

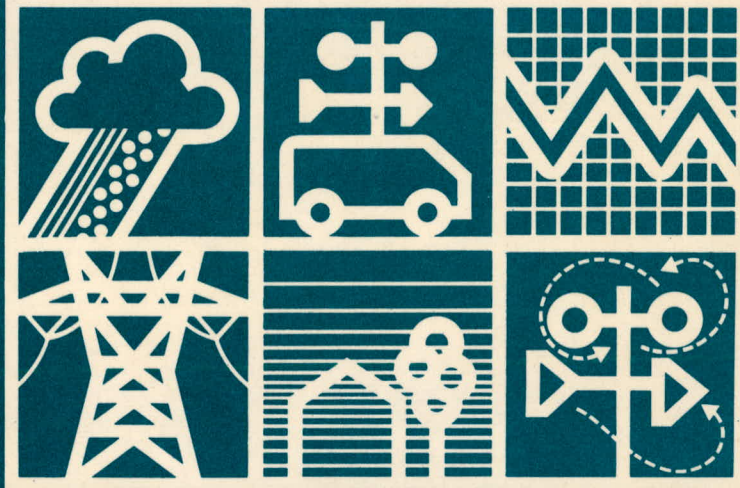
Technical Report

Meteorology Research, Inc.

MEASUREMENT OF SULFATE AEROSOLS
FROM WESTERN LOW-RANK-COAL-FIRED
BOILERS WITH FGD: RESULTS OF TESTS
AT CLAY BOSWELL UNIT 4

MRI 81 R1805

MASTER



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MEASUREMENT OF SULFATE AEROSOLS FROM WESTERN LOW-RANK-COAL-FIRED BOILERS WITH FGD: RESULTS OF TESTS AT CLAY BOSWELL UNIT 4

MRI 81 R1805

Submitted to:

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Ion chromatographic sulfate analysis was done by EAL Corporation. Coal samples were analyzed by Analytical Research Laboratories, Inc.

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1. INTRODUCTION

1.1 Purpose of the Test

The test reported here was part of a program to investigate the quantity and type of sulfates emitted from Western low-rank coal-fired utility boilers with flue gas desulfurization (FGD) systems. The tests are being conducted by Meteorology Research, Inc. (MRI) for the Department of Energy, Grand Forks Energy Technology Center.

1.2 Plant Description

The measurements reported here were made on the FGD system on Unit 4 of the Clay Boswell Station of Minnesota Power and Light Company near Cohasset, Minnesota. The Unit 4 boiler burns pulverized Colstrip, Montana coal and has a generating capability of 554 MW (gross).

Flue gas particulate control is accomplished with venturi scrubbers. Sulfur dioxide is controlled using spray towers. There are four scrubber modules, three of which are generally in operation at full load. The flue gas is reheated by a 5 percent bypass. Sulfur dioxide control is accomplished using only fly ash in the slurry; no lime or limestone is added. The slurry pH is controlled by adding fly ash removed by the electrostatic precipitator on the bypass to that already put into the slurry in the venturis.

The mist elimination system consists of a sieve tray followed by chevrons. The sieve tray is normally continuously sprayed from beneath with makeup water (a mixture of pond return and river water) and sprayed intermittently (three minutes per hour) from above with river water. The chevrons are not washed.

The measurements reported here were made in the flue gas ducts before the venturi (inlet) and after the spray tower and mist eliminators (outlet) of scrubber module C.

1.3 List of Measurements Made

Table 1-1 summarizes the measurements made and samples collected at the Clay Boswell Station. Measurements were generally made on each of four days: 23, 25, 26 and 27 January 1981. The results of these measurements are presented and discussed briefly in the following sections. These results will be compared to those of future tests at other sites in the final report on this program.

Table 1-1
LIST OF MEASUREMENTS

Location	Method	Species or Parameter Measured
Gas stream inlet and outlet of a single scrubber module	Controlled condensation system (with H ₂ O ₂ impingers)	• SO₃/H₂SO₄ • Particulate sulfates (ion chromatography) • SO₂
	In-stack filter	• Particulate mass loading • Sulfates (ion chromatography)
	High volume sampler	• Fly ash for elemental analysis
	Pitot tube	• Flue gas velocity
	Thermocouple	• Temperature
	Impactor	• Size-segregated particulate • Sulfates (ion chromatography)
	Gas monitors (continuous)	• SO₂ • O₂
Outlet only	Plant process visiometer (continuous)	• Opacity
Liquid streams (slurry and makeup water)	Composite of 3 daily grab samples	• pH • Suspended solids • Dissolved solids • Sulfates (ion chromatography) • Sample for elemental analysis
Solid samples (coal, bottom ash)	Coal: Composite of grab samples	• Coal: ASTM D-271 and D-2492 for sulfur and sulfur form, sample for elemental analysis
	Ash: A single sample	• Ash: Sulfates (ion chromatography), sample for elemental analysis
Plant control rooms	Recorded from control room readouts	Unit load, scrubber liquid flow rates, gas concentrations, etc.

2. PLANT DATA

Table 2-1 shows plant data for the four test days. This data was generally recorded from the displays in the scrubber control room, except that absorber and venturi liquid flow rate were derived from the name plate ratings of the pumps and the numbers of pumps operating. Data have been averaged over the time the manual tests were conducted. In addition to Module C, Modules A and D were operating during each test. Note that stack opacity, O₂ concentration and SO₂ concentration apply to the combined outputs of Modules A, C, and D, and the bypass. The measurements made by MRI apply to Module C only.

Table 2-1
PLANT DATA

<u>Date (1981)</u>	<u>1/23</u>	<u>1/25</u>	<u>1/26</u>	<u>1/27</u>
Unit 4 Load (MW)	540	550	450	530
Module C Absorber liquid flow (GPM)	16,700	16,700	16,700	16,700
Module C Venturi liquid flow (GPM)	13,360	13,360	13,360	13,360
Module C Sieve tray underspray (GPM)	340	355	355	0
Module C Sieve tray overspray (GPM)	*	*	*	350
Module C Venturi pressure drop (in.H ₂ O)	12.5	14.0	11.8	13.8
Module C Absorber pressure drop (in.H ₂ O)	4.7	2.5	1.7	2.2
Module C Inlet temperature (°F)	238	245	223	229
Module C Outlet temperature (°F)	110	110	106	107
Module C Inlet SO ₂ concentration (ppm)	410	390	392	428
Module C Outlet SO ₂ concentration (ppm)	152	152	124	159
Unit 4 O ₂ concentration at boilers (%)	-	5.07	6.2	5.04
Unit 4 O ₂ concentration at stack (%)	7.2	7.2	8.3	7.4
Unit 4 SO ₂ concentration at stack (ppm)	130	122	-	123
Unit 4 Opacity at stack (%)	44	44	48	43

* intermittent

3. SOLID AND LIQUID SAMPLE ANALYSIS

3.1 Coal Analysis

Coal samples were taken from the belt filling the Unit 4 bunkers. Samples were collected by plant personnel, some MRI personnel were not allowed access to the belt. The four samples analyzed were composites of either two or three grab samples.

The coal samples were analyzed for total sulfur according to ASTM method 0271 and for sulfate and pyritic sulfur according to ASTM method D2492. The results of this analysis are shown in Table 3-1. Note that the organic sulfur content is derived by subtraction; this accounts in part for the large variation in that concentration.

Table 3-1
COAL ANALYSIS RESULTS

<u>Date</u> <u>(1981)</u>	<u>Total</u> <u>Sulfur(%)</u>	<u>Sulfate</u> <u>Sulfur(%)</u>	<u>Pyritic</u> <u>Sulfur(%)</u>	<u>Organic</u> <u>Sulfur(%)</u>
1/22	0.44	0.07	0.24	0.13
1/25	0.54	0.12	0.34	0.08
1/26	0.92	0.06	0.77	0.09
1/27	0.67	0.04	0.08	0.55

3.2 Bottom Ash Analysis

A bottom ash sample was collected by plant personnel on 27 January. The bottom ash handling system uses pond return water (a separate pond from the one in the FGD system) to remove the ash. The sample was therefore wet. Water was decanted from the ash immediately on receipt of the sample. The remaining ash and the water were analyzed separately for sulfate content by ion chromatography.

The sulfate content of the water was 84 mg/l . The sulfate content of the ash was 5000 mg/kg (0.5%) on a dry basis.

3.3 Makeup Water Analysis

The FGD system makeup water is a mixture of pond return and river water. On each test day a composite of three grab samples was made and analyzed for suspended solids (filtration), dissolved solids (evaporation), pH, and sulfate content (ion chromatography, three samples only). The results are shown in Table 3-2.

Table 3-2
RESULTS OF MAKEUP WATER ANALYSIS

<u>Date (1981)</u>	<u>Suspended Solids (mg/l)</u>	<u>Dissolved Solids (mg/l)</u>	<u>pH</u>	<u>Sulfate Concentration (mg/l)</u>
1/22	--	5600	4.08	--
1/25	680	5600	4.00	1100
1/26	1200	7400	4.00	1500
1/27	700	5400	4.03	1200

3.4 Slurry Analysis

FGD Module C slurry samples were collected three times on each test day and composited. Slurry samples were analyzed for the same parameters as the makeup water. Results are shown in Table 3-3.

Table 3-3
RESULTS OF SLURRY ANALYSIS

<u>Date (1981)</u>	<u>Suspended Solids (mg/l)</u>	<u>Dissolved Solids (mg/l)</u>	<u>pH</u>	<u>Sulfate Concentration (mg/kg)</u>
1/22	--	--	3.65	--
1/25	42,400	19,600	3.64	14,000
1/26	45,000	21,000	3.67	15,000
1/27	47,000	21,000	3.62	15,000

4. FLUE GAS VELOCITY AND TEMPERATURE

On each test day, flue gas velocity and temperature were measured in both the inlet and outlet ducts of FGD Module C. Velocity was measured with an S-type pitot tube and temperature with a thermocouple. The results are listed in Table 4-1. The velocities and temperatures shown are averages from multiple traverse points.

Table 4-1
FLUE GAS VELOCITY AND TEMPERATURE DATA

<u>Date (1981)</u>	<u>Location</u>	<u>Velocity (ft/sec)</u>	<u>Temperature (°F)</u>
1/23	inlet	77	254
1/25	inlet	78	254
1/26	inlet	65	233
1/27	inlet	64	239
1/23	outlet	104	117
1/25	outlet	112	119
1/26	outlet	91	116
1/27	outlet	85	117

5. FLUE GAS SO₂ AND O₂ CONCENTRATIONS

Flue gas SO₂ and O₂ Concentrations were measured in the inlet and outlet ducts with continuous gas monitors. The instruments were switched from inlet to outlet (or vice versa) every 15 minutes during the test day. SO₂ concentrations were also measured using hydrogen peroxide impingers in the controlled condensation trains. The results of these measurements are listed in Table 5-1. Wet chemical results at the inlet on 23 and 25 January were anomalously low and so are not reported. The table lists SO₂ concentrations as measured and also values corrected to 3% oxygen using the factor $(20.9-3)/(20.9 - \% O_2)$. The results from the gas monitors are considered to be more accurate than the wet chemical results. The inlet SO₂ concentrations are generally larger than those measured by the permanent monitors installed at the plant, while the outlet concentrations are generally lower than the plant instrument values. The gas monitor results reported here are considered to be accurate. The inlet results are consistent with the sulfur content and approximate heat content of the coal. The oxygen concentrations are consistent with those measured by the plant instruments.

Table 5-1

FLUE GAS SO₂ AND O₂ CONCENTRATIONS

Date	Location	Average Gas Monitor O ₂ Concentration (%)	Average Uncorrected Gas Monitor SO ₂ Concentration (ppm)	Average Corrected (to 3% O ₂) Gas Monitor SO ₂ Concentration (ppm)	Average SO ₂ Removal (%)	Average Uncorrected Wet Chemical SO ₂ Concentration (%)	Average Corrected (to 3% O ₂) Wet Chemical SO ₂ Concentration (ppm)
1/23	inlet	7.16	751	979	--	--	--
∞ 1/25*	inlet	--	--	--	--	--	--
1/26	inlet	8.90	650	970	--	540	808
1/27	inlet	6.95	748	960	--	457	587
1/23	outlet	7.13	142	184	81	178	234
1/25*	outlet	--	--	--	--	166	218
1/26	outlet	8.61	60.9	88.2	90	115	167
1/27	outlet	7.26	117	154	84	151	198

* Gas monitors were not operated on 1/25 so that the instrument technician could repair the opacity instrument.

6. FLUE GAS SO₃ CONCENTRATIONS

Flue gas SO₃ and/or H₂SO₄ concentrations were measured in the inlet and outlet ducts with the controlled condensation systems. The results are listed in Table 6-1. The concentrations are expressed as ranges or as "less than" values because there are detection limits associated with the titrations used. The detection limit is a function of the gas volume sampled and of the quantity of liquid used to rinse the apparatus and so varies from one run to another. The outlet concentrations on 23 and 25 January were anomalously high, possibly because of contamination of the glassware, and so are not reported.

Table 6-1
FLUE GAS SO₃ CONCENTRATIONS

<u>Date (1981)</u>	<u>Location</u>	<u>Observed SO₃ Concentration (ppm)</u>	<u>Corrected (to 3% O₂) SO₃ Concentration (ppm)</u>
1/23	inlet	0.4-0.8	0.5-1.0
1/25	inlet	<0.8	<1.0
1/26	inlet	0.4-0.8	0.6-1.2
1/27	inlet	<0.9	<1.2
1/23	outlet	--	--
1/25	outlet	--	--
1/26	outlet	1.9-3.2	2.7-4.7
1/27	outlet	<1.1	<1.5

7. TOTAL PARTICULATE AND PARTICULATE SULFATE CONCENTRATIONS

Total particulate concentrations in the inlet and outlet ducts were measured using instack filters (EPA Method 17). The filter used at the inlet was operated at the flue gas temperature. The filter used at the outlet was heated (to approximately 250°F) and preceded by a short heated probe in order to prevent the condensation of water droplets. The material collected on the filters was analyzed for sulfate content by ion chromatography. The particulate and sulfate concentration results are listed in Table 7-1 in units of mass of particulate or sulfate per unit volume of flue gas. Note that the inlet and outlet sulfate concentrations are about the same, while the total mass loading is greatly reduced from inlet to outlet.

In addition to the instack filter, a high volume sampler which collects particles larger than about 5 micrometers in a cyclone and smaller particles on a filter was operated at both the inlet and outlet. Fly ash samples were obtained at the inlet and sent to DOE GFETC for analysis. At the outlet, water droplets were collected by the cyclone. This liquid was analyzed for sulfate content; the results were 32 mg/l on 26 January and 30 mg/l on 27 January.

