerator furnace and baghouse building created a new job and substantially altered the exposure profile for the foreman and clean-up personnel. Since job descriptions had changed through time, a job-by-job trend analysis could not be made.

Table 4-5 contains a summary of the employee exposure monitoring data developed by East Penn Manufacturing. For the most part, monitoring was conducted monthly and included four or five samples. Although not job-specific, Table 4-5 provides a general idea of exposure levels and exposure level variations for workers in the smelter. The data show a wide range of variability.

The first set of employee monitoring data developed by this study was collected in January, 1979. Results are consistent with data collected by East Penn at about the same time (refer to Tables 4-1 and 4-5). The second set of data was collected in August, 1980. Parallel (opposite shoulder) sampling was done by East Penn and is reported as sampling data for August (also shown in Table 4-2). These data appear consistent with independent

TABLE 4-3. COMPARISON OF TIME-WEIGHTED AVERAGE LEAD-IN-AIR EXPOSURES FOR THE INITIAL AND FOLLOW-UP EVALUATIONS

	Time-Weighted Average Lead-in-Air Concentration ($\mu g\ Pb/m^3$)*	
Job Description	Initial Evaluation 1-23 and 24-79	Follow-Up Evaluation 8-5 and 7-80
Furnace Operator	620	150
Hoist Operator	2,200	130
Payloader Operator	860	160
Cokeman	400	110
Potman	260	80
Foreman	600	160**
Industrial Battery Breaker	500	96
Clean-Up (General)	400	72
Battery Breaking	1,500	37
Agglomerator Operator	-	410
Clean-Up (Agglomerator)	-	150

* Time-weighted average lead-in-air concentrations for all job time sampled during two days of monitoring.

** Foreman assisted agglomerator operator.

TABLE 4-4. RESULTS OF BREATHING ZONE SAMPLING FOR ANTIMONY DURING THE FOLLOW-UP EVALUATION [1]

Job Description	Employee	Date	Sampling Interval	Interval Conc. (µg Sb/m³)*	8 hr. TWA Conc. (µg Sb/m³)**
Potman	WE	8-05-80	0742-1244	ND	ND
		8-05-80	1244-1544	ND	
Foreman	CS	8-05-80	0750-1257	ND	ND
		8-05-80	1257-1551	ND	
Cokeman	RH	8-05-80	0805-1240	20	11
		8-05-80	1240-1544	ND	

[1] Samples were analyzed for antimony following a combination of NIOSH Method Nos. P & CAM 173 and 261. The limit of detection was 10 µg Sb/filter.

* Time-weighted average for the period monitored.

** Eight-hour time-weighted average antimony-in-air concentration assuming no exposure during the period not sampled.

ND - None detected.

TABLE 4-5. EMPLOYEE LEAD-IN-AIR MONITORING DATA DECEMBER, 1976, TO AUGUST, 1980

	Month	Number of Samples	Mean*	—Exposure Range—	
				Minimum (µg/m^3)	Maximum (µg/m^3)
1976	December	4	670	580	760
1977	January	3	710	500	870
	February	6	970	330	2,040
	April	4	770	410	1,120
	May	3	490	460	520
	June	3	570	450	630
	July	5	390	180	550
	August	6	800	190	1,490
	September	3	310	130	370
	October	3	870	800	1,000
	November	3	690	390	850
	December	4	380	300	420
1978	January	4	500	90	1,040
	February	3	770	580	890
	March	4	820	580	1,020
	April	3	2,100	1,850	2,550
	May	3	850	530	910
	June	4	300	170	470
	July	4	340	300	410
	August	5	320	100	770
	September	4	370	280	510
	October	4	790	350	1,340
	November	3	520	330	850
	December	4	690	570	780
1979	February	4	600	490	801
	March	5	920	590	1,498
	April	4	500	340	574
	May	2	430	290	579
	July	5	350	250	843
	October	6	310	99	594
	December	16	820	120	2,601
1980	January	6	820	400	1,561
	February	28	590	96	3,778
	March	32	350	20	2,542
	April	17	470	51	2,364
	May	10	220	78	496
	June	9	210	90	428
	July	11	260	73	758
	August	45	170	5	919

Source: Data supplied by East Penn Manufacturing
* Rounded to two significant figures.

sampling data collected during the two preceding months. Thus, it appears that the data collected by this study are not markedly out of step with historical data provided by the smelter.

Prior to the spring of 1980, distinct exposure trends are extant. There does, however, appear to be a downward trend beginning in May, 1980. This downward trend is coincident with major exposure control improvements made prior to the follow-up evaluation at East Penn. The results of subsequent monitoring will determine if this is a continuing trend.

Work Area Concentrations of Lead and Antimony in Air

During both the initial and follow-up evaluations, stationary sampling at specific work areas was performed to obtain information regarding lead and antimony concentrations in air. Figure 4-1 shows where stationary samplers were located in the main smelter building.

Sampling media, sampling rate measurement and sample analysis were identical to that described for personal monitoring. Personal sampling pumps were used to collect work area samples during the initial visit, while sequential samplers were used for the same purpose during the follow-up evaluation.

Table 4-6 presents the results of work area monitoring for lead and antimony conducted during the initial evaluation. No detectable levels of antimony were found. As was the case with personal monitoring data, lead-in-air concentrations were generally higher on January 24, 1979, when gusty winds and rain prevailed.

Work area concentrations tend to be much lower than breathing zone concentrations and reflect the fact that employees are much closer to the sources of emission within the smelting building than were the stationary air samplers positioned at the locations shown in Figure 4-1.

Area sampling results from the initial evaluation do indicate that the employee breakroom or lunchroom was significantly contaminated with airborne lead. This condition offered the distinct possibility for employees to eat food and use smoking and chewing materials which were contaminated by lead. The contamination of the lunchroom may have resulted from a variety of sources. As shown in Figure 4-2, the lunchroom is adjacent to an industrial battery department which may have given rise to infiltration of lead contaminated air. A more obvious source of contamination was the traffic of employees dressed in work clothing to and from the lunchroom. Lead particulate lodged on clothing, hardhats, etc., may have been dislodged while these materials are removed or during normal movement within the lunchroom.

TABLE 4-8. RESULTS OF WORK AREA MONITORING FOR ANTIMONY DURING THE FOLLOW-UP EVALUATION[1]

Work Area	Date	Sampling Interval	Interval Conc. (μg Sb/m³)*
Location No. A - Refining Area (Refer to Figure 4-1)	08-05-80	1020-1620	ND
	08-05-80	1620-2220	ND
	08-05/06-80	2220-0420	ND
	08-06-80	0420-1020	19
	08-06-80	1135-1735	ND
	08-06-80	1735-2335	ND
	08-06/07-80	2335-0535	15

---

[1] Samples were analyzed for antimony following a combination of NIOSH Method Nos. P & CAM 173 and 261. The limit of detection was 10 μg Sb/filter.

* Time-weighted average antimony-in-air concentration for the period sampled.

ND - None detected.

TABLE 4-9. RESULTS OF BREATHING ZONE AND WORK AREA MONITORING FOR ARSENIC DURING THE FOLLOW-UP EVALUATION[1]

	Date	Sample Interval	Interval Conc. (µg As/m^3)*	8-hr. TWA Conc. (µg As/m^3)**
Job Description				
Lead Pot Tender (WE)	08-07-80	0807-1228	0.32	0.91
	08-07-80	1228-1547	1.8	
Foreman (CS)	08-07-80	0814-1241	0.24	0.52
	08-7-80	1241-1553	1.1	
Work Area				
Agglomerator Building	08-06-80	0923-1717	0.21	
Location No. A - Refining Area†	08-06-80	0924-1725	0.24	
	08-07-80	0535-1135	0.44	
	08-07-80	1135-1740	0.96	
Location No. B - Blast Furnace Charging Area†	08-06-80	0925-1730	0.39	

[1] Samples were analyzed for Arsenic by hydride generation following the method of Pierce, et al., "Applied Spectroscopy," Vol. 30, pp. 38-42, 1976. The limit of detection was 25 ng As/filter.

* Time-weighted average arsenic-in-air concentration for the period sampled.

** Eight-hour time-weighted average arsenic-in-air concentration assuming no exposure during periods not sampled.

† Refer to Figure 4-1.

Table 4-10 presents the results of this monitoring. All measured exposures were low when compared to the OSHA permissible exposure limit of 1.0 mg/m^3 set forth in 29 CFR 1910.1000. This same exposure limit is also recommended in the NIOSH criteria document for sulfuric acid. It is interesting to note that measured exposures were generally lower during the follow-up visit. This is logically attributable to the presence of local exhaust ventilation during the follow-up evaluation which was not in existence at the time of the initial evaluation.

Work Area Concentrations of Carbon Monoxide

During the follow-up evaluation, a cursory carbon monoxide monitoring survey was performed. A Model 2000 Ecolyzer carbon monoxide detector was used. The instrument was zeroed and then spanned with 50 ppm CO calibration gas prior to commencement of monitoring. Following the monitoring survey, the instrument zero and calibration were rechecked.

Table 4-11 presents the results of the carbon monoxide monitoring survey. Concentrations measured ranged from less than one to approximately 15 ppm. These levels are low by comparison to the OSHA permissible exposure limit of 50 ppm or the NIOSH criteria document recommendation of 35 ppm on a time-weighted average basis.

EMPLOYEE BLOOD LEAD LEVELS

An important test of the effectiveness of exposure control strategies (engineering controls, personal hygiene, respiratory protection) is biological monitoring of employee absorption of lead. One of the biological indicators thought to provide an acceptable assessment of cumulative lead absorption is the concentration of lead in blood. This lead concentration is traditionally expressed in units of micrograms of lead per 100 grams of whole blood (µg/100g). Current OSHA policy and regulations (29 CFR 1910.1025) regard 40 µg/100g as an acceptable maximum blood lead level concentration for working people. The current standard also provides for removal of employees from lead exposure areas should their blood lead levels exceed 70 µg/100g. This level for medical removal will be lowered to 50 µg/100g over the next few years.

East Penn Manufacturing has monitored employee blood lead levels for a number of years. Under this interagency-sponsored study, no biological monitoring could be performed. East Penn Manufacturing supported this study by providing blood lead data collected from January, 1977, through September, 1980, for smelter employees. It was hoped that a review of these data would provide another way of assessing the effectiveness of improving exposure control measures at East Penn.

TABLE 4-10. RESULTS OF BREATHING ZONE MONITORING FOR SULFURIC ACID MIST DURING BATTERY BREAKING OPERATIONS[1]

Initial Evaluation				Follow-Up Evaluation			
Employee	Date	Sampling Interval	Sulfuric Acid (mg/m^3)*	Employee	Date	Sampling Interval	Sulfuric Acid (mg/m^3)*
WD	01-23-79	1211-1515	0.10	WD	08-06-80	0759-1507	0.069
WD	01-24-79	0821-1200	0.18	KA	08-06-80	0758-1507	0.061
KA	01-24-79	1203-1520	0.067				

[1] Samples collected during the follow-up evaluation were analyzed following NIOSH Method No. P & CAM 268. Samples collected during the initial evaluation were analyzed by an ion chromatography method similar to NIOSH Method No. P & CAM 268.

* Time-weighted average concentration during the period sampled.

TABLE 4-11. WORK AREA CONCENTRATIONS OF CARBON MONOXIDE AUGUST 6, 1980

Work Area	Carbon Monoxide Concentration ppm*
Ambient background near flue dust landfill	<1
Center of baghouse building	<1
Near area sampling location between the refining kettles (Refer to Figure 4-1, Location No. A)	2
At right side of blast furnace slag tap	10 - 15
At left side of blast furnace slag tap	4
At work bench behind Refining Kettle No. 1	3 - 4
At blast furnace lead tapping hood	5
At tuyeres on charging side of blast furnace	3
At tuyeres on refining kettle side of blast furnace	3
Near skip hoist at ground level	1
Near skip hoist at top of blast furnace	2
Smelter foreman's office	<1
Near the burner exhaust of Refining Kettle No. 2	5 - 10
Beneath the U-tube coolers	5 - 10
Near the blast furnace water jacket cooler	5 - 15

* ppm = parts per million of carbon monoxide as measured by a Model 2000 Ecolyzer carbon monoxide detector.

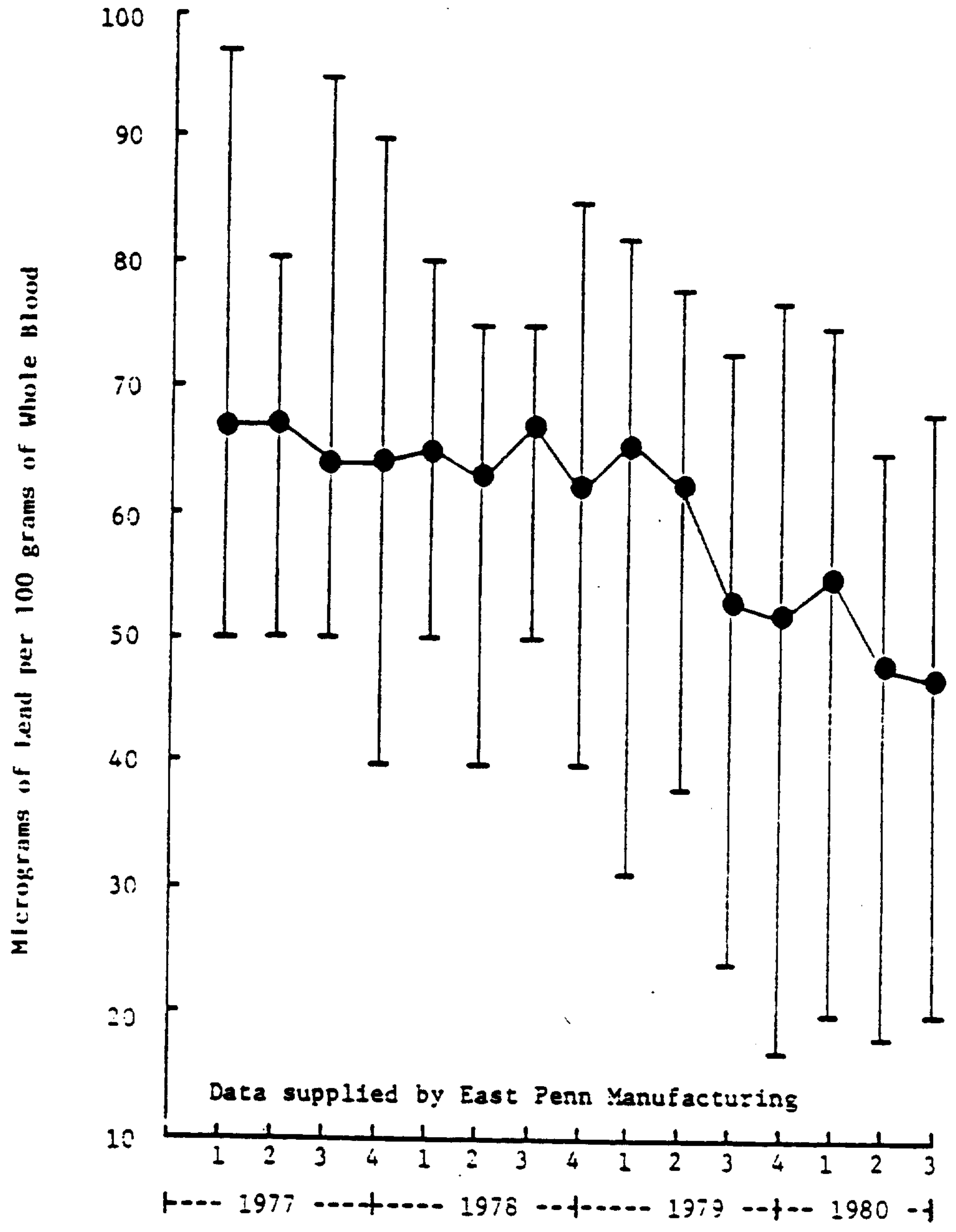
Review of historical blood lead data has revealed an apparent slight downward trend in employee blood lead levels which as a group show that substantial lead absorption has occurred. This trend is consistent with a reduction in employee exposure potential brought about by improved control of emissions, personal hygiene and respirator usage.

Figure 4-3 shows the mean quarterly average blood lead values for all employees working at the smelter (including battery breakers). Solid vertical lines indicate the range of quarterly average values. The mean values were determined from quarterly averages computed for each employee listed on the blood monitoring record sheets. Quarterly averages were determined as the simple mean of all blood lead data available for a particular employee during the three-month period. The number of blood lead samples per individual per quarter ranged from one to three.

The workforce did not remain constant throughout the three-year period. New employees (including some with very low blood lead values) joined the smelter workforce; other employees, whose blood lead levels exceeded the medical removal limits were transferred out of the smelter to low-exposure areas. Also, the total number of individuals for whom blood lead data were available varied from quarter to quarter. Blood lead data were available for a total of 56 employees during the three-year period. The number of workers for whom sampling data were available each quarter varied from 20 to 37 individuals.

To control for biases introduced by the inclusion of all workers in the sample group, it was decided that a more stable sub-group should be considered. This sub-group consisted of all employees who had worked in the smelter throughout the three-year period and for whom blood lead data were available for each quarter. A total of nine workers fell into this category. It is thought that the collective exposures of these individuals, as indicated by their blood lead concentrations, is more representative of the real effectiveness of the smelter's lead exposure control program.

Figure 4-4 shows the mean quarterly average blood lead values for these nine workers. Solid vertical lines indicate the range of quarterly average values. A slight downward trend is noticeable. Mean quarterly average values for these nine workers do not vary greatly from the mean values for all smelter workers, until the last quarter of 1979. This is thought to result from the elimination of high blood lead values (workers removed in response to the medical removal provisions of the OSHA standard) and the inclusion of low blood lead values (workers new to the smelter).



Data supplied by East Penn Manufacturing

FIGURE 4-3. MEAN QUARTERLY-AVERAGE BLOOD LEAD VALUES FOR ALL SMELTER EMPLOYEES

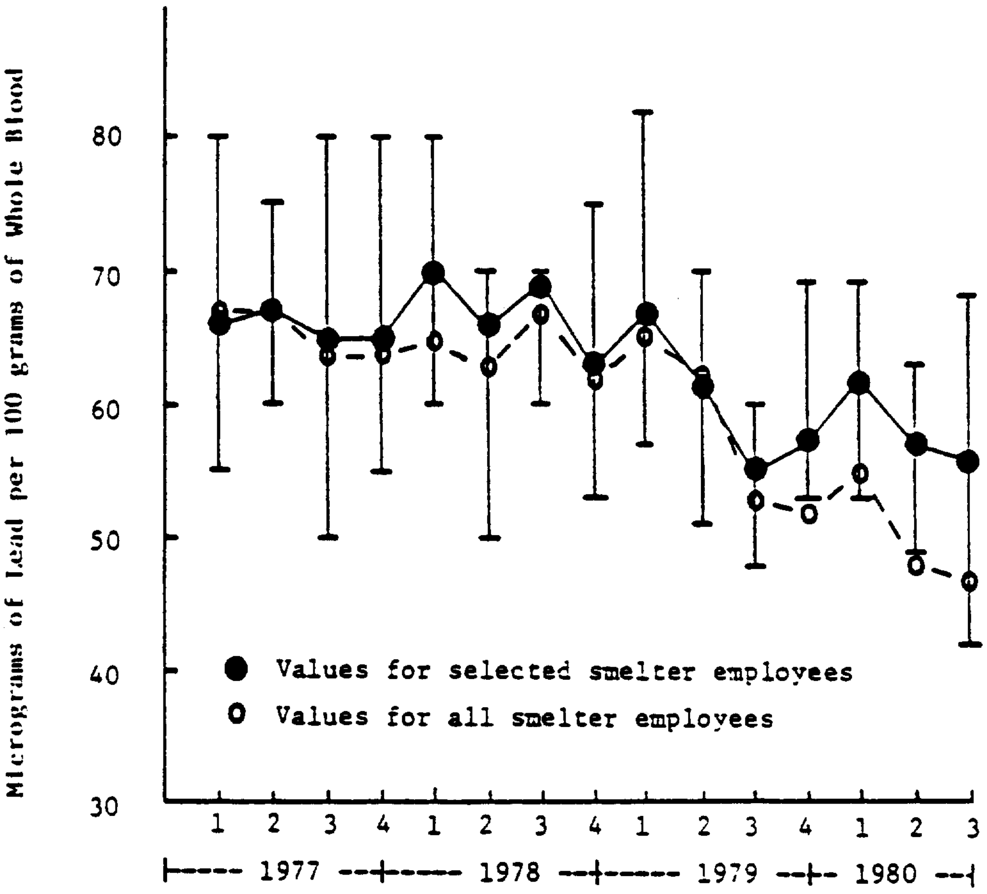


FIGURE 4-4. MEAN QUARTERLY-AVERAGE BLOOD LEAD VALUES FOR SELECTED SMELTER EMPLOYEES

Although the mean blood lead level for veteran smelter workers appears to be gradually falling, the measured blood levels reflect significant occupational exposure to lead. Other biological tests would be necessary to determine whether these relatively elevated blood lead levels are being maintained by current exposure to lead or by release of lead stored in other body tissues to the blood stream. Given the history of exposures at the smelter and current conditions, it is likely that both current exposure and the body burden of lead are contributing to elevated blood lead levels in these individuals.

EVALUATION OF WORKPLACE EXHAUST VENTILATION CONTROL SYSTEMS

Background and Methodology

Exhaust ventilation systems are a very important means of controlling employee exposures in secondary lead smelters. Careful documentation of ventilation system design and performance was developed during both the initial and follow-up evaluations.

A variety of information was sought with respect to individual elements of exhaust ventilation control systems. Among the desired data were:

- A physical description of the system element.
- Visual observations of the apparent effectiveness of the system element:
  - capture of visible emissions (e.g. fumes or dust).
  - compatibility with work required of employees.
  - situations when the control system element fails to provide contaminant exposure control.
- Physical measurements of control element performance (e.g. volumetric exhaust rate, face/control velocities).
- Feasible changes to processes/operations or the control system element which could improve overall control effectiveness.

To obtain this information, each control system element was observed during various process and operating conditions. Physical measurements of air flow were made at various times reflecting performance during specific operations.

Air flows in ductwork were measured using standard pitot tubes and an inclined manometer. Ten-point velocity traverses were made on two perpendicular duct diameters at each measurement location. Whenever possible, measurements were made in straight runs of duct, several duct diameters from upstream and downstream flow disturbances. Air stream temperature was also measured.

Face and control velocities were measured using a Model 6000 P Alnor Velometer and an Alnor Velometer Jr. These measurements indicate the effective strength of the exhaust draft created by the hood. Smoke tubes were used in conjunction with these instruments to observe air flow patterns near exhaust ventilation hoods and other structures.

Coefficients of entry were calculated for most exhaust hoods. This coefficient is an indication of how efficiently air flows into the hood.

Design and Performance Characteristics of Smelter Local Exhaust Ventilation System

Each of the local exhaust ventilation hoods and their respective air moving/contaminant collecting systems was studied during both the initial and follow-up evaluations. As described earlier, individual exhaust air handling systems underwent dramatic modification between the initial and follow-up evaluations. The figures presented in Section 2 illustrate the physical modifications made to specific exhaust system elements. These figures also present some basic information regarding volumetric flows of exhaust air control/face velocities and hood entry coefficients.

Table 4-12 presents a summary of volumetric air flow measurements made during the initial evaluation, during an interim visit to the smelter and during the follow-up evaluation. This table does not present all air flow volumes measured, but does include those directly associated with exhaust hoods or total system capacities.

Data collected during the initial evaluation are shown in column one of the table. As indicated, no exhaust ventilation was provided for the blast furnace access doors, refining kettle No. 2 and the pigging machine. The agglomeration furnace was not constructed or installed. Due to lack of physical access, separate measurements could not be made for the furnace charging hood and skip hoist furnace charging hood. The total capacity of the hygiene exhaust air system (excluding the slag tapping baghouse) was 4.4 m^3/s (9,300 scfm). The slag tapping exhaust system was operating at 1.8 m^3/s (3,900 scfm).

TABLE 4-12. COMPARISON OF EXHAUST AIR FLOWS ASSOCIATED WITH WORKROOM EXPOSURE CONTROLS BETWEEN THE INITIAL, INTERIM AND FOLLOW-UP EVALUATIONS

Exhaust Hood or Flow Measurement Location	Volumetric Flow Rate - Q					
	Initial Evaluation(1)		Interim Visit(2)		Follow-Up Evaluation(3)	
	m^3/s	acfm	m^3/s	acfm	m^3/s	acfm
Battery Breaking						
Shear Exhaust Hood	NC	NC	NC	NC	1.4	(3,000)
Plate Dumping Hood	NC	NC	NC	NC	1.5	(3,200)
Total System	NC	NC	NC	NC	2.9	(6,200)
Blast Furnace						
Skip Hoist Hood (Ground Level)	0.66	1,400	1.7	3,700	0.80	1,700
Skip Hoist Furnace Charging Hood	1.7	3,600			1.9	4,000
Furnace Charging Hood			5.7	12,000	3.2	6,800
Slot Hood Over Furnace Access Doors	NC	NC	0.90	1,900	0.34	730
Slag Tapping Hood (Separate Baghouse)	1.8	(3,900)	2.1	(4,500)	2.5	(5,300)
Metal Tapping Hood	0.66	1,400	1.7	3,700	2.2	4,700
Launder Hood	0.39	820	1.2	2,500	0.90	1,900
Block Casting Hood	0.30	630	0.80	1,700	2.2	4,600
Refining Kettles						
Exhaust Hood for Kettle No. 1	0.71	1,500	2.2	4,700	1.0	2,200
Exhaust Hood for Kettle No. 2	NC	NC	NC	NC	1.6	3,400
Pigging Machine						
Canopy Hoods	NC	NC	NC	NC	0.94	2,000
Agglomeration Furnace						
Flue Gas Stream and Dust Feed Exhaust Control	NC	NC	NA	NA	2.8	5,900
Tote Box Dumping Hood	NC	NC	NA	NA	0.31	660
Tapping Hood	NC	NC	NA	NA	0.36	760
System Total (Sanitary Baghouse)	4.4 (4)	9,500 (4)	20.0 (5)	42,000 (5)	18.0 (6)	39,000 (6)

(1) Flow measurements made in January, 1979, during the initial evaluation.

(2) Flow measurements made in June, 1979, during an interim visit to the smelter.

(3) Flow measurements made in August, 1980, during the follow-up evaluation.

(4) Total measured flow to old exhaust system. Baghouse located above employee locker room.

(5) Total measured flow to new exhaust system. Flow includes air entering system at open pickup points intended to serve new exhaust hoods (measured but not shown) and agglomeration furnace exhaust air service (not measured).

(6) Total measured flow to new exhaust system. This flow equals (rounded to two significant figures) the sum of flows from all listed exhaust hoods.

Air flows shown in brackets are part of independent exhaust systems.

NC - Not constructed, therefore, no measurement.

NA - No access, therefore, no measurements.

The second column of Table 4-12 presents measurements made during an interim visit to the smelter in June, 1979. At the time of this visit, the new hygiene air exhaust system had been temporarily connected to the old or existing exhaust hoods. No careful attempt to balance the system had been made. The new air moving system greatly increased air flows through all exhaust hoods connected to it.

Column three of Table 4-12 shows the volumetric flow rates measured during the follow-up evaluation. During this visit, the new exhaust system for the battery breaking facility was operational. The new hygiene air exhaust system had been roughly balanced to distribute exhaust service to various exhaust hoods including the agglomeration furnace. Within the accuracy of the air flow measurement techniques employed, all air entering and leaving the system was accounted for.

Table 4-13 presents a summary comparison of exhaust hood performance characterisitics. Data are included from only the initial and follow-up evaluations. In some cases, additional information is included in figures illustrating individual hoods presented in Section 2.

BATTERY BREAKING

The two exhaust hoods serving the battery breaking facility are shown in Figure 2-5. Nearly equal exhaust flow volumes are associated with each hood. Slots are used to distribute the control zone of each hood along the roller conveyor work surface. Slot velocities of 13 m/s (2,600 fpm) and 7.1 m/s (1,400 fpm) result in control velocities near the roller conveyor of 0.61 m/s (120 fpm) and 0.66 m/s (130 fpm) respectively, for the shear and plate dumping hoods. These exhaust air flows do not control projection of relatively large, lead-laden acid droplets toward the battery breaking employees caused by battery shearing and plate dumping. However, the exhaust ventilation has had an apparent dramatic effect on employee exposures to lead as summarized by data contained in Table 4-3. Reductions in exposure levels to sulfuric acid mist were also achieved as indicated by data presented in Table 4-10.

Additional protection against splashes of battery acid could be afforded by the installation of transparent barriers mounted at the front edge of the roller conveyor beginning several inches above the conveyor (to permit hand and arm access) and extending to worker head level or above. Improved contaminant capture may be achieved by keeping the rubber flaps to the case chute in their down position.

BLAST FURNACE

The blast furnace is the hub of the lead smelting activity and includes many significant sources of contaminant emission. Each major emission source is provided with some form of exhaust hood and/or enclosure.

TABLE 4-13. COMPARISON OF EXHAUST HOOD PERFORMANCE BETWEEN THE INITIAL AND FOLLOW-UP EVALUATIONS

Exhaust Hood	Initial Evaluation(1) Exhaust Rate - Q m³/s (acfm)	Face/Capture Velocity m/s (fpm)	Hood Entry Coefficient Ce*	Follow-Up Evaluation(2) Exhaust Rate - Q m³/s (acfm)	Face/Capture Velocity m/s (fpm)	Hood Entry Coefficient Ce*
Battery Breaking						
Shear Exhaust Hood	NC	NC	NC	1.4(3,000)	v_c=0.61 (120)	0.57
Plate Dumping Hood	NC	NC	NC	1.5(3,200)	v_c=0.66 (130)	0.56
Blast Furnace						
Skip Hoist Hood (Ground Level)	0.66(1,400)	(3)	--	0.80(1,700)	v_f=0.25-0.5(50-100)	0.90
Skip Hoist Furnace Charging Hood	1.7(3,600)	NM	--	1.9(4,000)	NM	0.59
Furnace Charging Hood			--	3.2(6,800)	NM	--
Slot Hood Over Furnace Access Doors	NC	NC	NC	0.34(730)	v_f=2.5-3.0(500-600)	0.58
Slag Tapping Hood	1.8(3,900)	--	0.47	2.5(5,300)	v_c=2.5-5.1(500-1,000)	0.75
Metal Tapping Hood	0.66(1,400)	v_f=0.5-1.0(100-200)	0.71**	2.2(4,700)	v_f=2.5-4.1(500-800)	0.89
Launder Hood	0.39(820)	v_f=<.25-1.0(<50-200)	0.30	0.90(1,900)	v_f=2.5-4.1(500-800)	0.54
Block Casting Hood	0.30(630)	v_f=<.25(<50)	0.47	2.2(4,600)	v_f=0.75-1.8(150-350)	0.63
Refining Kettles						
Exhaust Hood for Kettle No. 1	0.71(1,500)	v_f=0.5-1.0	0.67 to 0.73	1.0(2,200)	(3)	--
Exhaust Hood for Kettle No. 2 (doors closed)	NC	NC	NC	1.6(3,400)	NM	--
Pigging Machine						
Canopy Hoods (curtains closed)	NC	NC	NC	0.94(2,000)	v_c=0.25-0.5(50-100)	0.48
Agglomeration Furnace						
Flue Gas Stream and Dust Feed Exhaust Control	NC	NC	NC	2.8(5,900)	NM	--
Tote Box Dumping Hood	NC	NC	NC	0.31(660)	NM	0.25
Tapping Hood	NC	NC	NC	0.36(760)	v_f=1.3-1.5(250-300)	0.32

(1) Data collected in January, 1979.

(2) Data collected in August, 1980.

(3) Room air currents much stronger than draft induced in hood.

* $Ce = \sqrt{\frac{VP}{SP_h}}$, where SP_h = hood static pressure.

NC = not constructed, therefore, no measurement or calculation.

NM = no measurement.

** Blast gate directly above hood partially closed.

Skip Hoist Hood (Ground Level)

The skip hoist loading station is exhausted as shown in Figure 2-6 to control dust emissions created by filling the skip hoist bucket. The design of this hood evolved from two flanged entries to opposing banks of slot entries. Air is also drawn directly up the hoist shaft to the skip hoist furnace charging hood shown in Figure 2-7.

The performance of this hood, as evidenced by the face velocity at the open entrace to the hood, improved from negligible to 0.25 to 0.50 m/s (<50 to 100 fpm) between the initial and follow-up evaluations (refer to Table 4-13). Since the volume of air exhausted through the two ground level pickups did not change significantly 0.66 m^3/s (1,400 scfm) to 0.80 m^3/s (1,700 scfm), the increase in hood face velocity is due in part to greater exhaust volume for the skip hoist furnace charging hood.

The slot pickups do spread the control zone over the sides of the hood. Since no dry flue dust or similar material was charged to the skip hoist bucket during the follow-up evaluation, the practical effectiveness of this hood could not be observed. Practically all materials charged to the bucket were wet or damp. It should be stated, however, that the ground level skip hoist hood is located in an open air work area which is subject to strong drafts. Drafts like those witnessed during windy weather at the time of the initial evaluation interfere with the control pattern of the hood making it less effective.

No lead-in-air concentration data are available which specifically reflect the effect of improved ventilation at the skip hoist charging station. The hoist operator's exposure was dramatically reduced from the initial to the follow-up evaluations. But the exposure reduction is more likely due to other changes (such as wetting of charge materials, discontinued charging of dry flue dust and improved control of blast furnace emission sources) than to modest control improvements at the skip hoist charging station.

Skip Hoist Furnace Charging Hood

The skip hoist charging hood is shown in Figure 2-7. The configuration of this enclosure did not change between the initial and follow-up evaluations. However, the amount of air exhausted from this point did increase by several times. This hood helps to control emissions which overload the main furnace charging hood also shown in Figure 2-7. Observation of the control effectiveness of the skip hoist hood showed it to be much improved from the initial evaluation. However, when the furnace top temperature rose and burnthrough of the charge approached, visible emissions of fume and dust were observed to escape from this hood. These emissions rose to the roof of the smelter building, cooled and eventually settled into lower levels where employees work.

Furnace Charging Hood

The blast furnace charging hood is shown in Figure 2-7. The enclosure configuration of this hood did not change appreciably from the initial to the follow-up evaluation. The exhausted flow volume did increase substantially to approximately 3.2 m^3/s (6,800 scfm). As shown in Table 4-12, an even larger exhaust air flow of 5.7 m^3/s (12,000 scfm) was measured during an interim visit to the smelter. This exhaust rate was excessive since it reportedly caused competition between the hygiene exhaust air system and the process gas (flue gas) exhaust system. This resulted in heavy accumulations of material in the refractory lined process gas flue leading away from the furnace top and entrainment of hot gases and particulate into the hygiene air exhaust system.

Even though the production rate of crude lead and furnace top temperatures were higher during the follow-up visit, the furnace charging hood appeared to be collecting a much higher percentage of all emissions from the charging area. (Total emissions captured by the hood are shown in Table 3-3.) During near burnthroughs (high furnace top temperatures), visible fume and dust emissions do escape capture. It is likely that incomplete emission control will continue as long as the smelter elects to operate the furnace with high throughput rates and high furnace top temperatures.

Slot Hood Over Furnace Access Doors

Following the initial evaluation, a new exhaust hood was constructed to capture fumes and smoke escaping from blast furnace access doors. This hood is shown in Figure 2-7 together with the access doors which leak during moments of elevated positive pressure inside the furnace. Escaping fume and smoke rise from the furnace doors and follow the shell of the furnace. The hood incorporates a long slot to distribute the control zone across the width of the furnace.

At the time of the interim visit to the smelter 0.90 m^3/s (1,900 scfm) of air was being exhausted through this hood. This exhaust rate decreased prior to the follow-up evaluation when only 0.34 m^3/s (7,300 scfm) were exhausted.

This hood captures some of the emissions from the access doors. Better control could be achieved if the hood were nearer the emission sources and if it extended out from the furnace to collect emissions which do not rise close to the furnace shell. The entire problem of emission from these doors could be reduced by improving the design and maintenance of the doors to limit emissions.

Slag Tapping Hood

The slag tapping hood is served by a separate small baghouse. Figure 2-8 shows how the configuration of the hood changed between the initial and follow-up evaluations. The new design affords much better enclosure with small doors allowing access or observation.

Some increase in the exhaust rate from this hood was measured and the coefficient of entry for the hood improved. Control velocities appear sufficient to contain fume and smoke but particles of molten slag are projected out of the enclosure during active slag flow.

During the initial evaluation slag was allowed to cool and form a thick crust before the crucible was removed from under the hood. Less cooling time was allowed during the follow-up evaluation. Crucibles were removed while very hot. The impact of this practice on lead exposures is not exactly known, however, the data in Table 3-3 suggest that molten slag may be a significant source of lead fume emission.

Metal Tapping Hood

The metal tapping hood encloses and ventilates the furnace tap hole and lead well. The configuration of the hood did not change between the initial and follow-up evaluations. The hood is shown in Figure 2-10.

The exhaust rate and face velocity for this hood increased dramatically with the installation of the new hygiene exhaust air system. Opening the blast gate above the hood improved the coefficient of entry.

The blast furnace tap hole and lead well are significant potential sources of lead emission. Improved emission control at these sources has undoubtedly helped to reduce employee exposures. This exhaust hood could be further improved by tightening the enclosure around the lead well and extending it to the shell of the furnace. Additional exposure reduction could be gained if the hood were redesigned to permit easier access for punching the tuyere near this hood. These modifications may permit redistribution of exhausted air volume to the launder hood without compromising control at the lead well.

Launder Hood

Molten lead is transferred from the lead well to block molds via a launder. A movable exhaust hood is provided for the launder. This hood underwent some modification as shown in Figure 2-11. The quantity of air exhausted from this hood more than doubled and face velocities increased sharply. These changes improved emission control.

Figure 2-13 shows a side view photograph of the launder hood. The metal tapping hood is to the left and the block casting hood is to the right. Improved control could be accomplished by shortening and more completely enclosing the launder, replacing the launder with a closed transfer system such as a pump and pipe or providing one large exhaust enclosure for the lead well and block molds. These possible modifications would close gaps in the existing arrangement and help to minimize the effects of crossdrafts which can entrain contaminated air from the hood enclosures.

Block Casting Hood

The old and new block casting hoods are shown in Figure 2-12. The new hood provides more complete enclosure of the block molds. The exhaust rate from this hood is roughly seven times that for the old hood. These modifications resulted in better control of lead fumes emanating from block casting.

The new hood has an open back which could be provided with sliding or flexible flaps. This would improve overall enclosure of the operation. The flexible duct section could be shortened to reduce air flow resistance. This hood could also be integrated into a larger enclosure serving the metal tapping and casting operation.

REFINING KETTLES

Exhaust Hood for Refining Kettle No. 1

Figures 2-15 and 2-16 indicate the changes made in exhaust ventilation structures for refining kettle No. 1. The new hood originally had curtains hanging in the open area of the hood shown in Figure 2-17. These curtains were drawn into the hood by the flow of exhausted air. This design deficiency was corrected in the new hood for refining kettle No. 2.

The exhausted air volume for refining kettle No. 1 was approximately 40 percent of the total air flow devoted to the two refining kettles. Correction of this imbalance in air flow and modification of this hood to be more like the hood for kettle No. 2, would improve emission control.

