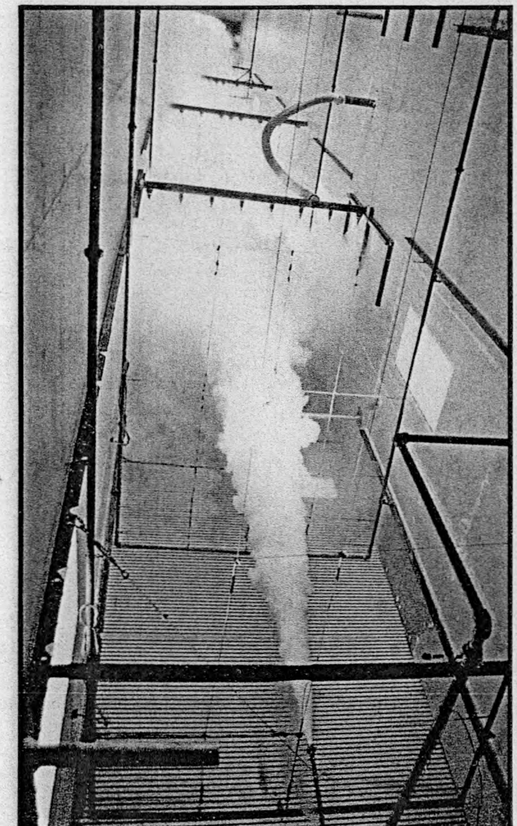

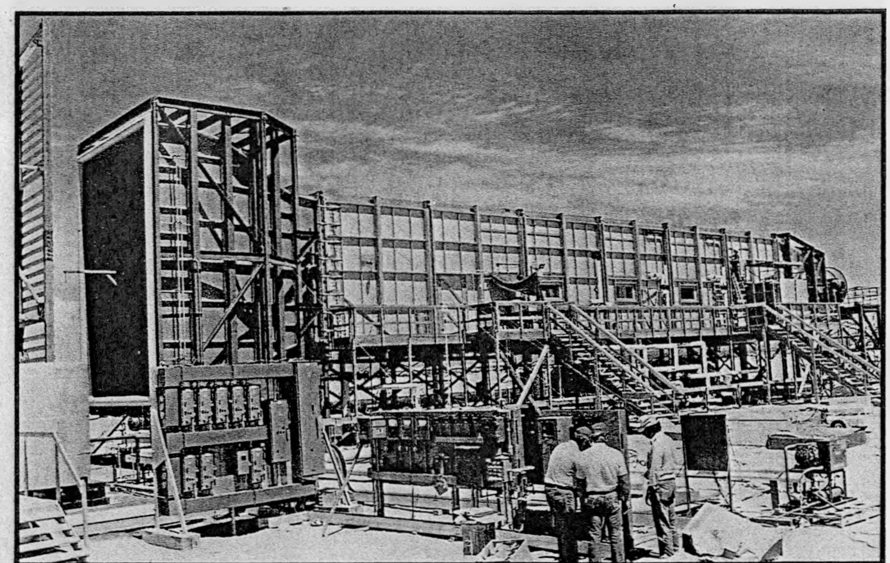

Effectiveness of Water Spray Mitigation Systems for Accidental Releases of Hydrogen Flouride

Volume V
Appendix G
Aerosol Measurements

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for:
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Water Spray Subcommittee
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PREFACE

This report is one of several work products generated by the Industry Cooperative HF Mitigation/Assessment Program. This ad hoc industry program began in late 1987 to study and test techniques for mitigating accidental releases of hydrogen fluoride (HF) and alkylation unit acid (AUA) and to better estimate ambient impacts from such releases.

The hazards of HF have long been recognized. Standard operating practices focused on minimizing the possibility of a release and mitigating the effects if a release should occur. These practices are continually monitored and improved to maximize safety protection based on the available technical data. This recent program targeted further improvements based on new technical data.

Twenty companies from the chemical and petroleum industries sponsored and funded this program. These include:

Allied-Signal	Elf Aquitaine	Shell Internationale
Amoco	Exxon	Sun/Suncor
Ashland	Kerr-McGee	Tenneco
BP	Marathon	Texaco
Chevron	Mobil	Unocal
Conoco/Dupont	Phillips	3M
Dow	Saras	

K. W. Schatz, Mobil Research and Development Corporation (MRDC) and R. P. Koopman, Lawrence Livermore National Laboratories (LLNL) prepared this document as part of the work for the Water Spray Subcommittee.

The cooperation of the members of the following groups is gratefully acknowledged:

1. Allied-Signal for providing anhydrous hydrogen fluoride, analytical equipment and personnel.

2. Chevron for providing personnel.

3. Colorado State University, for consulting on scale-up, flow chamber design and flow chamber testing.

4. Conoco/DuPont, for providing personnel, safety training and data modeling.

5. Dow Chemical for providing personnel.

6. Exxon R&E for providing personnel.

7. Industry cooperative HF Mitigation/Assessment program sponsors for funding the program.

8. Insitec for conducting the aerosol measurements.

9. Lawrence Livermore National Laboratories for providing personnel and services.

10. Mobil Central Research Laboratories for providing laboratory space and consulting on experiments.

11. Mobil Refineries, Paulsboro, NJ, and Joliet, IL, for providing alkylation unit acid.

12. Mobil R&D Corp., for providing personnel and services.

13. Phillips for providing personnel.

14. United Engineers & Constructors, Stearns Roger Division, Denver, for engineering, procurement and construction of the flow chamber.

15. U. S. Department of Energy and contractors EG&G and ReeCo for providing the test site and services.

The results of this study are being published with the intent of making them available to any interested party. The deliverables of the program consist of a report with several appendices, a supplementary report (with a planned release date of third quarter 1989), a volume of still pictures, video tapes and magnetic data tapes. These can be obtained through the U.S. Department of Commerce, National Technical Information Services (NTIS), Springfield, Virginia 22161. Anyone may use these results, subject to the rights of others, to contribute to the further maximization of safety protection. However, neither the sponsors for this work, nor their contractors, accept any legal liability or responsibility whatsoever for the consequences of its use or misuse.

FINAL REPORT

JOINT INDUSTRIAL HF MITIGATION PROJECT:

IN SITU AEROSOL MEASUREMENTS

Work performed for Mobil Oil Corporation, Summer, 1988
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PROJECT WORK STATEMENT

Insitec performed 10 days of particle size distribution measurements of hydrofluoric acid (HF) sprays at the Nevada Test Site (NTS), Mercury, Nevada. Insitec provided the PCSV-P particle counter and additional equipment (oscilloscopes, tools, calibration reticle, etc.) to support and maintain the PCSV-P in the field. The total value of equipment provided was approximately $100,000. Because of the corrosive nature of the acid environment, it was necessary to fabricate new parts for exposed elements of the probe, including a new flow window, polycarbonate windows, and probe extension pipe. All exposed parts except for the windows were teflon-coated. A sealing system was designed and modified during the test series to protect the optical system from exposure to corrosion. Insitec provided two operating and data processing personnel for performance of the measurements defined by the program manager.

SIZE DISTRIBUTION RESULTS SUMMARY

A total of 86 useable data sets were obtained during the test period. We acquired as many as 10 data sets for an 11 minute duration HF release. All primary objectives of the test program were achieved, except for measurements in the dense regions of the plume where light transmission was less than 1%. Prior to the measurements reported here and to the HF Mitigation Consortium in mid-September, 1988, no data were available on the type of HF aerosol formed during a release.

Briefly summarizing the results, the PCSV-P measured predominantly submicron aerosols at the exit of the sharp-edged orifice. The aerosol then grew to larger particles at the outlet of the flow chamber. This result points to the formation of an aerosol through vaporization-condensation as opposed to a conventional shear spray. Temperature, humidity, release pressure, radial position in the plume, and type of acid did not appear to have any significant effect on the measured size distributions for the range of conditions investigated.

Understanding the size characteristics of the aerosol is particularly important in determining the extent of plume dispersion. The size distribution and dispersion characteristics are important both for design of water spray mitigation systems and as inputs for numerical models. Modeling simulates a broader range of accidental release conditions than can be studied in a necessarily limited series of high cost experiments.

1.0 INTRODUCTION

The HF aerosol measurements were performed during August and September, 1988, and involved collaboration between a consortium of HF users and manufacturers, Lawrence Livermore National Laboratory personnel, and other subcontractors, including Insitec. The primary objective was to determine the extent of HF aerosol mist formation in a potential accidental release of HF. The PCSV-P is the only available instrument which can provide on-line measurements of this toxic and volatile material in a large scale experiment.

This project was carried out in a specially developed flow chamber with a cross-section of 8 X 16 feet, and approximately 140 feet long. These tests were carried out at the DOE Hazardous Spills facility at the Nevada Test Site at Mercury, Nevada. Lawrence Livermore National Laboratories coordinated the test program in conjunction with Mobil Research and Development Corporation and provided many of the diagnostic measurements.

1.1 MOTIVATION

Prior to the measurements obtained this summer Dr. R.P. Koopman of LLNL summarized the primary motivation for detailed HF aerosol measurements. A partial summary of this motivation is given in the following:

A. For aerosols produced at the release orifice:

1. The aerosol size and production mechanism are unknown. There are no data.

2. Aerosol size data will be useful for input to atmospheric dispersion models.

3. Water curtain models depend on knowledge of water spray and HF aerosol size, velocity and number density.

B. For aerosols which penetrate the water spray:

1. No adequate theory exists to describe the removal of HF aerosol by water sprays. Is removal due to droplet-droplet or droplet-vapor interactions?

2. Aerosol measurements are needed because not all variables can be controlled or examined in the field measurements or accurately simulated in the numerical models.

The measurements obtained with the PCSV-P have addressed these primary issues.

1.2 SUMMARY OF PCSV-P TECHNIQUE

A description of the PCSV-P instrument is given in summary form in the following brochure and technique summaries (Figure 1 and Figure 2). As shown in Figure 1, this probe consists of a stainless-steel enclosure for the optical transmitter and receiver with a 10 X 4 cm aerosol flow access region. The region from which size distribution and velocity information is obtained is a small portion of the beam focus centered within the flow access opening. The aerosol flowing through the center has been shown to be entirely undisturbed by probe purge flow or probe boundary layer growth. Thus the PCSV-P provides a true in situ measurement of the aerosol. Appendix A gives a more detailed description of the PCSV technique.

The PCSV-P is a single particle counting instrument based on absolute light scattering. This implies that the measurement volume must be as small as possible to measure higher particle concentrations. The PCSV-P measures the flux rate of particles passing through the optically defined sample volume, one at a time in time sequence. From an applications perspective, the primary requirements of this instrument are dictated by the minimum size and maximum number density constraints. The minimum size is limited by signal/noise considerations and is greater than 0.3 microns. In addition, the maximum number density must be less than 10^6/cc. For example, if the number density is 10^6/cc at 1 micron diameter, then the concentration limit dictates the smallest measureable particle size, namely 1 micron. To summarize, the lower bound of the instrument is controlled by the size or concentration limits, whichever value is exceeded first. The maximum size is typically limited by the statistical uncertainty for less than 10 counts in the uppermost size bin. The absolute upper limit is 200 microns.

1.2.1 Graphical Data Presentation

It should be noted that the graphed distributions are given in terms of log-frequency (histogram) and cumulative concentration (solid curve) units. Physically, the cumulative distribution is the integral of the frequency distribution. In addition, the data is also normalized to give percentage distributions along with tabulated cumulative values of the absolute concentration. However, normalized distributions should only be used as a relative comparison when the apparent range of the data exceeds the instrument range, i.e. the normalization is artificially constrained by the instrument range. The Sauter mean diameter, D32, is the ratio of the weight to area distributions, and may also be artifically constrained by the instrument range.

The advantage of using absolute frequency and concentration units is that they give a correct measure of the concentration distribution independent of the instrument limitations. In general, the upper size bound can be increased by counting for a longer period of time. The other reasons for using logarithmic frequency units are due to the large dynamic range in particle size and concentration of typical aerosols. The mass frequencies and concentrations are obtained by computing the weight of each spherical particle size class from the number frequency data.

1.2.2 Oscilloscope Traces of Scattering Signals

Figure 3 shows a typical oscilloscope trace of log-amplified particle scattering signals in a dilute aerosol flow (water spray droplets in this case). The normalized width measurement gives a measure of the particle velocity, while the peak height measurement gives the particle amplitude spectrum, C(A), from which the number density distribution is derived. We obtained velocity measurements with the PCSV-P for several runs and confirmed that these values were within 10% of the values determined by the flow chamber anemometers. In order to save time during the test, we used the velocity values reported for the flow chamber. Figure 4 shows the linear and log-amplified signals in parallel for a somewhat higher concentration water spray condition. Individual scattering pulses still dominate the spectrum.

Figure 5 shows an oscilloscope trace of the amplitude spectrum for a typical HF test run downstream of the water-spray curtain. We note that the majority of pulses can still be individually discriminated if the lower level discriminator (LLD) of the signal processor is set sufficiently high. The "measure of sufficiency" is given by the "Valid" percentage shown in the header of each data plot. The "Valid" percentage indicates the ratio of "peak-sensed" signals to total counted signals exceeding the LLD level. The "invalid" signals may be due to baseline noise, shot-noise superimposed on the scattering pulse, or partial particle overlaps in the sample volume.

Before taking any data, the discriminator is set above the baseline noise. Next the signal input filter is set to minimize shot noise. Therefore, the primary contributor to invalid signals in high density aerosol measurements is due to particle overlaps which occur in a random Poisson-distributed fashion. In order to satisfy single particle counting conditions, the signal processor discriminator must be set high enough to avoid particle overlaps. However, the lower size range cutoff also increases with increased LLD. Therefore, for the high density aerosols encountered in these measurements, a compromise is taken between lower size range limit and high percentage validation rates.

Given that the PCSV-P measures absolute scattering signals, the measured scattering amplitude is dependent on the total beam power and light transmission through windows and aerosol. In order to properly acount for these variations, the instrument measures the percentage of light transmission relative to a standard calibration condition for each data set. This "beam power" or "Trans" measurement ensures that the optical system is properly aligned and that the scattering amplitudes are properly normalized. For turbulent plumes, however, there is an additional complication, since the light transmission for measurements on the edge of the plume can vary markedly as the aerosol optical pathlength and concentration vary. Under these conditions, we typically acquired three or more data sets at the same nominal run condition, which randomly sampled the time variation of aerosol flow conditions and light transmission. This in turn gives a band of possible aerosol size distributions which are discussed in the data results sections.

1.2.3 Light-Scattering Response Functions

Figures 6 and 7 show the normalized response functions which give the relative scattering amplitudes of the PCSV-P as a function of non-dimensional particle size, alpha. For the red (Helium-Neon) laser used, particle sizes are given by alpha/5. Figure 6 shows the response function for the small beam size range of 0.2-15 microns, while Figure 7 shows the response function for the big beam range of 2-150 microns. Figure 6 shows some oscillations and less size sensitivity in the light scattering response above 1 micron, while Figure 7 shows uniform geometric sensitivity above 8-10 microns for the big beam measurements. Except for the water spray measurements, all the HF measurements were taken with the small beam only.

1.3 MODIFICATION OF PCSV-P FOR CORROSIVE ENVIRONMENT

In order to perform measurements in a corrosive environment, significant changes in the protective probe design were required. Because the operating temperatures were less than 120 F, we used PVC pipe for the outer probe instead of the normal water-cooled stainless steel probe; the stainless-steel flow window was teflon-coated; O-ring seals were used to provide the primary seal between the PVC outer pipe and the teflon-coated flow window. In addition to the O-ring seal, silicone sealant was used to fill the gap, and then PVC tape provided the final seal. Polycarbonate windows (1/16 inch thick) were used to cover the standard fused silica windows. Silicone sealant was again used to ensure a seal. This system provided a very satisfactory seal for the 3 week testing period, which at the conclusion, showed no deterioration.

2.0 HYDROFLUORIC ACID SIZE DISTRIBUTION MEASUREMENTS

2.1 MEASUREMENT CONDITIONS

Figure 8 shows a sketch of the flow chamber instrumentation and relative location of the upstream and downstream measurement positions of the PCSV-P (elevation is 33 inches). Table I lists all the experiments for which particle size distributions were obtained. The first part of the filename "NTS", refers to "Nevada Test Site". Run numbers in the file correspond with those taken by Mobil and LLNL personnel for each HF run condition. The final alphabetical designation refers to a separate PCSV-P measurement within the typical 11 minute run period (environmental conditions are identical for a given run number). In general, 2-3 measurements were taken at each measurement position within a run as shown in Tables I and IA. Position indications (Pos) for the upstream measurements are qualitatively referenced to the plume, i.e. "edge" refers to the plume edge and "center" refers to the plume centerline. For Run NTS43WB and the downstream measurements (Runs 49-57), transverse positions are identified in the "End View" of Figure 8. Variations in light transmission (Trans), discriminator (Disc) level and resulting validation rate (Valid) are shown in adjacent columns, along with general test conditions in the last four columns. HF refers to anhydrous hydro-fluoric acid and AUA refers to alkylation unit acid which contains approximately 10% hydrocarbons. RH is the relative humidity in %. See Appendix A for detailed discussion of data format and calibration conditions.

TABLE I NEVADA TEST SITE (NTS) DATA LIST AND DESCRIPTION; UPSTREAM POSITION (10 FT DOWNSTREAM OF RELEASE ORIFICE)

Filename	Pos	Trans	Valid	Disc	Water	Type	Temp(F)	Press	RH
NTS41A	edge	112	49	45	na	HF	99	32	50
NTS41B	edge	109	49	50					
NTS41C	edge	75	52	51					
NTS42A	edge	101	48	50	na	HF	102	63	50
NTS42B	edge	95	54	53					
NTS42C	center	112	48	52					
NTS42D	center	110	60	55					
NTS43WB	1'	84	82	40	only	na	na	na	na

TABLE IA NEVADA TEST SITE (NTS) DATA LIST AND DESCRIPTION; DOWNSTREAM POSITION (55 FT DOWNSTREAM OF RELEASE ORIFICE)

Filename	Pos	Trans	Valid	Disc	Water	Type	Temp(F)	Press	RH
NTS49A	1'	92	73	65	no	HF	87	71	50
NTS49B	1'	87	74	65					
NTS49C	1'	94	72	60					
NTS49D	2'	60	74	60					
NTS49E	2'	83	77	65					
NTS49F	3'	60	82	70					
NTS49G	3'	32	80	65					
NTS50WA	1'	82	66	45	na	na	na	na	na
NTS50WB	1'	84	63	45					
NTS50A	3'	12	48	55	yes	HF	93	71	50
NTS50B	3'	53	77	65					
NTS50C	3'	31	64	60					
NTS50D	2'	87	83	60					
NTS51A	1'	25	70	65	no	HF	95	129	50
NTS51B	1'	18	69	65					
NTS51C	2'	52	80	65					
NTS51D	2'	87	84	68					
NTS51E	2'	51	84	68					
NTS51F	3'	42	84	68					
NTS51G	3'	44	85	68					
NTS51H	3'	70	84	68					
NTS51I	3'	64	85	68					
NTS52A	3'	43	71	60	yes	HF	92	132	50
NTS52B	3'	29	80	65					
NTS52C	3'	51	81	65					
NTS52D	2'	68	74	65					
NTS52E	2'	81	75	65					
NTS52F	2'	27	75	65					
NTS52G	1'	64	74	65					
NTS52H	1'	51	77	65					
NTS52I	1'	81	77	65					
NTS52J	1'	35	74	65					
NTS53A	1'	97	77	65	no	HF	96	61	Low
NTS53B	1'	94	77	65					
NTS53C	1'	101	78	60					
NTS53D	2'	84	75	65					
NTS53E	2'	94	79	65					
NTS53F	3'	100	80	65					
NTS53G	3'	101	81	65					
NTS53H	3'	77	80	65					

TABLE IA (continued)

Filename	Pos	Trans	Valid	Disc	Water	Type	Temp(F)	Press	RH
NTS54A	3'	32	68	65	no	AUA	86	143	50
NTS54B	3'	69	70	65					
NTS54C	3'	44	74	68					
NTS54D	3'	31	77	68					
NTS54E	2'	65	84	68					
NTS54F	2'	99	77	65					
NTS54G	2'	34	83	68					
NTS54H	1'	90	71	68					
NTS54I	1'	101	71	68					
NTS54J	1'	49	71	68					
NTS55A	1'	79	74	65	yes	AUA	82	145	50
NTS55B	1'	36	79	68					
NTS55C	1'	40	79	68					
NTS55D	1'	39	80	68					
NTS55E	2'	27	79	68					
NTS55F	2'	49	80	68					
NTS55G	2'	69	77	68					
NTS55H	3'	27	78	68					
NTS55I	3'	75	76	68					
NTS55J	3'	22	79	68					
NTS56A	3'	17	65	65	no	AUA	90	200	50
NTS56B	3'	18	63	65					
NTS56C	2'	13	56	62					
NTS56D	2'	9	57	62					
NTS56F	1'	17	54	62					
NTS57A	1'	21	70	64	yes	AUA	92	201	50
NTS57B	1'	94	74	65					
NTS57C	1'	31	76	65					
NTS57D	2'	38	80	65					
NTS57E	2'	86	82	65					
NTS57F	2'	43	81	65					
NTS57G	2'	36	86	67					
NTS57H	2'	19	87	67					
NTS57I	3'	27	79	67					
NTS57J	3'	23	81	67					
NTS57K	3'	88	78	67					
NTS57L	3'	29	80	67					
NTS57M	3'	19	78	67					

Appendix B includes representative measurements for all experimental runs. Files that were not plotted were considered to be representative of repeated measurements, or in a few cases were considered to be "bad" data files. Following the individual data files are a series of cumulative concentration cross-plots which isolate comparisons of specific parameters in the test matrix. For convenience, we will duplicate the most interesting results in the main text. The following discussion will begin with measurements downstream of the release orifice and progress downstream of the mitigation water spray.

2.2 RELEASE ORIFICE AEROSOL

We have obtained limited data near the release orifice (approximately 10 ft. downstream from the orifice) because of the high concentrations. Nevertheless, this data shows that the aerosol is initially submicron as shown in Figure 9. We note that both the number and mass distributions are strongly peaking at the smallest measureable particle sizes at 0.5 microns. Note that the number concentrations increase by 2.5 to 4 orders of magnitude from the largest to smallest measureable particle sizes. This lower bound is a limit of the PCSV-P instrument because of number concentration limitations. In all probability, the peak concentration of this aerosol occurs at smaller particle sizes and higher concentrations.

All of the measurements at the near-field condition were obtained at the edge of the plume, so as to obtain sufficient light transmission. Measurements at the center of the plume showed nearly zero light transmission, indicating a very dense aerosol. Thus the absolute concentrations shown in Figure 9 are probably low by several orders of magnitude, although they give an indication of the relative size distribution.

All other distributions taken at the edge of the spray plume are essentially consistent. File NTS42D (Figure 10) was taken with a higher discriminator setting, showing a resulting higher value for the "Valid" percentage. The absolute concentration distribution is somewhat higher than the other Run 42 files, but the distribution shape is essentially the same.

As mentioned in our discussion of the measurement technique, we observed strong variations in the light transmission, (Trans) at the edge of the turbulent spray plume. During these initial tests, all measurements of "Trans" were taken with no aerosol attenuation, even though the measured size spectra and transmission values showed significant variations over time. Indeed, the "Valid" percentages are rather poor, due to the flux of high concentration eddies through the probe. Nevertheless we find that the distributions are consistent for a range of Valid percentages and measurement conditions. For Run 42 we artificially reduced the transmission values down to 6%, in order to assess this effect. Even though the modified transmission results shift the distributions to larger size values to account for light attenuation in the scattered signal, the bulk of the number distribution remains below 1-2 microns. This conclusion will be significant in comparing with the downstream results.

2.3 AEROSOL CONCENTRATIONS DOWNSTREAM OF THE WATER SPRAY

Figure 11 shows the aerosol distribution at the downstream position (approximately 55 ft downstream of release orifice, and 40 ft. downstream of water curtain spray) with the water mitigation spray off. We note an apparent increase in particle size and concentration compared to the upstream measurements. At the same time the number concentration is still increasing rapidly with decreasing particle size, similar to the upstream condition. Again, because of the instrument concentration limits we infer that the number concentration peak occurs in the submicron range. In contrast to the upstream measurements, the downstream data showed measureable light transmissions throughout the plume. Therefore, the downstream absolute concentration measurements are representative of actual concentration conditions.

2.4 CROSS-COMPARISONS FOR VARIOUS PARAMETERS

2.4.1 Beam Transmission Effects

As described in the general discussion, we found a significant time variation in the measured beam transmission, attributed to turbulent fluctuations of the aerosol plume. Figure 12, TEST 52 shows a comparison of four cumulative measurements during run 52. Table II specifies which data files are used in the comparative plots. We note a general increase in the upper end of the size distribution as the light transmission decreases. In theory, all these curves should be identical for steady-state flows where the beam transmission remains constant. We artificially altered the beam transmission for file NTS52I to be exactly the same as NTS52J to see if the entire shift is due to light transmission variations alone, or whether there is some change in the amplitude scattering spectrum between the two measurements.

Comparisons of the two data files show that the entire effect can be attributed to light transmission variations, i.e. the amplitude scattering spectra are nearly identical when averaged over the 10-20 second time period required to acquire 100,000 scattering amplitudes. This in turn implies that we should use a time-averaged light transmission value to obtain reasonable interpretations of the size distributions. The only rigorous way to accomodate large variations in the light transmission during a measurement is to obtain an instantaneous normalization of each scattering signal. The PCSV-P, at present, does not have this capability. In the absence of instantaneous normalization, the best approach is to take the average distribution obtained for a range of randomly sampled transmission values.

Another method of assessing these fluctuations is to compare the effect of position and beam transmission. As shown in Table II, we compared a variety of position measurements to determine if there is any systematic aerosol variation as a function of radial position in the plume. Run 52, Figure 12 shows that the lowest transmission run is shifted to larger sizes, with the highest transmission condition giving smaller sizes. We conclude that NO systematic position effects exist. All variations are within the uncertainty of the transmission variations measured above.

TABLE II - TABULATION OF DATA FILE CROSSPLOT INFORMATION

1. ATTENUATION COMPARISON AT FIXED TRANSVERSE POSITION (POSITION, TRANSMISSION)

52G (1,64); 52H (1,51); 52I (1,81); 52J (1,35)

57D (2,38); 57E (2,86); 57F (2,43); 57G (2,36); 57H (2,19)

2. TRANSVERSE POSITION COMPARISONS

RUN #	DATA FILE (POSITION, TRANSMISSION %)
42	A (3, 101); D (1, 112)
49	B (1, 87); E (2, 83); G (3, 32)
50	B (3, 53); D D(2, 87)
51	A (1,25); C (2,52); G (3,44)
52	A (3,43)); F (2,27); J (1,35)
53	B (1,94); E (2,94); G (3,101)
54	C (3,44);. G (2,34); J (1,49)
55	D (1,39); E (2,27); H(3,27)
56	B (3,18); C (2,13); F(1,17)
57	C (1,31); D(2,38); L (3,29)

TABLE II - TABULATION OF DATA FILE CROSSPLOT INFORMATION

3. UPSTREAM - DOWNSTREAM COMPARISON (POSITION, TRANSMISSION)

UPSTREAM	DOWNSTREAM
42A (3,101); 42B (3,95);	50A (3,12); 50C (3,31)
42A (3,101); 42B (3,95);	49A (1,92); 49B (1,87)

4. WATER SPRAY SCRUBBING COMPARISON (POSITION, TRANSMISSION)

WATER ON	WATER OFF
49G (3,32)	50C (3,31)
51A (1,25)	52J (1,35)
54H (1,90)	55A (1,79)
56F (1,17)	57A (1,21)

5. ACID FEEDRATE COMPARISON (PRESSURE, TRANSMISSION)

41A (32,112);	41B(32,109);	42A(63,101);	42B (63,95)
49A (71,92);	49B (71, 87);	51A(129,25);	51B (129,18)
50A (71,12);	50C (71,31);	52A(132,43);	52C (132,51)
55B (145,36);	55D (145,39);	57A (201,21);	57C (200,31)

2.4.2 Upstream-Downstream Distributions

Figure 13 shows a comparison of the cumulative distributions for upstream and downstream conditions for anhydrous HF. Based on these results we note a significant increase in the particle size distribution at the downstream condition, even if we account for lower transmission values as computed from the modified upstream data files.

Figure 14 gives another comparison of upstream and downstream measurements for runs with similar transmission values. The concentration values for the upstream measurements in both Figure 13 and 14 are low by unknown orders of magnitude because it was required to obtain measurements at high transmission and low flux rates on the edge of the plume. We believe that the concentration values obtained in the downstream measurements are correct.

2.4.3 Water Spray Distributions

Figure 15 shows a measurement of the water spray carryover distribution. The water spray has a dramatically lower concentration than for the acid aerosols (Figure 16). The water spray has a mass distribution which is concentrated in the size range above 50 microns, consistent with manufacturer specifications for the spray nozzles. In comparison to all the HF aerosol distributions, the water spray concentration is orders of magnitude lower, indicating a low probability of collision rates, particularly on a mass basis. In future studies it would be interesting to study the effects of water spray diameters on scrubbing efficiency in more detail.

Figure 17 shows some apparent removal of HF aerosol by the water spray. However, three other comparisons as listed in Table II (also see Figure 18 as an example) show little apparent effect on the measured HF aerosol distribution. Indeed the last comparison for Alkylation Unit Acid (AUA) in Figure 19 shows an increase in size distribution with the water spray on. These results are not clearly understood at this time. All these comparisons were performed with similar values of beam transmission in order to minimize transmission effects in the comparisons. Because of the large mismatch between the water spray and HF aerosol size distributions, it is possible that most of the HF removal is occurring by submicron absorption on the larger water droplets. This process would have little apparent effect on the measured size distribution range.

2.4.4 Release Orifice Pressure

Cross comparisons were performed on the effects of release orifice pressure, Figure 20. Except for the anticipated effects of light transmission, there is no discernible effect of pressure on the aerosol distribution, for both upstream and downstream cases.

2.4.5 Anhydrous HF vs AUA

Comparisons of anhydrous HF with AUA (Figures 21,22) showed no significant change in the aerosol distribution for these two materials.

2.4.6 Radial Position in Plume

Figure 23 demonstrates the general effects of radial position in the plume, showing no significant variation.

In Situ Particle Measurements in Large Scale Applications

PCSV-P

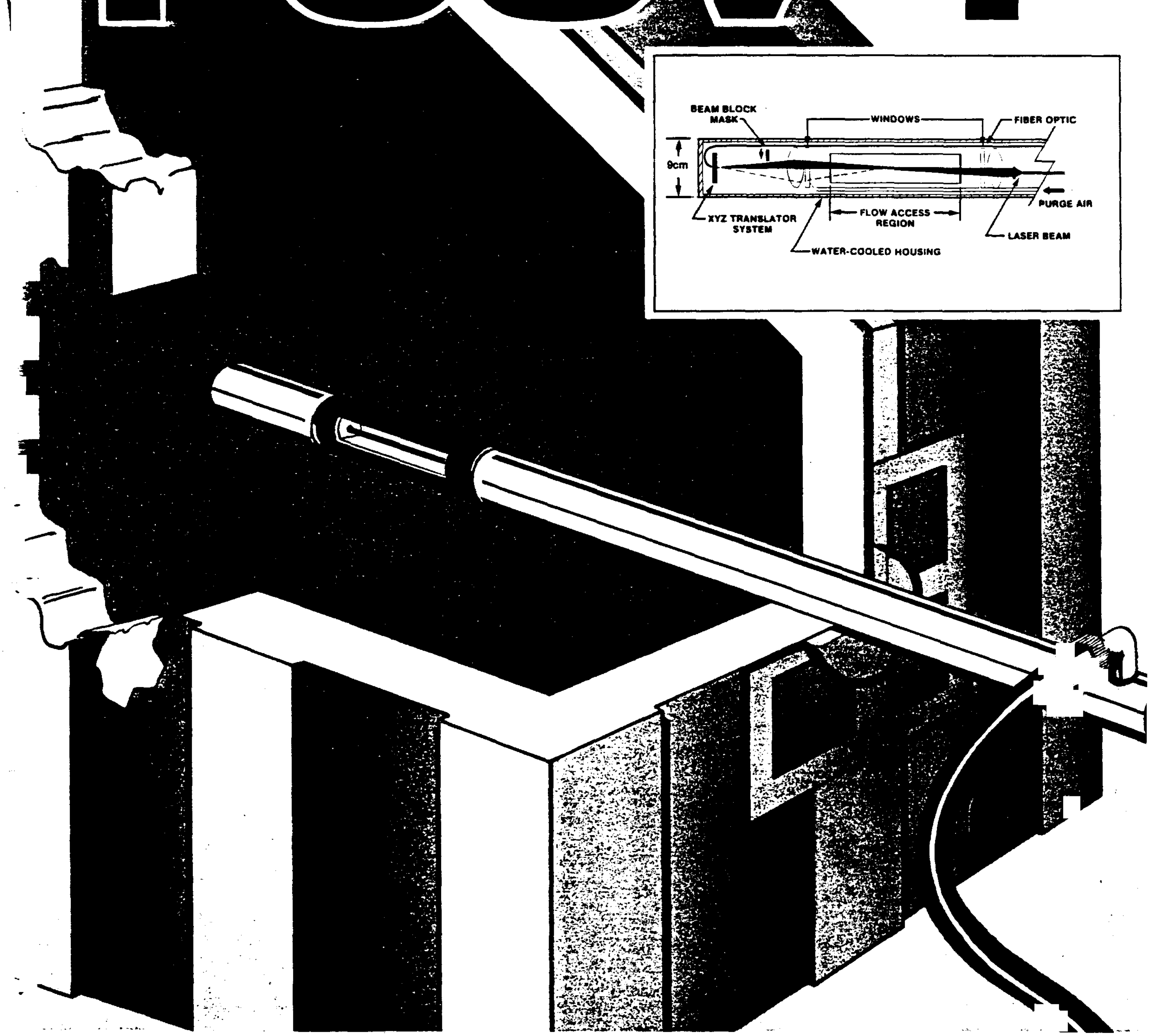

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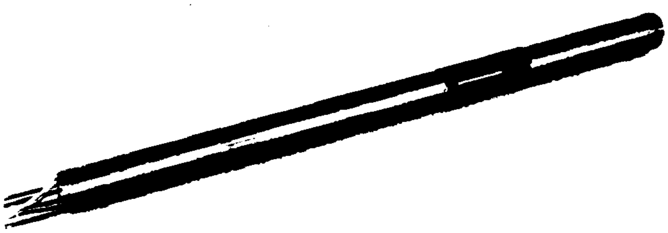
FIGURE 1

PCSV-P



In Situ Particle Measurements in Large Scale Applications

Insitec's new PCSV-P provides real time, in situ measurements of absolute particle concentration, size, and velocity in large scale combustors and processing equipment. The PCSV-P provides rapid, on-line measurements of all types of aerosol flows, including powders, liquid sprays, and slurry sprays. The PCSV-P optical system is contained in a rugged, compact, water or gas-cooled probe which can be extended several meters into the processing unit. The probe is designed to operate at temperatures up to 1400° C and at pressures from vacuum to atmospheric. Contact Insitec for high pressure applications.

Built-in, gas-purged windows provide optical access to the flow stream. They are a valuable design feature which minimize both fouling and interference with the process flow. Fiber optic signal transmission provides remote operation and noise immunity in harsh environments. The menu-driven software program permits convenient alignment and control of the optical system from the computer keyboard.

The PCSV-P is designed for measurements in large scale systems: fossil energy combustors, waste processing and incineration facilities, and powder and materials processing applications. In all these applications remote measurement of particle number and mass concentration distributions provides valuable information for process monitoring and control.

SPECIFICATIONS

System Performance

Size Range: General capability from 0.20 to 200 μm. A typical specific configuration is 0.30 - 100 μm.

Concentration: Up to 10^7/cm^3 for submicron range or up to 100 ppm (volume basis) for supermicron range.

Velocity: 0.1 - 400 m/sec.

Particle type: Solid, liquid, composite, volatile or non-volatile.

Working Environment: 0 - 1400° C, vacuum to atmospheric.

Accuracy: Typically ± 10% of indicated size.

Calibration: Factory calibrated with monodispersed polystyrene latex spheres, standard polydispersed aerosols, and Insitec Reference Reticle. No further calibration required.

Particle Pulse Rate: Up to 500 kHz.

Optical System

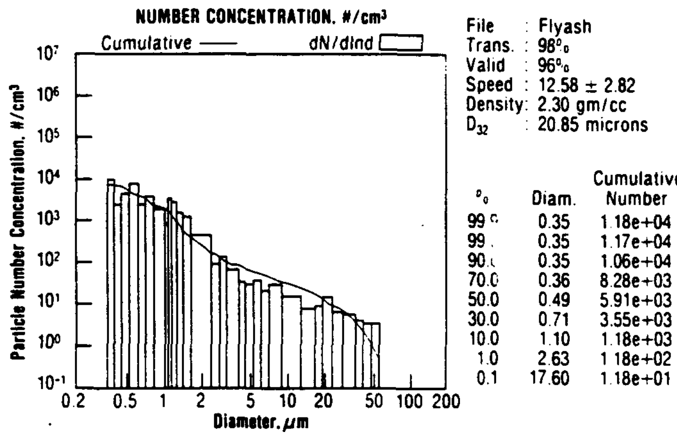
Water or gas-cooled optical probe measures 9cm OD and up to 5 meters in length. Gas-purged window system has 10cm×4cm aerosol flow access region. The 5 mW He-Ne laser beam is split to form two independent beams with typical beam diameters of 200 and 20 μm. Beam diameters are selected to suit user's specific particle size and concentration requirements. Particle measurements are based on the analysis of light scattered by single particles passing through the focused laser beams. Computer-driven, precision stepper motors control optical alignment.

Signal Processor

Input power: 88-258 VAC 47-63 Hz. Contains modules for signal processing, laser and photomultiplier power supplies, fiber optic detector, and IEEE-488 port.

Computation and Display

Menu-driven, color graphics programs for system control and data acquisition, processing, and display. Flexible data formatting. Requires IBM or IBM-compatible computer, 80286 or 80386 CPU, math coprocessor, and color monitor. Software supports hardcopy output on six-pen, color graphics plotter.



Example of Data Display

Instrument configurations are optimized for specific user applications. The above specifications represent the best value for each item. IBM is a registered trademark of the International Business Machines Corporation.

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FIGURE 1

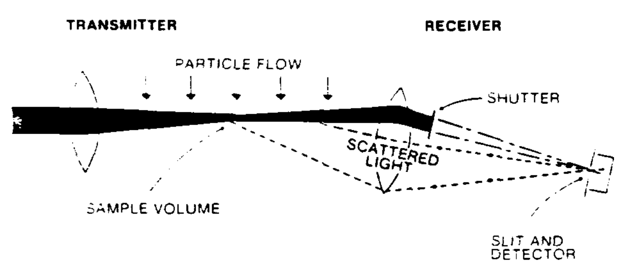
Principle of Operation

PSCV instruments use laser-based, light scattering techniques to make direct, in-line measurements of particles in the flow stream. No sample collection or conditioning is required. The instruments can be applied to systems with the following particle size, concentration and velocity ranges:

size:	0.2 - 200 μm
concentration:	up to 10^7 particles/cm^3 for sub-micron particles up to 100 ppm by volume for super-micron particles
velocity:	0.1 - 400 m/sec

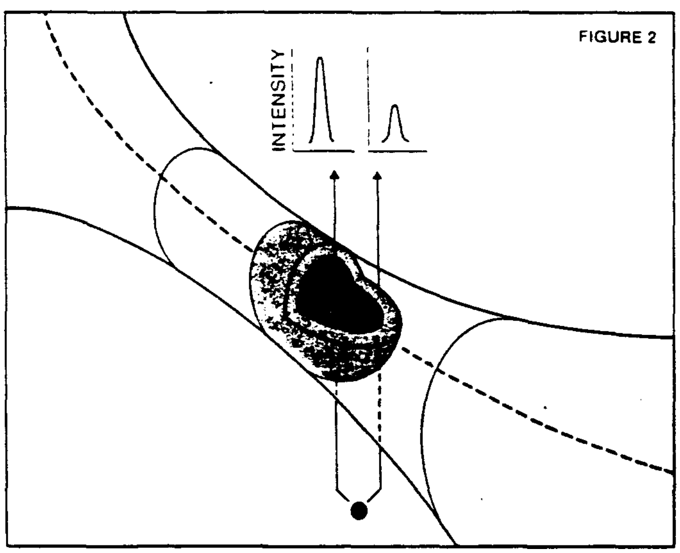
Instruments based on the analysis of scattered light signals can be divided into two groups: ensemble particle counters and single particle counters. Ensemble particle counters, such as transmissometers and ensemble diffraction techniques, measure light scattered from a collection, or ensemble, of particles. Single particle counters, such as laser doppler velocimeters and the PCSV instruments, measure light scattered from individual particles as they pass, one by one, through a focused laser beam. Although it measures the light scattered from individual particles, a complete PCSV measurement is based on information acquired from thousands to millions of particles.

FIGURE 1



Focused laser beam and receiver optics determine sample volume.

FIGURE 2



Scattered light intensity depends on particle trajectory through the sample volume.

Different single particle counting instruments collect different parts of the scattered light signal. PCSV instruments collect light scattered in the "near forward" direction, just a few degrees off axis from the direction of the incident light *(Figure 1)*. The advantage of analyzing near forward scattered light is that its main component is diffracted light. Therefore, the intensity of the scattered light signal is mainly dependent on the particle's cross sectional area; it is nearly independent of the particle's surface characteristics or its shape. This optical arrangement gives PCSV instruments the capability to measure spherical drops as well as irregular particles, such as coal or flyash.

PCSV single particle counting is accomplished by using a single, focused laser beam and a carefully aligned receiver to define a sample volume *(Figure 1)*. Particles may pass anywhere along the length of the laser beam. However, only those particles passing through the sample volume scatter light which is collected by the receiver optics. For each scattered light pulse, the signal processor measures the peak signal intensity, which is related to particle size, and the signal width, which is related to particle speed. Since the laser light intensity varies across the measurement volume, a particle trajectory through the center of the measurement volume results in a much higher signal intensity than does a particle trajectory near the boundary *(Figure 2)*. Therefore, the amplitude of the scattered light signal depends not only on the particle size, but on its trajectory. Also, larger particles experience a larger sample volume than do smaller particles.

PCSV instruments resolve both of these issues (the unknown particle trajectory and the variation in sample volume size) through use of an intensity deconvolution algorithm. The intensity deconvolution algorithm is based on the statistical analysis of a large number of individual events, the scattered light signals from single particles passing through the measurement volume. This analysis has the advantage that no assumptions are required about the shape of the size distribution. Use of the intensity deconvolution algorithm allows the absolute particle concentration, particle size distribution, and particle speed to be obtained directly from the experimental data.

$$C(A) = \int U\, S(Af)\, n(f)\, d\ln f$$

count spectrum of scattered light intensities	particle speed	sample volume intensity	particle number concentration

The intensity deconvolution algorithm provides absolute particle concentrations.

FIGURE 2

PCSV REFERENCES

Principle of Operation

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- ☐ Holve, D. J., Davis, G.W., "Sample Volume and Alignment Analysis for an Optical Particle Counter-Sizer, and Other Applications," *Applied Optics*, 24(7), 998-1005 (1985).
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- ☐ Holve, D. J., Self, S. A., "Optical Measurements of Mean Particle Size in Coal-Fired MHD Flows," *Combustion and Flame*, 37, 211-214 (1980).
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Applications

- ☐ Holve, D. J., Meyer, P. L., Muzio, L. J., and Shiomoto, G. H., "On-Line, In Situ Particle Measurements in a Large Scale Coal-Fired Furnace," The Combustion Institute Western States Meeting, Salt Lake City, UT, 1-21, WSS-88-60, Spring 1988.
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- ☐ Holve, D. J., Fletcher, T. H., Gomi, K., "Comparative Combustion Studies of Ultrafine Coal/Water Slurries and Pulverized Coal," *Combustion Science and Technology*, 52, 269-291 (1987).
- ☐ Holve, D. J., Meyer, P. L., "Coal-Water Slurries: Fuel Preparation Effects on Atomization and Combustion," *Combustion Science and Technology*, 52, 243-268 (1987).
- ☐ Dunn-Rankin, D., Hoornstra, J., Holve, D. J., "In Situ Non-Doppler Laser Anemometer Particle Sizer Applied in Heterogeneous Combustion," Proceedings of the Third International Symposium on Applications of Laser Anemometry to Fluid Mechanics, Lisbon, Portugal, July 7-9, 1986.
- ☐ Holve, D. J., "In Situ Measurements of Flyash Formation From Pulverized Coal," *Combustion Science and Technology*, 44, 269-288 (1986).

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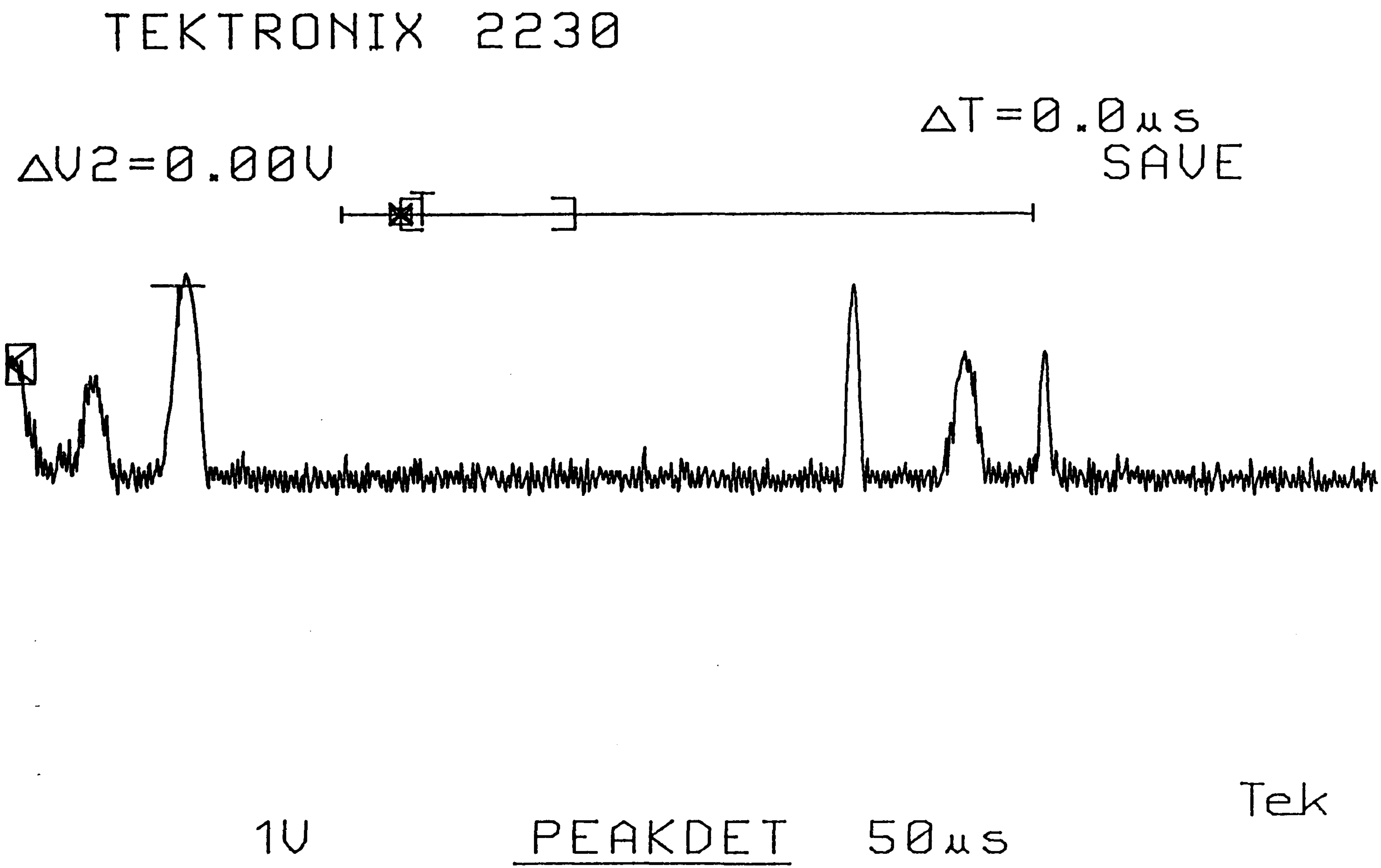


Figure 3. Oscilloscope trace of logarithmic amplitude spectrum for dilute conditions.