Table 7-1

INSTACK FILTER PARTICULATE AND SULFATE CONCENTRATIONS

Date (1981)	Location	Particulate Concentration (mg/dscm)*	Particulate Removal (%)	Sulfate Concentration (mg/dscm)	Ratio of Sulfate To Total Mass Concentration
1/23	inlet	4710	--	24.2	0.00893
1/25	inlet	4996	--	18.0	0.00360
1/26	inlet	5819	--	23.0	0.00395
1/27	inlet	5738	--	12.4	0.00216
1/23	outlet	25.41	99.5	20.2	0.795
1/25	outlet	81.46	98.4	20.6	0.253
1/26	outlet	53.28	99.1	18.0	0.338
1/27	outlet	37.04	99.4	14.2	0.383

* dscm: dry standard cubic meter (pressure = 1 atmosphere, temperature = 70°F)

8. OPACITY

Opacity was measured at the outlet on three of the test days; instrument failure possibly caused by the high ambient temperature prevented measurements on the first test day. The principal physical mechanism related to plume opacity is light scattering by small particles (absorption is negligible except for material such as carbon). This light scattering can be characterized by the light scattering coefficient b_{scat} , which has the units of m^{-1} . Opacity (in percent) is defined as $100 (1 - I/I_0)$, where I_0 is the initial intensity of a light source and I is the remaining light intensity after the light has passed through the flue gas. In terms of the light scattering coefficient,

$$I = I_0 \exp (-b_{\text{scat}} \ell),$$

where ℓ is the path length. Then opacity (in percent) is then given by

$$\text{Opacity (\%)} = 100 [1 - \exp (-b_{\text{scat}} \ell)].$$

Opacity was measured at the outlet using the MRI Plant Process Visiometer (PPV), which is a hardened version of the integrating nephelometer. The PPV measures scattered light; therefore, its output is directly proportional to b_{scat} . The PPV is heated to evaporate water droplets and so does not measure light scattered from condensed water.

Table 8-1 lists b_{scat} measurements and opacity. The opacity values were calculated using a path length of 37 feet, the diameter of the unit 4 stack. They therefore represent the opacities that would be observed across the stack if the flue gas had the same particulate concentration as that at the outlet of Module C. The actual opacity could be different, since the flue gas in the stack came from Modules A, C, and D and from the bypass.

Values for different parts of the day are listed separately for 27 January, corresponding to before and after the mist eliminator wash procedure was changed. The opacity decreased significantly when the wash procedure was changed. This observation suggests a possible cause-effect relationship, although other measured parameters did not appear to change significantly.

Table 8-1
OPACITY MEASUREMENTS

<u>Date (1981)</u>	<u>Time (CST)</u>	<u>Average b_{scat} (m^{-1})</u>	<u>Equivalent Opacity* (%)</u>
1/25	2000-2400	0.0245	24.2
1/26	1000-2200	0.0236	23.4
1/27	1200-1500	0.0245	24.2
1/27	1700-2300	0.0180	18.4

* Opacity that would be observed for flue gas of the same characteristics across a 37 ft stack.

9. SIZE SEGREGATED PARTICULATE AND SULFATE CONCENTRATIONS

Size segregated particulate material was collected from the inlet and outlet ducts using MRI inertial cascade impactors. The inlet impactor was operated at the stack temperature. The outlet impactor was heated to about 210°F to evaporate water droplets.

The results of the impactor measurements are shown in Tables 9-1 to 9-13 and shown in Figures 9-1 to 9-15. The most meaningful results listed in these printouts and shown in the computer-generated plots are the "interpolated size distribution results" ($dm/d \log d$) which show the mass concentration of material per unit of size range on a logarithmic scale. The dashed lines on the plots of averaged values indicate plus and minus one standard deviation in the weight values. Penetration is the ratio of outlet to inlet differential size distribution, so that the smaller the penetration, the greater the particle collection efficiency of the scrubber (efficiency = $1 - \text{penetration}$). All particle sizes are physical diameter and assume a density of 2.59 g/cm^3 , which was measured from a fly ash sample with a pycnometer.

Particulate samples collected on two of the test days were analyzed for sulfate content by ion chromatography. The results of this analysis are listed and compared to total mass in Tables 9-14 and 9-15.

Table 9-1

TITLE: INLET BOSWELL MINNESOTA RUN 1 1-23-R1 PORT 4 MRI IMPACTOR
TEST DATA

TEST DURATION =	1.6 MINUTES	TEMP IMPACTOR =	255. DEGS. F
METER TEMP. =	60. DEGS. F	TEMP ATMOS. =	101. DEGS. F
METER PRES =	0.00 IN.	VELOCITY =	71.70 FT/SFC
BARO. PRES =	28.65 INCH HG	SAMPLE RATE =	.47 CF (STACK COND.)
NOZZLE DIA. =	.1250 INCHES	TOTAL VOLUME (STACK) =	.75 CF (STACK COND.)
VOL. METER =	.48 CUBIC FEET	PARTICLE DENSITY =	2.59 GRAM/CC
STACK PRESSURE =	27.69 INCH HG	STACK SUCTION =	-.955E+00 INCH HG
COND. WATER =	.9 CC	VISCOSITY =	.22E-03 POISE

TEST RESULTS

PERCENT MOISTURE = 8.69
VOLUME GAS STD. DRY = .133E-01 CUBIC METER
PERCENT ISOKINETIC = 127.54
CONCENTRATION = .532E+03 MGRAM/CUBIC METER (DRY, 21.1 DEG C, 760 MM HG)

SIZE DISTRIBUTION RESULTS

PLATE	CUM COR	HOLE NUMBER	PRES. RATIO	HOLE DIAMETER	D50 (MICRONS)	VFL CM/SFC	MASS FRACT MGRAMS	CONC MG/CUBIC M	CUM CONC MG/CUBIC M	DM/DLOGD MG/CUBIC M	SQRT PSISO
1	1.01	8.	1.000	.864E+00	.174E+02	.471E+02	.408E+02	.308E+04	.532E+04	.101E+05	.33
2	1.03	12.	1.000	.475E+00	.864E+01	.104E+03	.602E+01	.454E+03	.224E+04	.149E+04	.33
3	1.08	24.	1.000	.198E+00	.322E+01	.298E+03	.922E+01	.696E+03	.179E+04	.162E+04	.33
4	1.18	24.	1.000	.119E+00	.144E+01	.821E+03	.868E+01	.655E+03	.109E+04	.188E+04	.33
5	1.37	24.	1.000	.838E-01	.691E+00	.167E+04	.441E+01	.333E+03	.435E+03	.104E+04	.29
6	1.75	24.	1.000	.533E-01	.353E+00	.411E+04	.570E+00	.450E+02	.103E+03	.144E+03	.33
					FILTER WEIGHT		.790E+00	.596E+02	.596E+02		
					TOTAL WEIGHT		.705E+02				
							NEG SLOPE POINT 1	SLOPE = -279.		NP = 1	

INTERPOLATED SIZE DISTRIBUTION RESULTS

POINT	DIAMETER (MICRONS)	CUM CONC MG/CUBIC M	DM/DLOGD MG/CUBIC M
1	.360	60.05	55.0
2	.500	74.77	162.
3	.700	106.3	520.
4	1.00	235.4	.104E+04
5	1.40	417.0	.150E+04
6	1.90	648.2	.180E+04
7	2.70	938.0	.188E+04
8	3.70	1195.	.177E+04
9	5.20	1440.	.162E+04
10	7.20	1664.	.156E+04
11	10.0	1883.	.151E+04
12	14.0	2102.	.147E+04

Table 9-2

TITLE: OUTLET ROSWELL MINNESOTA RUN 2 1-23-R1 PORT 2 MRI IMPACTOR
TEST DATA

TEST DURATION =	18.0 MINUTES	TEMP IMPACTOR =	200. DEGS. F
METER TEMP. =	60. DEGS. F	TEMP ATMOS. =	101. DEGS. F
METER PRES =	0.00 IN.	VELOCITY =	108.00 FT/SEC
BARO. PRES =	28.65 INCH HG	SAMPLE RATE =	.57 CF (STACK COND.)
NOZZLE DIA. =	.1250 INCHES	TOTAL VOLUME (STACK) =	10.32 CF (STACK COND.)
VOL. METER =	7.33 CURIC FEET	PARTICLE DENSITY =	2.52 GRAM/CC
STACK PRESSURE =	25.86 INCH HG	STACK SUCTION =	-.279E+01 INCH HG
COND. WATER =	13.7 CC	VISCOSITY =	.21E-03 POISE

TEST RESULTS

PERCENT MOISTURE = 8.84
VOLUME GAS STD. DRY = .202E+00 CURIC METER
PERCENT ISO KINETIC = 101.54
CONCENTRATION = .589E+02 MGRAM/CURIC METER (DRY, 21.1 DEG C, 760 MM HG)

SIZE DISTRIBUTION RESULTS

PLATE	CUM COR	HOLE NUMBER	PRES. RATIO	HOLE DIAMETER	D50 (MICRONS)	VEL CM/SEC	MASS FRACT MGRAMS	CONC MG/CURIC M	CUM CONC MG/CURIC M	DM/DLOGD MG/CURIC M	SGRT PSI50
1	1.02	8.	1.000	.864E+00	.146E+02	.633E+02	.187E+01	.924E+01	.589E+02	.303E+02	.33
2	1.03	12.	1.000	.475E+00	.723E+01	.139E+03	.200E-01	.988E-01	.497E+02	.324E+00	.33
3	1.09	24.	1.000	.198E+00	.268E+01	.401E+03	.800E-01	.395E+00	.446E+02	.917E+00	.33
4	1.21	24.	1.000	.119E+00	.119E+01	.110E+04	.600E-01	.296E+00	.492E+02	.843E+00	.33
5	1.44	24.	1.000	.838E-01	.564E+00	.224E+04	.860E+00	.425E+01	.489E+02	.131E+02	.29
6	1.93	24.	1.000	.533E-01	.282E+00	.553E+04	.143E+01	.706E+01	.447E+02	.234E+02	.33
					FILTER WEIGHT		.761E+01	.376E+02	.376E+02		
					TOTAL WEIGHT		.119E+02				
							NEG SLOPE POINT u	SLOPE = -2.32	NP = 3		

INTERPOLATED SIZE DISTRIBUTION RESULTS

POINT	DIAMETER (MICRONS)	CUM CONC MG/CURIC M	DM/DLOGD MG/CURIC M
1	.360	40.43	24.9
2	.500	43.65	20.2
3	.700	46.26	15.4
4	1.00	48.24	8.79
5	1.40	48.97	2.97
6	1.90	49.08	.843
7	2.70	49.21	.932
8	3.70	49.35	.964
9	5.20	49.49	.862
10	7.20	49.60	.637
11	10.0	49.67	.348
12	14.0	49.70	.107

Table 9-3

DAY RESULTS
-----AVERAGES BUSWELL MINNESOTA 1-23-R1
DAY NUMBER 1

AVERAGE DIFFERENTIAL SIZE DISTRIBUTIONS

INLET SIDE

OUTLET SIDE

NUMBER	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS
1	.360	55.0		1.	.360	24.9		1.
2	.500	162.		1.	.500	20.2		1.
3	.700	520.		1.	.700	15.4		1.
4	1.00	.104E+04		1.	1.00	8.79		1.
5	1.40	.150E+04		1.	1.40	2.97		1.
6	1.90	.180E+04		1.	1.90	.843		1.
7	2.70	.188E+04		1.	2.70	.932		1.
8	3.70	.177E+04		1.	3.70	.964		1.
9	5.20	.162E+04		1.	5.20	.862		1.
10	7.20	.156E+04		1.	7.20	.637		1.
11	10.0	.151E+04		1.	10.0	.348		1.
12	14.0	.147E+04		1.	14.0	.107		1.

PENETRATIONS (FRACTIONAL)

NUMBER 1

DIAMETER (MICRONS)	.360	.500	.700	1.00	1.40	1.90	2.70	3.70	5.20	7.20	10.0	14.0
PENETRATION STANDARD DEVIATION	.453	.125	.296E-01	.842E-02	.198E-02	.468E-03	.495E-03	.544E-03	.531E-03	.408E-03	.230E-03	.726E-04

Table 9-4

TITLE: INLET BOSWELL MINNESOTA RUN 3 1-25-81 PORT 4 MRI IMPACTOR

TEST DATA

TEST DURATION =	1.5 MINUTES	TEMP IMPACTOR =	254. DEGS. F
METER TEMP. =	60. DEGS. F	TEMP ATMOS. =	94. DEGS. F
METER PRES =	0.00 IN.	VELOCITY =	91.30 FT/SEC
BARO. PRES =	26.20 INCH HG	SAMPLE RATE =	.48 CF (STACK COND.)
NOZZLE DIA. =	.1250 INCHES	TOTAL VOLUME (STACK) =	.71 CF (STACK COND.)
VOL. METER =	.45 CUBIC FEET	PARTICLE DENSITY =	2.59 GRAM/CC
STACK PRESSURE =	26.71 INCH HG	STACK SUCTION =	-.149E+01 INCH HG
COND. WATER =	.8 CC	VISCOSITY =	.22E-03 POISE

TEST RESULTS

PERCENT MOISTURE =	8.77
VOLUME GAS STD. DRY =	.122E-01 CURIC METER
PERCENT ISOKINETIC =	102.15
CONCENTRATION =	.677E+04 MGRAM/CURIC METER (DRY, 21.1 DEG C, 760 MM HG)

SIZE DISTRIBUTION RESULTS

PLATE	CUN COR	HOLE NUMBER	PRES. RATIO	HOLE DIAMETER	D50 (MICRONS)	VEL CM/SEC	MASS FRACT MGRAMS	CONC MG/CUBIC M	CUM CONC MG/CUBIC M	DM/DLOGD MG/CUBIC M	SQRT PST50
1	1.02	8.	1.000	.864E+00	.172E+02	.480E+02	.504E+02	.412E+04	.677E+04	.135E+05	.33
2	1.03	12.	1.000	.475E+00	.855E+01	.106E+03	.720E+01	.589E+03	.265E+04	.193E+04	.33
3	1.08	24.	1.000	.198E+00	.318E+01	.304E+03	.102E+02	.837E+03	.206E+04	.195E+04	.33
4	1.18	24.	1.000	.119E+00	.142E+01	.838E+03	.100E+02	.822E+03	.122E+04	.235E+04	.33
5	1.39	24.	1.000	.838E-01	.678E+00	.170E+04	.329E+01	.269E+03	.402E+03	.838E+03	.29
6	1.80	24.	1.000	.533E-01	.344E+00	.420E+04	.720E+00	.589E+02	.133E+03	.200E+03	.33
FILTER WEIGHT							.910E+00	.744E+02	.744E+02		
TOTAL WEIGHT							.828E+02				
							NEG SLOPE POINT 1	SLOPE = -105.	NP = 1		