Exhaust Hood for Refining Kettle No. 2

Kettle No. 2 was not enclosed or exhaust ventilated at the time of the initial evaluation. Figure 2-18 shows the hood which was designed and installed. This hood provides nearly complete enclosure during block melting. Skimming is still manually performed in front of the hood. The hood doors are opened to allow pumping of molten lead to the pigging machine.

PIGGING MACHINE

Prior to the follow-up evaluation, the pigging machine was equipped with a series of enclosing canopy hoods. As shown in Figures 2-20 and 2-21, canvas curtains are employed to complete the enclosure. Neither this hood nor the kettle hoods control emissions from the heating of lead transfer piping, which is accomplished using gas torches.

The data in Table 3-3 indicate that uncontrolled emissions from the pigging machine would be roughly equal to those from refining kettles. Most of the emission from the pigging machine is thought to be caused by the flame heating of the molten metal reservoir and nearby surfaces.

The side curtains for this hood may become contaminated with lead dust. When disturbed, they could become a further source of exposure. Some of these curtains could be replaced with solid side panels. The length of other curtains could be shortened by lowering the canopies or providing partial solid side panels. Measurements along the ingot cooling chain could be performed to see whether hooding is necessary at the cool end. If no emissions are detected at the cool end, the hood could be shortened. This, in combination with previously mentioned changes, could increase the hood face velocity. Increased face velocity will help minimize the effects of workroom air currents.

AGGLOMERATION FURNACE

The agglomeration furnace and associated dust feeding and exhaust ventilation systems are shown in Figures 2-23, 24, 25 and 26. Table 4-13 presents exhaust air flow information regarding the furnace flue gas stream, tote box dumping hood and metal tapping hood.

The agglomeration furnace does not meet expectations as being part of the solution to dust control problems at the smelter. This has been true since its installation. Problems with the dust feed mechanism and the agglomerating properties of the dust cause a range of operating problems which result in serious potential exposures to lead-in-air for several smelter employees.

Dust Feed Mechanisms

The dust feed mechanism consists of screw conveyors, bucket elevators and a gravity feed chute. Additionally, tote boxes of leady dust are fed to the system through the hopper shown in Figure 2-24. This feeding mechanism leaks dust from many transfer points. It is also prone to clogging or jamming which requires employees to open the system and clear the material.

Repeated opening and closing of the system aggravates the problem of minimizing leaks.

The gravity dust feed chute is an almost constant source of dust jams. Employees use a vibrator, hammers and metal rods to dislodge clogged material in this chute.

Dust feed leaks and jams create exposures which are not controlled by the exhaust ventilation system. Vacuum and wet washing techniques are used to clean up spills.

The dumping of tote boxes is performed in a simple hopper. This hopper is provided with some exhaust ventilation. The amount of dust which escapes the tote box dumping operation is highly dependent on worker technique. Uncontrolled emissions from dumping tote boxes could be reduced by improved design of the dump station or by using a different transfer mechanism.

Furnace Operation

The agglomeration furnace is operated at high temperature to counteract the poor agglomerating properties of the flue dust and the fluctuating dust feed rate. High temperature operation introduces heavy lead loadings into the furnace flue gases. Table 3-3 presents emission rate data for the agglomeration furnace. Any interruption in flue gas control results in heavy contamination of the agglomerator/baghouse building.

Another consequence of high temperature operation is overheating of the gravity dust feed chute. This results in smoke and fume formation in the chute which cannot be controlled by exhaust ventilation. Under these conditions fumes and smoke emanate from a number of points in the dust feed mechanism above the furnace and eventually contaminate the building.

Furnace Tapping

Molten material leaves the furnace through a spout and falls into a crucible. The crucible is housed in an exhausted enclosure shown in Figure 2-25. Air flows into the enclosure through the small box opening at a velocity of 1.3 to 1.5 m/s (250 to 300 fpm) which appeared to control fumes and smoke from the crucible.

The box opening is used to observe the furnace spout. When the spout becomes clogged, a metal hoe or rod is inserted through the box opening in the hood to clear the spout.

HOUSEKEEPING

Housekeeping practices at East Penn improved between the initial visit and the follow-up survey. The plant yard and roadways were paved with asphalt and a mobile sweeper/vacuum is used to keep these areas clean.

A central vacuum system was installed for the smelter building, the yard between the smelter and the agglomerator (baghouse) building and the agglomerator (baghouse) building itself. Water hosebibs, a concrete floor and a central floor drain were also installed in the agglomerator building. A metal partition was built to separate the charge preparation and smelting areas of the main smelter building. The number of workers routinely assigned to clean-up duties each shift was increased. The lunchroom was scheduled for daily janitorial attention. These changes resulted in a better level of control for settled dust and fume particles.

A problem is noted, however, with the use of water for clean up. Water alone is not an effective wetting agent for the leady dusts. The dust-water mixture is slippery and can create a hazard on walking surfaces. The spraying of water on piles of leady flue dust actually stirs up the dust and redisperses it into the air. Also, it is not practical to use water for washing down floors and roadways in the winter due to the formation of ice. It is possible that a wetting agent could be added to the washdown water to alter the hydrophobic surface of the leady dusts. This action, however, would not solve the problem of ice formation in the winter.

Improved lead contamination control provided by janitorial attention to the lunchroom is partially offset because employees do not clean or remove their work coveralls before entering the lunchroom. This practice introduces lead contaminants into an area that should be kept uncontaminated.

The mobile sweeper/vacuum is effective in removing dirt and dust accumulations from the plant roadway and yard. There is a question, however, of how much dust is redispersed as a result of the operation of this sweeper/vacuum. To investigate this issue, a real-time dust concentration monitor (the RAM-1), manufactured by GCA Technology, was used. Dust concentration measurements were taken as the sweeper approached and as the sweeper passed by. There was a noticeable increase in airborne dust concentration as the sweeper passed. It took several minutes for dust concentrations to return to general background levels. A similar evaluation was made for clean up acitivites using the central vacuum system. The passing of the hand-operated vacuum nozzle did not increase airborne dust concentrations for the vacuum operator.

PERSONAL PROTECTIVE EQUIPMENT AND EMPLOYEE HYGIENE PRACTICES

Employee-related exposure controls are a complement to engineering control measures. The use of personal protective equipment and the maintenance of good hygiene practices are two employee-related controls that can reduce exposures.

East Penn Manufacturing supplies respirators and protective clothing to workers to help protect them from lead exposure. The respirators are half-mask, air purifying respirators with high efficiency filters. These respirators are cleaned daily in a central respirator maintenance facility and are stored in lockers in the employee lunchroom. This respirator cleaning facility is an improvement initiated by East Penn following the initial visit for this study. Another improvement was the construction of a central laundry. This laundry facility has made it possible for East Penn to provide a daily change of protective clothing for smelter employees. This daily change of clothing eliminates lead exposure associated with locker storage of contaminated workclothes or the wearing home of contaminated workclothes. Workers do not always clean off contaminated workclothes or remove coveralls before entering the lunchroom for lunch or breaks. As a consequence, lead-bearing dusts are carried into the lunchroom on the workers' clothing. This source of contamination could be reduced by requiring the removal of coveralls and/or providing equipment (vacuum or a downdraft booth) for the workers to use to dust off their clothing.

Company policy prohibits smoking and eating in the smelter building, the agglomerator building and the immediate yard area. Smoking and eating are permitted in the employee lunchroom. Enforcement of this policy has become more strict since the plant was first visited. During the follow-up visit all employees were observed to comply with the policy. Handwashing facilities are provided for workers to use before eating lunch or smoking.

It appears that employees are conscientious in the use of respirators. During the follow-up visit, it was observed that workers wore respirators in required areas. It was also observed that the respirators were worn properly.

The half-mask respirators worn by most workers may not provide adequate protection in all plant areas. Workers in jobs where exposure measurements routinely exceed 500 ug/m^3 should use more effective forms of respiratory protection prescribed in 29 CFR 1910.1025.

SECTION 5

COSTS OF NEW CONTROL SYSTEMS AND PRACTICES

During the follow-up evaluation, cost data was obtained from East Penn Manufacturing regarding control modifications made at the smelter. Individual cost items have been organized in major categories and are presented in the following sections. Costs for materials/equipment and fabrication were primarily taken from vendor/fabricator invoices. Installation costs were estimated by plant personnel using hourly wage rates for specific labor categories.

IMPROVED EXHAUST VENTILATION SYSTEM TO REDUCE EMPLOYEE EXPOSURES TO LEAD IN THE SMELTER AND BAGHOUSE BUILDINGS

Sanitary Baghouse

Baghouse	$ 95,876
Baghouse foundation	3,200
Baghouse erection - outside	5,132
Fan	6,000
Fan base	2,361
Fan preparation	800
Fan erection	1,500
Service walkway	1,600
Vibrators	2,162
Electrical	33,400
Shipping	11,019
	$163,050

Enclosure for Baghouses and Agglomeration Furnace

Building	$ 37,205
Bolts and design	3,117
Siding and roof	16,076
Doors	7,400
Foundations	5,500
Floors and control room	9,080
Erection	12,705
Labor	6,148
	$ 97,231

Ductwork, Dropout Chambers, Catwalks, Etc.

48 inch ductwork	$ 9,020
Baghouse ductwork	34,800
Inlet and outlet ductwork	14,995
Damper	1,150
Dropout unit and rotary valve	4,800
Agglomeration furnace ductwork	12,624
Ducts from smelter building	23,204
Cleanouts for ductwork	3,451
Catwalk material	6,468
Labor	2,880
	$113,392

Design, Fabrication and Installation of Exhaust Ventilation Enclosures

Modifications to blast furnace charging hoods	$ 17,803
Modifications to skip hoist loading hood	1,557
New slag tapping hood	2,361
New hoods for metal tapping, launder and block molding	1,962
Hood for refining kettle No. 1	8,395
Hood for refining kettle No. 2	19,180
Hood for pigging machine	5,188
Hood for dumping tote boxes into agglomerator feed system	5,600
Hood for tapping spout of agglomeration furnace	2,470
	$ 64,516

Total Cost of Exhaust Ventilation for Smelter and Baghouse Buildings

$438,189

FLUE DUST AGGLOMERATION FURNACE AND FEEDING SYSTEM

Agglomeration Furnace

License fee	$ 25,000
Cover	1,325
Tubing	1,105
Steel	4,154
Spout	250
Refractory	7,218
Hoist	234
Thermocouple	181
Burner	468
Main burner	7,853
Rebrick agglomerator	4,361
Replace burner	874
Installation labor	10,000
	$ 63,023

Agglomerator Feeding Equipment

Elevators and screw conveyor	$ 7,442
Inclined conveyor	1,908
Dump hopper	3,600
Chutes	797
Transition section	808
Feed pipe	906
Vibrator	557
High temperature belts	1,391
Chain belt and chute	838
Electrical	9,000
Installation labor	16,000
	$ 43,247

Cost of Agglomeration Furnace and Feeding Equipment (Exhaust Ventilation Control not Included)

$106,270

CENTRAL VACUUM SYSTEM FOR SMELTER BUILDING AND BAGHOUSE BUILDING

Concrete pad	$ 750
System purchase price	15,000
System installation	4,500
	$ 20,250

EXHAUST VENTILATION SYSTEM FOR THE BATTERY BREAKING OPERATION

Fan and some ductwork (1971)	$ 4,820
New motor and fan rebuild	2,207
New ducts and hoods	5,624
Wire mesh	318
Additional fiberglass material	134
Installation labor	800
	$ 13,903

OTHER SMELTER MODIFICATIONS

Yard paving materials	$ 6,300
Partition separating blast furnace charging and refining areas	$ 2,520
Gravity stacks for kettle burner exhaust	$ 1,251

Laundry Facility

Four clothes washers	$ 1,526
Two individual clothes dryers	3,032
Used sewing machine	90
Two water heaters	1,490
Piping	300
Valves	80
Sink and faucets	70
Sorting tables	200
Installation labor	900
	$ 7,688

ADDITIONAL LABOR FOR IMPROVED HOUSEKEEPING AND MAINTENANCE OF NEW CONTROLS

$ 3,080

COSTS ASSOCIATED WITH IMPROVING THE RESPIRATORY PROTECTION PROGRAM

Ultrasonic cleaner (installed)	$ 7,500
Labor and materials for respiratory cleaning and maintenance (monthly cost)	$ 1,027

SECTION 6

DISCUSSION OF RESULTS

This section presents a discussion and correlation of results developed in the various characterization activities. Measurements obtained on controlled process sources are reviewed first. Then, the effectiveness of the baghouses will be discussed. The properties of the flue dust, like particle size, settling velocity and agglomeration properties are summarized next. A discussion of employee exposures to workroom contaminants and workplace exposure controls follows. Finally, a brief summary of control costs and control status is presented.

CONTROL PROCESS SOURCES

In-duct measurements were made to determine the quantities of contamination collected by exhaust ventilation enclosures serving specific process emission sources. The sources evaluated include: blast furnace charging, slag tapping and lead tapping, kettle refining, ingot casting and flue dust agglomeration. The amount of lead captured from each of these sources is as follows:

• Blast furnace charging	~85,000 g/hr
• Agglomeration furnace	~50,000 g/hr
• Blast furnace slag tapping	~900 g/hr
• Blast furnace metal tapping	~340 g/hr
• Ingot casting (pigging machine)	~14 g/hr
• Refining kettles	~13 g/hr

Dust generation from blast furnace charging is primarily caused by mechanical entrainment. This is evidenced by the particle size distribution. Seventy percent of the particulate matter is larger than 15μ. The contribution of the agglomeration furnace with 50,000 g/hr is surprisingly high. Two mechanisms seem responsible for this high figure. First, the high gas flow rates in the agglomerator furnace of 8,500 m^3/hr leads to mechanical entrainment of dust. Second, the high furnace temperature leads to evaporation of volatile lead compounds.

The emissions of the other process sources seem to correlate with the temperature. The hottest stream is the slag. Slag temperatures are in the 1,150°C to 1,200°C range. The vapor pressure of lead is 15 mm Hg at 1,200°C. This means air in equilibrium with pure lead at this temperature contains 2.3 g Pb/m^3. Equilibrium values at other temperatures are 0.8 g Pb/m^3 at 1,100°C and 0.2 g Pb/m^3 at 1,000°C. The temperature of the lead well is lower than that of the slag. Kettle refining is done in the neighborhood of 450°C and pigging at 350°C. The Pb partial pressure can be estimated using the following correlation:

$$\log p_{Pb} = -9.368 \times 10^3 \left(\frac{1}{T}\right) + 7.523 \qquad (6\text{-}1)$$

p = partial pressure of lead in mm Hg

T = absolute temperature in °K

We find

$$p_{Pb} \text{ at } 350°C = 3 \times 10^{-[illegible]} \text{ mm Hg}$$

and

$$p_{Pb} \text{ at } 450°C = 3.7 \times 10^{-6} \text{ mm Hg}$$

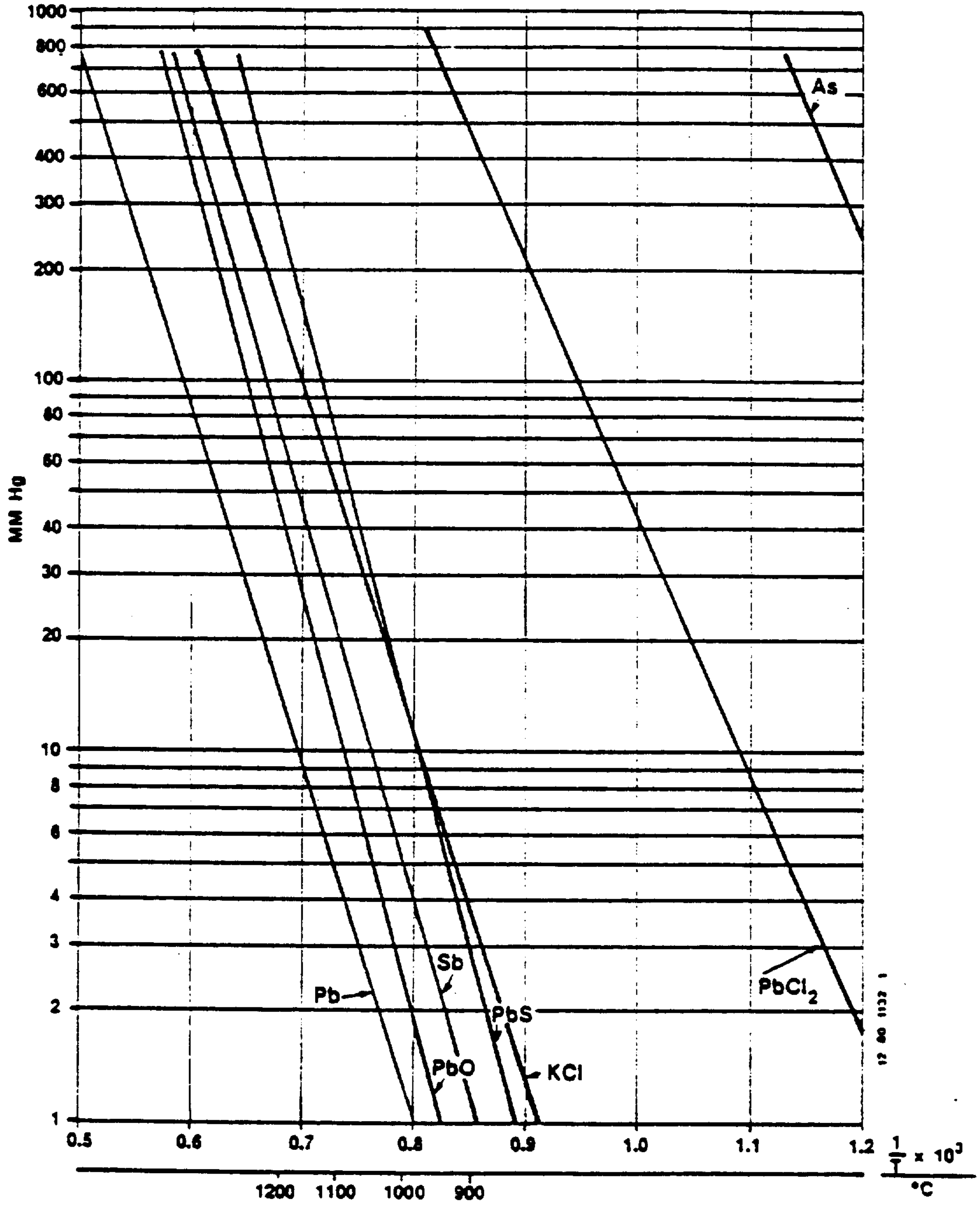
This corresponds to equilibrium concentrations of 3.6 $\mu g/m^3$ at 350°C and -50 $\mu g/m^3$ at 450°C.

From these figures it is obvious that process sources with high temperatures and large flow volumes need to be controlled closest. Even a small amount of emission escape from large high temperature sources can result in heavy contamination of the workplace.

Although ingot casting (pigging) is performed at a relatively low temperature, a torch is used to heat the lead reservoir on the pigging machine. This results in evaporation of lead. Without enclosure and control, the pigging machine could be a significant source of workplace contamination.

Some compounds of lead are even more volatile than elemental lead. Examples are PbO and PbS. This is shown in Figure 6-1. Data for Sb, KCl, $PbCl_2$ and As are also represented.

The high vapor pressures of these lead compounds lead to evaporation in the hot areas of the smelting process and to condensation in the colder ones. This has a pronounced influence on the particle size distribution found in the smelter gas streams.



Ordinate: Pressure in mm Mercury.

Abscissas: Reciprocal absolute temperature $\frac{1}{T}$ and °C.

FIGURE 6-1. VAPOR PRESSURE OF Pb, PbO, Sb, PbS, KCl, PbCl$_2$ AND As

The amounts of lead carried by a gas stream with a flow rate of 4,000 m^3/hr at equilibrium conditions are 10,500 kg/day at 1,155°C, 1,200 kg/day at 977°C and 140 kg/day at 838°C. Dust production by evaporation-condensation increases with increasing blast furnace temperatures.

PARTICLE SIZE DISTRIBUTION

The particle size distribution measured at the process sources support the above findings. The lead content was found to increase with decreasing particle size for the hottest streams.

Source	>15u	2.5 - 15u	<2.5u
Blast furnace slag tapping	11% Pb	11% Pb	78% Pb
Blast furnace lead tapping	12% Pb	5% Pb	83% Pb
Agglomerator flue	7% Pb	22% Pb	71% Pb

Temperatures at these points are in the 1,000°C to 1,200°C area. In comparison, temperatures around the charging operation are much lower. Mechanical entrainment seems to be a major mechanism of dust production. This is reflected in a particle size distribution skewed to larger particulates.

Source	>15u	2.5 - 15u	<2.5u
Blast furnace charging	60% Pb	8% Pb	32% Pb

This can be explained by an evaporation-condensation mechanism for the first three streams and a more pronounced mechanical entrainment around the charging area. An evaporation condensation mechanism leads to an increasing lead concentration with decreasing particle size, since small particles exhibit a much larger specific surface area (m^2/g) than larger particles. The element concentration after condensation on nuclei is directly proportional to the specific surface area.

The particle size distribution measured with impactors is supported by the findings of surface electron microscopy. Figure 6-2 shows dust collected in the ducting of the lead tapping. The magnification was 4.75 KX. The dust seems to be composed of small spheres, with a diameter smaller than 1u. Several spheres stick together to form larger aggregates. This again supports an evaporation-recondensation mechanism. The phase changes from:

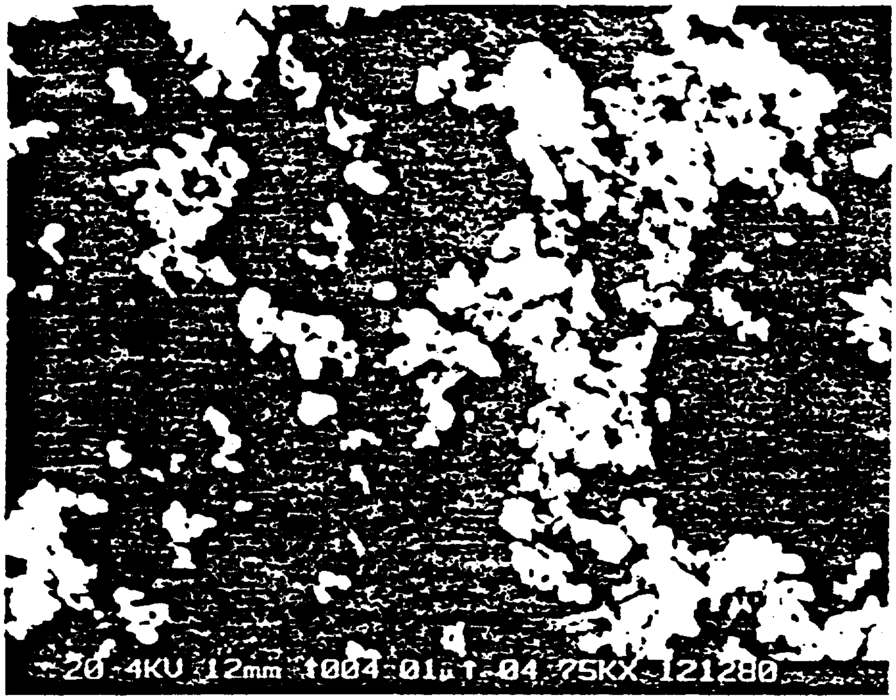


FIGURE 6-2. ELECTRON MICROGRAPH OF LEAD WELL DUST
MAGNIFICATION - 4.75 KX

create liquid droplets (spheres) which bake together upon solidification. Temperature regimes similar to the lead well are prevalent in the agglomerator furnace, which was heated to a yellowish-white and also at the slag tap. What is of great relevance here is the fact that particulate matter escaping the hooding exhibits very low settling velocities. It will, therefore, contribute significantly to the lead level in the workroom area and to the ambient lead level.

CONTROL EFFICIENCY OF BAGHOUSES

Dust collected in the hooding systems of the point sources is carried to three baghouses. The collection efficiency of these control devices fluctuated during the sampling period; namely, from 99.2 to 99.9 percent for the process baghouse, 99.9 to 97.2 percent for the sanitary baghouse and 97.6 to 97.9 percent for the slag tap baghouse. Control efficiencies in the 97 percent range are low. Expected values are in the 99+ percent range. A reason may be the high concentration of particulate matter in the <2.5μ size range. The total lead released to the environment is:

• Slag tap baghouse	10 g/hr
• Process baghouse	195 g/hr
• Sanitary baghouse	84 g/hr

or a total of about 7,000 grams per day. Again, it is noteworthy to stress that about 70 percent of this escaping material consists of inhalable particles with diameters <2.5μ. The baghouse fabric consists of orlon and dralon. The air to cloth ratios of 1:0.7 (slag tapping baghouse), 1:1.3 (sanitary baghouse) and 1:1.8 (process baghouse) are not atypical for these applications.

The figure of 7 kg/day of dust released through the stacks controlled by baghouses compares to 8,000 kg/day of dust produced in the total smelting operation.

DUST AGGLOMERATION

Proper handling of flue dust is critical to the prevention of workplace and environmental contamination. The dust handling procedures implemented at East Penn are, however, not sufficient. Dust collected in the air coolers is transported by screw conveyors to one central collection point. Here the dust is filled into tote boxes. Leaks at the points of transfer and at the joint where the flexible hoses connect with the tote boxes are constant sources of dust leaks. The most difficult situation, however, exists in the agglomerator building. Lead in the workroom reached 2,200 µg/m^3 during a process upset. Time-weighted average exposure of the agglomerator furnace operator was 410 µg/m^3 over two workdays sampled. These high levels of air contamination were caused by poorly controlled dust handling operations and emissions from the charging equipment for the agglomeration furnace.

A study of flue dust agglomeration properties was undertaken after significant differences in the agglomeration behavior of East Penn, General Battery and Bergsøe dusts were observed. A summary of the findings was presented in Section 2. A detailed description is included in Appendix A.

In summary, it was found that the dusts are composed of Pb, PbS, PbO and lead oxysulfates. These compounds are expected at blast furnace operating conditions according to the phase diagram reproduced in Figure 6-3.

The amount and type of these phases found, depends on the profile of temperature and oxidation potential (p_{CO_2}/p_{CO}), and on the residence time.

The second observation is of fundamental importance. The Bergsøe flue dust contained up to 24 percent chlorine in the chemical phases of $PbCl_2$ and KPb_2Cl_5. The presence of these low melting compounds allowed dust agglomeration at temperatures as low as 410°C. This compares to ~900°C necessary at East Penn, where the chlorine content is only 2 percent.

In secondary lead smelting, the chlorine source is polyvinylchloride used in battery manufacture. Polyvinylchloride (PVC) is used in Europe to a much higher degree than in the USA. It is estimated that 30 percent of battery plate separators are made of PVC in Europe. In the US only 3 percent of car batteries contain PVC. These organic materials decompose under blast furnace conditions and the chlorine combines with lead to form low melting lead compounds. An attempt to raise the chlorine content was made during the August sampling effort. Feeding of PVC scrap and flue dust recycling led to a build-up to 4 percent Cl on August 14. However, this practice was discontinued before sufficient chlorine had accumulated to significantly change agglomeration properties of the flue dust.

The high melting flue dust compounds necessitate the high energy input of two million Btu/hr to the agglomeration furnace at East Penn. Mechanical dust entrainment, evaporation of lead compounds, clogging of the gravity feed system and low furnace throughput are the consequence.

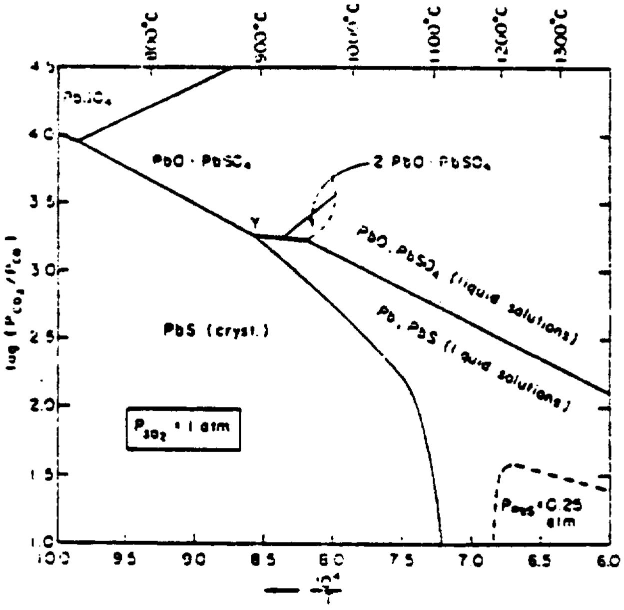


FIGURE 6-3. EQUILIBRIUM DIAGRAM FOR Pb-S-O SYSTEM, P_{SO_2} = 1 atm

Due to the poor agglomerating properties of the flue dust at East Penn, the Bergsφe agglomeration furnace seems unsuitable to solve the dust handling problems at East Penn. Before flue dust agglomeration is attempted using the Bergsφe technology or other approaches at US secondary lead smelters, careful study of dust agglomeration properties should be performed.

SETTLING VELOCITY AND PARTICLE IMPACTION

Both phenomena; the settling velocity of particles and the collection mechanism of impactors, are correlated with the particle behavior in a gravitational force field.

The terminal settling velocity in the atmosphere is reached when the gravitational force equals the force of friction. Stokes derived:

$$K = m \cdot g = \eta \cdot 6\pi r \cdot \upsilon \qquad (6\text{-}2)$$

or:

$$\upsilon = \frac{\left(\rho_p - \rho_{air}\right) \cdot d^2 \cdot g}{18\eta} \approx \frac{g}{18\eta} \cdot \rho_p \cdot d^2 \qquad (6\text{-}3)$$

υ = settling velocity

ρ_p = particle density [g/cm^3]

ρ_{air} = density of air [g/cm^3]

d = particle diameter [µ]

g = gravity constant 9.81 [m/sec^2]

η = viscosity of air 1.8×10^{-5} [Dyn · sec/m^2]

m = mass of particle [g]

With this correlation the settling velocities for lead particles (ρ = 11.3 g/cm^3) of different diameter at ambient temperature are estimated to be the following:

Settling Velocity v [cm/sec]	Particle Diameter d [μ]
0.0003	0.1
0.008	0.5
0.015	0.7
0.06	1.4
0.6	4.5
3	10
8	15
30	30

Lead particles with diameters less than 4.5μ have sufficiently long airborne residence times to be inhaled. Their deposition in the respiratory system is dependent on particle size also. Smaller particles have higher potential to reach the deep lung. Larger particles may be deposited in the upper airways and can eventually be swallowed.

Particle size distribution measurements indicated that most of the emitted particles (60 to 70 percent) are in the <2.5μ size range. The settling velocity for this material is very low. This means fumes and fine particles escaping from process enclosures may remain airborne in the workroom for long periods. Similarly, small particles emitted from baghouse stacks may be carried far downwind before deposition occurs.

In aerosol physics, it is customary to treat particles as spheres with the density of one g/cm^3 and to work with aerodynamic diameters. The correlation:

$$d_{real} = \frac{d_{aerodynamic}}{\left(\rho_{real}\right)^{1/2}} \qquad (6-4$$

can be used to correlate the aerodynamic diameter (ρ = 1) and the real diameter ($\rho = \rho_{real}$). Particles with aerodynamic diameter of 2.5 to 15μ stay in the upper respiratory tract. Particles with an aerodynamic diameter of <2.5μ reach the lungs and partly diffuse into the bloodstream.

In the case of lead ($\rho = 11.3$), particles with a nominal diameter $d = 15 : \sqrt{11.3} = 4.5\mu$ are inhalable and particles with a nominal diameter of $d = 2.5 : \sqrt{11.3} = 0.7\mu$ can reach the deep lung. The corresponding settling velocities of lead spheres are 0.6 and 0.06 cm/sec, respectively.

The collection efficiency of impactors depend on the same aerodynamic principles. A particle is collected if it settles in the centrifugal force field of the air jet reflection. It is customary to report the aerodynamic diameter of particles collected with 50 percent efficiency.

$$\psi_{50} = C \cdot \frac{\rho_p \cdot d^2}{18\eta} \cdot \frac{V}{D} \qquad (6\text{-}5)$$

C = constant

V = velocity of gas in jet

D = diameter of jet (hole in impactor stage)

ψ = 50 percent collection efficiency for particles of diameter d.

With this correlation we derive, for instance, that a Smith Greenberg impinger collects 50 percent of particles of 1μ aerodynamic diameter.

The above equations gain importance in the light that the instruments designed to collect particles as function of size are always calibrated to measure aerodynamic diameter. The particle size information given in this report follows this custom.

AMBIENT LEAD LEVELS

Three sources contribute to ambient lead levels, namely, the baghouse stacks, fugitive emissions from the smelter and agglomerator building and surface entrainment from yard areas. The three stack emissions were amenable to measurement. Fugitive sources are more difficult to measure. To estimate entrainment from area sources imposes the greatest problem. Principle area sources are the dust pile (Figure 6-4), the smelter service road, the battery storage piles along the pond and other contaminated surface areas.

The integral effect of these sources was measured by placing hi-vol samplers upwind and downwind of the smelter. The locations selected, namely Reinhart's farm, the pond garage and the water tower, were dictated by:

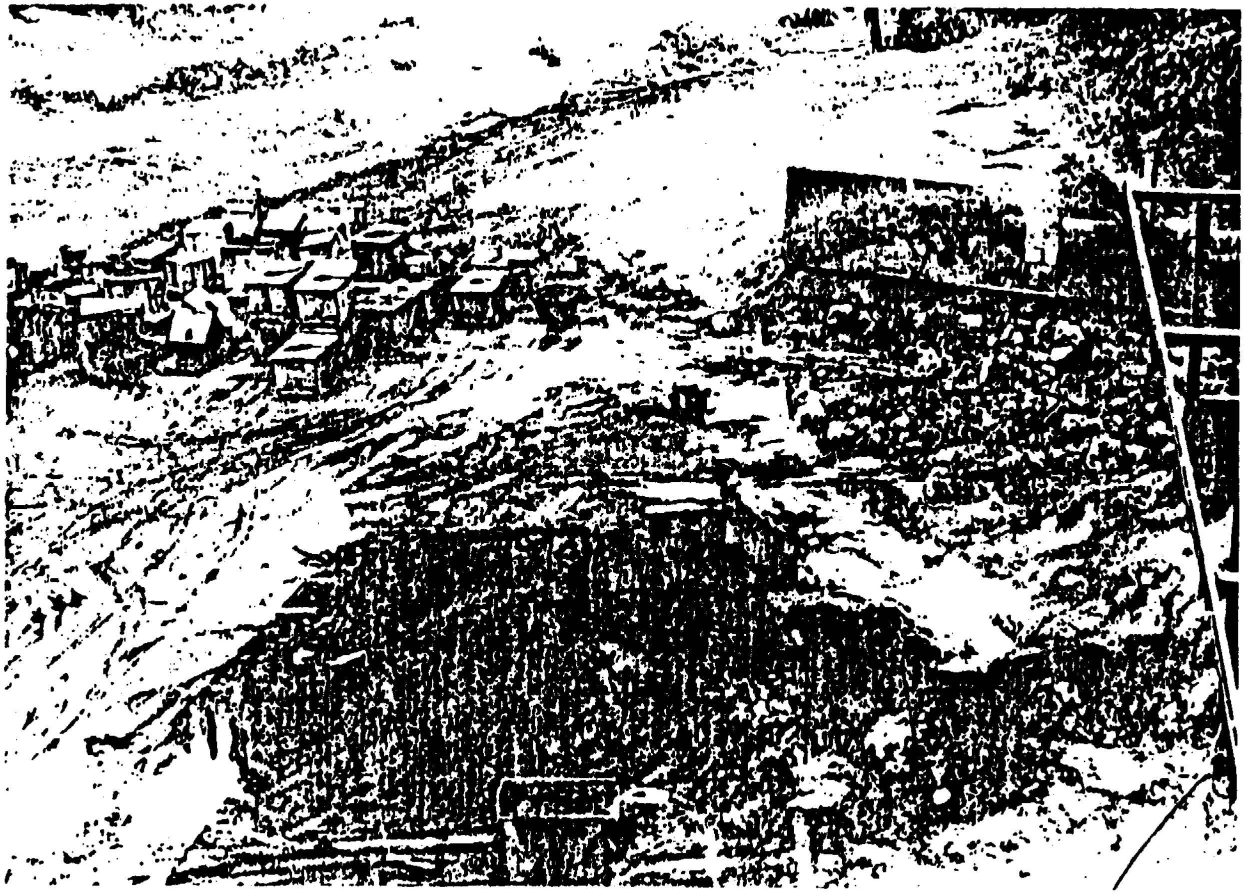


FIGURE 6-4. STORAGE AREA FOR SLAG, DUST AND AGGLOMERATED DUST PLUGS

- area topography
- distribution of buildings and vegetation
- wind rose, and
- the availability of electricity

Lead analysis of the filters was performed for days with favorable wind direction predominantly from the west. The upwind location, Reinhart's farm, showed in all cases very low lead concentrations (0.1 to 0.6 $\mu g/m^3$). Values at the water tower were 0.7, 1.4 and 3.5 $\mu g/m^3$ during the August sampling effort. The pond location showed values of 2.1, 7.0 and 11 $\mu g/m^3$. This can be caused by the closer proximity to the smelter and the battery storage piles at this location.

An effort was made to correlate ambient lead concentrations resulting from the two hi-vol monitors with those resulting from the modeling of known emission points. This was done using the Industrial Source Complex Short-Term dispersion model (ISCST). The data inputs, assumptions and results of that modeling effort are described in the following paragraphs.

The process baghouse stack, the slag tapping baghouse stack and the sanitary baghouse stack were the three point sources modeled. Locations and stack parameters are shown in Table 3-9. The lead emission rates for the three point sources were 0.056, 0.003 and 0.028 grams per second, respectively (see Table 3-6). Particle size distributions are given in Table 3-7.

Due to the nature of the orientation of the slag and sanitary baghouse stacks, they were modeled as volume sources. This means that for the purpose of the model they were modeled as virtual stacks located some distance upwind of their actual locations. The purpose of this is to account for the extra dispersion caused by the atypical stack configurations.

The dust storage area was modeled as an area source. It was assumed to be a square with each side 45 meters. An emission rate of 1×10^{-8} grams per square meter per second was calculated based on a literature estimate of 1 gram per thousand square meters per day for storage piles.[2] Particle size distribution was taken from Table 3-13. An effective emission height of 2 meters was assumed.

Meteorological data came from two sources. Wind direction and wind speed were measured every three hours at the plant site. Other meteorological data, such as cloud cover, ambient temperature and hourly wind direction and wind speed data, came from FAA Surface Weather Observations taken at Reading, Pennsylvania. The meteorological data from the two sources were integrated to provide the best possible picture of conditions at the plant site.

The receptor grid configuration chosen for the ISCST model runs is shown in Figure 6-5. The process baghouse stack location was used as the origin. Receptors were located at 50 meter intervals. Additional receptors were placed at locations coinciding with two of the hi-vol sites (sites 2 and 3).

The nineteen hours between 1500 hours August 7, 1980, and 0900 hours August 8, 1980, were selected to be modeled since monitoring data were also available for this time period. Prevailing winds during that time were generally from the southwest, which aligns the emission sources reasonably well with the two hi-vol sites.