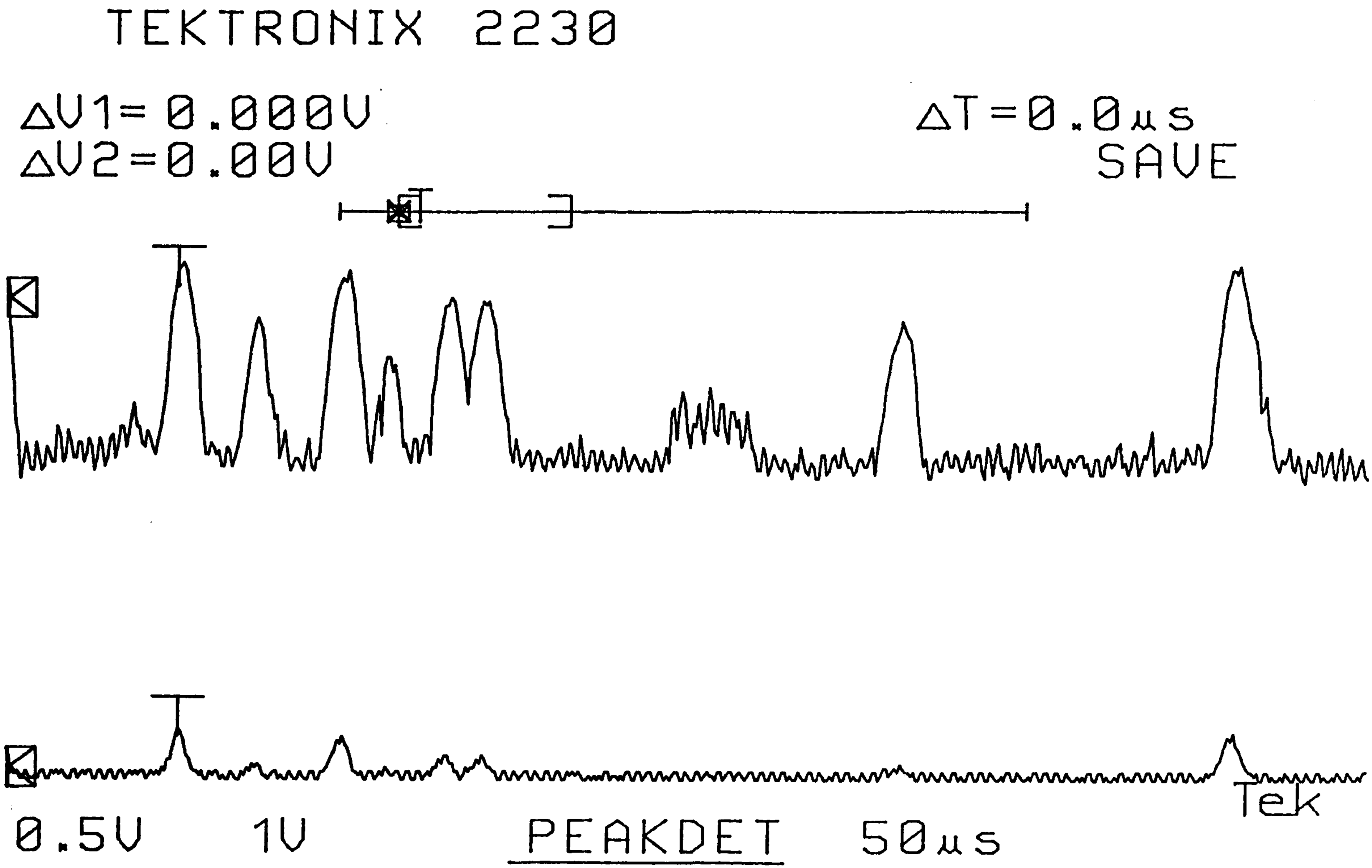


Figure 4. Linear and logarithmic oscilloscope traces of amplitude spectra for dilute conditions.

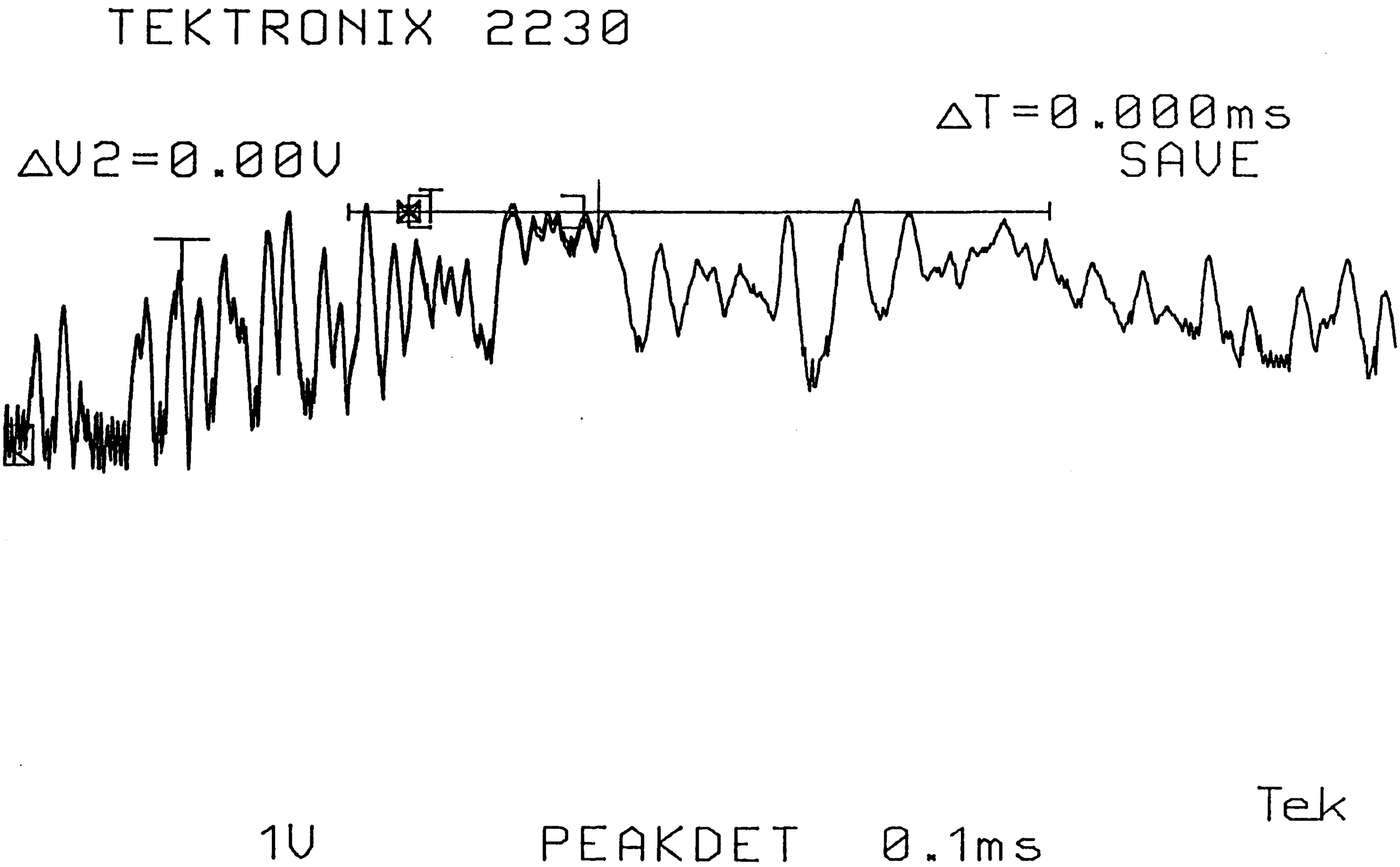


Figure 5. Oscilloscope trace of logarithmic amplitude spectrum for HF.

Figure 6   Response Function for transparent small particles.

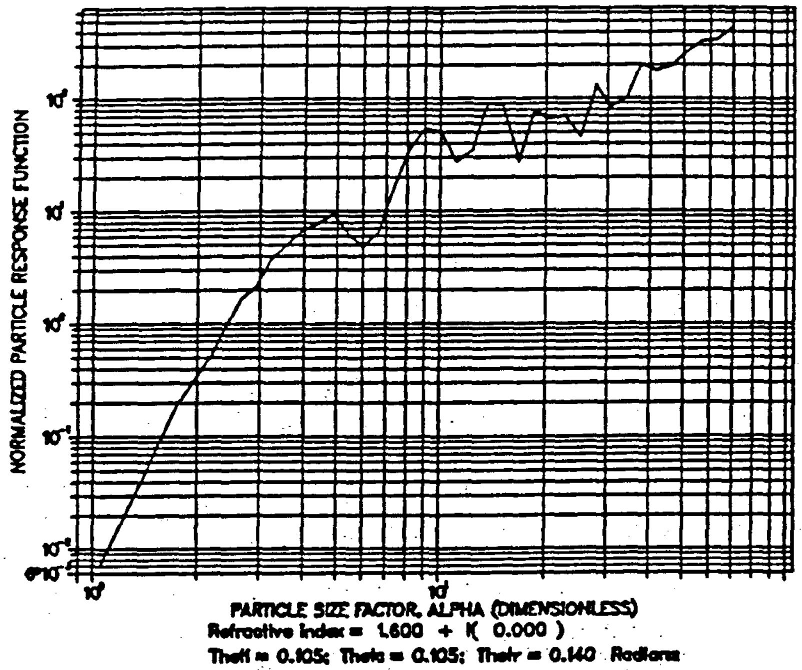
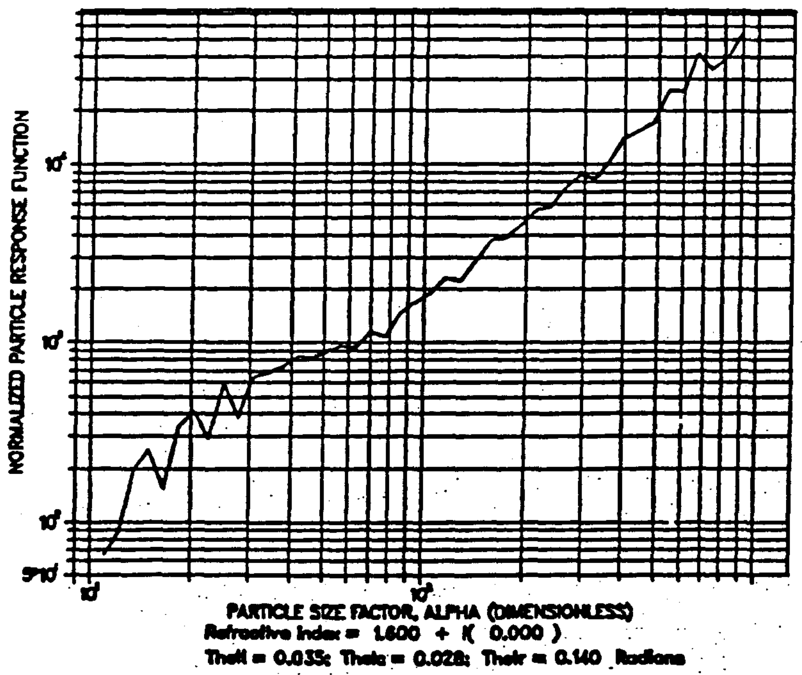
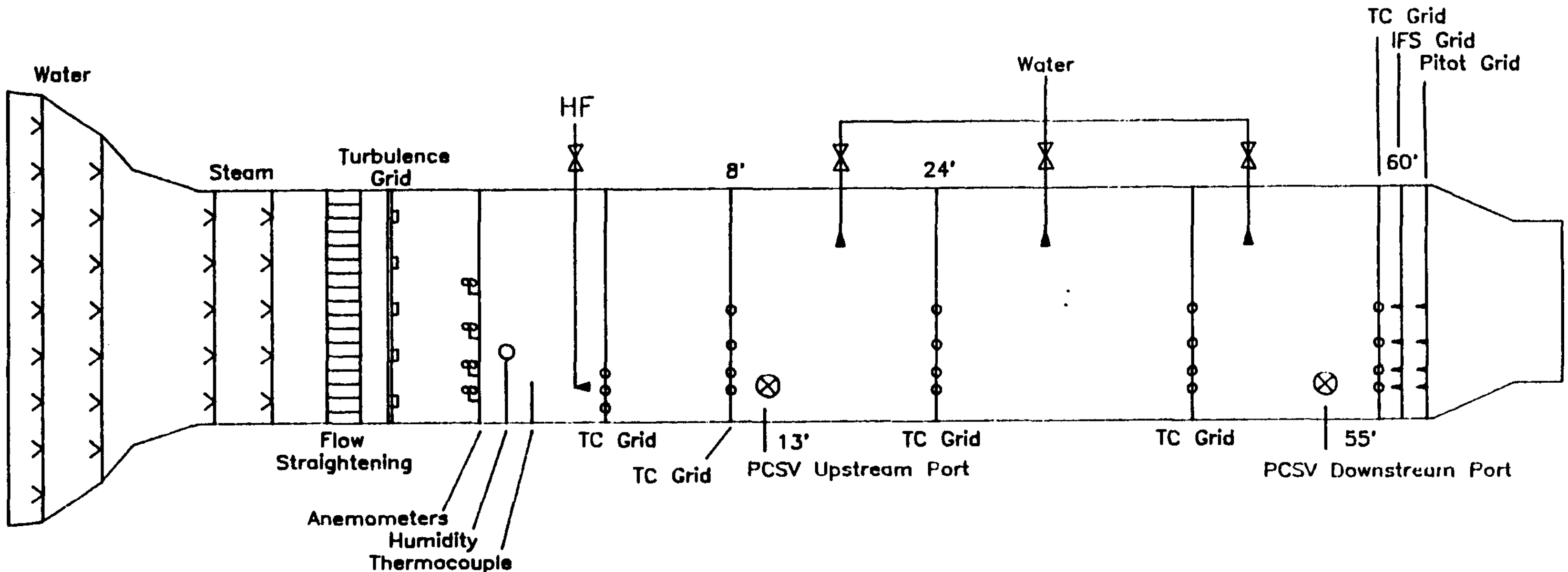


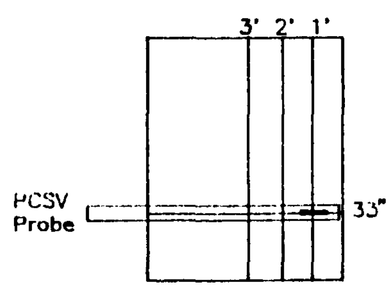
Figure 7   Response Function for transparent large particles.



INSITEC PCSV Probe Locations

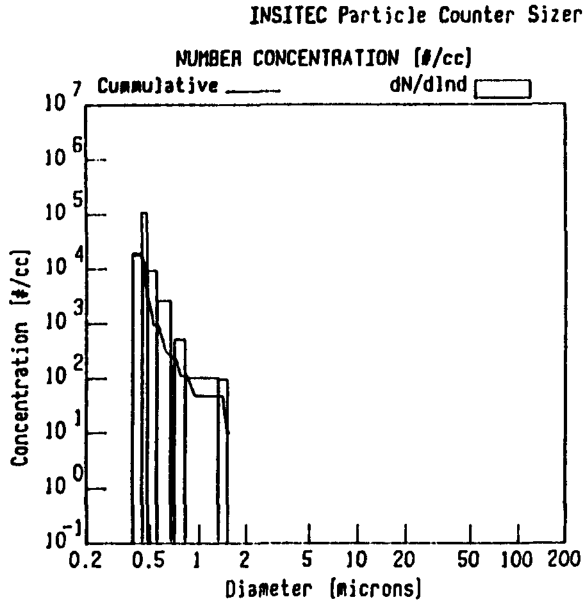


SIDE VIEW



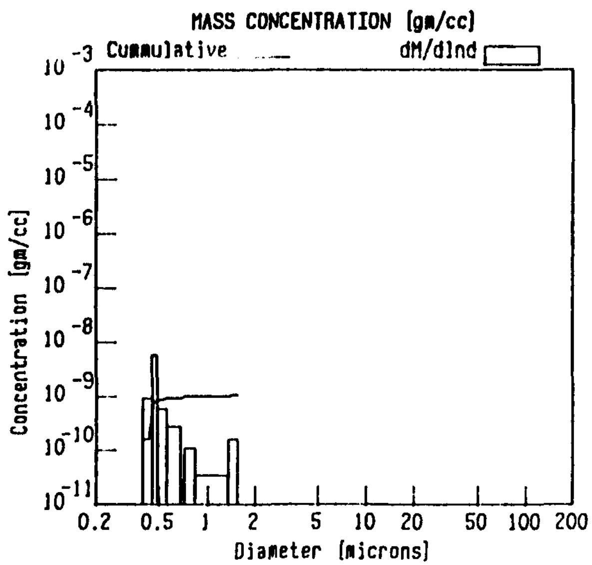
END VIEW

FIGURE 8



File : NTS42A.DAT
Date : 31-Aug-88
Time : 17:32:13
Trans. : 101 %
Valid : 48 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.50 microns

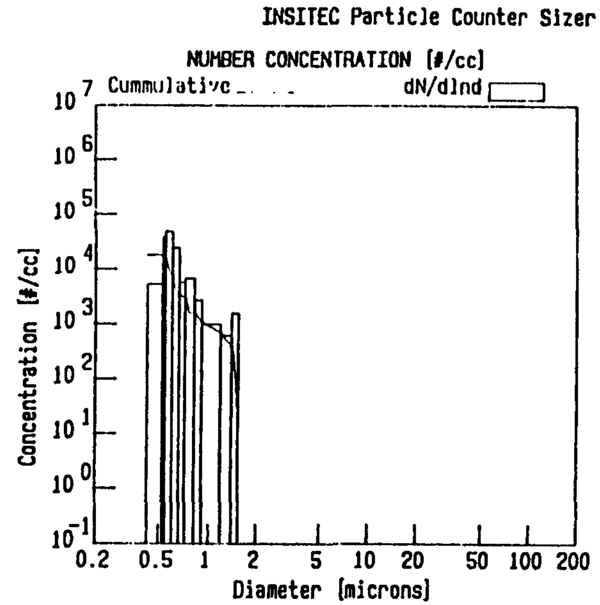
%	Diam	Cum Numb
99.9	0.43	1.81e+04
99.0	0.43	1.79e+04
90.0	0.44	1.63e+04
70.0	0.45	1.27e+04
50.0	0.45	9.06e+03
30.0	0.46	5.44e+03
10.0	0.49	1.81e+03
1.0	0.71	1.81e+02
0.1	1.48	1.81e+01



File : NTS42A.DAT
Date : 31-Aug-88
Time : 17:32:13
Trans. : 101 %
Valid : 48 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.50 microns

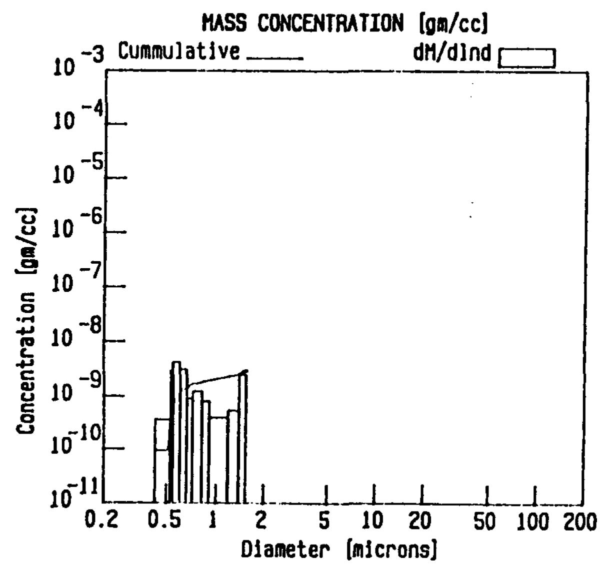
%	Diam	Cum Mass
99.9	1.58	1.08e-09
99.0	1.56	1.07e-09
90.0	0.72	9.73e-10
70.0	0.47	7.56e-10
50.0	0.45	5.40e-10
30.0	0.45	3.24e-10
10.0	0.44	1.08e-10
1.0	0.43	1.08e-11
0.1	0.43	1.08e-12

Figure 9. Size Distributions at Plume Edge (approximately 2' from center) and 10' downstream r ase if .



File : NTS42D.DAT
Date : 31-Aug-88
Time : 17:41:19
Trans. : 110 %
Valid : 60 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.74 microns

%	Diam	Cum Numb
99.9	0.49	1.89e+04
99.0	0.49	1.87e+04
90.0	0.50	1.70e+04
70.0	0.52	1.32e+04
50.0	0.54	9.44e+03
30.0	0.60	5.66e+03
10.0	0.71	1.89e+03
1.0	1.43	1.89e+02
0.1	1.55	1.89e+01

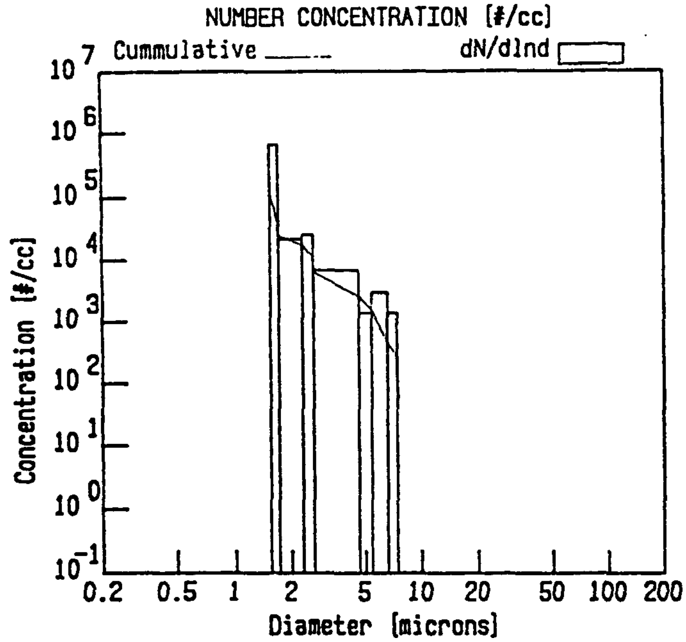


File : NTS42D.DAT
Date : 31-Aug-88
Time : 17:41:19
Trans. : 110 %
Valid : 60 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.74 microns

%	Diam	Cum Mass
99.9	1.56	2.95e-09
99.0	1.55	2.92e-09
90.0	1.43	2.66e-09
70.0	0.92	2.07e-09
50.0	0.66	1.48e-09
30.0	0.56	8.85e-10
10.0	0.52	2.95e-10
1.0	0.49	2.95e-11
0.1	0.49	2.95e-12

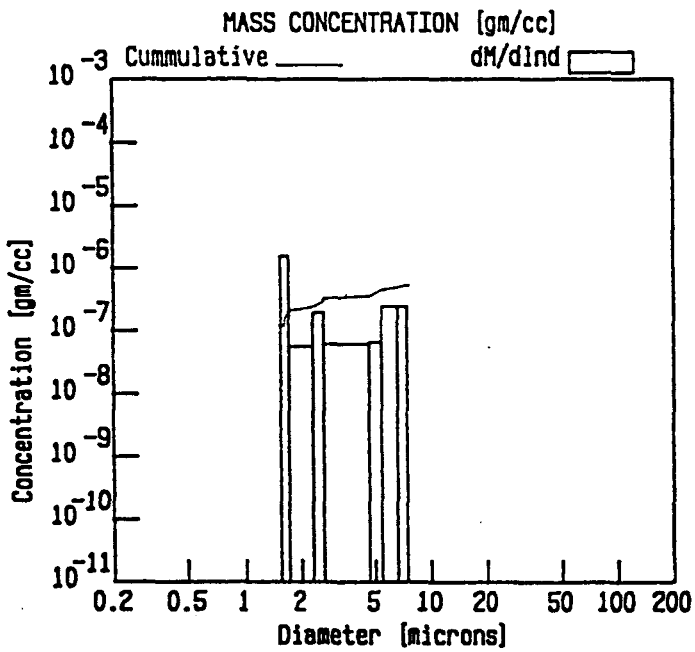
Figure 10. Size Distributions at Plume Center and 10' downstream from release orifice.

INSITEC Particle Counter Sizer Velocimeter



File : NTS51A.DAT
Date : 08-Sep-88
Time : 15:14:53
Trans. : 25 %
Valid : 70 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 2.54 microns

%	Diam	Cum Numb
99.9	1.57	1.11e+05
99.0	1.57	1.10e+05
90.0	1.57	1.00e+05
70.0	1.57	7.81e+04
50.0	1.60	5.58e+04
30.0	1.64	3.35e+04
10.0	2.54	1.12e+04
1.0	4.68	1.12e+03
0.1	7.16	1.12e+02

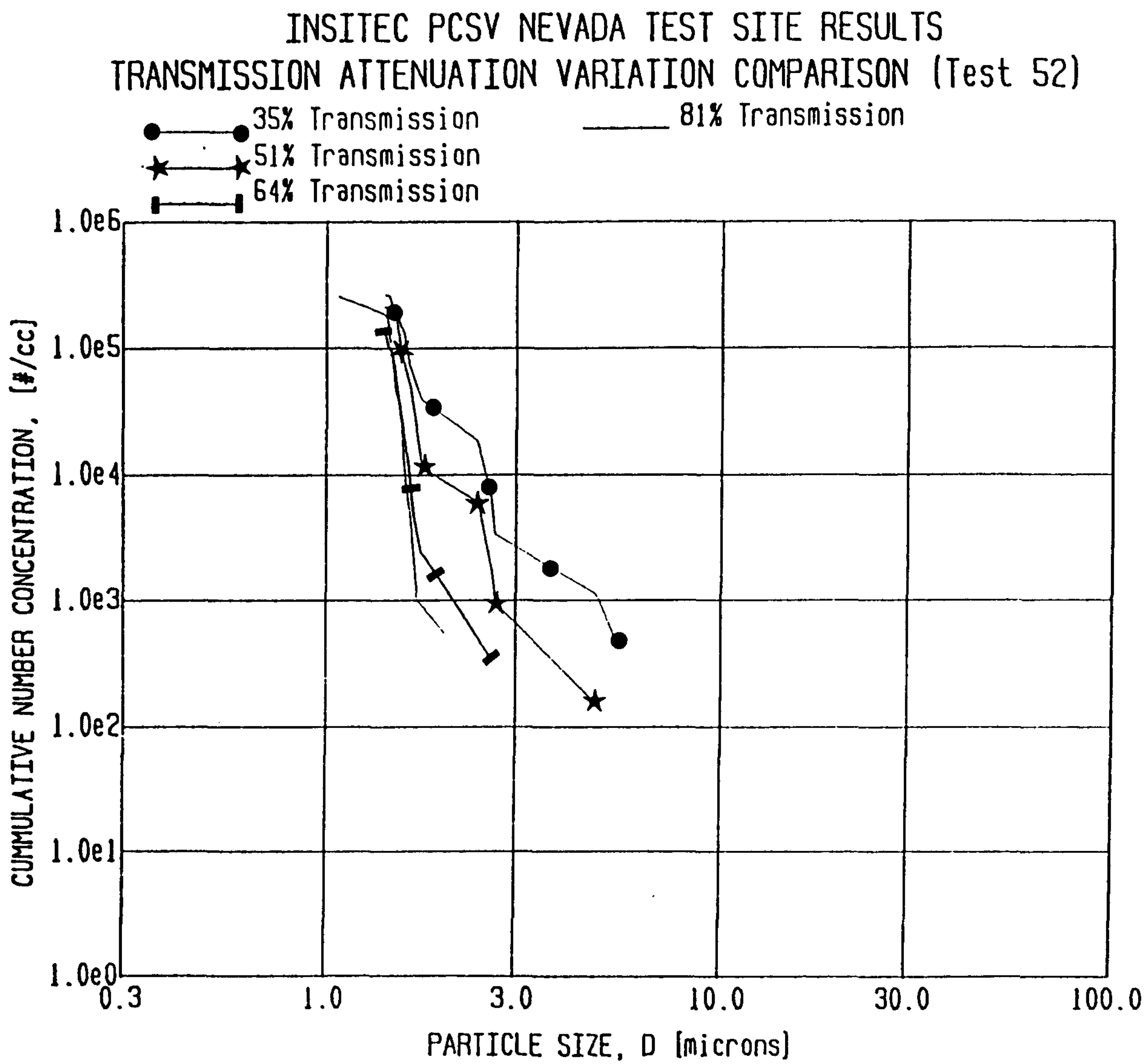


File : NTS51A.DAT
Date : 08-Sep-88
Time : 15:14:53
Trans. : 25 %
Valid : 70 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 2.54 microns

%	Diam	Cum Mass
99.9	7.41	5.50e-07
99.0	7.32	5.45e-07
90.0	6.65	4.96e-07
70.0	4.62	3.86e-07
50.0	2.48	2.75e-07
30.0	1.65	1.65e-07
10.0	1.59	5.51e-08
1.0	1.57	5.51e-09
0.1	1.57	5.51e-10

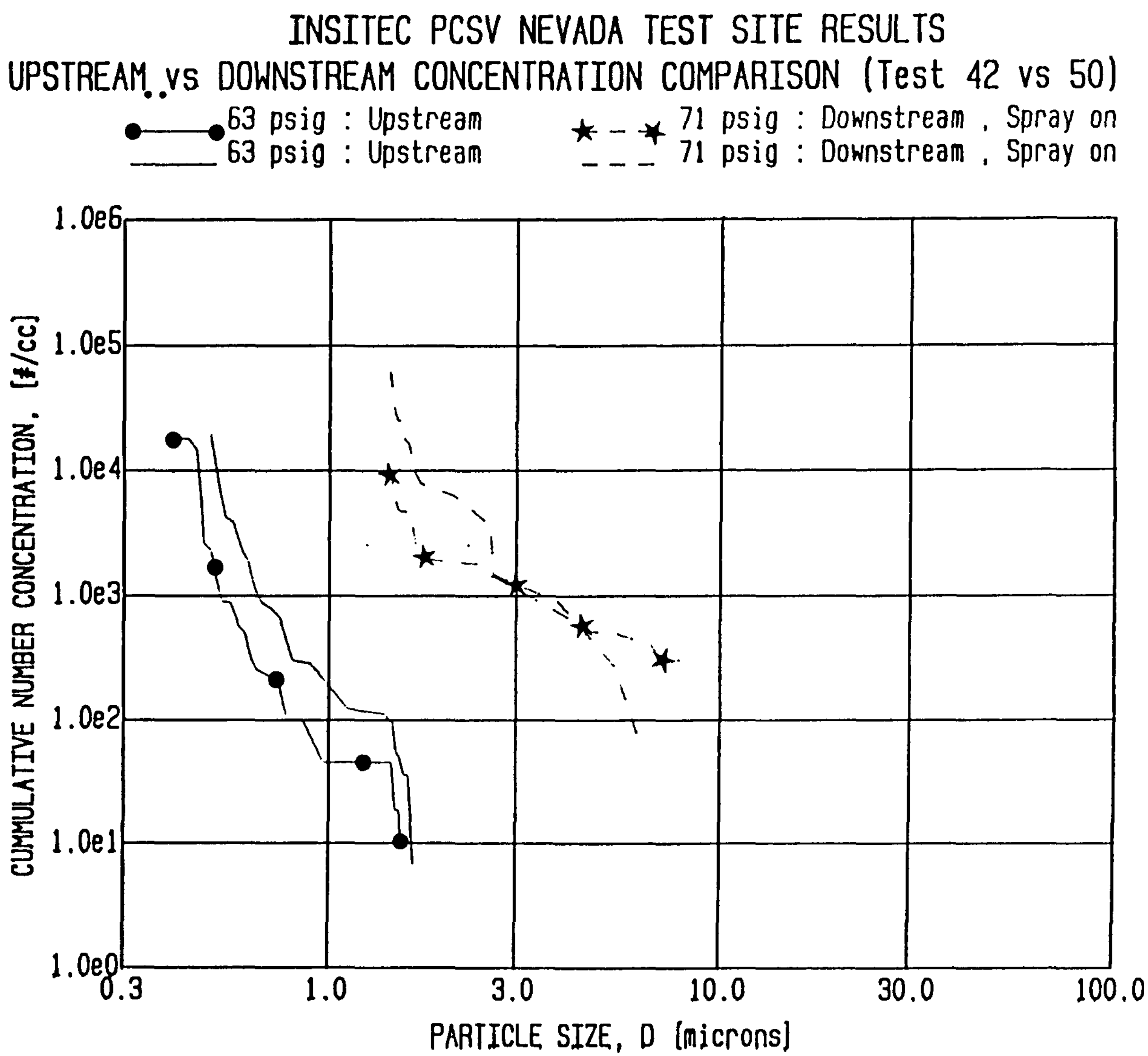
Figure 11. Size Distributions 55 Feet downstream of release orifice.

Figure 12



INSITEC PCSV NEVADA TEST SITE RESULTS
TRANSMISSION ATTENUATION VARIATION COMPARISON (Test 52)
35% Transmission
51% Transmission
64% Transmission
81% Transmission
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

Figure 13



INSITEC PCSV NEVADA TEST SITE RESULTS
UPSTREAM vs DOWNSTREAM CONCENTRATION COMPARISON (Test 42 vs 50)
63 psig : Upstream
63 psig : Upstream
71 psig : Downstream , Spray on
71 psig : Downstream , Spray on
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

Figure 14

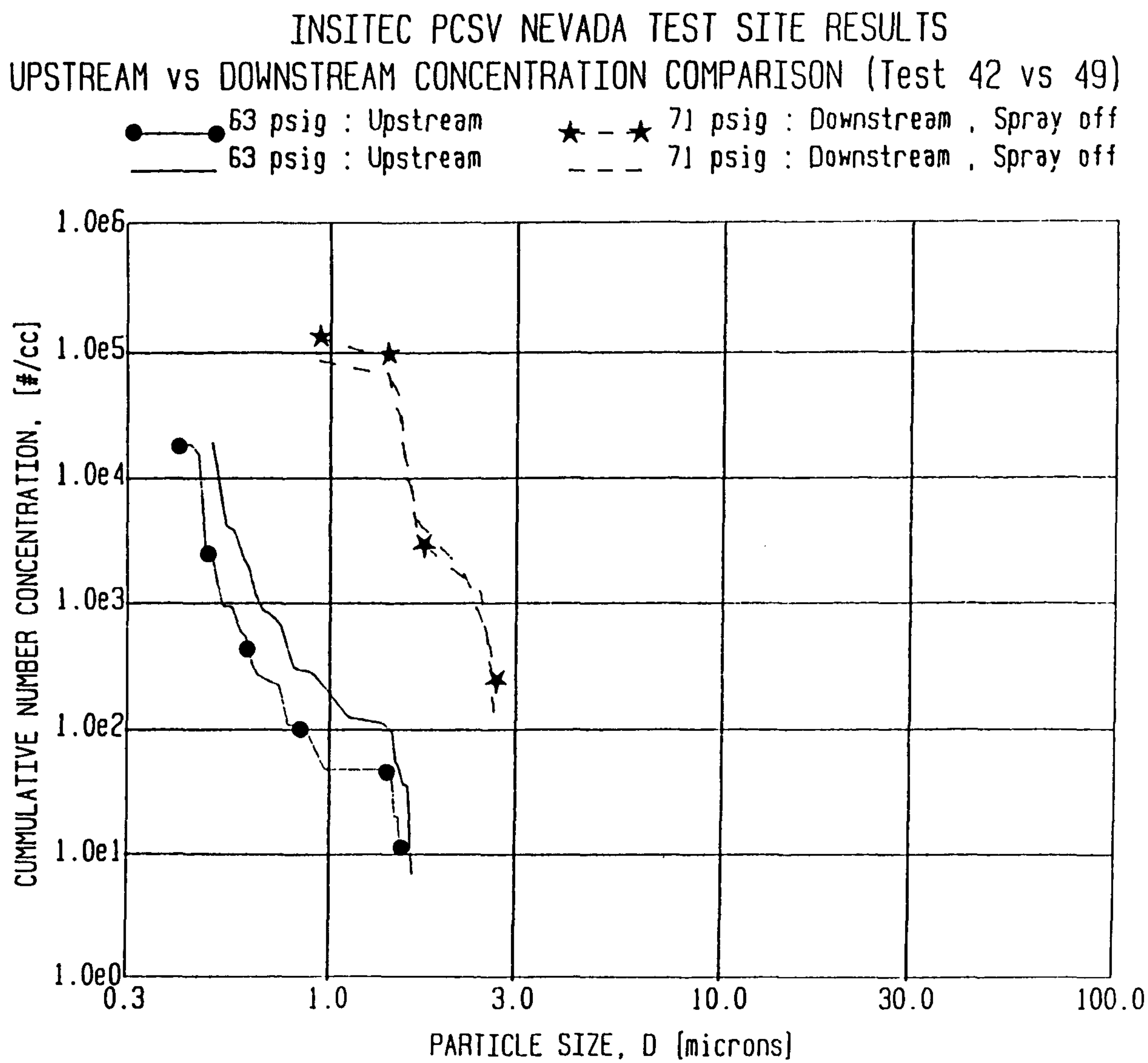
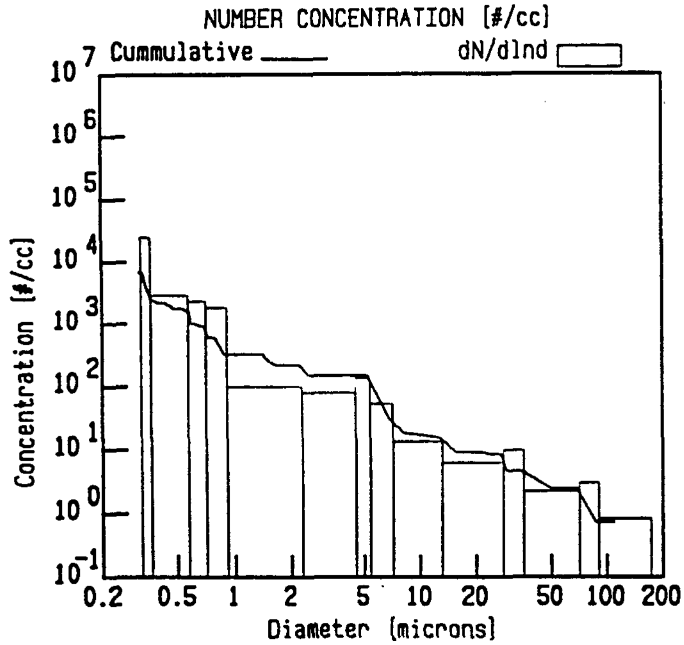

INSITEC PCSV NEVADA TEST SITE RESULTS
UPSTREAM vs DOWNSTREAM CONCENTRATION COMPARISON (Test 42 vs 49)
63 psig : Upstream
63 psig : Upstream
71 psig : Downstream , Spray off
71 psig : Downstream , Spray off
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

Figure 15

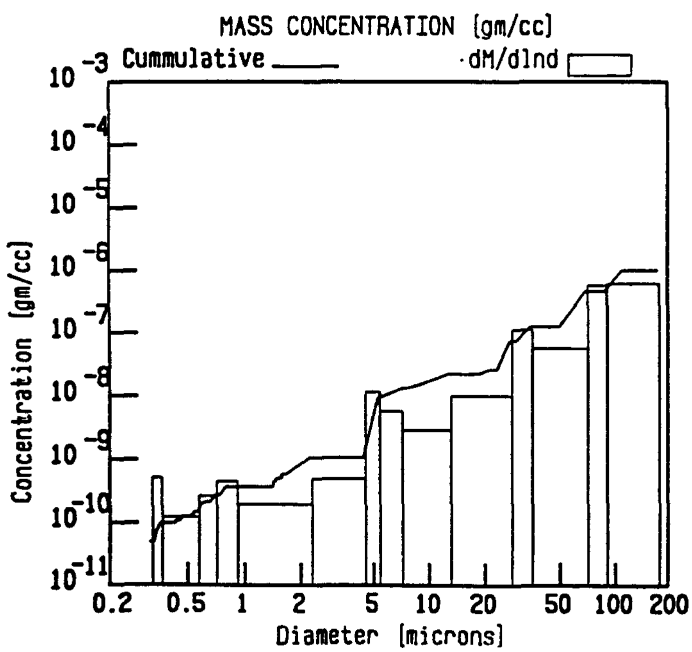
INSITEC Particle Counter Sizer Velocimeter

Water spray only, downstream



File : NTS43WB.DAT
Date : 01-Sep-88
Time : 16:16:40
Trans. : 84 %
Valid : 82 %
Speed : 2.55 ± 0.45
Density: 1.00 gm/cc
D32 : 61.28 microns

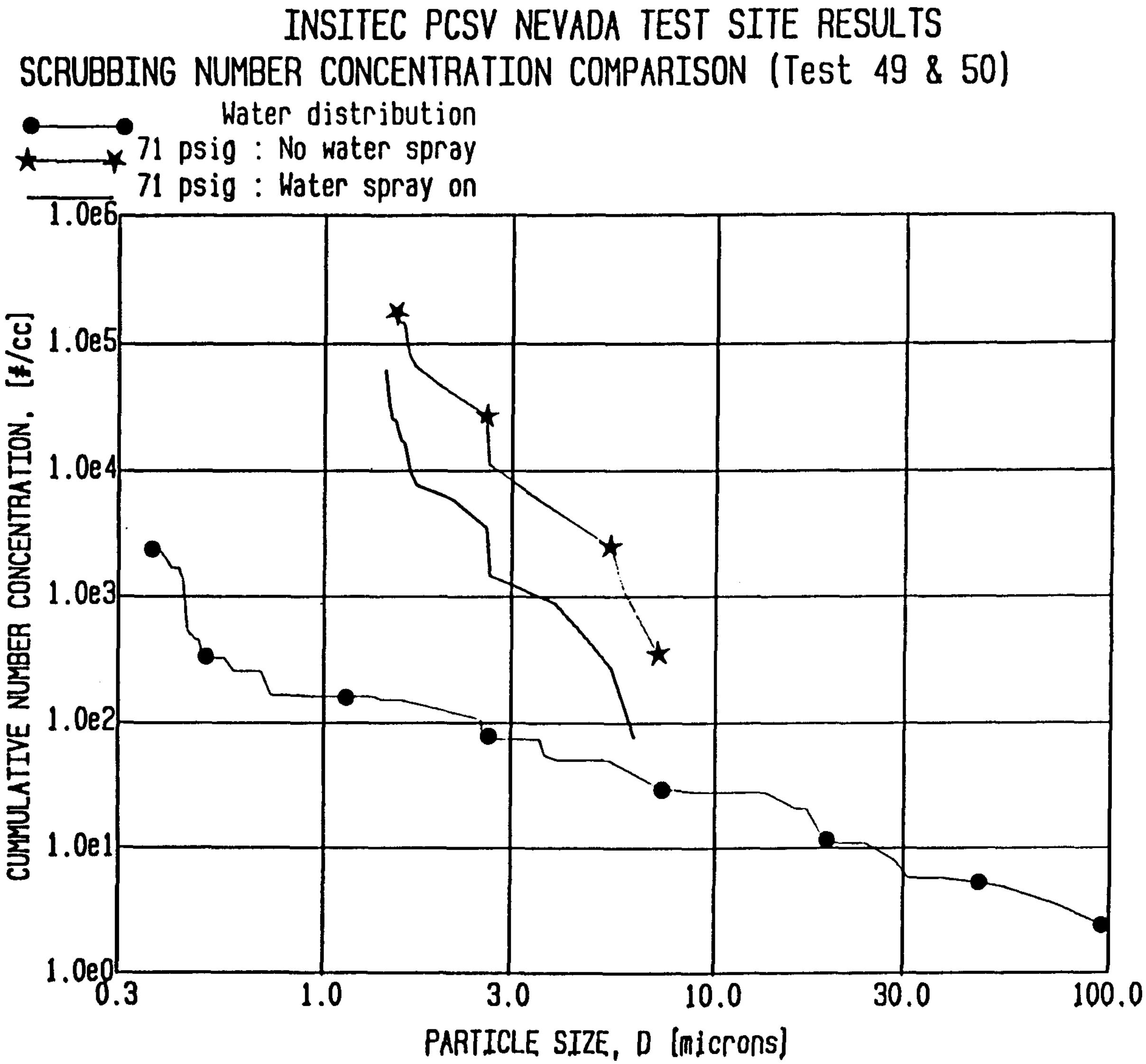
%	Diam	Cum Numb
99.9	0.33	6.57e+03
99.0	0.33	6.51e+03
90.0	0.34	5.92e+03
70.0	0.34	4.60e+03
50.0	0.35	3.29e+03
30.0	0.47	1.97e+03
10.0	0.71	6.57e+02
1.0	4.88	6.57e+01
0.1	26.93	6.57e+00



File : NTS43WB.DAT
Date : 01-Sep-88
Time : 16:16:40
Trans. : 84 %
Valid : 82 %
Speed : 2.55 ± 0.45
Density: 1.00 gm/cc
D32 : 61.28 microns