INTERPOLATED SIZE DISTRIBUTION RESULTS

POINT	DIAMETER (MICRONS)	CUM CONC MG/CUBIC M	DM/DLOGD MG/CUBIC M
1	.360	75.85	84.0
2	.500	97.06	213.
3	.700	137.8	438.
4	1.00	232.1	864.
5	1.40	393.5	.162E+04
6	1.90	674.4	.221E+04
7	2.70	1041.	.235E+04
8	3.70	1359.	.217E+04
9	5.20	1653.	.195E+04
10	7.20	1923.	.190E+04
11	10.0	2193.	.191E+04
12	14.0	2476.	.193E+04

Table 9-5

TITLE: OUTLET BOSWELL MINNESOTA RUN 4. 1-25-81 PORT 3 MRI IMPACTOR
TEST DATA

TEST DURATION =	15.0 MINUTES	TEMP IMPACTOR =	200. DEGS. F
METER TEMP. =	60. DEGS. F	TEMP ATMOS. =	94. DEGS. F
METER PRES =	0.00 IN.	VFLOCITY =	109.00 FT/SEC
BARO. PRES =	28.12 INCH HG	SAMPLE RATE =	.50 CF (STACK COND.)
NOZZLE DIA. =	.1250 INCHES	TOTAL VOLUME (STACK) =	0.73 CF (STACK COND.)
VOL. METER =	6.12 CUBIC FEET	PARTICLE DENSITY =	2.59 GRAM/CC
STACK PRESSURE =	25.18 INCH HG	STACK SUCTION =	-.294E+01 INCH HG
COND. WATER =	14.6 CC	VISCOSITY =	.21E-03 POISE

TEST RESULTS

PERCENT MOISTURE =	11.20
VOLUME GAS STD. DRY =	.166E+00 CUBIC METER
PERCENT ISOINETIC =	104.30
CONCENTRATION =	.597E+02 MGRAM/CUBIC METER (DRY, 21.1 DEG C, 760 MM HG)

SIZE DISTRIBUTION RESULTS

PLATE	CUN	HOLE	PRES.	HOLE	D50	VFL	MASS FRACT	CONC	CUM CONC	DM/DLOGD	SORT
	COR	NUMBER	RATIO	DIAMETER	(MICRONS)	CM/SEC	MGRAMS	MG/CUBIC M	MG/CUBIC M	MG/CUBIC M	PS150
1	1.02	8.	1.000	.864E+00	.143E+02	.656E+02	.100E-01	.603E-01	.597E+02	.198E+00	.33
2	1.04	12.	1.000	.475E+00	.709E+01	.145E+03	.210E+00	.127E+01	.597E+02	.415E+01	.33
3	1.10	24.	1.000	.198E+00	.263E+01	.415E+03	.210E+00	.127E+01	.584E+02	.293E+01	.33
4	1.22	24.	1.000	.119E+00	.117E+01	.114E+04	.100E+00	.603E+00	.572E+02	.171E+01	.33
5	1.47	24.	1.000	.838E-01	.549E+00	.232E+04	.350E+00	.211E+01	.566E+02	.645E+01	.29
6	1.99	24.	1.000	.533E-01	.272E+00	.573E+04	.111E+01	.669E+01	.544E+02	.220E+02	.33
						FILTER WEIGHT	.792E+01	.477E+02	.477E+02		
						TOTAL WEIGHT	.991E+01				

INTERPOLATED SIZE DISTRIBUTION RESULTS

POINT	DIAMETER	CUM CONC	DM/DLOGD
	(MICRONS)	MG/CUBIC M	MG/CUBIC M
1	.360	50.96	23.5
2	.500	53.81	15.8
3	.700	55.49	8.76
4	1.00	56.39	4.08
5	1.40	56.74	2.13
6	1.90	56.99	1.56
7	2.70	57.18	1.87
8	3.70	57.52	2.72
9	5.20	57.96	3.20
10	7.20	58.44	3.66
11	10.0	59.00	4.14
12	14.0	59.64	4.62

Table 9-6

DAY RESULTS

AVERAGES BOSWELL MINNESOTA 1-25-81

DAY NUMBER 2

AVERAGE DIFFERENTIAL SIZE DISTRIBUTIONS

INLET SIDE

OUTLET SIDE

NUMBER	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS
1	.360	84.0		1.	.360	23.5		1.
2	.500	213.		1.	.500	15.8		1.
3	.700	438.		1.	.700	8.76		1.
4	1.00	864.		1.	1.00	4.08		1.
5	1.40	.162E+04		1.	1.40	2.13		1.
6	1.90	.221E+04		1.	1.90	1.56		1.
7	2.70	.235E+04		1.	2.70	1.87		1.
8	3.70	.217E+04		1.	3.70	2.72		1.
9	5.20	.195E+04		1.	5.20	3.20		1.
10	7.20	.190E+04		1.	7.20	5.66		1.
11	10.0	.191E+04		1.	10.0	4.14		1.
12	14.0	.193E+04		1.	14.0	4.62		1.

PENETRATIONS (FRACTIONAL)

NUMBER 2

DIAMETER (MICRONS)	.360	.500	.700	1.00	1.40	1.90	2.70	3.70	5.20	7.20	10.0	14.0
PENETRATION STANDARD DEVIATION	.279	.741E-01	.200E-01	.472E-02	.132E-02	.705E-03	.794E-03	.125E-02	.164E-02	.192E-02	.216E-02	.239E-02

Table 9-7

TITLE: INLET BOSWELL MINNESOTA RUN 5 1-26-R1 PORT 4 MRI IMPACTOR
TEST DATA

TEST DURATION =	1.2 MINUTES	TEMP IMPACTOR =	233. DEGS. F
METER TEMP. =	60. DEGS. F	TEMP ATMOS. =	84. DEGS. F
METER PRES =	0.00 IN.	VELOCITY =	75.00 FT/SEC
BARO. PRES =	28.50 INCH HG	SAMPLE RATE =	.49 CF (STACK COND.)
NOZZLE DIA. =	.1560 INCHES	TOTAL VOLUME (STACK) =	.57 CF (STACK COND.)
VOL. METER =	.38 CUBIC FEET	PARTICLE DENSITY =	2.59 GRAM/CC
STACK PRESSURE =	27.45 INCH HG	STACK SUCTION =	-.105E+01 INCH HG
COND. WATER =	.6 CC	VISCOSITY =	.22E-03 POISE

TEST RESULTS

PERCENT MOISTURE = 7.14
VOLUME GAS STD. DRY = .104E-01 CURIC METER
PERCENT ISO KINETIC = .81.27
CONCENTRATION = .515E+04 MGRAM/CURIC METER (DRY, 21.1 DEG C, 760 MM HG)

SIZE DISTRIBUTION RESULTS

PLATE	CUM COR	HOLE NUMBER	PRES. RATIO	HOLE DIAMETER	D50 (MICRONS)	VFL CM/SEC	MASS FRACT MGRAMS	CONC MG/CUBIC M	CUM CONC MG/CUBIC M	DM/DLOGD MG/CUBIC M	SQRT PS150
1	1.01	8.	1.000	.864E+00	.169E+02	.489E+02	.308E+02	.295E+04	.515E+04	.968E+04	.33
2	1.03	12.	1.000	.475E+00	.839E+01	.108E+03	.420E+01	.402E+03	.220E+04	.132E+04	.33
3	1.08	24.	1.000	.198E+00	.312E+01	.309E+03	.761E+01	.729E+03	.180E+04	.170E+04	.33
4	1.18	24.	1.000	.119E+00	.140E+01	.852E+03	.704E+01	.674E+03	.107E+04	.193E+04	.33
5	1.37	24.	1.000	.838E-01	.670E+00	.173E+04	.271E+01	.260E+03	.398E+03	.813E+03	.29
6	1.75	24.	1.000	.533E-01	.342E+00	.427E+04	.520E+00	.498E+02	.138E+03	.171E+03	.33
							FILTER WEIGHT	.920E+00	.881E+02	.881E+02	
							TOTAL WEIGHT	.538E+02			
							NEG SLOPE POINT 1	SLOPE = -135.		NP = 1	

INTERPOLATED SIZE DISTRIBUTION RESULTS

POINT	DIAMETER (MICRONS)	CUM CONC MG/CUBIC M	DM/DLOGD MG/CUBIC M
1	.360	89.56	73.9
2	.500	108.1	194.
3	.700	145.6	443.
4	1.00	244.6	856.
5	1.40	398.3	.142E+04
6	1.90	635.3	.185E+04
7	2.70	937.8	.197E+04
8	3.70	1208.	.187E+04
9	5.20	1467.	.169E+04
10	7.20	1698.	.156E+04
11	10.0	1911.	.141E+04
12	14.0	2104.	.125E+04

Table 9-8

TITLE: OUTLET BOSWELL MINNESOTA RUN 6 1-26-81 PORT 3 MRI IMPACTOR

TEST DATA

TEST DURATION	15.0 MINUTES	TEMP IMPACTOR	212. DEGS. F
METER TEMP.	60. DEGS. F	TEMP ATMOS.	84. DEGS. F
METER PRES.	0.00 IN.	VELOCITY	87.20 FT/SEC
BARO. PRES.	20.55 INCH HG	SAMPLE RATE	.49 CF (STACK COND.)
NOZZLE DIA.	.1250 INCHES	TOTAL VOLUME (STACK)	7.39 CF (STACK COND.)
VOL. METEP	5.25 CUBIC FEET	PARTICLE DENSITY	2.59 GRAM/CC
STACK PRESSURE	26.42 INCH HG	STACK SUCTION	-.213E+01 INCH HG
COND. WATER	11.1 CC	VISCOSITY	.21E-03 POISE

TEST RESULTS

PERCENT MOISTURE	9.92
VOLUME GAS STD. DRY	.144E+00 CURIC METER
PERCENT ISOKINETIC	106.62
CONCENTRATION	.584E+02 MGRAM/CURIC METER (DRY, 21.1 DEG C, 760 MM HG)

SIZE DISTRIBUTION RESULTS

PLATE	CUN COR	HOLE NUMBER	PRES. RATIO	HOLE DIAMETER	D50 (MICRONS)	VEL CM/SEC	MASS FRACT MGRAMS	CONC MG/CURIC M	CUM CONC MG/CURIC M	DM/DLOGD MG/CURIC M	SQRT PS150
1	1.02	8.	1.000	.864E+00	.158E+02	.547E+02	.175E+01	.121E+02	.584E+02	.347E+02	.33
2	1.03	12.	1.000	.475E+00	.784E+01	.120E+03	.400E-01	.277E+00	.463E+02	.909E+00	.33
3	1.08	24.	1.000	.198E+00	.291E+01	.346E+03	.300E-01	.208E+00	.460E+02	.443E+00	.33
4	1.19	24.	1.000	.119E+00	.130E+01	.953E+03	.100E-01	.692E-01	.458E+02	.198E+00	.33
5	1.40	24.	1.000	.838E-01	.620E+00	.193E+04	.390E+00	.270E+01	.458E+02	.838E+01	.29
6	1.82	24.	1.000	.533E-01	.314E+00	.478E+04	.890E+00	.616E+01	.431E+02	.208E+02	.33
						FILTER WEIGHT	.533E+01	.369E+02	.369E+02		
						TOTAL WEIGHT	.844E+01				
							NFG SLOPE POINT 4	SLOPE = -1.87	NP = 3		

INTERPOLATED SIZE DISTRIBUTION RESULTS

POINT	DIAMETER (MICRONS)	CUM CONC MG/CURIC M	DM/DLOGD MG/CURIC M
1	.360	38.43	24.4
2	.500	41.49	18.4
3	.700	43.73	12.4
4	1.00	45.18	6.59
5	1.40	45.76	2.11
6	1.90	45.79	.198
7	2.70	45.82	.251
8	3.70	45.86	.369
9	5.20	45.92	.518
10	7.20	46.01	.673
11	10.0	46.12	.849
12	14.0	46.25	1.02

Table 9-9

DAY RESULTS

AVERAGES ROSWELL MINNESOTA 1-26-81

DAY NUMBER 3

AVERAGE DIFFERENTIAL SIZE DISTRIBUTIONS

INLET SIDE

OUTLET SIDE

NUMBER	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS
1	.360	73.9		1.	.360	24.4		1.
2	.500	194.		1.	.500	18.4		1.
3	.700	443.		1.	.700	12.4		1.
4	1.00	856.		1.	1.00	6.59		1.
5	1.40	.142E+04		1.	1.40	2.91		1.
6	1.90	.185E+04		1.	1.90	.198		1.
7	2.70	.197E+04		1.	2.70	.251		1.
8	3.70	.187E+04		1.	3.70	.369		1.
9	5.20	.169E+04		1.	5.20	.518		1.
10	7.20	.156E+04		1.	7.20	.673		1.
11	10.0	.141E+04		1.	10.0	.849		1.
12	14.0	.125E+04		1.	14.0	1.02		1.