The results of the modeling study were inconclusive. Shown in Figure 6-6 are the receptor grid concentrations resulting from the modeling of the three point sources. (Modeling of the dust storage area showed virtually no impact at any of the receptors). The modeled values of 0.13 $\mu g/m^3$ at hi-vol site 2 (pond) and 0.0 $\mu g/m^3$ at site 3 (water tower) disagree with the monitored values of 2.1 and 0.68 $\mu g/m^3$, respectively (see Table 3-10). However, a number of possible sources of error could have caused these differences. First, buildings, terrain and trees (see Figure 3-9) could have caused the wind to be channelled to the southeast. This effect would not have been accounted for by the meteorological data used in the modeling study. Small shifts in actual wind conditions may well have contributed to the higher monitored values. Therefore, the larger predicted values of 6.6 $\mu g/m^3$ at locations just to the north of the receptors (Figure 6-6, particularly at $x = 200m$, $y = 150m$) could indeed indicate that the point sources were impacting upon the two hi-vols.

Second, the emission rates used could be inaccurate. Note that the rates given in Table 3-6 vary substantially from day to day. In addition, for the slag tap and sanitary baghouses, the emission rates were sampled on days other than the one modeled.

Lastly, it is possible that additional sources of lead contributed to the measured hi-vol results. Given the large amount of lead in the soil around the plant site, entrainment from surrounding areas could have caused a significant portion of the monitored lead. Lead dust disturbed by nearby vehicular traffic may also have been responsible for some of the lead picked up by the monitors. Furthermore, fugitive emissions from the agglomerator and smelter buildings could have impacted upon the hi-vols if the wind were being channelled in that direction. From the measured workroom concentrations, estimated lead emissions from the building openings could be as much as 360 g/hr for the smelter and 20 g/hr for the agglomerator building.

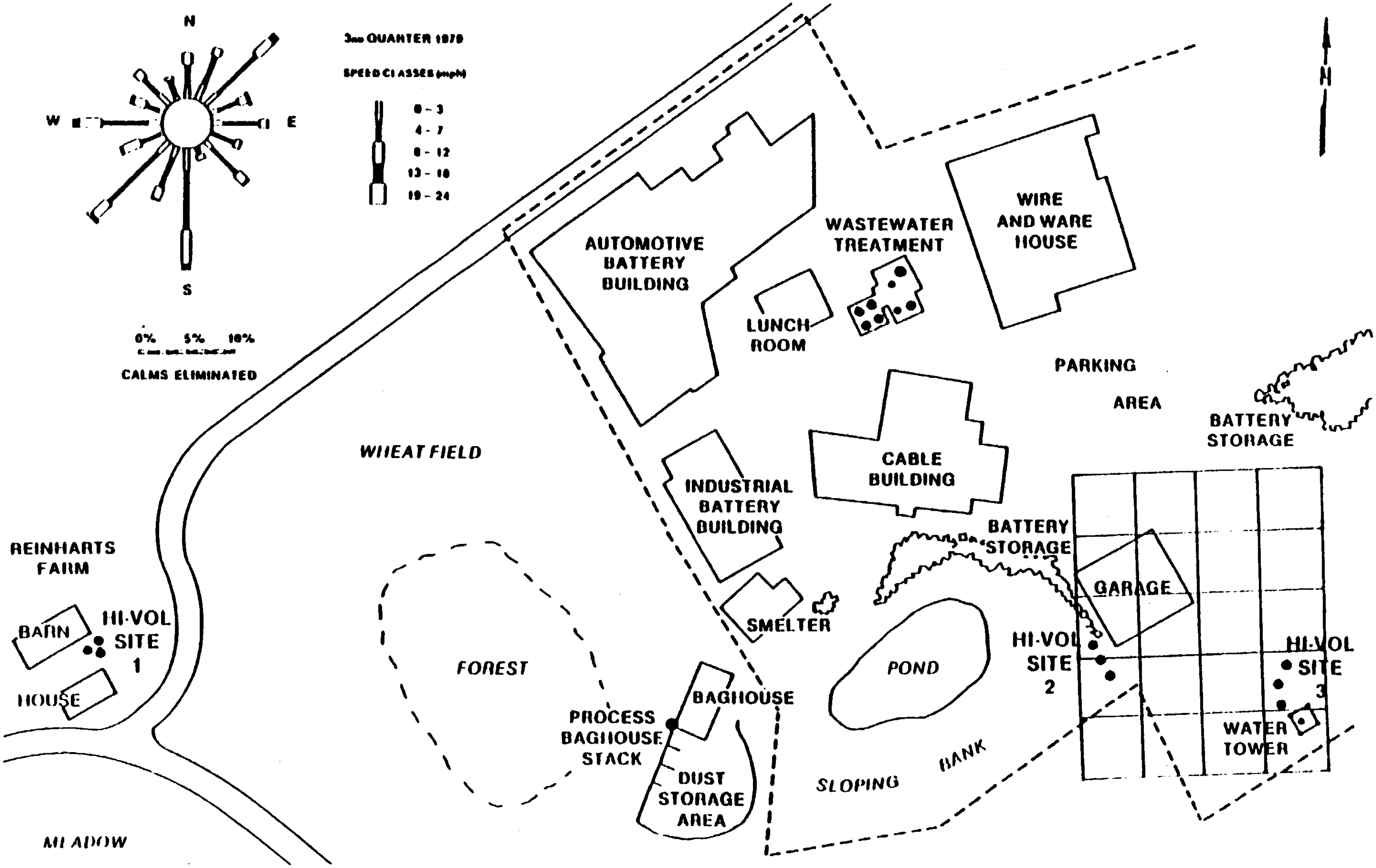
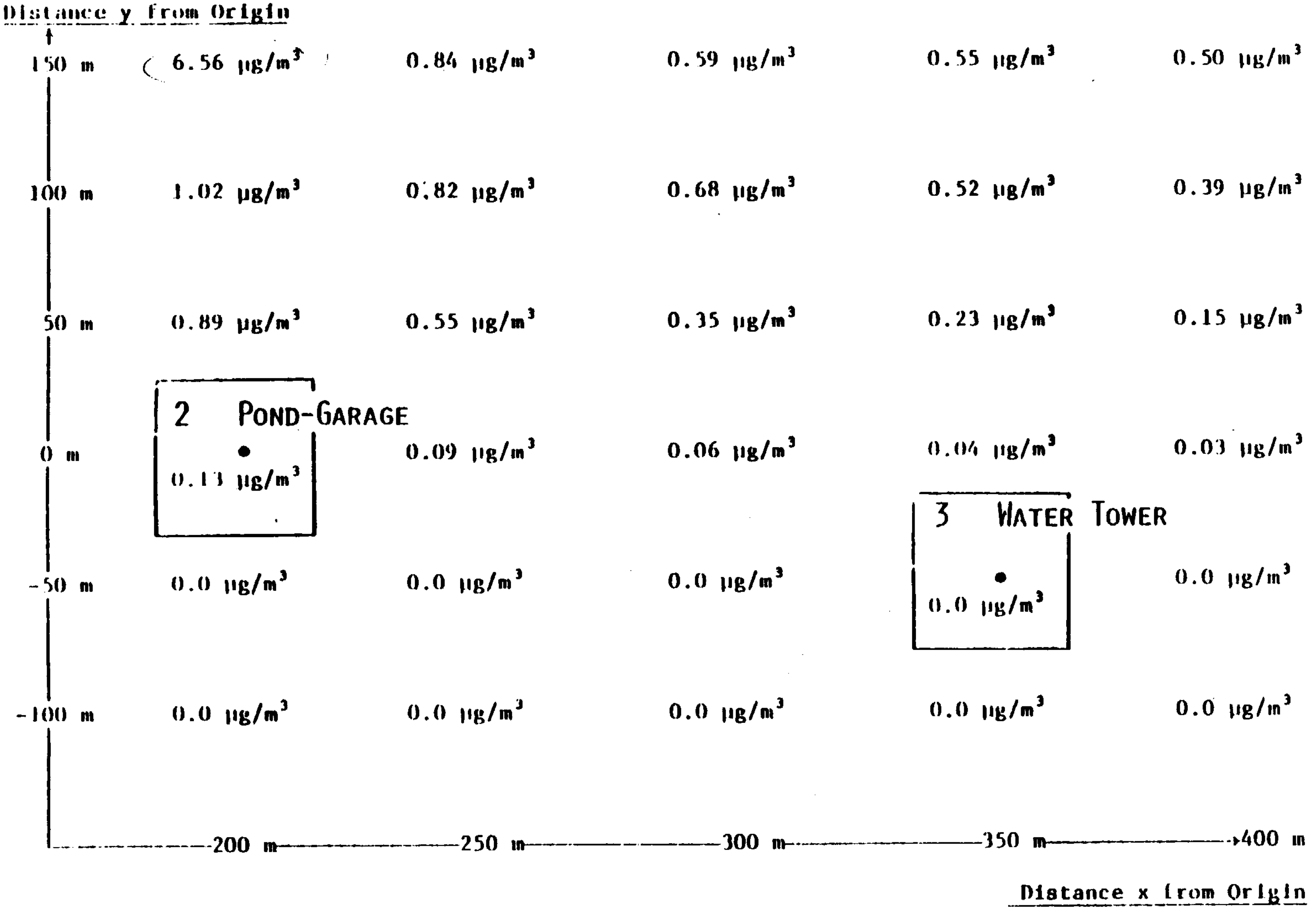


FIGURE 6-5. ISCST MODEL RECEPTOR GRID



Distance y from Origin	200 m	250 m	300 m	350 m	400 m
150 m	6.56 μg/m³	0.84 μg/m³	0.59 μg/m³	0.55 μg/m³	0.50 μg/m³
100 m	1.02 μg/m³	0.82 μg/m³	0.68 μg/m³	0.52 μg/m³	0.39 μg/m³
50 m	0.89 μg/m³	0.55 μg/m³	0.35 μg/m³	0.23 μg/m³	0.15 μg/m³
0 m	0.13 μg/m³	0.09 μg/m³	0.06 μg/m³	0.04 μg/m³	0.03 μg/m³
-50 m	0.0 μg/m³	0.0 μg/m³	0.0 μg/m³	0.0 μg/m³	0.0 μg/m³
-100 m	0.0 μg/m³	0.0 μg/m³	0.0 μg/m³	0.0 μg/m³	0.0 μg/m³

FIGURE 6-6. ISCST RECEPTOR GRID CONCENTRATIONS (μg/m³) FROM THE THREE POINT SOURCES. HI-VOL SITES 2 AND 3 AND THEIR RESULTING CONCENTRATIONS ARE ALSO SHOWN. VALUES SHOWN ARE 19 HOUR AVERAGES.

ASSESSMENT OF EMPLOYEE EXPOSURE CONTROL

As described in Section 4, the assessment of employee exposure controls considered the following types of information:

- Air sampling for workroom contaminants.
- Observation of work practices, use of protective clothing and equipment, housekeeping and personal hygiene.
- Biological monitoring data.
- Engineering measurements and observations relative to performance and design of engineered exposure controls.

Although occupational permissible exposure limits were used for reference in this evaluation, the major focus was not to determine the compliance status of the smelter.

Conditions at this smelter allowed study of retrofitting available control technology to common smelting equipment. In some instances, comparison between the totally uncontrolled and controlled state could be made. Other situations offered comparisons between existing and improved control of specific operations. Finally, the adaptability of the Bergsøe agglomeration furnace to a US smelter could be assessed.

Workplace Air Contamination and Employee Exposures

The initial evaluation found the workplace to be heavily contaminated by airborne lead. Breathing zone and work area measurements were made on two consecutive workdays in January of 1979. All smelter jobs involved exposures to breathing zone concentrations of lead ranging from near 200 $\mu g/m^3$ to many times that value. Work area monitoring indicated relatively lower airborne lead concentrations than found in worker breathing zones. This result indicated that employee exposures were influenced by the close proximity of their work to sources of lead emission. Rotation between jobs at midshift had been practiced for several quarters to lessen the impact of extremely high exposures associated with some jobs.

The follow-up evaluation, which was conducted in August, 1980, indicated that control of employee exposures to airborne lead had been dramatically improved. This evaluation was conducted immediately following a major shutdown for maintenance and clean-up. Job rotation at midshift had been discontinued.

Eight-hour time-weighted average exposures in the battery breaking facility were below 50 $\mu g/m^3$. Exposures associated with work in the main smelter building and yard areas were below 200 $\mu g/m^3$. The exposure of the agglomerator furnace operator was found to be the highest, averaging 410 $\mu g/m^3$ for all time monitored during the two days.

Work area measurements indicated relatively lower airborne lead concentrations during the day shift when employee exposures were measured. These results paralleled those of the initial evaluation and suggested that work conducted near specific sources of emission caused increases in breathing zone lead concentrations. Work area monitoring conducted during the evening and night shifts indicated relatively less effective workplace control of airborne lead for these periods. This finding and observations of smelter operation suggest that employee exposures would tend to be somewhat higher during sustained smelter operation that those measured during the follow-up evaluation.

Exposure monitoring data provided by the smelter were reviewed. Job rotation and redefinition of some jobs prevented detailed analyses. However several relevant conclusions are drawn. First, exposures measured during the initial evaluation were similar in magnitude to those reported by the smelter for sampling conducted in the same general time period. Second, simultaneous, opposite shoulder sampling conducted by the smelter at the time of the follow-up evaluation was in good agreement with the exposures measured in this study. Third, exposures at the smelter have varied over a wide range which do not correlate with changes of season or weather. In the months directly preceding the follow-up evaluation, exposures appear to have been on the decline to levels approaching those found in August.

Monitoring of employee exposures to antimony and sulfuric acid mist was conducted during both the initial and follow-up evaluations. All quantifiable exposures were well below the applicable permissible exposure limits.

Limited monitoring for arsenic-in-air and carbon monoxide was conducted during the follow-up evaluation. Exposures to arsenic associated with the production of arsenic lead were measurable, but well below the permissible exposure limit (29 CFR 1910.1018). A cursory survey of all smelter work areas using a direct reading carbon monoxide detector, failed to discover areas where significant exposure was likely.

Employee Blood Lead Levels

East Penn Manufacturing provided blood lead data for smelter workers covering the period January, 1977, through September, 1980. The average blood lead level for all smelter workers has decreased through this period from between 65 and 70 µg Pb/100g whole blood to approximately 50 µg Pb/100g whole blood. This reduction was in part due to removal of persons with high blood lead levels from smelter work and the introduction of new smelter workers with low blood lead levels.

An analysis of average blood lead levels for nine workers who have worked in the smelter since January, 1977, was made. Their mean blood lead levels also appeared to be slowly falling. In 1977, it was approximately 65 μg Pb/100g, and in 1980 the mean is closer to 60 μg Pb/100g whole blood. With improved exposure control, a greater decrease in blood lead levels would have been expected. It could not be determined whether the continuation of elevated blood lead levels was due to new exposure to lead or from gradual release of lead to the blood from other body tissues.

Evaluation of Workplace Exhaust Ventilation Control Systems

At the time of the initial evaluation, some exhaust service was provided to major emission sources from the blast furnace. Refining kettle No. 1 also had some exhaust service. The entire system consisted of exhaust hoods which partially enclosed or skirted sources of emission. Only the slag tapping hood was found to have a relatively vigorous volumetric exhaust rate and significant face velocity. The other hoods served by a 4.4 m^3/s (9,500 scfm) baghouse were weakly exhausted. Face velocities were low and emissions were observed to escape the hoods. Several sources of workplace lead emission were not served by exhaust ventilation. They included: the battery breaker, refining kettle No. 2 and the pigging machine.

As part of the initial evaluation, an inventory of sources contributing to employee lead exposure was compiled. This inventory and recommendations for improved control were provided to the smelter in an interim report. These items are included in Appendix C of this report. The smelter was not obligated to implement these recommendations.

Prior to the follow-up evaluation, the smelter upgraded exhaust ventilation control of workplace emission sources. The design engineering for changes to the exhaust system was provided by the plant engineering staff. Fabrication and installation was performed by a combination of outside contractors and plant labor. At the heart of the upgraded control system is a new exhaust fan and baghouse to replace the old 4.4 m^3/s (9,500 scfm) system. The measured operating exhaust rate for the new system is 18.0 m^3/s (39,000 scfm).

In general, the new systems and increased exhaust air flow improved control of many emission sources. In several cases even better control could be achieved by further refinement of exhaust enclosure designs and balancing of exhaust air service to the various hoods. In other situations improved control will be dependent on closer control of blast furnace operation to preclude near burnthrough conditions.

A new exhaust system was also provided for the battery breaking facility. This system dramatically improved control of employee exposures. For the two non-consecutive days monitored, exposures were below 50 $\mu g/m^3$ on an eight-hour time-weighted average basis.

Exhaust service and enclosures associated with the agglomeration furnace were observed to have varying degrees of effectiveness. Exhaust control for flue dust feeding to the furnace was ineffective. This was due to poor design of the tote box dumping station and basic materials handling/furnace operation difficulties affecting the gravity dust feed chute. The furnace tapping hood appeared to perform satisfactorily.

Housekeeping

The initial evaluation conducted at this smelter identified a number of sources of employee exposure to lead which were directly attributable to housekeeping considerations. These sources which related mainly to reentrainment of settled dust by materials handling, wind, traffic movement, equipment vibration, etc., were inventoried and presented in an interim report to the smelter.

East Penn Manufacturing recognized the housekeeping problems associated with leady flue dust long before this study was initiated. The smelter hoped to greatly improve flue dust handling by converting it to a solid material using an agglomeration furnace. As discussed elsewhere, poor agglomerating properties of the flue dust at this smelter and other difficulties have precluded the success of this control approach.

Although the agglomeration furnace did not fulfill all expectations, many other housekeeping improvements initiated by the smelter have helped to control workplace lead levels. They include:

- Cessation of recycling flue dust to the blast furnace.
- Installation of a central vacuum system.
- Paving of yard areas.
- Wetting of floors and materials in the main smelter building.
- Prohibition of dry sweeping and shovelling.
- Frequent mechanical vacuum sweeping of yard areas.

Even though great strides have been made, improvement in housekeeping and materials handling remain the two areas where substantial improvement is necessary if employee exposures are to be reduced to 100 or 50 ug/m^3. Conveying and handling of flue dust continues to be a major contributor to workplace contamination and employee exposures.

Personal Protective Equipment and Hygiene Practices

General improvements in respiratory protection, provision of clean work clothing and cleanliness of lockerroom and lunchroom facilities were observed between the initial and follow-up evaluations. Provisions for cleaning work clothing before entering the lunchroom still need to be provided.

COSTS OF NEW CONTROL SYSTEMS AND PRACTICES

East Penn Manufacturing has made large capital expenditures to improve control of environmental and workplace contamination by lead. Nearly $600,000 in capital expenditures has been committed. Of this amount, somewhat in excess of $100,000 has been spent for purchasing, installing and modifying the agglomeration furnace and associated equipment. The remaining funds were used for more traditional exhaust ventilation controls, a central vacuum system, yard paving and a laundry facility. The controls purchased with these expenditures have reduced employee exposures in most smelter work areas to below or near the 200 $\mu g/m^3$ level.

The new local exhaust ventilation system serving most of the smelter work areas was purchased and installed for approximately $11/scfm. This figure does not include system design costs. Purchases and installation were made in 1978, 1979 and 1980.

SECTION 7

REFERENCES

1. Coleman, R.T., Jr., and R. Vandervort, Evaluation of the Paul Bergsφe and Son Secondary Lead Smelter, EPA-600/2-80-022, January, 1980.

2. <u>Technical Guidance for Controls of Industrial Process Fugitive Particulate Emissions</u>, EPA-450/3-77-010. PEDCO Environmental, Inc., March, 1977.

APPENDICES

APPENDIX A

BAGHOUSE DUST AGGLOMERATION
IN THE
SECONDARY LEAD INDUSTRY

Prepared by:

Klaus Schwitzgebel

INTRODUCTION

A key element to achieve a workroom lead concentration[1] of 50 μg/m^3 and 1.5 μg/m^3 at the fence line[2] in the secondary lead industry is the handling of the flue dust. One approach developed by Bergsøe, Copenhagen, is agglomeration of baghouse dust in a patented agglomeration furnace.[3]

A Bergsøe agglomeration furnace was installed at the East Penn secondary lead smelter. However, difficulties were encountered at this test site.

This technical note describes the characterization of Bergsøe, East Penn and General Battery's flue dust. Slag analyses are also given. Methods of investigation were energy dispersive X-ray fluorescence, X-ray diffraction and chemical analyses using atomic absorption, ICAP, differential thermal analysis and Differential Scanning Calorimetry.

The findings of this effort can be summarized as follows:

- Chlorine appears to be quite beneficial in the agglomeration of lead dusts due largely to the low melting point of $PbCl_2$ and due to eutectics formed at fairly low temperatures.
- The more prevalent use of PVC in battery manufacture in Europe than in the U.S. facilitates control of lead emissions from secondary smelters through easier flue dust agglomeration.
- As a result of this fact, European technology may not transfer to U.S. operation without some alterations or development work.
- Too large a buildup of $PbCl_2$ in systems where the baghouse dust is recycled can be easily remedied by leaching.

Survey Analyses of Flue Dust Samples

Energy dispersive X-ray fluorescence analysis was used to qualitatively characterize the flue dust samples. This technique has a detection limit in the order of a few percent. It covers the elements with an atomic number 9 (fluorine) and greater.

The Bergsøe samples showed lead and chlorine being present in major concentrations. Potassium and iron were found to be minor constituents. The non agglomerated flue dust samples collected at East Penn were markedly different. Lead was still found to be the major component, however, chlorine was present only in traces, whereas potassium was absent. Calcium was found to be present as a trace constituent. The sample received from General Battery contains lead, chlorine, potassium and calcium.

These qualitative results are summarized in Table A-1.

Determination of the Crystalline Phases

A Siemens goniometer using CuK_α - radiation was used to determine the major crystalline phases. Again, the Bergsøe and East Penn samples proved to be drastically different.

The Bergsøe flue dust proved to be composed of potassium lead chloride KPb_2Cl_5 as the major phase.

Lead chloride, $PbCl_2$, and lead sulfide, PbS, were indicated to be present in moderate concentration. On the contrary, lead and lead sulfide were the major phases in the East Penn samples. The findings of the X-ray diffraction investigation are summarized in Table A-2.

Quantitative Analyses of Flue Dust Samples

The analysis results of the Bergsøe, East Penn, and General Battery samples using quantitative chemical analysis procedures are given in Table A-3. The Bergsøe sample #1825 collected on September 26, 1978, was composed of 65% Pb, 26% Cl and 3.2% K. This translates to a molar ratio $K : Pb : Cl = 1 : 3.8 : 8.9$ or a ratio of $KPb_2Cl_5 : PbCl_2 = 1 : 1.8$.

The sample collected on September 27, 1978, showed the following composition. Pb = 60%, Cl = 24% and K = 4%. This corresponds to a molar ratio of $K : Pb : Cl = 1 : 2.8 : 6.6$ or $KPb_2Cl_5 : PbCl_2 = 1 : 0.8$.

The East Penn samples have a much higher lead concentration. Potassium was not detected while the chlorine concentration was between 1 and 3 percent.

Agglomeration Properties of Flue Dusts

The X-ray diffraction results indicated that the East Penn samples consisted of lead, lead oxide and lead sulfide as the major phases. The phase diagram of the system lead - lead oxide is shown in Figure A-1.[4] It is readily seen that lead melts at 326°C and PbO at 850°C. What is most important is the fact that the two compounds form two individual phases in

TABLE A-1. FLUE DUST COMPOSITION - SEM SURVEY ANALYSES

Sample	Collected	Pb	Cl	K	Ca	Fe
Bergsøe 1825 Baghouse dust	Sept. 26-78	major	major	minor	-	minor
Bergsøe 1826 Baghouse dust	Sept. 27-78	major	major	minor	-	minor
Bergsøe Agglomerated Baghouse dust	Sept. 1978	major	medium	trace	-	trace
East Penn 1742 Non agglomerated Baghouse dust	Sept. 20-79	major	trace	-	trace	-
East Penn 1743 Non agglomerated Baghouse dust	Sept. 21-79	major	trace	-	trace	-
Synthetic KPb_2Cl_5		major	major	minor	-	-

(Continued)

TABLE A-1 (Continued). FLUE DUST COMPOSITION - SEM SURVEY ANALYSES

Sample	Collected	Pb	Cl	K	Ca	Fe
Agglomerated Baghouse dust East Penn from Storage Pile	Jan. 9, 1980	Major	Trace	-	Trace	-
Non Agglomerated Baghouse dust East Penn	Jan. 9, 1980	Major	Trace	-	Trace	-
Agglomerated Baghouse dust East Penn	Jan 9, 1980	Major	Trace	-	-	Trace
Non Agglomerated Baghouse dust General Battery	Received Jan. 7, 1980	Major	Minor	Trace	Trace	-

TABLE A-2. X-RAY DIFFRACTION RESULTS OF THE FLUE DUSTS

Source	Sample	Collected	KPb_2Cl_5	$PbCl_2$	PbS	Pb	$2PbO \cdot PbSO_4$	α-$3PbO \cdot PbCl_2$	$2PbO \cdot 3PbCl_2$	$PbSO_4$	$2PbO \cdot PbCl_2$	Other	Unidentified*
I	Bergsøe 1025 Baghouse Dust	Sept. 26, 1978	Major	Mod.	Mod.								
	Bergsøe 1026 Baghouse Dust	Sept. 27, 1978	Major	Mod.	Mod.								
II	East Penn 1742 Non Agglomerated Baghouse Dust	Sept. 20, 1979			Major	Minor To Trace		Mod.	Mod.				Mod.
	East Penn 1743 Non Agglomerated Baghouse Dust	Sept. 21, 1979			Major	Trace	Mod.						Mod.
	East Penn 1744 Non Agglomerated Baghouse Dust	Oct. 31, 1979			Major	Mod.		Mod.		Mod.			Mod. To Minor
	East Penn 1745 Agglomerated Baghouse Dust	Oct. 31, 1979			Major	Mod.					Mod. To Minor		Mod.
	East Penn Agglomerated from Pile	Jan. 9, 1980			Major	Minor		Mod.				$PbO \cdot PbSO_4$ Mod. PbO Trace	Mod.
	East Penn Non Agglomerated Baghouse Dust	Jan. 9, 1980			Major	Mod.				Mod.		$PbO \cdot PbSO_4$ Major	Mod.
	East Penn Agglomerated Baghouse Dust	Jan. 9, 1980			Major	Trace						PbO Trace $2PbO \cdot PbSO_4$ Mod.	Mod.
III	Baghouse Dust General Battery	Rec'd Jan. 1, 1980		Major						Major		$PbO \cdot PbSO_4$ Mod.	Mod.
	Melting Point		440°C	496°C	1114°C	326°C	960°C	710°C	530°C	1170°C	711°C		

*Unidentified crystal patterns are believed to be various stoichiometries of $xPbO \cdot yPbCl_2$.

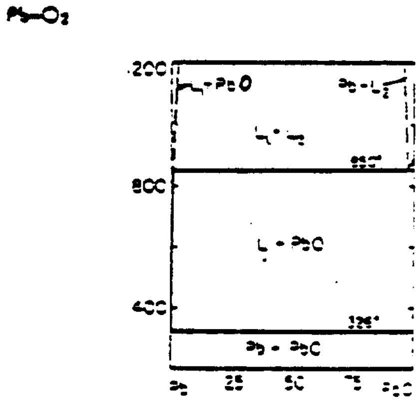


FIGURE A-1. SYSTEM Pb-PbO

TABLE A-3. FLUE DUST COMPOSITION

Source	Sample	Collected	% Pb	% Cl	% K	Remarks
I	Bergsøe 1825 Baghouse dust	Sept. 26-78	65	26	3.2	Molar ratio K : Pb : Cl = 1 : 3/8 : 8.9 or 1 KPb_2Cl_5 : 1.8 $PbCl_2$
	Bergsøe 1826 Baghouse dust	Sept. 27-78	60	24	4	Molar ratio K : Pb : Cl = 1 : 2.8 : 6.6 or 1 KPb_2Cl_5 : 0.8 $PbCl_2$
II	East Penn 3742 Non agglomerated Baghouse dust	Sept. 20-79	78	3		
	East Penn 3743 Non agglomerated Baghouse dust	Sept. 21-79	99	1		
	East Penn 3744 Non agglomerated Baghouse dust	Oct. 31-79	79	1.4		
	East Penn 3745 Agglomerated Baghouse dust	Oct. 31-79	86			Sample consisted of 95% elemental lead. The rest contained 86% Pb

(Continued)

TABLE A-3 (Continued). FLUE DUST COMPOSITION

Source	Sample	Collected	% Pb	% Cl	% K	% S	Remarks
II	East Penn Agglomerated from Pile	Jan. 9, 1980	65	2.5	.32	3.9	
	East Penn Non Agglomerated	Jan. 9, 1980	70	1.7	.31	4.8	
	East Penn Agglomerated	Jan. 9, 1980	64	1.5	.30	3.8	
III	Baghouse Dust General Battery	Received Jan. 7, 1980	53	8.5	1.3	6.6	

this temperature regime, namely liquid lead and solid lead oxide. Liquid lead does not wet lead oxide. An agglomeration of a mixture of the two components is, therefore, not possible below 850°C.

The phase diagram of the KCl-$PbCl_2$-$CaCl_2$ system is reproduced in Figure A-2.[5]

The lowest melting temperatures are indicated for the $PbCl_2$-KCl system. Two intermediates are formed namely $2PbCl_2 \cdot KCl$ and $PbCl_2 \cdot 2KCl$. These compounds can be synthesized by melting KCl and $PbCl_2$ in the indicated stoichiometric amount. The lowest melting temperature is 411°C for a mixture of 50% $PbCl_2$ - 50% KCl.

The binary phase diagram of the system $PbCl_2$-KCl, shown in Figure A-3[6] indicates a third potassium-lead-chloride compound, namely $4KCl \cdot PbCl_2$. This double salt melts at 480°C. The lowest melting eutectics exist at 20 and 50 mole percent KCl. The melting temperatures are 410 and 405°C respectively.

The X-ray diffraction results showed the presence of lead chloride-lead oxides. The binary phase diagram $PbCl_2$-PbO is reproduced in Figure A-4.[6] Compounds considered are: $PbCl_2 \cdot PbO$, $PbCl_2 \cdot 2PbO$, and $PbCl_2 \cdot 4PbO$. The melting temperatures are given as 524°C, 693°C and 711°C. The lowest eutectic is at 430°C consisting of a mixture of 20% PbO and 80% $PbCl_2$.

The X-ray diffraction literature points to the existence of a series of other compounds of the general composition $xPbO \cdot yPbCl_2$, like:

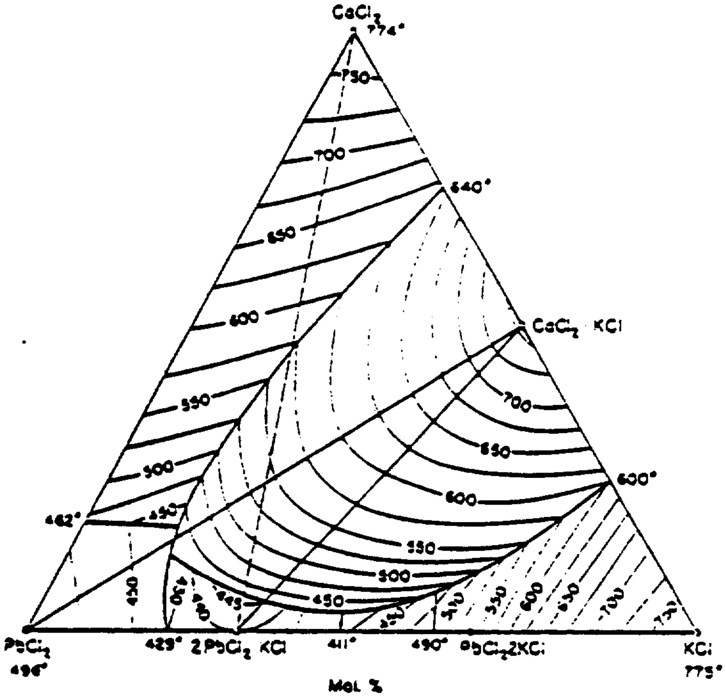
- αPbO - $PbCl_2$ (melting point 710°C), and,
- $2PbO$ - $3PbCl_2$ (melting point 530°C).

A synthetic sample of $KCl \cdot 2PbCl_2$ was produced by melting KCl and $PbCl_2$ in a 1:2 molar ratio at 500°C. The liquid $KCl \cdot 2PbCl_2$ behaved like a liquid of low surface tension. It readily wetted PbO. The mixture formed a glassy compound upon solidification. These facts explain the different results obtained in agglomeration attempts of Bergsoe and East Penn flue dusts.

Vapor Pressures

A compound can enter the flue gas by two mechanisms, either by physical entrainment or by evaporation in the blast furnace and condensation in the flue gas cooler. The blast furnace temperatures are between 800°C - 1100°C. The vapor pressures of Pb and $PbCl_2$ are high enough in this temperature range that the evaporation-condensation mechanism plays an important role in the mass transfer.

$KCl–CaCl_2–PbCl_2$



—System $KCl–CaCl_2–PbCl_2$.

Ya. A. Ugai, *Doklady Akad. Nauk S.S.S.R.*, 70 [4] 553 (1950).

FIGURE A-2. PHASE DIAGRAM OF THE KCl - $CaCl_2$ - $PbCl_2$ SYSTEM

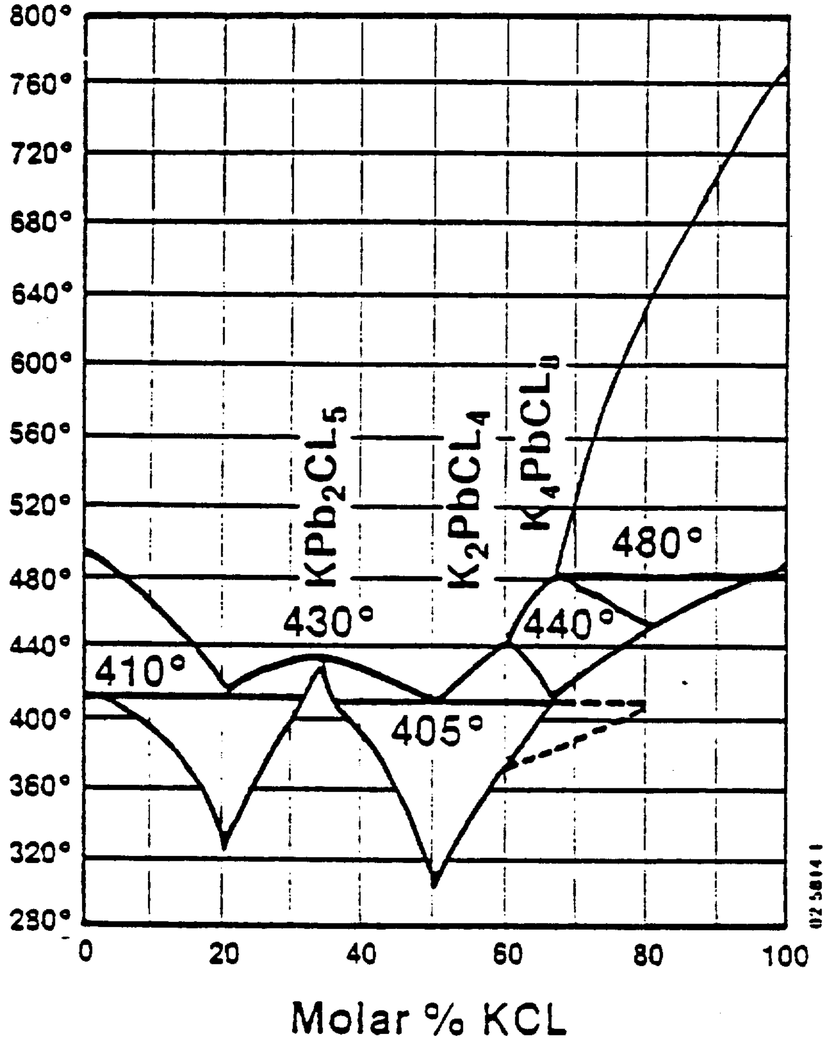


FIGURE A-3. PHASE DIAGRAM OF THE BINARY SYSTEM $PbCL_2 \cdot KCL$

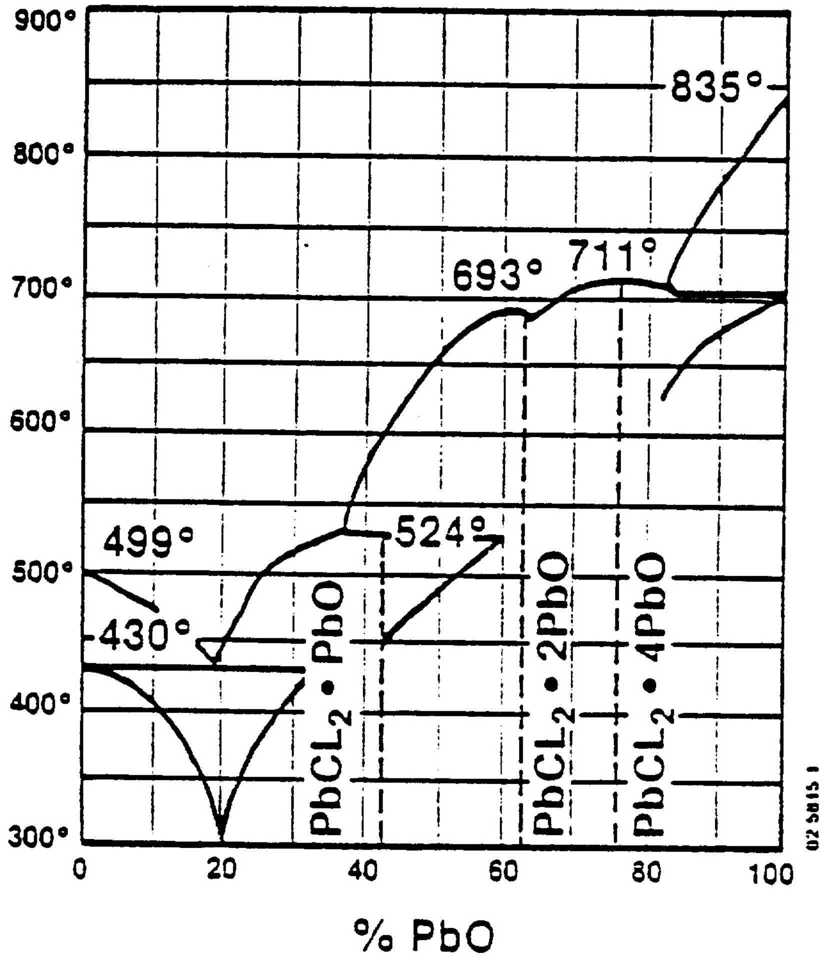


FIGURE A-4. PHASE DIAGRAM OF THE BINARY SYSTEM $PbCL_2 \cdot PbO$

The Handbook of Chemistry and Physics lists vapor pressures shown in Table A-4. These data were used to construct the vapor pressure curves in Figure A-5.[7] The evaporation rate of Pb, KCl and $PbCl_2$ as a function of blast furnace temperature was calculated from these data. The results are shown in Table A-5. The gas flow rate in the blast furnace was assumed to be 4,000 Nm^3/hr.

It is readily seen that all the $PbCl_2$ is evaporated in the blast furnace. Recycling of baghouse dust will build up the $PbCl_2$ in the system. This is desirable since $PbCl_2$ is a good agglomeration agent. This practice is used by Bergsøe. Potassium chloride also extends an appreciable vapor pressure and can be expected to be evaporated.

The vapor pressure of lead is lowest. However, in the range of 1000°C - 1100°C, an appreciable carryover can be expected. This seems to be the case at East Penn.

Slag Composition

The Bergsøe and East Penn slags were qualitatively analyzed using energy dispersive X-ray fluorescence and quantitatively using ICAP. The results are shown in Table A-6.