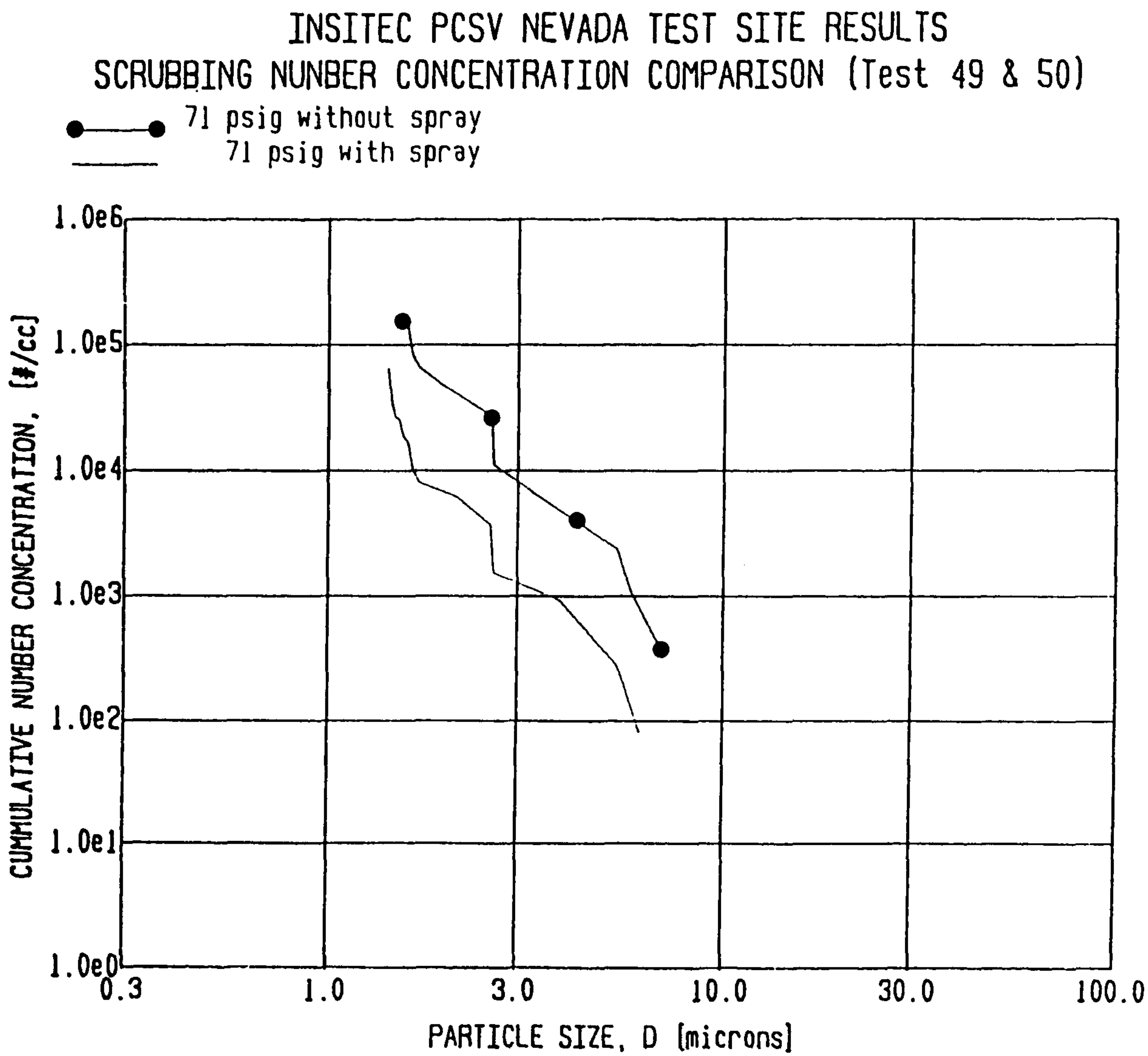
%	Diam	Cum Mass
99.9	112.90	1.03e-06
99.0	112.55	1.02e-06
90.0	109.06	9.27e-07
70.0	101.29	7.21e-07
50.0	93.52	5.15e-07
30.0	62.41	3.09e-07
10.0	33.65	1.03e-07
1.0	5.88	1.03e-08
0.1	2.28	1.03e-09

Figure 16



INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUMBER CONCENTRATION COMPARISON (Test 49 & 50)
Water distribution
71 psig : No water spray
71 psig : Water spray on
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
PARTICLE SIZE, D [microns]

Figure 17



INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUNBER CONCENTRATION COMPARISON (Test 49 & 50)
71 psig without spray
71 psig with spray
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

Figure 18

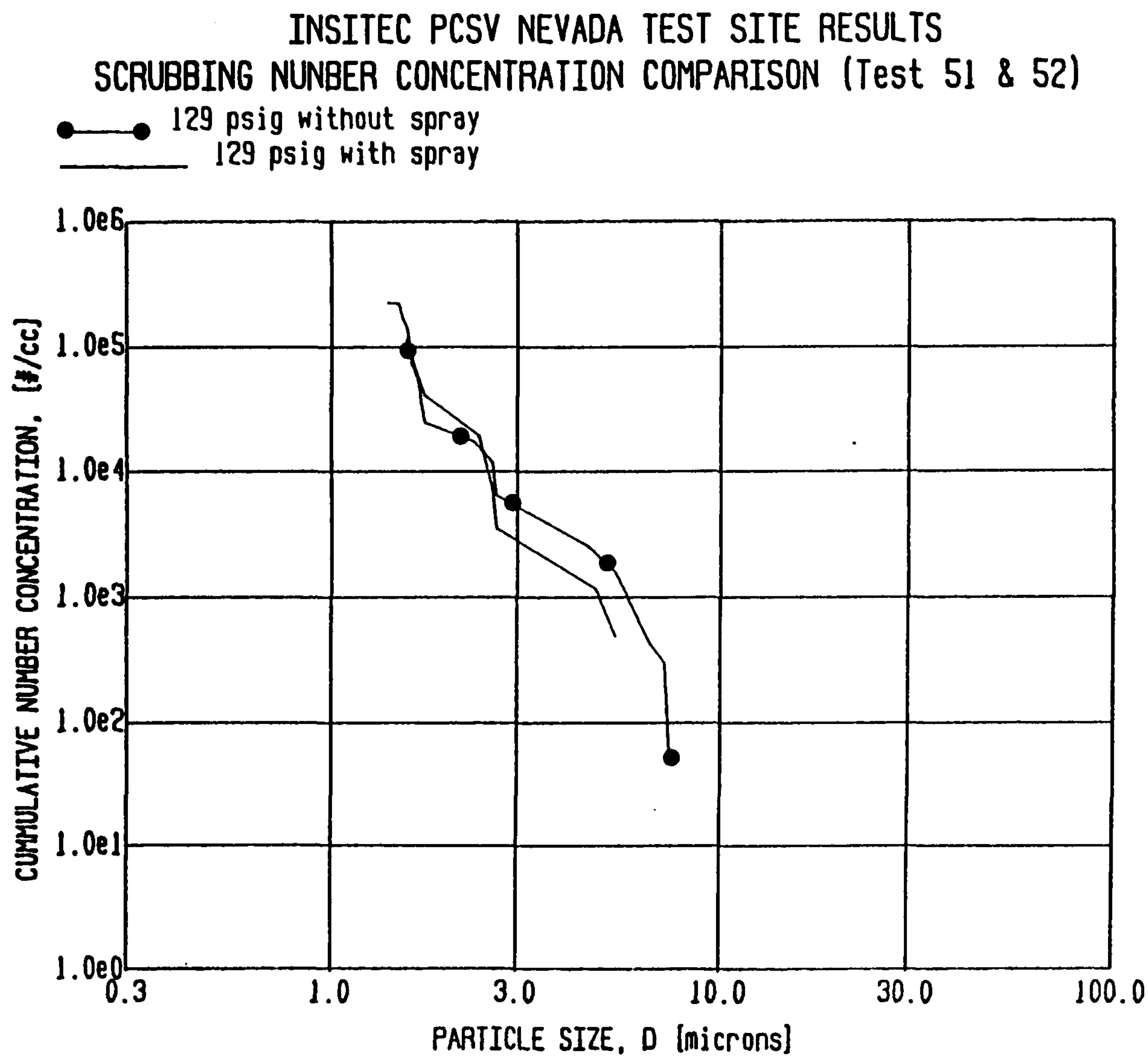
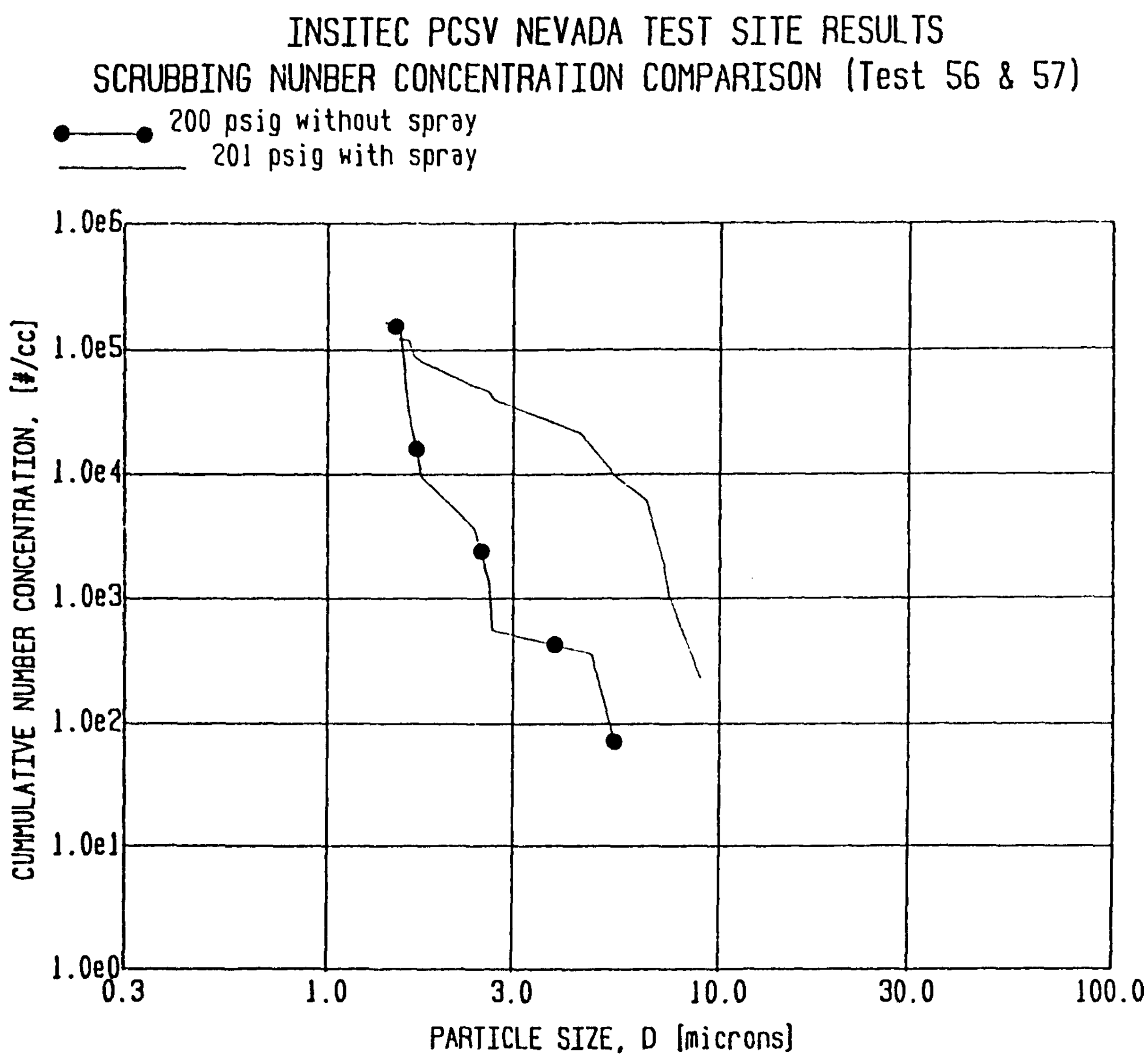

INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUNBER CONCENTRATION COMPARISON (Test 51 & 52)
129 psig without spray
129 psig with spray
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
PARTICLE SIZE, D [microns]

Figure 19



INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUNBER CONCENTRATION COMPARISON (Test 56 & 57)
200 psig without spray
201 psig with spray
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
PARTICLE SIZE, D [microns]

Figure 20

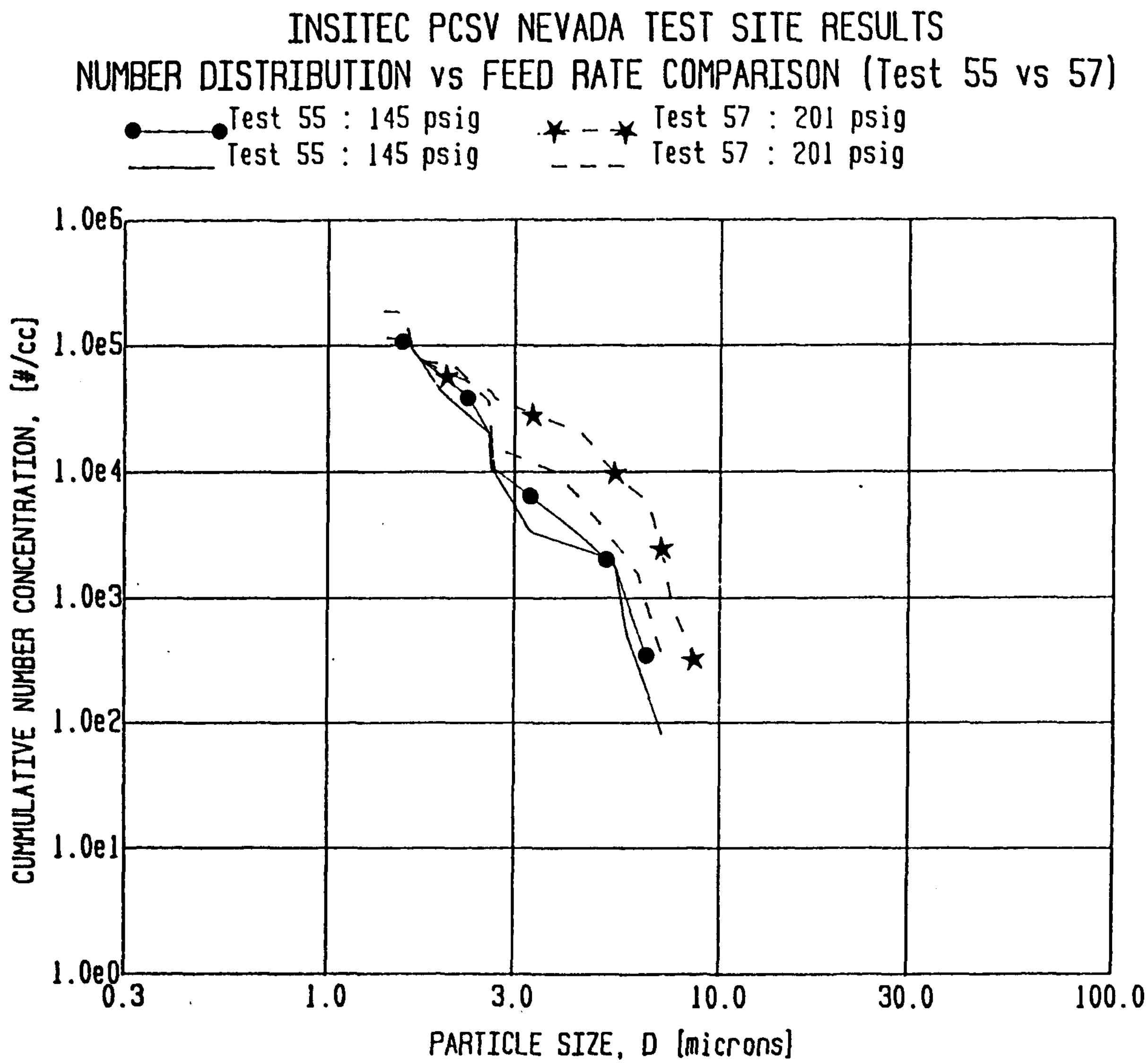

INSITEC PCSV NEVADA TEST SITE RESULTS
NUMBER DISTRIBUTION vs FEED RATE COMPARISON (Test 55 vs 57)
Test 55 : 145 psig
Test 55 : 145 psig
Test 57 : 201 psig
Test 57 : 201 psig
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

Figure 21

INSITEC PCSV NEVADA TEST SITE RESULTS
AUA - HF COMPARISON (Tests 51c & 54e)

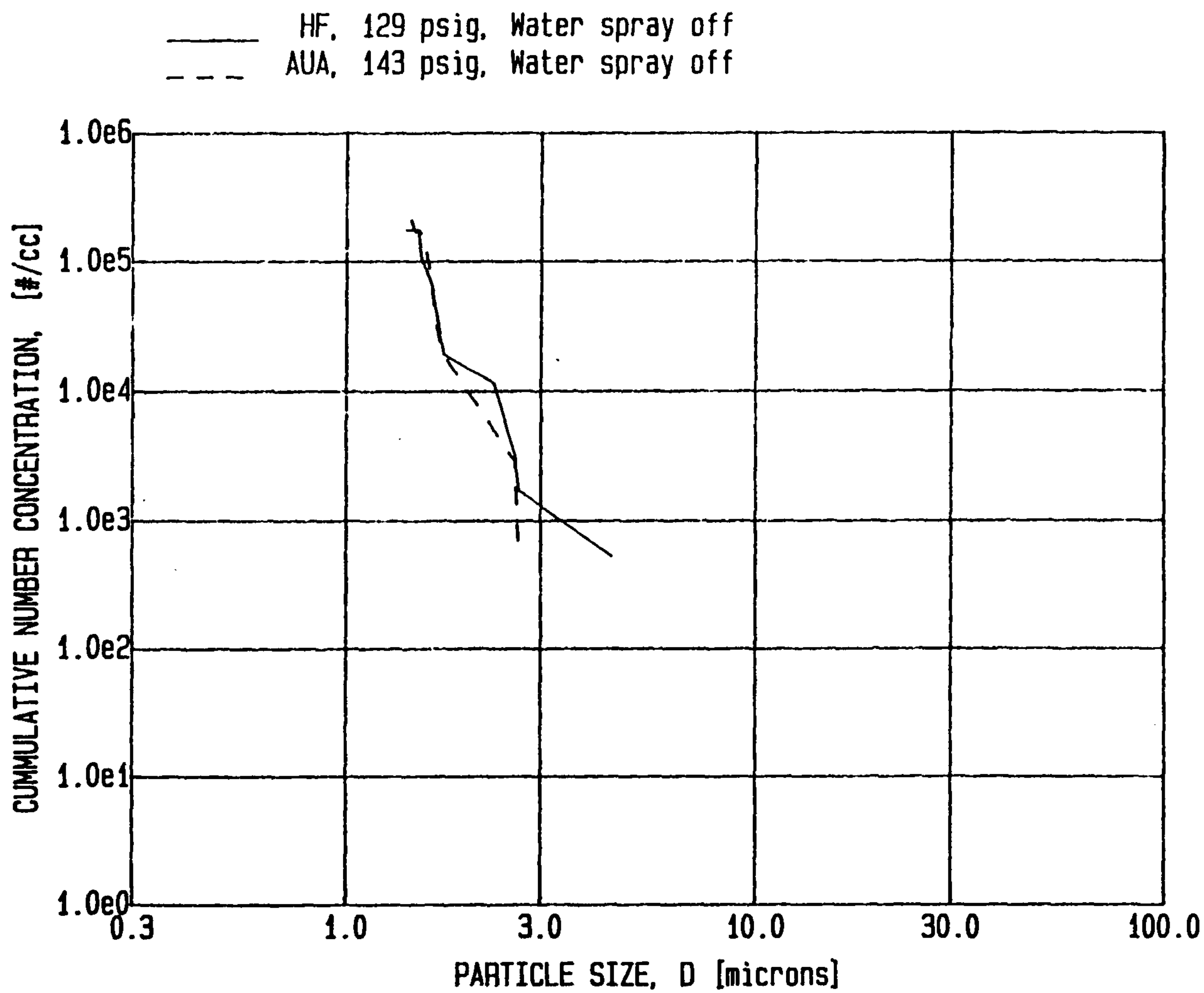


Figure 22

INSITEC PCSV NEVADA TEST SITE RESULTS
AUA - HF COMPARISON (Tests 52j & 55b)

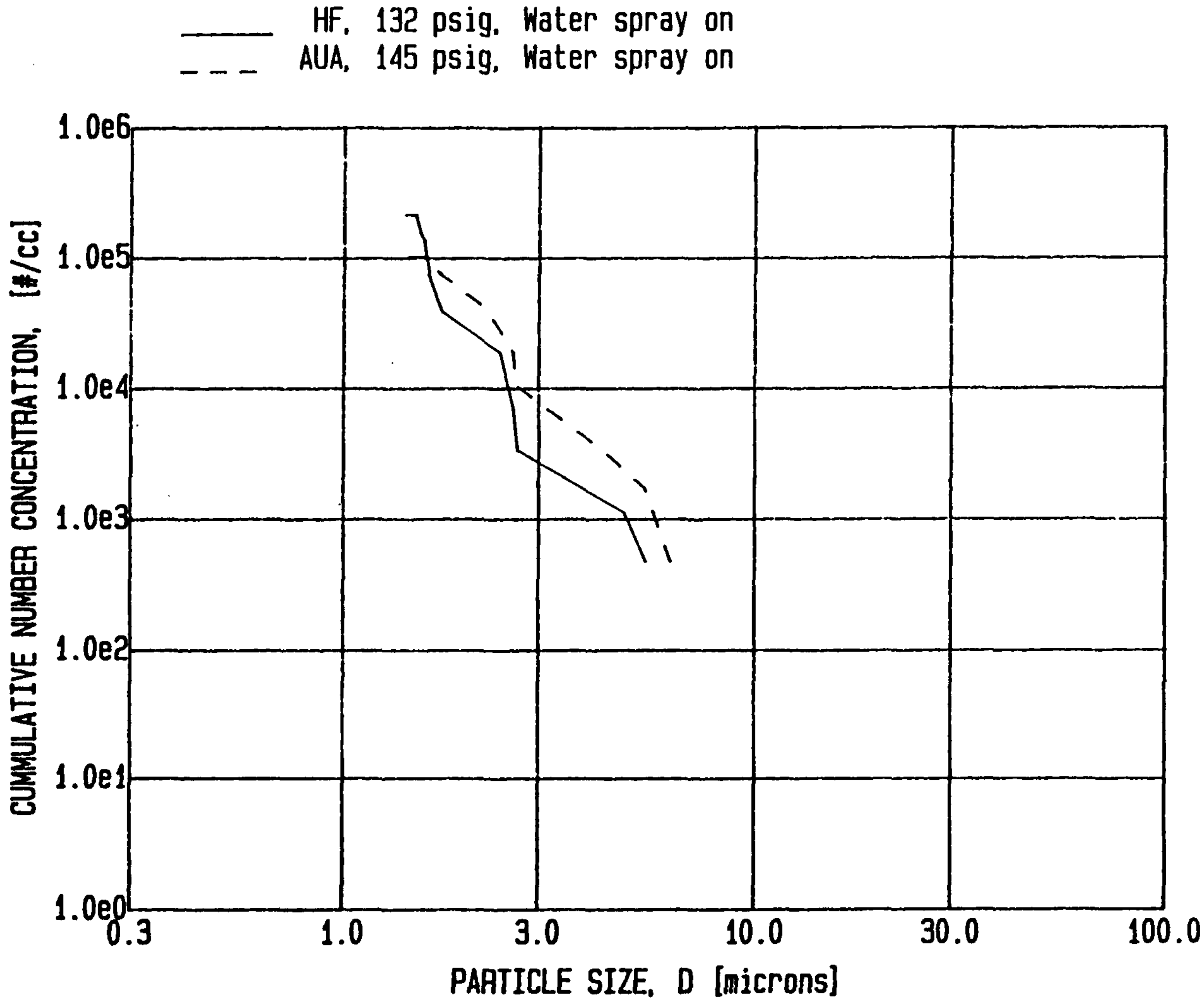
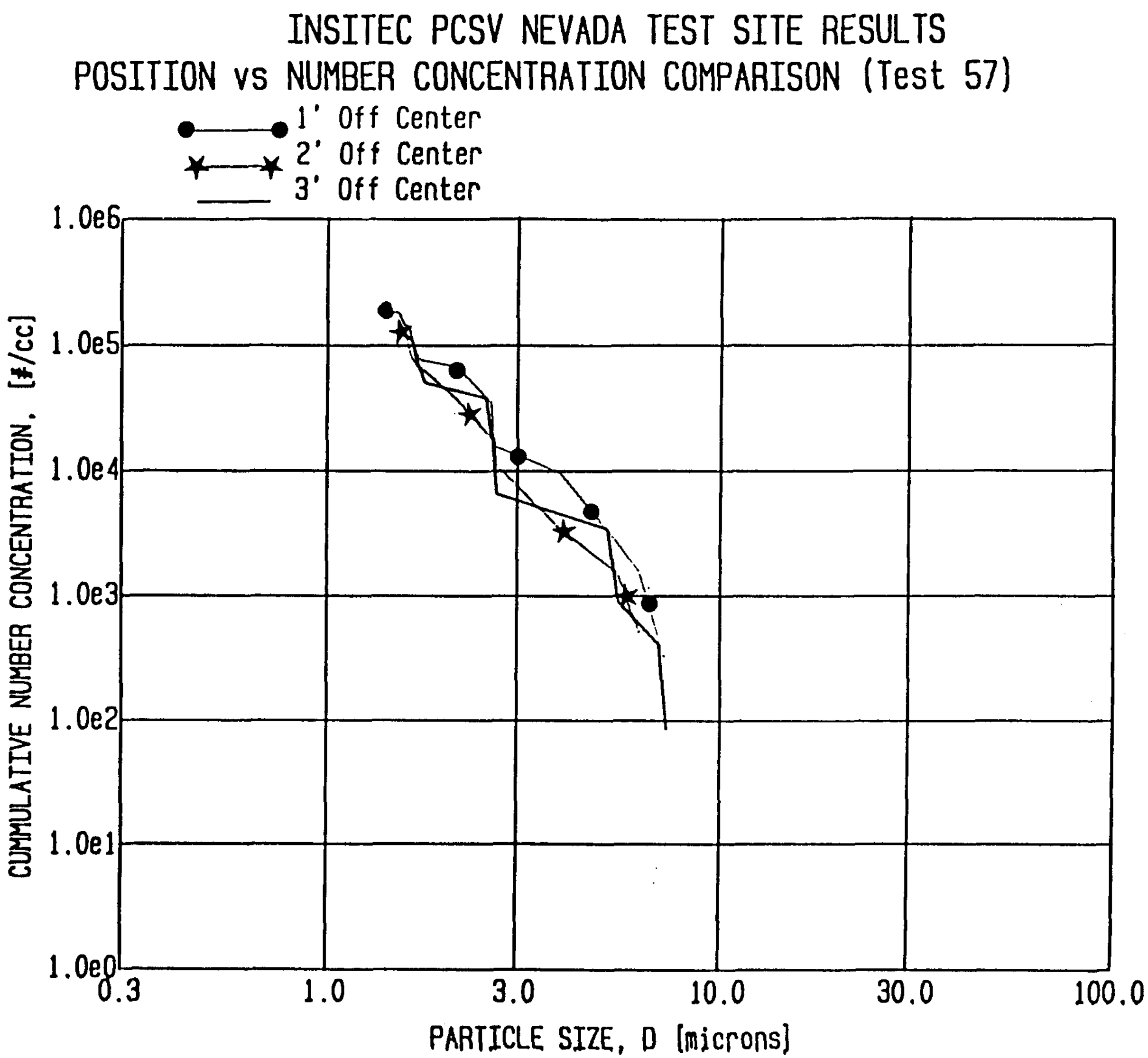


Figure 23



G 37 - G 38

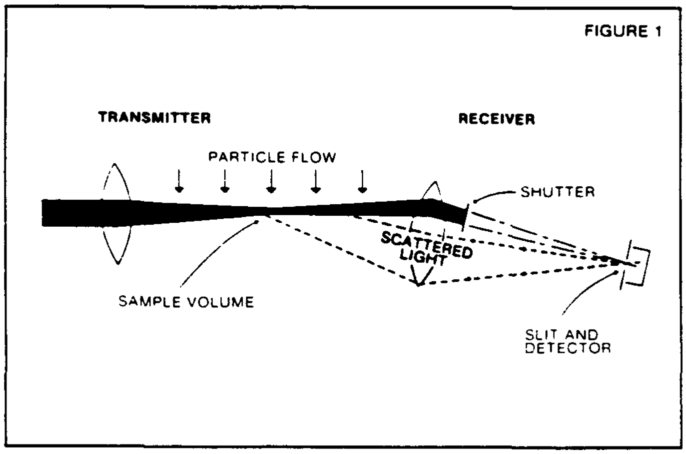
PCSV

Principle of Operation

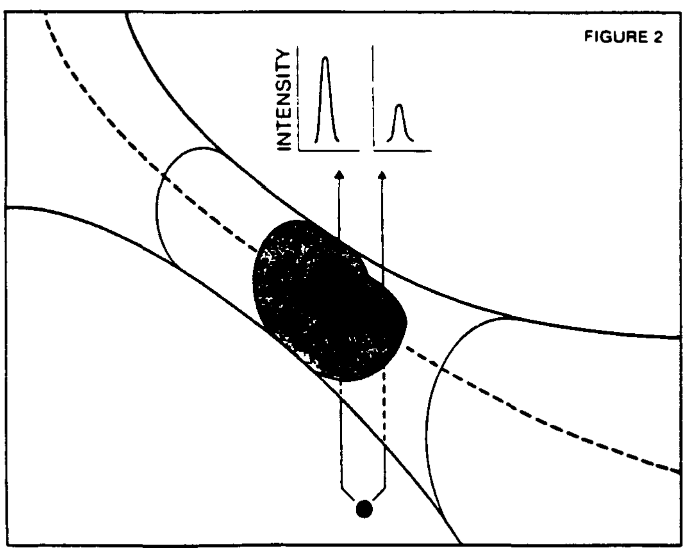
PSCV instruments use laser-based, light scattering techniques to make direct, in-line measurements of particles in the flow stream. No sample collection or conditioning is required. The instruments can be applied to systems with the following particle size, concentration and velocity ranges:

size:	0.2 - 200 μm
concentration:	up to 10^7 particles/cm^3 for sub-micron particles up to 100 ppm by volume for super-micron particles
velocity:	0.1 - 400 m/sec

Instruments based on the analysis of scattered light signals can be divided into two groups: ensemble particle counters and single particle counters. Ensemble particle counters, such as transmissometers and ensemble diffraction techniques, measure light scattered from a collection, or ensemble, of particles. Single particle counters, such as laser doppler velocimeters and the PCSV instruments, measure light scattered from individual particles as they pass, one by one, through a focused laser beam. Although it measures the light scattered from individual particles, a complete PCSV measurement is based on information acquired from thousands to millions of particles.



Focused laser beam and receiver optics determine sample volume.



Scattered light intensity depends on particle trajectory through the sample volume.

Different single particle counting instruments collect different parts of the scattered light signal. PCSV instruments collect light scattered in the "near forward" direction, just a few degrees off axis from the direction of the incident light *(Figure 1)*. The advantage of analyzing near forward scattered light is that its main component is diffracted light. Therefore, the intensity of the scattered light signal is mainly dependent on the particle's cross *sectional area; it is nearly independent of the particle's* surface characteristics or its shape. This optical arrangement gives PCSV instruments the capability to measure spherical drops as well as irregular particles, such as coal or flyash.

PCSV single particle counting is accomplished by using a single, focused laser beam and a carefully aligned receiver to define a sample volume *(Figure 1)*. Particles may pass anywhere along the length of the laser beam. However, only those particles passing through the sample volume scatter light which is collected by the receiver optics. For each scattered light pulse, the signal processor measures the peak signal intensity, which is related to particle size, and the signal width, which is related to particle speed. Since the laser light intensity varies across the measurement volume, a particle trajectory through the center of the measurement volume results in a much higher signal intensity than does a particle trajectory near the boundary *(Figure 2)*. Therefore, the amplitude of the scattered light signal depends not only on the particle size, but on its trajectory. Also, larger particles experience a larger sample volume than do smaller particles.

PCSV instruments resolve both of these issues (the unknown particle trajectory and the variation in sample volume size) through use of an intensity deconvolution algorithm. The intensity deconvolution algorithm is based on the statistical analysis of a large number of individual events, the scattered light signals from single particles passing through the measurement volume. This analysis has the advantage that no assumptions are required about the shape of the size distribution. Use of the intensity deconvolution algorithm allows the absolute particle concentration, particle size distribution, and particle speed to be obtained directly from the experimental data.

$$C(A) = \int U\, S(Af)\, n(f)\, d\ln f$$

$C(A)$: count spectrum of scattered light intensities; U: particle speed; $S(Af)$: sample volume intensity; $n(f)$: particle number concentration

The intensity deconvolution algorithm provides absolute particle concentrations.

PCSV REFERENCES

Principle of Operation

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- Holve, D. J., "In Situ Measurements of Flyash Formation From Pulverized Coal," *Combustion Science and Technology*, 44, 269-288 (1986).

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PCSV APPLICATIONS

In addition to having in-situ, in-line measurement features, the PCSV technique is unique in incorporating all the following capabilities:

* Measurement of all particle types
* Submicron to 200 micron size range
* Bench-top to large scale systems with remote operation
* High Velocity, Temperature, and Pressure

The combination of all these features has been the primary challenge for developing an application-oriented particle measurement system.

Examples of research and industrial applications include the following:

* "Clean" high temperature gases for power generation, air pollution diagnosis and control

* High value industrial powders - powdered metals, toners, pharmaceuticals, catalysts

* Harsh, severe environments or materials - hazardous wastes, radioactive or toxic materials

* Large-scale applications - PCSV-P

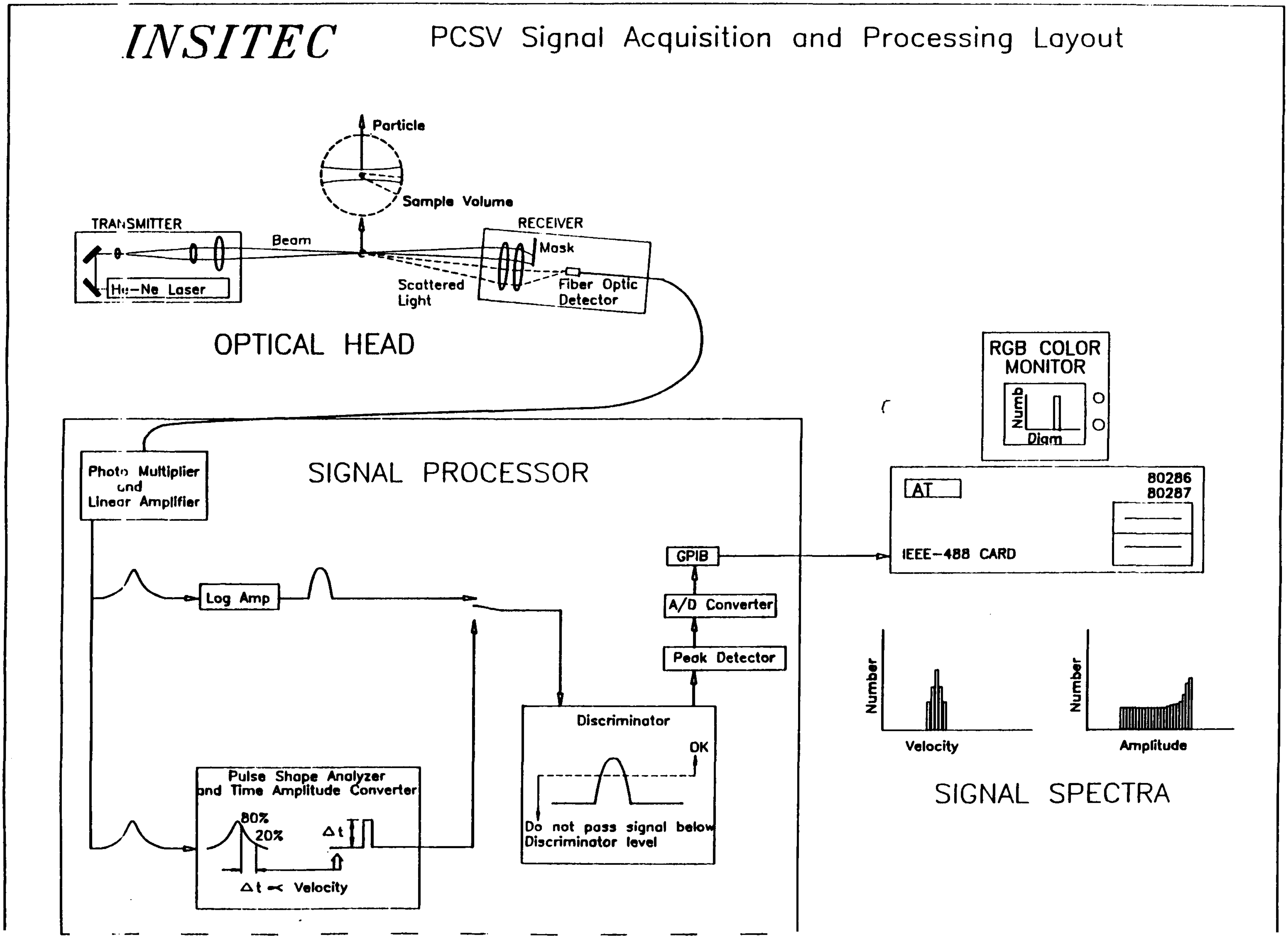
* Research applications in Universities Industry, Defense

New examples of innovative applications for product control and improvement continue to be discovered.

A schematic diagram of the PCSV system is shown in Figure 1. This diagram shows the three basic system components, including the optical head, signal processor, and computer-software. Also shown is the primary signal and data acquisition sequence for Particle Concentration, Size, and Velocity. Particle size and velocity information are derived through the measurement of peak amplitude spectra. Figure 1 shows the amplitude spectrum for monodisperse particles. The velocity is derived from the pulse width spectrum, knowing the laser beam focus diameter. The velocity, number, area, and mass distributions are then computed by means of the intensity deconvolution algorithm in less than a fraction of a second and displayed on the color monitor.

The Optical Head can be in the form of a completely non-intrusive external system (PCSV-E), or for industrial and large scale systems, in a probe form (PCSV-P). The signal processor and computer-software can be used with either/or both of the optical detectors. Both systems can be remotely operated (up to 200 ft.), with alignment controlled by means of a computer-driven motor system, and signal transmission through a noise-immune fiber otpic cable.

FIGURE 1


INSITEC
PCSV Signal Acquisition and Processing Layout
Particle
Sample Volume
TRANSMITTER
Beam
RECEIVER
Mask
He-Ne Laser
Scattered Light
Fiber Optic Detector
OPTICAL HEAD
RGB COLOR MONITOR
Numb
Diam
Photo Multiplier and Linear Amplifier
SIGNAL PROCESSOR
AT
80286
80287
GPIB
IEEE-488 CARD
Log Amp
A/D Converter
Peak Detector
Number
Number
Discriminator
OK
Velocity
Amplitude
Pulse Shape Analyzer and Time Amplitude Converter
SIGNAL SPECTRA
80%
20%
Δt
Do not pass signal below Discriminator level
Δt ∝ Velocity

PCSV SYSTEM COMPONENTS

1. IBM AT COMPATIBLE 80286 COMPUTER (110/220V)*

   A. EGA VIDEO CARD
   B. MULTI I/O CARD
   C. SCIENTIFIC SOLUTIONS IEEE-488 CARD
   D. 80287 MATH COPROCESSOR
   E. DOS 3.0 OR HIGHER OPERATING SYSTEM

2. INPUT/OUTPUT DEVICES (110/220V)

   A. RGB COLOR MONITOR*
   B. HPGL PEN PLOTTER

3. SIGNAL PROCESSOR (110/220V)*

4. MONITOR OSCILLOSCOPE (110/220V)*

5. OPTICAL HEAD, PCSV-E OR PCSV-P

   A. LASER POWER SUPPLY (110/220V)

6. PCSV-P TEMPERATURE CONTROL AND PURGE (110/220V)*

   A. HIGH TEMPERATURE WATER COOLING JACKET (10 FT)
   B. WINDOW PURGE FLOW CONTROL*

7. CABLE LIST AND STANDARD LENGTHS FOR PCSV-E AND -P

   A. RGB MONITOR (4 FT)
   B. PEN PLOTTER, RS-232 (5 FT)
   C. SIGNAL PROCESSOR, IEEE-488 (6 FT)
   D. OSCILLOSCOPE, 4 BNC (6 FT)
   E. FIBER OPTIC, 600 MICRON, 905 SMA (30 FT)
   F. CONTROLLER, 40 PIN LEMO, (30 FT)
   G. LASER POWER, HIGH VOLTAGE, (10 FT)

8. CABLE LIST FOR PCSV-P HIGH TEMPERATURE CONTROL

   A. INLET COOLING WATER/AIR (30 FT)
   B. OUTLET COOLING WATER (30 FT)
   C. TEMPERATURE SENSORS (30 FT)
   D. AIR PURGE (30FT)

* STARRED ITEMS CAN BE PROVIDED AS TABLE TOP OR RACK-MOUNT

UTILITIES SUPPLIED BY USER

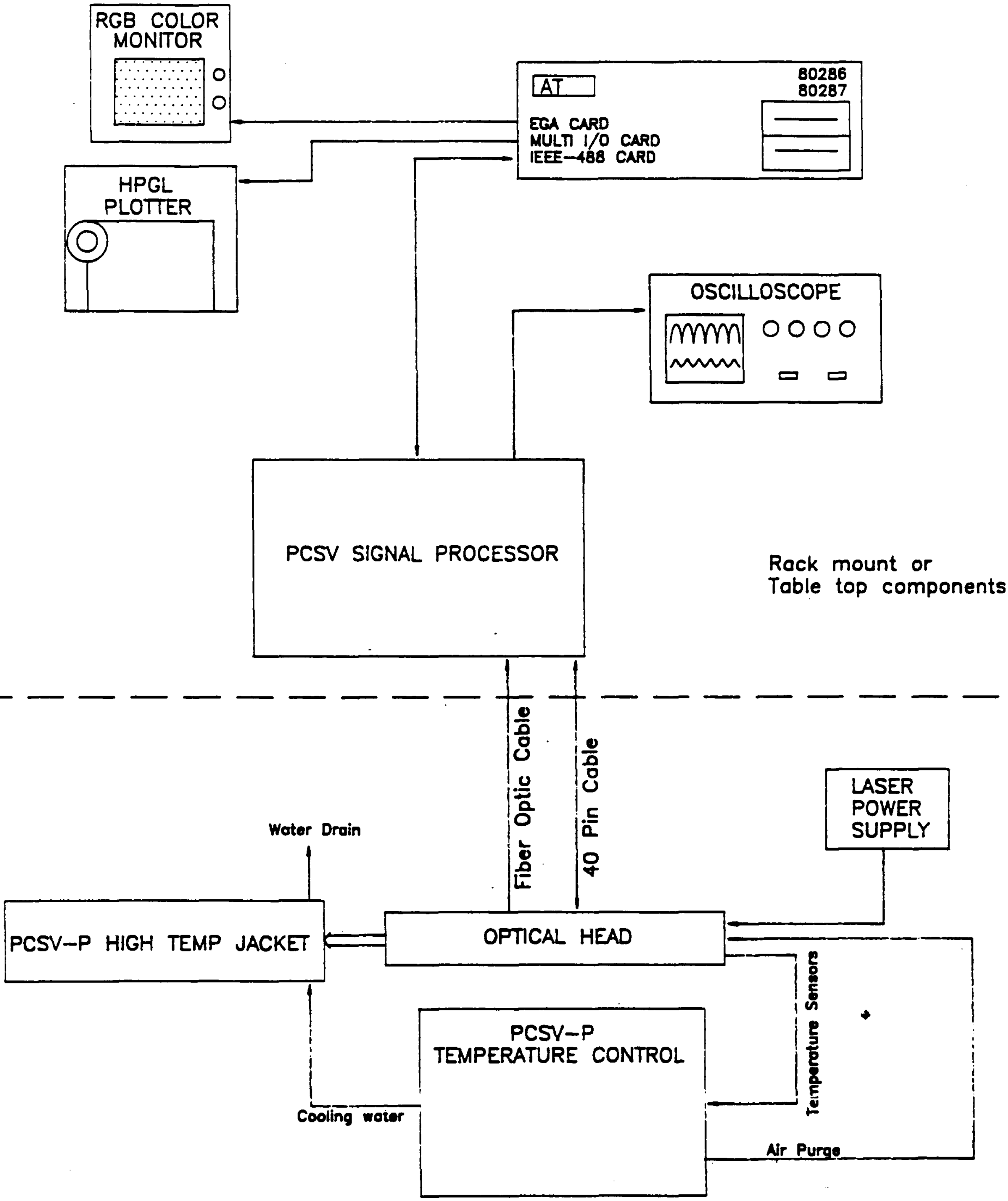
1. * 110/220V, 8 OUTLETS; PCSV-P OR PCSV-E

2. DRY GAS FOR WINDOW PURGE, 50-100 PSI; PCSV-P

3. COOLING WATER OR AIR, 50-100 PSI; PCSV-P

INSITEC

PCSV System Layout



MODIFICATIONS TO STANDARD PCSV CONFIGURATION

1. We can accomodate the need for a longer access cable (up to approximately 200 ft) for the probe signal and motor control lines. The fiber optic cable and 40 line cable will be tied together so that the user can roll them up on approximately a 2 ft. diameter drum. The minimum bending radius for the fiber is approximately 6 inches, but a larger drum diameter is preferable to minimize flex wear for repeated use. The additional cost is $6.00 per ft. for lengths greater than 30 ft.

2. Please note that the laser supply, air purge, and water cooling controls are placed within 30 ft. of the probe for the PCSV-P. This requires the user to turn on the laser power and utilities locally, which is a good idea for startup procedure. However, for remote operation, the probe temperature, air, and water flow alarms should be wired back to the control location. This is a simple procedure but requires additional cabling and separate annunciators.

The approximate flow requirements are as follows:

A. Air purge maximum is 300 SCFH
@ 50-100 PSI supply pressure.

B. Water cooling maximum is 15 GPM
@ 50-100 PSI supply pressure.

4. The length of the PCSV-P cooling jacket is dictated by the required insertion distance to the center of the optical sample volume plus approximately 16 inches additional distance to the end of the water-cooled jacket plus enough length to accomodate the wall thickness and "handling" length. For example, if the required insertion distance is 5 ft. then a jacket length of at least 8 ft. would be desireable to give approximately 20 inches of handling length.

5. General physical dimensions are given in the brochure. Utilities connections are quick disconnect. Connection details can be supplied.

PCSV DEMONSTRATION SOFTWARE AND APPLICATION RESULTS

PCSV SOFTWARE INSTALLATION, Version 2.1

INTRODUCTION

The INSITEC PCSV applications software is a multi-purpose software package which runs the PCSV system. LOTUS (tm) style menus allow you to navigate your way through the program and the on-line help facility provides extended explanations for new users. This file contains some important tips which will allow you to avoid aggravating problems.

GENERAL INFORMATION

The program is set up to run on a hard disk with the following directory structure (see Figure 2 for organization):

C:\PCSV	-	Main PCSV directory
C:\PCSV\BIN	-	Executable, Help, and Error files
C:\PCSV\CAL	-	Configuration and Calibration files
C:\PCSV\DATA	-	Data files

There are 3 environment variables you may set to change this structure using the DOS SET command (see PCSV.BAT for an example), these are:

PCSVROOT	-	Executable and configuration files
PCSVCAL	-	Calibration and matrix files
PCSVDATA	-	Data files

These directories may also be changed by using the Path command in the PCSV program. We recommend you only change the data directory since changing the root or the cal directories requires moving all of the appropriate files to the new directories first.