PENETRATIONS (FRACTIONAL)

NUMBER 3

DIAMETER (MICRONS)	.360	.500	.700	1.00	1.40	1.90	2.70	3.70	5.20	7.20	10.0	14.0
PENETRATION STANDARD DEVIATION	.330	.951E-01	.280E-01	.770E-02	.149E-02	.107E-03	.127E-03	.198E-03	.306E-03	.431E-03	.603E-03	.820E-03

Table 9-10

TITLE: INLET BOSWELL MINNESOTA RUN 7 1-27-R1 PORT 4 MRI IMPACTOR
TEST DATA

TEST DURATION =	1.2 MINUTES	TEMP IMPACTOR =	237. DEGS. F
METER TEMP. =	60. DEGS. F	TEMP ATMOS. =	84. DEGS. F
METER PRES =	0.00 IN.	VELOCITY =	71.10 FT/SEC
BARO. PRES =	28.63 INCH HG	SAMPLE RATE =	.66 CF (STACK COND.)
NOZZLE DIA. =	.1560 INCHES	TOTAL VOLUME (STACK) =	.77 CF (STACK COND.)
VOL. METER =	.49 CURIC FEET	PARTICLE DENSITY =	2.59 GRAM/CC
STACK PRESSURE =	27.56 INCH HG	STACK SUCTION =	-.107E+01 INCH HG
COND. WATER =	1.2 CC	VISCOSITY =	.22E+03 POISE

TEST RESULTS

PERCENT MOISTURE =	11.03	
VOLUME GAS STD. DRY =	.135E-01	CURIC METER
PERCENT ISOKINETIC =	116.10	
CONCENTRATION =	.441E+04	MGRAM/CURIC METER (DRY, 21.1 DEG C, 760 MM HG)

SIZE DISTRIBUTION RESULTS

PLATE	CUN COR	HOLE NUMBER	PRES. RATIO	HOLE DIAMETER	D50 (MICRONS)	VEL CM/SEC	MASS FRACT MGRAMS	CONC MG/CURIC M	CUM CONC MG/CURIC M	DM/DLOGD MG/CURIC M	SORT PS150
1	1.02	8.	1.000	.864E+00	.145E+02	.662E+02	.295E+02	.218E+04	.441E+04	.715E+04	.33
2	1.03	12.	1.000	.475E+00	.720E+01	.146E+03	.680E+01	.503E+03	.223E+04	.165E+04	.33
3	1.09	24.	1.000	.198E+00	.267E+01	.419E+03	.109E+02	.809E+03	.172E+04	.188E+04	.33
4	1.21	24.	1.000	.119E+00	.119E+01	.115E+04	.770E+01	.569E+03	.914E+03	.162E+04	.33
5	1.44	24.	1.000	.838E-01	.562E+00	.234E+04	.301E+01	.223E+03	.345E+03	.684E+03	.29
6	1.93	24.	1.000	.533E-01	.280E+00	.578E+04	.330E+00	.244E+02	.122E+03	.808E+02	.33
					FILTER WEIGHT		.132E+01	.976E+02	.976E+02		
					TOTAL WEIGHT		.596E+02				

INTERPOLATED SIZE DISTRIBUTION RESULTS

POINT	DIAMETER (MICRONS)	CUM CONC MG/CURIC M	DM/DLOGD MG/CURIC M
1	.360	102.7	65.7
2	.500	115.7	204.
3	.700	161.7	506.
4	1.00	271.4	947.
5	1.40	442.8	.137E+04
6	1.90	648.9	.167E+04
7	2.70	923.0	.184E+04
8	3.70	1179.	.188E+04
9	5.20	1457.	.188E+04
10	7.20	1723.	.179E+04
11	10.0	1965.	.166E+04
12	14.0	2200.	.156E+04

Table 9-11

TITLE: OUTLET ROSWELL MINNESOTA RUN R 1-27-R1 PORT 3 MRI IMPACTOR
TEST DATA

TEST DURATION =	14.0 MINUTES	TEMP IMPACTOR =	722. DEGS. F
METER TEMP. =	60. DEGS. F	TEMP ATMOS. =	84. DEGS. F
METER PRES =	0.00 IN.	VELOCITY =	47.30 FT/SEC
BARO. PRES =	28.60 INCH HG	SAMPLE RATE =	.53 CF (STACK COND.)
NOZZLE DIA. =	.1250 INCHES	TOTAL VOLUME (STACK) =	7.40 CF (STACK COND.)
VOL. METER =	5.07 CUBIC FEET	PARTICLE DENSITY =	2.54 GRAM/CC
STACK PRESSURE =	26.25 INCH HG	STACK SUCTION =	-.235E+01 INCH HG
COND. WATER =	11.4 CC	VISCOSITY =	.21E-03 POISE

TEST RESULTS

PERCENT MOISTURE = 10.47
VOLUME GAS STD. DRY = .140E+00 CUBIC METER
PERCENT ISOKINETIC = 112.16
CONCENTRATION = .577E+02 MGRAM/CUBIC METER (DRY, 21.1 DEG C, 760 MM HG)

SIZE DISTRIBUTION RESULTS

PLATE	CUM COR	HOLE NUMBER	PRES. RATIO	HOLE DIAMETER	D50 (MICRONS)	VEL CM/SEC	MASS FRACT MGRAMS	CONC MG/CUBIC M	CUM CONC MG/CUBIC M	DM/DLOGD MG/CUBIC M	SORT PS150
1	1.02	8.	1.000	.864E+00	.154E+02	.582E+02	.880E+00	.630E+01	.577E+02	.206E+02	.33
2	1.03	12.	1.000	.475E+00	.763E+01	.128E+03	.260E+00	.186E+01	.514E+02	.610E+01	.33
3	1.09	24.	1.000	.198E+00	.283E+01	.369E+03	.500E-01	.358E+00	.495E+02	.831E+00	.33
4	1.20	24.	1.000	.119E+00	.126E+01	.102E+04	.700E-01	.501E+00	.492E+02	.143E+01	.33
5	1.43	24.	1.000	.838E-01	.598E+00	.206E+04	.280E+00	.200E+01	.487E+02	.618E+01	.29
6	1.89	24.	1.000	.533E-01	.300E+00	.509E+04	.680E+00	.487E+01	.467E+02	.162E+02	.33
FILTER WEIGHT							.584E+01	.418E+02	.418E+02		
TOTAL WEIGHT							.806E+01				
NEG SLOPE POINT 4 SLOPE = -.547										NP = 4	

INTERPOLATED SIZE DISTRIBUTION RESULTS

POINT	DIAMETER (MICRONS)	CUM CONC MG/CUBIC M	DM/DLOGD MG/CUBIC M
1	.360	43.35	18.5
2	.500	45.67	13.7
3	.700	47.28	8.86
4	1.00	48.29	4.89
5	1.40	48.77	2.59
6	1.90	49.03	1.41
7	2.70	49.15	.767
8	3.70	49.25	.760
9	5.20	49.38	.831
10	7.20	49.49	2.48
11	10.0	50.07	5.30
12	14.0	51.05	7.70

Table 9-12

DAY RESULTS

AVERAGES ROSWELL MINNESOTA 1-27-81

DAY NUMBER 4

AVERAGE DIFFERENTIAL SIZE DISTRIBUTIONS

INLET SIDE

OUTLET SIDE

NUMBER	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS
1	.360	65.7		1.	.360	18.5		1.
2	.500	204.		1.	.500	13.7		1.
3	.700	506.		1.	.700	8.86		1.
4	1.00	947.		1.	1.00	4.89		1.
5	1.40	.137E+04		1.	1.40	2.59		1.
6	1.40	.167E+04		1.	1.90	1.41		1.
7	2.70	.184E+04		1.	2.70	.767		1.
8	3.70	.188E+04		1.	3.70	.760		1.
9	5.20	.188E+04		1.	5.20	.831		1.
10	7.20	.179E+04		1.	7.20	2.48		1.
11	10.0	.166E+04		1.	10.0	5.30		1.
12	14.0	.156E+04		1.	14.0	7.70		1.

PENETRATIONS (FRACTIONAL)

NUMBER 4

DIAMETER (MICRONS)	.360	.500	.700	1.00	1.40	1.90	2.70	3.70	5.20	7.20	10.0	14.0
PENETRATION STANDARD DEVIATION	.282	.668E-01	.175E-01	.516E-02	.190E-02	.844E-03	.417E-03	.405E-03	.443E-03	.139E-02	.320E-02	.492E-02

Table 9-13

GRAND AVERAGE RESULTS

GRAND AVERAGES: BUSWELL MINNESOTA 1-23-81, 1-25-81, 1-26-81, 1-27-81

AVERAGE DIFFERENTIAL SIZE DISTRIBUTIONS

INLET SIDE				OUTLET SIDE				
NUMBER	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS	DIAMETER (MICRONS)	DM/DLOGD MG/CUBIC M	STD DEVIATION MG/CUBIC M	NUMBER TESTS
1	.360	69.7	12.3	4.	.360	22.8	2.91	4.
2	.500	193.	22.2	4.	.500	17.0	2.90	4.
3	.700	477.	42.1	4.	.700	11.4	3.18	4.
4	1.00	928.	87.9	4.	1.00	6.09	2.09	4.
5	1.40	.148E+04	108.	4.	1.40	2.45	.410	4.
6	1.90	.188E+04	233.	4.	1.90	1.00	.618	4.
7	2.70	.201E+04	235.	4.	2.70	.954	.675	4.
8	3.70	.192E+04	171.	4.	3.70	1.20	1.04	4.
9	5.20	.179E+04	152.	4.	5.20	1.35	1.24	4.
10	7.20	.170E+04	171.	4.	7.20	1.86	1.48	4.
11	10.0	.162E+04	218.	4.	10.0	2.66	2.44	4.
12	14.0	.155E+04	283.	4.	14.0	3.36	3.48	4.

PENETRATIONS (FRACTIONAL)

-----												NUMBER 1
DIAMETER (MICRONS)	.360	.500	.700	1.00	1.40	1.90	2.70	3.70	5.20	7.20	10.0	14.0
PENETRATION	.328	.880E-01	.238E-01	.656E-02	.166E-02	.532E-03	.475E-03	.626E-03	.757E-03	.109E-02	.164E-02	.216E-02
STANDARD DEVIATION	.357E-01	.904E-02	.350E-02	.117E-02	.152E-03	.167E-03	.170E-03	.272E-03	.349E-03	.437E-03	.758E-03	.114E-02

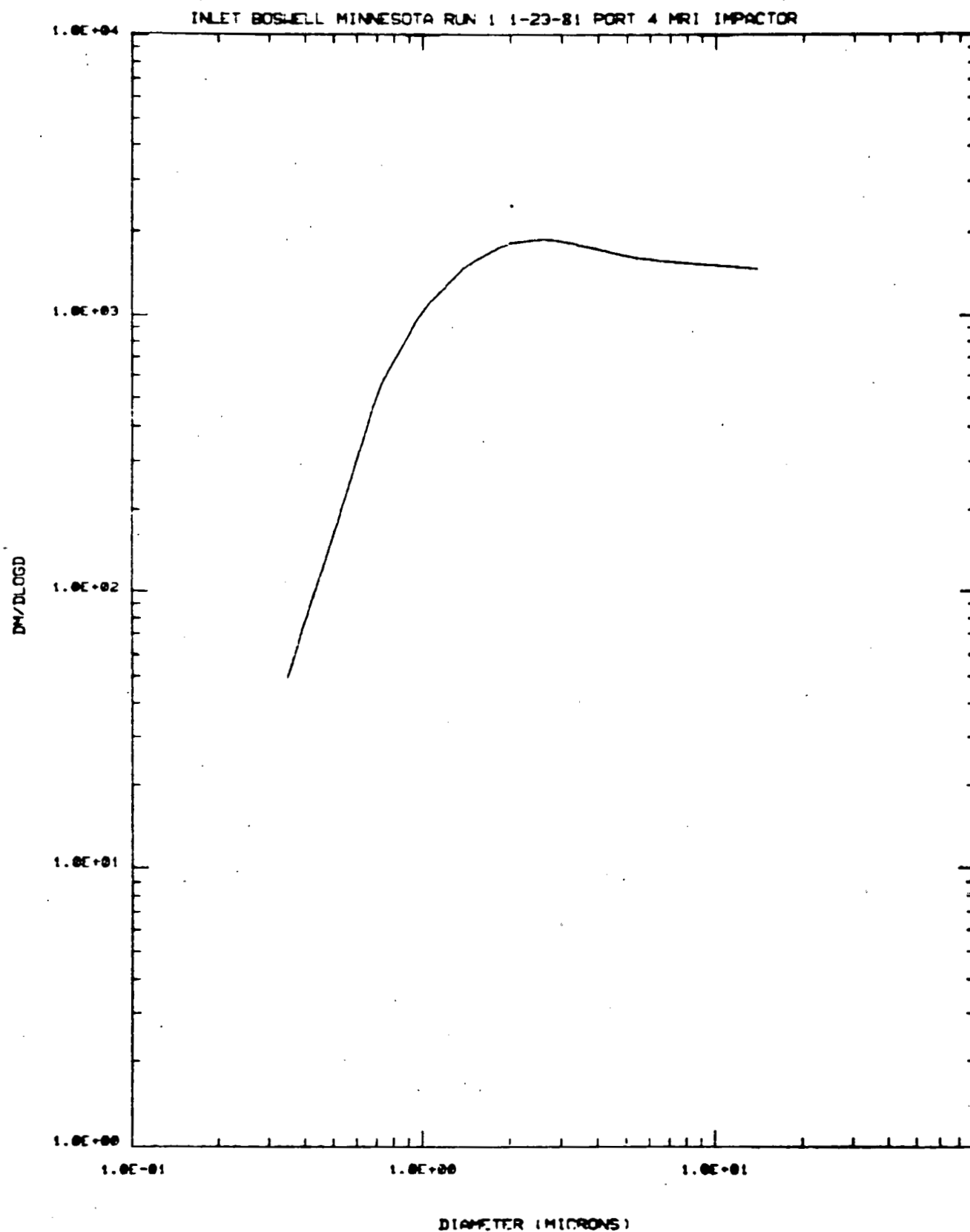


Figure 9-1. Inlet Mass Size Distribution, 23 January 1981.