The Bergsøe slag contains a higher concentration of alkaline metals. The presence of these compounds tend to lower the slag melting temperature. This is substantiated by the findings of the differential thermal analysis (DTA). The Bergsøe sample showed a compound melting at 820°C, whereas the first endothermic peak of the East Penn sample showed at 853°C.

Thermal Analysis

Bergsøe samples #1825 and #1826, the General Battery sample and a non agglomerated East Penn sample were subjected to Differential Scanning Calorimetry. The Bergsøe samples showed large endotherms in the range from 360°C to 700°C. This finding is in agreement with the chemical analysis results and the X-ray diffraction findings and the phase diagrams of the KCl - $PbCl_2$ and $PbCl_2$ - PbO systems.

The sample obtained from General Battery showed two endotherms at 430°C and 610°C. The endotherms were much smaller than those obtained from Bergsøe #1826.

East Penn unagglomerated baghouse dust collected on January 9, 1980, showed a broad, however small endotherm between 500 - 580°C.

TABLE A-4. VAPOR PRESSURES OF $PbCl_2$, KCl AND Pb IN mm Hg^7

Compound	Formula	Temperature °C					
		1 mm	10 mm	40 mm	100 mm	400 mm	760 mm
Lead chloride	$PbCl_2$	547	648	725	784	893	954
Potassium chloride	KCl	821	968	1078	1164	1322	1407
Lead	Pb	973	1162	1309	1421	1630	1744

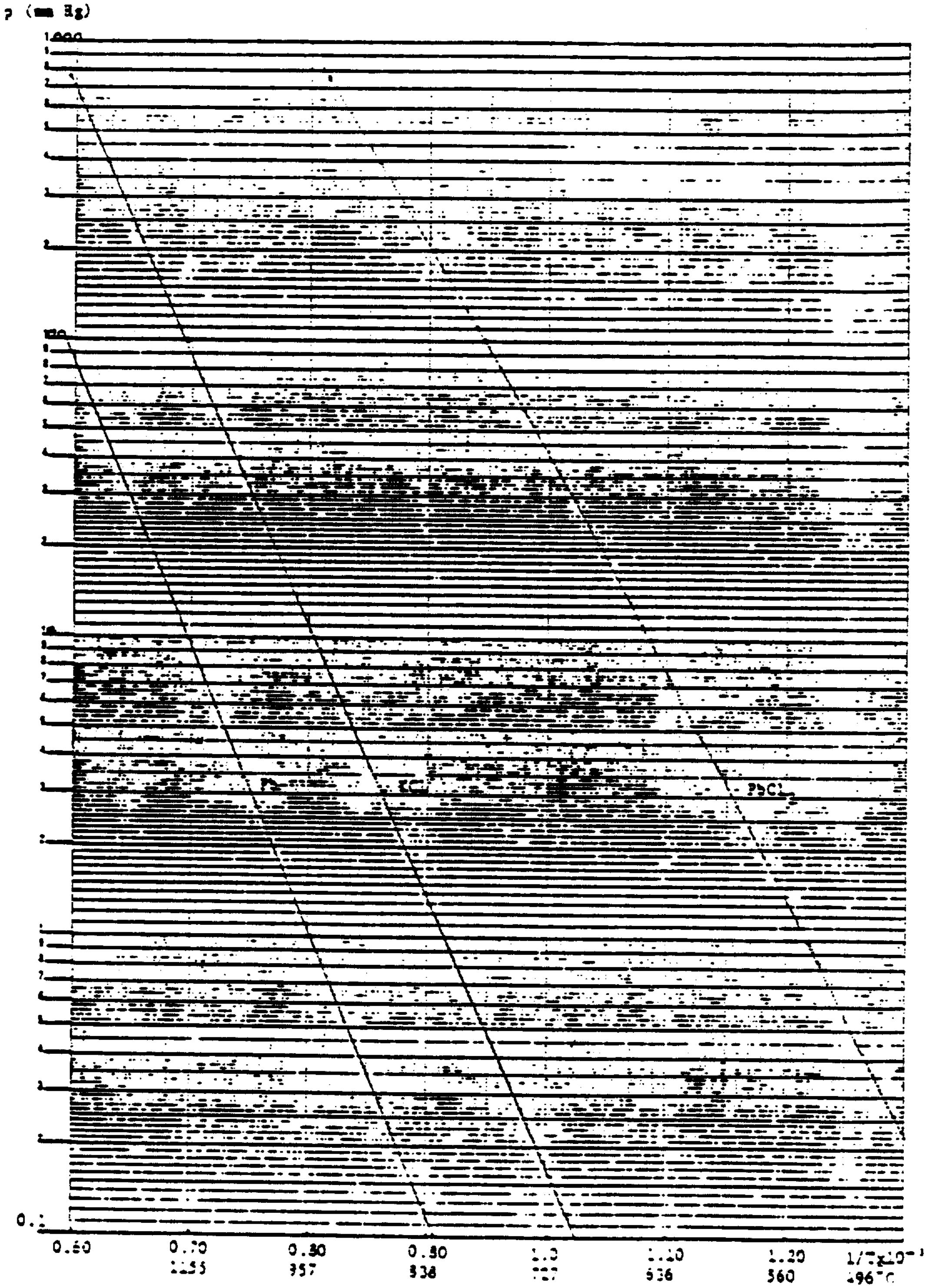


FIGURE A-5. VAPOR PRESSURES OF Pb, KCl AND $PbCl_2$ AS FUNCTION OF TEMPERATURE

TABLE A-5. EVAPORATION RATES IN THE BLAST FURNACE

Furnace Temperator °C	Pb kg/day	$PbCl_2$ kg/day	KCl kg/day
1,155	10,500		
977	1,200		4,700
838	140		592
727	16	63,000	72
636	2	11,000	
560		2,000	

TABLE A-6. SLAG ANALYSIS BY SEM AND ICAP (VALUES IN PERCENT)

Sample	Method	Na_2O	K_2O	MgO	CaO	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	ZnO	S	Cl
Bergsoe	SEM	trace	trace	trace	major	major	minor	major	trace	trace	moderate	minor
#1822	ICAP	2.5	0.7	1.6	11.2	30.0	7.9	33.4	0.4	1.0		
East Penn	SEM	-	-	trace	major	minor	minor	major	trace	trace	moderate	minor
#2170	ICAP	0.3	0.2	1.4	25.2	19.3	7.4	34.7	0.4	.4		

Agglomeration was possible in the following temperature ranges:

Bergsøe #1826	410°C
General Battery	650°C
East Penn	900°C

These findings potentially have a profound impact with regard to the optimum agglomeration furnace design. The findings of the thermal analysis studies are summarized in Table A-7.

Chlorine Source

The battery plates are separated by nonconductive materials to avoid shorts. Compounds used for this purpose are microporous rubber, extruded polyethylene sheet, heat fused PVC sheet, fiberglass coated wood pulp, and impregnated cellulose.

Industrial and other long life batteries use microporous rubber, fiberglass coated wood pulp, or PVC. It is estimated that about 50% of the industrial batteries contain PVC separators.[8] In contrast, normal car batteries contain mainly resin impregnated cellulose. Only about 3% of the U.S. car batteries are manufactured with PVC separators. The newest maintenance free batteries contain polyethylene enveloped battery plates. This is in contrast to European batteries in which PVC is used to an estimated extent of 25 - 30 percent.[9]

This has an important consequence. Much less chlorine is introduced into U.S. secondary lead smelters than in Europe. This causes the different dust compositions and the different agglomeration properties described previously.

Chlorine Cycle

The chlorine-containing battery plate separators break down in the blast furnace. The liberated chlorine combines with lead to form $PbCl_2$.

Recycling of the $PbCl_2$ leads to its builduip in the system. A slip stream eventually needs to be treated for $PbCl_2$ removal. This can be done by leaching. The solubility of $PbCl_2$ in water is 10 g/l at 20°C and 33 g/l at 100°C.[10]

TABLE A-7. SCANNING COLORIMETRY RESULTS

Sample	Endotherms °C	Estimated Concentration	Remarks
Bergsøe 1825	370 385 518 565 708	Large Endotherms	
Bergsøe 1826	362 385 568 600 635	Large Endotherms	Agglomeration was possible at 410°C
General Battery	430 610	Both Endotherms small	Good Agglomeration was possible at 650°C
East Penn	500–580	Large broad Endotherms	Agglomeration was possible at 900°C

REFERENCES

[1] Federal Register, Vol. 43, No. 220, Tuesday, Nov. 14, 1978, p. 52952.

[2] Federal Register, Vol. 43, No. 194, Thursday, Oct. 5, 1978, p. 46246.

[3] T. S. Mackey and Svend Bergs e, Flash Agglomeration of Flue Dust, J. Met., 29 (11) (1977), p. 12.

[4] E. Gebhardt and Walter Obrowski, Uber den Aufbau des Systems Kupfer-Blei-Sauerstoff, Z. Metall R., (45), 1954, p. 333.

[5] Ya. A. Ugai, Doklady Akad. Nauk S.S.S.R. 70[4], 653 (1950).

[6] J. W. Mellor, Comprehensive Treatise on Inorganic and Theoretical Chemistry, Vol. 7, New York, Longmans, Green, and Co., 1927, p. 728 and p. 736.

[7] Handbook of Chemistry and Physics, 59th Edition, CRC Press, 1978-1979, D-235 through D-239.

[8] Karl Keckan, Ford Motor Company, Battery Division, telephone communication, June, 1980.

[9] F. C. Keller, East Penn Manufacturing Company, Inc., Lyons Station, PA, 19536, oral communication, August, 1980.

[10] Handbook of Chemistry and Physics, 59th Edition, CRC Press, 1978-1979, B-129.

APPENDIX B

PARTICLE SIZING DATA

Prepared by:

Larry J. Holcombe

and

William C. Hawn

PARTICLE SIZING DATA

A summary of the results of the University of Washington Cascade Impactor runs is presented in Tables B-1 through B-3. Table B-1 describes the stack and sampling conditions for each impactor run. In Table B-2 the size cuts that were analyzed for total lead are identified. The total grain loading for each of the size cuts is presented. The three or four size cuts were selected based on their similarity to the proposed cut-offs for inhalable (2.5 microns) and respirable (15 microns) particles. In Table B-3 the lead emission rates for each size cut are listed.

Following Table B-3 are the computer printouts of the in-stack cascade impactor results. For each sampling period the following information is presented:

- The interval endpoints in microns for each stage of the impactor.
- The mass fraction collected on each stage.
- The interval geometric midpoint.
- The grain loading for each size interval.

Two graphs are presented for each sample run; one showing mass fraction less than a given aerodynamic particle diameter and the other presenting the differential mass concentration plot.

TABLE B-1. WASHINGTON MK-5 IMPACTOR RUNS

Sample Identifier	Date	Percent Isokinetic	Stream Flow Rate (DSM^3/M)[1]	Stream Velocity (M/sec)	Stream Temperature (°C)	Volume Sampled (DSM^3)[1]	Total Particulate Emissions (g/hr)[2]	Total Pb Emissions (g/hr)[3]
Slag Tap Baghouse-In								
Impactor-1	08-05-80	98.4	7,000	19.14	46.1	1.686	1,300	870
Impactor-2	08-06-80	101.0	6,800	18.30	46.1	1.831	1,800	910
Slag Tap Baghouse-Out								
Impactor-1	08-05-80	95.6	8,600	22.06	46.1	2.369	30	14
Impactor-2	08-06-80	106.9	7,900	20.24	51.0	2.674	38	35
Blast Furnace Metal Tapping								
Impactor-1	08-12-80	76.1	18,000	25.22	34.1	1.459	570	290
Impactor-2	08-15-80	65	18,000	29.34	28.9	1.447	950	460
Blast Furnace Charging								
Impactor-2	08-12-80	146.5	11,000	9.73	56.1	0.0561	84,000	37,000
Impactor-4	08-15-80	139	9,100	9.85	56.1	0.0153	160,000	125,000
Sanitary Baghouse-In								
Impactor-3	08-09-80	101.4	62,000	16.95	65.5	0.470	50,000	23,000
Impactor-4	08-11-80	99.6	62,000	16.93	65.5	0.366	190,000	130,000
Sanitary Baghouse-Out								
Impactor-5	08-09-80	92.9	59,000	15.93	43.9	0.517	1,300	240
Impactor-6	08-11-80	78.6	56,000	18.63	57.2	0.771	245	64
Process Baghouse-Out								
Impactor-3	08-07-80	93.2	33,000	20.57	82.2	0.894	820	280
Impactor-4	08-08-80	92.6	32,000	21.88	71.1	1.944	260	84
Agglomerator								
Impactor-1	08-13-80	93.6	9,100	33.41	83.9	0.0331	72,000	50,000
Impactor-2	08-14-80	102.1	8,000	31.52	85.0	0.0339	85,000	53,000

---

[1] STP = 68°F, 760mm Hg

[2] Based on EPA Method 12 Runs

[3] Based on Lead Analysis of Impactor Substrates (gPb/g Particulate)

TABLE B-2. EMISSION RATES BY PARTICLE SIZE[1]

		Particle Size of Impactor Cuts for Pb Analysis (Microns)[2]				Total Particulate Emissions by Size Cuts (mg/DSM^3)[2,3]				Total Particulate Emissions[1] (g/hr)				
Sample Identifier	Date	Cut #1	Cut #2	Cut #3	Cut #4	Cut #1	Cut #2	Cut #3	Cut #4	Cut #1	Cut #2	Cut #3	Cut #4	Total Particulate Emissions (g/hr)
Slag Tap Baghouse-In														
Impactor-1	08-05-80	>36.2	36.2-3.0	<3.6		5.0	25	160		35	180	1,100		1,300
Impactor-2	08-06-80	>36.5	36.5-3.0	<3.0		77	43	150		530	290	1,000		1,800
Slag Tap Baghouse-Out														
Impactor-1	08-05-80	>13.3	13.3-2.5	<2.5		0.8	0.6	2.1		6.9	5.5	18		30
Impactor-2	08-06-80	>13.2	13.2-2.5	<2.5		0.1	1.6	3.1		0.8	13	24		38
Blast Furnace Metal Tapping														
Impactor-1	08-12-80	>30.2	30.2-5.1	<5.1		2.7	1.2	28		49	22	500		570
Impactor-2	08-15-80	>30.9	30.9-5.2	<5.2		5.9	1.6	45		110	29	810		950
Blast Furnace Charging														
Impactor-2	08-12-80	>38.0	38.0-3.2	<3.2		5,900	520	1,300		65,000	5,700	14,000		84,000
Impactor-4	08-15-80	>38.5	38.5-3.2	<3.2		8,100	860	8,600		74,000	7,800	78,000		160,000
Sanitary Baghouse-In														
Impactor-3	08-09-80	>38.2	38.2-3.2	<3.2		610	23	180		38,000	1,400	11,000		50,000
Impactor-4	08-11-80	>38.4	38.4-3.2	<3.2		1,700	340	1,100		105,000	21,000	68,000		190,000
Sanitary Baghouse-Out														
Impactor-5	08-09-80	>15.8	15.8-6.1	6.1-3.0	<3.0	3.0	3.0	2.3	14	180	180	140	830	1,300
Impactor-6	08-11-80	>36.2	36.2-6.1	<6.1		.02	0.6	3.8		1.1	34	210		245
Process Baghouse-Out														
Impactor-3	08-07-80	>12.7	12.7-2.4	<2.4		2.1	4.8	18		69	160	590		820
Impactor-4	08-08-80	>12.2	12.2-2.3	<2.3		1.0	1.8	5.3		32	58	170		260
Agglomerator														
Impactor-1	08-13-80		>5.0	5.0-2.5	<2.5		1,100	690	6,200		10,000	6,300	56,000	72,000
Impactor-2	08-14-80	>29.6	29.6-4.9	4.9-2.4	<2.4	810	940	1,600	7,200	6,600	7,500	13,000	58,000	85,000

[1] Based on Washington MK-5 Impactor Runs which have been normalized to duplicate the particulate grainloadings of the EPA Method 12 Runs

[2] Aerodynamic size (spherical particle, density = 1.0)

[3] STP = 68°F, 760mm Hg

TABLE B-3. LEAD EMISSIONS BY SIZE FRACTIONS[1]

		Particle Size of Impactor Cuts for Pb Analysis (Microns)[2]				gPb/g Particulate				Pb Emissions (g/hr)				
Sample Identifier	Date	Cut #1	Cut #2	Cut #3	Cut #4	Cut #1	Cut #2	Cut #3	Cut #4	Cut #1	Cut #2	Cut #3	Cut #4	Total Pb Emissions (g/hr)
Slag Tap Baghouse-In														
Impactor-1	08-05-80	>36.2	36.2-3.0	<3.0		0.85	0.57	0.67		30	100	740		870
Impactor-2	08-06-80	>36.5	36.5-3.0	<3.0		0.22	0.32	0.70		120	93	700		910
Slag Tap Baghouse-Out														
Impactor-1	08-05-80	>13.3	13.3-2.5	<2.5		0.06	0.52	0.61		0.4	2.9	11		14
Impactor-2	08-06-80	>13.2	13.2-2.5	<2.5		1.9	0.75	1.00		0.8	9.8	24		35
Blast Furnace Metal Tapping														
Impactor-1	08-12-80	>30.2	30.2-5.1	<5.1		0.66	0.66	0.49		32	15	245		290
Impactor-2	08-15-80	>30.9	30.9-5.2	<5.2		0.53	0.76	0.47		58	22	380		460
Blast Furnace Charging														
Impactor-2	08-12-80	>38.0	38.0-3.2	<3.2		0.35	0.76	0.71		23,000	4,300	9,900		37,000
Impactor-4	08-15-80	>38.5	38.5-3.2	<3.2		0.79	0.94	0.77		58,000	7,300	60,000		125,000
Sanitary Baghouse-In														
Impactor-3	08-09-80	>38.2	38.2-3.2	<3.2		0.36	0.75	0.72		14,000	1,100	7,900		23,000
Impactor-4	08-11-80	>38.4	38.4-3.2	<3.2		0.59	0.80	0.72		62,000	17,000	49,000		130,000
Sanitary Baghouse-Out														
Impactor-5	08-09-80	>15.8	15.8-6.1	6.1-3.0	<3.0	0.13	0.06	0.10	0.23	23	11	14	190	240
Impactor-6	08-11-80	>36.2	36.2-6.1	<6.1		1.3	0.18	0.27		1.1	6.1	57		64
Process Baghouse-Out														
Impactor-3	08-07-80	>12.7	12.7-2.4	<2.4		0.22	0.36	0.35		15	58	210		280
Impactor-4	08-08-80	>12.2	12.2-2.3	<2.3		0.37	0.37	0.34		5.4	21	58		84
Agglomerator														
Impactor-1	08-13-80		>5.0	5.0-2.5	<2.5		0.84	0.83	0.65		8,400	5,200	36,000	50,000
Impactor-2	08-14-80	>29.6	29.6-4.9	4.9-2.4	<2.4	0.87	0.36	0.68	0.62	5,700	2,700	8,800	36,000	53,000

[1] Based on Washington MK-5 Impactor Runs which have been normalized to duplicate the particulate grainloadings of the EPA Method 12 Runs

[2] Aerodynamic size (spherical particle, density = 1.0)

IMPACTOR RESULTS SUMMARY

SLAG TAP BAGHOUSE INLET

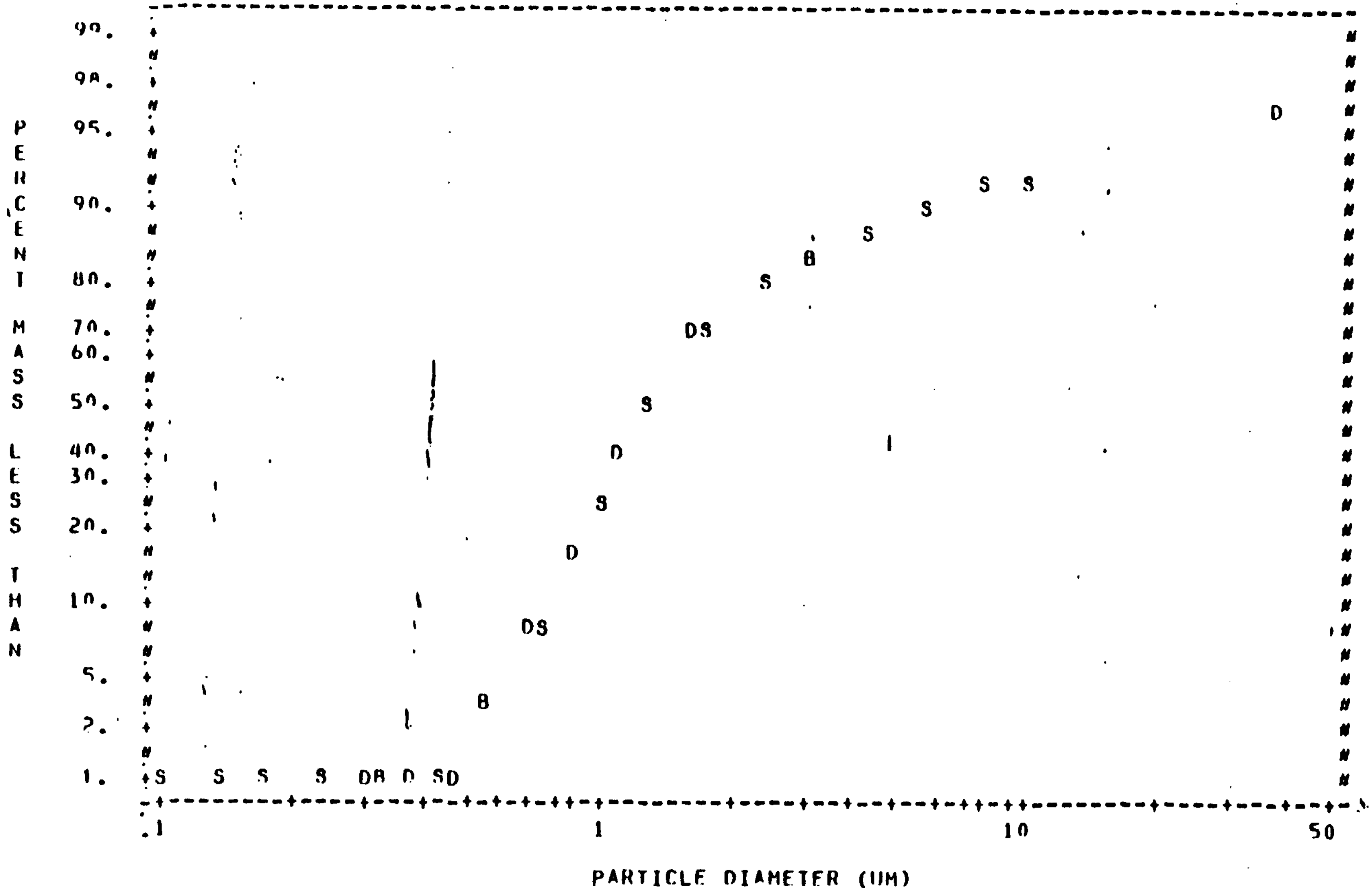
AUGUST 5, 1980

CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-1

PLANT NAME: EAST PENN
SAMPLING LOCATION: SLAG TAP BAG-/N
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  0/ 8/ 5 (MMDDYY)           TIME START: 16:35 (HHMM)          TIME FINISH: 19:50 (HHMM)

INTERVAL       INTERVAL          MASS          MASS           INTERVAL       DM/DLOG DP
   #           ENDPOINT        FRACTION      FRACTION        GEOMETRIC   DRY STAND. CONDITI
                                             LESS THAN       MIDPOINT      GR/DSCF      GMS/

   1            23.71           .0385         .9615 *         34.4336      .381E-02  .871E-0
   2            17.78           .0101         .9514 *         20.5352      .260E-02  .596E-0
   3            13.34           .0122         .9392 *         15.3992      .313E-02  .715E-0
   4            10.00           .0144         .9248 *         11.5478      .371E-02  .848E-0
   5             7.50           .0169         .9079 *          8.6596      .434E-02  .992E-0
   6             5.62           .0195         .8884 *          6.4938      .500E-02  .115E-01
   7             4.22           .0222         .8662 *          4.8697      .570E-02  .131E-01
   8             3.16           .0250         .8411 *          3.6517      .642E-02  .147E-01
   9             2.37           .0644         .7767            2.7384      .165E-01  .378E-01
  10             1.78           .0752         .7015            2.0535      .193E-01  .442E-01
  11             1.33           .1818         .5197            1.5399      .467E-01  .107E 00
  12             1.00           .2762         .2435            1.1548      .709E-01  .162E 00
  13              .75           .1498         .0937             .8660      .385E-01  .880E-01
  14              .56           .0572         .0365             .6494      .147E-01  .336E-01
  15              .42           .0313         .0052             .4870      .804E-02  .184E-01
  16              .32           .0046         .0006             .3652      .117E-02  .268E-02
  17              .24           .0000         .0006             .2738      .727E-05  .166E-04

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:               15.00  UM
MASS FRACTION LESS THAN:          .946
MASS LESS THAN:                   .030  GR/DSCF
                                  .069  GMS/M3
```

CUMULATIVE LOG PROBABILITY PLOT

SAMPLE IDENT: IMPAC-1

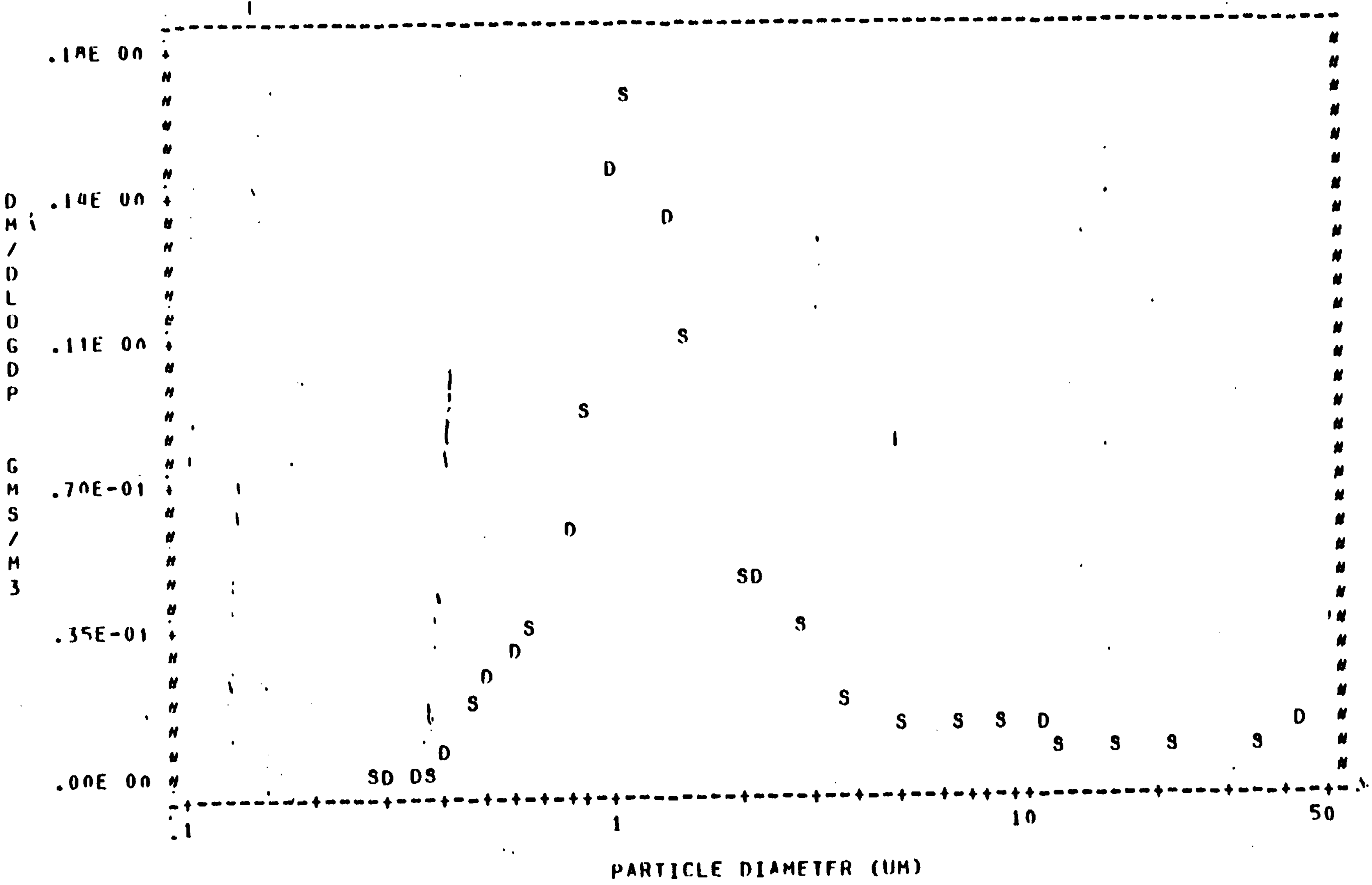


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

RADIAN CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-1



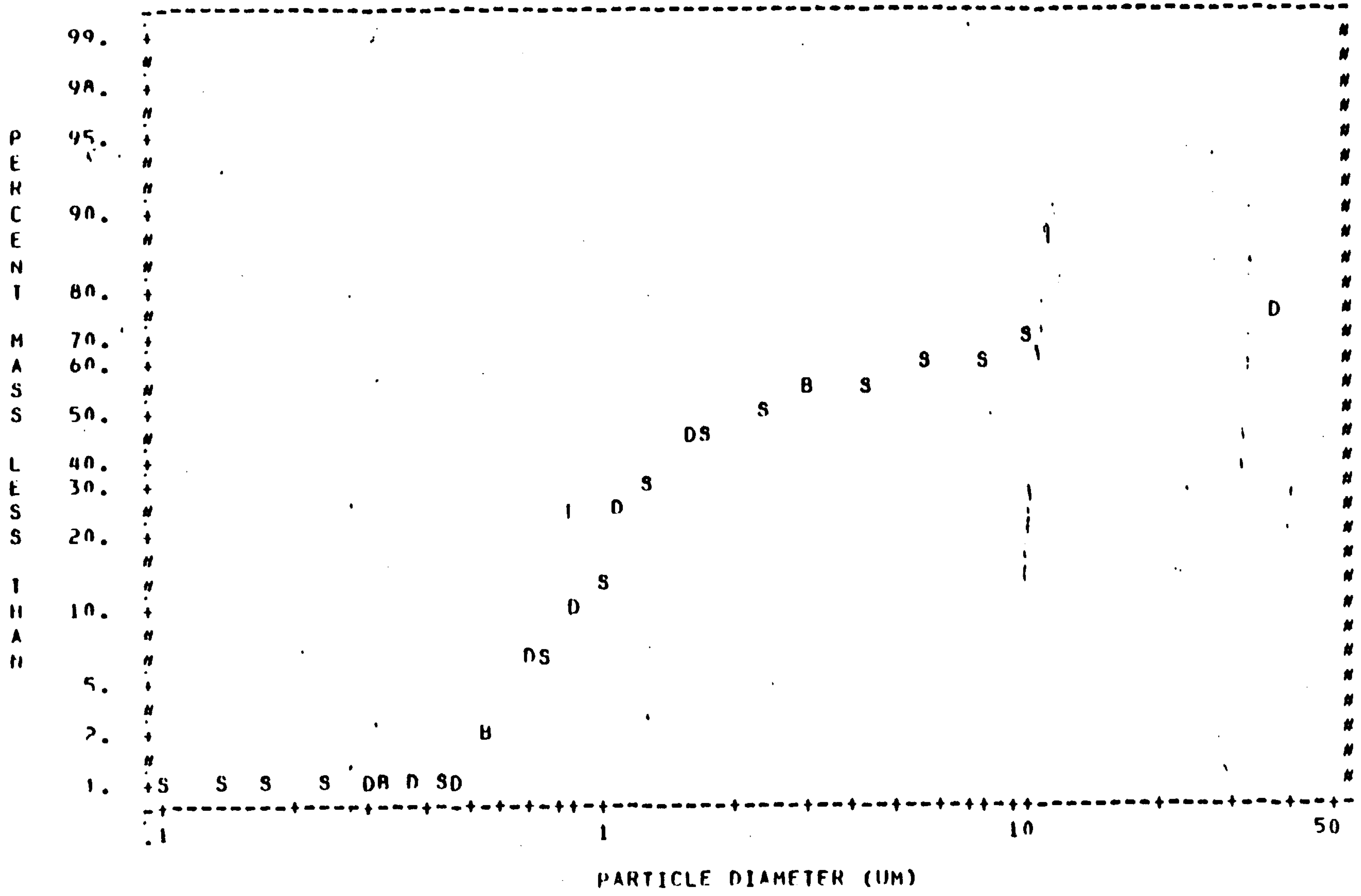
D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY
SLAG TAP BAGHOUSE INLET
AUGUST 6, 1980

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-2

PLANT NAME: EAST PENN
SAMPLING LOCATION: SLAG TAP BAG-IN
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/ 6/80 (MMDDYY)          TIME START: 12:25 (HHMM)          TIME FINISH: 16: 0 (HHMM)

INTERVAL       INTERVAL           MASS          MASS          INTERVAL          DM/DLOG DP
   #           ENDPOINT         FRACTION       FRACTION      GEOMETRIC     DRY STAND. CONDITI
                                               LESS THAN      MIDPOINT       GR/DSCF      GMS/

   1             23.71            .3036          .6964         34.4336      .327E-01   .748E-0
   2             17.78            .0106          .6859         20.5352      .295E-02   .675E-0
   3             13.34            .0125          .6734         15.3992      .348E-02   .796E-0
   4             10.00            .0151          .6583         11.5478      .422E-02   .966E-0
   5              7.50            .0186          .6396          8.6596      .520E-02   .119E-0
   6              5.62            .0230          .6166          6.4938      .643E-02   .147E-0
   7              4.22            .0283          .5883          4.8697      .790E-02   .181E-0
   8              3.16            .0345          .5538          3.6517      .962E-02   .220E-0
   9              2.37            .0472          .5067          2.7384      .132E-01   .301E-0
  10              1.78            .0530          .4537          2.0535      .148E-01   .338E-0
  11              1.33            .1138          .3398          1.5399      .318E-01   .727E-0
  12              1.00            .1872          .1527          1.1548      .522E-01   .120E 0
  13               .75            .0900          .0627           .8660      .251E-01   .575E-0
  14               .56            .0392          .0235           .6494      .109E-01   .250E-0
  15               .42            .0184          .0051           .4870      .513E-02   .117E-0
  16               .32            .0032          .0019           .3652      .901E-03   .206E-0
  17               .24            .0008          .0011           .2738      .234E-03   .536E-0

 RESPIRABLE LIMIT:              15.00  UM
 MASS FRACTION LESS THAN:        .681
 MASS LESS THAN:                 .024  GR/DSCF
                                 .054  GMS/M3
```

CUMULATIVE LOG PROBABILITY PLOT

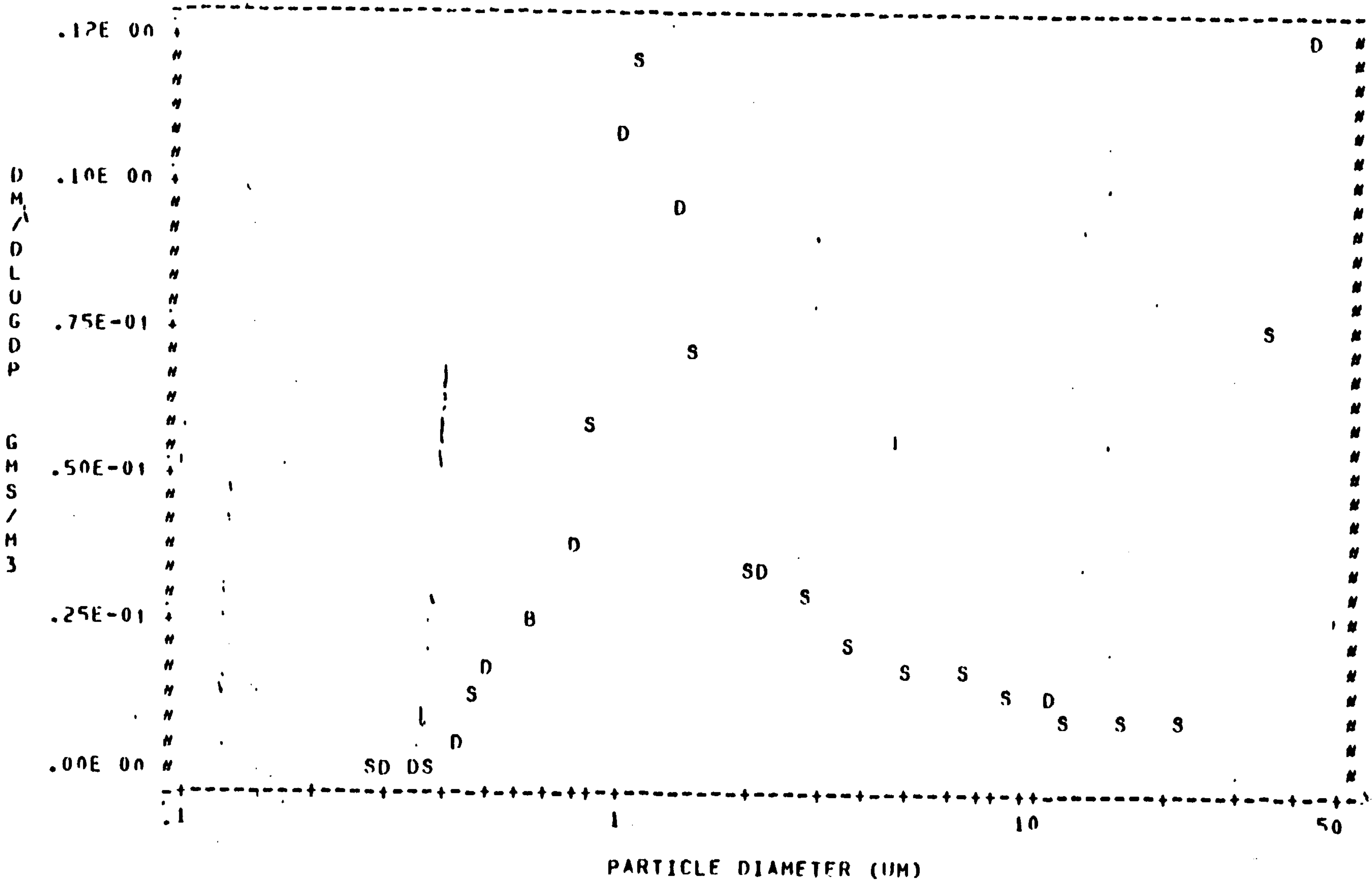
SAMPLF IDENT: IMPAC-2



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-2



D= ORIGINAL DATA POINT.
S= SPLINE INTERPOLATED POINT.
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

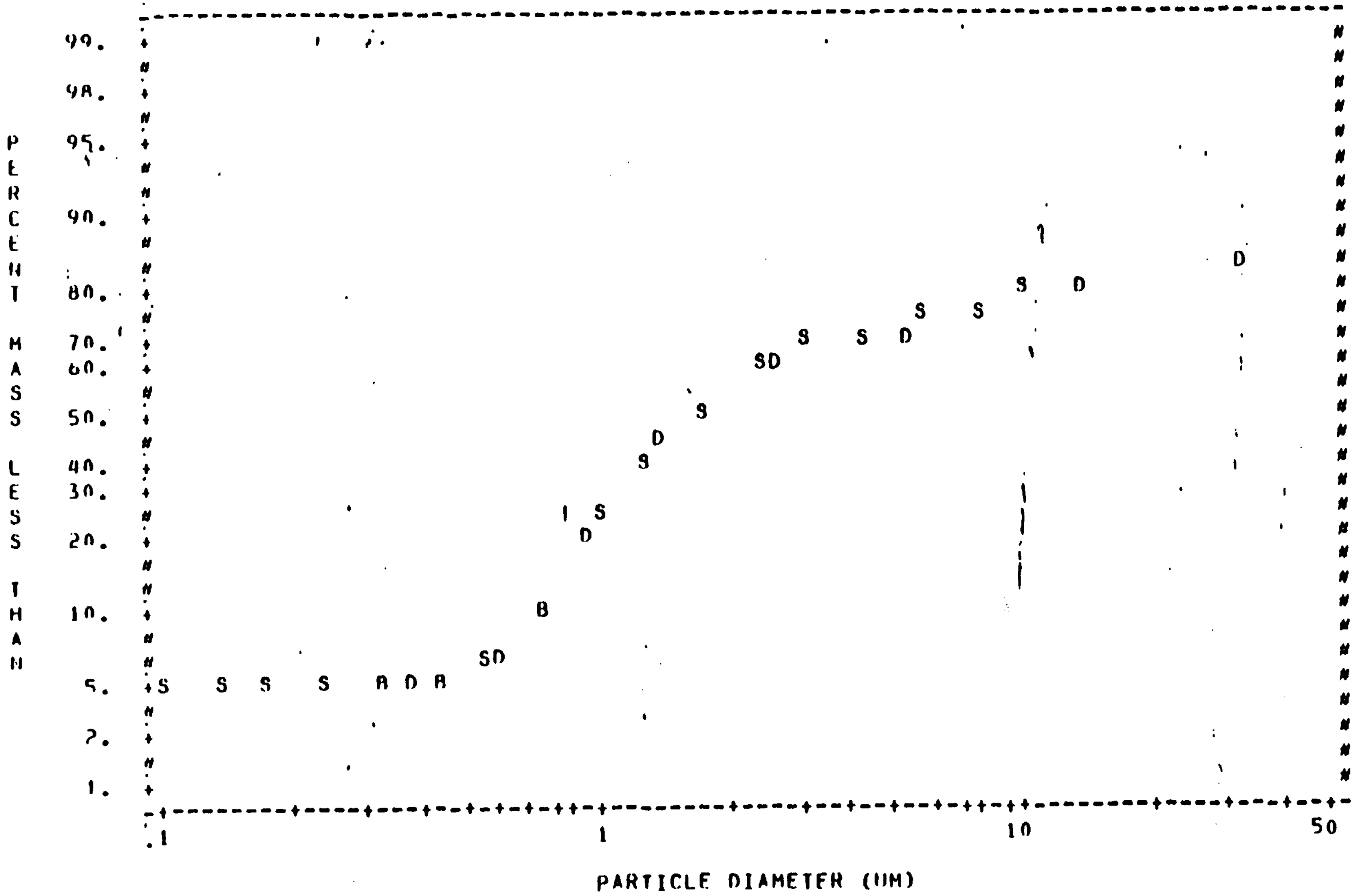
IMPACTOR RESULTS SUMMARY
SLAG TAP BAGHOUSE OUTLET
AUGUST 5, 1980