For the plotter output there is another environment variable, PCSVPLOT. If this variable is not set, the program will choose COM1 as the default plotter port. PCSV.BAT sets this variable to COM2 as the default. You will have to change this with a text editor for PCSV.BAT or in the Options menu if necessary.

INSTALLING THE PROGRAM

Your distribution diskette contains all the necessary files to run the system. To load the program on your hard disk boot up the system and execute the following steps.

1. Place the distribution diskette in drive A:
2. Type A:
3. Run PCSVINST with a drive specifier.
   For example - A>PCSVINST D: (Installs on D:)

The program is now loaded into the default subdirectories on the hard disk.

RUNNING THE PROGRAM

You must either enter C:\PCSV directory and type PCSV or put C:\PCSV in your path statement. (Type PCSV/S for simulate mode.) Remember that PCSV.BAT sets the plotter mode using the DOS MODE command so your DOS directory must have been specified in PATH or you must copy MODE.COM into the pcsv directory. To view any of the data output files use the "REDUCE" function followed by the appropriate filename.

SAMPLE CALIBRATION FILES USING RS-1 RETICLE

The filenames indicate the particle diameter and calibration device, e.g. "60retx.dat" is the 60 micron reticle. The letter "x" refers to repeat files, a,b,c....etc. The filename "61at.dat" refers to 0.62 micron latex spheres. All reticle velocities were 5.1 m/s. The latex flow velocity was not independently measured.

SAMPLE APPLICATIONS FILES:

The following applications filenames show results obtained in the Insitec laboratory using a DeVilbiss powder feeder.

TONERx.dat - Carbon black toner for laser printers

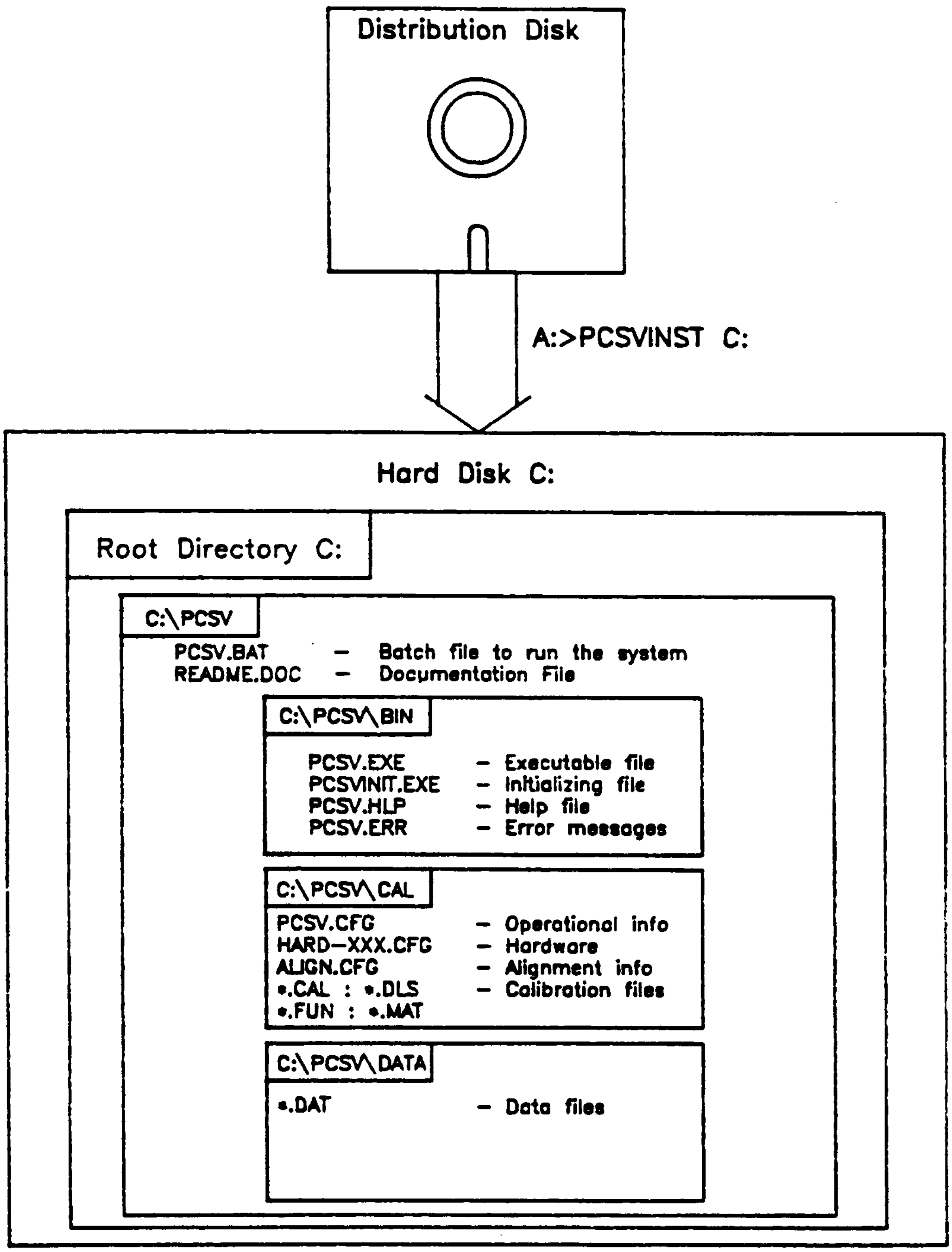
PPGxx.dat - Pigment, unknown applications

OMYAxx.dat - CaCO3 used as extenders, etc.

SIMCOAL.dat- Pulverized coal flyash at high temperature

INSITEC

PCSV SOFTWARE FILE STRUCTURE
(The C: drive may be substituted with D:)



PCSV DATA PRESENTATION GRAPHICS

The standard size distribution format shows both the NUMBER and MASS distributions on a pen plotter output. The data header is self explanatory except for the following:

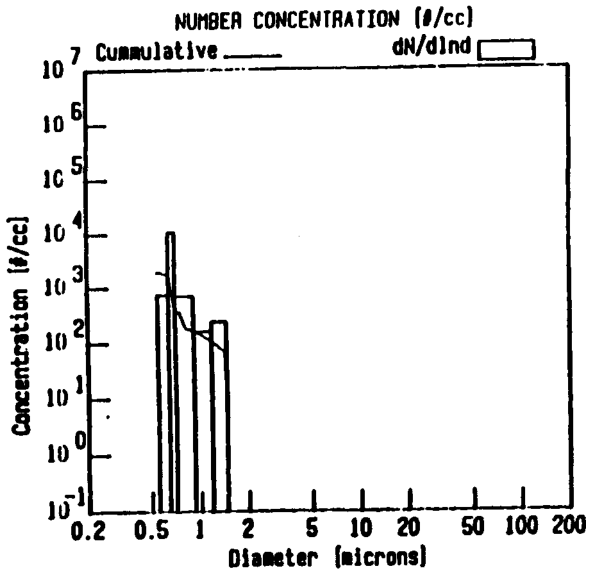
Trans.	-	Percentage light transmission compared to calibration conditions
Valid	-	Percentage of validated pulses
Speed	-	Median speed with RMS variation in m/s
D32	-	Sauter Mean Diameter

Each plot shows both a frequency distribution (the histogram) and a cumulative (integral of the frequency) distribution (the line). In order to cover the wide dynamic range in concentration and size, logarithmic scales are used. The entire size range is covered by each of two laser beams. The beam which measures the smaller particle sizes has an approximate size range from 0.3 to 2-3 microns. The beam measuring the larger particle sizes spans a size range from 3 to 100-200 microns depending on beam size and particle concentration. At higher concentrations where the two size ranges do not overlap, an interpolation is made between the two size ranges. Note that the total distribution is the combination of two independent measurements using laser beam diameters which differ by a factor of 10. The congruence of the two measurements is a significant consistency check for the PCSV. The lower bound of each beam for any given distribution is set by the lower discriminator level, which in turn is dictated by the single particle counting requirement. The upper bound is given by the requirement to have at least 10 counts in the top bin to achieve adequate counting statistics.

The top figure on each plot shows the particle number density ($\#/cm^3$) as a function of particle size (microns). The frequency distribution shows the actual particle concentration for each size bin or channel. The cumulative number distribution is a summation of all the particles measured. Since there are generally lower numbers of large particles, the convention for the cumulative number distributions is to begin the summation with the largest particles and progress towards the smallest particles.

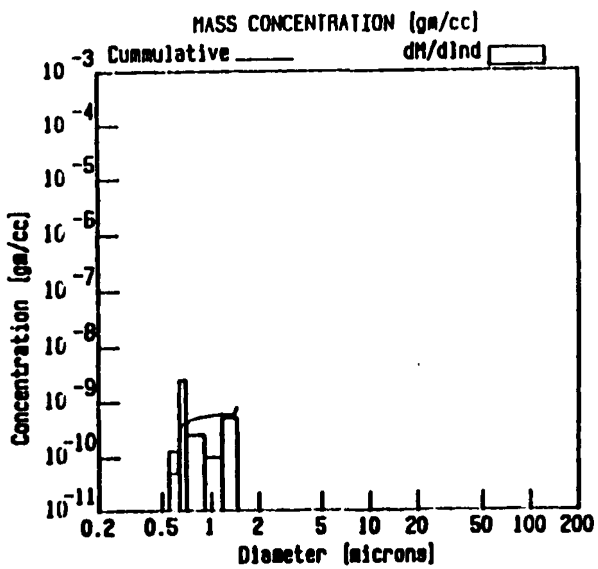
The bottom figure shows the corresponding particle mass density. The cumulative mass density of the particles (g/cm^3) is shown as a function of particle size (microns). As its name implies, the cumulative mass density is also a summation. Since the mass of particles in the bins at the small particle sizes is generally the lowest, the convention is to start the mass summation with the small particle sizes and progress towards the large particle sizes. Note that the mass and number cumulative distributions sum in opposite directions.

INSITEC Particle Counter Sizer Velocimeter



File : 6LAT.DAT
Date : 17-Nov-88
Time : 18:42:52
Trans. : 92 %
Valid : 100 %
Speed : 7.22 ± 0.94
Density: 1.60 gm/cc
D32 : 0.84 microns

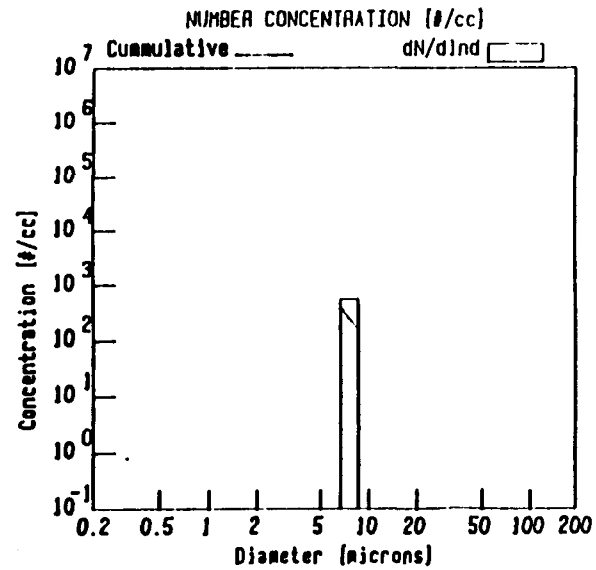
%	Diam	Cum Numb
99.9	0.56	2.07e+03
99.0	0.56	2.05e+03
90.0	0.61	1.86e+03
70.0	0.62	1.45e+03
50.0	0.64	1.04e+03
30.0	0.65	6.21e+02
10.0	0.75	2.07e+02
1.0	1.45	2.07e+01
0.1	1.47	2.07e+00



File : 6LAT.DAT
Date : 17-Nov-88
Time : 18:42:52
Trans. : 92 %
Valid : 100 %
Speed : 7.22 ± 0.94
Density: 1.60 gm/cc
D32 : 0.84 microns

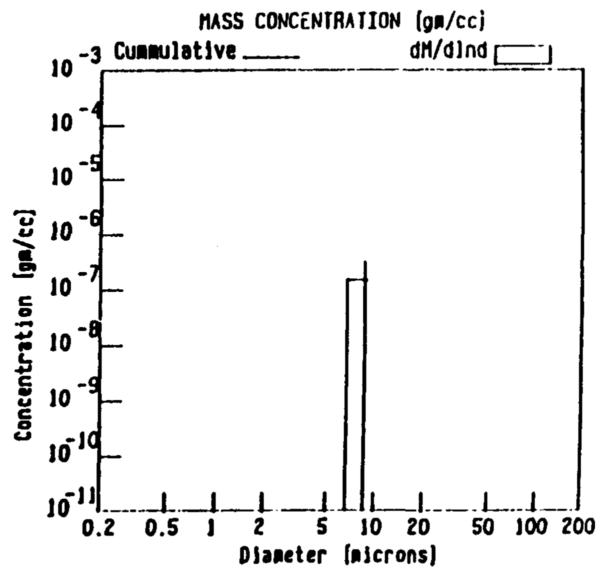
%	Diam	Cum Mass
99.9	1.47	7.65e-10
99.0	1.46	7.58e-10
90.0	1.43	6.89e-10
70.0	0.98	5.36e-10
50.0	0.67	3.83e-10
30.0	0.64	2.30e-10
10.0	0.62	7.66e-11
1.0	0.55	7.66e-12
0.1	0.55	7.66e-13

INSITEC Particle Counter Sizer Velocimeter



File : 7RET.DAT
Date : 01-Dec-88
Time : 23:25:08
Trans. : 96 %
Valid : 100 %
Speed : 5.12 ± 0.51
Density: 1.60 gm/cc
D32 : 7.93 microns

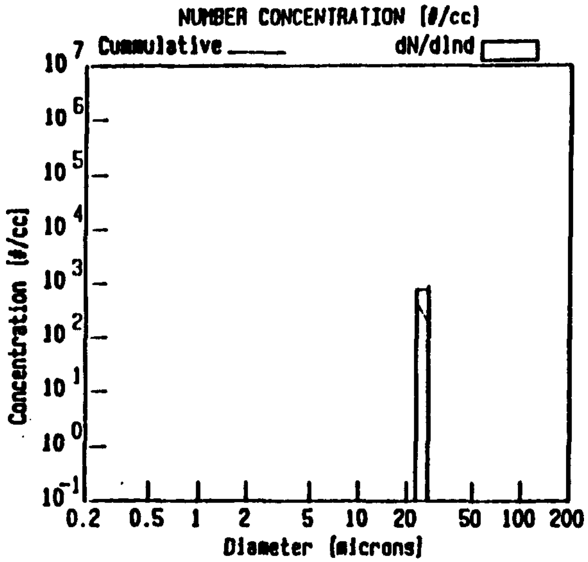
%	Diam	Cum Numb
99.9	6.80	3.77e+02
99.0	6.80	3.73e+02
90.0	6.80	3.39e+02
70.0	6.80	2.64e+02
50.0	6.80	1.88e+02
30.0	8.86	1.13e+02
10.0	8.91	3.77e+01
1.0	8.93	3.77e+00
0.1	8.93	3.77e-01



File : 7RET.DAT
Date : 01-Dec-88
Time : 23:25:08
Trans. : 96 %
Valid : 100 %
Speed : 5.12 ± 0.51
Density: 1.60 gm/cc
D32 : 7.93 microns

%	Diam	Cum Mass
99.9	8.93	1.49e-07
99.0	8.91	1.47e-07
90.0	8.72	1.34e-07
70.0	8.29	1.04e-07
50.0	7.86	7.43e-08
30.0	7.44	4.46e-08
10.0	7.01	1.49e-08
1.0	6.82	1.49e-09
0.1	6.80	1.49e-10

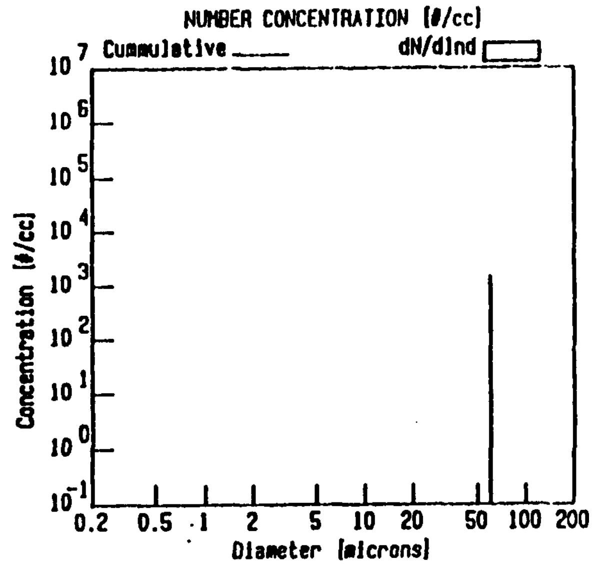
INSITEC Particle Counter Sizer Velocimeter



File : 24RETC.DAT
Date : 05-Dec-88
Time : 15:22:40
Trans. : 95 %
Valid : 100 %
Speed : 5.08 ± 0.36
Density: 1.60 gm/cc
D32 : 25.24 microns

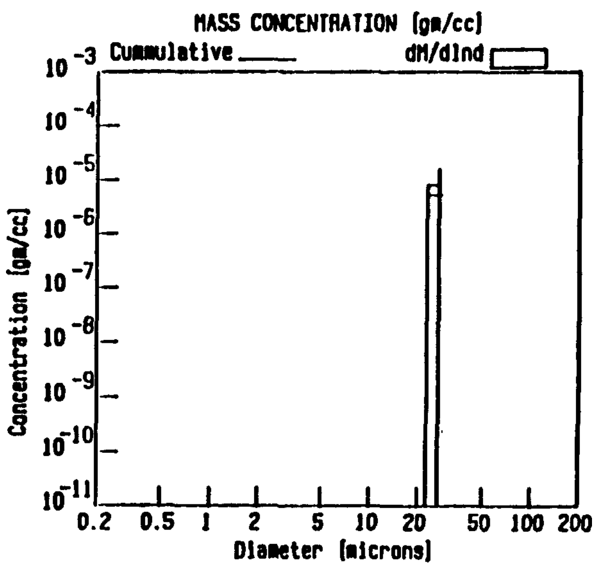
%	Diam	Cum Numb
99.9	22.82	3.85e+02
99.0	22.82	3.81e+02
90.0	22.82	3.47e+02
70.0	22.82	2.70e+02
50.0	22.82	1.93e+02
30.0	27.17	1.16e+02
10.0	27.30	3.85e+01
1.0	27.35	3.85e+00
0.1	27.36	3.85e-01

INSITEC Particle Counter Sizer Velocimeter



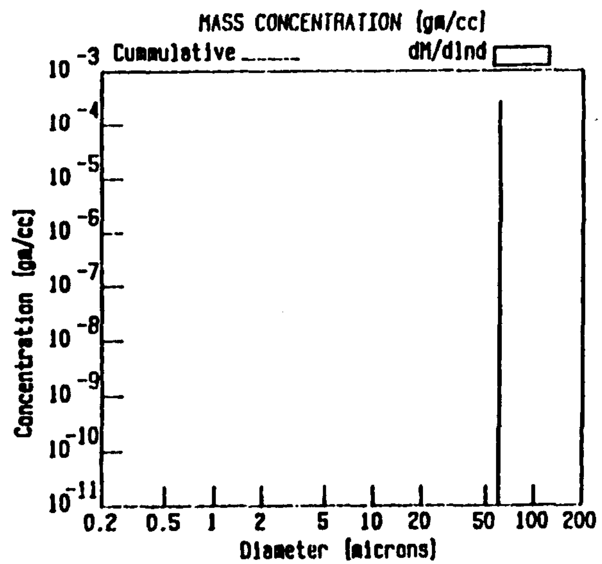
File : 60RETB.DAT
Date : 02-Dec-88
Time : 10:49:29
Trans. : 98 %
Valid : 100 %
Speed : 3.96 ± 0.44
Density: 1.60 gm/cc
D32 : 61.04 microns

%	Diam	Cum Numb
99.9	61.04	4.31e+02
99.0	61.04	4.27e+02
90.0	61.04	3.88e+02
70.0	61.04	3.02e+02
50.0	61.04	2.16e+02
30.0	61.04	1.29e+02
10.0	61.04	4.32e+01
1.0	61.04	4.32e+00
0.1	61.04	4.32e-01



File : 24RETC.DAT
Date : 05-Dec-88
Time : 15:22:40
Trans. : 95 %
Valid : 100 %
Speed : 5.08 ± 0.36
Density: 1.60 gm/cc
D32 : 25.24 microns

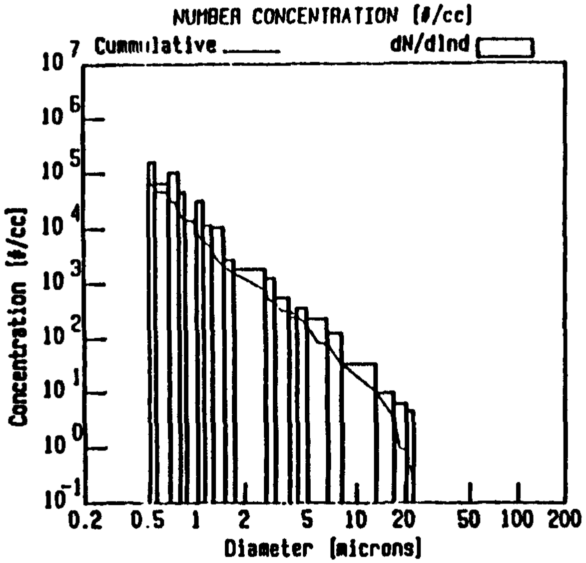
%	Diam	Cum Mass
99.9	27.35	5.05e-06
99.0	27.31	5.01e-06
90.0	26.90	4.55e-06
70.0	26.00	3.54e-06
50.0	25.09	2.53e-06
30.0	24.18	1.52e-06
10.0	23.27	5.06e-07
1.0	22.86	5.06e-08
0.1	22.82	5.06e-09



File : 60RETB.DAT
Date : 02-Dec-88
Time : 10:49:29
Trans. : 98 %
Valid : 100 %
Speed : 3.96 ± 0.44
Density: 1.60 gm/cc
D32 : 61.04 microns

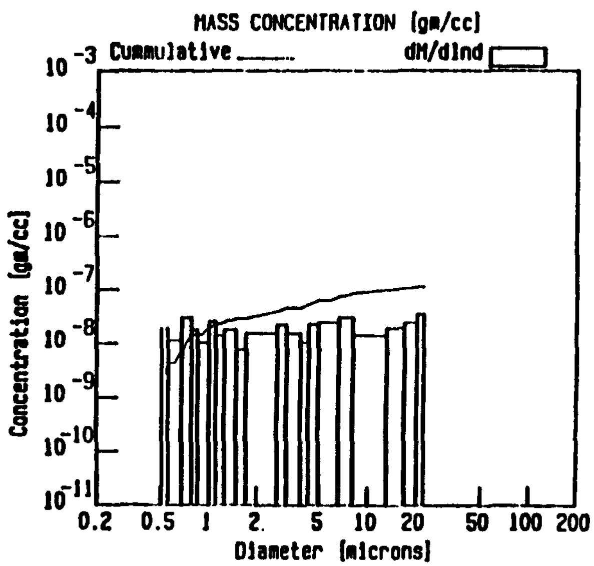
%	Diam	Cum Mass
99.9	61.65	8.22e-05
99.0	61.65	8.14e-05
90.0	61.65	7.40e-05
70.0	61.65	5.76e-05
50.0	61.65	4.11e-05
30.0	61.65	2.47e-05
10.0	61.65	8.22e-06
1.0	61.65	8.22e-07
0.1	61.65	8.22e-08

INSITEC Particle Counter Sizer Velocimeter



File : OMYAFB.DAT
Date : 06-Dec-88
Time : 12:37:52
Trans. : 96 %
Valid : 87 %
Speed : 4.25 ± 0.82
Density: 1.60 gm/cc
D32 : 2.33 microns

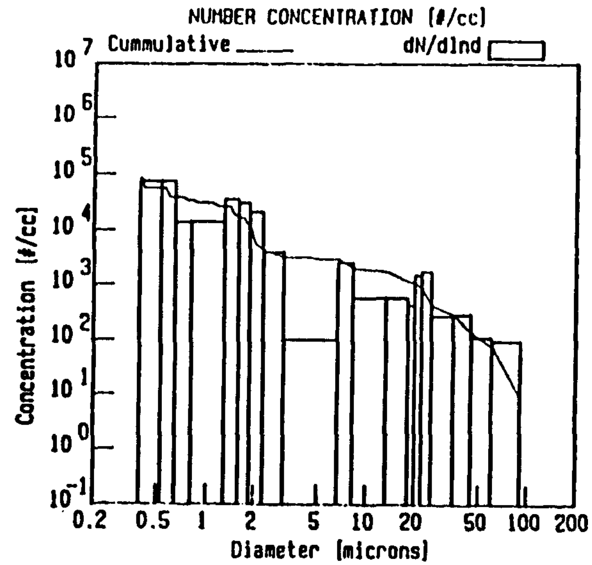
%	Diam	Cum Numb
99.9	0.51	8.10e+04
99.0	0.51	8.03e+04
90.0	0.51	7.30e+04
70.0	0.53	5.67e+04
50.0	0.64	4.05e+04
30.0	0.73	2.43e+04
10.0	0.99	8.11e+03
1.0	1.67	8.11e+02
0.1	5.52	8.11e+01



File : OMYAFB.DAT
Date : 06-Dec-88
Time : 12:37:52
Trans. : 96 %
Valid : 87 %
Speed : 4.25 ± 0.82
Density: 1.60 gm/cc
D32 : 2.33 microns

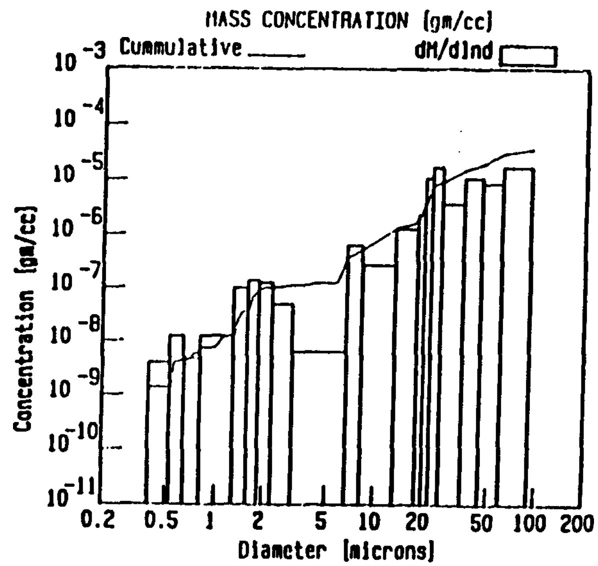
%	Diam	Cum Mass
99.9	22.10	1.18e-07
99.0	21.33	1.17e-07
90.0	15.40	1.07e-07
70.0	7.64	8.29e-08
50.0	4.60	5.92e-08
30.0	2.28	3.55e-08
10.0	0.75	1.18e-08
1.0	0.52	1.18e-09
0.1	0.51	1.18e-10

INSITEC Particle Counter Sizer Velocimeter



File : PPGINB.DAT
Date : 06-Dec-88
Time : 11:59:32
Trans. : 95 %
Valid : 87 %
Speed : 3.29 ± 0.79
Density: 1.60 gm/cc
D32 : 34.54 microns

%	Diam	Cum Numb
99.9	0.39	8.47e+04
99.0	0.39	8.39e+04
90.0	0.39	7.63e+04
70.0	0.39	5.93e+04
50.0	0.56	4.24e+04
30.0	1.35	2.54e+04
10.0	1.77	8.48e+03
1.0	20.30	8.48e+02
0.1	41.98	8.48e+01

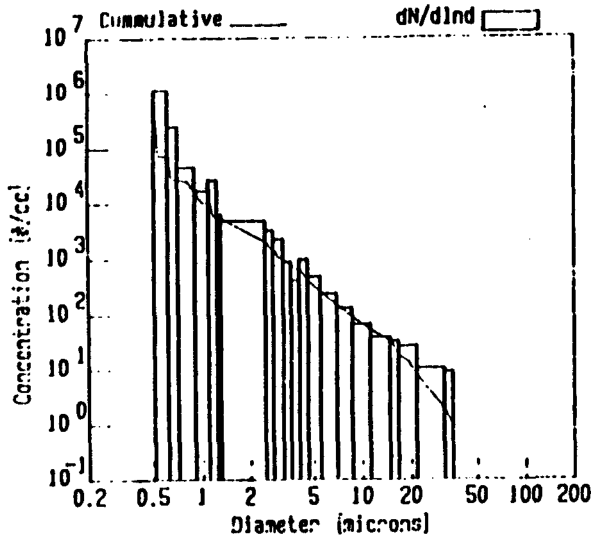


File : PPGINB.DAT
Date : 06-Dec-88
Time : 11:59:32
Trans. : 95 %
Valid : 87 %
Speed : 3.29 ± 0.79
Density: 1.60 gm/cc
D32 : 34.54 microns

%	Diam	Cum Mass
99.9	92.06	3.81e-05
99.0	90.22	3.78e-05
90.0	71.72	3.43e-05
70.0	53.70	2.67e-05
50.0	42.83	1.91e-05
30.0	28.69	1.14e-05
10.0	20.22	3.81e-06
1.0	6.87	3.81e-07
0.1	1.62	3.81e-08

INSITEC Particle Counter Sizer Velocimeter

NUMBER CONCENTRATION (#/cc)

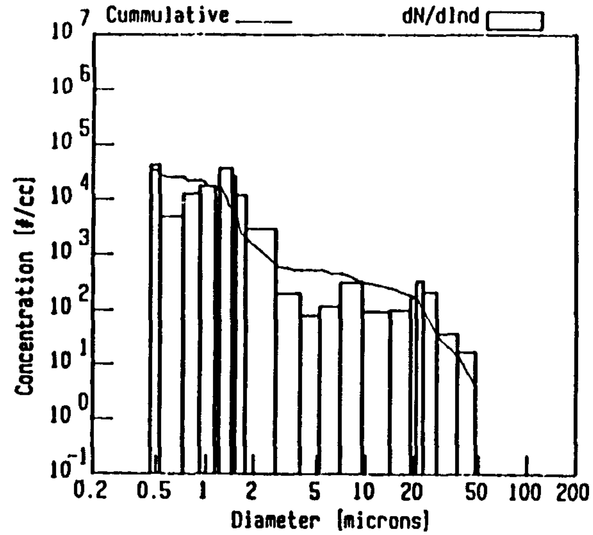


File : SIMCOAL.DAT
Date : 09-DEC-86
Time : 11:26:23
Trans. : 66 %
Valid : 100 %
Speed : 5.89 ± 0.75
Density: 1.60 gm/cc
D32 : 3.06 microns

%	Diam	Cum Numb
99.9	0.52	3.32e+05
99.0	0.52	3.29e+05
90.0	0.52	3.00e+05
70.0	0.52	2.33e+05
50.0	0.52	1.66e+05
30.0	0.52	9.98e+04
10.0	0.62	3.33e+04
1.0	0.87	3.33e+03
0.1	4.16	3.33e+02

INSITEC Particle Counter Sizer Velocimeter

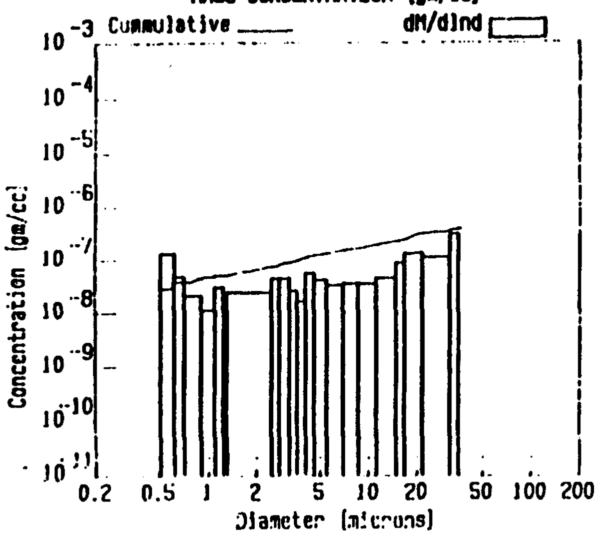
NUMBER CONCENTRATION (#/cc)



File : TONERI.DAT
Date : 06-Dec-88
Time : 10:40:31
Trans. : 96 %
Valid : 96 %
Speed : 3.84 ± 0.41
Density: 1.60 gm/cc
D32 : 18.07 microns

%	Diam	Cum Numb
99.9	0.48	3.43e+04
99.0	0.48	3.40e+04
90.0	0.49	3.09e+04
70.0	0.70	2.40e+04
50.0	0.98	1.72e+04
30.0	1.24	1.03e+04
10.0	1.50	3.43e+03
1.0	6.62	3.43e+02
0.1	22.71	3.43e+01

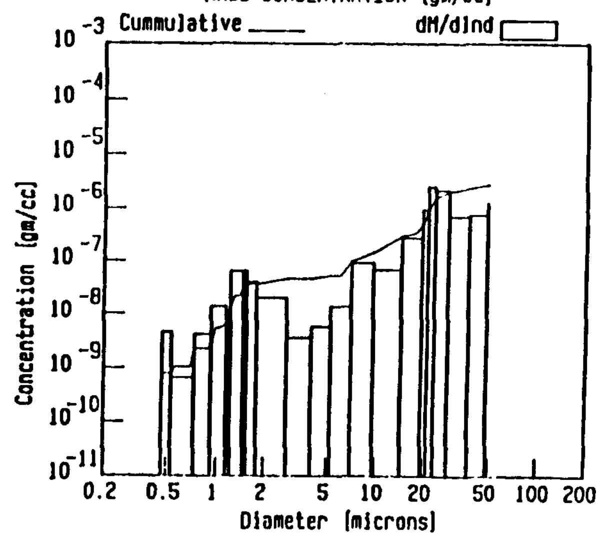
MASS CONCENTRATION (gm/cc)



File : SIMCOAL.DAT
Date : 09-DEC-86
Time : 11:26:23
Trans. : 66 %
Valid : 100 %
Speed : 5.89 ± 0.75
Density: 1.60 gm/cc
D32 : 3.06 microns

%	Diam	Cum Mass
99.9	36.16	4.06e-07
99.0	35.71	4.03e-07
90.0	31.49	3.66e-07
70.0	18.70	2.85e-07
50.0	11.68	2.03e-07
30.0	4.49	1.22e-07
10.0	0.74	4.07e-08
1.0	0.52	4.07e-09
0.1	0.52	4.07e-10

MASS CONCENTRATION (gm/cc)



File : TONERI.DAT
Date : 06-Dec-88
Time : 10:40:31
Trans. : 96 %
Valid : 96 %
Speed : 3.84 ± 0.41
Density: 1.60 gm/cc
D32 : 18.07 microns

%	Diam	Cum Mass
99.9	48.23	2.72e-06
99.0	47.42	2.69e-06
90.0	39.39	2.45e-06
70.0	26.97	1.90e-06
50.0	22.05	1.36e-06
30.0	20.15	8.16e-07
10.0	13.89	2.72e-07
1.0	1.44	2.72e-08
0.1	0.93	2.72e-09

In addition to graphical frequency and cumulative distributions, each plot includes a table of particle sizes corresponding to standard cut points in the distribution (shown with column headers "%" and "Diam"). These standard cutpoints are simply another way of presenting information from the cumulative distribution. They offer a convenient way to compare data taken at different conditions. For example, in the top figure, the D_{01} diameter represents the diameter below which is 1% of the number of particles, and above which is 99% of the number of particles. Similarly, D_{50} represents the mass median diameter. This diameter corresponds to the point where fifty percent of the mass of particles is below D_{50} and fifty percent of the total particle mass is above D_{50}.

Please note, however, that for any instrument, percentage normalized distributions will be a function of the instrument dynamic range if the actual distribution exceeds the instrument range. Thus, the percentage values will be artificial if a significant portion of the actual distribution lies outside the instrumental range. In this case, the % values should only be used for relative comparison between runs. In contrast, the absolute concentration measurements are independent of the instrument type and dynamic range over the indicated measurement range. The absolute concentration measurements can thus be used for comparisons between different measurement methods.

DISCUSSION OF SAMPLE DATA COMPARISONS

Please note the following points about the 60 micron reticle results. File 60ret.dat looks like it has a large bin from 8-60 microns, but note that the frequency is approx. 2.5 orders of magnitude less than the 60 micron frequency and represents an error of less than a few %. This error is an artifact of the deconvolution algorithm. The other two files look "better" but are statistically equivalent.

The frequency can be a "point value" (infinitesimal bin width). It depends on how the details of the numerical calulations and data work themselves out in a particular case. Because the particle flux for all reticle data files are approximately the same, varying with the measured velocity, all cumulative number densities should be approximately the same regardless of the frequency bin width. You can check all the reticle data files to see that this holds independent of deconvolved bin width. Note that for the reticle, the data interpretation assumes uniform flux throughout the sample volume (i.e. along the z-axis). Although the uniform flux condition only holds in the x-coordinate for the reticle, the comparison between reticle data files is a good "relative" check on the number density measurement accuracy of the PCSV method.

The latex particle measurements show some "broadening" which is due to production of droplet doublets and triplets by the droplet nebulizer. The measurement at sizes below 0.6 microns are due to deconvolution errors, but are less than 10%.

The median velocity accuracy is typically ±8%. The velocities for the 60 micron files are considerably lower at 4 m/s than the other smaller particles. For the present optical geometry, the beam diameter is 125 microns and thus is only twice as large as the measured 60 micron particle. When particles are larger than approximately 1/3 of the beam diameter, there is an effective broadening of the beam profile. This results in an effective reduction of the measured velocity. If a specific application requires measurements of these larger particles we would increase the "big" beam diameter to 200-250 microns. The velocity accuracy would then fall within the stated limits. The tradeoff is a larger sample volume and thus lower number density capability for the instrument.

PCSV OPTICAL PARAMETERS

The specific choice of PCSV optical components depends on the application requirements. The primary variables in any application are the particle size range, concentration, refractive index, and shape. The following discussion outlines the basic requirements for optimizing the optical system.

PCSV OPTICAL SYSTEM CHARACTERISTICS

Transmitter

The PCSV transmitter uses a combined double-beam expander set of optics to generate two beam foci midway between the transmitter and receiver. Typical beam foci are 20 microns (small beam) and 200 microns (big beam). A solenoid driven shutter selects the choice of beam and size range sequentially.

Sample Volume

The sample volume is defined by the intersection of the laser beam waist (focus) and the detector optics as shown in the Principle of Operation discussion. The sample volume size must be small enough that only one particle is in the sample volume at a time. The PCSV instruments are single particle counters. The instruments must measure light scattered from individual, separate particles in order to obtain an absolute number density.

In the design of a single particle counter for a particular application, the size of the required sample volume is inversely related to the particle number density. For flows with low particle concentrations, larger sample volumes can be tolerated, whereas flows with high particulate loading require smaller sample volumes in order to ensure that only one particle at a time passes through the sample volume.

While sampling instruments which are single particle counters can direct the particle trajectory through a portion of the sample volume having a known intensity, this type of sample manipulation is not possible in an in situ particle counter. Since the particle trajectory can occur anywhere within the sample volume, the light intensity distribution throughout the sample volume must be known in order to solve for particle size and concentration.

The sample volume intensity distribution is defined for each instrument configuration and is a fixed characteristic of that instrument. If the sample volume distribution were not taken into account, the effect would be to undercount small particles by a factor equal to the area ratio of the small particle sample volume to the large particle sample volume.

Depending on the size range, the sample volume cross sectional area can vary by one or two orders of magnitude between the smallest and the largest particles measured. In order to accurately determine particle concentrations, it is essential to account for the variation in sample volume size as a function of particle size.

Instrument Configuration

The PCSV typically uses two beams with different beam diameters and sample volume sizes to measure the large dynamic range of size and number density defined in the specifications. Sample volume size, V, is defined by the following equation:

$$V = (const)*W_0^2*W_s/\sin\theta$$

where W_0 is the beam waist diameter, W_s is the detector slit width, and $\sin\theta$ is the view angle. Each instrument configuration can be chosen to optimally suit the application of interest. A discussion of the optimal choice of beam parameters is given at the end of this section.

Off axis configurations have smaller sample volumes and therefore, the ability to make measurements at higher number densities. The tradeoff is that off-axis configurations have more sensitivity to particle shape and refractive index. For transparent spherical particles, off-axis configurations are suitable, and to be preferred. However, for irregularly shaped particles, (transparent or opaque) it is essential to perform measurements at near-forward angles, where the scattering is dominated by diffraction.

Backscattering configurations provide a convenient single-ended geometry for convenient access to some applications, but have two main disadvantages. The first is that the signal level is 10-100 times lower than in forward-scatter geometries, and the second limitation is non-monitonic scattering functions. Both of these restrictions reduce the sizing sensitivity. However, for some applications, the convenience and capabilities of single-ended access may over-ride the disadvantages.

Particle Characteristics

The PCSV measures all particles which traverse the sample volume. It does not distinguish between particles having different compositions or shapes.

Particle shape effects - The PCSV provides a quantitative measure of spherical and/or irregular particles, provided that they have aspect ratios (length/diameter ratios) of 2:1 or less. The PCSV technique can provide number density information, but not accurate size information, on fibrous materials.

Mie Scattering Response Function

For near-forward scattering PCSV instruments, the typical signal response for the PCSV as a function of particle size is shown in Figure 2 for both transparent and opaque particles. The general power dependence is summarized in the following Table I.

Table I. Particle Size Power dependence for PCSV Instruments for forward scatter geometry

Particle Size Range, microns	Opaque Signal Dependence	Transparent Spherical Signal Dependence
<0.2	d^6	d^6
0.2 - 1.0	d^4	d^4
1.0 - 10.0	d^{2-3}	d^{2-3}
>10.0	d^1	$d^{1.5}$

The size ranges are approximate, and may vary by a factor of two depending on the specific optical scattering geometry chosen. In addition, there are resonances in the response function (primarily for transparent spherical particles) which reduce the size resolution locally. Nevertheless, the tabulated power dependencies give one a general understanding of the size sensitivity in different ranges.

Working Space

Working space is defined as the exposed beam length between the transmitter and receiver. Larger path-lengths require larger lens apertures, and are more sensitive to beam-pointing errors, vibration, and turbulent beam steering in high temperature operations. The PCSV-E has an upper length of approximately 1 meter, where the tradeoffs in system performance become less desireable. The PCSV-P can be used more effectively in large scale systems where the pathlength becomes large.

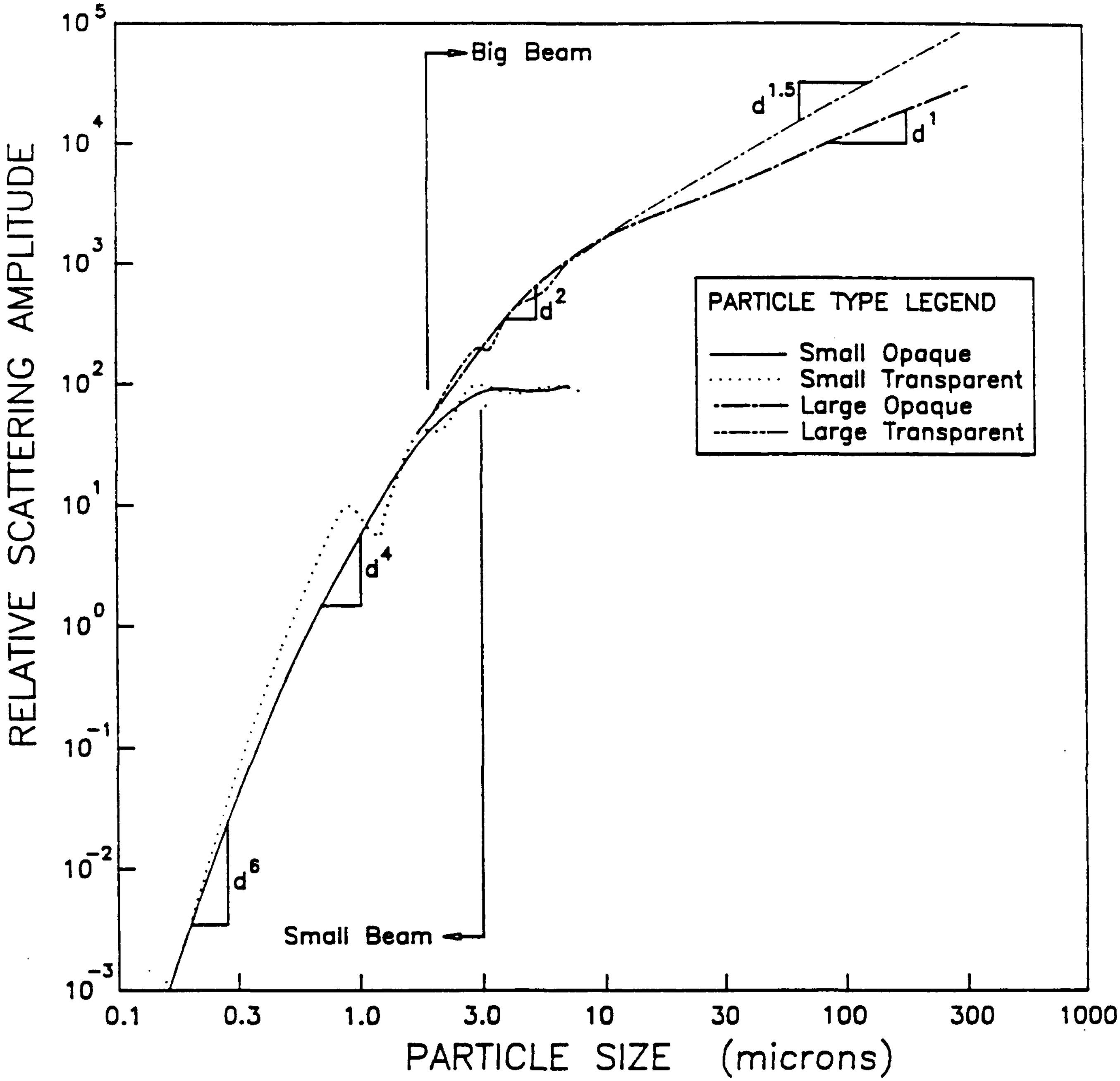
Receiver Lens

The receiver lens pair must be corrected for spherical aberrations and have an F/# of 4.0 or less. Longer pathlengths require larger diameter achromats.

Optical Fiber

The optical fiber is mounted on a 3D stage which is motor driven for alignment. The PCSV uses a large fiber of 600 microns in diameter with a masking slit that is typically 150-300 microns wide. Fiber lengths of up to 100 meters in length can be used with minimal light attenuation.

INSITEC PCSV Response Function Curves



Note : Slope triangles show approximate power law dependence as a function of particle size.