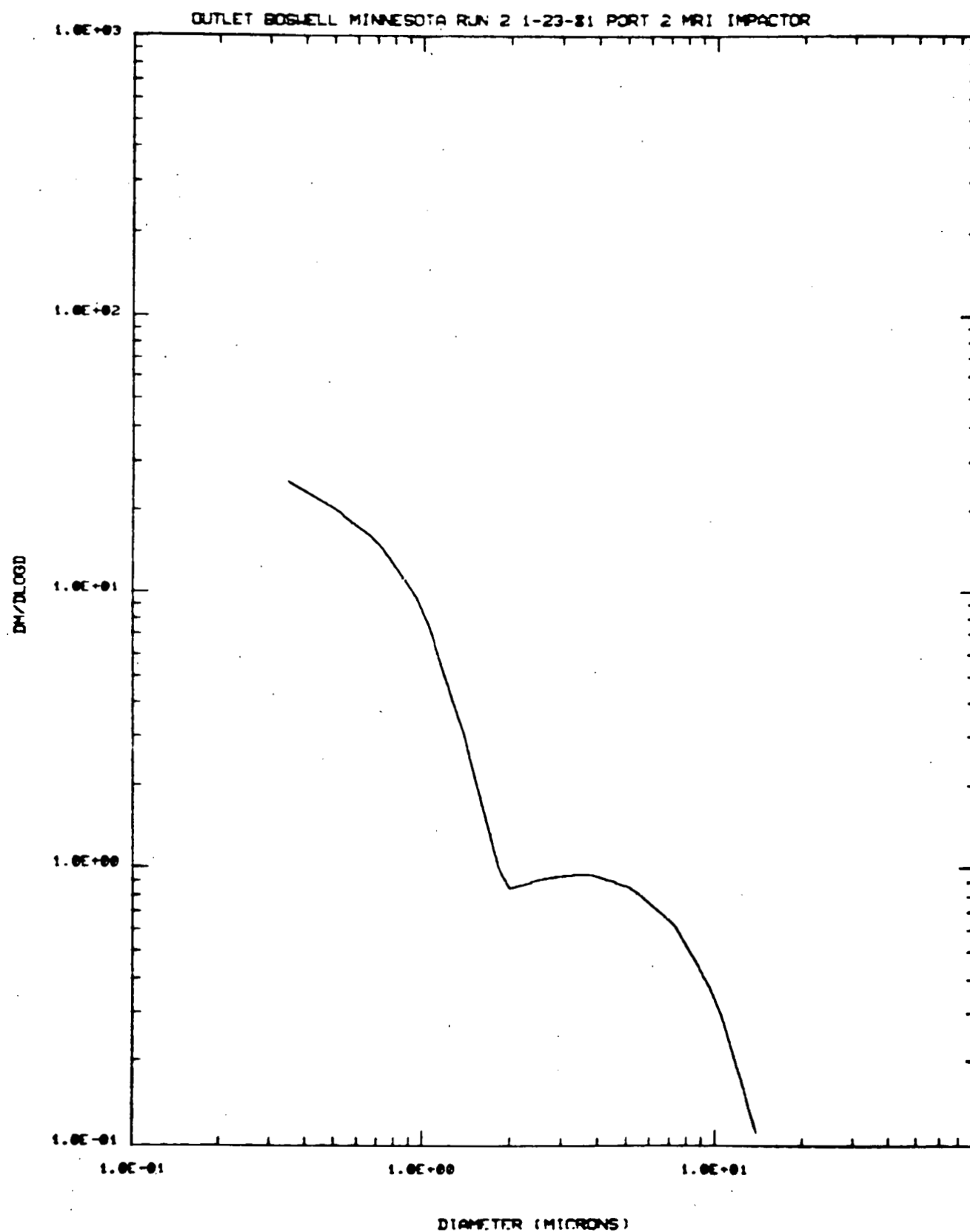


Figure 9-2. Outlet Mass Size Distribution, 23 January 1981.

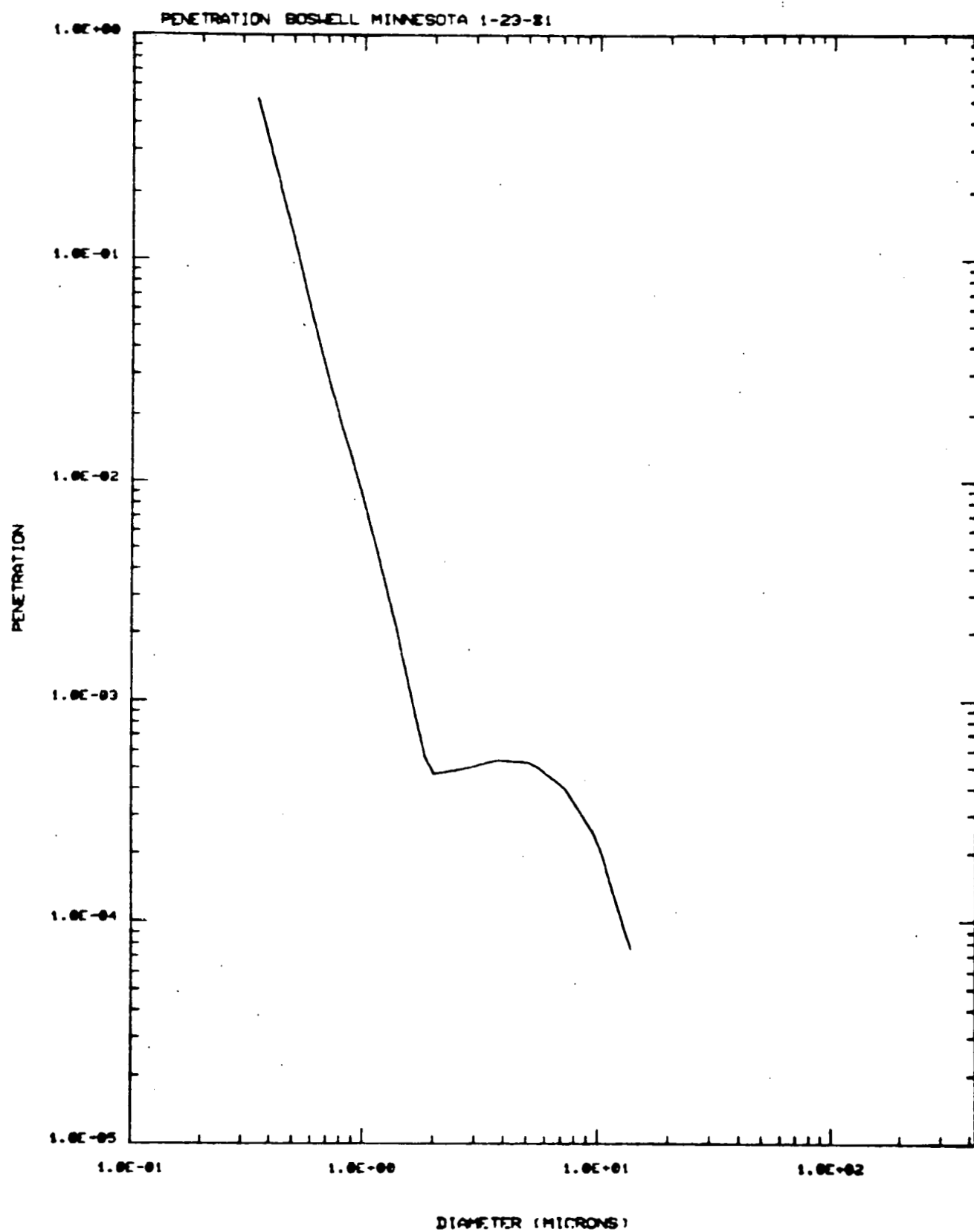


Figure 9-3. Size-dependent Penetration, 23 January 1981.

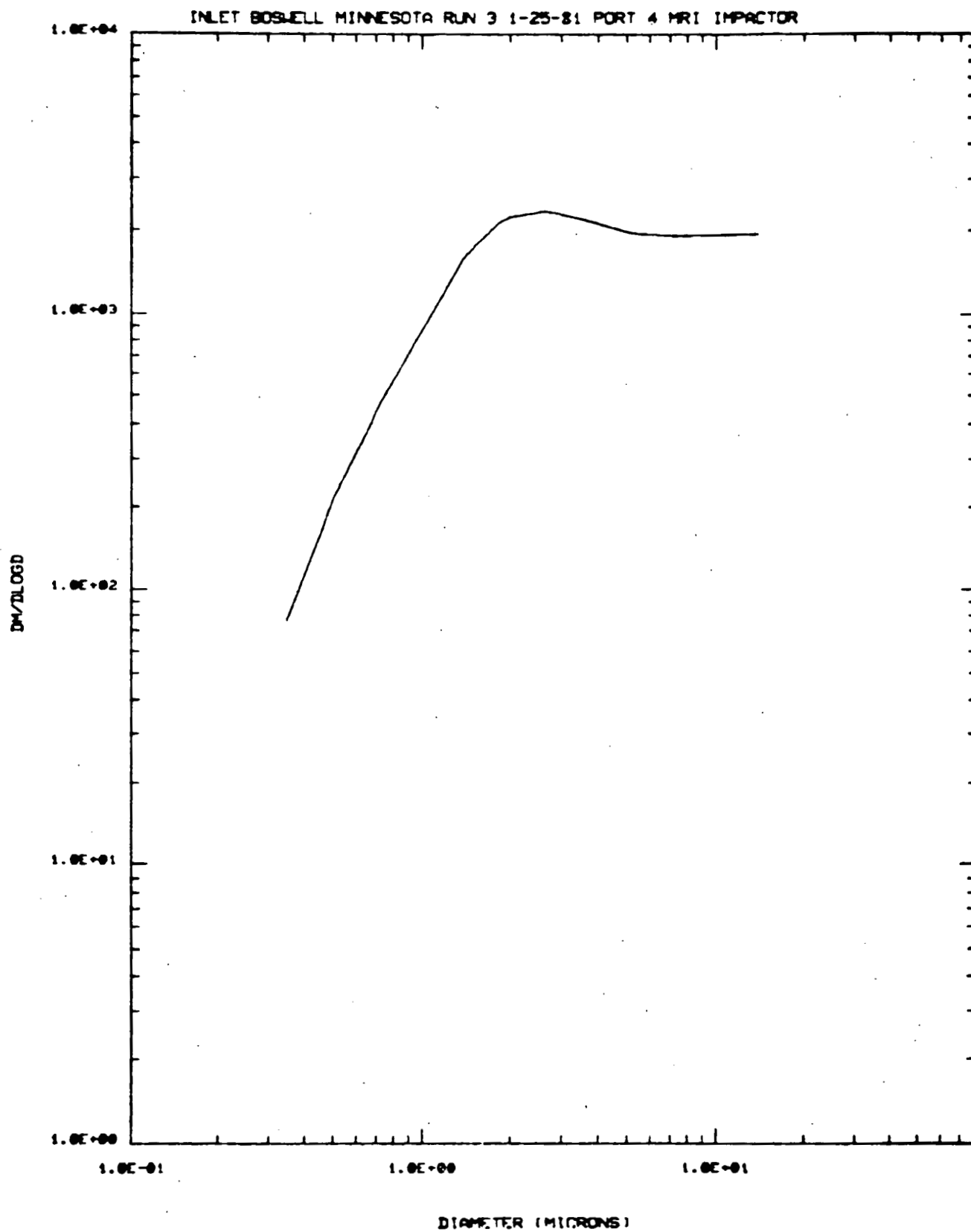


Figure 9-4. Inlet Mass Size Distribution, 25 January 1981.

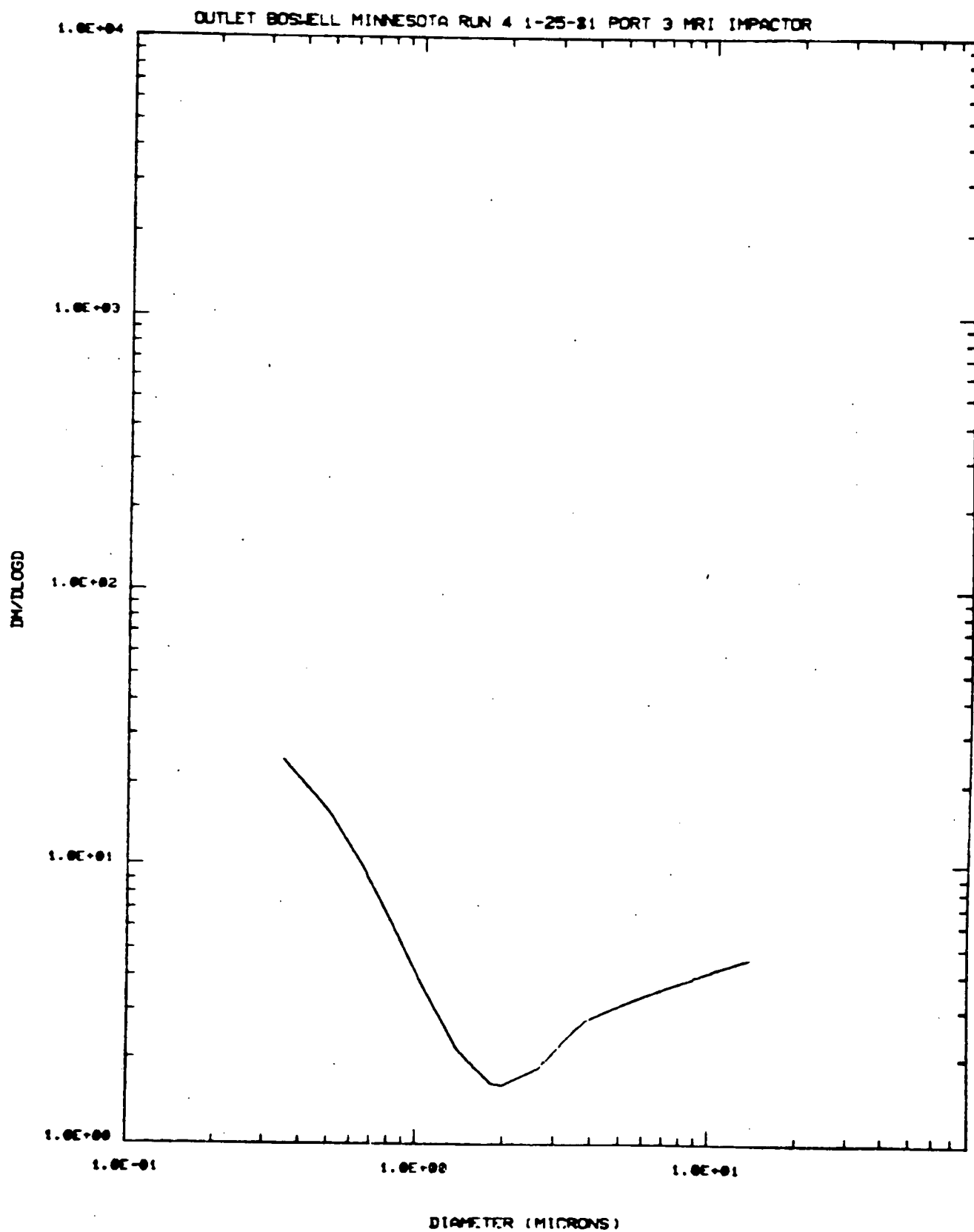


Figure 9-5. Outlet Mass Size Distribution, 25 January 1981.