RADIAN
CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-1

PLANT NAME: EAST PENN
SAMPLING LOCATION: SLAG TAP BAG-OUT
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/ 5/80 (MMDDYY)          TIME START: 16:35 (HHMM)          TIME FINISH: 19:50 (HHMM)

INTERVAL      INTERVAL             MASS          MASS             INTERVAL          DM/DLOG DP
   N.         ENDPOINT           FRACTION       FRACTION          GEOMETRIC     DRY STAND. CONDITI
                                                LESS THAN         MIDPOINT        GR/DSCF      GMS/

    1           23.71              .1856          .8144            34.0336      .287E-03   .658E-0
    2           17.78              .0121          .8022            20.5352      .487E-04   .111E-0
    3           13.34              .0266          .7757            15.3992      .107E-03   .240E-0
    4           10.00              .0171          .7585            11.5478      .688E-04   .157E-0
    5            7.50              .0268          .7317             8.6596      .108E-03   .247E-0
    6            5.62              .0222          .7095             6.4938      .890E-04   .204E-0
    7            4.22              .0261          .6834             4.8697      .105E-03   .240E-0
    8            3.16              .0309          .6525             3.6517      .124E-03   .284E-0
    9            2.37              .0550          .5975             2.7384      .221E-03   .505E-0
   10            1.78              .0961          .5014             2.0535      .386E-03   .882E-0
   11            1.33              .1121          .3893             1.5399      .450E-03   .103E-0
   12            1.00              .1377          .2516             1.1548      .553E-03   .126E-0
   13             .75              .1458          .1058              .8660      .585E-03   .134E-0
   14             .56              .0541          .0517              .6494      .217E-03   .497E-0
   15             .42              .0115          .0402 *            .4870      .461E-04   .106E-0
   16             .32              .0000          .0402 *            .3652      .000E 00   .000E 0
   17             .24              .0000          .0402              .2738      .000E 00   .000E 0

 *  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

 RESPIRABLE LIMIT:              15.00  UM
 MASS FRACTION LESS THAN:         .784
 MASS LESS THAN:                  .000  GR/DSCF
                                  .001  GMS/M3
```

CUMULATIVE LOG PROBABILITY PLOT

SAMPLE IDENT: IMPAC-1

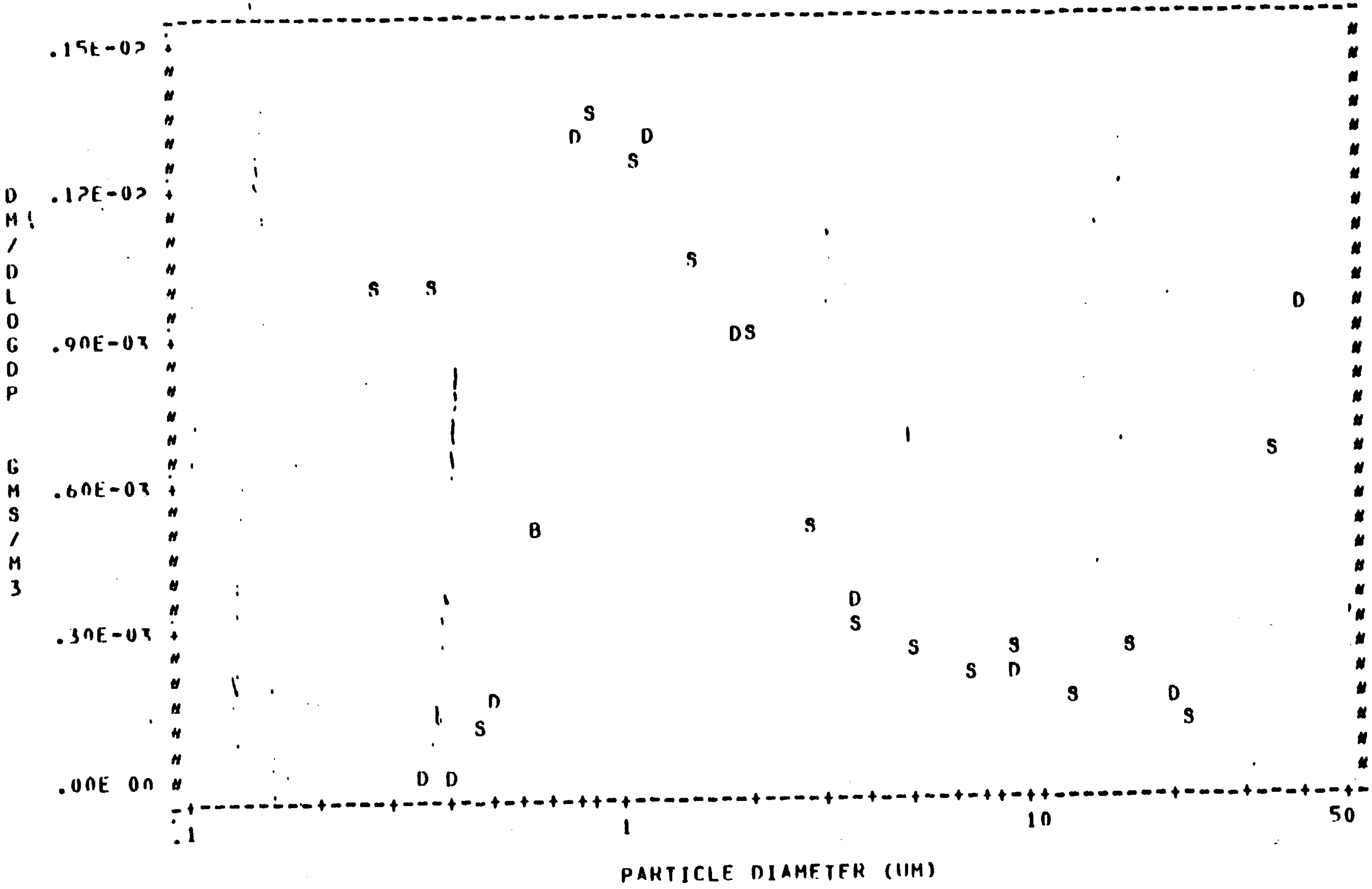


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-1



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

SLAG TAP BAGHOUSE OUTLET

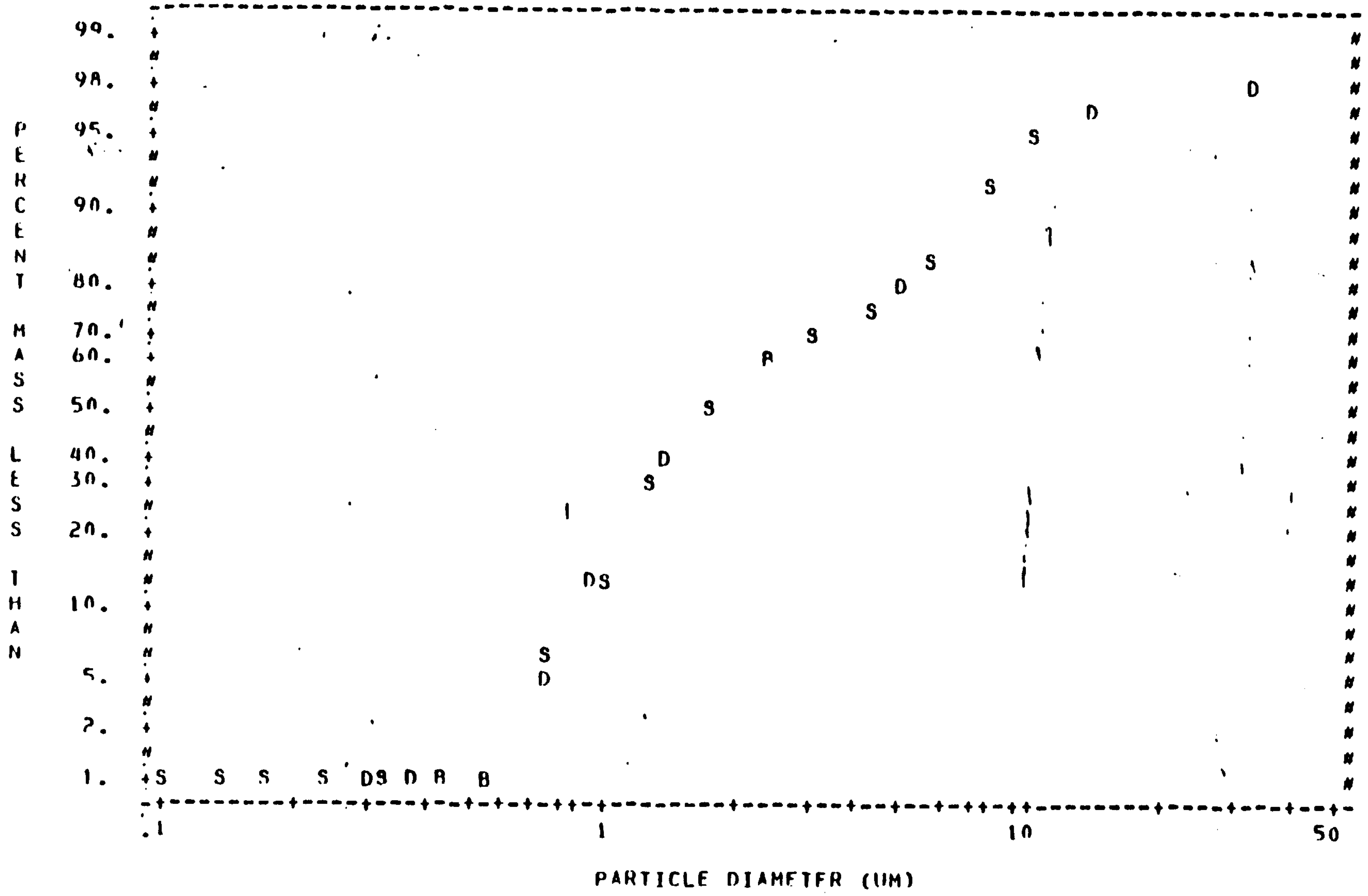
AUGUST 6, 1980

RADIAN
CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-2

PLANT NAME: EAST PENN
SAMPLING LOCATION: SLAG TAP BAG-OUT
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/ 6/80 (MMDDYY)          TIME START: 12:15 (HHMM)          TIME FINISH: 16: 0 (HHMM)

INTERVAL       INTERVAL          MASS          MASS          INTERVAL        DM/DLOG DP
   #           ENDPOINT        FRACTION      FRACTION       GEOMETRIC    DRY STAND. CONDITI
                                             LESS THAN      MIDPOINT      GR/DSCF      GMS/

   1            23.71            .0223         .9777 *       34.4336      .214E-04   .489E-0
   2            17.78            .0018         .9759 *       20.5352      .447E-05   .102E-0
   3            13.34            .0019         .9740 *       15.3992      .477E-05   .109E-0
   4            10.00            .0179         .9561         11.5478      .445E-04   [illegible]
   5             7.50            .0400         .9161          8.6596      .994E-04   [illegible]
   6             5.62            .0835         .8325          6.4938      .208E-03   .475E-0
   7          [illegible]        .0900         .7425          4.8697      .224E-03   .512E-0
   8             3.16            .0728         .6697          3.6517      .181E-03   .414E-0
   9             2.37            .0536         .6161          2.7384      .133E-03   .305E-0
  10             1.78            .1043         .5117          2.0535      .259E-03   .593E-0
  11             1.33            .1866         .3252          1.5399      .464E-03   .106E-0
  12             1.00            .1806         .1445          1.1548      .449E-03   .103E-0
  13              .75            .0930         .0515           .8660      .231E-03   .529E-0
  14              .56            .0512         .0004 *         .6494      .127E-03   .291E-0
  15              .42            .0000         .0004 *         .4870      .000E 00   .000E 0
  16              .32            .0000         .0004 *         .3652      .000E 00   .000E 0
  17              .24            .0000         .0004           .2738      .000E 00   .000E 0

 * COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

 RESPIRABLE LIMIT:              15.00  UM
 MASS FRACTION LESS THAN:         .983
 MASS LESS THAN:                  .000  GR/DSCF
                                  .001  GMS/M3
```

CUMULATIVE LOG PROBABILITY PLOT

SAMPLE IDENT: IMPAC-2

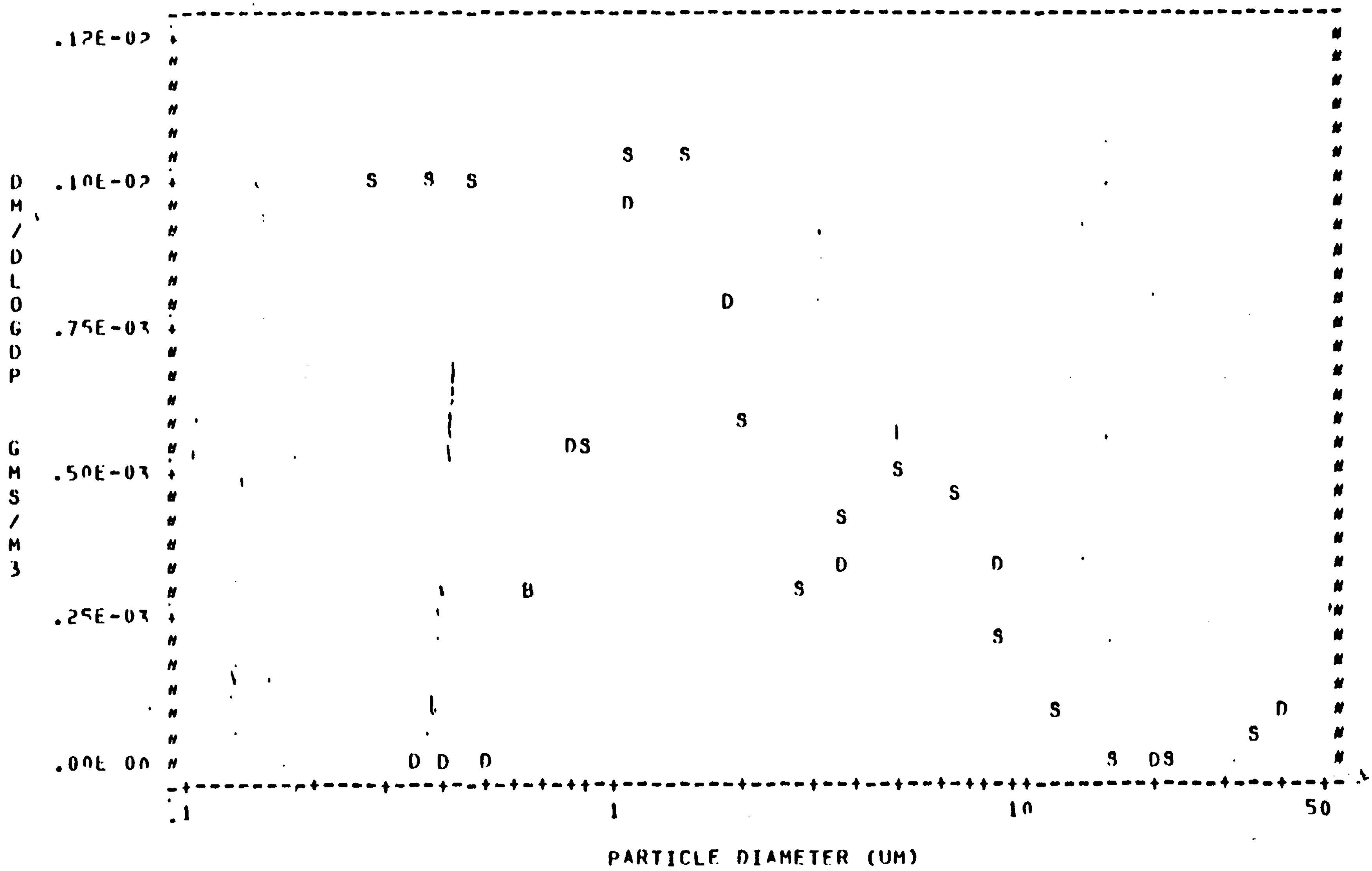


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-2



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

BLAST FURNACE METAL TAPPING

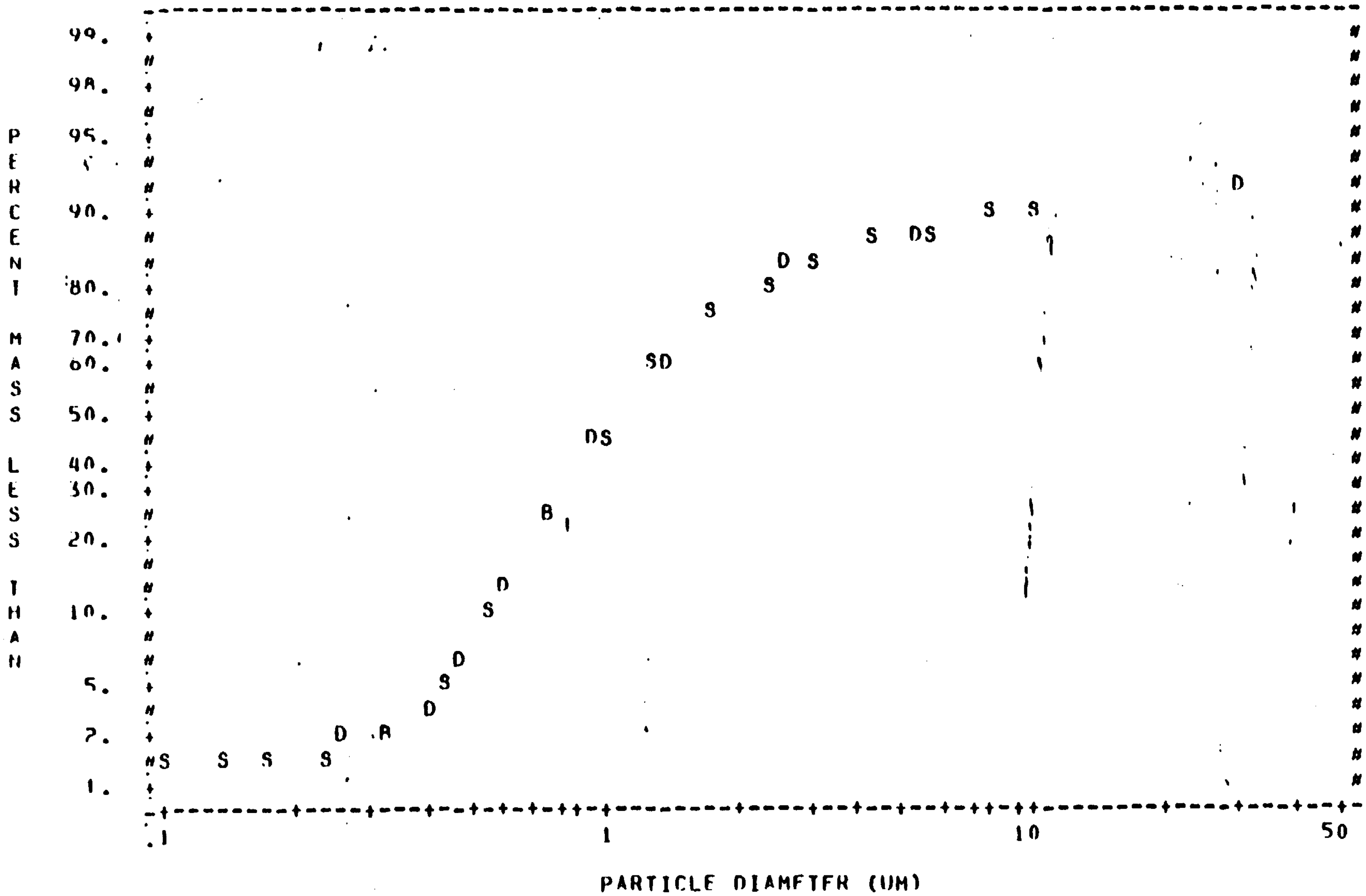
AUGUST 12, 1980

CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-1

PLANT NAME: EAST PENN
SAMPLING LOCATION: LEAD WELL
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/12/80 (MMDDYY)          TIME START: 15: 5 (HHMM)          TIME FINISH: 19:41 (HHMM)

INTERVAL        INTERVAL          MASS          MASS            INTERVAL         DM/DLOG DP
   #            ENDPOINT        FRACTION      FRACTION          GEOMETRIC    DRY STAND. CONDITI
                                              LESS THAN         MIDPOINT       GR/DSCF      GMS/

    1             23.71           .0914        .9086 *          34.4336      .185E-02   .424E-0
    2             17.78           .0059        .9028 *          20.5352      .308E-03   .706E-0
    3             13.34           .0061        .8966 *          15.3992      .322E-03   .738E-0
    4             10.00           .0064        .8902 *          11.5478      .337E-03   .770E-0
    5              7.50           .0067        .8836 *           8.6596      .351E-03   .803E-0
    6              5.62           .0070        .8766 *           6.4938      .366E-03   .837E-0
    7              4.22           .0181        .8585             4.8697      .953E-03   .218E-0
    8              3.16           .0210        .8375             3.6517      .110E-02   .252E-0
    9              2.37           .0351        .8024             2.7384      .185E-02   .422E-0
   10              1.78           .0722        .7302             2.0535      .380E-02   .868E-0
   11              1.33           .1036        .6266             1.5399      .545E-02   .125E-01
   12              1.00           .1620        .4646             1.1548      .852E-02   .195E-01
   13               .75           .2203        .2444              .8660      .116E-01   .265E-01
   14               .56           .1270        .1174              .6494      .668E-02   .153E-01
   15               .42           .0784        .0390              .4870      .412E-02   .943E-0
   16               .32           .0177        .0213              .3652      .931E-03   .213E-0
   17               .24           .0038        .0175              .2738      .197E-03   .452E-0

 *  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

 RESPIRABLE LIMIT:                 15.00  UM
 MASS FRACTION LESS THAN:            .900
 MASS LESS THAN:                     .006  GR/DSCF
                                     .014  GMS/M3
```

CUMULATIVE LOG-PROBABILITY PLOT

SAMPLE IDENT: IMPAC-1

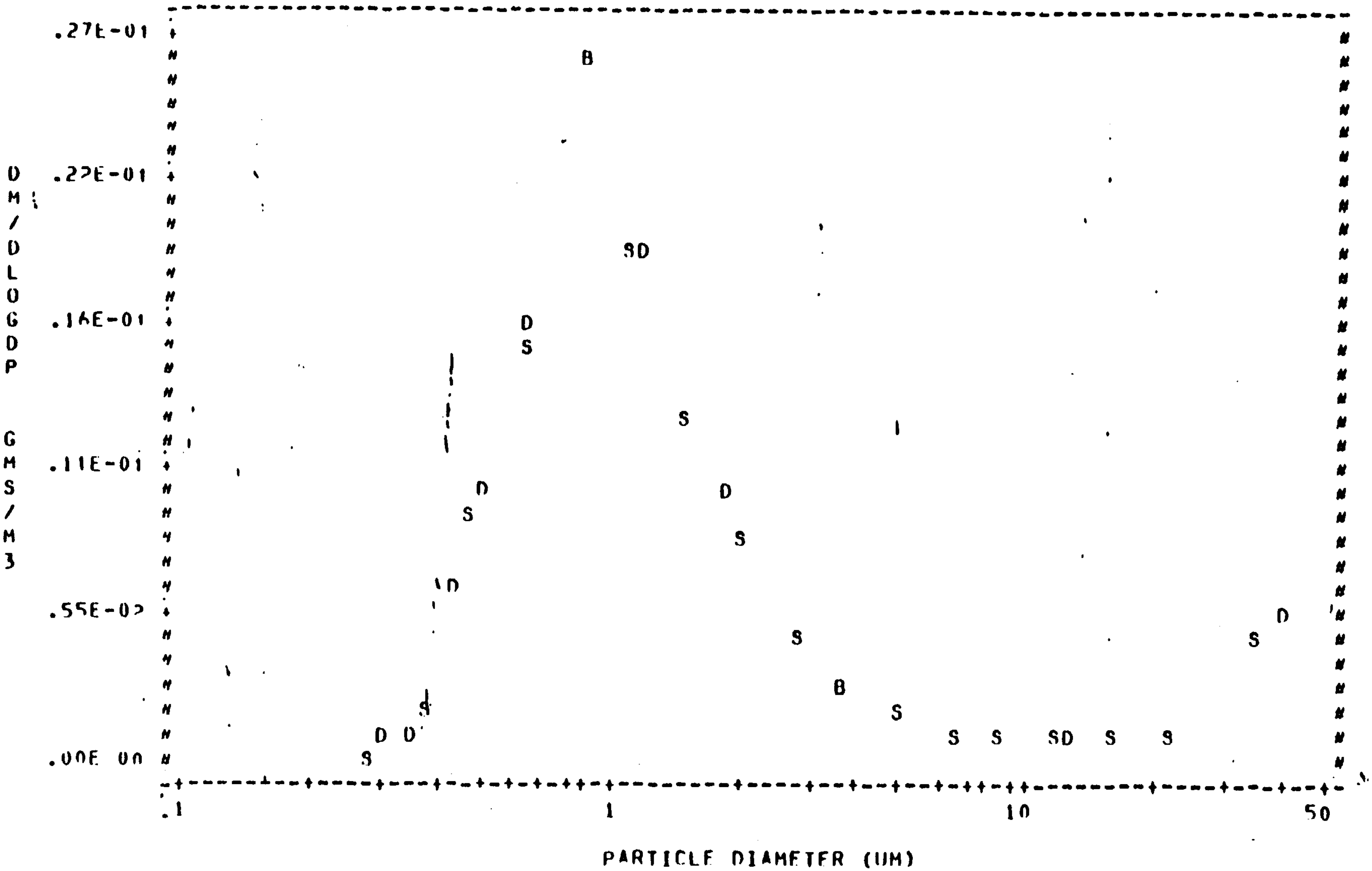


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

RADIAN
CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-1



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

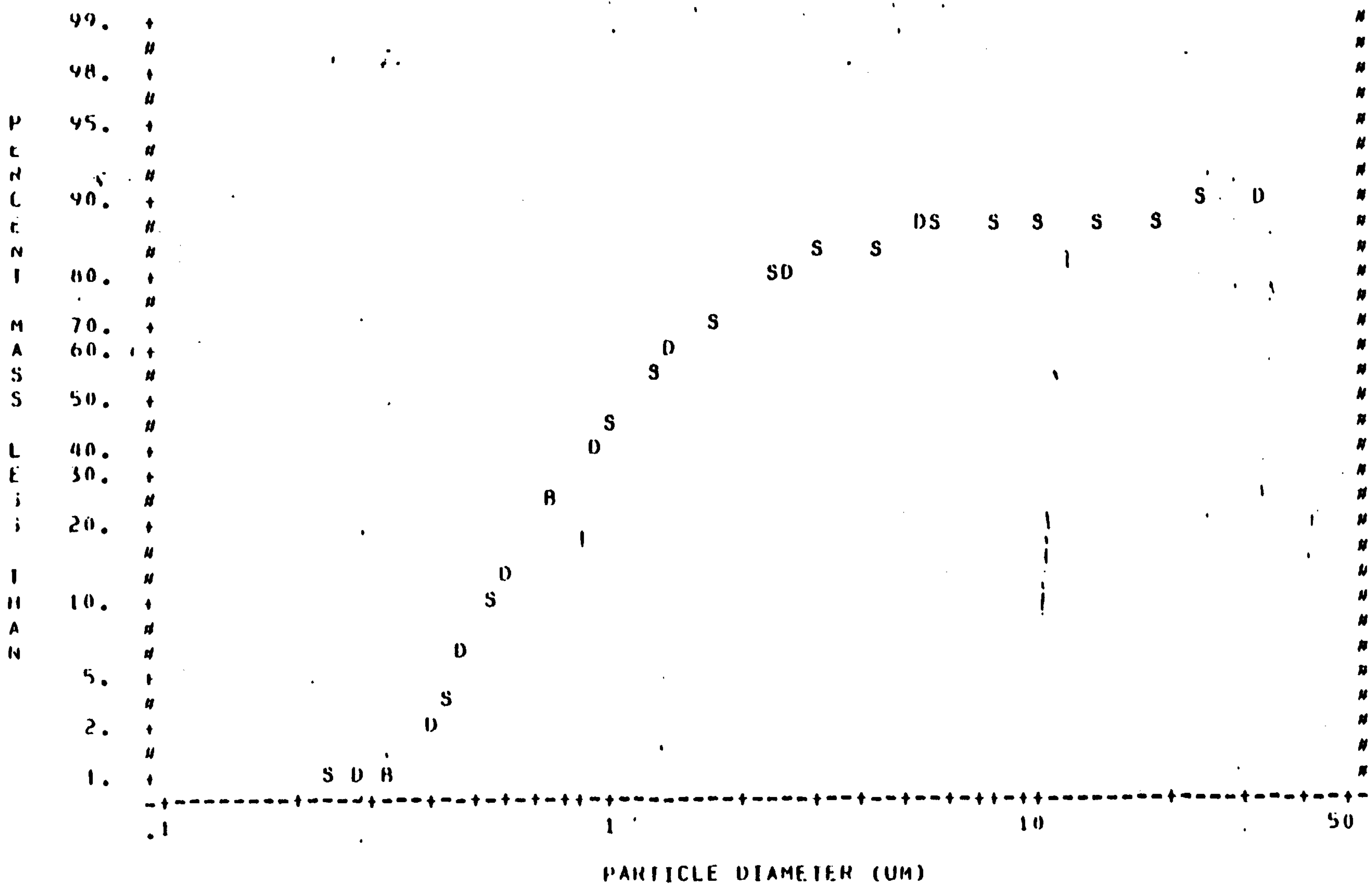
BLAST FURNACE METAL TAPPING

AUGUST 15, 1980

```
IMPACTOR CORPORATION - SPLINE FIT OF EXPERIMENTA DATA
SAMPLE IDENT:  IMPAC-2

PLANT NAME: EAST PENN
SAMPLING LOCATION: LEAD WELL
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/15/80 (MMDDYY)           TIME START: 13:45 (HHMM)                TIME FINISH: 16:30 (HHMM)

                                                                                     DM/DLOG DP
INTERVAL      INTERVAL           MASS            MASS              INTERVAL      DRY STAND. CONDITIO
   #          ENDPOINT         FRACTION        FRACTION           GEOMETRIC       GR/DSCF     GMS/M
                                               LESS THAN           MIDPOINT

   1           23.71            .1192           .8808 *            34.4336       .382E-02   .873E-02
   2           17.78            .0049           .8759 *            20.5352       .403E-03   .921E-03
   3           13.34            .0050           .8710 *            15.3992       .414E-03   .946E-03
   4           10.00            .0051           .8658 *            11.5478       .425E-03   .972E-03
   5            7.50            .0053           .8606 *             8.6596       .436E-03   .997E-03
   6            5.62            .0054           .8552 *             6.4938       .447E-03   .102E-02
   7            4.22            .0181           .8372               4.8697       .150E-02   .343E-02
   8            3.16            .0204           .8167               3.6517       .169E-02   .386E-02
   9            2.37            .0386           .7782               2.7384       .320E-02   .732E-02
  10            1.78            .0845           .6937               2.0535       .701E-02   .160E-01
  11            1.33            .1254           .5683               1.5399       .104E-01   .238E-01
  12            1.00            .1566           .4118               1.1548       .130E-01   .297E-01
  13             .75            .1647           .2470                .8660       .137E-01   .313E-01
  14             .56            .1335           .1136                .6494       .111E-01   .253E-01
  15             .42            .0874           .0262                .4870       .725E-02   .166E-01
  16             .32            .0223           .0039                .3652       .185E-02   .423E-02
  17             .24            .0024           .0015                .2738       .198E-03   .453E-03