Figure 2

Interference Filter

An interference filter, which is a narrow band pass filter centered at 632.8 nm is used to screen out light at wavelengths other than the illuminating He-Ne laser light. An interference filter is required for high temperature applications, where the thermal background can interfere with small light scattering signals. All PCSV systems use an interference filter. However, there is a tradeoff in the angle sensitivity and precision of alignment as the bandpass characteristic is narrowed. An optimum

OPTIMAL SELECTION OF OPTICAL SYSTEM PARAMETERS

With the above discussion as a background, optimal selection of beam foci dimensions can be made by considering the anticipated particle concentration and distribution. Figure 3 shows a normalized operational limit map of the available size range as a function of particle concentration. The upper bound is given by the limit that the largest particles must be less than 1/3 of the beam diameter; more recent results show that corrections to the response function allow extension of this limit to approximately 1/2 the beam diameter. The lower lim it assumes a typical aerosol distribution shape which increase with the inverse 3rd power of particle diameter. Thus the available particle size dynamic range decreases with increasing particle concentration. From Figure 3 one can determine operating bounds for a given beam diameter.

Figures 4a, 4b, and 4c show dashed lines of a typical particle distribution shape (where the particle concentration increases inversely with the 3rd power of the particle diameter) at varying concentrations. Although this ideal distribution shape may vary widely, our experience shows that it generally represents a worst case for estimating particle concentrations as a function of particle size.

Superimposed on the graphs are rectangular boxes for each of the two indicated beam diameters. These boxes represent the operational range for the selected beam diameter, which is constrained by the size range and concentration. Note for example, that at high particle concentrations smaller size ranges of measurement capability are available to the PCSV. Nevertheless, even at high concentrations, distribution information can be obtained by interpolating between the two size ranges. The assumption here is that there are not rapid variations in the distribution slope.

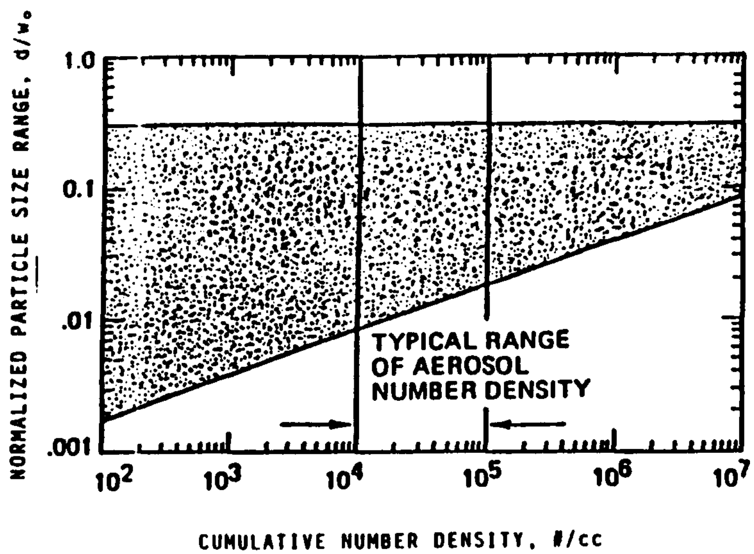


FIGURE 3. Operational map for size range as a function of particle concentration.

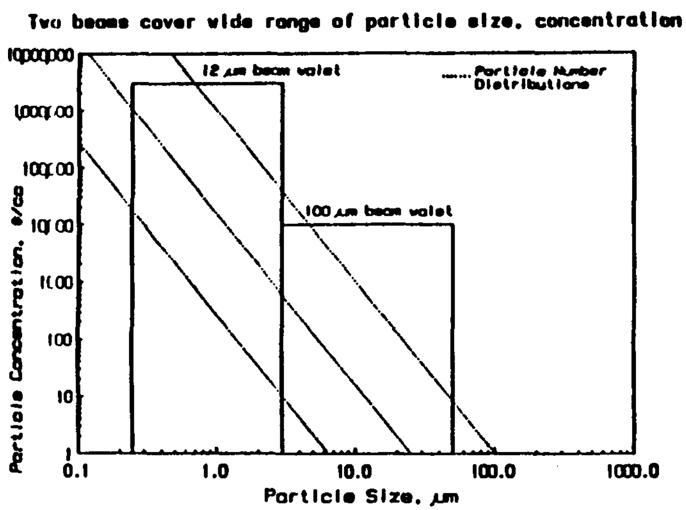


FIGURE 4a. Operational range for size and concentration for indicated beam diameters.

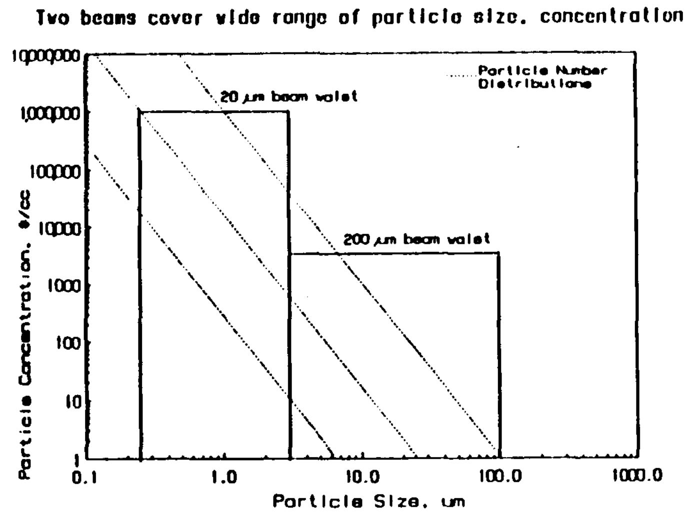


FIGURE 4b. Operational range for size and concentration for indicated beam diameters.

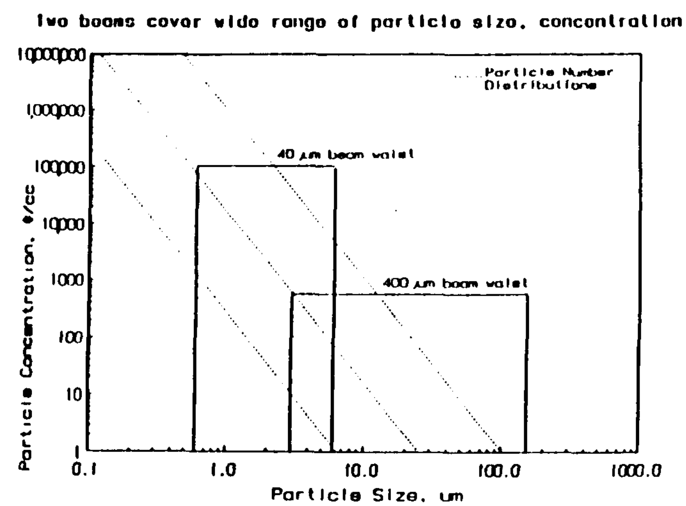


FIGURE 4c. Operational range for size and concentration for indicated beam diameters.

PARTICLE LOADING CONVERSION TABLES

g/m^3 mg/liter ppm	g/ft^3	$grains/ft^3$	$ounces/ft^3$ g/liter	volume %		#/cc	$\#/ft^3$
					1um:	2x10**3	5x10**7
0.001		0.0004			10um:	2	5x10**4
					100um:	0.002	5x10**1
					1um:	2x10**4	5x10**8
0.01	0.0003	0.004			10um:	2x10**1	5x10**5
					100um:	0.02	5x10**2
					1um:	2x10**5	5x10**9
0.1	0.003	0.04			10um:	2x10**2	5x10**6
					100um:	0.2	5x10**3
					1um:	2x10**6	5x10**10
1	0.03	0.4	0.001	0.0001	10um:	2x10**3	5x10**7
					100um:	2	5x10**4
					1um:	2x10**7	5x10**11
10	0.3	4	0.01	0.001	10um:	2x10**4	5x10**8
					100um:	2x10**1	5x10**5
					1um:	2x10**8	5x10**12
100	3	40	0.1	0.01	10um:	2x10**5	5x10**9
					100um:	2x10**2	5x10**6
					1um:	2x10**9	5x10**13
1000	30	400	1	0.1	10um:	2x10**6	5x10**10
					100um:	2x10**3	5x10**7
					1um:	2x10**10	5x10**14
10,000	300	4000	10	1	10um:	2x10**7	5x10**11
					100um:	2x10**4	5x10**8
					1um:	2x10**11	5x10**15
100,000	3000	40,000	100	10	10um:	2x10**8	5x10**12
					100um:	2x10**5	5x10**9
					1um:	2x10**12	5x10**16
1×10^6	30,000	400,000	1000	100	10um:	2x10**9	5x10**13
					100um:	2x10**6	5x10**10

NOTE: PPM, Volume %, #/cc, and $\#/ft^3$ assume a particle density of 1 g/cc.

Conversions:

$g/cm^3 \times 10^9$	$= mg/m^3$
$g/m^3 \times 0.0283$	$= g/ft^3$
$g/m^3 \times 10^{-6}$	$= g/cm^3$
$2.3\ g/m^3$	$= grains/ft^3$
1 ppm	$= 1/10^6$

diameter	volume
1um	$5x10^{-13}\ cm^3$
10um	$5x10^{-10}\ cm^3$
100um	$5x10^{-7}\ cm^3$

7/1988

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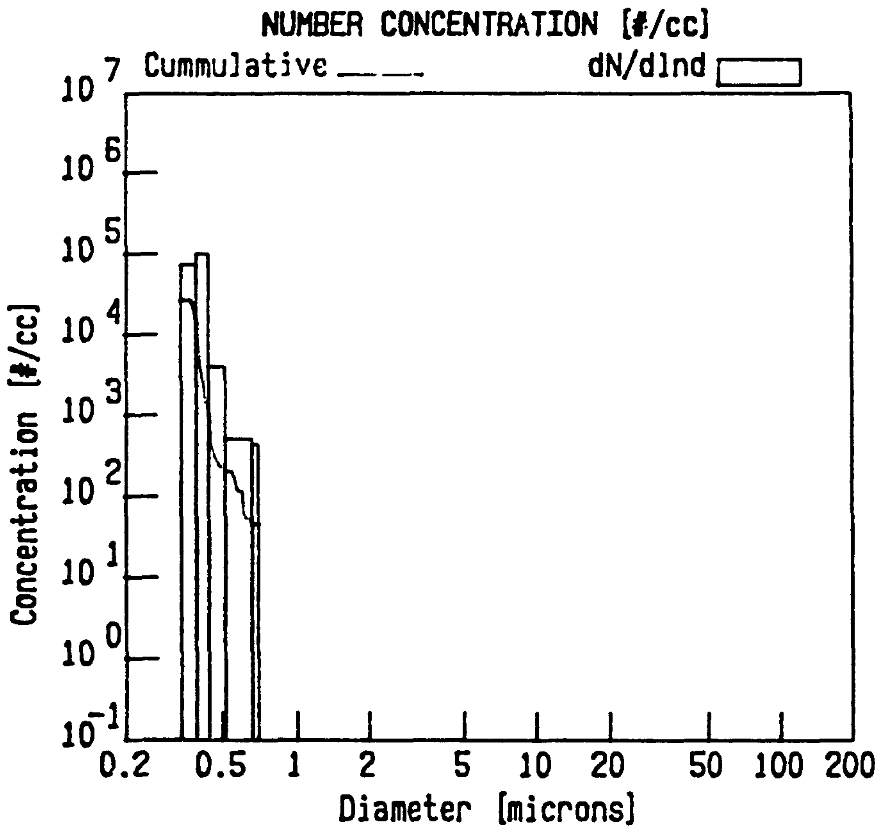
APPENDIX B - CHRONOLOGICAL SEQUENCE OF ALL TEST RUNS AND CROSS COMPARISON PLOTS

The following figures give a representative record of measurements obtained at the Nevada Test Site; not all data files have been plotted. Files that were not plotted were considered to be similar to those presented, or in a few cases were deemed to be "bad" data files. The following Table I is repeated from the main text and lists data files in sequence:

TABLE I NEVADA TEST SITE (NTS) DATA LIST AND DESCRIPTION; UPSTREAM POSITION (10 FT DOWNSTREAM OF RELEASE ORIFICE)

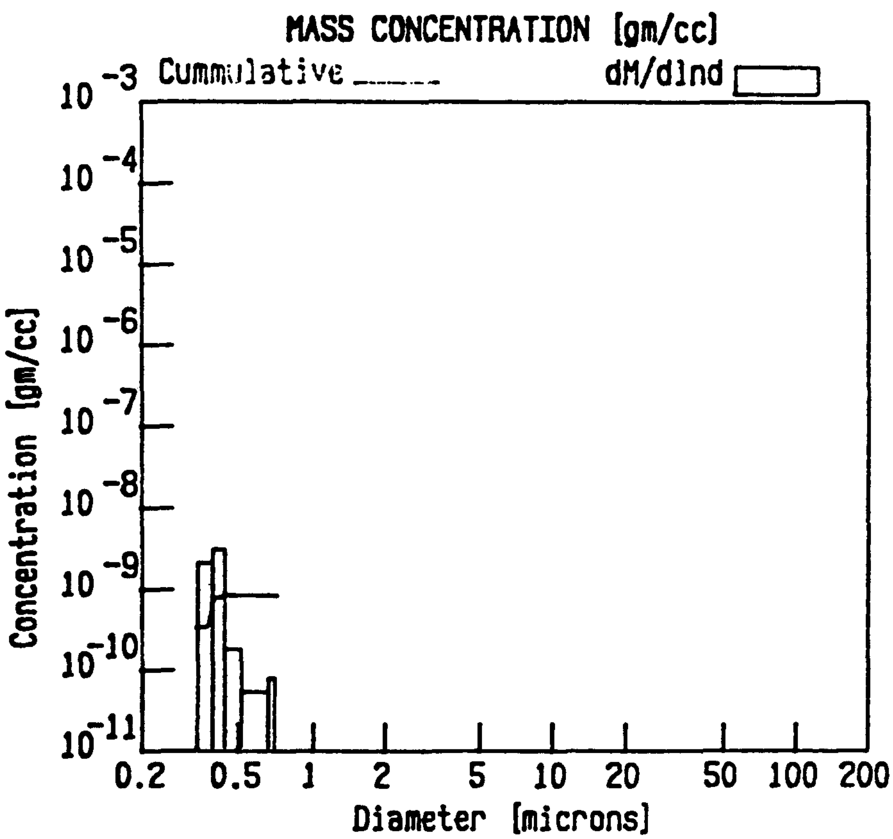
Filename	Pos	Trans	Valid	Disc	Water	Type	Temp(F)	Press	RH
NTS41A	edge	112	49	45	na	HF	99	32	50
NTS41B	edge	109	49	50					
NTS41C	edge	75	52	51					
NTS42A	edge	101	48	50	na	HF	102	63	50
NTS42B	edge	95	54	53					
NTS42C	center	112	48	52					
NTS42D	center	110	60	55					
NTS43WB	1'	84	82	40	only	na	na	na	na

INSITEC Particle Counter Sizer Velocimeter



File : NTS41A.DAT
Date : 31-Aug-88
Time : 16:43:57
Trans. : 112 %
Valid : 49 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.39 microns

%	Diam	Cum Numb
99.9	0.36	2.77e+04
99.0	0.36	2.74e+04
90.0	0.37	2.49e+04
70.0	0.37	1.94e+04
50.0	0.38	1.38e+04
30.0	0.39	8.31e+03
10.0	0.40	2.77e+03
1.0	0.46	2.77e+02
0.1	0.71	2.77e+01

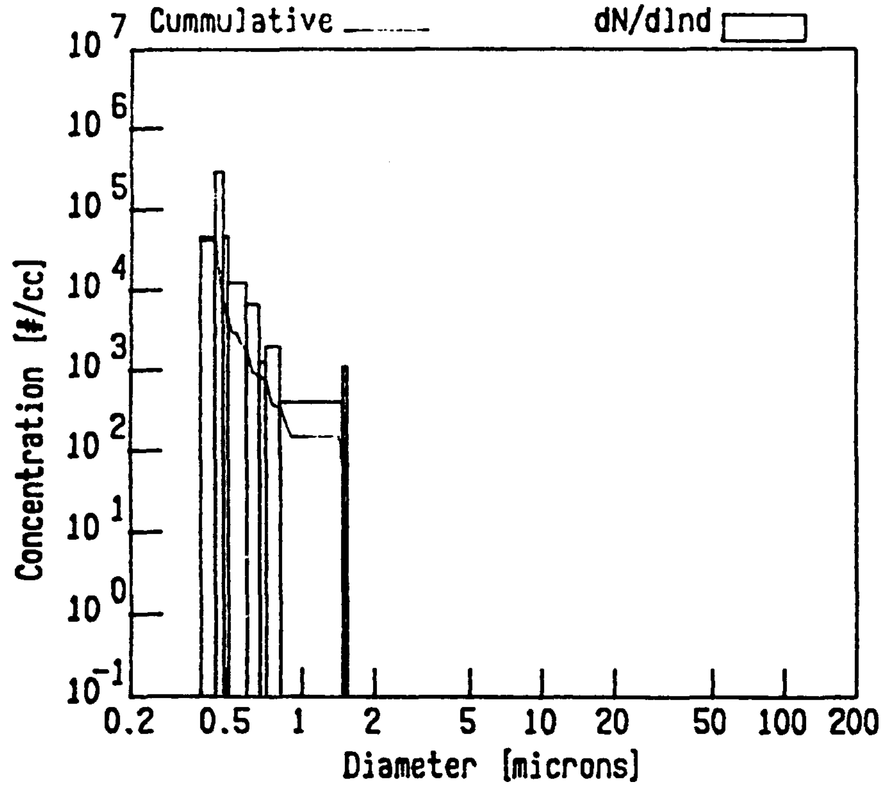


File : NTS41A.DAT
Date : 31-Aug-88
Time : 16:43:57
Trans. : 112 %
Valid : 49 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.39 microns

%	Diam	Cum Mass
99.9	0.71	8.74e-10
99.0	0.64	8.67e-10
90.0	0.41	7.88e-10
70.0	0.39	6.13e-10
50.0	0.38	4.38e-10
30.0	0.37	2.63e-10
10.0	0.37	8.75e-11
1.0	0.36	8.75e-12
0.1	0.36	8.75e-13

INSITEC Particle Counter Sizer Velocimeter

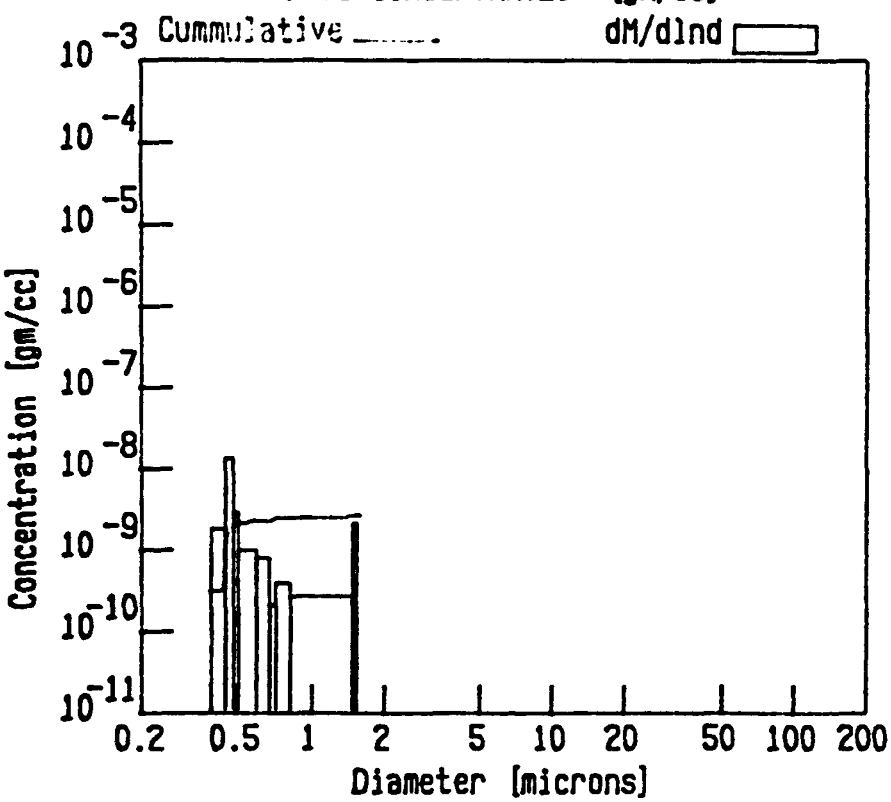
NUMBER CONCENTRATION [#/cc]



File	: NTS41B.DAT	
Date	: 31-Aug-88	
Time	: 16:45:35	
Trans.	: 109 %	
Valid	: 49 %	
Speed	: 3.20	± 0.00
Density	: 1.00	gm/cc
D32	: 0.51	microns

%	Diam	Cum Numb
99.9	0.43	4.59e+04
99.0	0.43	4.55e+04
90.0	0.44	4.14e+04
70.0	0.44	3.22e+04
50.0	0.45	2.30e+04
30.0	0.45	1.38e+04
10.0	0.49	4.60e+03
1.0	0.71	4.60e+02
0.1	1.56	4.60e+01

MASS CONCENTRATION [gm/cc]

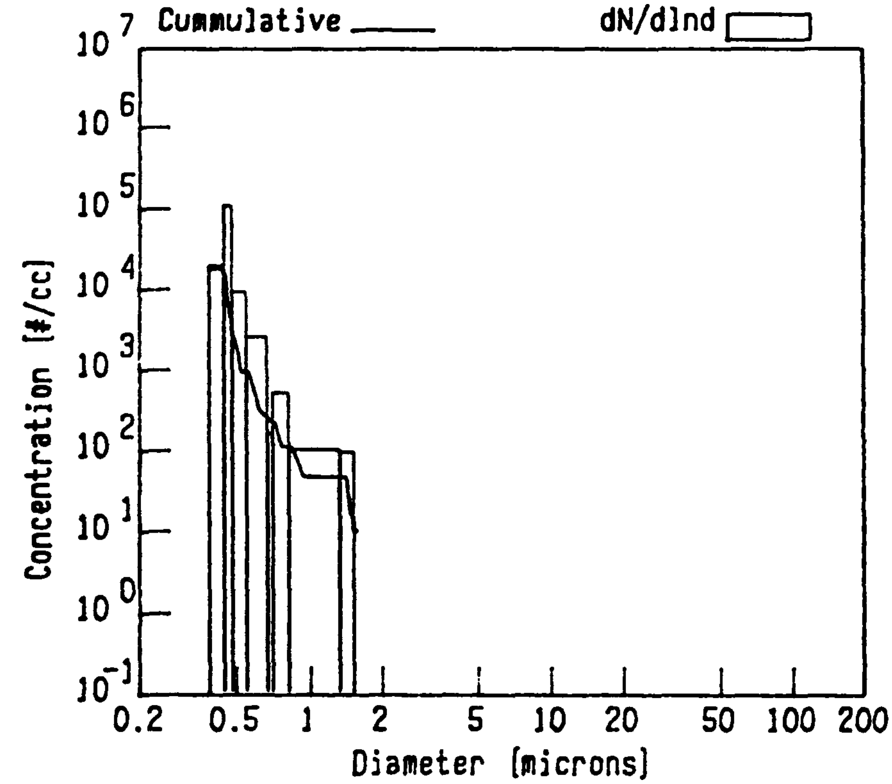


File	: NTS41B.DAT	
Date	: 31-Aug-88	
Time	: 16:45:35	
Trans.	: 109 %	
Valid	: 49 %	
Speed	: 3.20	± 0.00
Density	: 1.00	gm/cc
D32	: 0.51	microns

%	Diam	Cum Mass
99.9	1.57	2.78e-09
99.0	1.56	2.75e-09
90.0	0.81	2.50e-09
70.0	0.48	1.95e-09
50.0	0.45	1.39e-09
30.0	0.45	8.35e-10
10.0	0.44	2.78e-10
1.0	0.43	2.78e-11
0.1	0.43	2.78e-12

INSITEC Particle Counter Sizer Velocimeter

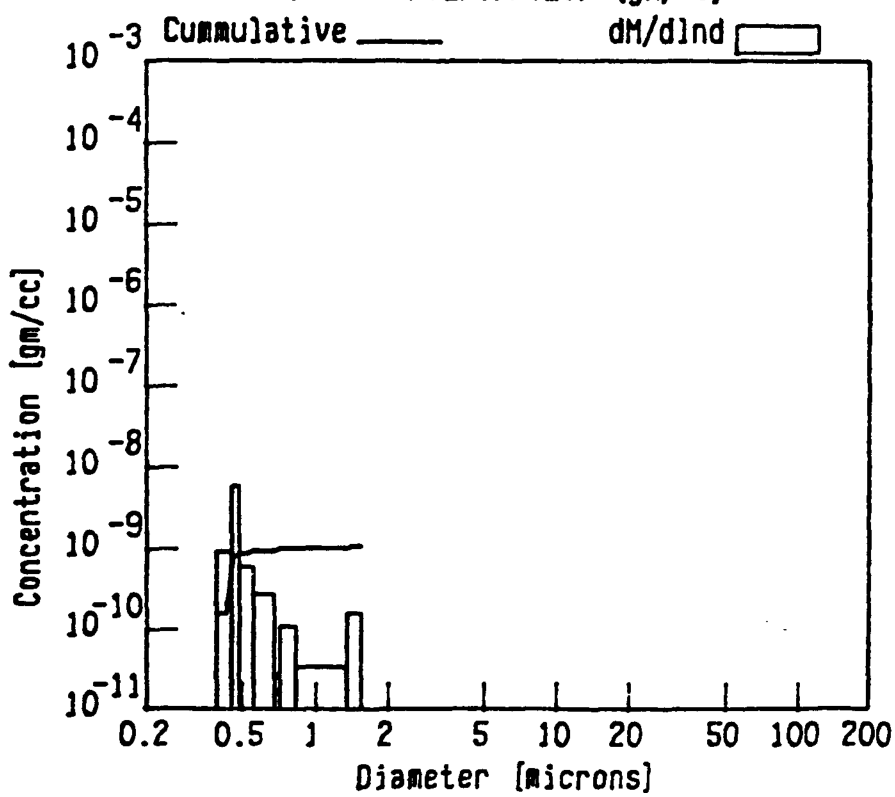
NUMBER CONCENTRATION [#/cc]



File : NTS42A.DAT
Date : 31-Aug-88
Time : 17:32:13
Trans. : 101 %
Valid : 48 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.50 microns

%	Diam	Cum Numb
99.9	0.43	1.81e+04
99.0	0.43	1.79e+04
90.0	0.44	1.63e+04
70.0	0.45	1.27e+04
50.0	0.45	9.06e+03
30.0	0.46	5.44e+03
10.0	0.49	1.81e+03
1.0	0.71	1.81e+02
0.1	1.48	1.81e+01

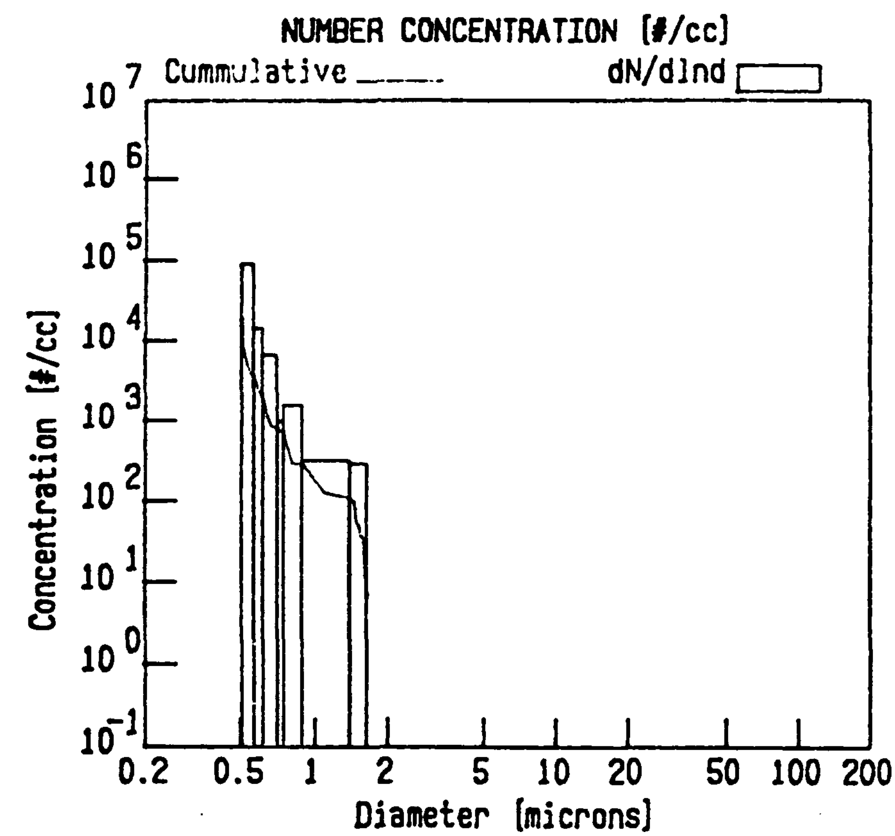
MASS CONCENTRATION [gm/cc]



File : NTS42A.DAT
Date : 31-Aug-88
Time : 17:32:13
Trans. : 101 %
Valid : 48 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.50 microns

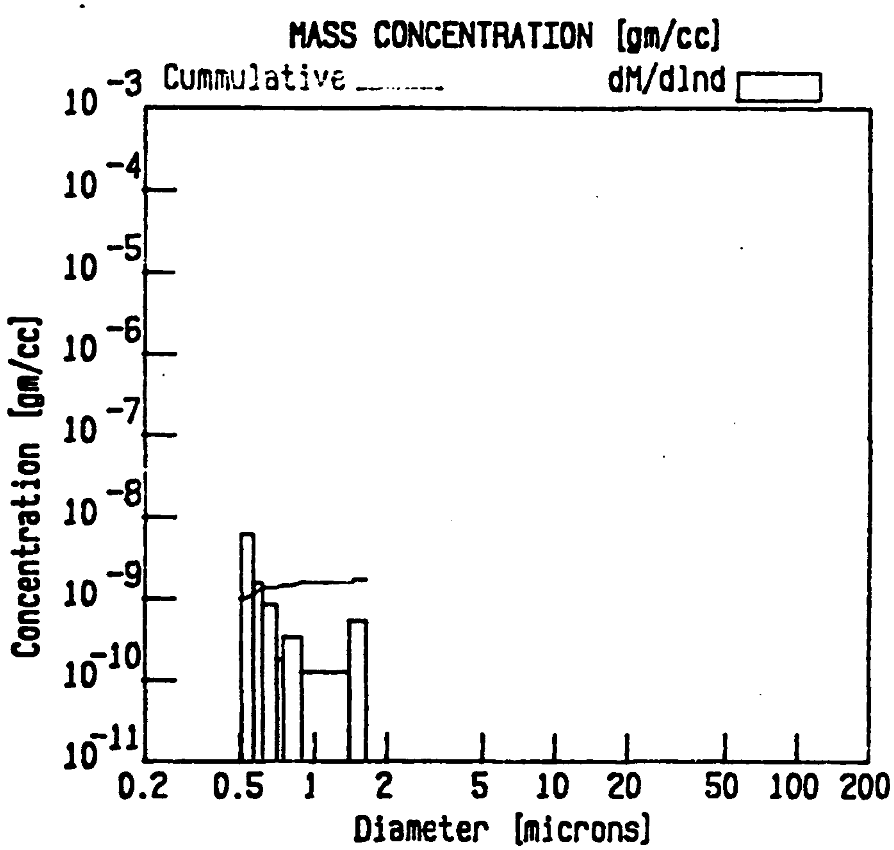
%	Diam	Cum Mass
99.9	1.58	1.08e-09
99.0	1.56	1.07e-09
90.0	0.72	9.73e-10
70.0	0.47	7.56e-10
50.0	0.45	5.40e-10
30.0	0.45	3.24e-10
10.0	0.44	1.08e-10
1.0	0.43	1.08e-11
0.1	0.43	1.08e-12

INSITEC Particle Counter Sizer Velocimeter



File : NTS42B.DAT
Date : 31-Aug-88
Time : 17:34:05
Trans. : 95 %
Valid : 54 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.59 microns

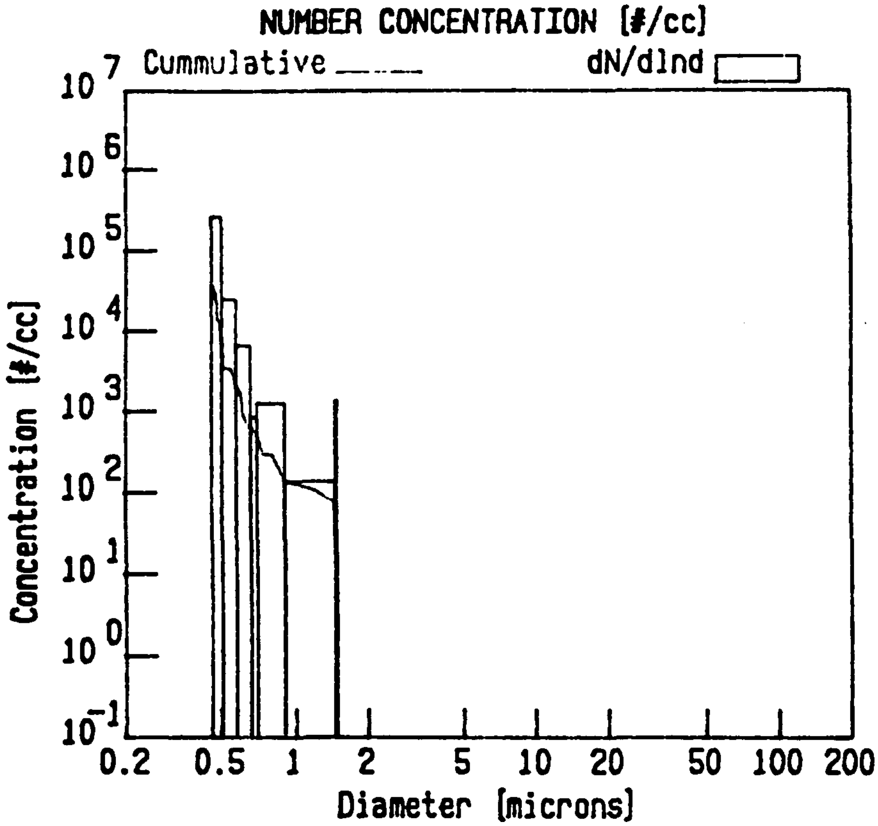
%	Diam	Cum Numb
99.9	0.50	1.92e+04
99.0	0.50	1.90e+04
90.0	0.50	1.73e+04
70.0	0.50	1.34e+04
50.0	0.50	9.59e+03
30.0	0.51	5.76e+03
10.0	0.60	1.92e+03
1.0	0.80	1.92e+02
0.1	1.58	1.92e+01



File : NTS42B.DAT
Date : 31-Aug-88
Time : 17:34:05
Trans. : 95 %
Valid : 54 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.59 microns

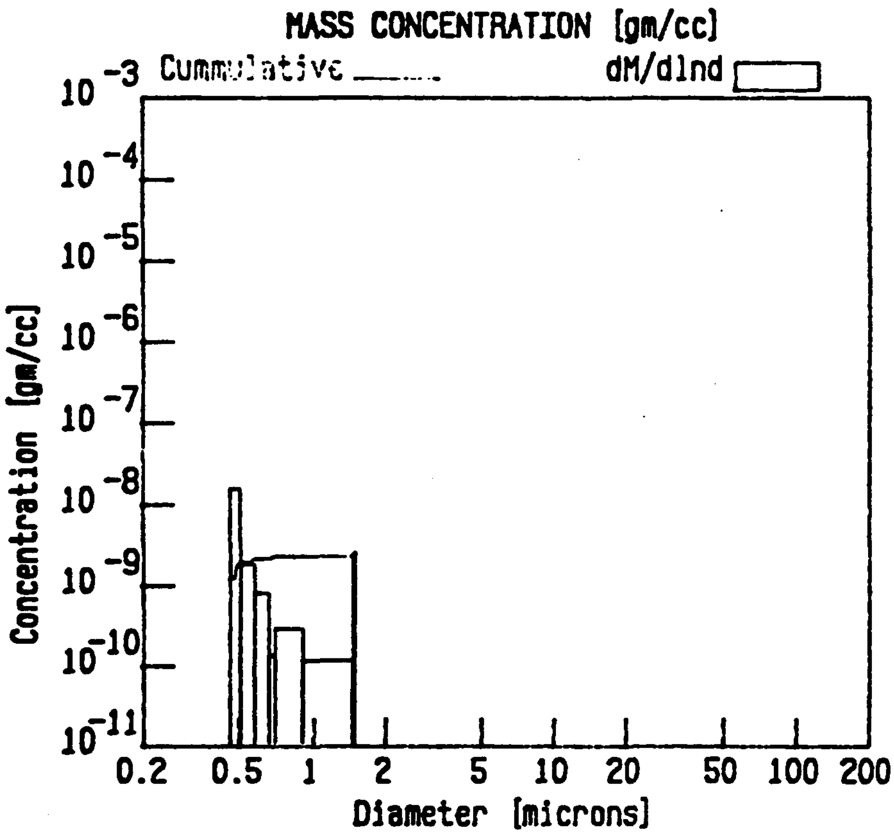
%	Diam	Cum Mass
99.9	1.64	1.76e-09
99.0	1.60	1.75e-09
90.0	1.43	1.59e-09
70.0	0.59	1.24e-09
50.0	0.52	8.83e-10
30.0	0.51	5.30e-10
10.0	0.50	1.77e-10
1.0	0.50	1.77e-11
0.1	0.50	1.77e-12

INSITEC Particle Counter Sizer Velocimeter



File : NTS42C.DAT
Date : 31-Aug-88
Time : 17:37:30
Trans. : 112 %
Valid : 48 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.52 microns

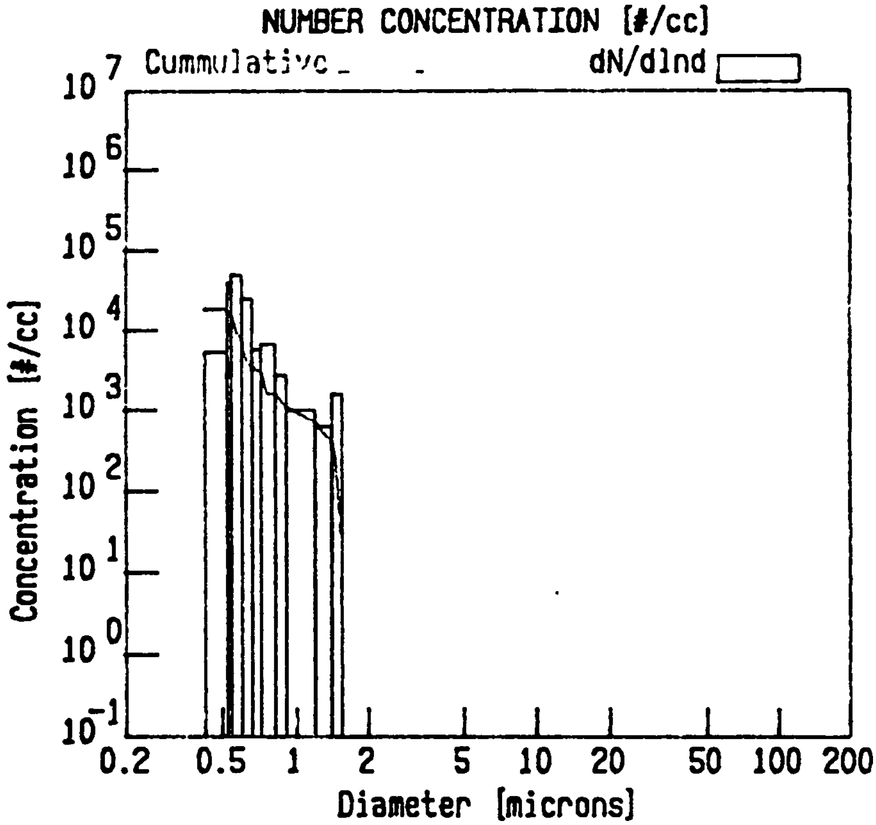
%	Diam	Cum Numb
99.9	0.46	3.73e+04
99.0	0.46	3.69e+04
90.0	0.46	3.36e+04
70.0	0.47	2.61e+04
50.0	0.47	1.87e+04
30.0	0.48	1.12e+04
10.0	0.50	3.73e+03
1.0	0.70	3.73e+02
0.1	1.49	3.73e+01



File : NTS42C.DAT
Date : 31-Aug-88
Time : 17:37:30
Trans. : 112 %
Valid : 48 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.52 microns

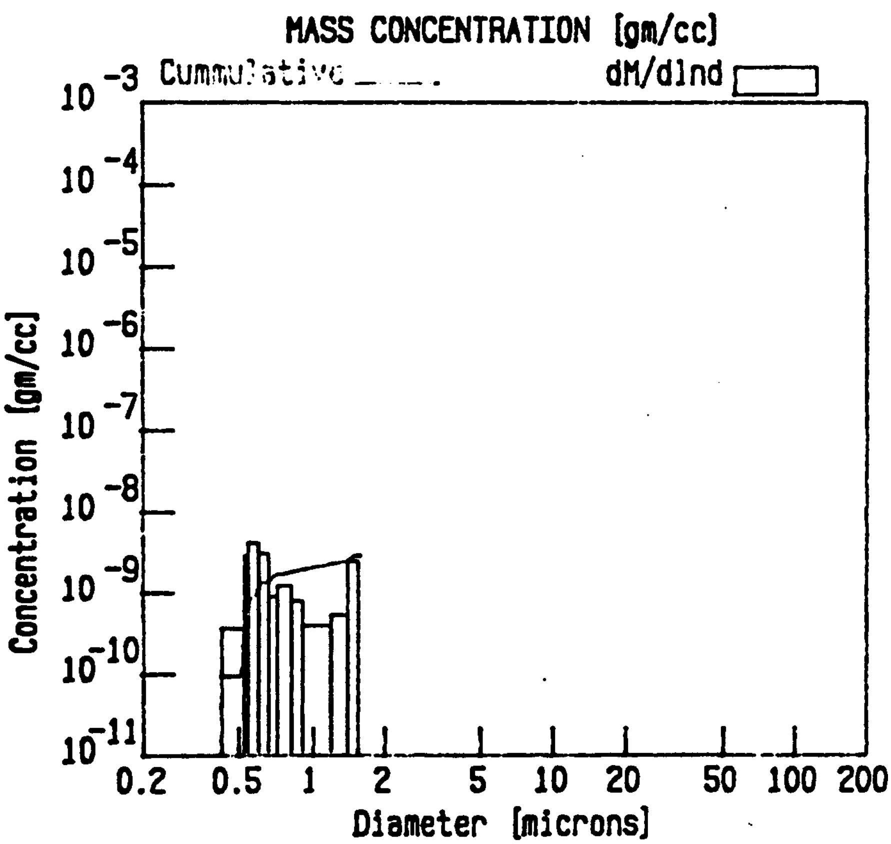
%	Diam	Cum Mass
99.9	1.50	2.49e-09
99.0	1.49	2.47e-09
90.0	0.68	2.25e-09
70.0	0.49	1.75e-09
50.0	0.48	1.25e-09
30.0	0.47	7.48e-10
10.0	0.46	2.49e-10
1.0	0.46	2.49e-11
0.1	0.46	2.49e-12

INSITEC Particle Counter Sizer Velocimeter



File : NTS42D.DAT
Date : 31-Aug-88
Time : 17:41:19
Trans. : 110 %
Valid : 60 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.74 microns

%	Diam	Cum Numb
99.9	0.49	1.89e+04
99.0	0.49	1.87e+04
90.0	0.50	1.70e+04
70.0	0.52	1.32e+04
50.0	0.54	9.44e+03
30.0	0.60	5.66e+03
10.0	0.71	1.89e+03
1.0	1.43	1.89e+02
0.1	1.55	1.89e+01

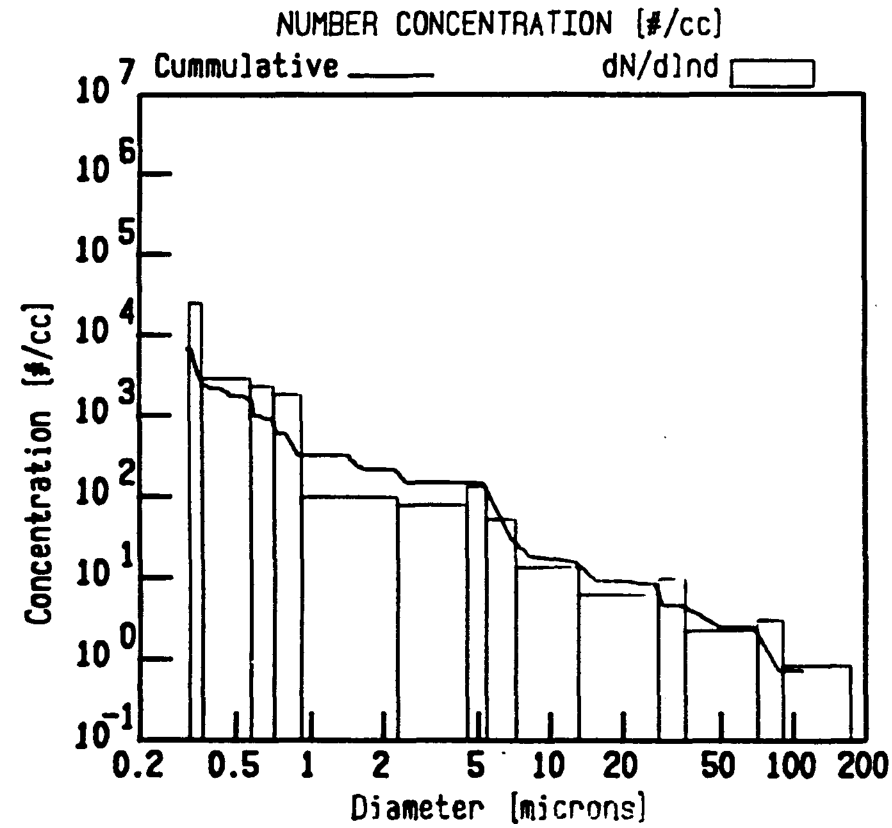


File : NTS42D.DAT
Date : 31-Aug-88
Time : 17:41:19
Trans. : 110 %
Valid : 60 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 0.74 microns

%	Diam	Cum Mass
99.9	1.56	2.95e-09
99.0	1.55	2.92e-09
90.0	1.43	2.66e-09
70.0	0.92	2.07e-09
50.0	0.66	1.48e-09
30.0	0.56	8.85e-10
10.0	0.52	2.95e-10
1.0	0.49	2.95e-11
0.1	0.49	2.95e-12