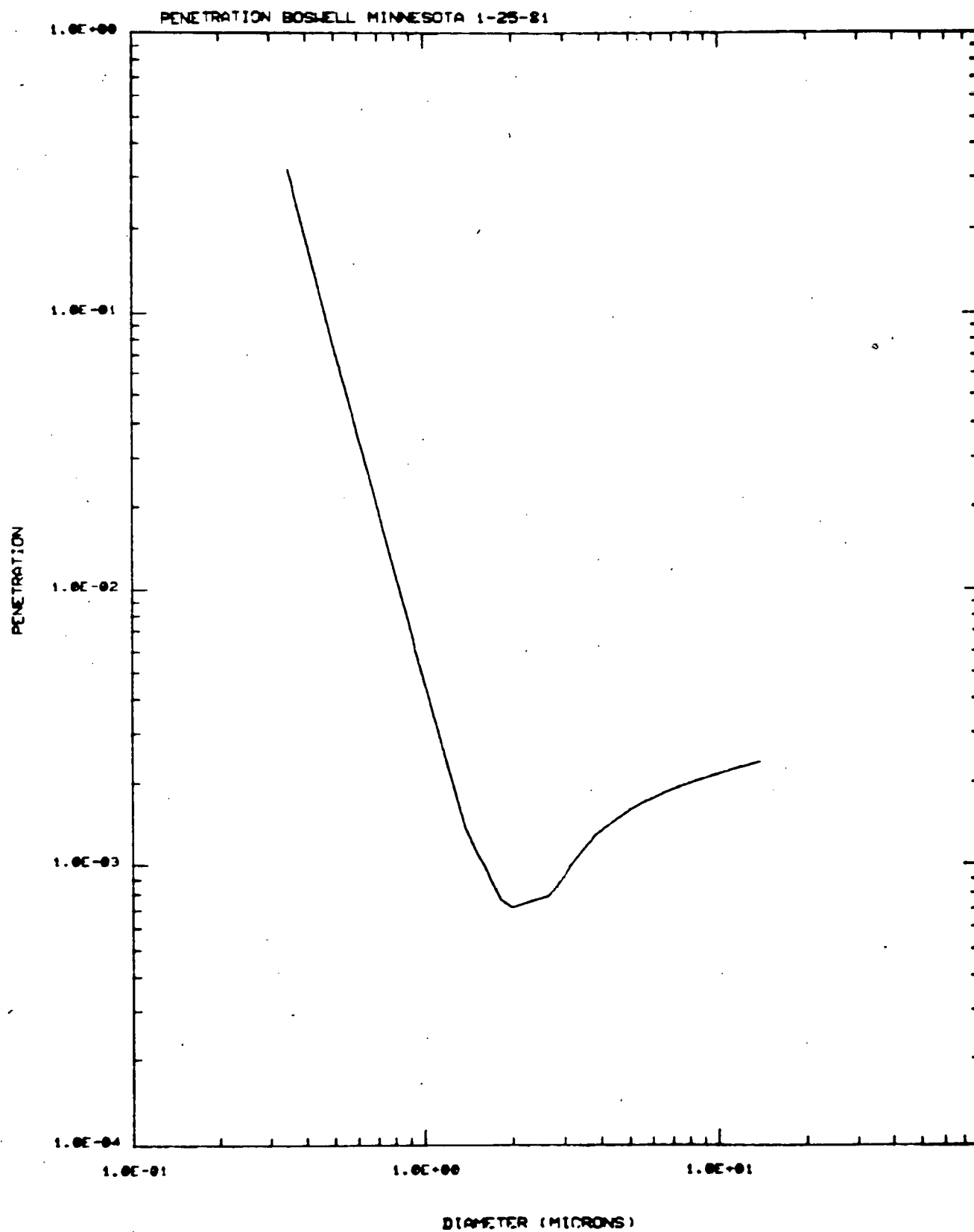


Figure 9-6. Size-dependent Penetration, 25 January 1981.

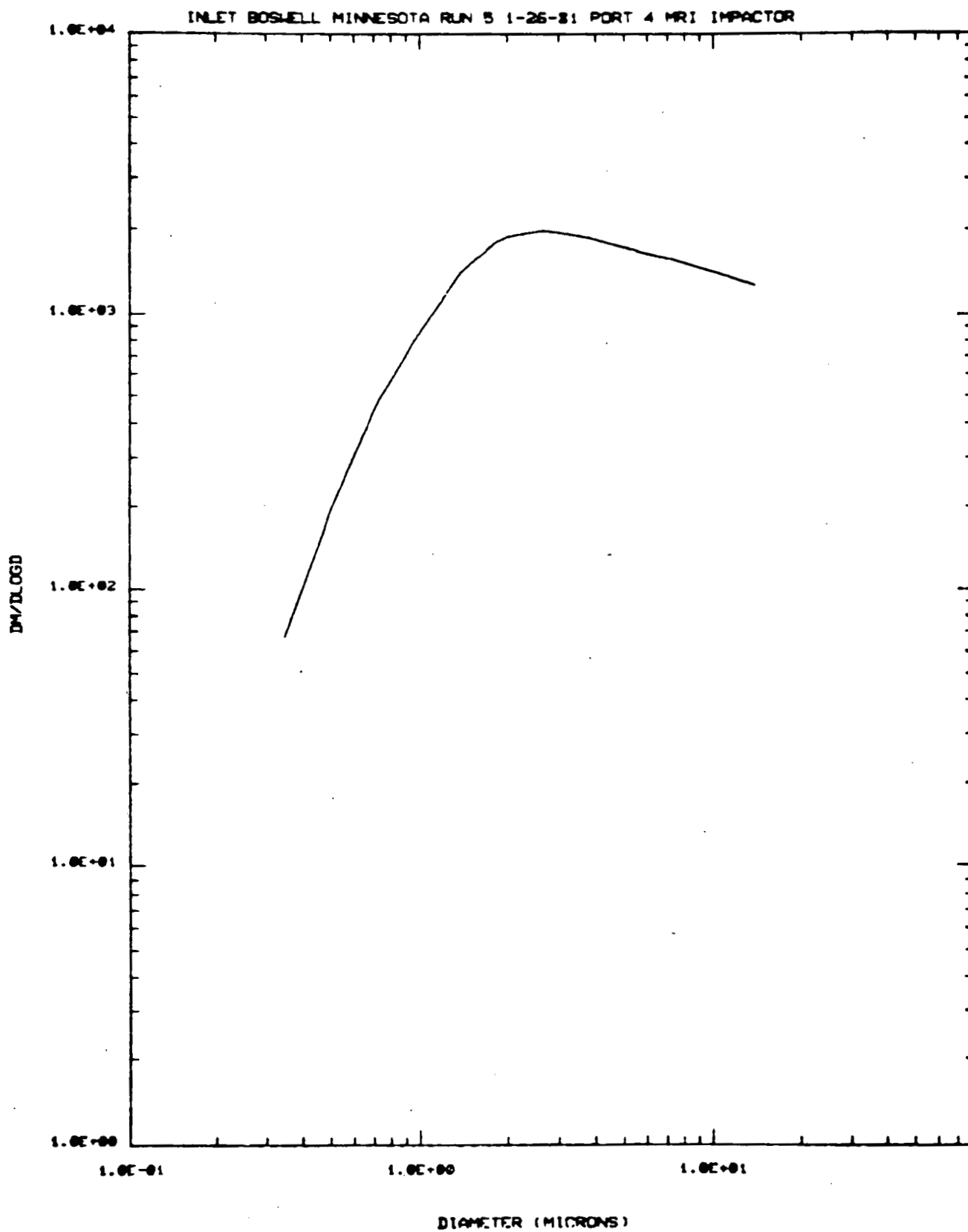


Figure 9-7. Inlet Mass Size Distribution, 26 January 1981.

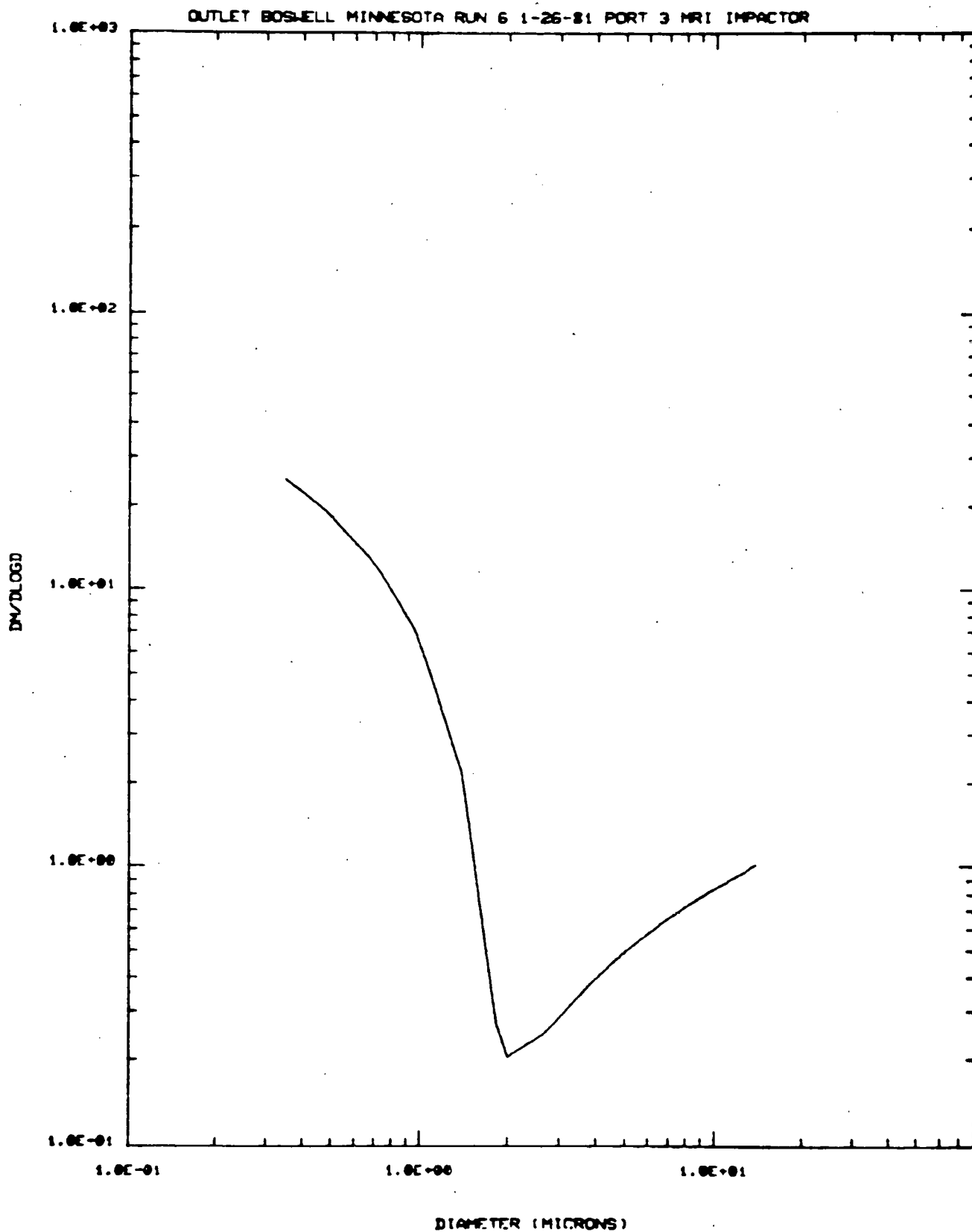


Figure 9-8. Outlet Mass Size Distribution, 26 January 1981.

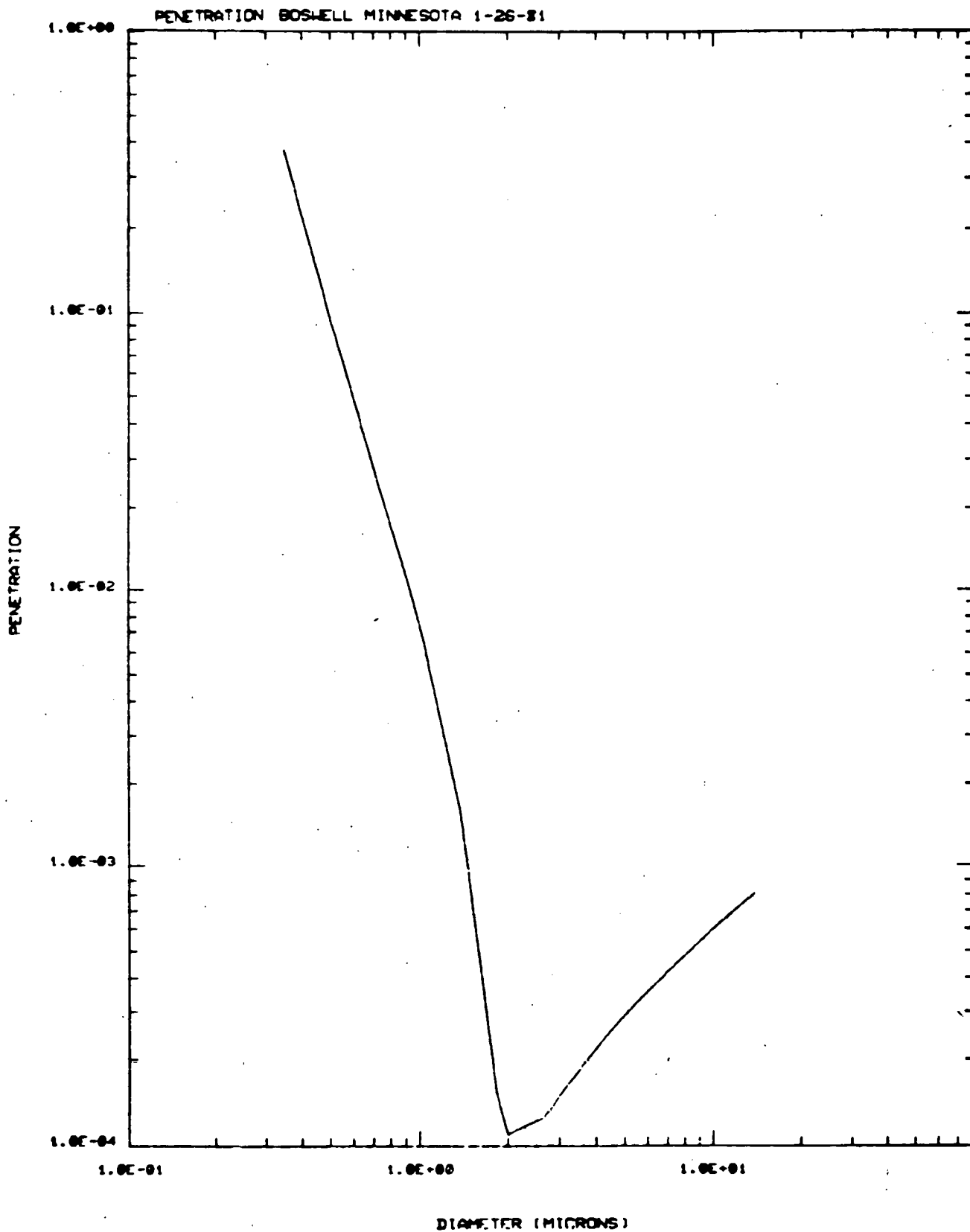


Figure 9-9. Size-dependent Penetration, 26 January 1981.