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:                 15.00  UM
MASS FRACTION LESS THAN:           .874
MASS LESS THAN:                    .009  GR/DSCF
                                   .021  GMS/M3
```

RPORATION CUMULATIVE LO ILITY PLOT

AMPLE IDENT: IMPAC-2

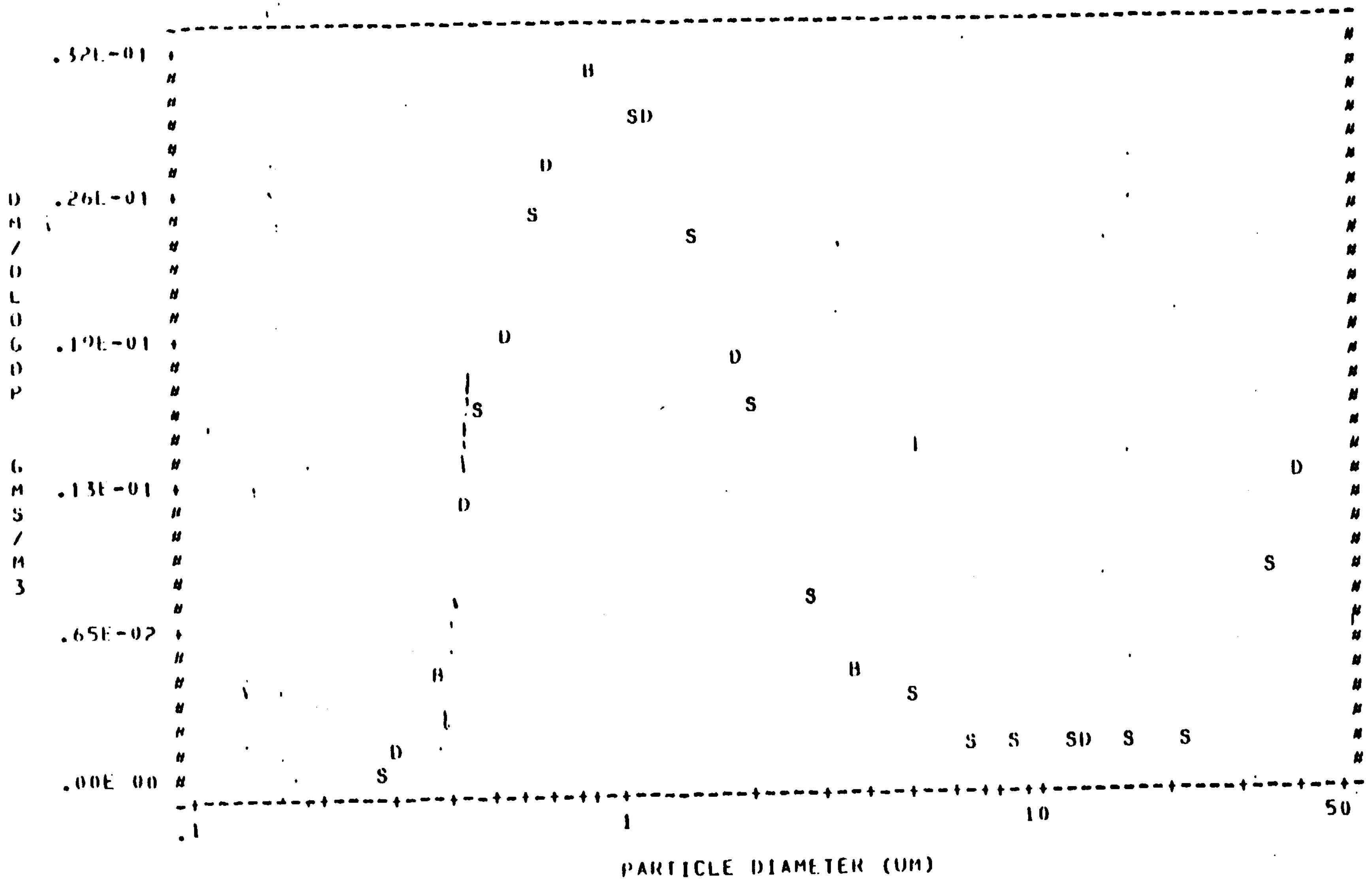


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

CORPORATION

SAMPLE IDENT: IMPAC-2

DIFFERENTIAL MASS CONCENTRATION PLOT



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

BLAST FURNACE CHARGING

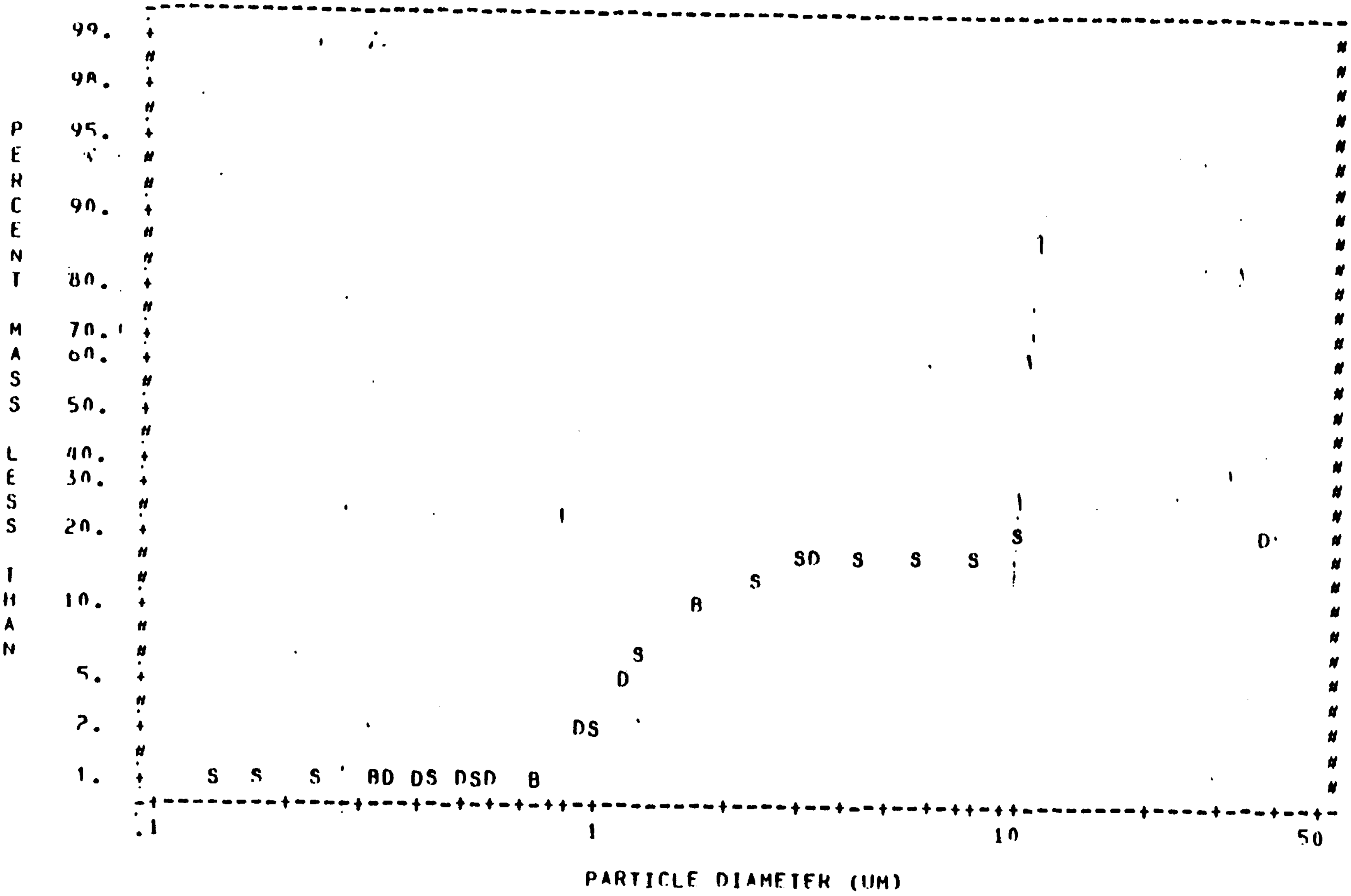
AUGUST 12, 1980

CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-2

PLANT NAME: EAST PENN
SAMPLING LOCATION: CHARGING HOOD
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/12/80 (MMDDYY)          TIME START: 18:45 (HHMM)          TIME FINISH: 18:55 (HHMM)

INTERVAL     INTERVAL          MASS          MASS           INTERVAL       DM/DLOG DP
  # 1        ENDPOINT        FRACTION      FRACTION        GEOMETRIC   DRY STAND. CONDITI
                                           LESS THAN        MIDPOINT     GR/DSCF      GMS/

   1           23.71           .7789         .2211 *        34.4336     .123E 02   .282E 0
   2           17.78           .0081         .2130 *        20.5352     .333E 00   .762E 0
   3           13.34           .0079         .2051 *        15.3992     .326E 00   .745E 0
   4           10.00           .0078         .1973 *        11.5478     .318E 00   .728E 0
   5            7.50           .0076         .1897 *         8.6596     .311E 00   .711E 0
   6            5.62           .0074         .1823 *         6.4938     .304E 00   .695E 0
   7            4.22           .0072         .1751 *         4.8697     .296E 00   .677E 0
   8            3.16           .0079         .1671           3.6517     .325E 00   .744E 0
   9            2.37           .0369         .1302           2.7384     .151E 01   .346E 01
  10            1.78           .0292         .1010           2.0535     .120E 01   .274E 01
  11            1.33           .0465         .0545           1.5399     .191E 01   .436E 01
  12            1.00           .0314         .0231           1.1548     .129E 01   .295E 01
  13             .75           .0144         .0087            .8660     .589E 00   .135E 01
  14             .56           .0055         .0032            .6494     .224E 00   .512E 0
  15             .42           .0026         .0006            .4870     .106E 00   .243E 0
  16             .32           .0006         .0000            .3652     .243E-01   .555E-01

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:              15.00  UM
MASS FRACTION LESS THAN:         .209
MASS LESS THAN:                 1.070  GR/DSCF
                                2.449  GMS/M3
```

CUMULATIVE LO[illegible]OBABILITY PLOT

SAMPLE IDENT: IMPAC-2

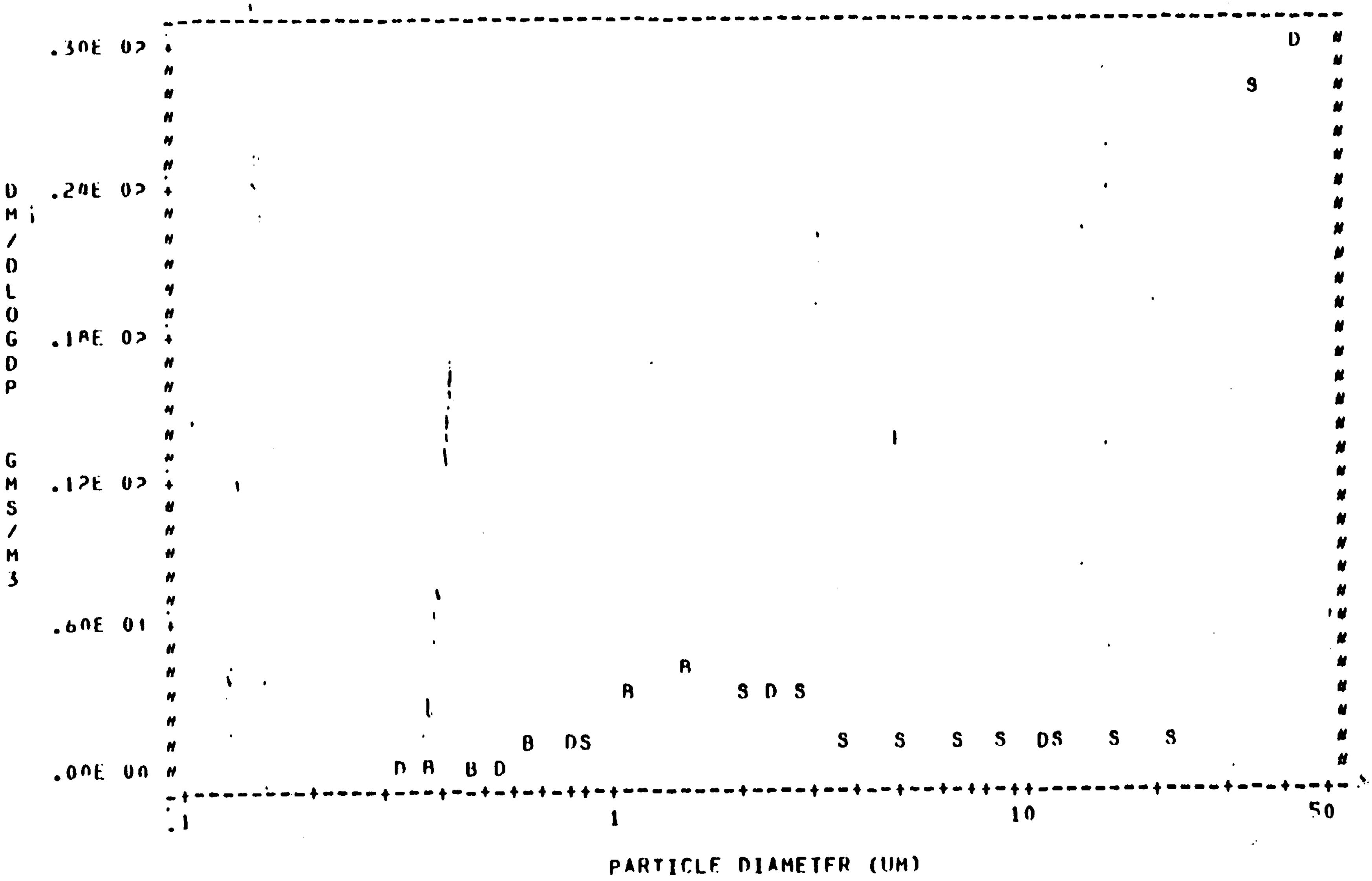


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-2



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

BLAST FURNACE CHARGING

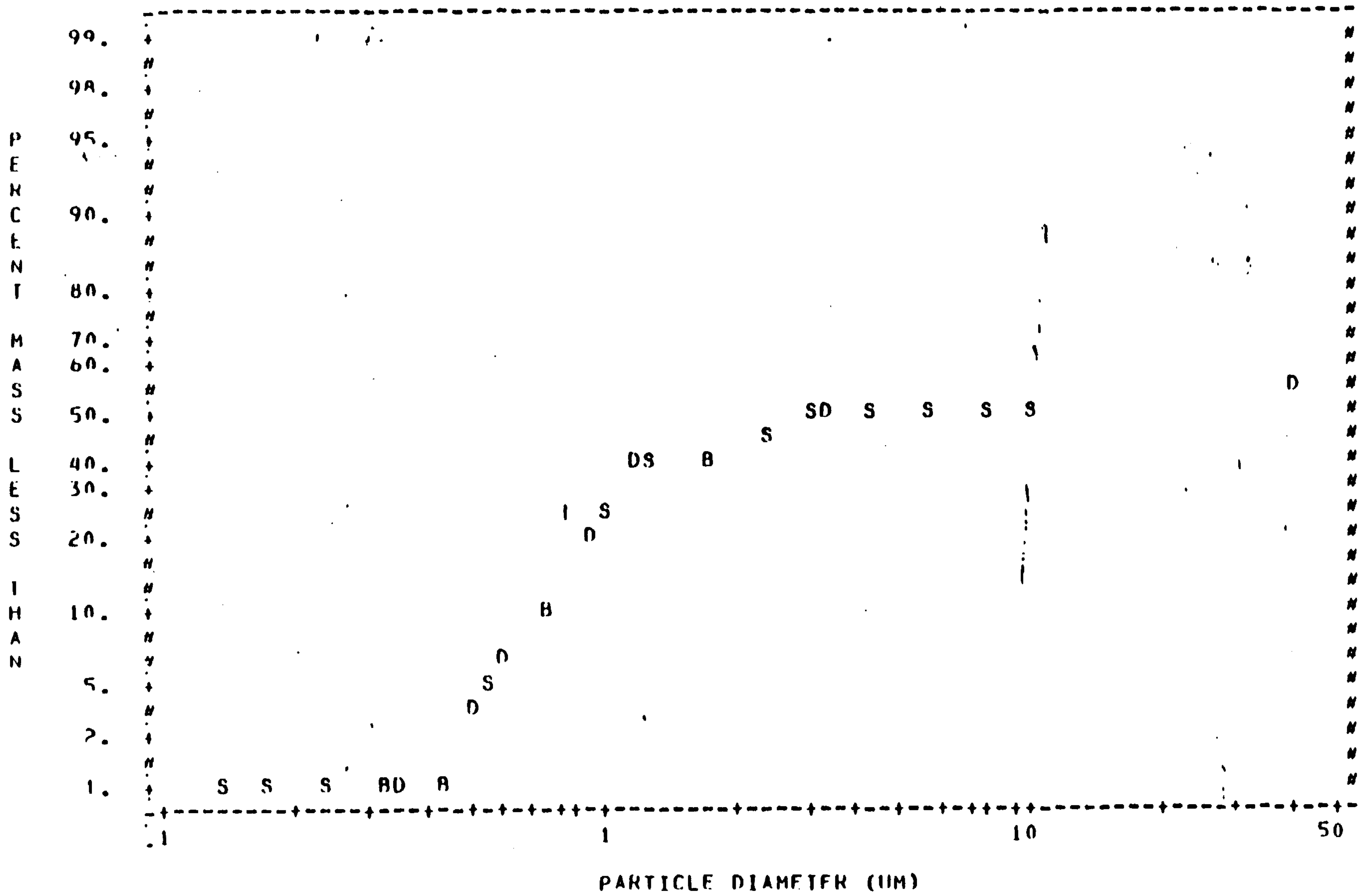
AUGUST 15, 1980

RADIAN CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-4

PLANT NAME: EAST PENN
SAMPLING LOCATION: CHARGING HOOD
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/15/80 (MMDDYY)           TIME START:  9:46 (HHMM)              TIME FINISH:  9:49 (HHMM)

                                                                                      DM/DLOG DP
INTERVAL        INTERVAL           MASS          MASS          INTERVAL         DRY STAND. CONDITI
  # 1           ENDPOINT         FRACTION      FRACTION       GEOMETRIC          GR/DSCF      GMS/
                                               LESS THAN      MIDPOINT

                                   .4718        .5282 *        34.4336          .197E 01   .450E 01
   1              23.71            .0057        .5226 *        20.5352          .613E-01   .140E 0
   2              17.78            .0057        .5169 *        15.3992          .612E-01   .140E 0
   3              13.34            .0057        .5112 *        11.5478          .611E-01   .140E 0
   4              10.00            .0056        .5056 *         8.6596          .610E-01   .140E 0
   5               7.50            .0056        .5000 *         6.4938          .609E-01   .139E 0
   6               5.62            .0056        .4943 *         4.8697          .609E-01   .139E 0
   7               4.22            .0079        .4864 *         3.6517          .859E-01   .197E 0
   8               3.16            .0404        .4460 *         2.7384          .437E 00   .999E 0
   9               2.37            .0386        .4074 *         2.0535          .418E 00   .955E 0
  10               1.78            .0124        .3950 *         1.5399          .134E 00   .307E 0
  11               1.33            .1383        .2567           1.1548          .150E 01   .342E 01
  12               1.00            .1396        .1171            .8660          .151E 01   .345E 01
  13                .75            .0679        .0492            .6494          .734E 00   .168E 01
  14                .56            .0376        .0116            .4870          .407E 00   .931E 0
  15                .42            .0093        .0023            .3652          .101E 00   .230E 0
  16                .32

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:                15.00  UM
MASS FRACTION LESS THAN:           .520
MASS LESS THAN:                    .702  GR/DSCF
                                  1.607  GMS/M3
```

CUMULATIVE LOG PROBABILITY PLOT

SAMPLE IDENT: IMPAC-4

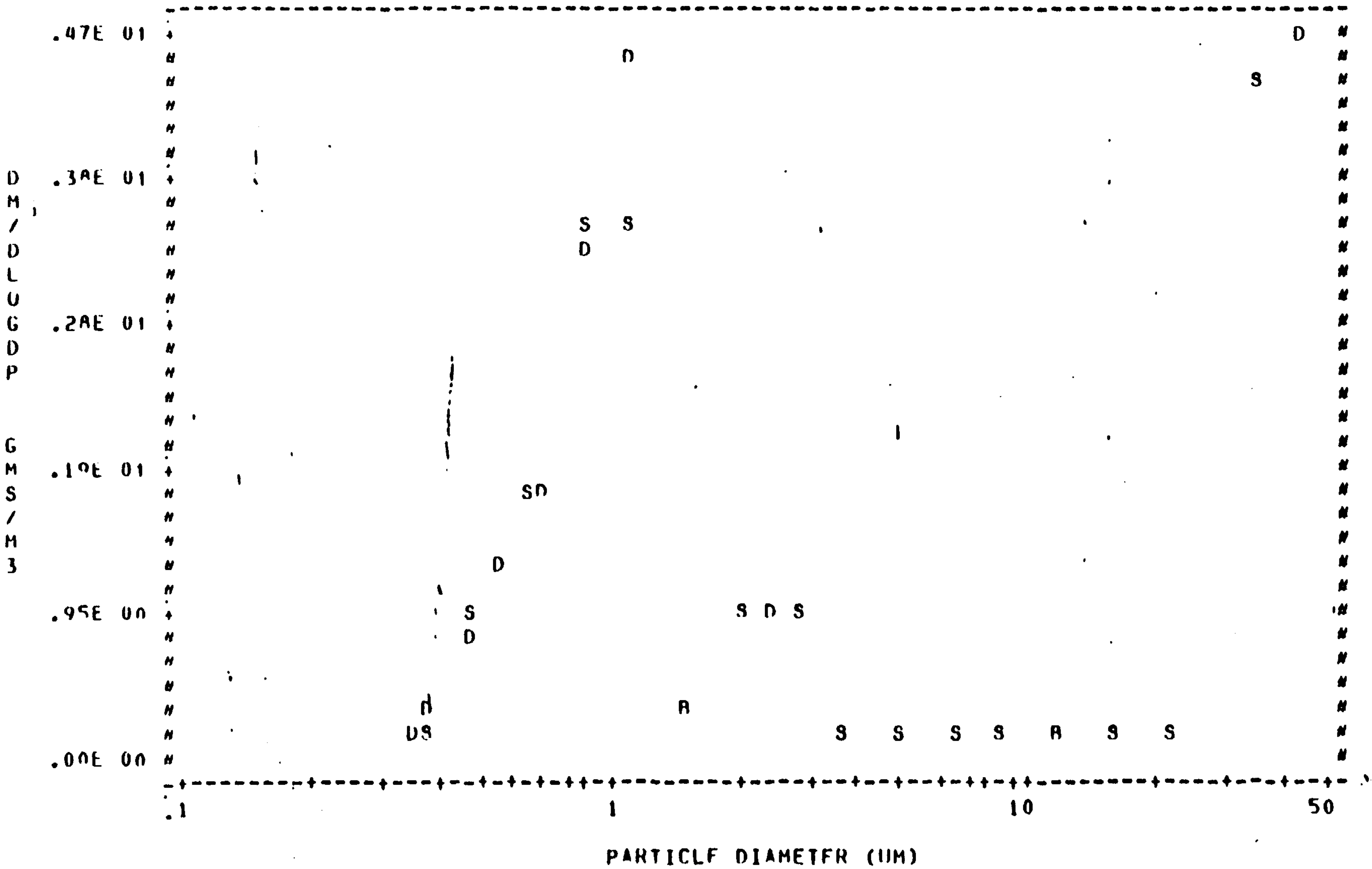


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-4



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

SANITARY BAGHOUSE INLET

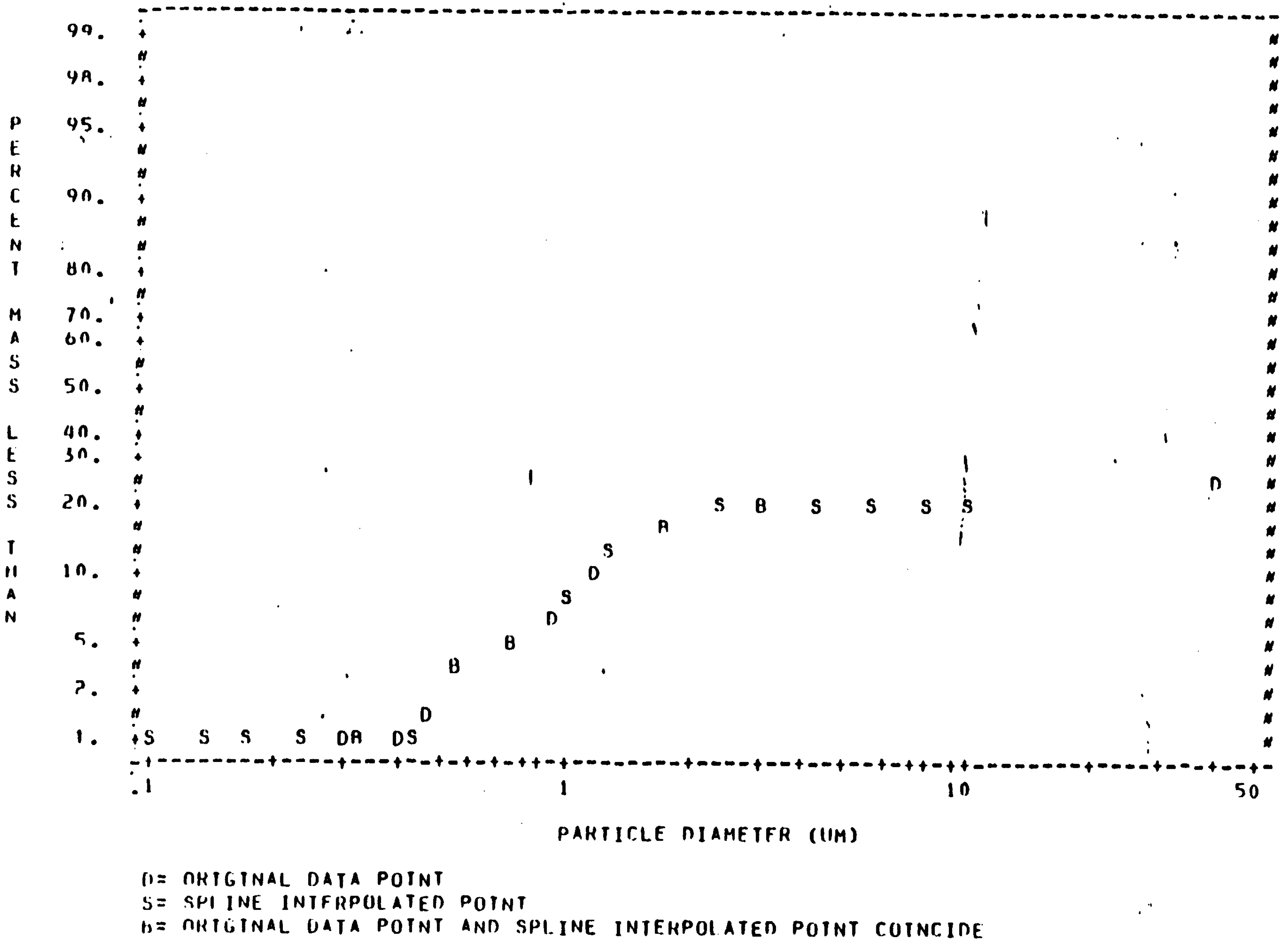
AUGUST 9, 1980

CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-3

PLANT NAME: EAST PENN
SAMPLING LOCATION: SANITARY BAG-IN
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/ 9/80 (MMDDYY)          TIME START: 16:15 (HHMM)          TIME FINISH: 17:18 (HHMM)

INTERVAL      INTERVAL          MASS          MASS            INTERVAL          DM/DLOG DP
   #          ENDPOINT        FRACTION      FRACTION         GEOMETRIC     DRY STAND. CONDITI
                                            LESS THAN         MIDPOINT       GR/DSCF     GMS/

   1            23.71           .7522        .2478 *          34.4336       .133E 01   .305E 01
   2            17.78           .0033        .2444 *          20.5352       .152E-01   .348E-01
   3            13.34           .0033        .2412 *          15.3992       .151E-01   .346E-0
   4            10.00           .0033        .2379 *          11.5478       .150E-01   .343E-0
   5             7.50           .0032        .2346 *           8.6596       .149E-01   .340E-0
   6             5.62           .0032        .2314 *           6.4938       .148E-01   .338E-01
   7             4.22           .0032        .2282 *           4.8697       .146E-01   .335E-01
   8             3.16           .0035        .2248             3.6517       .160E-01   .366E-01
   9             2.37           .0243        .2005             2.7384       .111E 00   .255E 0
  10             1.78           .0189        .1816             2.0535       .868E-01   .199E 0
  11             1.33           .0526        .1290             1.5399       .241E 00   .552E 0
  12             1.00           .0520        .0770             1.1548       .239E 00   .546E 0
  13              .75           .0264        .0507              .8660       .121E 00   .277E 0
  14              .56           .0220        .0287              .6494       .101E 00   .231E 0
  15              .42           .0195        .0092              .4870       .894E-01   .204E 0
  16              .32           .0075        .0017              .3652       .345E-01   .789E-01
  17              .24           .0017        .0000              .2738       .786E-02   .180E-01

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:              15.00  UM
MASS FRACTION LESS THAN:         .243
MASS LESS THAN:                  .139   GR/DSCF
                                 .319   GMS/M3
```

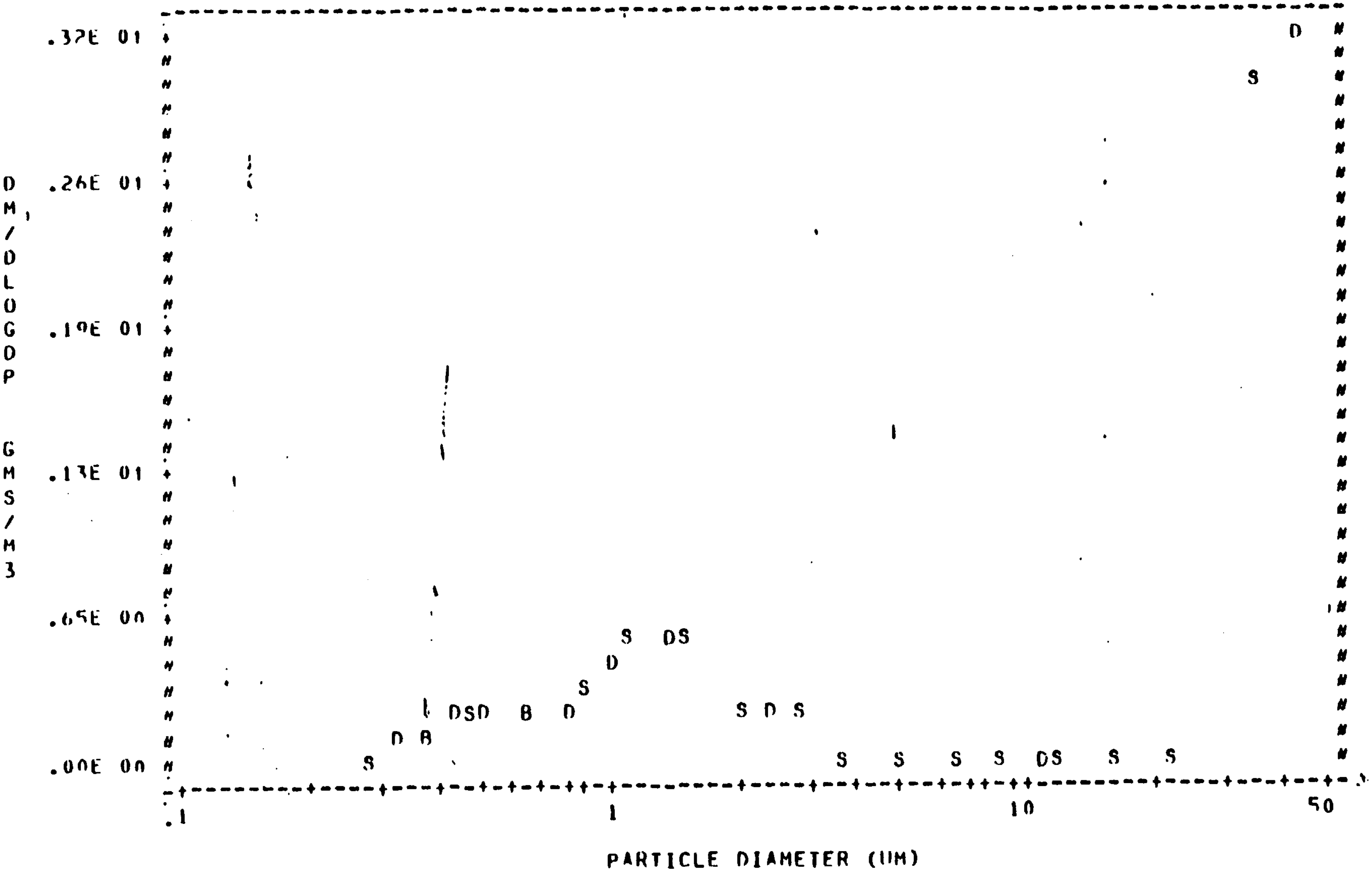
CUMULATIVE LOG [illegible]ABILITY PLOT

SAMPLE IDENT: IMPAC-3



DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-3



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

SANITARY BAGHOUSE INLET

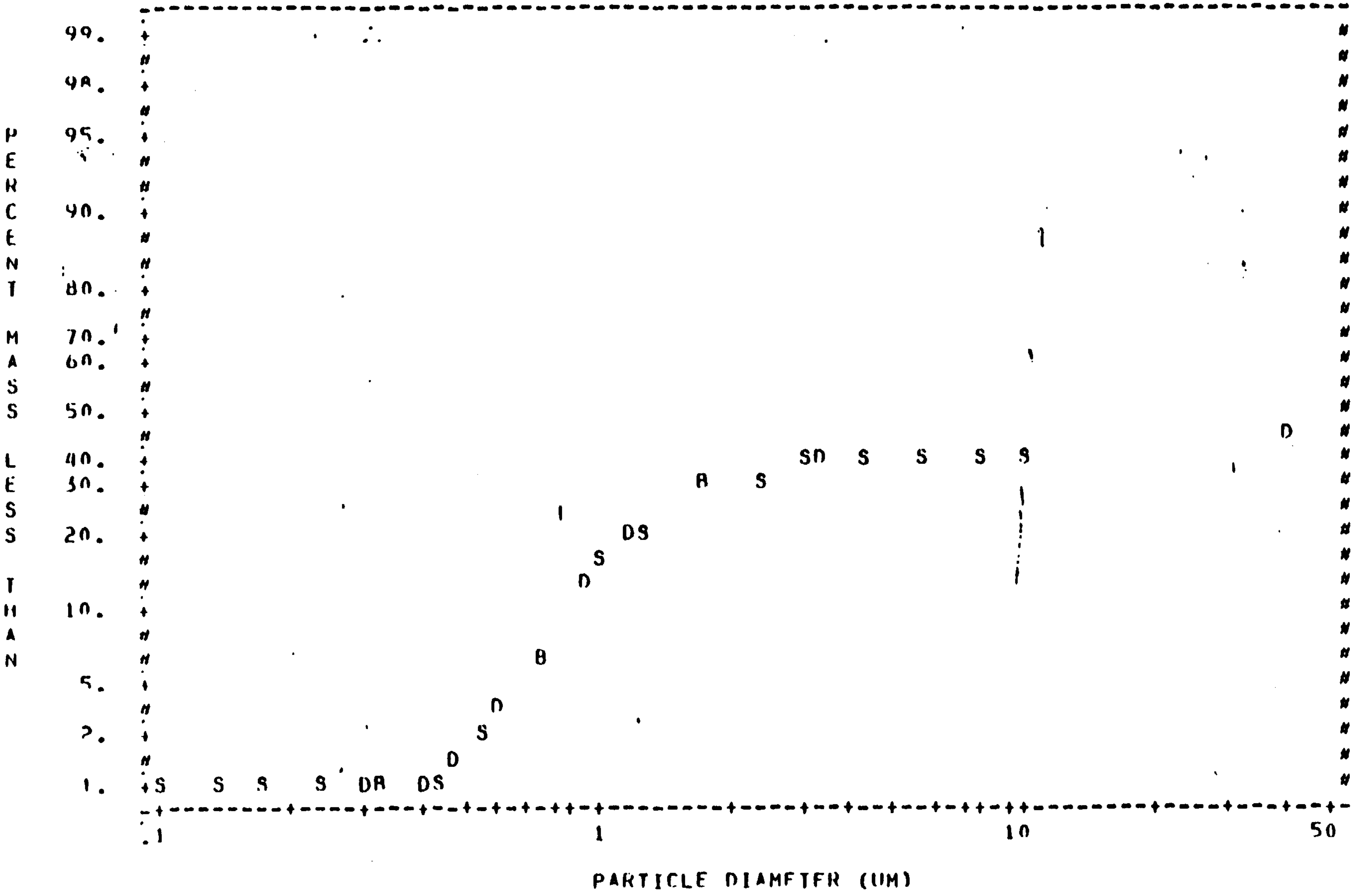
AUGUST 11, 1980

CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-4

PLANT NAME: EAST PENN
SAMPLING LOCATION: SANITARY BAG-IN
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/11/80 (MMDDYY)           TIME START: 19:25 (HHMM)              TIME FINISH: 20:15 (HHMM)


INTERVAL        INTERVAL             MASS          MASS            INTERVAL        DM/DLOG DP
   #            ENDPOINT           FRACTION       FRACTION         GEOMETRIC    DRY STAND.  CONDITI
                                                  LESS THAN        MIDPOINT      GR/DSCF      GMS/

    1             23.71              .5605          .4395 *         34.4336     .119E 01   .273E 0
    2             17.78              .0128          .4267 *         20.5352     .704E-01   .161E 0
    3             13.34              .0127          .4140 *         15.3992     .701E-01   .160E 0
    4             10.00              .0126          .4014 *         11.5478     .696E-01   .159E 0
    5              7.50              .0125          .3888 *          8.6596     .691E-01   .158E 0
    6              5.62              .0124          .3764 *          6.4938     .684E-01   .157E 0
    7              4.22              .0123          .3642 *          4.8697     .677E-01   .155E 0
    8              3.16              .0134          .3508            3.6517     .738E-01   .169E 0
    9              2.37              .0323          .3184            2.7384     .178E 00   .407E 0
   10              1.78              .0232          .2953            2.0535     .128E 00   .292E 0
   11              1.33              .0633          .2320            1.5399     .349E 00   .798E 0
   12              1.00              .0655          .1665            1.1548     .361E 00   .826E 0
   13               .75              .1043          .0622             .8660     .575E 00   .131E 01
   14               .56              .0367          .0255             .6494     .202E 00   .462E 0
   15               .42              .0195          .0060             .4870     .107E 00   .246E 0
   16               .32              .0050          .0010             .3652     .277E-01   .635E-01
   17               .24              .0010          .0000             .2738     .549E-02   .126E-01

 *  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

 RESPIRABLE LIMIT:                 15.00  UM
 MASS FRACTION LESS THAN:            .420
 MASS LESS THAN:                     .290  GR/DSCF
                                     .662  GMS/M3
```

CUMULATIVE LOG ABILITY PLOT

SAMPLE IDENT: IMPAC-4

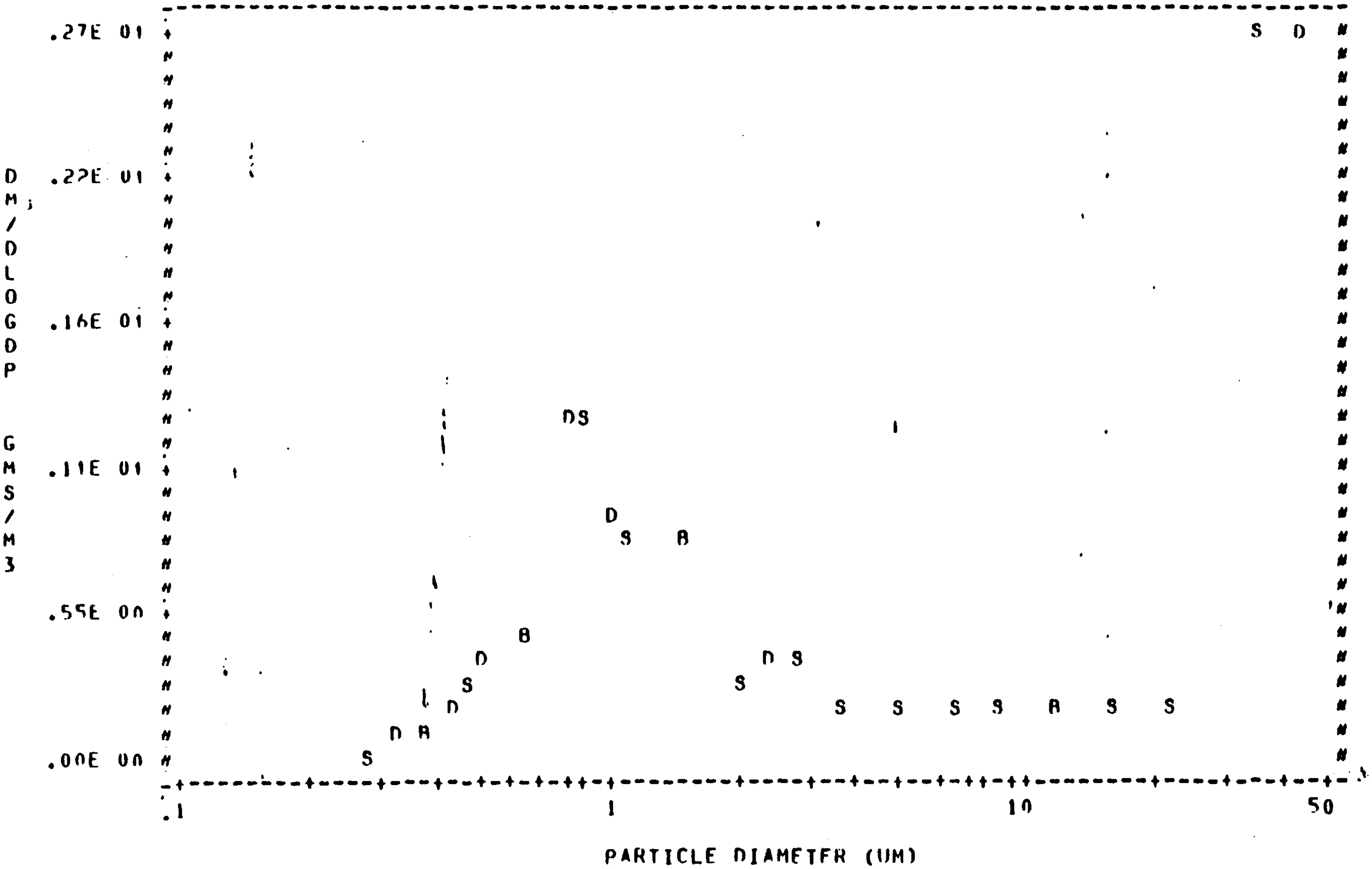


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-4



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

SANITARY BAGHOUSE OUTLET

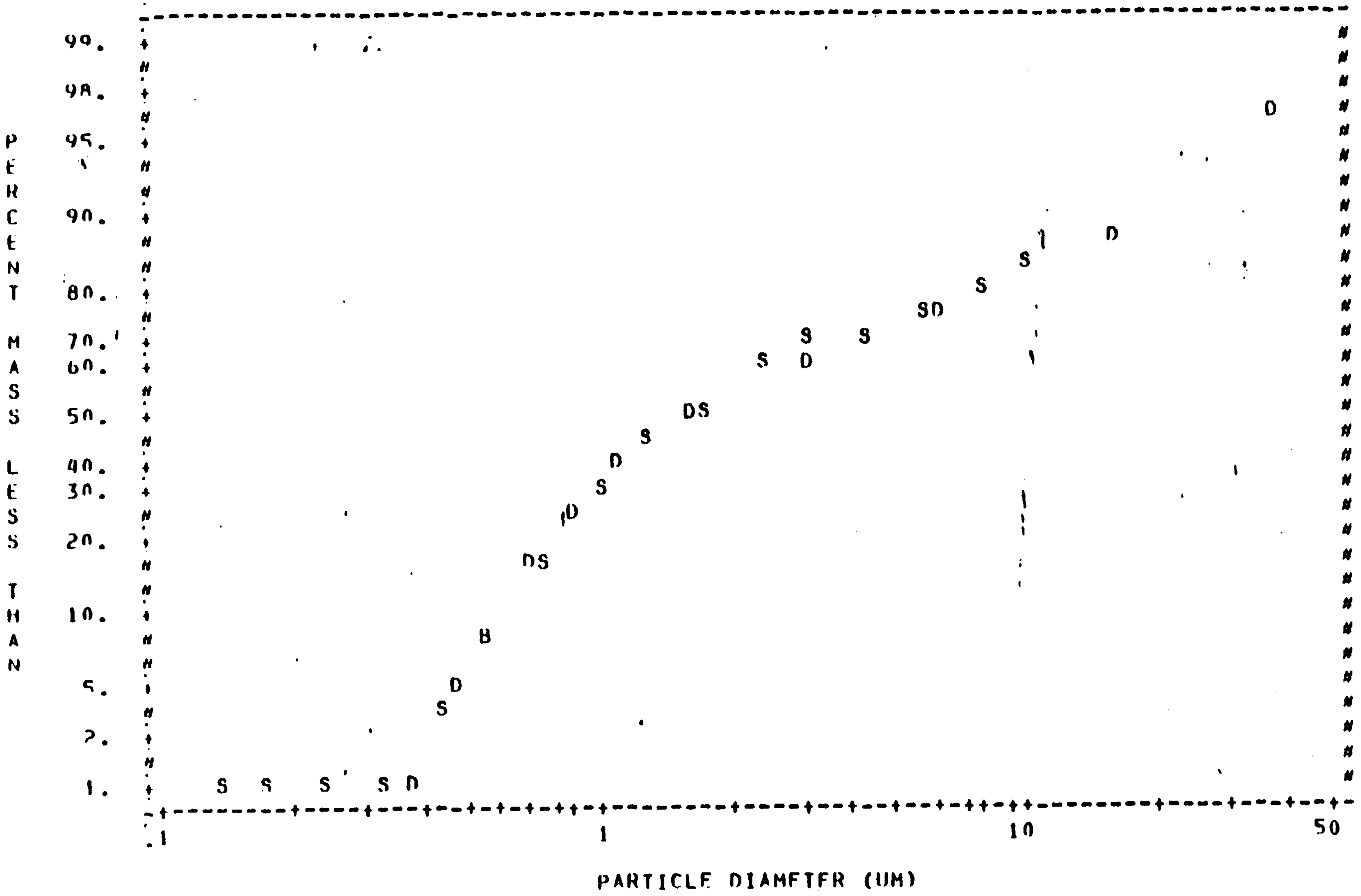
AUGUST 9, 1980

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-5

PLANT NAME: EAST PENN
SAMPLING LOCATION: SANITARY BAG-OUT
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/ 9/80 (MMDDYY)           TIME START: 16:21 (HHMM)            TIME FINISH: 17:24 (HHMM)

INTERVAL       INTERVAL           MASS          MASS          INTERVAL        DM/DLOG DP
  #)           ENDPOINT         FRACTION      FRACTION       GEOMETRIC    DRY STAND. CONDITI
                                              LESS THAN      MIDPOINT      GR/DSCF     GMS/M

   1             23.71            .0674         .9326         34.4336     .377E-03  .862E-03
   2             17.78            .0385         .8941         20.5352     .557E-03  .128E-02
   3             13.34            .0425         .8515         15.3992     .616E-03  .141E-02
   4             10.00            .0421         .8094         11.5478     .609E-03  .139E-02
   5              7.50            .0400         .7694          8.6596     .580E-03  .133E-02
   6              5.62            .0333         .7361          6.4938     .481E-03  .110E-02
   7              4.22            .0380         .6981          4.8697     .551E-03  .126E-02
   8              3.16            .0397         .6584          3.6517     .575E-03  .132E-02
   9              2.37            .0612         .5972          2.7384     .885E-03  .203E-02
  10              1.78            .0733         .5240          2.0535     .106E-02  .243E-02
  11              1.33            .0790         .4450          1.5399     .114E-02  .262E-02
  12              1.00            .1171         .3279          1.1548     .170E-02  .388E-02
  13               .75            .1352         .1927           .8660     .196E-02  .448E-02
  14               .56            .1119         .0808           .6494     .162E-02  .371E-02
  15               .42            .0519         .0289           .4870     .751E-03  .172E-02
  16               .32            .0285         .0004           .3652     .413E-03  .944E-03

RESPIRABLE LIMIT:               15.00  UM
MASS FRACTION LESS THAN:          .873
MASS LESS THAN:                   .002  GR/DSCF
                                  .004  GMS/M3
```