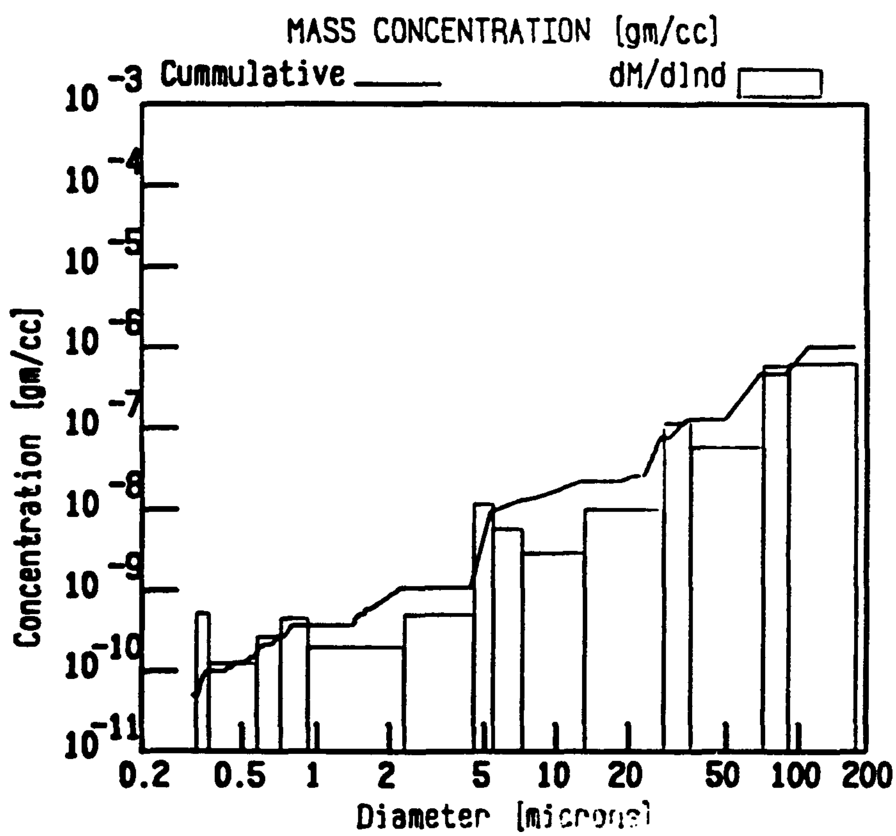
INSITEC Particle Counter Sizer Velocimeter

Water spray only, downstream



File : NTS43WB.DAT
Date : 01-Sep-88
Time : 16:16:40
Trans. : 84 %
Valid : 82 %
Speed : 2.55 ± 0.45
Density: 1.00 gm/cc
D32 : 61.28 microns

%	Diam	Cum Numb
99.9	0.33	6.57e+03
99.0	0.33	6.51e+03
90.0	0.34	5.92e+03
70.0	0.34	4.60e+03
50.0	0.35	3.29e+03
30.0	0.47	1.97e+03
10.0	0.71	6.57e+02
1.0	4.88	6.57e+01
0.1	26.93	6.57e+00



File : NTS43WB.DAT
Date : 01-Sep-88
Time : 16:16:40
Trans. : 84 %
Valid : 82 %
Speed : 2.55 ± 0.45
Density: 1.00 gm/cc
D32 : 61.28 microns

%	Diam	Cum Mass
99.9	112.90	1.03e-06
99.0	112.55	1.02e-06
90.0	109.06	9.27e-07
70.0	101.29	7.21e-07
50.0	93.52	5.15e-07
30.0	62.41	3.09e-07
10.0	33.65	1.03e-07
1.0	5.88	1.03e-08
0.1	2.28	1.03e-09

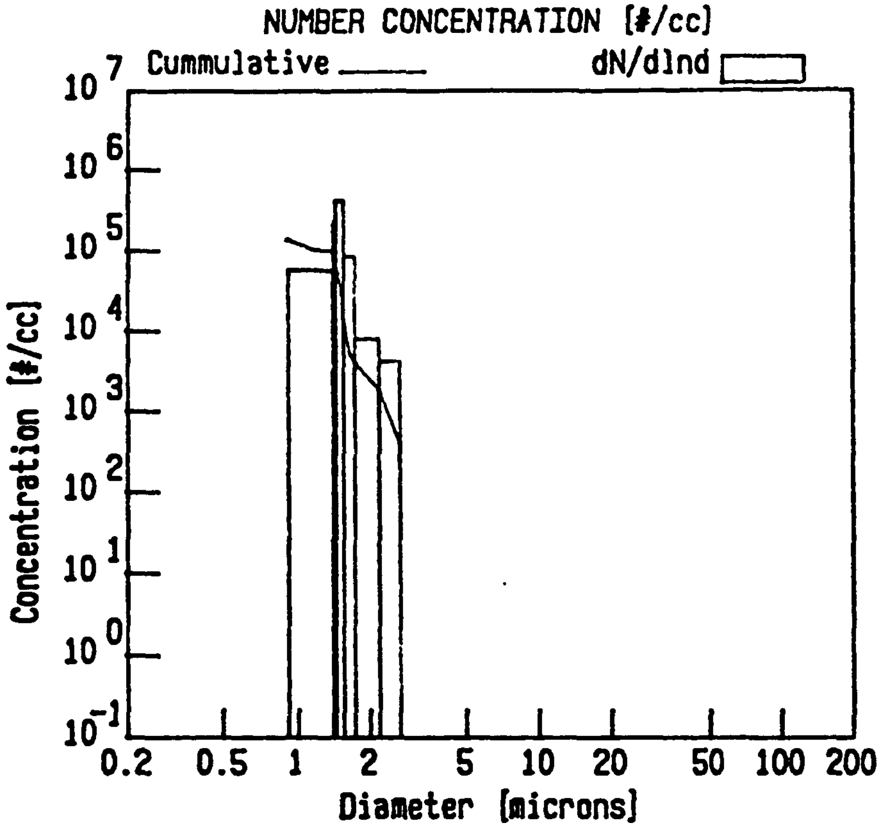
TABLE IA NEVADA TEST SITE (NTS) DATA LIST AND DESCRIPTION;
DOWNSTREAM POSITION (55 FT DOWNSTREAM OF RELEASE ORIFICE)

Filename	Pos	Trans	Valid	Disc	Water	Type	Temp(F)	Press	RH
NTS49A	1'	92	73	65	no	HF	87	71	50
NTS49B	1'	87	74	65					
NTS49C	1'	94	72	60					
NTS49D	2'	60	74	60					
NTS49E	2'	83	77	65					
NTS49F	3'	60	82	70					
NTS49G	3'	32	80	65					
NTS50WA	1'	82	66	45	na	na	na	na	na
NTS50WB	1'	84	63	45					
NTS50A	3'	12	48	55	yes	HF	93	71	50
NTS50B	3'	53	77	65					
NTS50C	3'	31	64	60					
NTS50D	2'	87	83	60					
NTS51A	1'	25	70	65	no	HF	95	129	50
NTS51B	1'	18	69	65					
NTS51C	2'	52	80	65					
NTS51D	2'	87	84	68					
NTS51E	2'	51	84	68					
NTS51F	3'	42	84	68					
NTS51G	3'	44	85	68					
NTS51H	3'	70	84	68					
NTS51I	3'	64	85	68					
NTS52A	3'	43	71	60	yes	HF	92	132	50
NTS52B	3'	29	80	65					
NTS52C	3'	51	81	65					
NTS52D	2'	68	74	65					
NTS52E	2'	81	75	65					
NTS52F	2'	27	75	65					
NTS52G	1'	64	74	65					
NTS52H	1'	51	77	65					
NTS52I	1'	81	77	65					
NTS52J	1'	35	74	65					
NTS53A	1'	97	77	65	no	HF	96	61	Low
NTS53B	1'	94	77	65					
NTS53C	1'	101	78	60					
NTS53D	2'	84	75	65					
NTS53E	2'	94	79	65					
NTS53F	3'	100	80	65					
NTS53G	3'	101	81	65					
NTS53H	3'	77	80	65					

TABLE IA (continued)

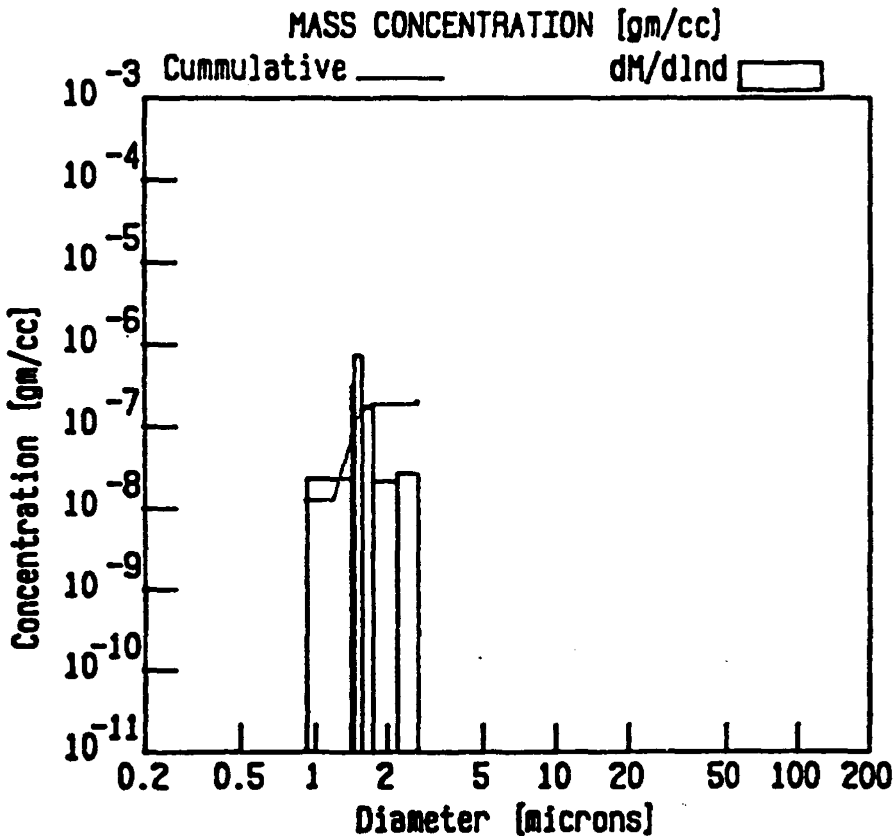
Filename	Pos	Trans	Valid	Disc	Water	Type	Temp(F)	Press	RH
NTS54A	3'	32	68	65	no	AUA	86	143	50
NTS54B	3'	69	70	65					
NTS54C	3'	44	74	68					
NTS54D	3'	31	77	68					
NTS54E	2'	65	84	68					
NTS54F	2'	99	77	65					
NTS54G	2'	34	83	68					
NTS54H	1'	90	71	68					
NTS54I	1'	101	71	68					
NTS54J	1'	49	71	68					
NTS55A	1'	79	74	65	yes	AUA	82	145	50
NTS55B	1'	36	79	68					
NTS55C	1'	40	79	68					
NTS55D	1'	39	80	68					
NTS55E	2'	27	79	68					
NTS55F	2'	49	80	68					
NTS55G	2'	69	77	68					
NTS55H	3'	27	78	68					
NTS55I	3'	75	76	68					
NTS55J	3'	22	79	68					
NTS56A	3'	17	65	65	no	AUA	90	200	50
NTS56B	3'	18	63	65					
NTS56C	2'	13	56	62					
NTS56D	2'	9	57	62					
NTS56F	1'	17	54	62					
NTS57A	1'	21	70	64	yes	AUA	92	201	50
NTS57B	1'	94	74	65					
NTS57C	1'	31	76	65					
NTS57D	2'	38	80	65					
NTS57E	2'	86	82	65					
NTS57F	2'	43	81	65					
NTS57G	2'	36	86	67					
NTS57H	2'	19	87	67					
NTS57I	3'	27	79	67					
NTS57J	3'	23	81	67					
NTS57K	3'	88	78	67					
NTS57L	3'	29	80	67					
NTS57M	3'	19	78	67					

INSITEC Particle Counter Sizer Velocimeter



File : NTS49A.DAT
Date : 08-Sep-88
Time : 12:52:51
Trans. : 92 %
Valid : 73 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 1.45 microns

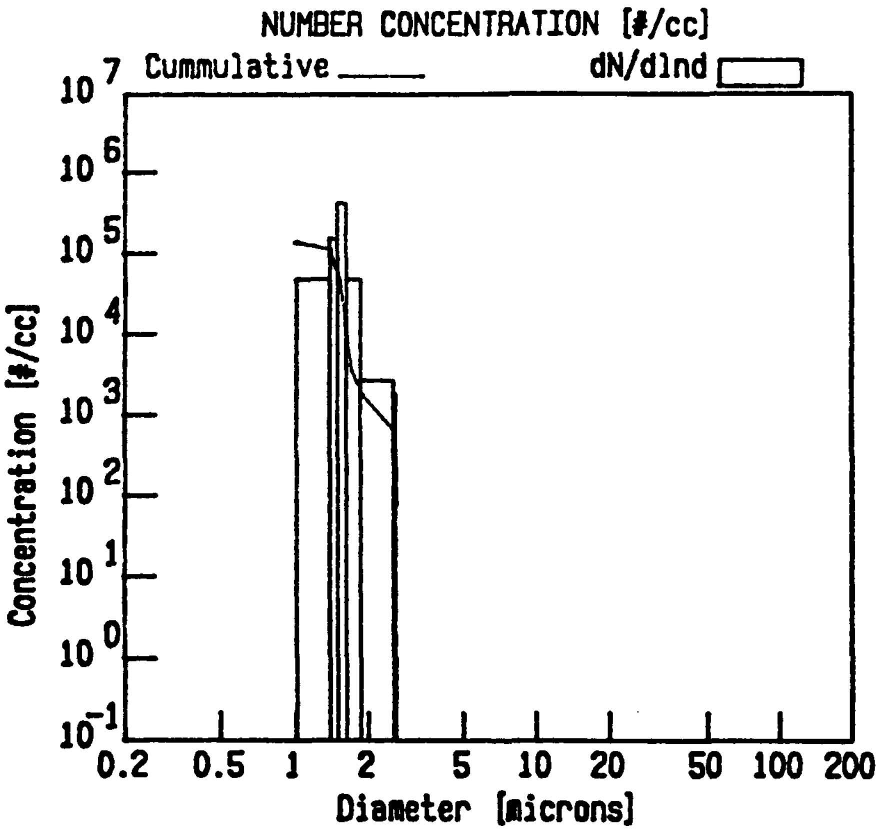
%	Diam	Cum Numb
99.9	0.91	1.33e+05
99.0	0.91	1.31e+05
90.0	0.91	1.19e+05
70.0	1.38	9.29e+04
50.0	1.40	6.64e+04
30.0	1.47	3.98e+04
10.0	1.53	1.33e+04
1.0	1.94	1.33e+03
0.1	2.62	1.33e+02



File : NTS49A.DAT
Date : 08-Sep-88
Time : 12:52:51
Trans. : 92 %
Valid : 73 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 1.45 microns

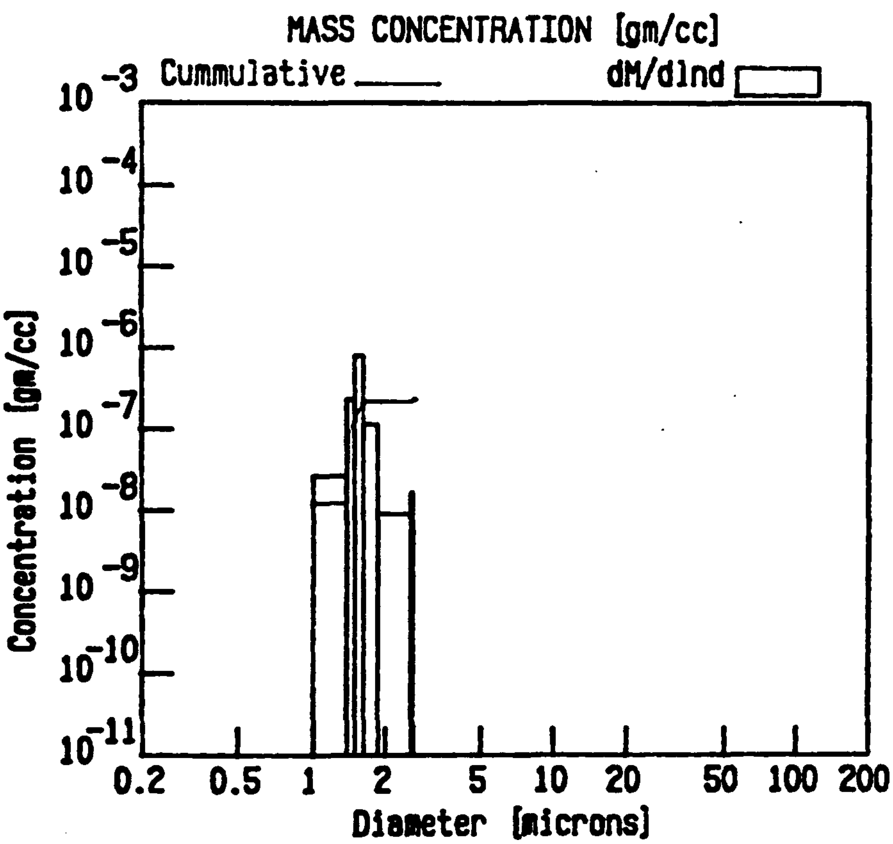
%	Diam	Cum Mass
99.9	2.64	1.92e-07
99.0	2.59	1.90e-07
90.0	1.62	1.73e-07
70.0	1.51	1.35e-07
50.0	1.46	9.62e-08
30.0	1.35	5.77e-08
10.0	1.21	1.92e-08
1.0	0.95	1.92e-09
0.1	0.91	1.92e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS49E.DAT
Date : 08-Sep-88
Time : 12:58:34
Trans. : 83 %
Valid : 77 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 1.47 microns

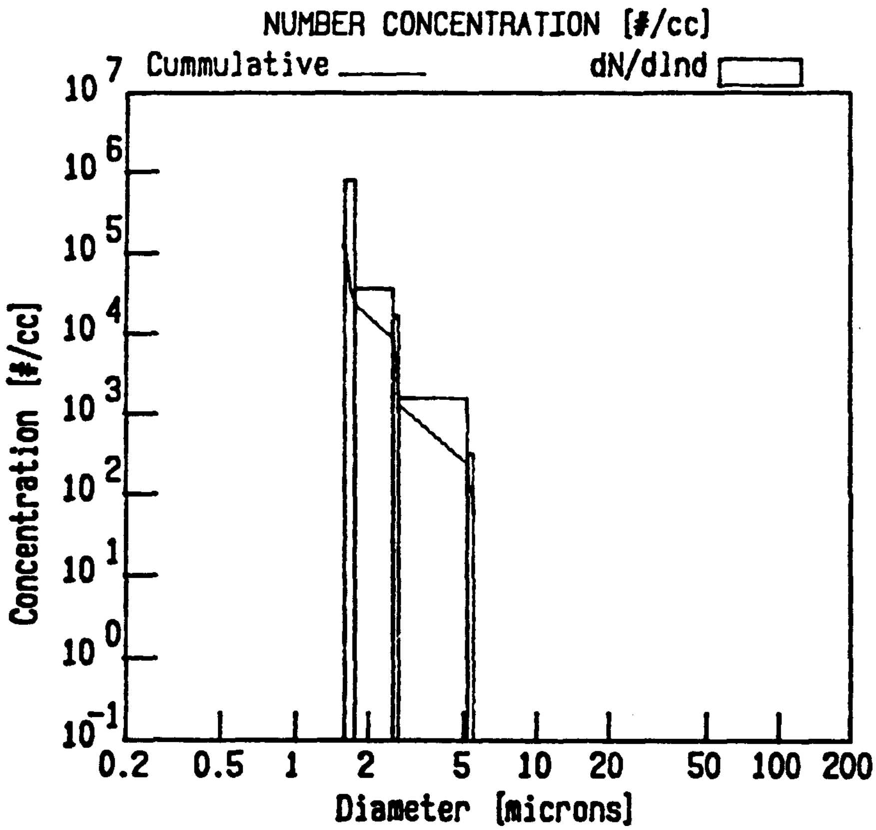
%	Diam	Cum Numb
99.9	1.00	1.44e+05
99.0	1.00	1.42e+05
90.0	1.00	1.29e+05
70.0	1.40	1.01e+05
50.0	1.42	7.19e+04
30.0	1.49	4.31e+04
10.0	1.54	1.44e+04
1.0	1.35	1.44e+03
0.1	2.57	1.44e+02



File : NTS49E.DAT
Date : 08-Sep-88
Time : 12:58:34
Trans. : 83 %
Valid : 77 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 1.47 microns

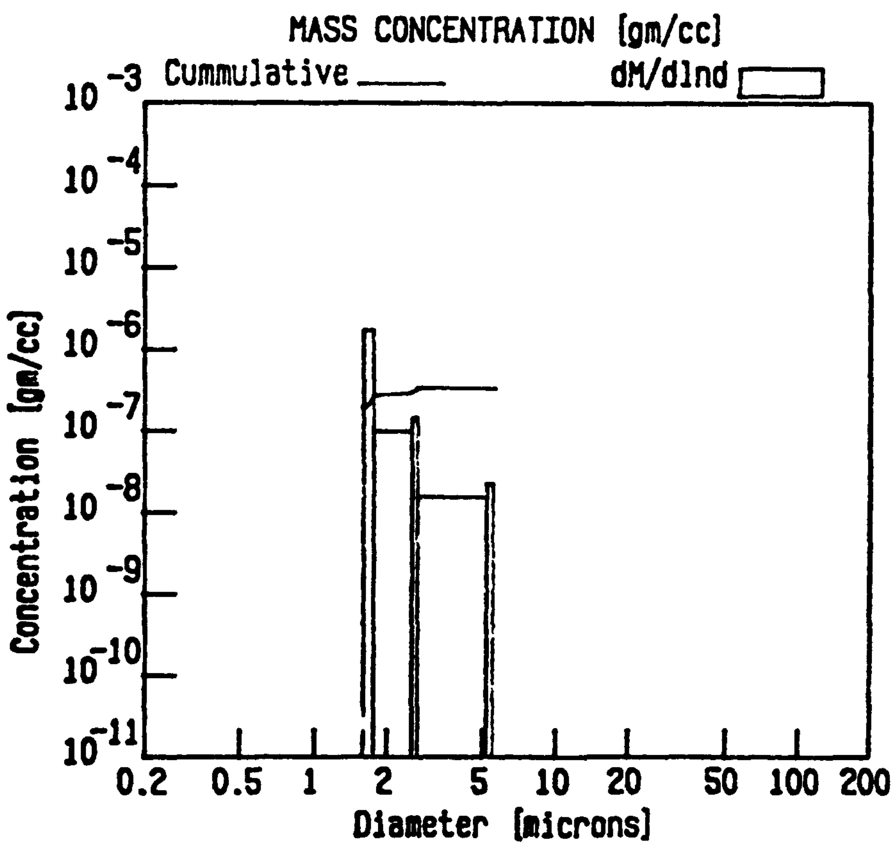
%	Diam	Cum Mass
99.9	2.60	2.24e-07
99.0	2.36	2.22e-07
90.0	1.60	2.02e-07
70.0	1.51	1.57e-07
50.0	1.46	1.12e-07
30.0	1.41	6.72e-08
10.0	1.39	2.24e-08
1.0	1.07	2.24e-09
0.1	1.01	2.24e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS49F.DAT
Date : 08-Sep-88
Time : 12:59:54
Trans. : 60 %
Valid : 82 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 1.83 microns

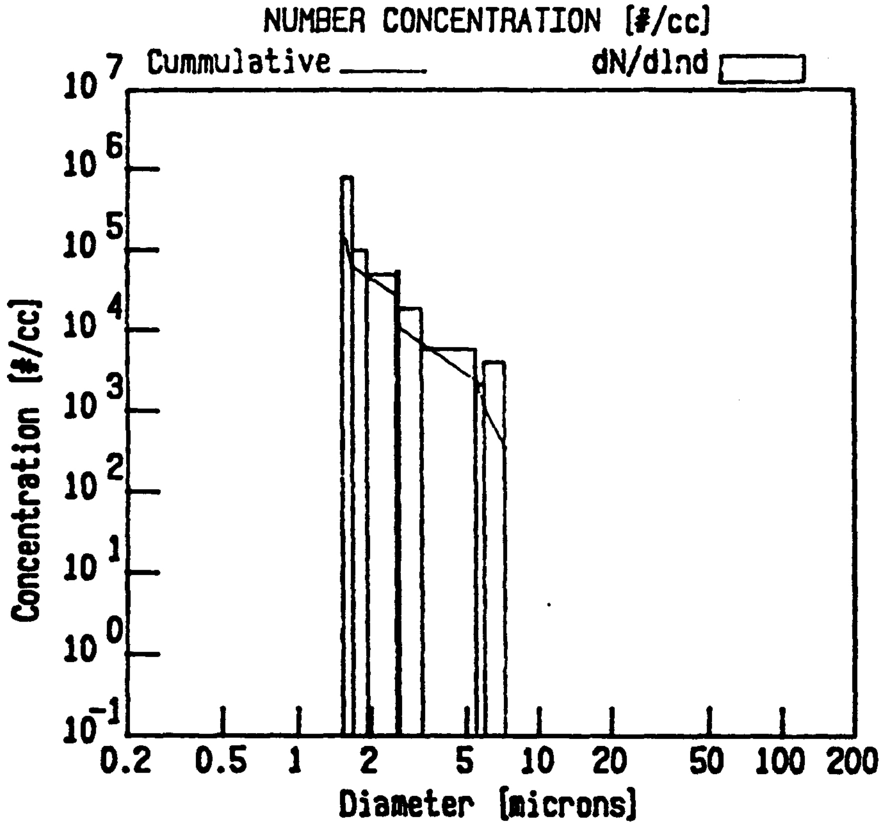
%	Diam	Cum Numb
99.9	1.58	1.24e+05
99.0	1.58	1.23e+05
90.0	1.58	1.12e+05
70.0	1.58	8.72e+04
50.0	1.59	6.23e+04
30.0	1.62	3.74e+04
10.0	1.54	1.25e+04
1.0	0.36	1.25e+03
0.1	4.97	1.25e+02



File : NTS49F.DAT
Date : 08-Sep-88
Time : 12:59:54
Trans. : 60 %
Valid : 82 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 1.83 microns

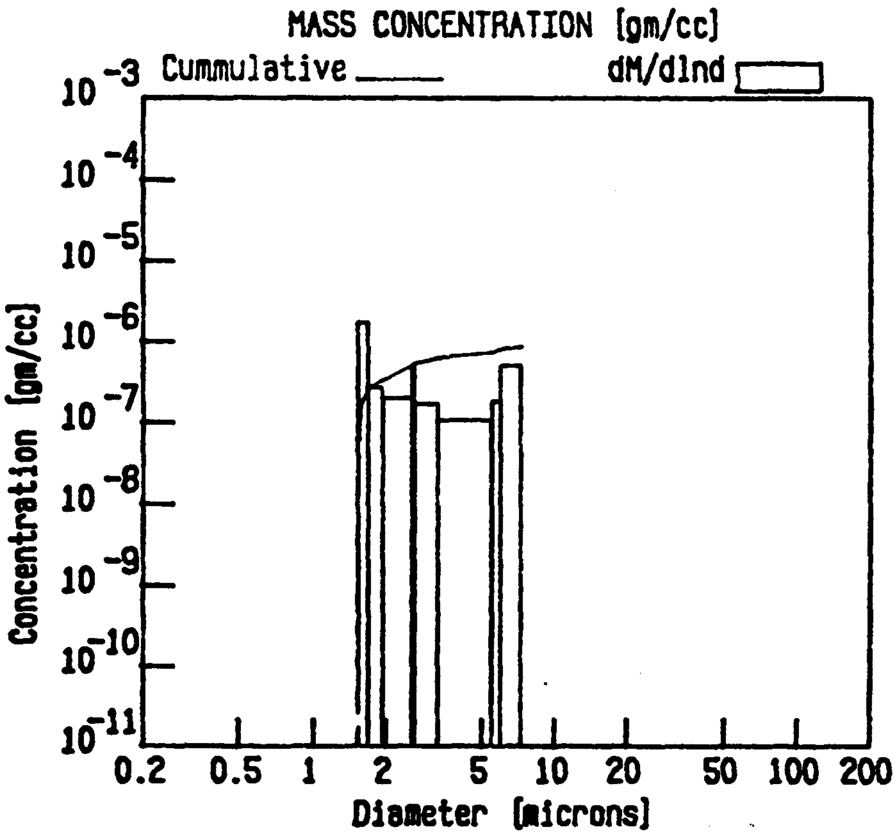
%	Diam	Cum Mass
99.9	5.42	3.50e-07
99.0	5.20	3.47e-07
90.0	2.57	3.16e-07
70.0	1.72	2.46e-07
50.0	1.62	1.75e-07
30.0	1.60	1.05e-07
10.0	1.58	3.51e-08
1.0	1.58	3.51e-09
0.1	1.58	3.51e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS49G.DAT
Date : 08-Sep-88
Time : 13:01:23
Trans. : 32 %
Valid : 80 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 2.47 microns

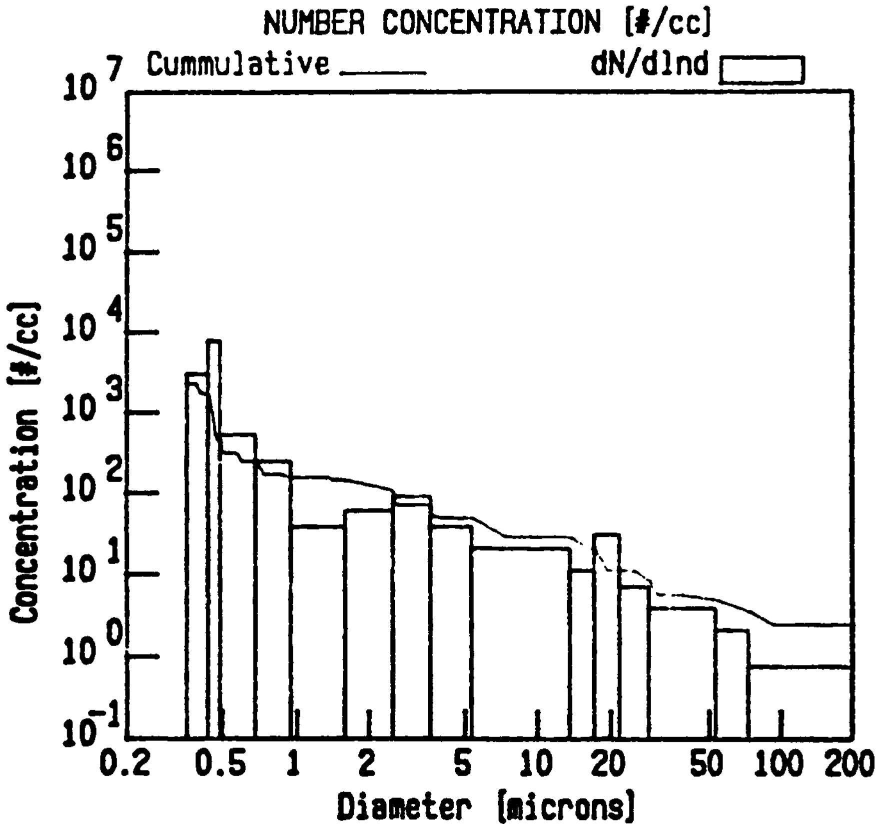
%	Diam	Cum Numb
99.9	1.52	1.74e+05
99.0	1.52	1.73e+05
90.0	1.52	1.57e+05
70.0	1.56	1.22e+05
50.0	1.58	8.72e+04
30.0	1.64	5.23e+04
10.0	2.56	1.74e+04
1.0	5.15	1.74e+03
0.1	7.08	1.74e+02



File : NTS49G.DAT
Date : 08-Sep-88
Time : 13:01:23
Trans. : 32 %
Valid : 80 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 2.47 microns

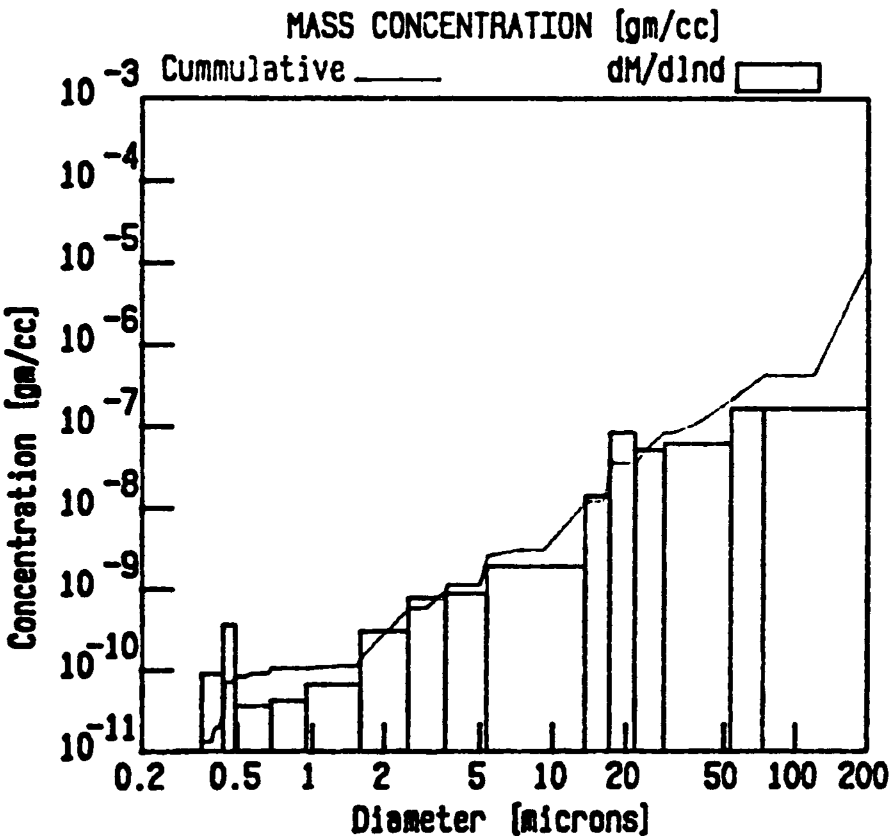
%	Diam	Cum Mass
99.9	7.10	8.52e-07
99.0	6.94	8.44e-07
90.0	5.68	7.68e-07
70.0	3.16	5.97e-07
50.0	2.29	4.27e-07
30.0	1.68	2.56e-07
10.0	1.56	8.53e-08
1.0	1.52	8.53e-09
0.1	1.52	8.53e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS50WA.DAT
Date : 08-Sep-88
Time : 13:40:44
Trans. : 82 %
Valid : 66 %
Speed : 3.00 ± 0.50
Density: 1.00 gm/cc
D32 : 172.16 microns

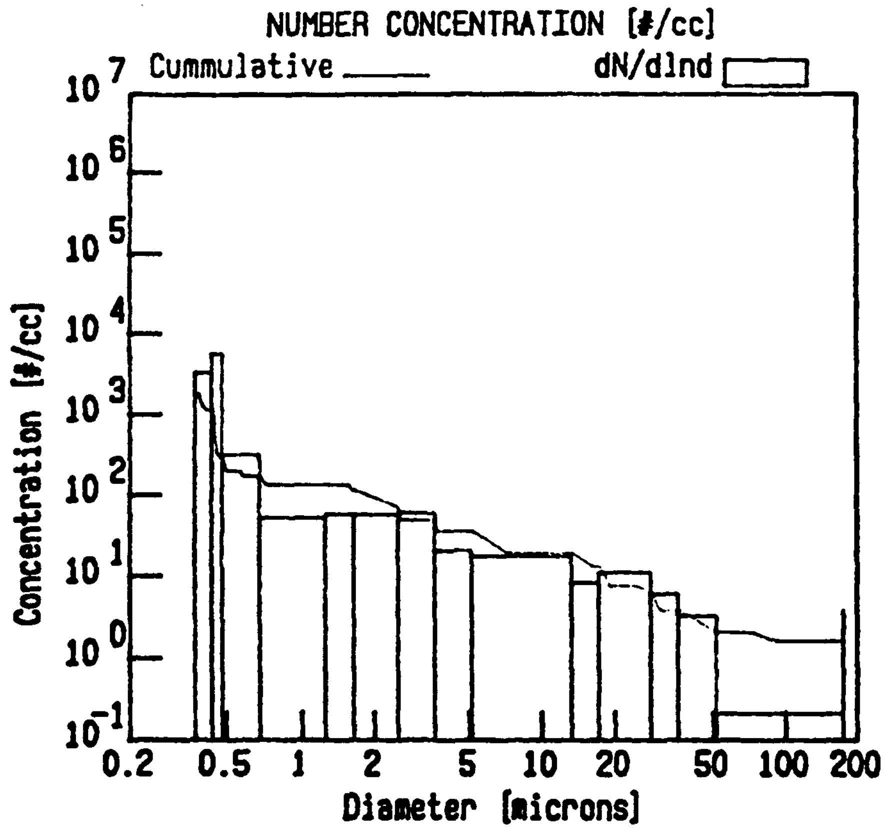
%	Diam	Cum Numb
99.9	0.37	2.36e+03
99.0	0.37	2.34e+03
90.0	0.38	2.13e+03
70.0	0.42	1.65e+03
50.0	0.43	1.18e+03
30.0	0.44	7.08e+02
10.0	0.65	2.36e+02
1.0	12.43	2.36e+01
0.1	196.70	2.36e+00



File : NTS50WA.DAT
Date : 08-Sep-88
Time : 13:40:44
Trans. : 82 %
Valid : 66 %
Speed : 3.00 ± 0.50
Density: 1.00 gm/cc
D32 : 172.16 microns

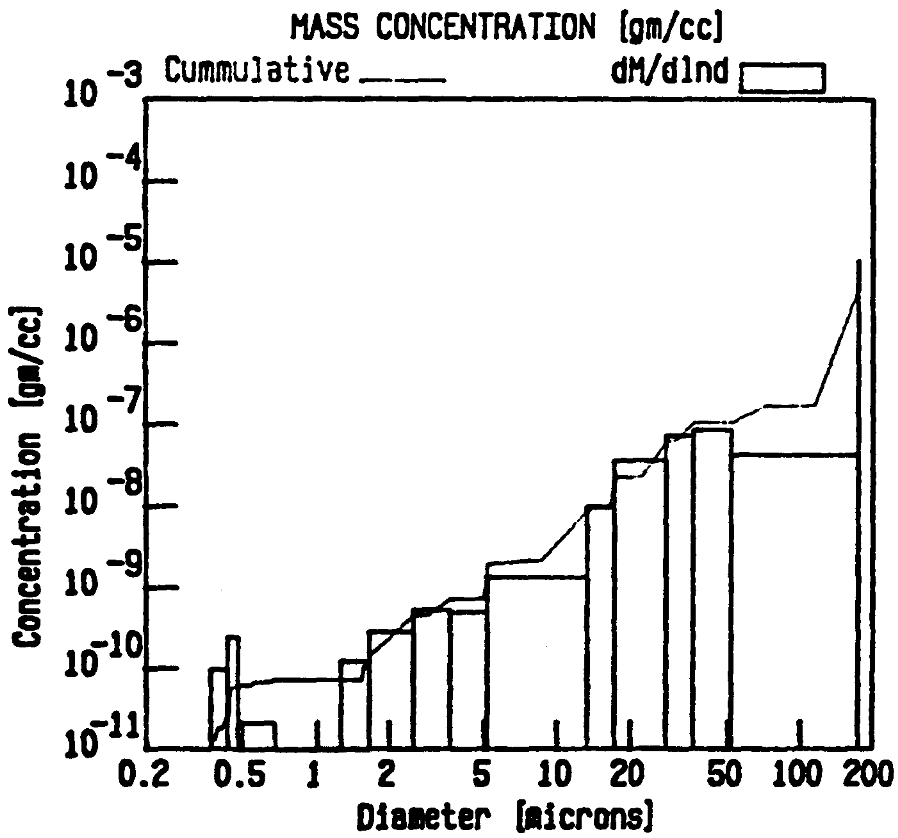
%	Diam	Cum Mass
99.9	198.43	1.10e-05
99.0	197.68	1.09e-05
90.0	190.15	9.91e-06
70.0	173.42	7.71e-06
50.0	156.70	5.51e-06
30.0	139.97	3.30e-06
10.0	123.24	1.10e-06
1.0	37.30	1.10e-07
0.1	12.70	1.10e-08

INSITEC Particle Counter Sizer Velocimeter



File : NTS50WB.DAT
Date : 08-Sep-88
Time : 13:47:36
Trans. : 84 %
Valid : 63 %
Speed : 2.49 ± 0.42
Density: 1.00 gm/cc
D32 : 148.46 microns

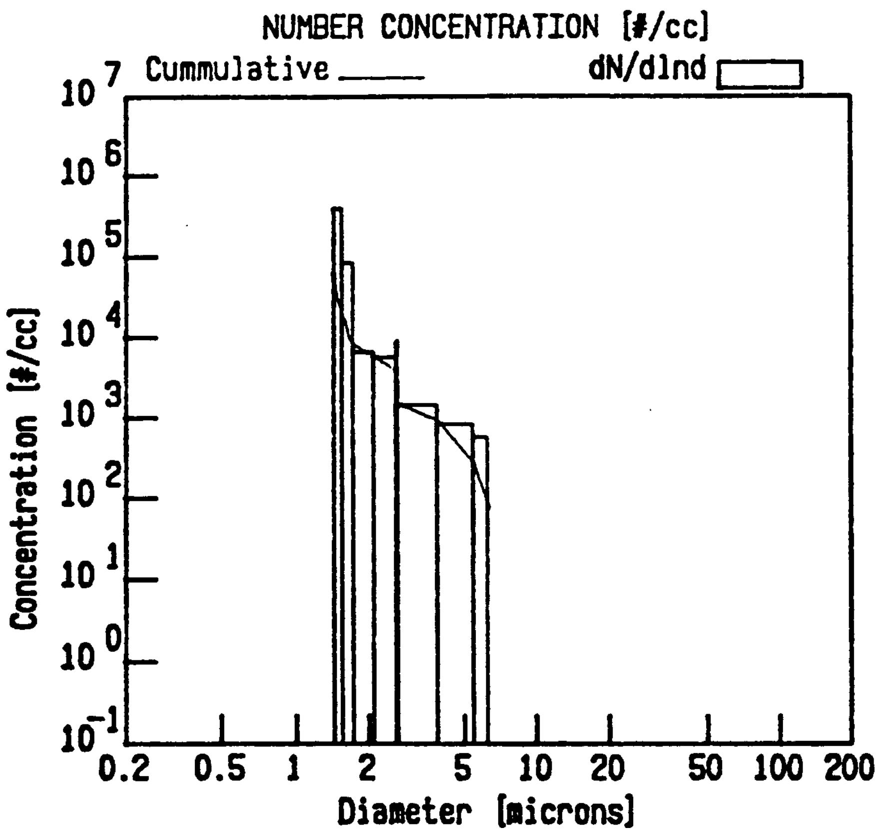
%	Diam	Cum Numb
99.9	0.37	1.81e+03
99.0	0.37	1.80e+03
90.0	0.37	1.63e+03
70.0	0.39	1.27e+03
50.0	0.43	9.08e+02
30.0	0.44	5.45e+02
10.0	0.54	1.82e+02
1.0	10.73	1.82e+01
0.1	66.28	1.82e+00



File : NTS50WB.DAT
Date : 08-Sep-88
Time : 13:47:36
Trans. : 84 %
Valid : 63 %
Speed : 2.49 ± 0.42
Density: 1.00 gm/cc
D32 : 148.46 microns

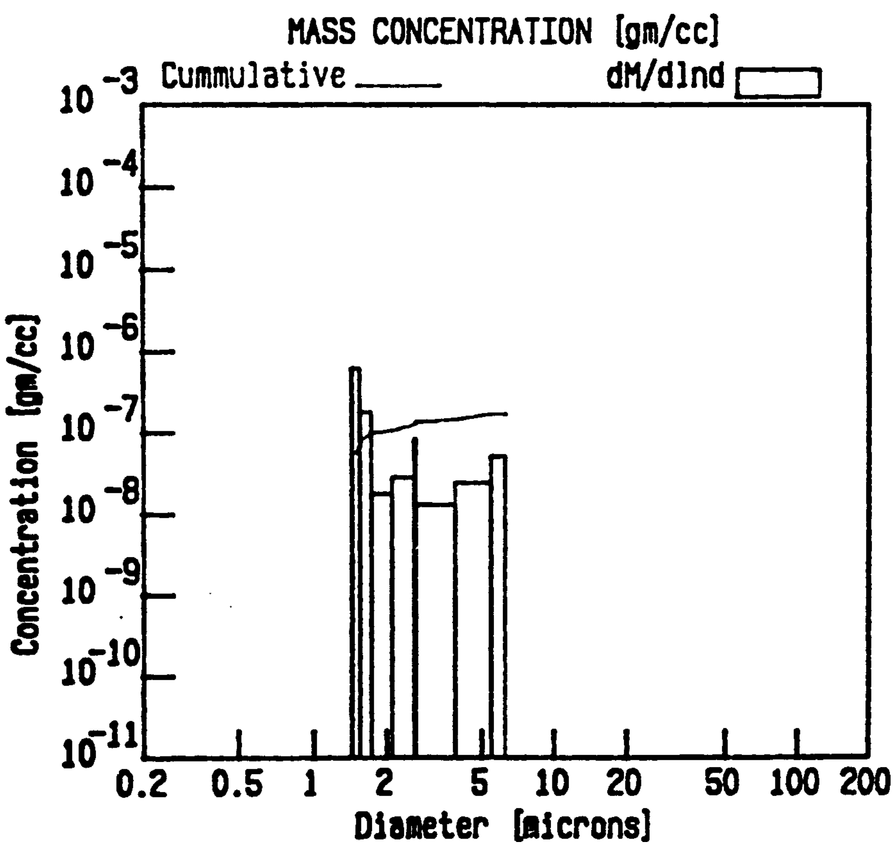
%	Diam	Cum Mass
99.9	173.05	4.86e-06
99.0	172.49	4.82e-06
90.0	166.88	4.38e-06
70.0	154.40	3.41e-06
50.0	141.92	2.43e-06
30.0	129.43	1.46e-06
10.0	116.95	4.87e-07
1.0	26.08	4.87e-08
0.1	10.31	4.87e-09

INSITEC Particle Counter Sizer Velocimeter



File : NTS50C.DAT
Date : 08-Sep-88
Time : 13:59:35
Trans. : 31 %
Valid : 64 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 1.99 microns

%	Diam	Cum Numb
99.9	1.43	6.14e+04
99.0	1.43	6.09e+04
90.0	1.43	5.53e+04
70.0	1.43	4.30e+04
50.0	1.44	3.07e+04
30.0	1.52	1.84e+04
10.0	1.68	6.15e+03
1.0	3.00	6.15e+02
0.1	6.12	6.15e+01