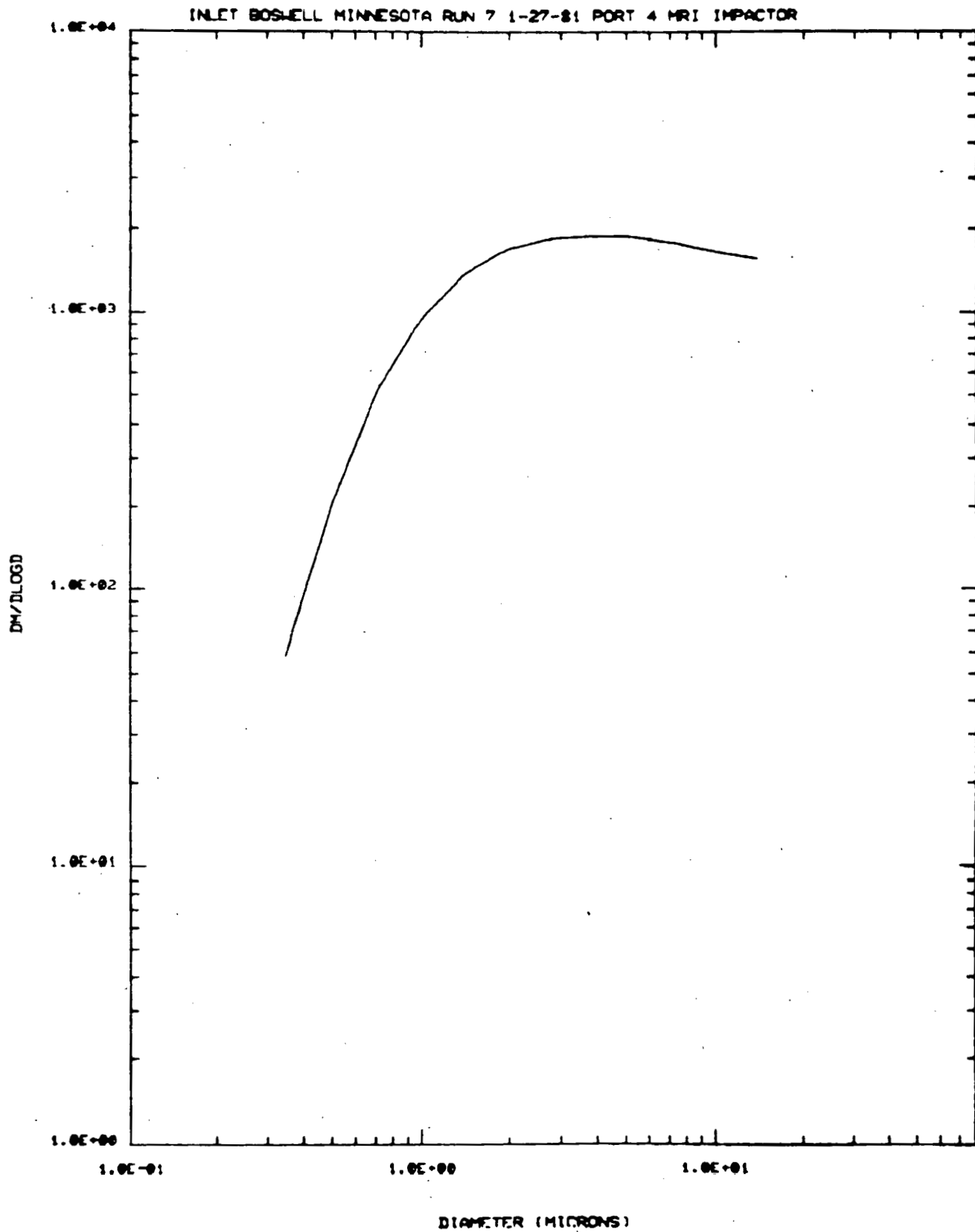


Figure 9-10. Inlet Mass Size Distribution, 27 January 1981.

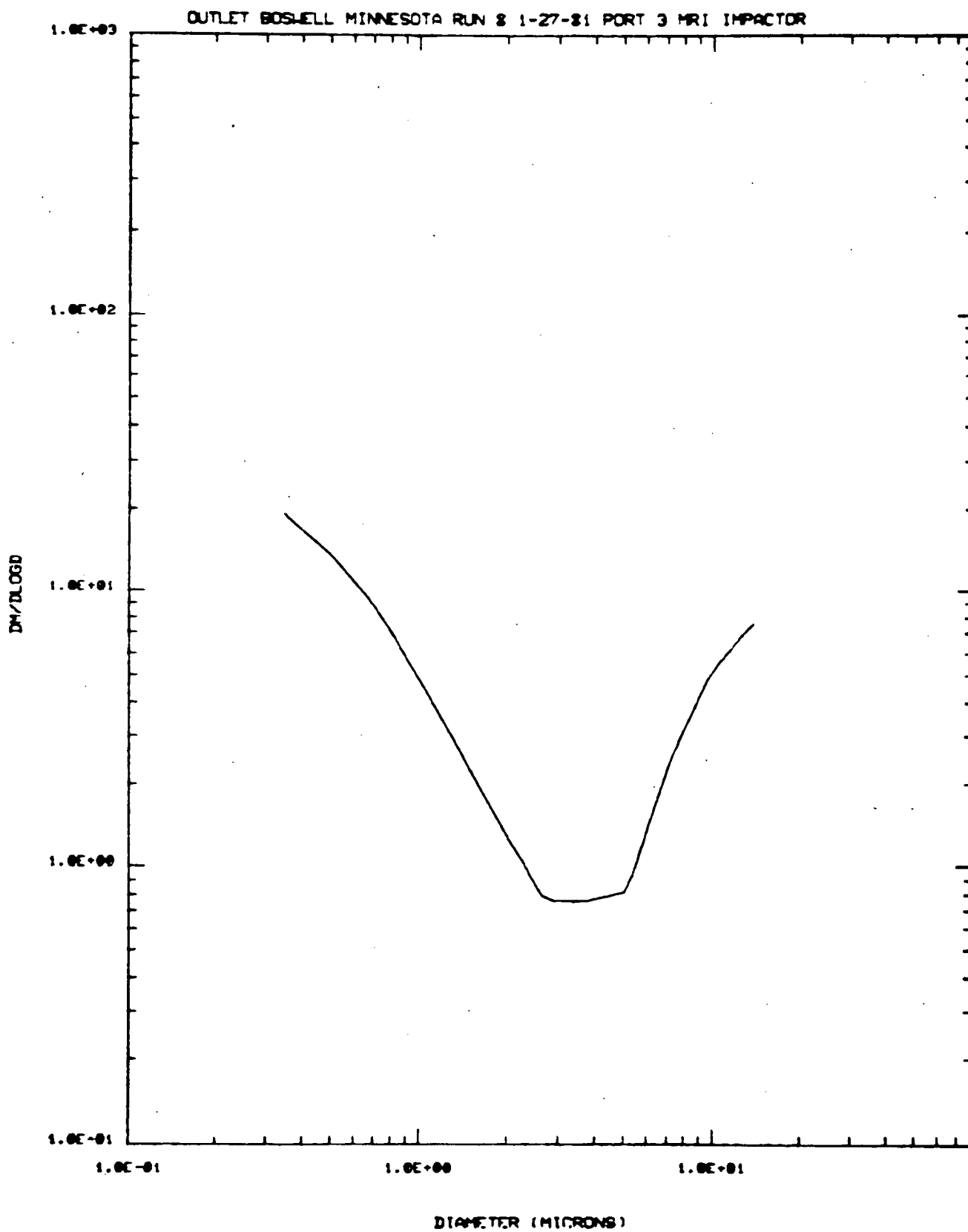


Figure 9-11. Outlet Mass Size Distribution, 27 January 1981.

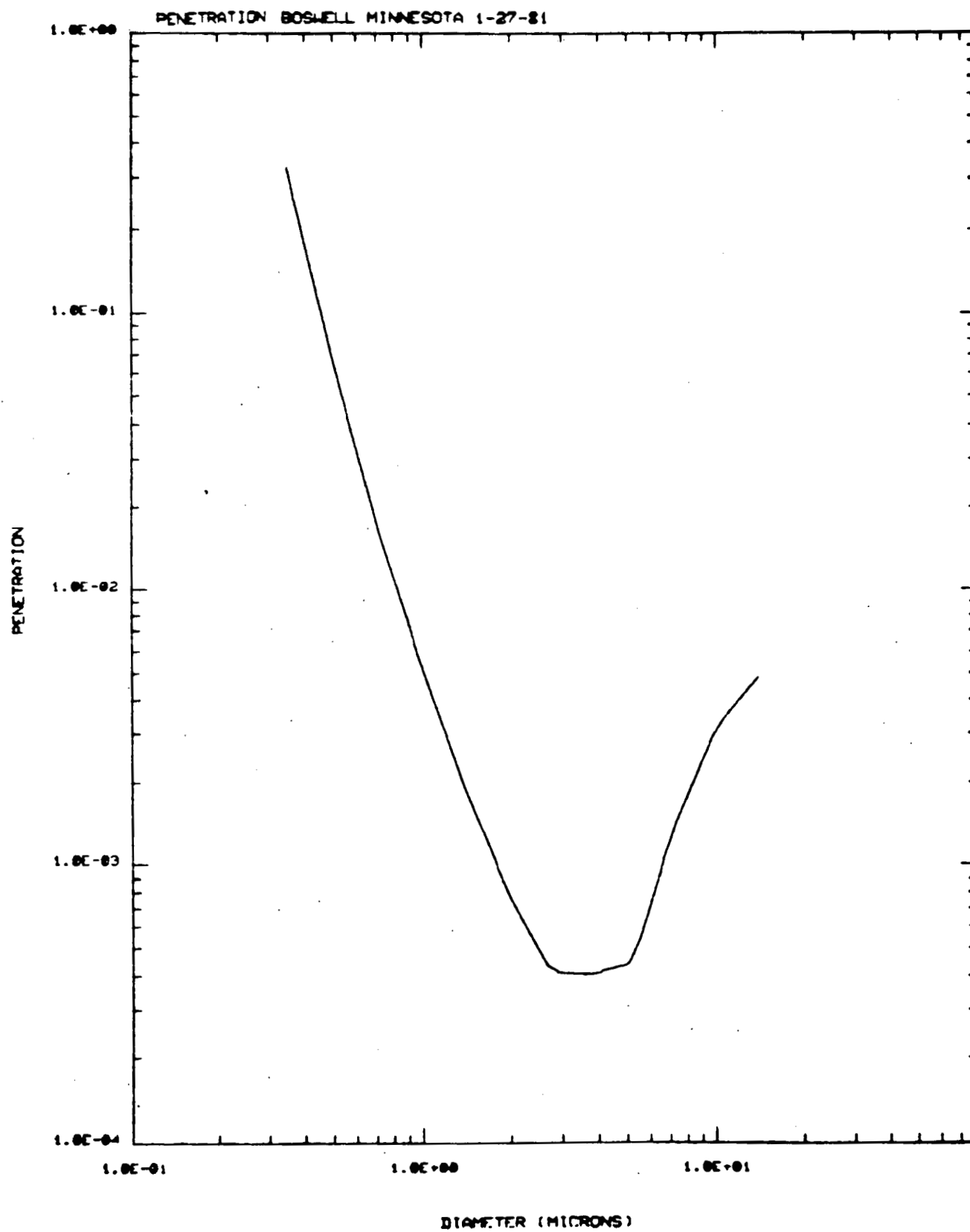


Figure 9-12. Size-dependent Penetration, 27 January 1981.