ORPORATION

CUMULATIVE LOG [illegible]ABILITY PLOT

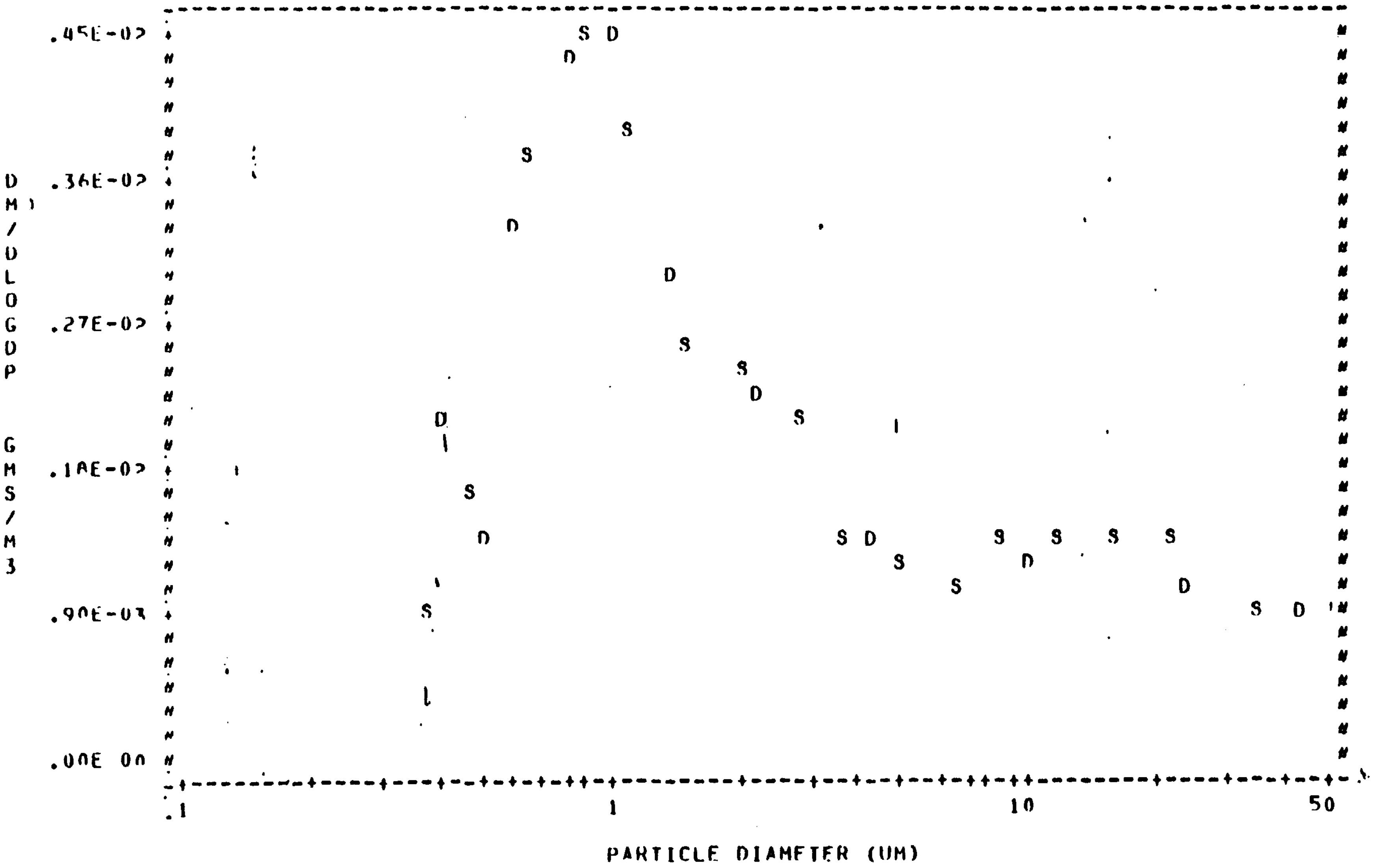
SAMPLE IDENT: IMPAC-5



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-5



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

SANITARY BAGHOUSE OUTLET

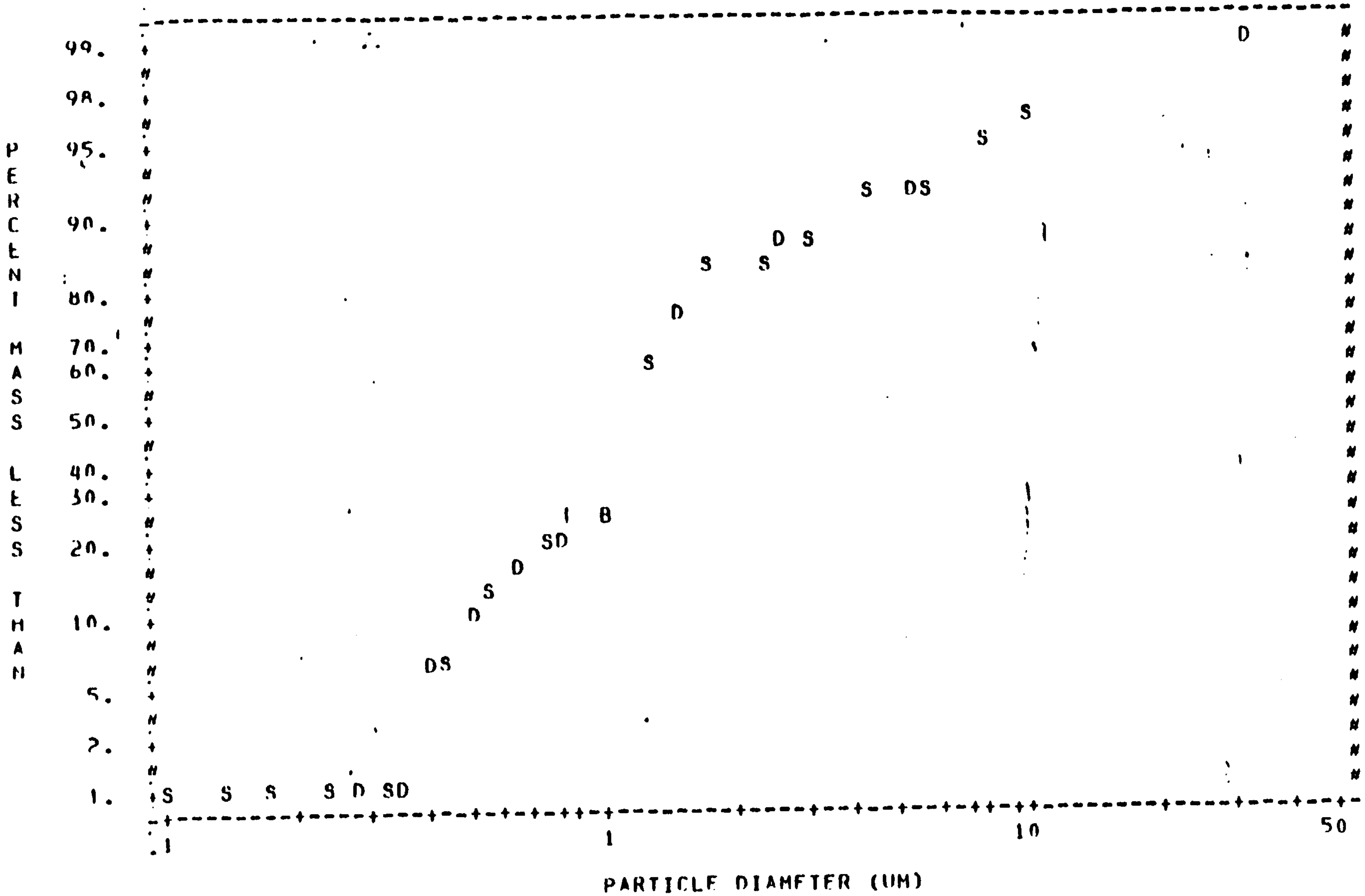
AUGUST 11, 1980

CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE,FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-6

PLANT NAME: EAST PENN
SAMPLING LOCATION: SANITARY BAG-OUT
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/11/80 (MMDDYY)           TIME START: 18:36 (HHMM)           TIME FINISH: 20:15 (HHMM)

INTERVAL        INTERVAL           MASS          MASS           INTERVAL         DM/DLOG DP
   #,           ENDPOINT         FRACTION      FRACTION        GEOMETRIC     DRY STAND. CONDITI
                                               LESS,THAN       MIDPOINT        GR/DSCF     GMS/

   1              23.71           .0084         .9916 *         34.4336       .310E-04   .710E-0
   2              17.78           .0052         .9864 *         20.5352       .497E-04   .114E-0
   3              13.34           .0079         .9785 *         15.3992       .757E-04   .173E-0
   4              10.00           .0117         .9668 *         11.5478       .111E-03   .255E-0
   5               7.50           .0165         .9503 *          8.6596       .158E-03   .362E-0
   6               5.62           .0225         .9278 *          6.4938       .216E-03   .493E-0
   7               4.22           .0116         .9161            4.8697       .111E-03   .255E-0
   8               3.16           .0532         .8629            3.6517       .509E-03   .116E-0
   9               2.37           .0235         .8395            2.7384       .224E-03   .513E-0
  10               1.78           .0123         .8272            2.0535       .118E-03   .269E-0
  11               1.33           .2043         .6229            1.5399       .195E-02   .447E-0
  12               1.00           .3666         .2562            1.1548       .351E-02   .802E-0
  13                .75           .0556         .2006             .8660       .532E-03   .122E-0
  14                .56           .0522         .1485             .6494       .499E-03   .114E-0
  15                .42           .0867         .0617             .4870       .829E-03   .190E-0
  16                .32           .0556         .0062             .3652       .531E-03   .122E-0
  17                .24           .0013         .0049             .2738       .122E-04   .279E-0

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:              15.00  UM
MASS FRACTION LESS THAN:         .984
MASS LESS THAN:                  .001   GR/DSCF
                                 .003   GMS/M3
```

CUMULATIVE LOG [illegible]BABILITY PLOT

SAMPLE IDENT: IMPAC-6

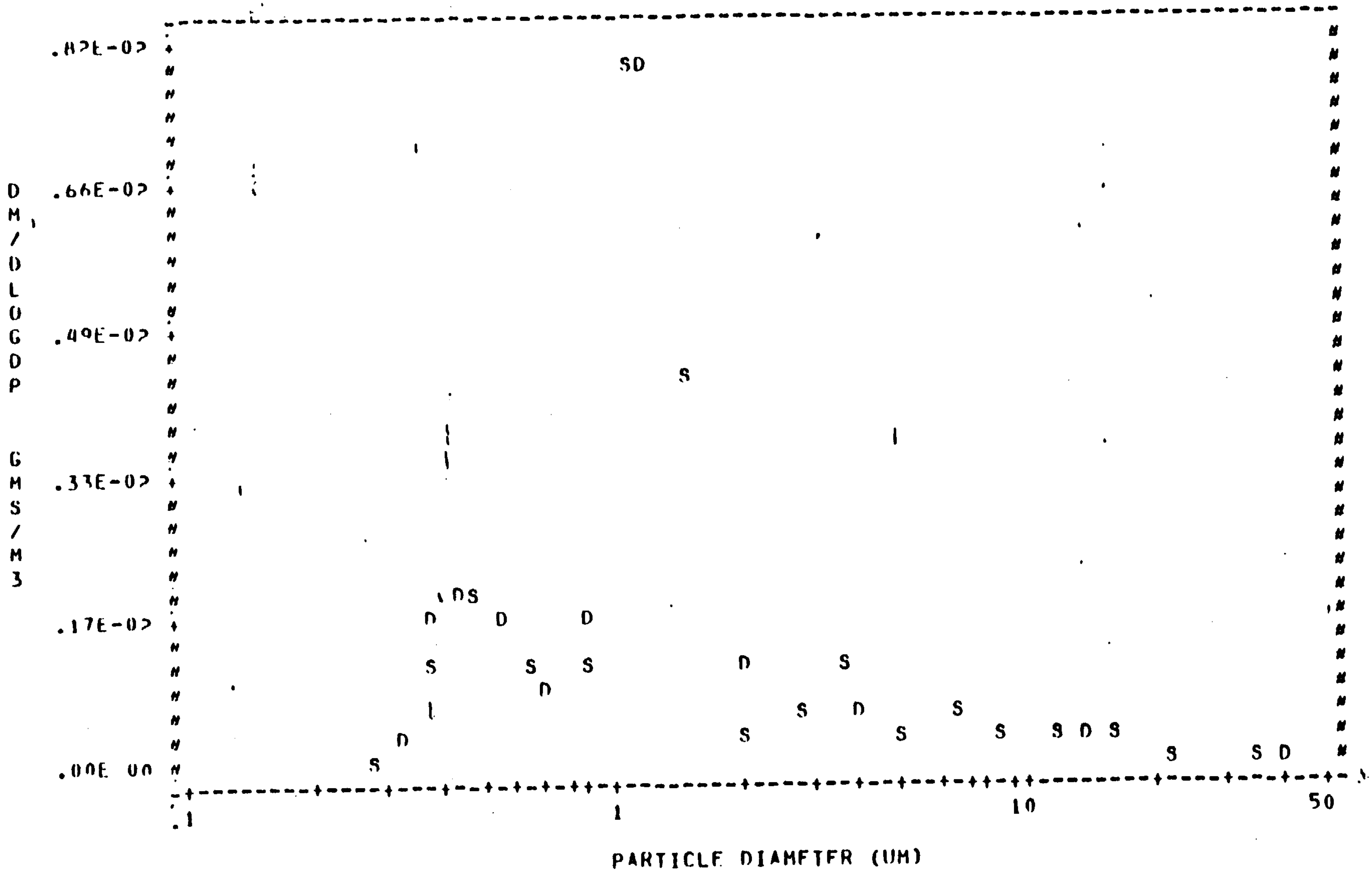


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-6



D= ORIGINAL DATA POINT

S= SPLINE INTERPOLATED POINT

B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

PROCESS BAGHOUSE OUTLET

AUGUST 7, 1980

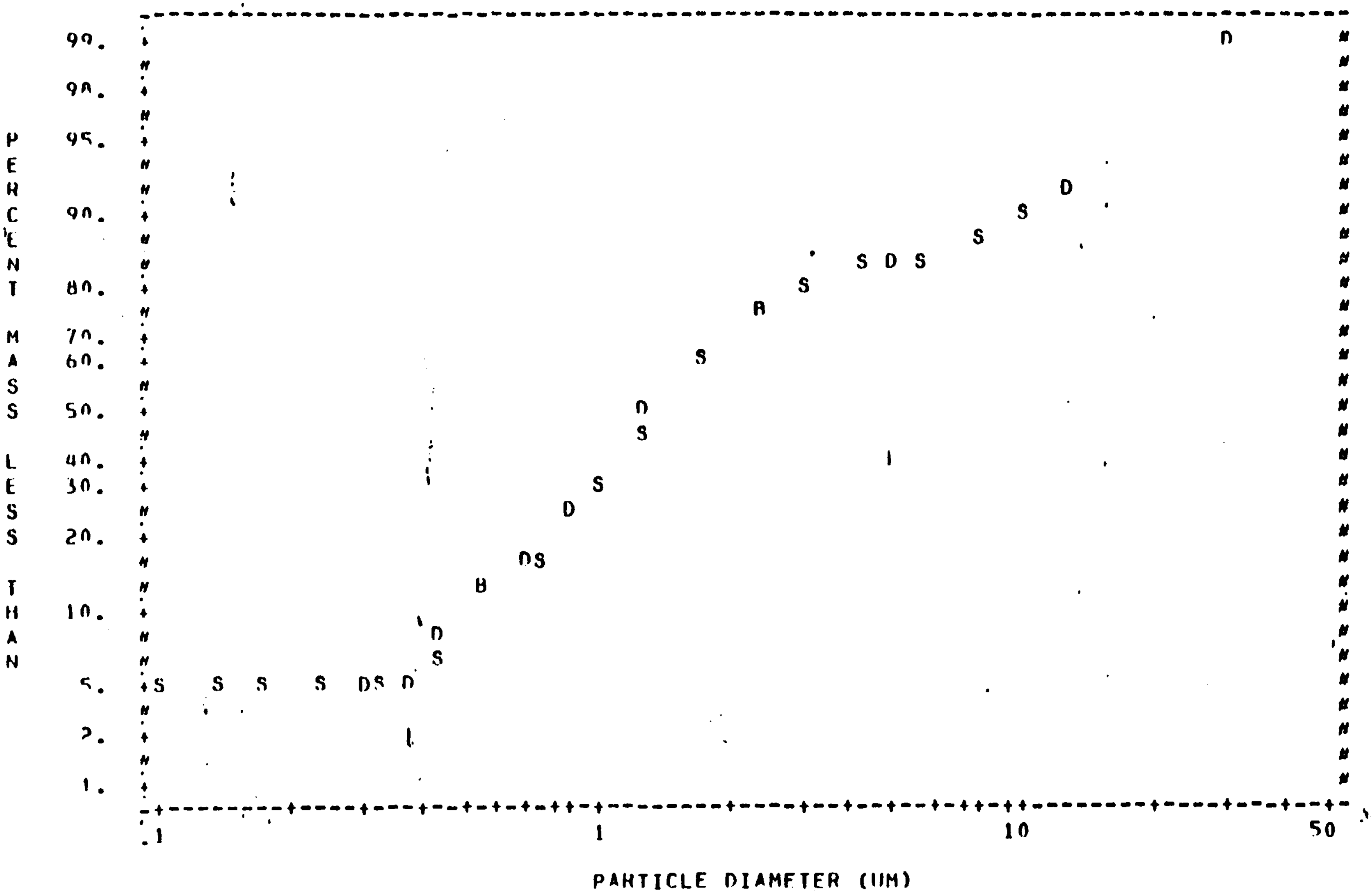
CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA.
SAMPLE IDENT:  IMPAC-3

PLANT NAME: EAST PENN
SAMPLING LOCATION: PROCESS BAG-OUT
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/ 7/80 (MMDDYY)          TIME START: 14:20 (HHMM)          TIME FINISH: 15:50 (HHMM)

                                                                                  DM/DLOG DP
ITERVAL       INTERVAL            MASS          MASS            INTERVAL    DRY STAND. CONDITIONS
  #           ENDPOINT          FRACTION      FRACTION         GEOMETRIC     GR/DSCF     GMS/M3
                                              LESS THAN        MIDPOINT

  1             23.71             .0067         .9933           34.4336     .530E-04   .121E-03
  2             17.78             .0201         .9733           20.5352     .413E-03   .946E-03
  3             13.34             .0479         .9254           15.3992     .987E-03   .226E-02
  4             10.00             .0287         .8967 *         11.5478     .591E-03   .135E-02
  5              7.50             .0249         .8718 *          8.6596     .513E-03   .117E-02
  6              5.62             .0287         .8430 *          6.4938     .591E-03   .135E-02
  7              4.22             .0367         .8063            4.8697     .756E-03   .173E-02
  8              3.16             .0364         .7700            3.6517     .749E-03   .171E-02
  9              2.37             .0520         .7180            2.7384     .107E-02   .245E-02
 10              1.78             .1081         .6099            2.0535     .223E-02   .510E-02
 11              1.33             .1424         .4675            1.5399     .293E-02   .671E-02
 12              1.00             .1432         .3243            1.1548     .295E-02   .675E-02
 13               .75             .1292         .1951             .8660     .266E-02   .609E-02
 14               .56             .0681         .1270             .6494     .140E-02   .321E-02
 15               .42             .0613         .0657             .4870     .126E-02   .289E-02
 16               .32             .0280         .0377 *           .3652     .576E-03   .132E-02
 17               .24             .0000         .0377             .2738     .000E 00   .000E 00

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:                  15.00  UM
MASS FRACTION LESS THAN:             .940
MASS LESS THAN:                      .002  GR/DSCF
                                     .006  GMS/M3
```

CORPORATION

CUMULATIVE LOG PROBABILITY PLOT

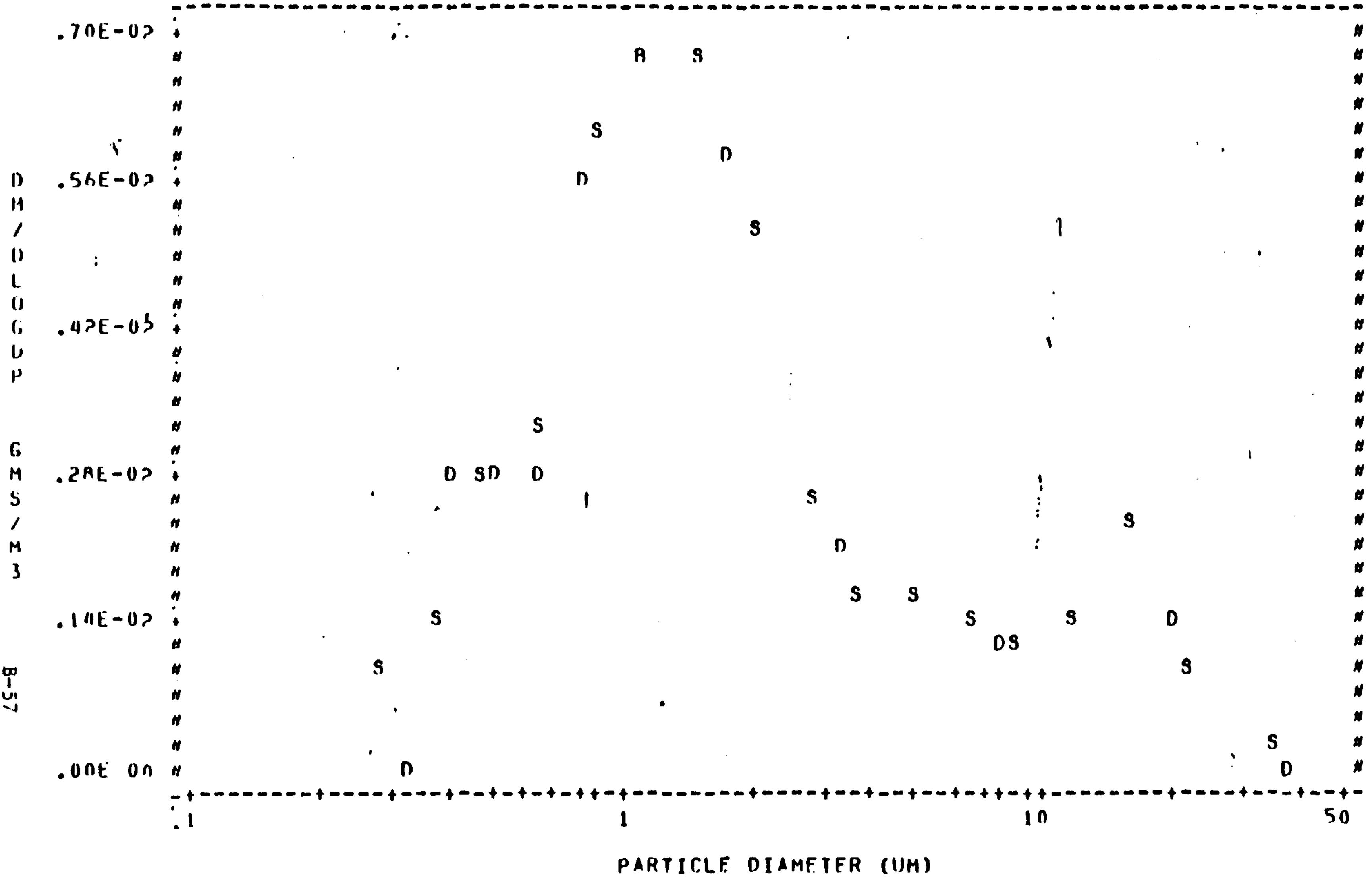
SAMPLE IDENT: IMPAC-3



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-3



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

PROCESS BAGHOUSE OUTLET

AUGUST 8, 1980

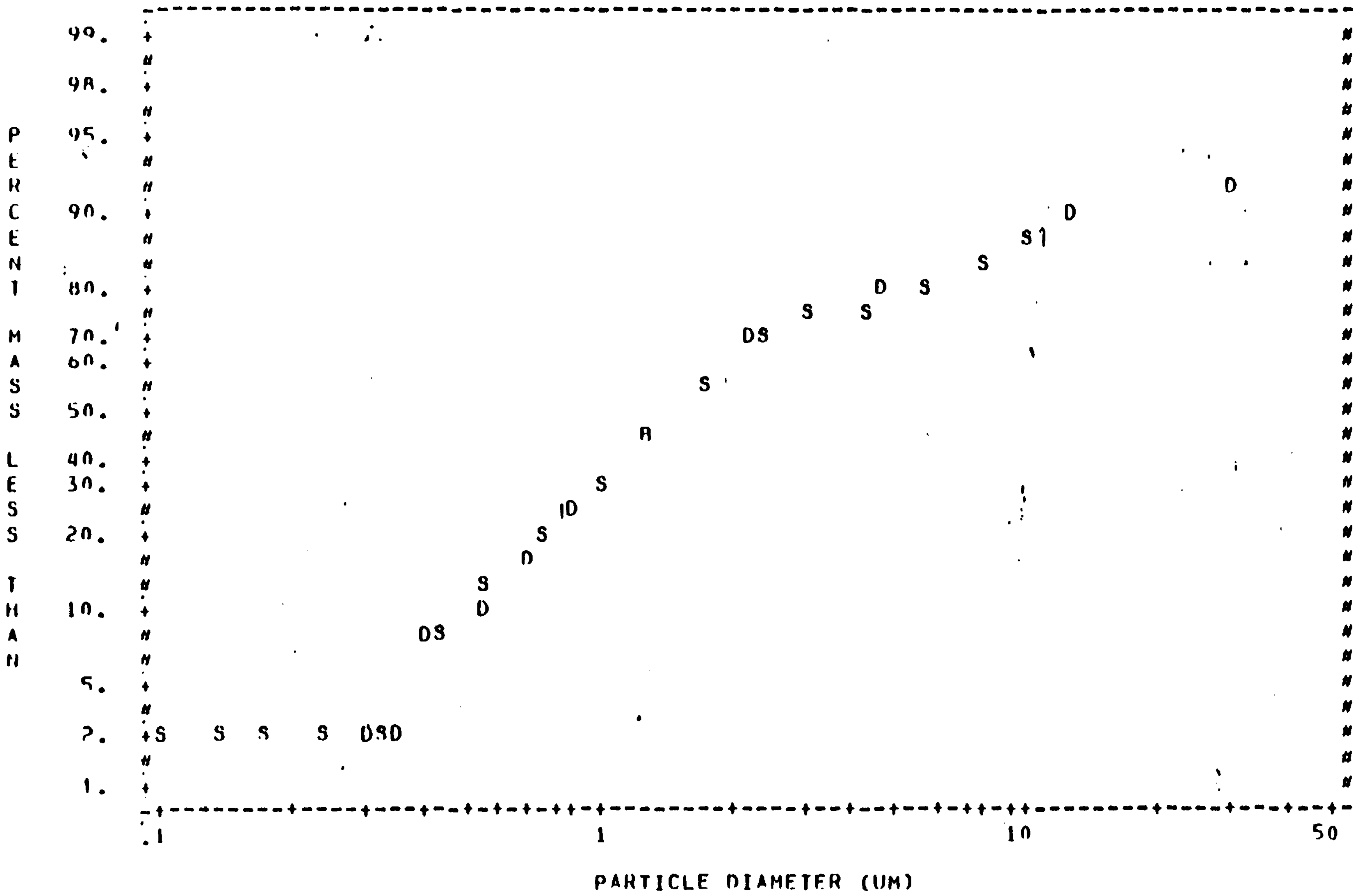
CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-4

PLANT NAME: EAST PENN
SAMPLING LOCATION: PROCESS BAG-OUT
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/ 8/80 (MMDDYY)            TIME START:  8:30 (HHMM)              TIME FINISH: 11:30 (HHMM)

INTERVAL        INTERVAL             MASS            MASS               INTERVAL          DM/DLOG DP
   #            ENDPOINT           FRACTION        FRACTION            GEOMETRIC     DRY STAND. CONDITI
                                                   LESS THAN            MIDPOINT       GR/DSCF      GMS/
                                                   
    1             23.71              .0847           .9153              34.4336       .347E-03   .793E-0
    2             17.78              .0135           .9018              20.5352       .144E-03   .328E-0
    3             13.34              .0175           .8843              15.3992       .186E-03   .425E-0
    4             10.00              .0228           .8615              11.5478       .242E-03   .553E-0
    5              7.50              .0295           .8319               8.6596       .313E-03   .717E-0
    6              5.62              .0363           .7956               6.4938       .385E-03   .882E-0
    7              4.22              .0417           .7539               4.8697       .443E-03   .101E-0
    8              3.16              .0462           .7077               3.6517       .490E-03   .112E-0
    9              2.37              .0511           .6566               2.7384       .542E-03   .124E-0
   10              1.78              .0911           .5655               2.0535       .966E-03   .221E-0
   11              1.33              .1274           .4381               1.5399       .135E-02   .309E-0
   12              1.00              .1390           .2991               1.1548       .147E-02   .337E-0
   13               .75              .0905           .2086                .8660       .961E-03   .220E-0
   14               .56              .0834           .1252                .6494       .885E-03   .202E-0
   15               .42              .0505           .0747                .4870       .536E-03   .123E-0
   16               .32              .0545           .0202 *              .3652       .578E-03   .132E-0
   17               .24              .0000           .0202                .2738       .000E 00   .000E 0

 *  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

 RESPIRABLE LIMIT:              15.00  UM
 MASS FRACTION LESS THAN:         .896
 MASS LESS THAN:                  .001   GR/DSCF
                                  .003   GMS/M3
```

RPORATION

CUMULATIVE LOG ABILITY PLOT

SAMPLE IDENT: IMPAC-4

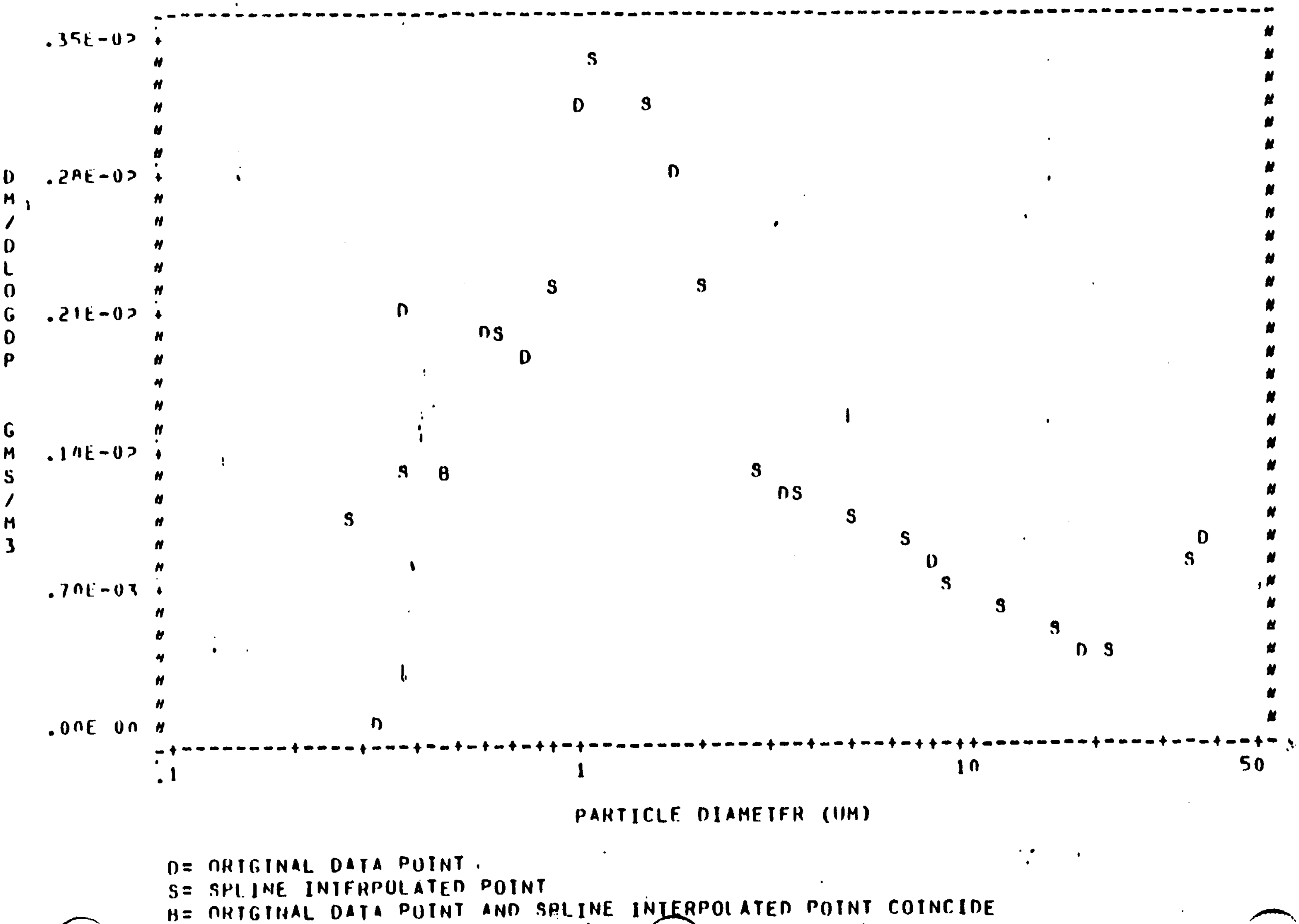


D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

CORPORATION

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-4



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

AGGLOMERATOR FLUE

AUGUST 13, 1980

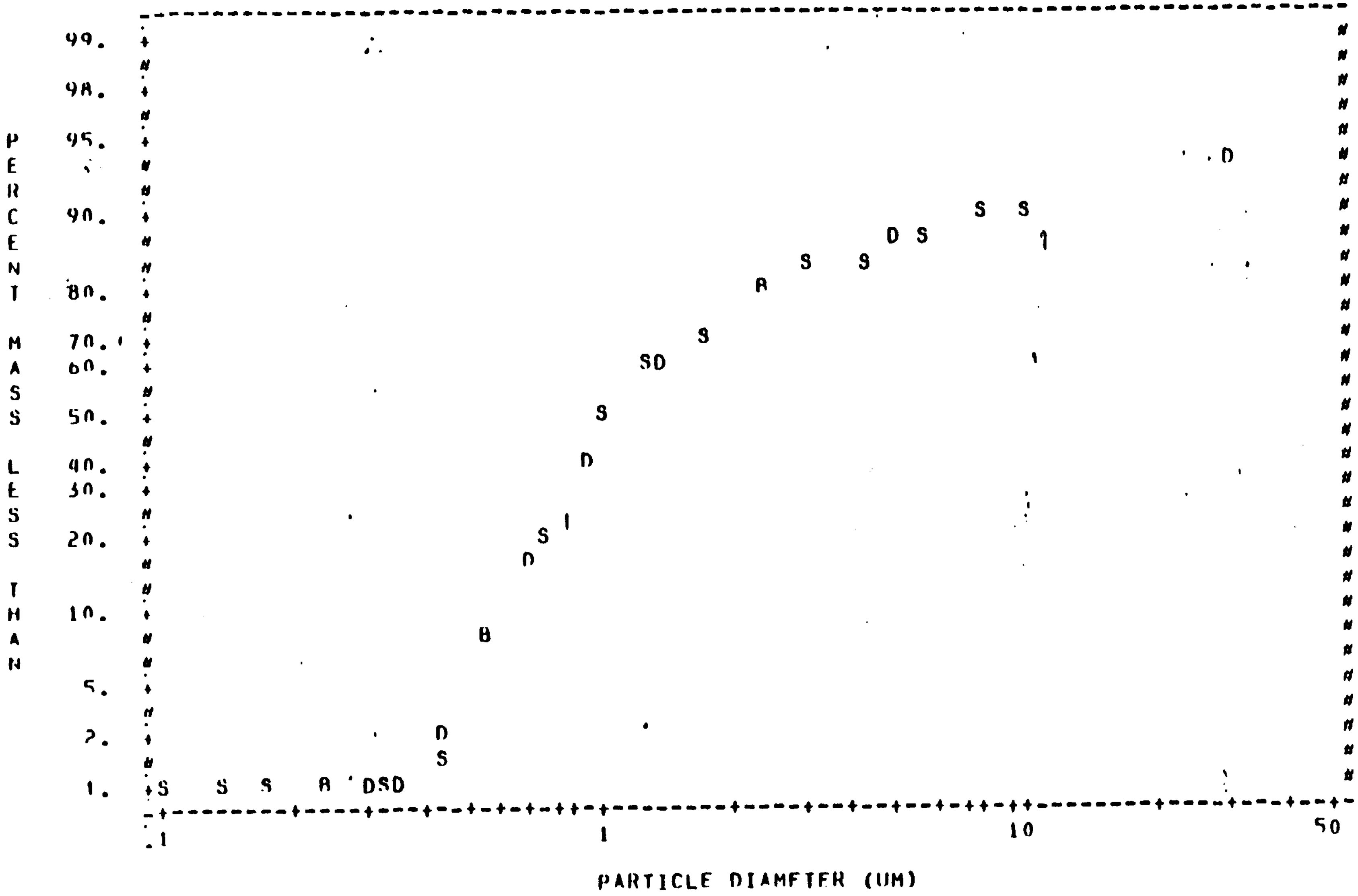
CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-1

PLANT NAME: EAST PENN
SAMPLING LOCATION: AGGLOMERATOR
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/13/80 (MMDDYY)          TIME START: 18:36 (HHMM)            TIME FINISH: 18:39 (HHMM)

INTERVAL       INTERVAL            MASS           MASS            INTERVAL         DM/DLOG DP
  #.           ENDPOINT          FRACTION        FRACTION         GEOMETRIC     DRY STAND. CONDITIC
                                                 LESS THAN        MIDPOINT        GR/DSCF      GMS/M

  1             23.71              .0758          .9242 *          34.4336        .147E 00   .336E 00
  2             17.78              .0090          .9151 *          20.5352        .453E-01   .104E 00
  3             13.34              .0098          .9053 *          15.3992        .491E-01   .112E 00
  4             10.00              .0106          .8947 *          11.5478        .531E-01   .122E 00
  5              7.50              .0114          .8833 *           8.6596        .572E-01   .131E 00
  6              5.62              .0122          .8711 *           6.4938        .614E-01   .140E 00
  7              4.22              .0287          .8424             4.8697        .144E 00   .329E 00
  8              3.16              .0264          .8160             3.6517        .132E 00   .303E 00
  9              2.37              .0447          .7713             2.7384        .224E 00   .513E 00
 10              1.78              .0847          .6866             2.0535        .425E 00   .971E 00
 11              1.33              .0883          .5983             1.5399        .443E 00   .101E 01
 12              1.00              .1272          .4711             1.1548        .638E 00   .146E 01
 13               .75              .2636          .2075              .8660        .132E 01   .302E 01
 14               .56              .1263          .0812              .6494        .633E 00   .145E 01
 15               .42              .0649          .0163              .4870        .326E 00   .745E 00
 16               .32              .0132          .0031 *            .3652        .663E-01   .152E 00
 17               .24              .0011          .0020              .2738        .562E-02   .129E-01
 18               .18              .0012          .0008              .2054        .612E-02   .140E-01

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:               15.00  UM
MASS FRACTION LESS THAN:          .911
MASS LESS THAN:                   .571  GR/DSCF
                                 1.306  GMS/M3
```