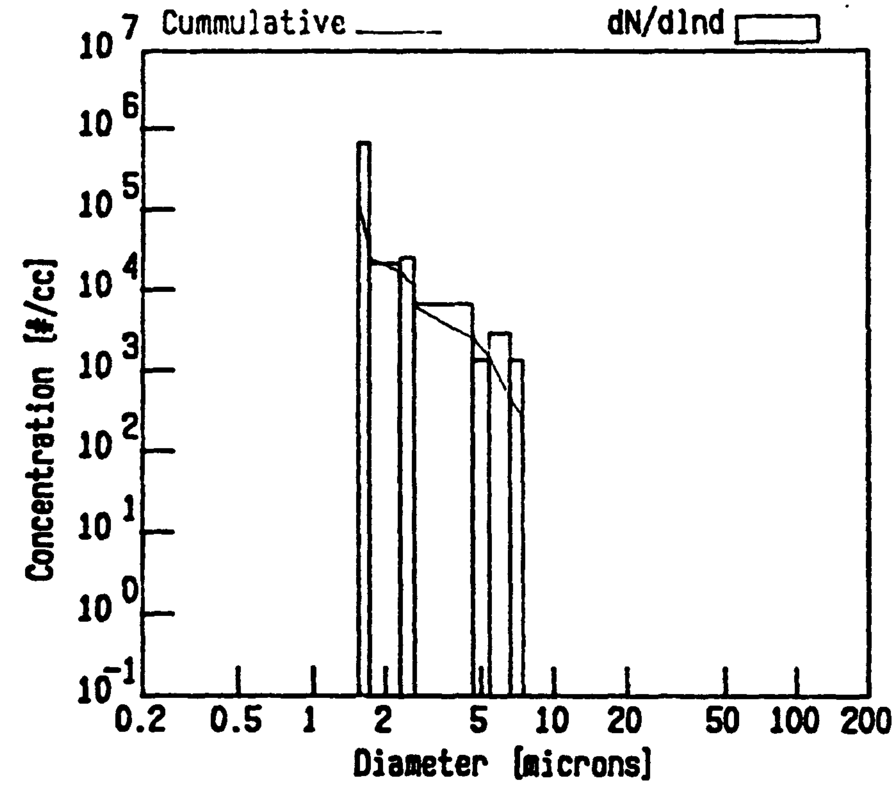


File : NTS50C.DAT
Date : 08-Sep-88
Time : 13:59:35
Trans. : 31 %
Valid : 64 %
Speed : 3.00 ± 0.00
Density: 1.00 gm/cc
D32 : 1.99 microns

%	Diam	Cum Mass
99.9	6.16	1.77e-07
99.0	6.03	1.75e-07
90.0	4.61	1.60e-07
70.0	2.50	1.24e-07
50.0	1.62	8.86e-08
30.0	1.46	5.32e-08
10.0	1.44	1.77e-08
1.0	1.43	1.77e-09
0.1	1.43	1.77e-10

INSITEC Particle Counter Sizer Velocimeter

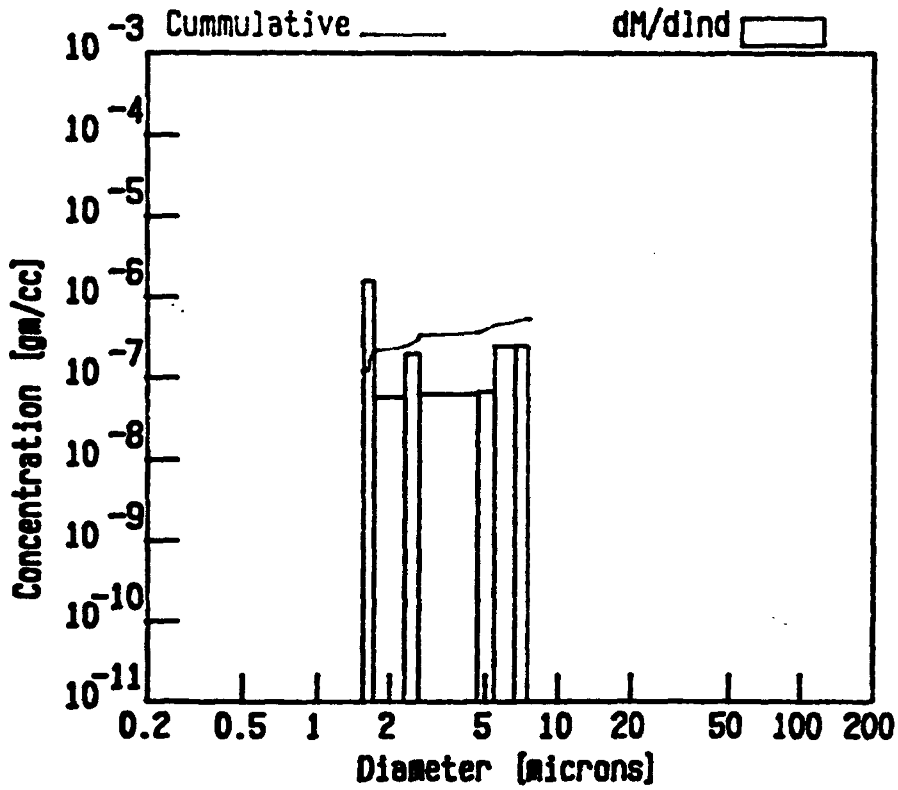
NUMBER CONCENTRATION [#/cc]



File : NTS51A.DAT
Date : 08-Sep-88
Time : 15:14:53
Trans. : 25 %
Valid : 70 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 2.54 microns

%	Diam	Cum Numb
99.9	1.57	1.11e+05
99.0	1.57	1.10e+05
90.0	1.57	1.00e+05
70.0	1.57	7.81e+04
50.0	1.60	5.58e+04
30.0	1.64	3.35e+04
10.0	2.54	1.12e+04
1.0	4.68	1.12e+03
0.1	7.16	1.12e+02

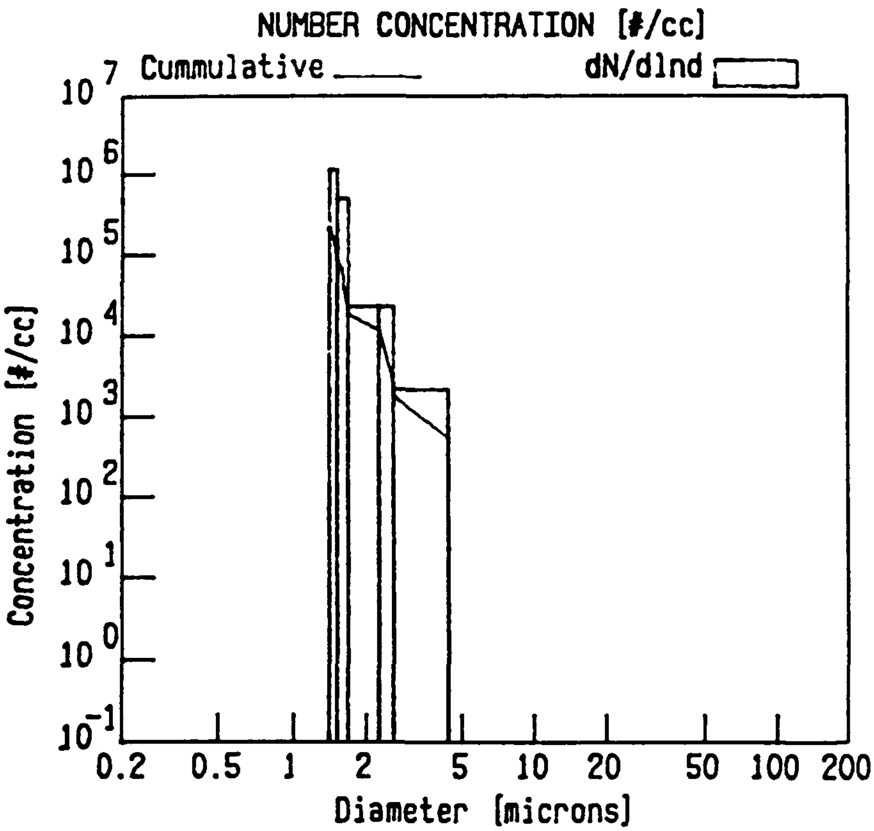
MASS CONCENTRATION [gm/cc]



File : NTS51A.DAT
Date : 08-Sep-88
Time : 15:14:53
Trans. : 25 %
Valid : 70 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 2.54 microns

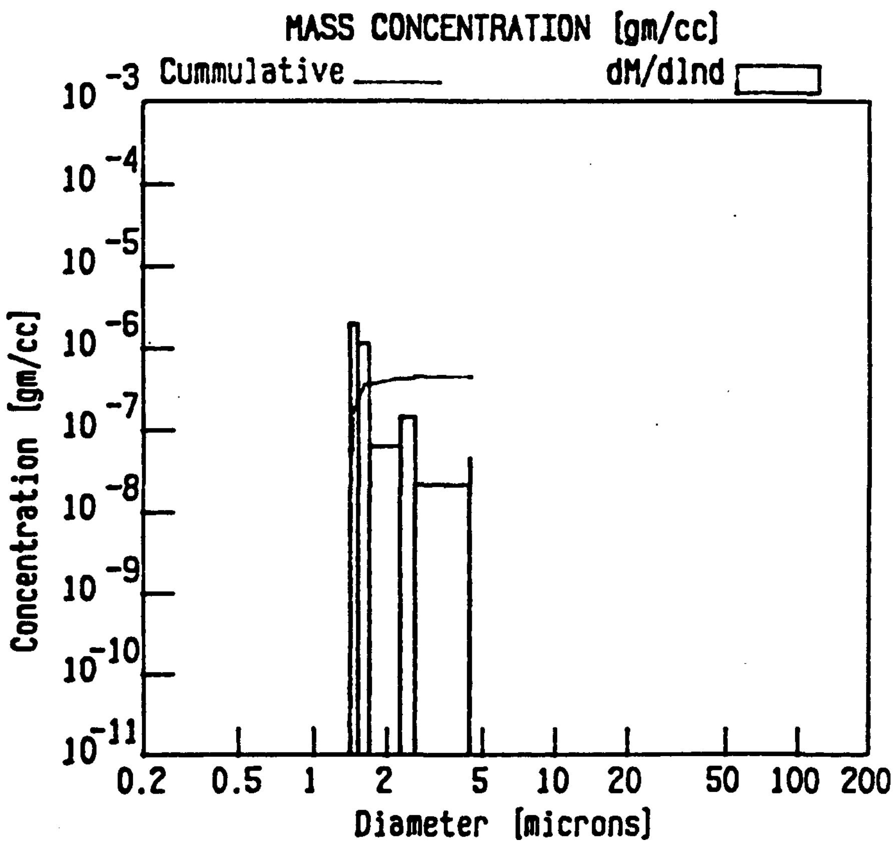
%	Diam	Cum Mass
99.9	7.41	5.50e-07
99.0	7.32	5.45e-07
90.0	6.65	4.96e-07
70.0	4.62	3.86e-07
50.0	2.48	2.75e-07
30.0	1.65	1.65e-07
10.0	1.59	5.51e-08
1.0	1.57	5.51e-09
0.1	1.57	5.51e-10

INSITEC Particle Counter Sizer Velocimeter



File	: NTS51C.DAT		
Date	: 08-Sep-88		
Time	: 15:17:39		
Trans.	: 52 %		
Valid	: 80 %		
Speed	: 3.20	± 0.00	
Density	: 1.00	gm/cc	
D32	: 1.70	microns	

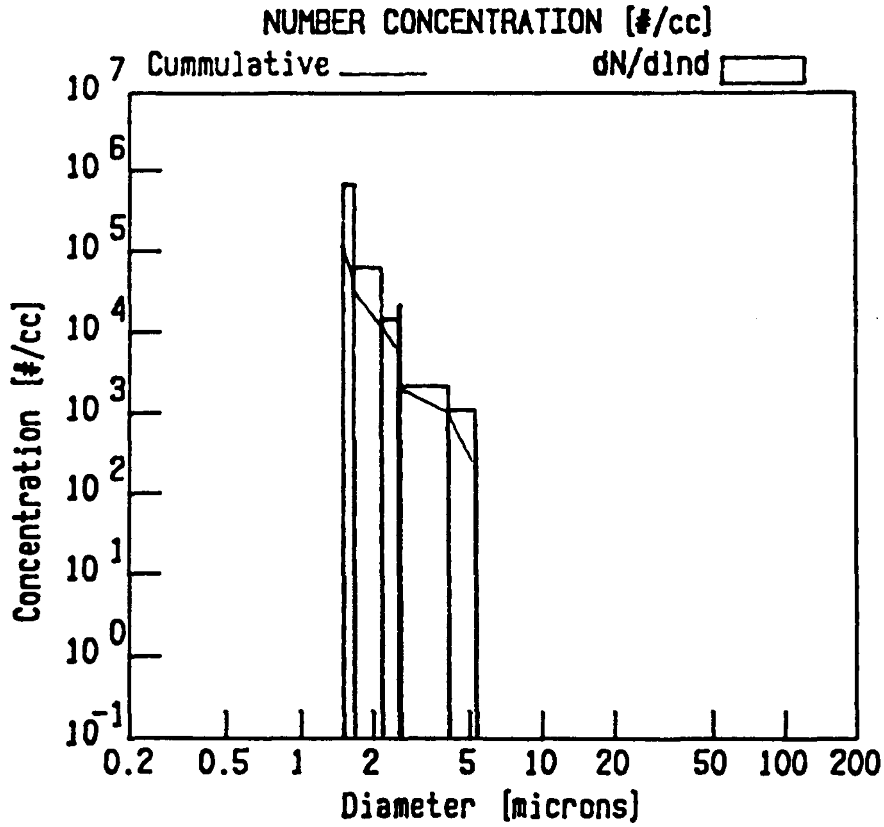
%	Diam	Cum Numb
99.9	1.44	2.07e+05
99.0	1.44	2.05e+05
90.0	1.44	1.87e+05
70.0	1.48	1.45e+05
50.0	1.50	1.04e+05
30.0	1.56	6.23e+04
10.0	1.66	2.08e+04
1.0	2.58	2.08e+03
0.1	4.44	2.08e+02



File	: NTS51C.DAT		
Date	: 08-Sep-88		
Time	: 15:17:39		
Trans.	: 52 %		
Valid	: 80 %		
Speed	: 3.20	± 0.00	
Density	: 1.00	gm/cc	
D32	: 1.70	microns	

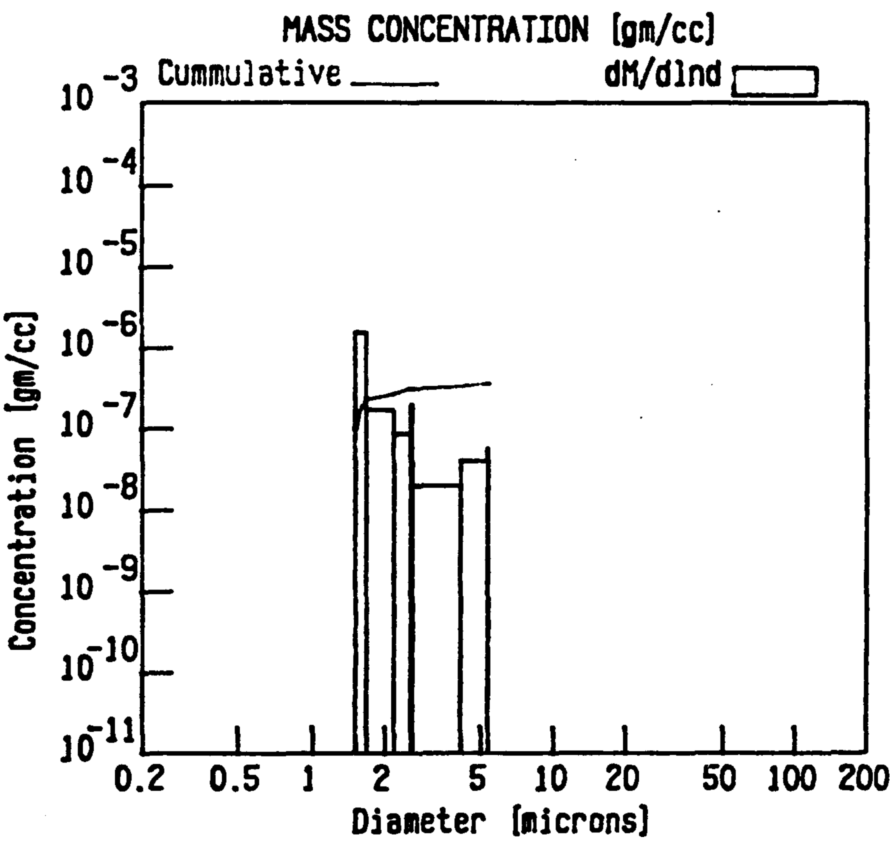
%	Diam	Cum Mass
99.9	4.42	4.76e-07
99.0	4.10	4.72e-07
90.0	2.32	4.29e-07
70.0	1.64	3.34e-07
50.0	1.56	2.38e-07
30.0	1.49	1.43e-07
10.0	1.46	4.77e-08
1.0	1.44	4.77e-09
0.1	1.44	4.77e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS51G.DAT
Date : 08-Sep-88
Time : 15:22:23
Trans. : 44 %
Valid : 85 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.93 microns

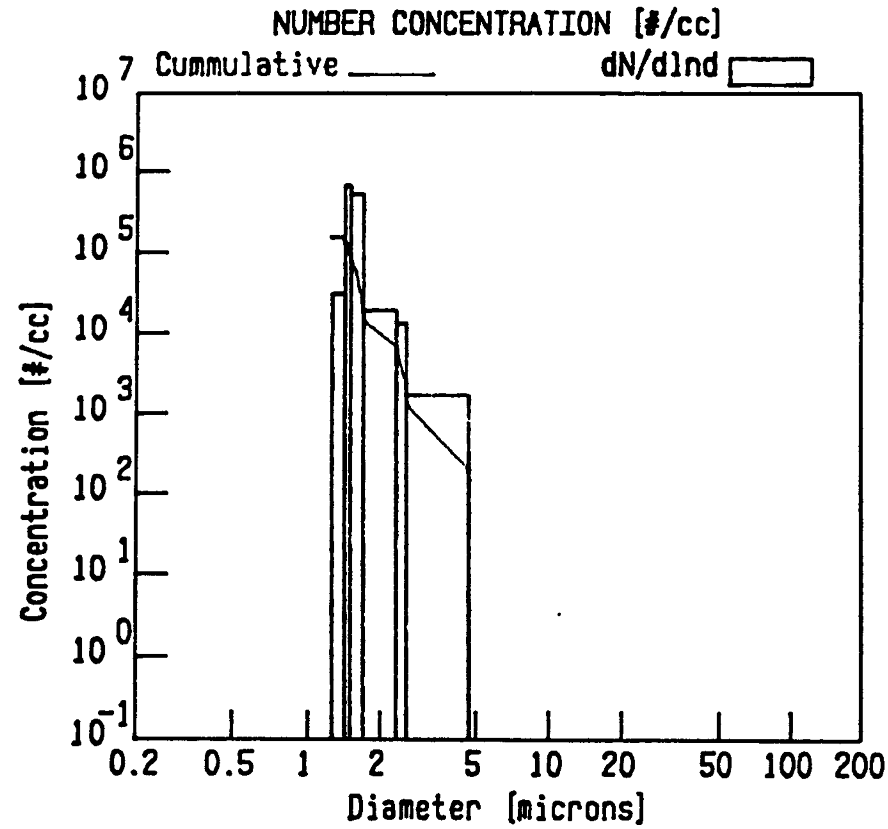
%	Diam	Cum Numb
99.9	1.56	1.15e+05
99.0	1.56	1.14e+05
90.0	1.56	1.03e+05
70.0	1.57	8.04e+04
50.0	1.61	5.74e+04
30.0	1.65	3.44e+04
10.0	1.85	1.15e+04
1.0	2.39	1.15e+03
0.1	5.38	1.15e+02



File : NTS51G.DAT
Date : 08-Sep-88
Time : 15:22:23
Trans. : 44 %
Valid : 85 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.93 microns

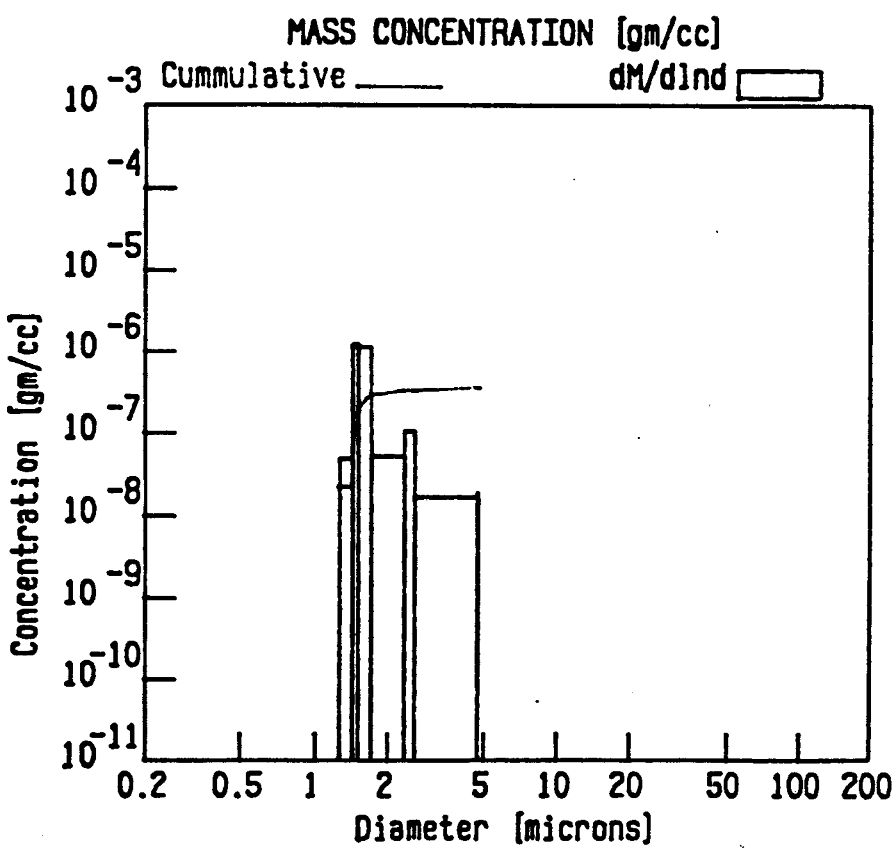
%	Diam	Cum Mass
99.9	5.38	3.61e-07
99.0	5.13	3.57e-07
90.0	3.12	3.25e-07
70.0	1.96	2.53e-07
50.0	1.65	1.81e-07
30.0	1.61	1.08e-07
10.0	1.58	3.61e-08
1.0	1.56	3.61e-09
0.1	1.56	3.61e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS52C.DAT
Date : 08-Sep-88
Time : 16:12:36
Trans. : 51 %
Valid : 81 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.70 microns

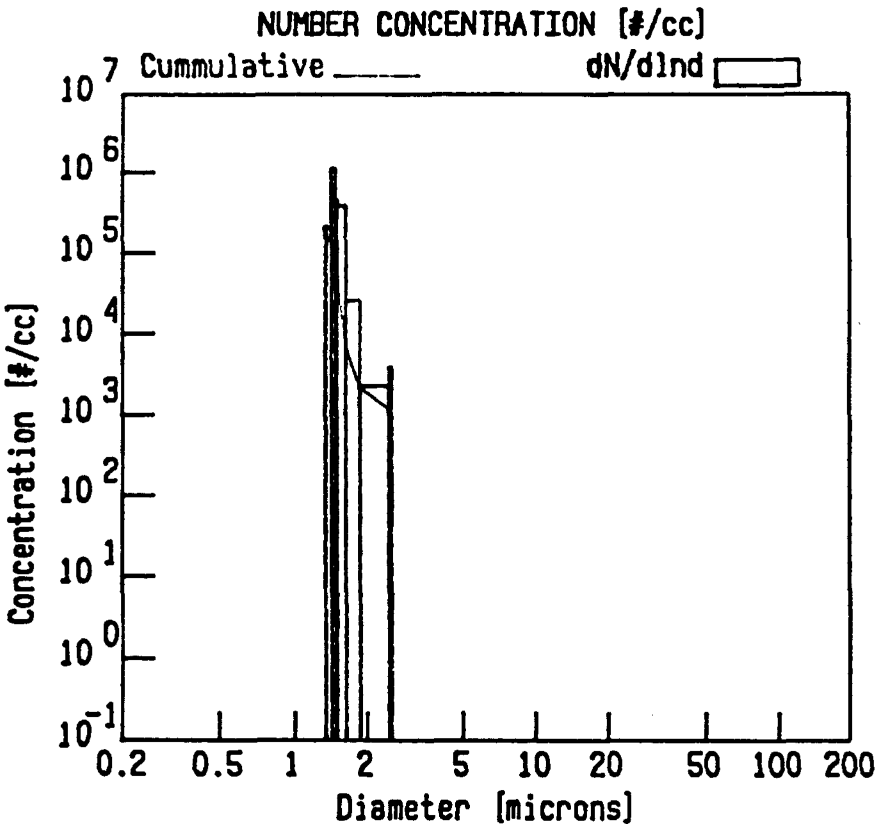
%	Diam	Cum Numb
99.9	1.41	1.54e+05
99.0	1.41	1.53e+05
90.0	1.47	1.39e+05
70.0	1.50	1.08e+05
50.0	1.54	7.73e+04
30.0	1.59	4.64e+04
10.0	1.67	1.55e+04
1.0	2.59	1.55e+03
0.1	4.79	1.55e+02



File : NTS52C.DAT
Date : 08-Sep-88
Time : 16:12:36
Trans. : 51 %
Valid : 81 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.70 microns

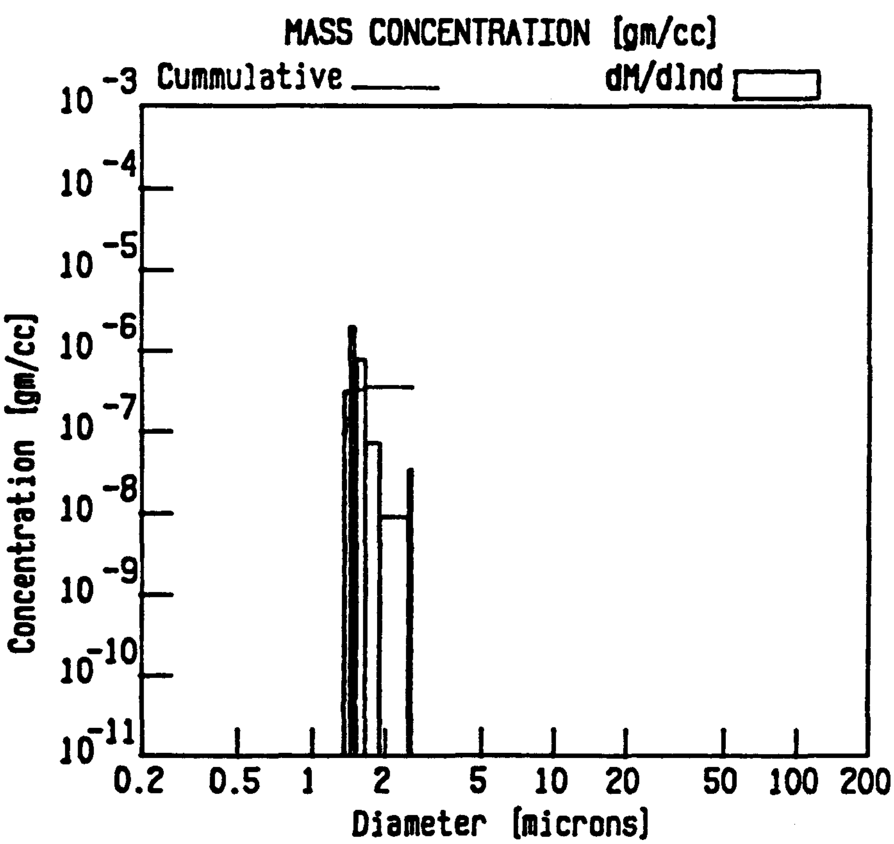
%	Diam	Cum Mass
99.9	4.76	3.65e-07
99.0	4.14	3.62e-07
90.0	2.32	3.29e-07
70.0	1.65	2.56e-07
50.0	1.58	1.83e-07
30.0	1.51	1.10e-07
10.0	1.48	3.65e-08
1.0	1.42	3.65e-09
0.1	1.41	3.65e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS52D.DAT
Date : 08-Sep-88
Time : 16:14:11
Trans. : 68 %
Valid : 74 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.51 microns

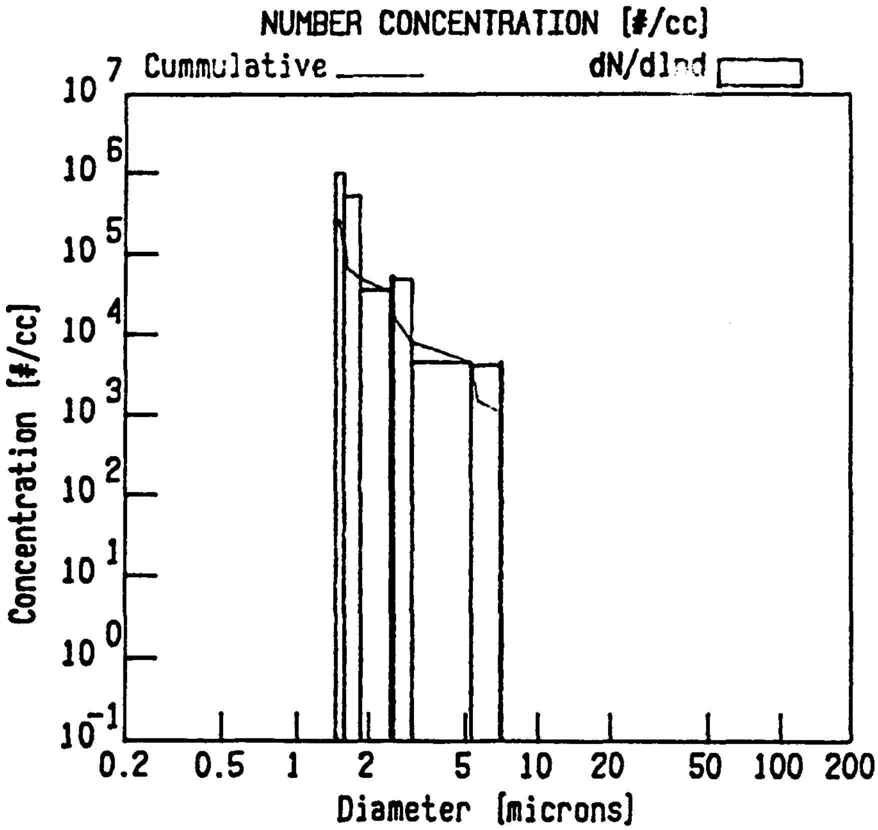
%	Diam	Cum Numb
99.9	1.39	2.18e+05
99.0	1.39	2.16e+05
90.0	1.39	1.96e+05
70.0	1.41	1.53e+05
50.0	1.45	1.09e+05
30.0	1.49	6.54e+04
10.0	1.56	2.18e+04
1.0	1.70	2.18e+03
0.1	2.57	2.18e+02



File : NTS52D.DAT
Date : 08-Sep-88
Time : 16:14:11
Trans. : 68 %
Valid : 74 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.51 microns

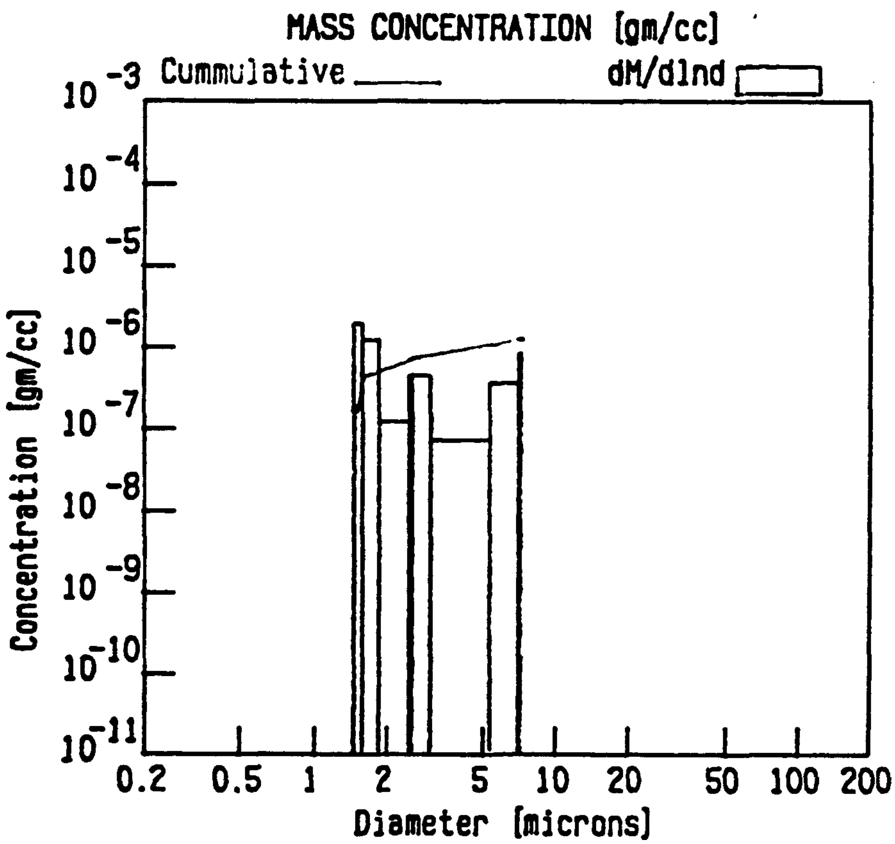
%	Diam	Cum Mass
99.9	2.60	3.80e-07
99.0	2.37	3.77e-07
90.0	1.60	3.43e-07
70.0	1.52	2.66e-07
50.0	1.45	1.90e-07
30.0	1.43	1.14e-07
10.0	1.41	3.81e-08
1.0	1.40	3.81e-09
0.1	1.39	3.81e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS52F.DAT
Date : 08-Sep-88
Time : 16:16:10
Trans. : 27 %
Valid : 75 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 2.58 microns

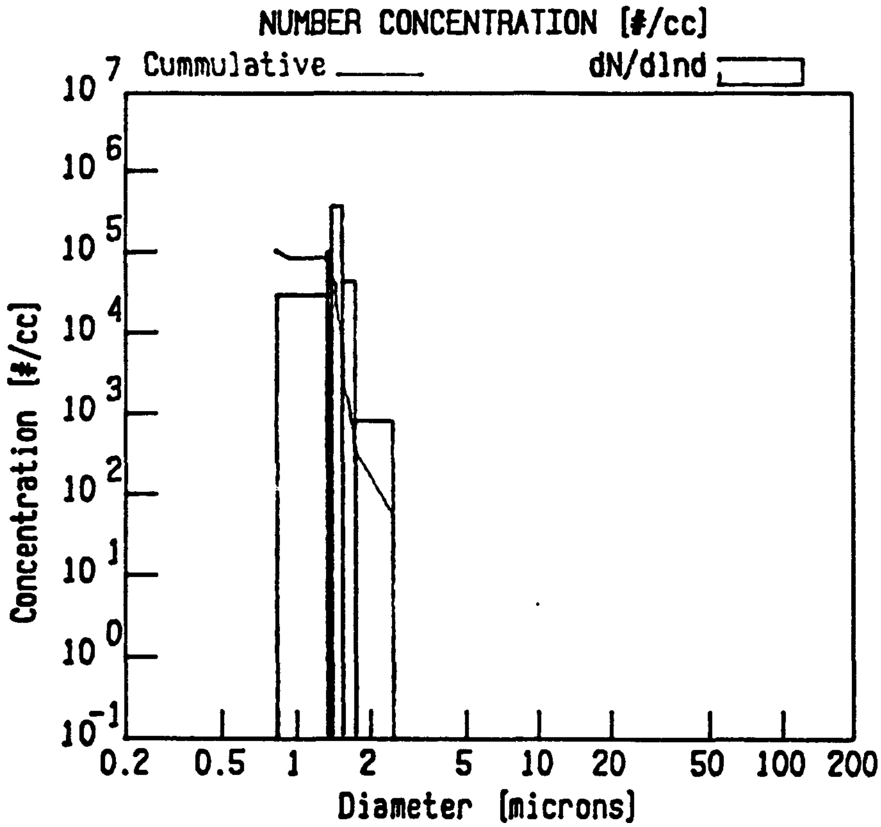
%	Diam	Cum Numb
99.9	1.51	2.62e+05
99.0	1.51	2.60e+05
90.0	1.52	2.36e+05
70.0	1.55	1.84e+05
50.0	1.58	1.31e+05
30.0	1.63	7.88e+04
10.0	2.55	2.63e+04
1.0	5.24	2.63e+03
0.1	7.10	2.63e+02



File : NTS52F.DAT
Date : 08-Sep-88
Time : 16:16:10
Trans. : 27 %
Valid : 75 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 2.58 microns

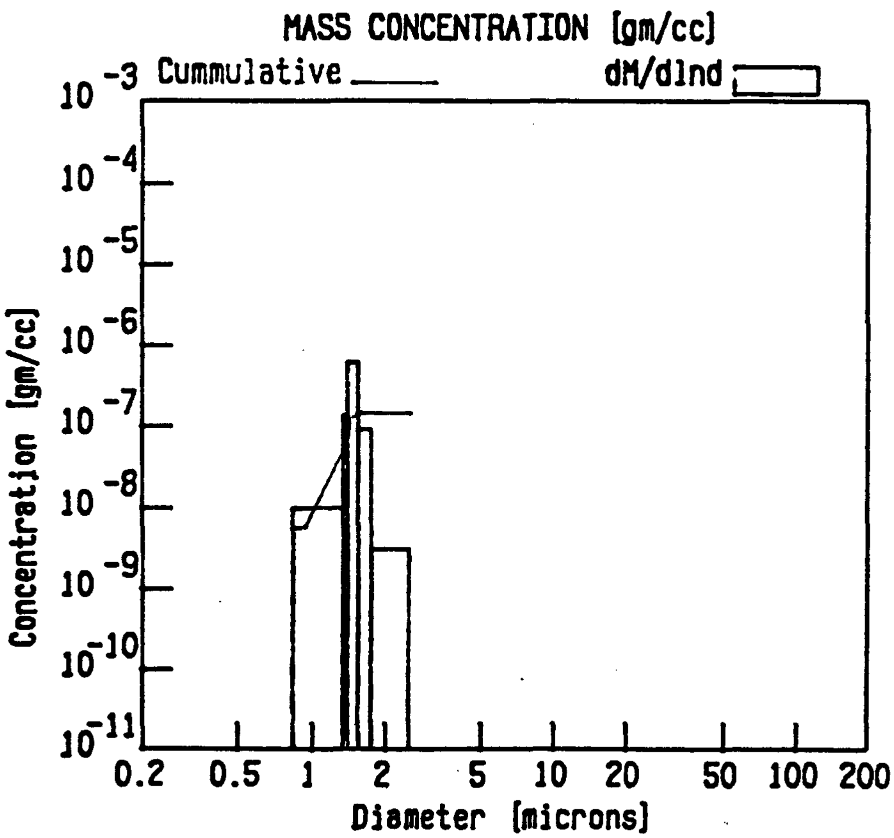
%	Diam	Cum Mass
99.9	7.29	1.30e-06
99.0	7.25	1.29e-06
90.0	6.40	1.17e-06
70.0	4.09	9.14e-07
50.0	2.52	6.53e-07
30.0	1.63	3.92e-07
10.0	1.54	1.31e-07
1.0	1.52	1.31e-08
0.1	1.52	1.31e-09

INSITEC Particle Counter Sizer Velocimeter



File : NTS53G.DAT
Date : 08-Sep-88
Time : 17:10:38
Trans. : 101 %
Valid : 80 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.43 microns

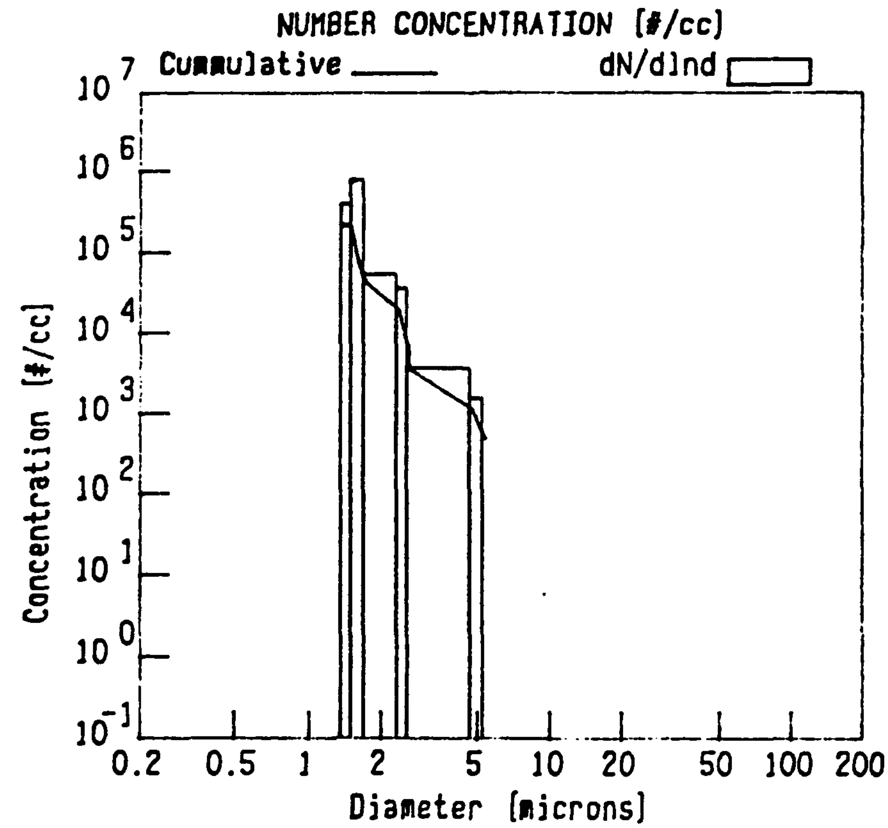
%	Diam	Cum Numb
99.9	0.86	1.05e+05
99.0	0.86	1.04e+05
90.0	0.86	9.47e+04
70.0	1.37	7.37e+04
50.0	1.40	5.26e+04
30.0	1.47	3.16e+04
10.0	1.51	1.05e+04
1.0	1.62	1.05e+03
0.1	1.64	1.05e+02



File : NTS53G.DAT
Date : 08-Sep-88
Time : 17:10:38
Trans. : 101 %
Valid : 80 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.43 microns

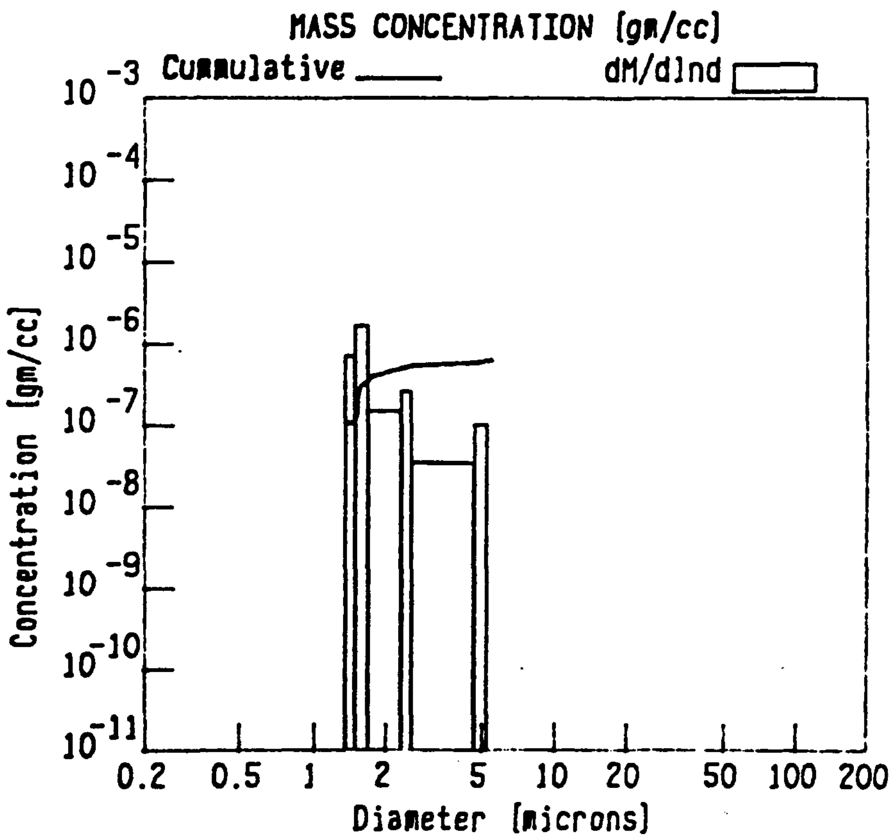
%	Diam	Cum Mass
99.9	2.32	1.50e-07
99.0	1.68	1.48e-07
90.0	1.54	1.35e-07
70.0	1.48	1.05e-07
50.0	1.45	7.49e-08
30.0	1.35	4.49e-08
10.0	1.06	1.50e-08
1.0	0.89	1.50e-09
0.1	0.86	1.50e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS52J.DAT
Date : 08-Sep-88
Time : 16:20:14
Trans. : 35 %
Valid : 74 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.90 microns

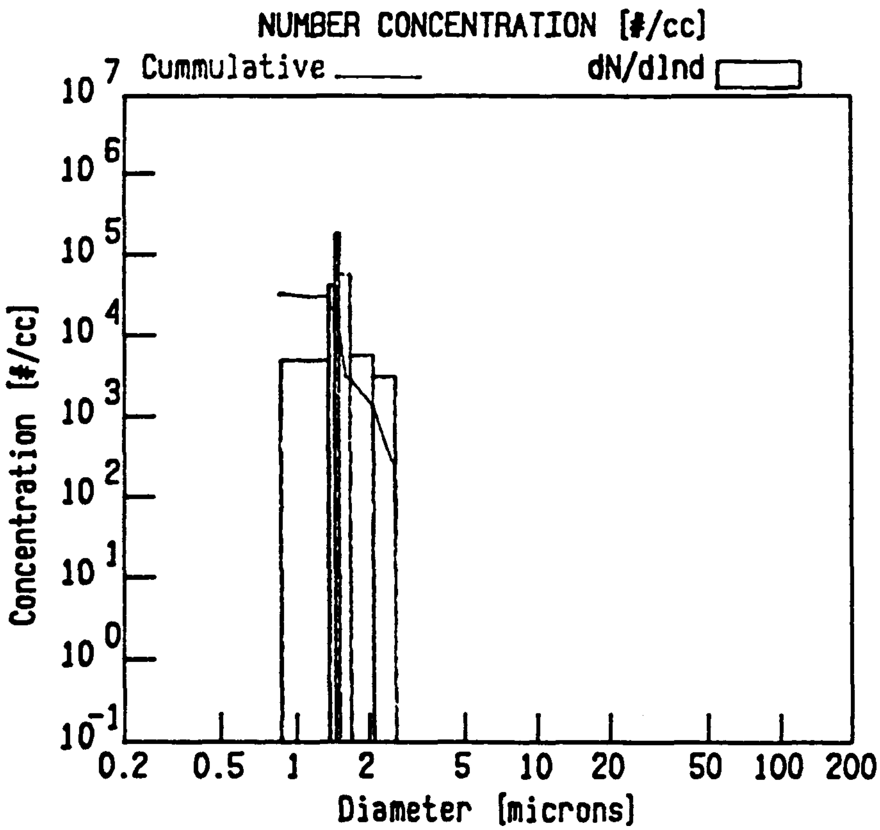
%	Diam	Cum Numb
99.9	1.47	2.14e+05
99.0	1.47	2.12e+05
90.0	1.48	1.93e+05
70.0	1.51	1.50e+05
50.0	1.55	1.07e+05
30.0	1.59	6.43e+04
10.0	1.64	2.14e+04
1.0	1.65	2.14e+03
0.1	5.41	2.14e+02