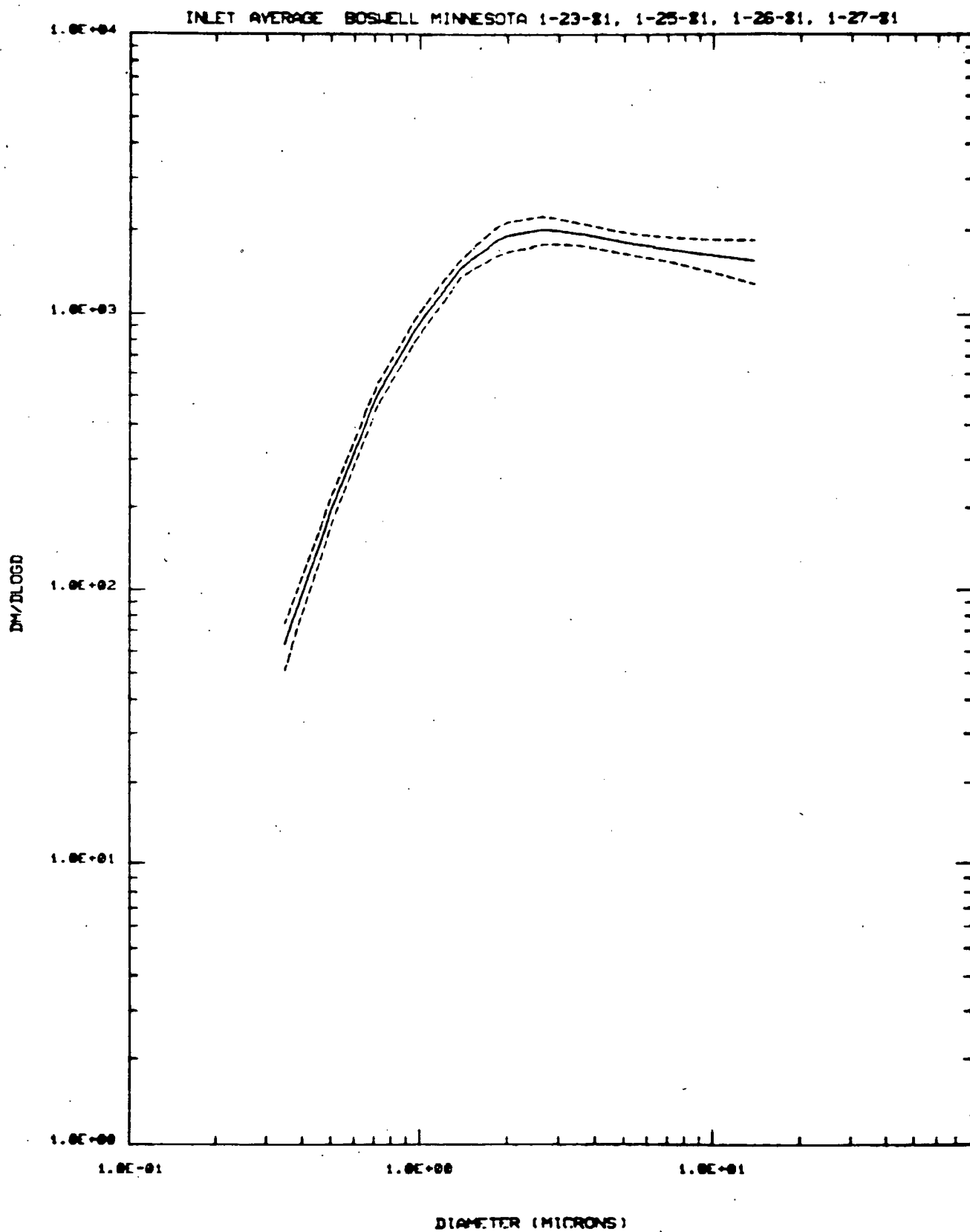


Figure 9-13. Average Inlet Size Distribution

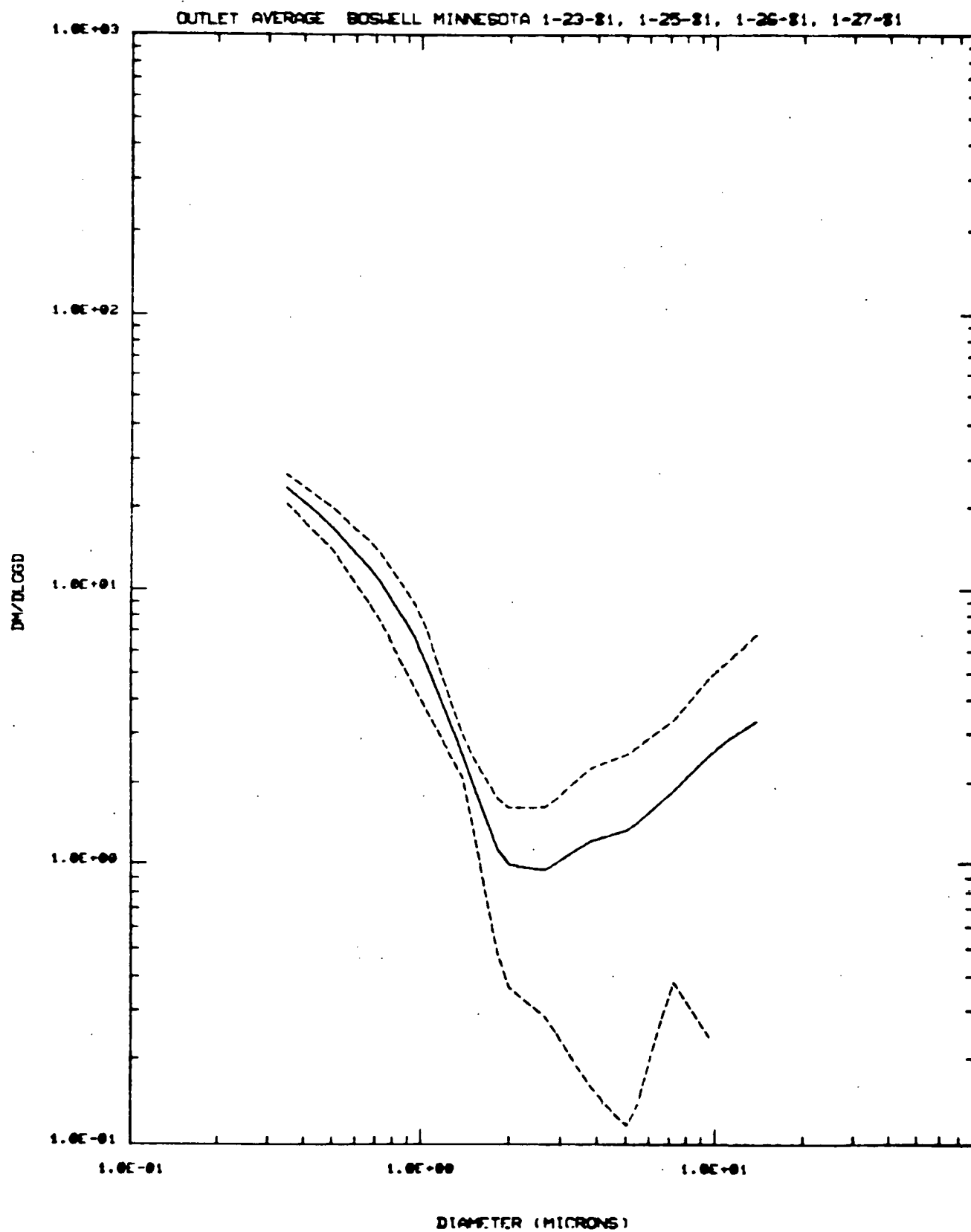


Figure 9-14. Average Outlet Size Distribution

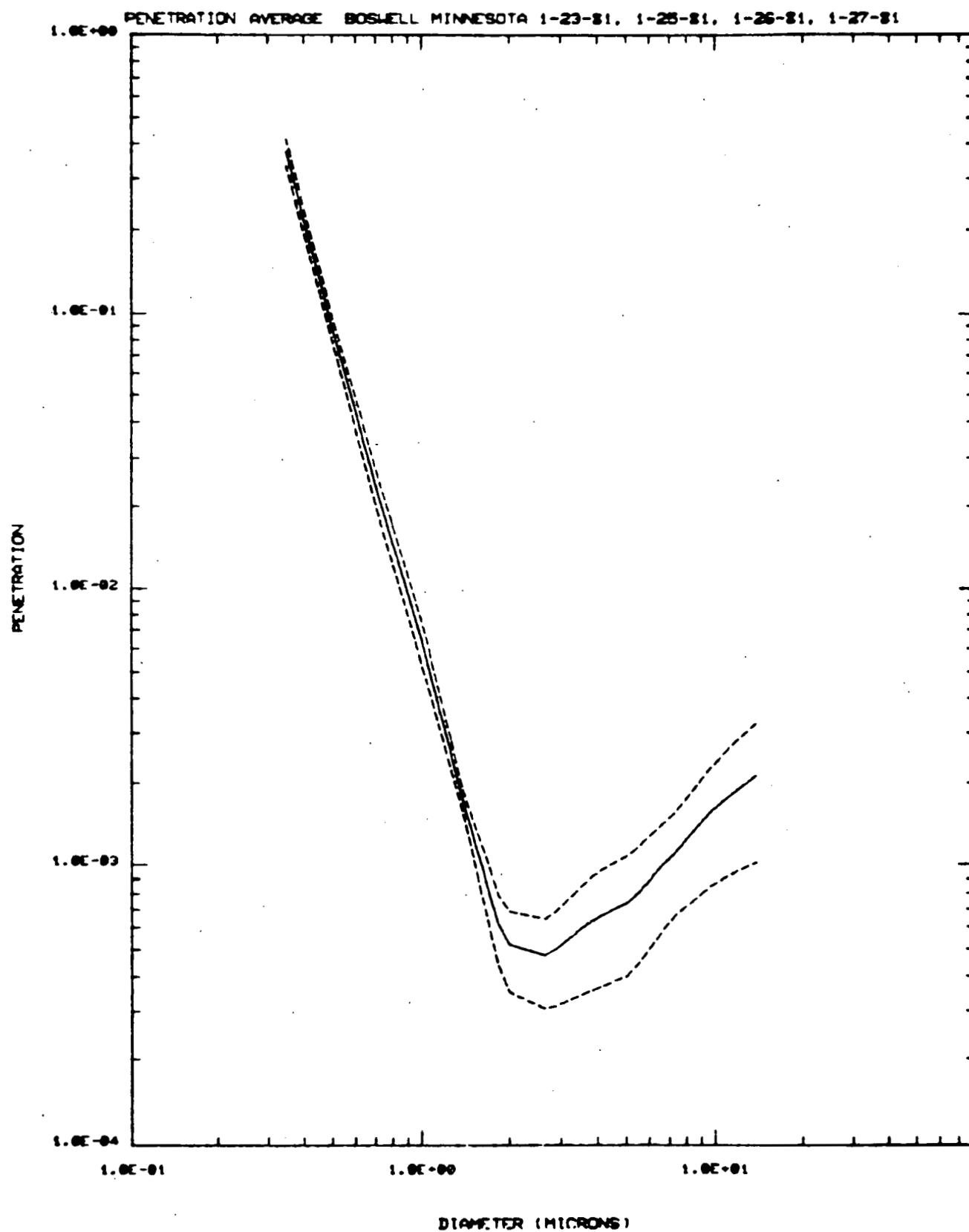


Figure 9-15. Average Size-dependent Penetration

Table 9-14

SIZE SEGREGATED PARTICULATE SULFATE CONCENTRATIONS AT THE INLET

<u>Date (1981)</u>	<u>Approximate Size Range (micrometers)</u>	<u>Mass Concentration (mg/dscm)</u>	<u>Sulfate Concentration (mg/dscm)</u>	<u>Ratio of Sulfate to Total Mass</u>
1/25	>17	4120	65.7	0.0159
	8.5-17	589	9.85	0.0167
	3.2-8.5	837	15.6	0.0186
	1.4-3.2	822	6.73	0.00819
	0.68-1.4	269	1.64-3.28	0.00610-0.0122
	0.34-0.68	58.9	<1.64	<0.0278
	<0.34	74.4	30.4	0.409
	Total	6770	129.9	0.0192
1/27	>17	2180	16.9	0.00775
	8.4-17	503	3.97	0.00789
	3.1-8.4	809	8.83	0.0109
	1.4-3.1	569	6.40	0.0112
	0.67-1.4	223	6.11-7.58	0.0274-0.0340
	0.34-0.67	24.4	<1.47	<0.0602
	<0.34*	97.6	25.7	0.263
	Total	4410	68.0	0.0154

* Final filter

Table 9-15

SIZE SEGREGATED PARTICULATE SULFATE CONCENTRATIONS AT THE OUTLET

<u>Date (1981)</u>	<u>Approximate Size Range (micrometers)</u>	<u>Mass Concentration (mg/dscm)</u>	<u>Sulfate Concentration (mg/dscm)</u>	<u>Ratio of Sulfate to Total Mass</u>
1/25	>14	0.0603	<0.120	<2.00
	7.1-14	1.27	0.720	0.567
	2.6-7.1	1.27	<0.120	<0.0945
	1.2-2.6	0.603	<0.120	<0.199
	0.55-1.2	2.11	0.360	0.171
	0.27-0.55	6.69	1.08	0.161
	<0.27*	47.7	10.2	0.214
	Total	59.7	12.4	0.208
1/27	>15	6.30	0.500	0.0794
	7.6-15	1.86	<0.143	<0.0769
	2.8-7.6	0.358	<0.143	<0.399
	1.3-2.8	0.501	<0.143	<0.285
	0.60-1.3	2.00	<0.286	<0.143
	0.30-0.60	4.87	0.457	0.0938
	<0.30	41.8	11.4	0.273
	Total	57.7	12.4	0.215

* Final filters

10. DISCUSSION OF RESULTS

The results presented in this report are discussed briefly in this section. The results will be discussed in more detail and compared to the results of future tests in the final report on this program.

10.1 Particulate Removal

The average particulate removal efficiency of the module tested was 99.1 percent, as calculated from the instack filter results. The impactor total mass loading results are in good agreement with those measured with the instack filters.

The size dependent particulate removal by the scrubber may be characterized by the size at 50 percent collection efficiency, or "cut point" of the scrubber. The cut point is about 0.35 micrometer physical diameter or about 0.7 micrometer aerodynamic diameter, which is typical for a venturi with about 13 inches water volume pressure drop.

10.2 SO₂ Removal

The SO₂ concentrations measured with the continuous monitors are believed to be more accurate than those measured by the plant's instruments or by wet chemical methods. The continuous monitor results at the inlet are most consistent with the sulfur content and heat content of the coal. On the basis of these measurements, the average SO₂ removal efficiency of Module 4C was 85 percent.

10.3 Sulfate Aerosol

On the average, based on the instack filter results, 0.47 percent of the particulate mass loading at the inlet is sulfate. At the outlet, this fraction increases to 18 percent. The absolute amount of sulfate is roughly the same at inlet and outlet.

The reason for this increase in relative sulfate concentration can be seen from the impactor results. The sulfate fraction is greatest at both the inlet and outlet in the size range smaller than 0.3 micrometer. This size particle is collected relatively inefficiently by the scrubber, and so remains in the flue gas.

Since the particulate material smaller than 0.3 micrometer was collected on the final filter in the impactor, a possible positive bias in sulfate concentration may have resulted from artifact sulfate formation from SO₂ on the filters.

This possible effect can be investigated during subsequent tests; however, it is believed to be relatively insignificant on the basis of published studies of artifact sulfate formation.

A significant fraction of this small sulfate aerosol is probably sulfuric acid which is formed by condensation of SO_3 with water. The inlet temperature was about equal to the acid dew point, and the outlet temperature was well below the acid dew point. Because of the low concentrations involved (close to the detection limits) the controlled condensation system results are approximate, but they do support this conclusion.

In addition to the submicrometer particulate matter that was not collected efficiently by the scrubber, the "vee" shape of the outlet size distribution indicates the existence of another aerosol mode (containing much less total sulfate) consisting of material whose size ranged from about 2 to greater than 10 micrometers. This material probably was contained in water droplets of a few hundred micrometers diameter at the scrubber outlet that evaporated, leaving a solid residue. This material may have originated in the scrubber slurry. The sulfate concentration of the droplets, as indicated by the high volume sampler cyclone catch at the outlet, was much less than that of the slurry, but the droplets were probably diluted by water condensation, as would be expected.

It should be noted that about 99 percent of the sulfur present in the flue gas stream at the inlet and about 96 percent at the outlet was in the form of SO_2 . Therefore, the potential amount of secondary sulfate aerosol was much greater than the primary sulfate aerosol present.

10.4 Opacity

The opacity that would have existed if the entire pollution control system on Unit 4 functioned as did Module 4C was, on the average, 24 percent. This result is probably not inconsistent with the average opacity of 45 percent measured by the plant's stack opacity instrument. This difference could have existed because the stack instrument measured the combined outputs of Modules A, C, D, and the bypass, because the pressure in the stack is higher than in the outlet duct, and because the gas in the stack may have contained more water droplets than the gas in the heated PPV.

It would be of interest to use existing mathematical models to calculate the opacity from the outlet particulate size distribution and compare it to the observed opacity.

The opacity decreased significantly (from 24 to 18 percent) on the last test day, when the sieve tray wash procedure was altered. However, the results of other measurements did not change significantly, and so the reason for the change in opacity is unknown.

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