ORPORATION

CUMULATIVE, LOG PROBABILITY PLOT

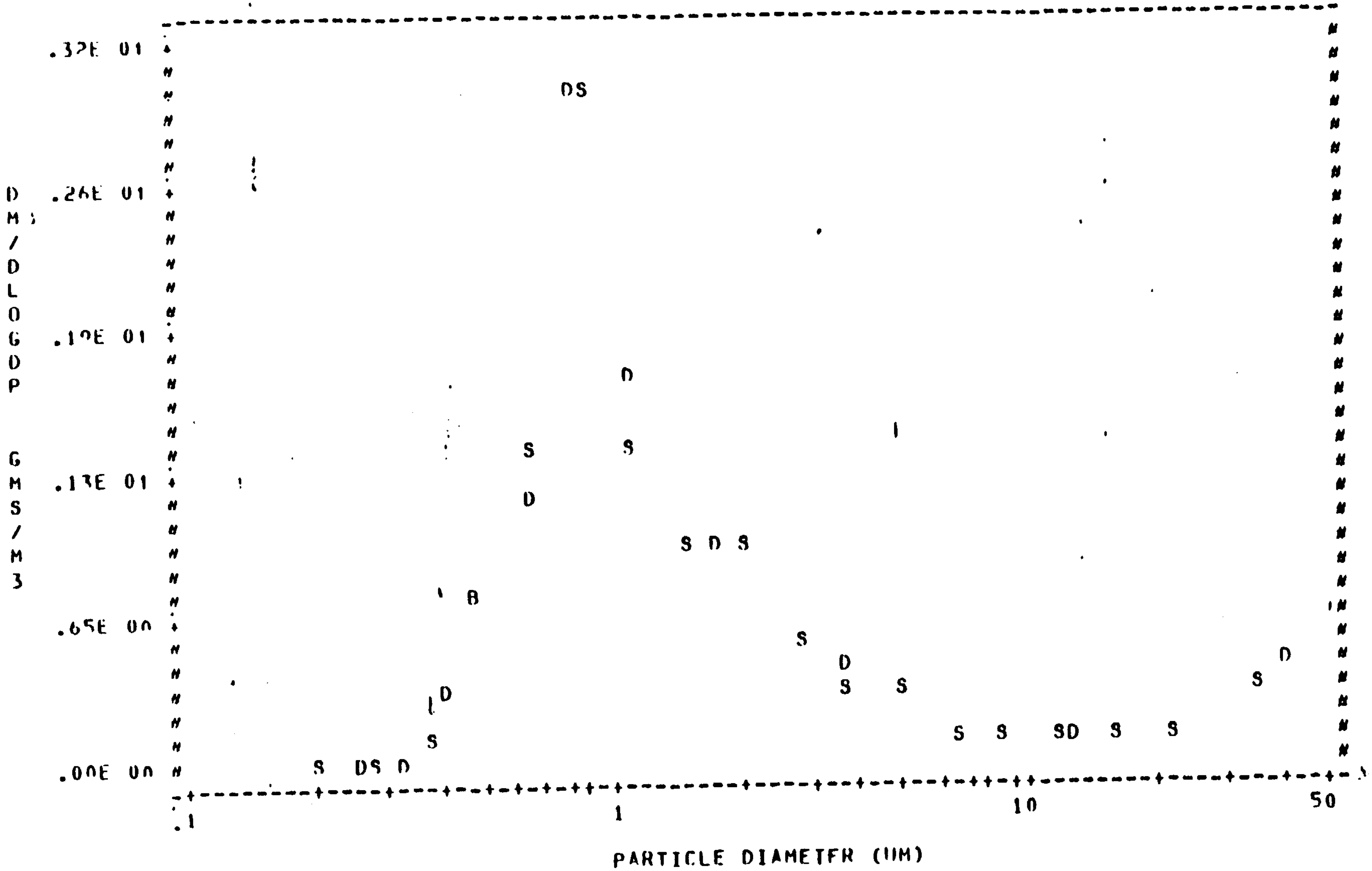
SAMPLE IDENT: IMPAC-1



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-1



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

IMPACTOR RESULTS SUMMARY

AGGLOMERATOR FLUE

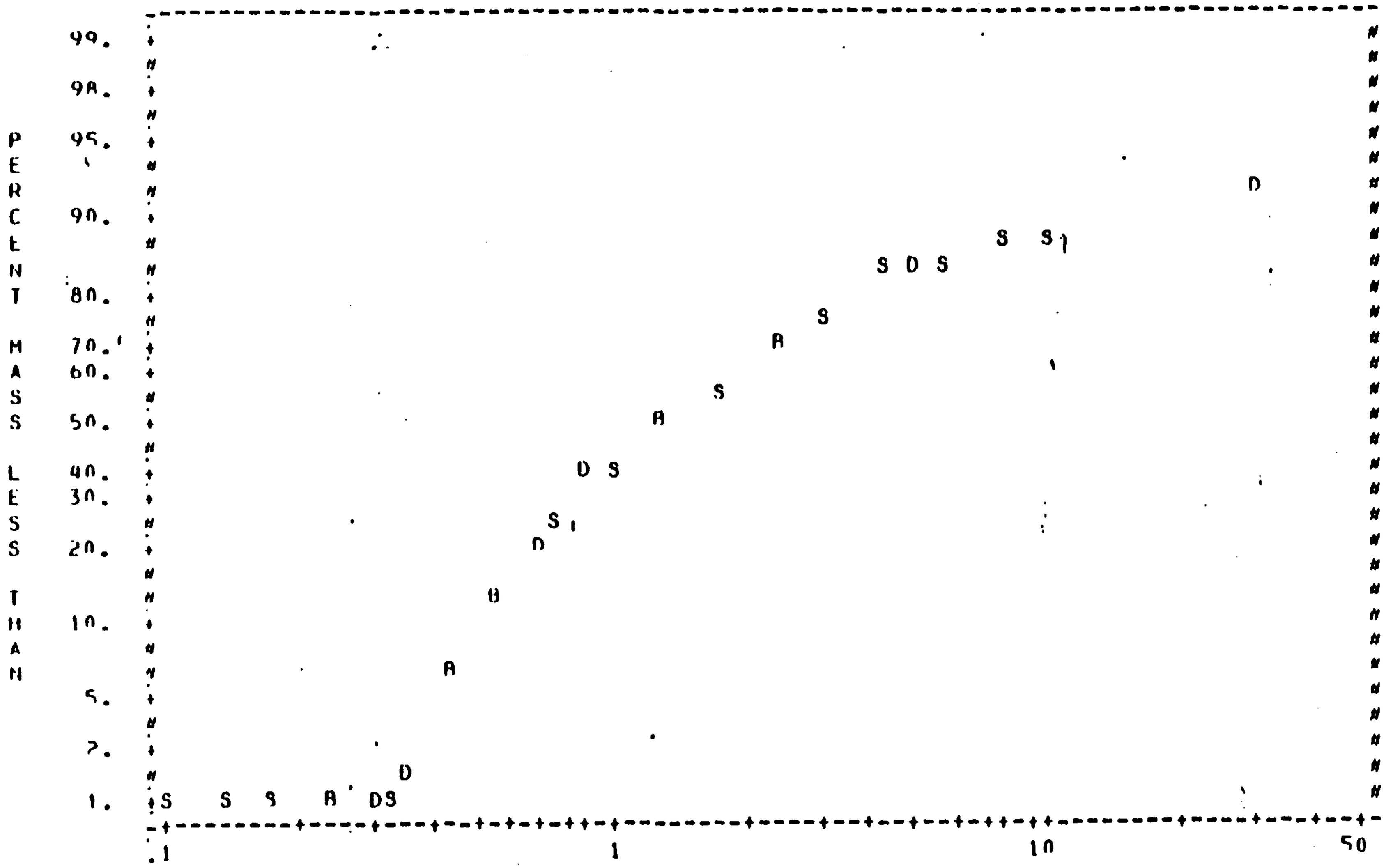
AUGUST 14, 1980

CORPORATION

```
IMPACTOR RESULTS SUMMARY - SPLINE FIT OF EXPERIMENTAL DATA
SAMPLE IDENT:  IMPAC-2

PLANT NAME: EAST PENN
SAMPLING LOCATION: AGGLOMERATOR
TYPE OF IMPACTOR: UNIVERSITY OF WASHINGTON
IMPACTOR SUBSTRATE: GLASS FIBER
DATE:  8/14/80 (MMDDYY)          TIME START: 13:10 (HHMM)               TIME FINISH: 13:13 (HHMM)

INTERVAL        INTERVAL            MASS            MASS            INTERVAL        DM/DLOG DP
   #            ENDPOINT          FRACTION        FRACTION          GEOMETRIC     DRY STAND. CONDITIO
                                                  LESS THAN         MIDPOINT       GR/DSCF     GMS/M

   1              23.71             .0878           .9122 *           34.4336      .119E 00   .273E 00
   2              17.78             .0122           .9001 *           20.5352      .429E-01   .983E-01
   3              13.34             .0133           .8867 *           15.3992      .471E-01   .108E 00
   4              10.00             .0145           .8722 *           11.5478      .513E-01   .117E 00
   5               7.50             .0158           .8564 *            8.6596      .556E-01   .127E 00
   6               5.62             .0170           .8394 *            6.4938      .599E-01   .137E 00
   7               4.22             .0353           .8042              4.8697      .124E 00   .285E 00
   8               3.16             .0544           .7498              3.6517      .192E 00   .439E 00
   9               2.37             .0726           .6772              2.7384      .256E 00   .586E 00
  10               1.78             .0932           .5840              2.0535      .329E 00   .752E 00
  11               1.33             .0972           .4868              1.5399      .343E 00   .785E 00
  12               1.00             .0970           .3898              1.1548      .342E 00   .783E 00
  13                .75             .1302           .2596               .8660      .459E 00   .105E 01
  14                .56             .1151           .1445               .6494      .406E 00   .929E 00
  15                .42             .0897           .0548               .4870      .316E 00   .724E 00
  16                .32             .0470           .0078               .3652      .166E 00   .379E 00
  17                .24             .0044           .0034               .2738      .155E-01   .356E-01
  18                .18             .0012           .0022               .2054      .421E-02   .963E-02

*  COMPUTED BY LINEAR INTERPOLATION DUE TO NON-MONOTONICITY IN CUBIC SPLINE FUNCTION

RESPIRABLE LIMIT:                 15.00  UM
MASS FRACTION LESS THAN:           .894
MASS LESS THAN:                    .394   GR/DSCF
                                   .902   GMS/M3
```

CUMULATIVE LOG PROBABILITY PLOT

SAMPLE IDENT: IMPAC-2

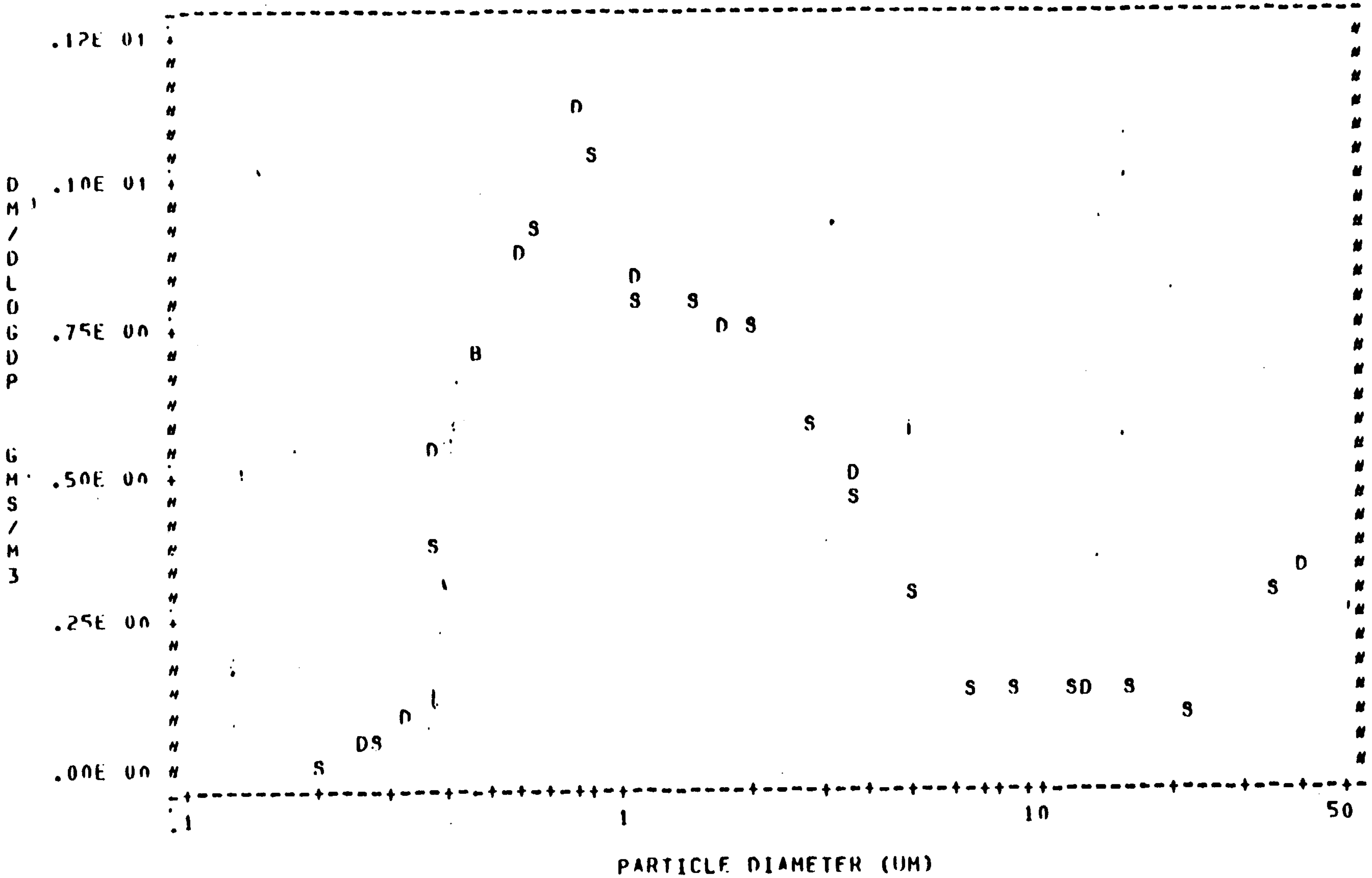


PARTICLE DIAMETER (UM)

D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

DIFFERENTIAL MASS CONCENTRATION PLOT

SAMPLE IDENT: IMPAC-2



D= ORIGINAL DATA POINT
S= SPLINE INTERPOLATED POINT
B= ORIGINAL DATA POINT AND SPLINE INTERPOLATED POINT COINCIDE

APPENDIX C

WORKPLACE EXPOSURE CONTROL INFORMATION PROVIDED TO EAST PENN MANUFACTURING FOLLOWING THE INITIAL EVALUATION

- Inventory of Emission Sources Contributing to Workplace Lead Contamination

- Recommended Control Considerations

Prepared by:

Robert Vandervort

INVENTORY OF EMISSION SOURCES CONTRIBUTING TO WORKPLACE LEAD CONTAMINATION

There are a number of emission sources which contribute to workroom lead-in-air contamination at this smelter. These emissions are from:

- pulvation of lead particulate by materials handling equipment (front end loaders, large and small),
- manual shoveling of lead bearing materials, especially settled particulate, flue dust and plant scrap,
- charging of lead bearing material to the skip hoist by manual shoveling, dumping of wheel barrows, and dumping of Bobcat bucket loads,
- charging at the top of the vertical shaft blast furnace,
- the slag tapping port during slag tapping,
- tuyere covers during tuyere punching,
- the lead well, launder, and molten lead molding operation,
- cooling crude lead molds,
- floor surfaces disturbed by traffic of personnel and machinery,
- the melting of lead in refining kettles,
- drossing operations in refining kettles,
- skimming operations associated with refining kettles,
- the pigging machine as ingots are formed,
- vibrating surfaces in the roof structure of the building,
- wind blown particulate from outside yard areas and materials handling,
- particulate which settles on work clothing and is introduced into the workers' breathing zone,
- splashes from lead bearing solutions which attach to work surfaces, dry and then are dislodged by movement of air or rubbing off by equipment or personnel (battery breaking and materials handling),

- tote bins used to collect settled particulate from knockout boxes or at the base of dust collectors, and
- cleanup operations such as sweeping and shoveling of materials.

Each of the above emission sources will contribute in varying degrees to employee exposure at this smelting facility. To effectively control exposures attention must be given to each of the possible emission sources listed.

RECOMMENDED CONTROL CONSIDERATIONS

Following the field work associated with the initial evaluation, a list of recommendations was developed to assist the smelter in controlling their lead exposure problem. These recommendations were made within the frame work of retrofitting controls to existing process equipment. This constraint ruled out some more radical changes that could be incorporated in new plant construction. Examples of changes which were not suggested to the smelter are:

- complete removal of existing smelter building floors and replacement with elaborate washdown and water collection sumps and drains, and
- complete separation of all raw materials handling from the furnace operating and refining areas of the smelter.

The recommendations which were forwarded to the smelter are described below. They are organized by smelting operation and other industrial hygiene control considerations. Several recommendations are included which pertain to respiratory protection, hygiene facilities and practices, employee training, etc. It was stressed that in the interim, while engineering controls are being designed and installed, that employees must be afforded maximum protection from exposure through use of protective devices and rigorous personal hygiene.

Battery Breaking.

- A suitable eye fountain and emergency shower station should be provided in close proximity to battery shearing work station.
- Lead mud deposits should be cleaned from all surfaces in the battery breaking area (walls, roller conveyor, shear, floor, etc.).
- Plexiglas or other transparent enclosures should be installed at the shear to prevent splashing of battery acid and mud onto employees.
- A means of periodically washing mud and acid from the transparent enclosure should be provided.
- A means of periodically washing down the battery breaking work area to remove accumulations of caked-on mud, etc. should be provided.

- Employees should be instructed to clean accumulations of battery mud from their protective aprons at periodic intervals. Water and a sponge should remove most of this material and prevent it from becoming dry and entering the air in the breathing zone of the worker.

- Depending on the reduction in employee exposures afforded by the above recommendations, an exhaust ventilation system should be designed and installed to serve the battery shears.

Skip Hoist Charging and Materials Handling.

- Improved materials handling should be instituted in association with skip hoist charging.

  a) Raw materials stored (piled) in the charging area should be kept damp. Sprinklers or hoses with spray nozzles could be utilized.

  b) Deliveries of plant scrap which can consist of reject battery plates, etc. should be brought to the smelter in covered tote boxes or other covered containers. Before dumping into a storage pile, dry materials should be thoroughly wetted.

  c) The floor area near the skip hoist should be kept as clean as possible and wetted to help limit dust generation.

  d) Cross drafts through the furnace charging area should be minimized by closing sliding doors.

  e) Sweeping and shoveling of dry lead bearing materials should be prohibited. Shoveling of wetted materials or vacuuming of dry materials is preferred.

- Improved local exhaust ventilation should be provided at the skip hoist loading station.

  a) Initially the new exhaust system should be attached to the existing exhaust ducts serving the loading station.

  b) Extensions from the side of the loading station should be considered to create better dust control in front of the loading station.

c) Tapered entires to exhaust ductwork should be considered for the exhaust pickups on each side of the loading station enclosure.

- The materials storage area should be kept as clean as possible. Splashes of mud should be cleaned from surfaces to prevent drying and entrainment into the air.

- Mechanized materials handling equipment (Bobcat) should not travel into other smelter areas tracking mud, etc.

<u>Tuyere Punching</u>.

- A hood above all tuyeres to control emissions when tuyere covers are removed should be considered.

<u>Blast Furnace Charging</u>.

- Improved local exhaust ventilation of the blast furnace charging port should be provided.

  a) Initially the new ventilation system should be attached to the charging hoods provided at the top of the furnace.

  b) Capture characteristics at the charging hood should be evaluated to determine whether improved enclosure or otherwise altered hood designs are necessary.

<u>Slag Tapping</u>.

- The slag tapping hood should be repaired to correct deformations in ductwork.

- Better enclosure of the taphole and receiving vessel should be provided.

  a) The hood front and side pieces should be made to fit together better reducing gaps where sparks, etc. may escape.

  b) The hood sides and front should fit more tightly around the slag receiving vessel to better contain sparks, splashes, etc. which drop to the floor at the base of the receiving vessel.

c) A means of clearing the slag taphole with the front portion of the slag tapping hood in its lowered position should be investigated. Possibly a small opening in the hood front would allow sufficient access.

- Sweeping and shoveling of dry particulate materials resulting from slag tapping should be discontinued. Fugitive settled particulate should be wetted before being cleaned up. Alternatively, it could be picked up using vacuum methods.

- The slag tapping work area should be protected from strong wind currents. Doors leading to the yard area should be closed during windy conditions.

- The filled slag receiving vessel should remain under the slag tapping hood until it has cooled sufficiently to prevent fuming.

Crude Metal Tapping from Blast Furnace.

- Initially the new exhaust ventilation system should be hooked up to the existing local exhaust hoods provided for the lead well, launder and molding line.

- Improved local exhaust ventilation enclosures should be designed and installed for the crude metal tapping/pouring operation.

  a) A stationary hood could be constructed which would enclose the lead well, launder and molding line. This hood could be provided with inspection or access panels to service the launder, etc. The launder could remain stationary with the ingot molds passed in front of the pouring station by means of a rolling molding car at the pouring station. The hood over the pouring station should accommodate the mold being poured and the one cooling after pouring.

  b) A movable hood similar in some respects to the existing three hood system could be constructed. This movable hood should be of one or two piece construction. The hood system should be self supporting (supported on pivots, etc.). The hood(s) should enclose the lead well, launder, the mold being poured and the mold in the cooling position.

c) A combination of fixed and movable hoods could be applied. Any movable hood should be self supporting. The hood system should enclose the mold being poured and the one in the cooling position. Transitions between hoods should overlap with no gaps in local exhaust coverage.

- Sweeping and shoveling of dry particulate materials resulting from metal tapping and pouring should be discontinued. Fugitive settled particulate should be wetted before being cleaned up or picked up using vacuum methods.

Kettle Refining.

- Local exhaust ventilation hoods should be designed and installed for the refining kettles.

  a) Sufficient enclosure should be provided to capture heated air from kettle firing and fumes from the surface of the molten lead in the kettle.

  b) The local exhaust hood should be designed to permit charging of the kettle with large crude lead ingots.

  c) The local exhaust hood should be designed to permit insertion of a mechanical stirring apparatus used during drossing. Sufficient enclosure during drossing and stirring should be provided to control fumes and particulate emanating from the molten lead.

  d) The local exhaust hood should accommodate the pigging operation. Swing away doors may provide reasonable access for the molten lead pumping device.

- Depending on the final design of refining kettle hoods, varying configurations of additional local exhaust ventilation for the skimming operation will be necessary.

  a) Fumes from kettle skimmings ("pies") should be controlled near their source.

  b) The present practice of building pies on a pallet should be reviewed to determine whether a more compact method of handling skimmings can be devised.

  c) Preferably, the auxiliary local exhaust ventilation for skimming should take advantage of the enclosure (swing away doors, etc.) of the kettle refining hoods. It may be possible to control skimming emissions by attaching local exhaust ductwork to the swing away portion of the hood thus eliminating the need for extra equipment.

d) Any additional local exhaust ventilation for skimming operations should be easily operated by employees. Complicated ductwork, hoisting, and moving systems should be avoided.

- Removing skimmings from the kettle could be accomplished by a long handled implement supported at a pivot point at the center of the handle. The increased handle length would give more mechanical advantage to the skimming operator than using a flat point shovel. Also the skimming operator would no longer have to reach out over the molten lead thereby decreasing his potential exposure to fumes.

- Sweeping and shoveling of dry particulate materials resulting from kettle refining and skimming operations should be discontinued. Fugitive settled particulate should be wetted before being cleaned up. Alternatively, it could be picked up using vacuum methods. Splashes of molten lead and skimmings will require manual removal from surfaces and placement into scrap containers.

- During windy weather, doors should be closed to help minimize cross drafts within the smelting building. These cross drafts can entrain contaminants which would otherwise be captured by kettle and skimming hood enclosures.

<u>Pigging</u>.

- Exhaust enclosure for the pigging machine should be designed and installed on the machine.

  a) Of primary importance is the portion of the pigging machine where the reservoir of molten lead and pouring of lead into the ingot molds occurs.

  b) An enclosure of the "hot" end of the pigging machine could be made with hinged side access doors. The hood could be supported by metal extensions from the machine framework.

  c) The hood could be made a permanent part of the traveling pigging machine. Drops of flexible ductwork from the overhead local exhaust ductwork could be attached to the hood when the machine was positioned beside either refining kettle.

- During windy weather, dross drafts which can blow by the pigging machine should be minimized by closing the large sliding doors. This will help to minimize entrainment of contaminants out from under the pigging machine exhaust hood.

Respiratory Protection Program.

- Plant management should review the respiratory protection requirements of 29 CFR 1910.134 and 29 CFR 1910.1025. Appropriate updating and improvement of the existing program should be instituted.

  Specifically attention to the following items should be applied

  a) A respiratory protection training session should be presented to employees. The intent of the session should be to refresh their knowledge with regard to the fitting, use, care, and limitations of the respirators they are required to wear.

  b) A determination should be made that all smelter employees can obtain a proper face fit from the respirators in use. It may be necessary to make available respirators of another brand to accommodate all variations in facial structure and size. All respirators utilized should carry appropriate NIOSH approvals.

  c) A determination should be made that all employees who are required to wear respirators can perform their normal duties with the respirator properly fitted and adjusted. Employees who cannot effectively breathe through the respirator during normal work activity should be identified. A different form of respiratory protection (i.e., powered air-purifying respirator) may be supplied or the employee transferred to an area where respirators are not required. The plant physician can be of assistance in determining whether employees are physically capable of wearing respirators.

  d) Special emphasis should be given to impressing the employees that respirators must be worn at all times while working in the smelting building and yard area.

e) Employees should be instructed to prevent contamination of the respirator when it is removed at breaks or during lunch. Paper towels or soft clean cloths should be provided to wipe off the respirator facepiece before it is reworn after a break.

Hygiene Facilities and Practices.

- Smoking and consuming of food and beverage in the smelter building and yard area should be strictly prohibited. Smoking and chewing materials should not be carried by employees into the smelter building and yard area.

- Use of the existing smelter lunchroom facility should be discontinued. Smelter employees should be required to use the main plant lunchroom or outside food establishments.

- Smelter employees should not enter lunchroom facilities with protective work clothing or equipment unless surface lead dust has been removed by vacuuming, downdraft booth or other cleaning method. Alternatively, smelter employees could be provided with overalls which can be worn over their work clothing and removed before entering lunchrooms, breakrooms, or food establishments. Clean smocks could be provided to put on over work shirts and trousers.

- A shoe/boot cleaning station should be provided at the entrance to the locker room and to areas where food and beverages are consumed.

- Smelter employees should be required to thoroughly wash their hands, forearms, face and neck before consuming food or drink. As a minimum, hands and face should be washed before smoking or chewing materials are utilized.

- Smelter employees should be provided with clean work clothing each day.

- The smelter employee locker room should receive frequent janitorial service (mopping, etc.) on all shifts of the working day.

- Smelter employees should shower and change into street clothing at the conclusion of the workshift. Work clothing should not be taken home. It should be deposited in closed containers.

Employee Training and Information.

- Employees should be informed in organized training sessions of the following:

  a) Content of 29 CFR 1910.1025.

  b) The hazards associated with exposure to lead and how they can be controlled.

  c) The purpose, proper selection, fitting, use, and limitations of respirators.

  d) The purpose and description of the medical surveillance program.

  e) The engineering controls and work practices associated with controlling employee exposure to lead associated with a particular job.

  f) The contents of existing compliance plans.

  g) The dangers of chelating agents.

- Privately each employee should be told what his measured lead-in-air exposure is (without regard to use of respiratory protection) and what the results of his blood lead monitoring are. These results should be explained in terms of compliance with OSHA standards and related to potential adverse health effects.

Housekeeping.

- A smelter-wide cleanup should be undertaken. Lead dust and mud should be removed from yard surfaces, building surfaces, equipment, etc. Settled particulate which has accumulated on building structural members should be removed.

- Dry sweeping and shoveling should be discontinued. Shoveling of wet materials or vacuum methods are preferred.

Medical Monitoring.

- The existing blood lead monitoring program should be continued.

- The medical monitoring requirements of 29 CFR 1910.1025 should be implemented.

Recordkeeping.

- The recordkeeping requirements of 29 CFR 1910.1025 should be implemented.

APPENDIX D

POINT SOURCE TOTAL PARTICULATE MATTER AND TOTAL LEAD DATA

Prepared by:

Larry J. Holcombe

POINT SOURCE TOTAL PARTICULATE MATTER AND TOTAL LEAD DATA

A summary of the results of the EPA Method 12 sampling is presented in Table D-1. These tests were conducted on point sources to determine total particulate and total lead emission rates. The table lists the physical parameters of each gas stream as well as the emission rates.

TABLE D-1. EPA METHOD 12 RESULTS

Sample Identifier	Date	Percent Isokinetic	Stream Flow Rate (DSM^3/Hr)[1]	Stream Velocity (M/SEC)	Stream Temperature (°C)	Volume Sampled (DSM^3)[1]	Particulate (grams/DSM^3)[1]	Source Emission Rates: Total Particulate (grams/hr)	Source Emission Rates: Pb Only (grams/hr)
Slag Tap Baghouse - In									
EPA-12-1	08-05-80	91	7,000	18.5	37	1.27	0.19	1,300	740[2]
EPA-12-2	08-06-80	101	6,800	17.5	28	1.24	0.27	1,000	1000[2]
Slag Tap Baghouse - Out									
EPA-12-1	08-05-80	124	8,600	22.3	47	1.46	0.0036	31	8.8
EPA-12-2	08-06-80	104	7,900	19.7	39	1.46	0.0049	39	11
Lead Well									
EPA-12-1	08-12-80	112	18,000	30.0	32	2.90	0.031	560	340
EPA-12-3	08-15-80	101	18,000	28.9	27	2.81	0.053	950	--[3]
Charging Hood									
EPA-12-1	08-12-80	90	11,000	9.4	67	1.52	7.7	85,000	67,000
EPA-12-2	08-15-80	97	9,100	8.7	106	0.56	17.5	160,000	120,000
Sanitary Baghouse - In									
EPA-12-4	08-09-80	106	62,000	17.6	64	1.39	0.81	50,000	36,000
EPA-12-7	08-11-80	105	62,000	17.7	63	1.37	3.24	200,000	150,000
Sanitary Baghouse - Out									
EPA-12-5	08-09-80	102	59,000	16.2	46	2.33	0.024	1,400	--[3]
EPA-12-6	08-11-80	102	56,000	15.7	49	2.25	0.0045	250	85
Process Baghouse - In									
EPA-12-3	08-07-80	119	4,300	14.7	525	0.28	24.4	100,000	80,000
EPA-12-4	08-08-80	118	4,400	11.2	447	0.11	130	570,000	260,000
Process Baghouse - Out									
EPA-12-3	08-07-80	96	33,000	19.8	81	2.82	0.025	830	250
EPA-12-4	08-08-80	97	32,000	19.4	74	2.65	0.008	260	140
Agglomerating Flue									
EPA-12-1	08-13-80	95	9,100	35.1	84	0.64	7.9	72,000	57,000
EPA-12-2	08-14-80	96	8,000	32.7	104	0.34	10.5	84,000	59,000
Refining Kettle									
EPA-12-1	08-15-80	94	3,600	27.2	42	4.05	0.012	43	11
EPA-12-2	08-15-80	99	3,400	24.8	41	3.96	0.008	27	15
Pigging Hood									
EPA-12-1	08-15-80	96	2,000	16.6	47	0.41	0.027	54	11
EPA-12-2	08-16-80	96	2,000	14.6	36	0.35	0.017	34	18

[1] STP = 68°F, 760 mm Hg.

[2] Value based on slag tap baghouse dust bulk sample.

[3] Sample lost in analysis.

APPENDIX E

AMBIENT SUSPENDED PARTICULATE DATA

Prepared by:

Larry J. Holcombe

AMBIENT SUSPENDED PARTICULATE DATA

Table E-1 contains the data gathered from the high volume samplers run during the August, 1980, sampling period. The table contains the total suspended particulate and suspended lead data from the standard hi-vols, the 15 micron selective inlet hi-vols and the hi-vols equipped with five stage cascade impactors. For the impactor hi-vols the five stages have been combined into three size cuts; less than 3.0, between 3.0 and 7.2 and greater than 7.2 microns.

TABLE E-1. LEAD CONTENT AND SIZE OF AMBIENT SUSPENDED PARTICULATE DATA AT EAST PENN

		SUSPENDED PARTICULATE DATA (µg/SM³)¹,³													Plant Weather Data	
		Standard Hi-Vol		<15µ Hi-Vol		>7.2µ			7.2 - 3.0µ			<3.0				
Date	Location	TSP²	Pb Only	TSP	Pb Only	TSP	Pb Only	% of Total Pb	TSP	Pb Only	% of Total Pb	TSP	Pb Only	% of Total Pb	Wind Speed (MPH)	Wind Direction
08-07/08-08-80	Pond	83	2.1	90	1.9	11	0.02	4.6	13	0.03	7.0	83	0.38	88.4	4	245° (WSW)
	Water Tower	79	0.7	74	0.6	12	0.005	4.3	12	0.01	8.7	82	0.10	87.0		
	Farm	96	0.3	89	0.2	12	0.007	8.0	14	0.001	1.1	85	0.08	90.9		
08-08/08-09-80	Pond	89	6.7	92	7.3	13	0.13	10.9	14	0.17	14.3	92	0.89	74.8	8	225° (SW)
	Water Tower	72	1.4	72	1.3	9.1	0.02	5.6	11	0.04	11.1	80	0.3	83.3		
	Farm	110	0.4	88	0.2	12	0.001	2.4	10	0.001	2.4	83	0.04	95.2		
08-09/08-10-80	Pond	71	11	65	10	24	0.09	5.8	12	0.15	9.7	55	1.3	84.5	5	315° (NW)
	Water Tower	59	3.5	52	3.0	16	0.03	5.5	10	0.06	10.9	45	0.46	83.6		
	Farm	52	0.6	46	0.5	7.8	0.001	0.7	6.5	0.005	3.7	49	0.13	95.6		
08-12/08-13-80	Dust Pile	120	60			30	1.4	11.1	26	1.3	10.3	87	9.9	78.6	2	240° (WSW)
	Smelter	94		82	25											
	Water Tower			49		8.7			7.6			53				
	Farm	48		43		4.9			6.3			42				
08-14/08-15-80	Dust Pile	160	36	170	14										3	225° (SW)
	Smelter	140	34			32	1.0	14.4	25	0.64	9.2	120	5.3	76.4		

¹ STP = 25°C, 760 mm Hg

² Total Suspended Particulate

³ Aerodynamic size (spherical particle, density = 1.0)