File : NTS52J.DAT
Date : 08-Sep-88
Time : 16:20:14
Trans. : 35 %
Valid : 74 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.90 microns

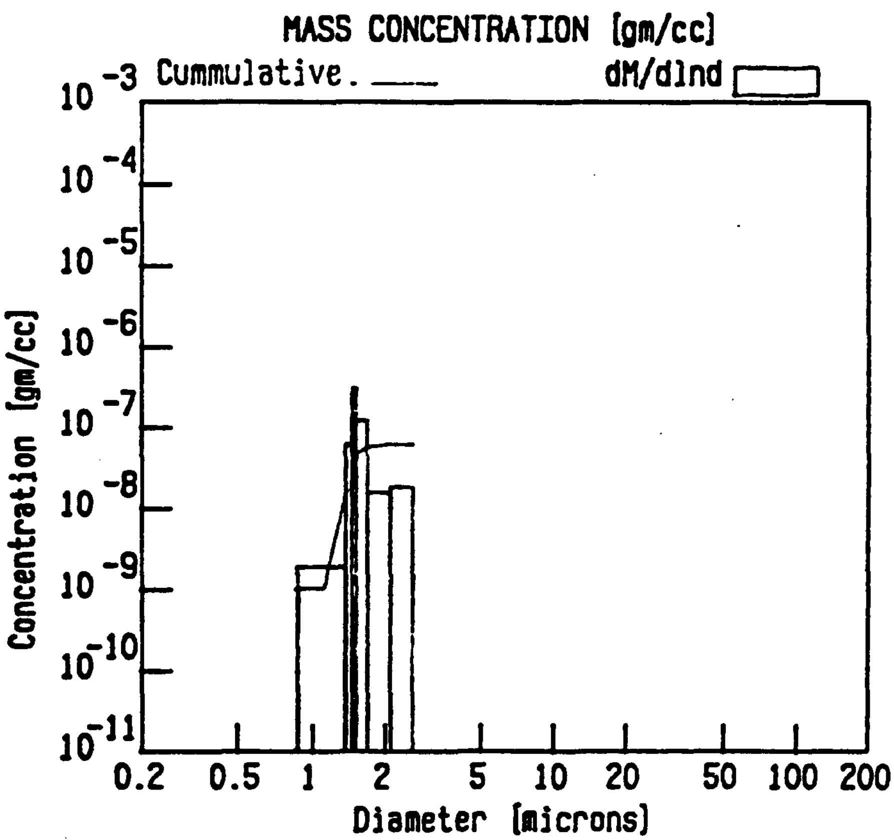
%	Diam	Cum Mass
99.9	5.42	6.21e-07
99.0	5.34	6.15e-07
90.0	3.49	5.59e-07
70.0	1.97	4.35e-07
50.0	1.62	3.11e-07
30.0	1.55	1.86e-07
10.0	1.49	6.21e-08
1.0	1.48	6.21e-09
0.1	1.48	6.21e-10

INSITEC Particle Counter Sizer Velocimeter



File : NTS53B.DAT
Date : 08-Sep-88
Time : 17:04:31
Trans. : 94 %
Valid : 77 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.56 microns

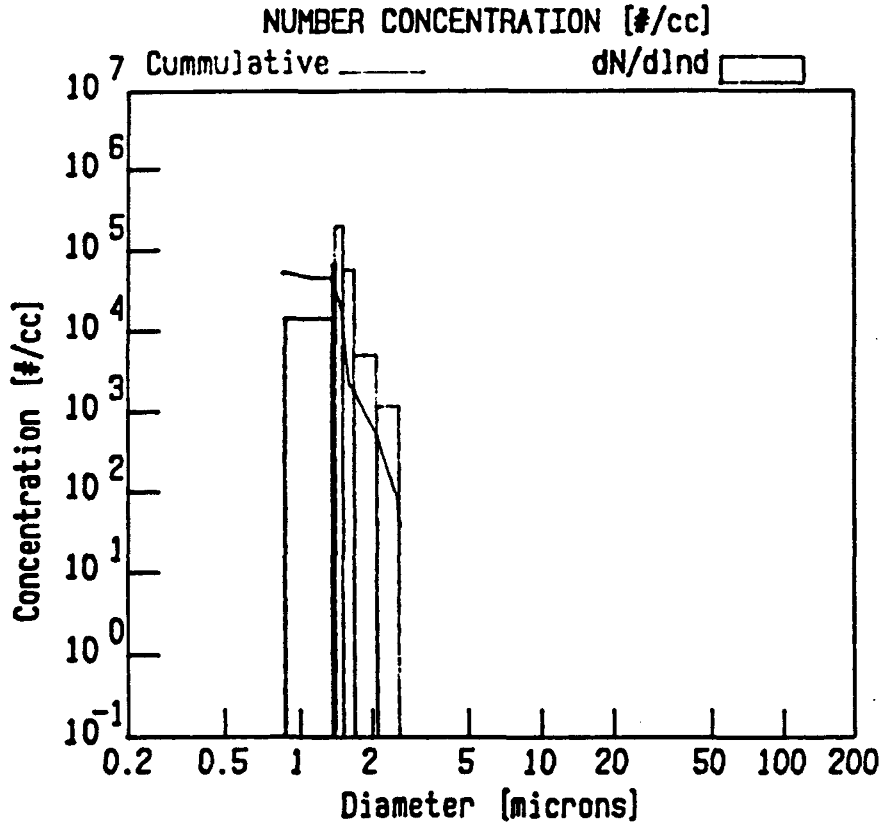
%	Diam	Cum Numb
99.9	0.90	3.50e+04
99.0	0.90	3.47e+04
90.0	1.37	3.16e+04
70.0	1.40	2.45e+04
50.0	1.49	1.75e+04
30.0	1.52	1.05e+04
10.0	1.60	3.51e+03
1.0	2.09	3.51e+02
0.1	2.62	3.51e+01



File : NTS53B.DAT
Date : 08-Sep-88
Time : 17:04:31
Trans. : 94 %
Valid : 77 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.56 microns

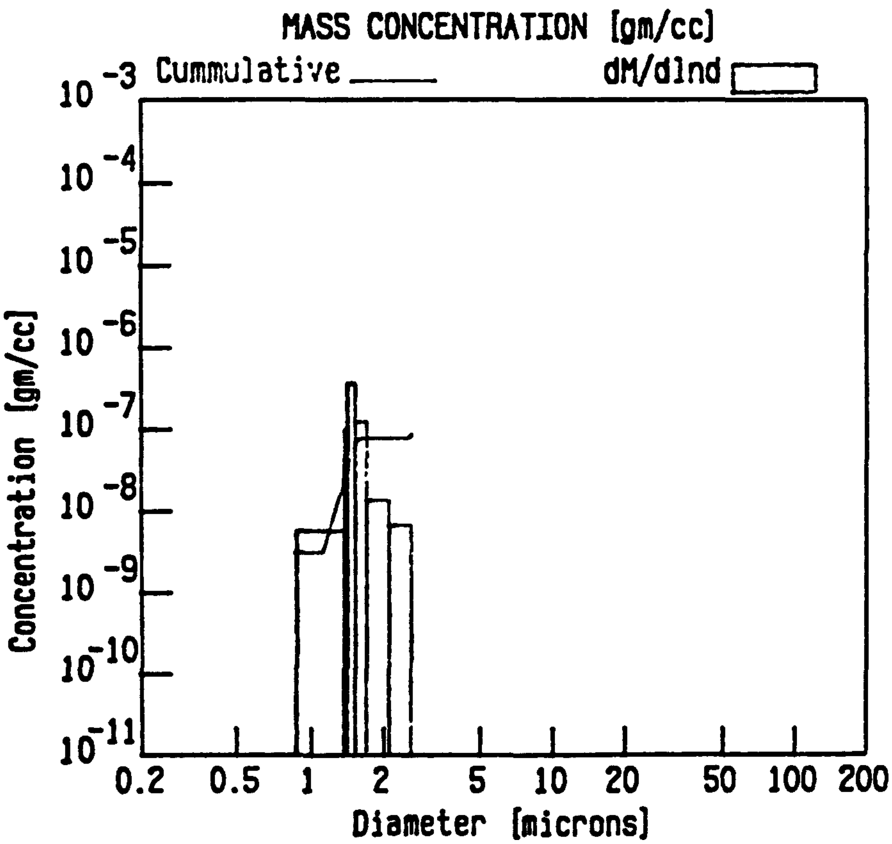
%	Diam	Cum Mass
99.9	2.63	6.42e-08
99.0	2.58	6.36e-08
90.0	1.81	5.78e-08
70.0	1.57	4.50e-08
50.0	1.51	3.21e-08
30.0	1.47	1.93e-08
10.0	1.26	6.43e-09
1.0	1.06	6.43e-10
0.1	0.92	6.43e-11

INSITEC Particle Counter Sizer Velocimeter



File : NTS53E.DAT
Date : 08-Sep-88
Time : 17:08:55
Trans. : 94 %
Valid : 79 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.47 microns

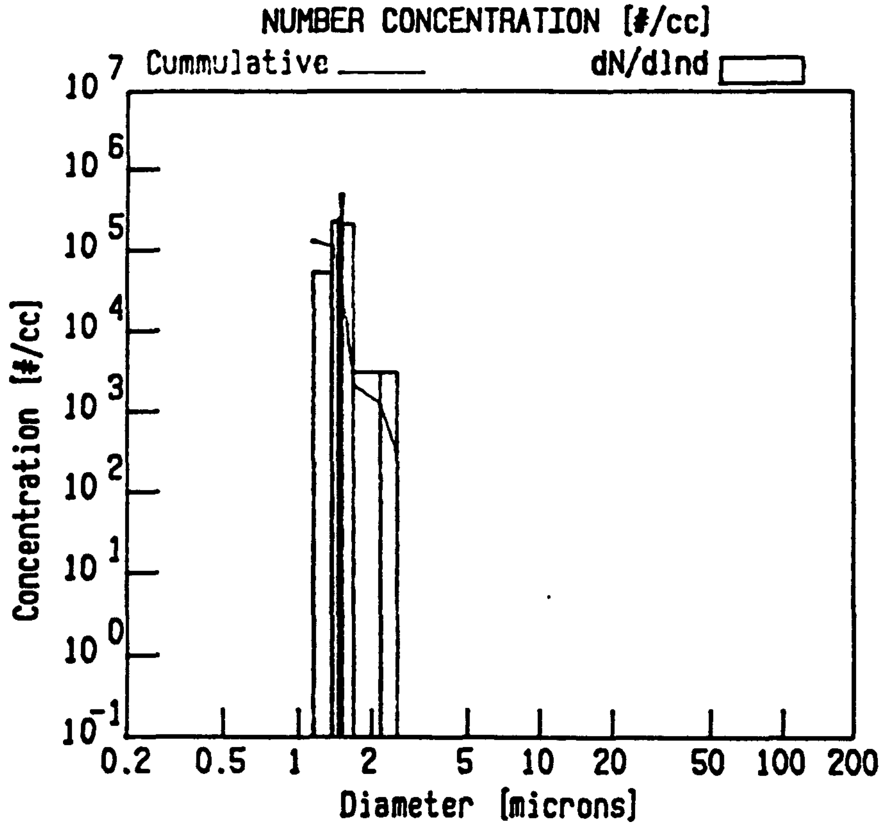
%	Diam	Cum Numb
99.9	0.90	5.30e+04
99.0	0.90	5.25e+04
90.0	0.90	4.77e+04
70.0	1.39	3.71e+04
50.0	1.44	2.65e+04
30.0	1.49	1.59e+04
10.0	1.56	5.30e+03
1.0	1.71	5.30e+02
0.1	2.57	5.30e+01



File : NTS53E.DAT
Date : 08-Sep-88
Time : 17:08:55
Trans. : 94 %
Valid : 79 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.47 microns

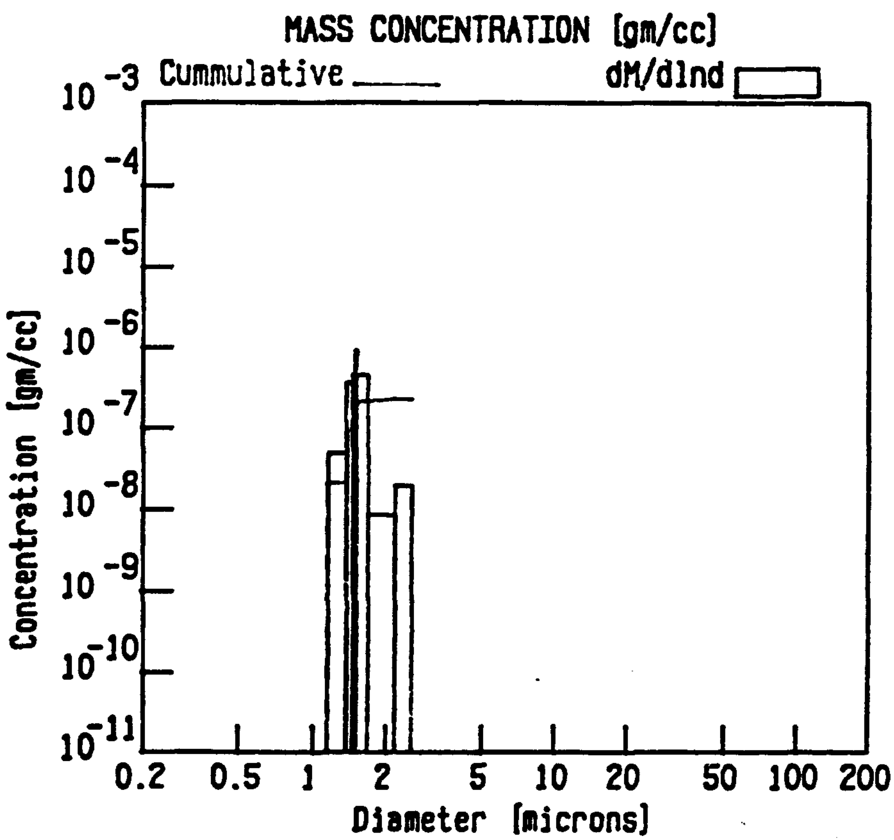
%	Diam	Cum Mass
99.9	2.62	8.27e-08
99.0	2.12	8.20e-08
90.0	1.60	7.45e-08
70.0	1.52	5.80e-08
50.0	1.48	4.14e-08
30.0	1.41	2.48e-08
10.0	1.22	8.28e-09
1.0	0.97	8.28e-10
0.1	0.91	8.28e-11

INSITEC Particle Counter Sizer Velocimeter



File : NTS53H.DAT
Date : 08-Sep-88
Time : 17:11:19
Trans. : 77 %
Valid : 80 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.49 microns

%	Diam	Cum Numb
99.9	1.19	1.38e+05
99.0	1.19	1.37e+05
90.0	1.19	1.24e+05
70.0	1.42	9.67e+04
50.0	1.45	6.91e+04
30.0	1.51	4.14e+04
10.0	1.56	1.38e+04
1.0	1.66	1.38e+03
0.1	2.58	1.38e+02

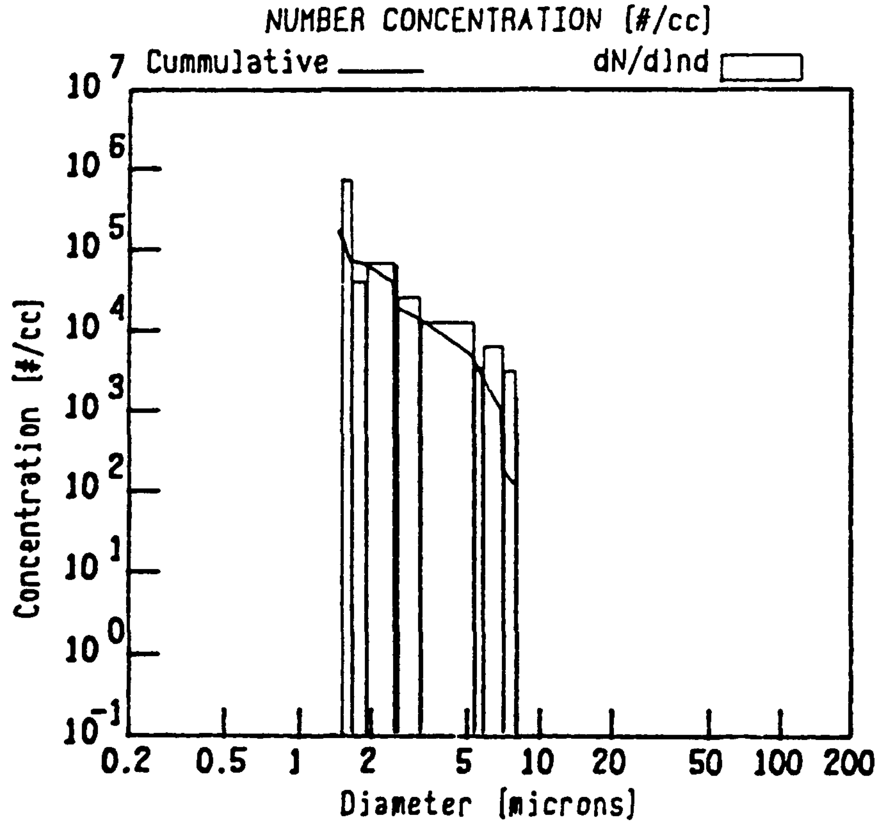


File : NTS53H.DAT
Date : 08-Sep-88
Time : 17:11:19
Trans. : 77 %
Valid : 80 %
Speed : 3.20 ± 0.00
Density: 1.00 gm/cc
D32 : 1.49 microns

%	Diam	Cum Mass
99.9	2.56	2.31e-07
99.0	2.28	2.29e-07
90.0	1.61	2.08e-07
70.0	1.53	1.62e-07
50.0	1.49	1.15e-07
30.0	1.43	6.93e-08
10.0	1.40	2.31e-08
1.0	1.22	2.31e-09
0.1	1.20	2.31e-10

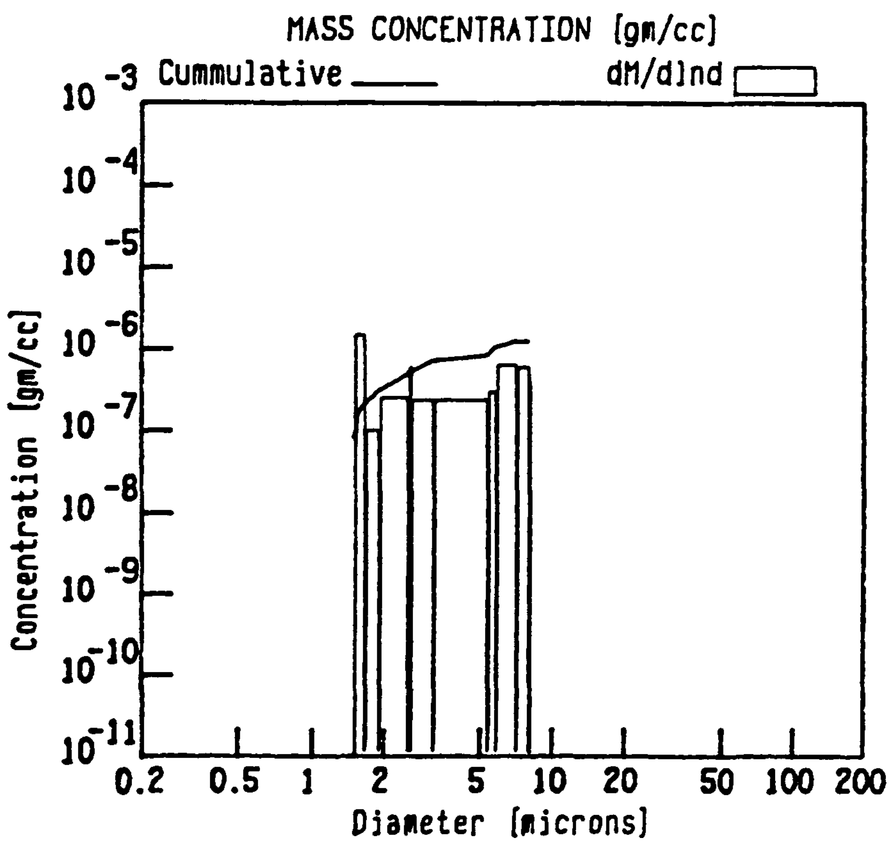
INSITEC Particle Counter Sizer Velocimeter

1' off wall, downstream, AUA P=143psig T=86F, 50% RH, Water spray off



File	: NTS54A.DAT	
Date	: 09-Sep-88	
Time	: 13:48:19	
Trans.	: 32 %	
Valid	: 68 %	
Speed	: 3.10	± 0.00
Density	: 1.00	gm/cc
D32	: 3.02	microns

%	Diam	Cum Numb
99.9	1.52	1.75e+05
99.0	1.52	1.73e+05
90.0	1.52	1.57e+05
70.0	1.55	1.22e+05
50.0	1.59	8.74e+04
30.0	1.64	5.25e+04
10.0	2.26	1.75e+04
1.0	5.33	1.75e+03
0.1	6.80	1.75e+02

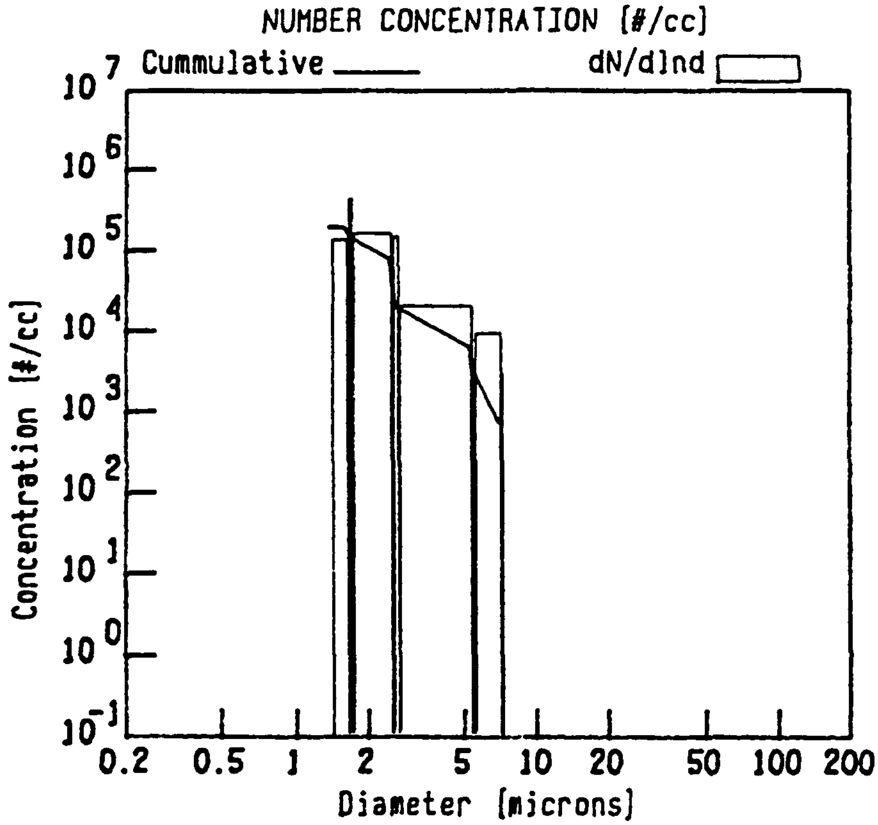


File	: NTS54A.DAT	
Date	: 09-Sep-88	
Time	: 13:48:19	
Trans.	: 32 %	
Valid	: 68 %	
Speed	: 3.10	± 0.00
Density	: 1.00	gm/cc
D32	: 3.02	microns

%	Diam	Cum Mass
99.9	7.94	1.29e-06
99.0	7.71	1.28e-06
90.0	6.48	1.16e-06
70.0	5.41	9.02e-07
50.0	2.96	6.44e-07
30.0	2.16	3.87e-07
10.0	1.57	1.29e-07
1.0	1.52	1.29e-08
0.1	1.52	1.29e-09

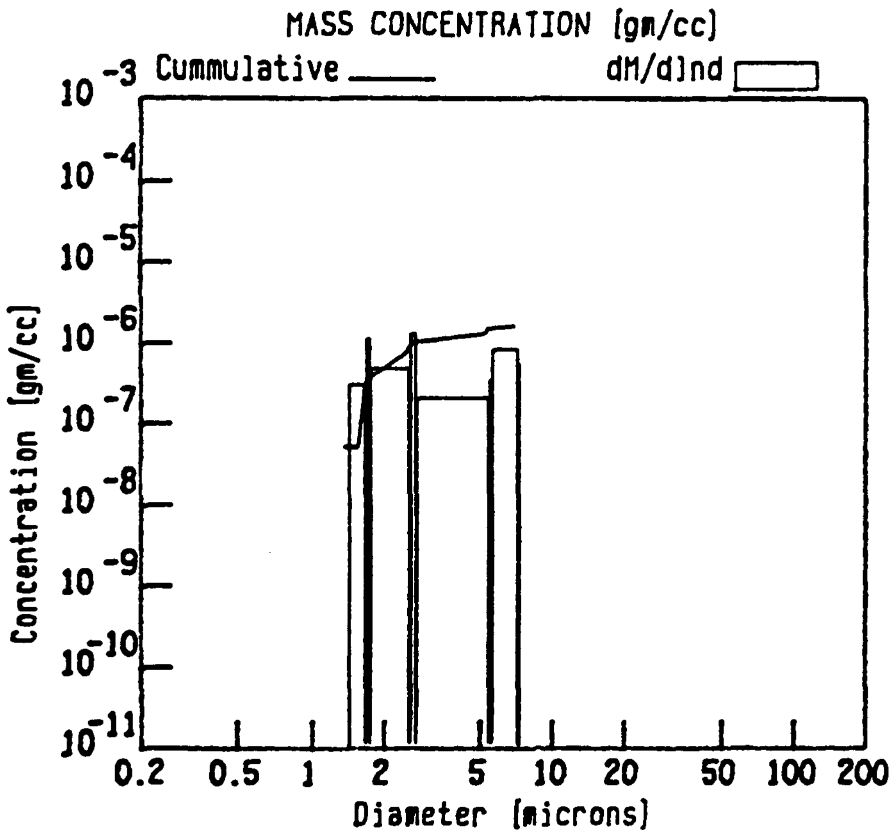
INSITEC Particle Counter Sizer Velocimeter

2' off center, downstream, AUA P=143psig T=86F, 50% RH, Water spray off



File : NTS54G.DAT
Date : 09-Sep-88
Time : 13:55:31
Trans. : 34 %
Valid : 83 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 2.88 microns

%	Diam	Cum Numb
99.9	1.57	2.06e+05
99.0	1.57	2.04e+05
90.0	1.62	1.85e+05
70.0	1.01	1.44e+05
50.0	1.49	1.03e+05
30.0	2.54	6.18e+04
10.0	2.61	2.06e+04
1.0	4.64	2.06e+03
0.1	7.06	2.06e+02

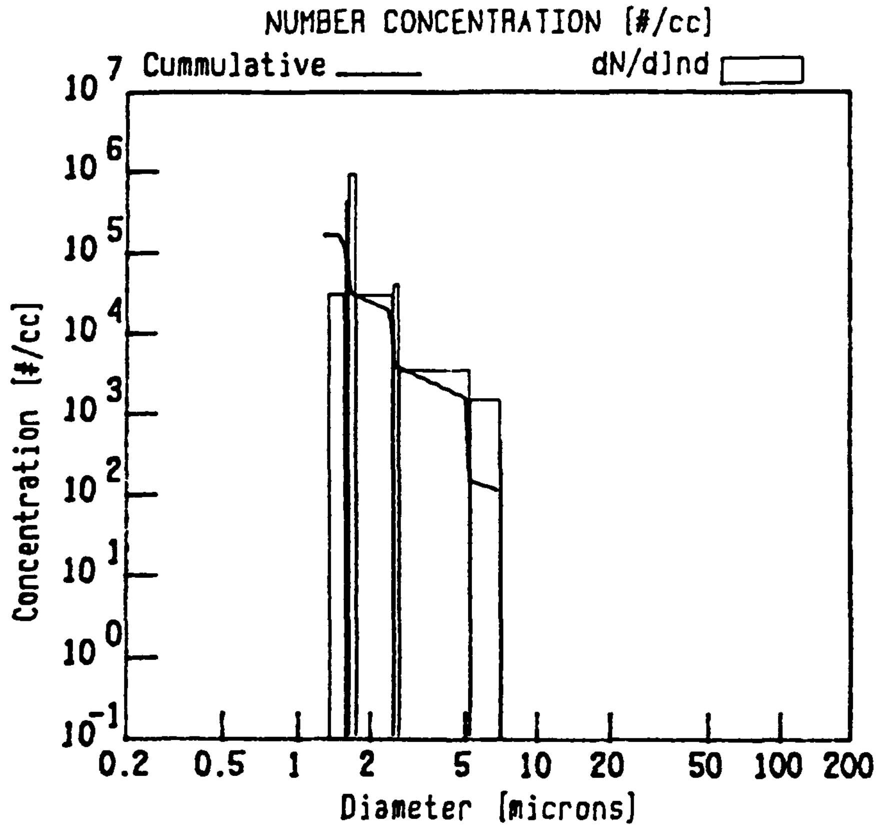


File : NTS54G.DAT
Date : 09-Sep-88
Time : 13:55:31
Trans. : 34 %
Valid : 83 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 2.88 microns

%	Diam	Cum Mass
99.9	7.06	1.61e-06
99.0	6.89	1.60e-06
90.0	5.45	1.45e-06
70.0	3.98	1.13e-06
50.0	2.59	8.07e-07
30.0	2.06	4.84e-07
10.0	1.69	1.61e-07
1.0	1.59	1.61e-08
0.1	1.58	1.61e-09

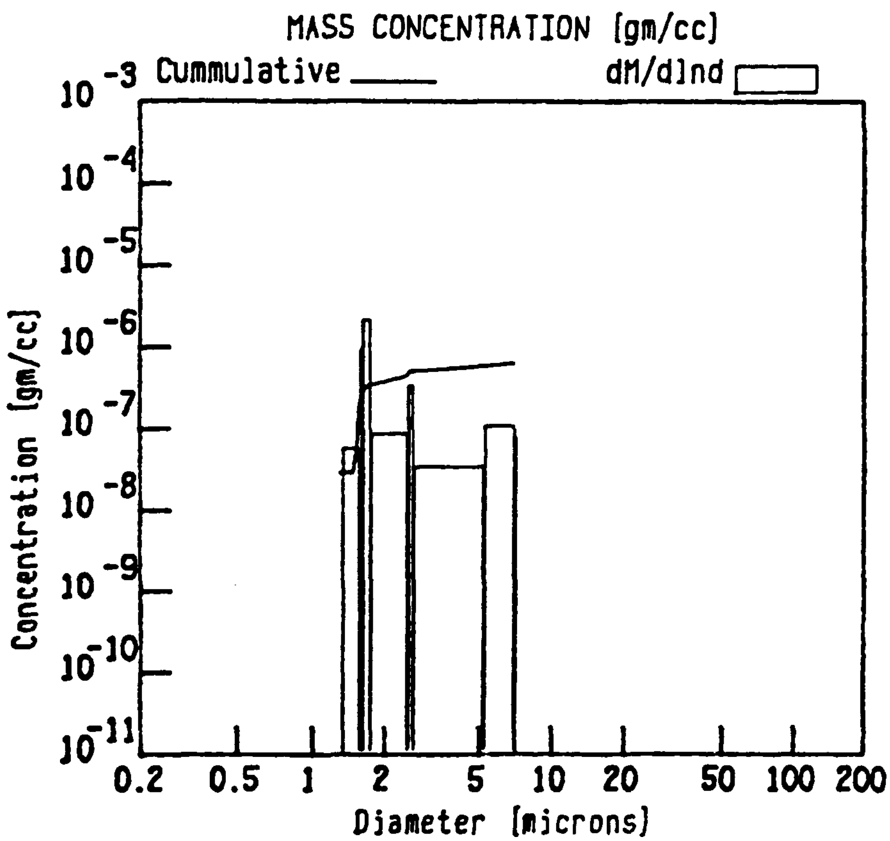
INSITEC Particle Counter Sizer Velocimeter

1' off center, downstream, AUA P=143psig T=86F, 50% RH, Water spray off



File : NTS54J.DAT
Date : 09-Sep-88
Time : 13:58:38
Trans. : 49 %
Valid : 71 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 2.14 microns

%	Diam	Cum Numb
99.9	1.50	1.67e+05
99.0	1.51	1.66e+05
90.0	1.54	1.51e+05
70.0	1.57	1.17e+05
50.0	1.61	8.36e+04
30.0	1.65	5.02e+04
10.0	2.46	1.67e+04
1.0	2.51	1.67e+03
0.1	5.20	1.67e+02

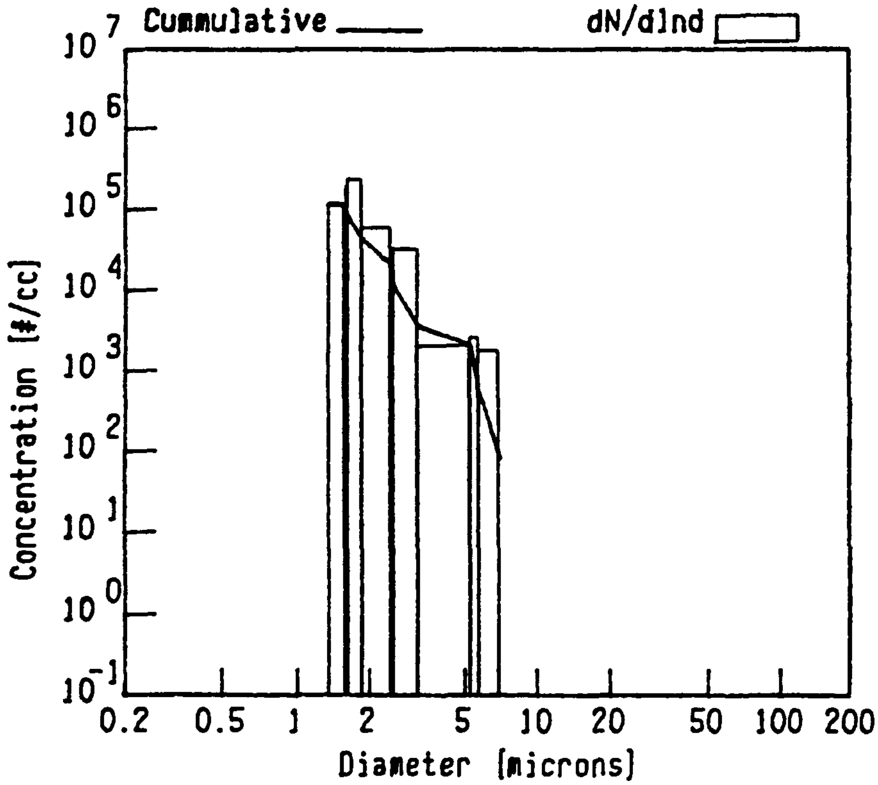


File : NTS54J.DAT
Date : 09-Sep-88
Time : 13:58:38
Trans. : 49 %
Valid : 71 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 2.14 microns

%	Diam	Cum Mass
99.9	6.94	6.25e-07
99.0	6.51	6.20e-07
90.0	4.22	5.63e-07
70.0	2.48	4.38e-07
50.0	1.70	3.13e-07
30.0	1.62	1.88e-07
10.0	1.57	6.26e-08
1.0	1.52	6.26e-09
0.1	1.51	6.26e-10

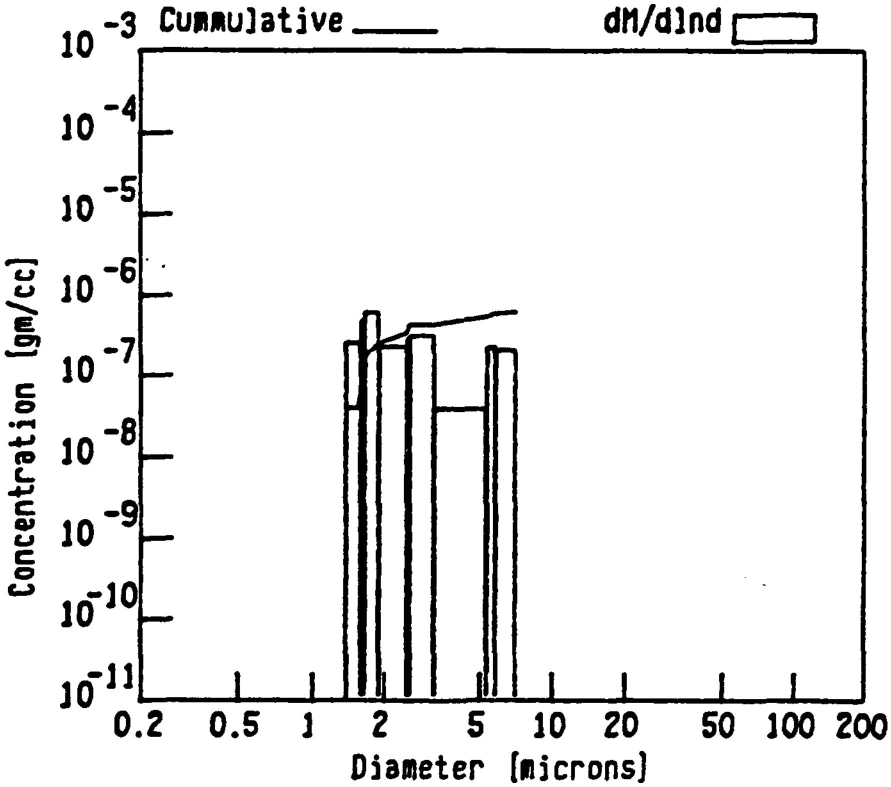
INSITEC Particle Counter Sizer Velocimeter

1' off center, downstream, AUA P=145psig T=82F, 50% RH, Water spray on



File : NTS55D.DAT
Date : 09-Sep-88
Time : 14:37:32
Trans. : 39 %
Valid : 80 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 2.50 microns

%	Diam	Cum Numb
99.9	1.54	1.14e+05
99.0	1.55	1.13e+05
90.0	1.57	1.03e+05
70.0	1.47	8.02e+04
50.0	1.62	5.73e+04
30.0	1.56	3.44e+04
10.0	2.57	1.15e+04
1.0	5.18	1.15e+03
0.1	5.72	1.15e+02

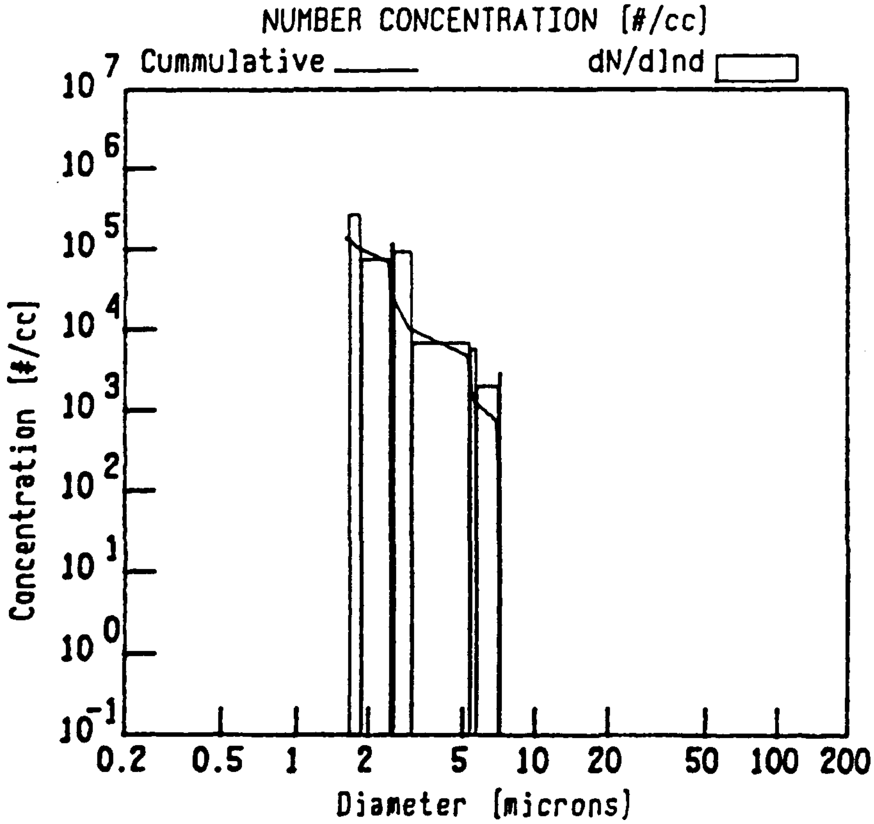


File : NTS55D.DAT
Date : 09-Sep-88
Time : 14:37:32
Trans. : 39 %
Valid : 80 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 2.50 microns

%	Diam	Cum Mass
99.9	7.07	6.18e-07
99.0	6.59	6.13e-07
90.0	5.31	5.57e-07
70.0	3.12	4.33e-07
50.0	2.31	3.10e-07
30.0	1.74	1.86e-07
10.0	1.62	6.19e-08
1.0	1.56	6.19e-09
0.1	1.55	6.19e-10

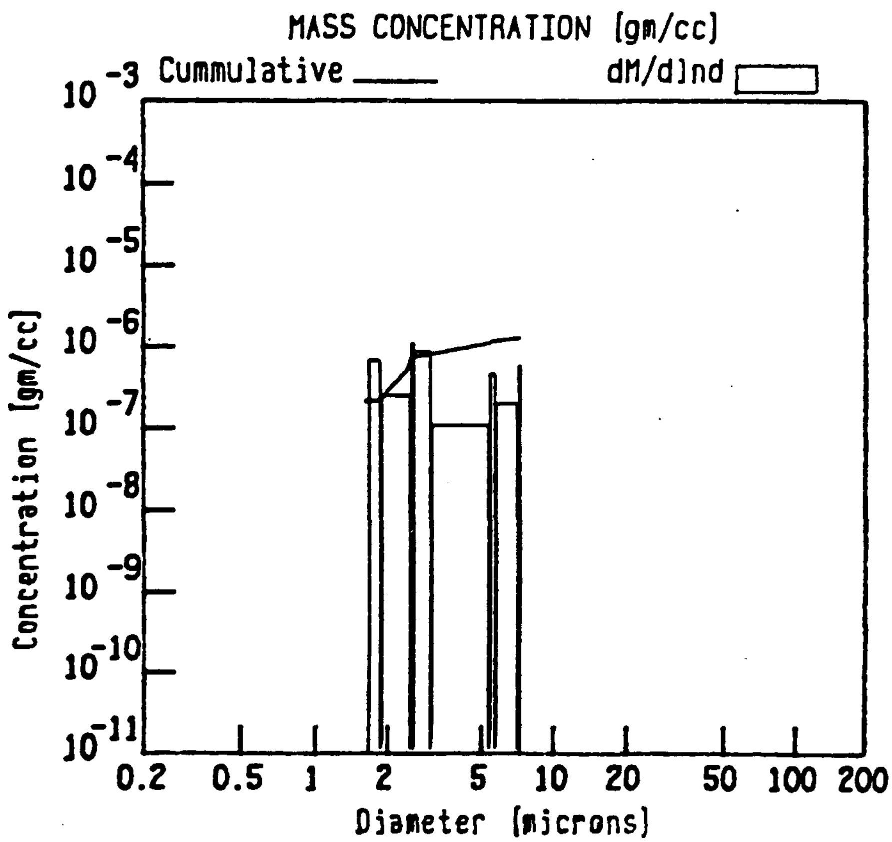
INSITEC Particle Counter Sizer Velocimeter

1' off wall, downstream, AUA P=145psig T=82F, 50% RH, Water spray on



File : NTS55H.DAT
Date : 09-Sep-88
Time : 14:41:50
Trans. : 27 %
Valid : 78 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 3.04 microns

%	Diam	Cum Numb
99.9	1.70	1.36e+05
99.0	1.70	1.34e+05
90.0	1.70	1.22e+05
70.0	1.26	9.51e+04
50.0	1.86	6.79e+04
30.0	2.56	4.08e+04
10.0	2.51	1.36e+04
1.0	5.37	1.36e+03
0.1	7.26	1.36e+02

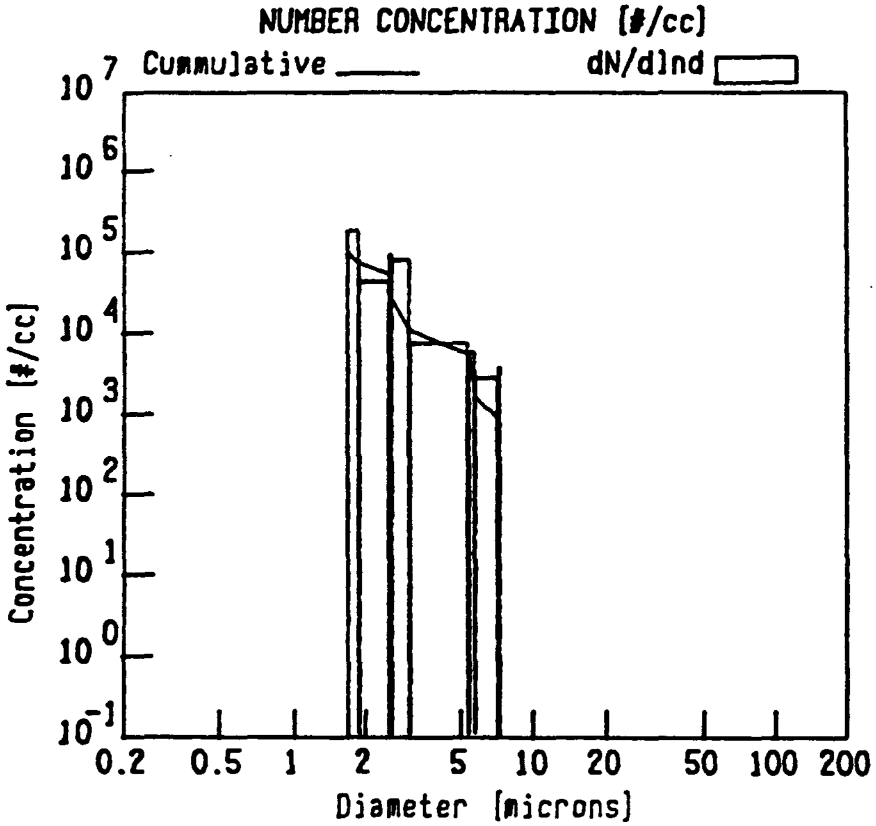


File : NTS55H.DAT
Date : 09-Sep-88
Time : 14:41:50
Trans. : 27 %
Valid : 78 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 3.04 microns

%	Diam	Cum Mass
99.9	7.29	1.28e-06
99.0	7.25	1.27e-06
90.0	5.93	1.16e-06
70.0	3.89	8.99e-07
50.0	2.60	6.42e-07
30.0	2.24	3.85e-07
10.0	1.82	1.28e-07
1.0	1.71	1.28e-08
0.1	1.70	1.28e-09

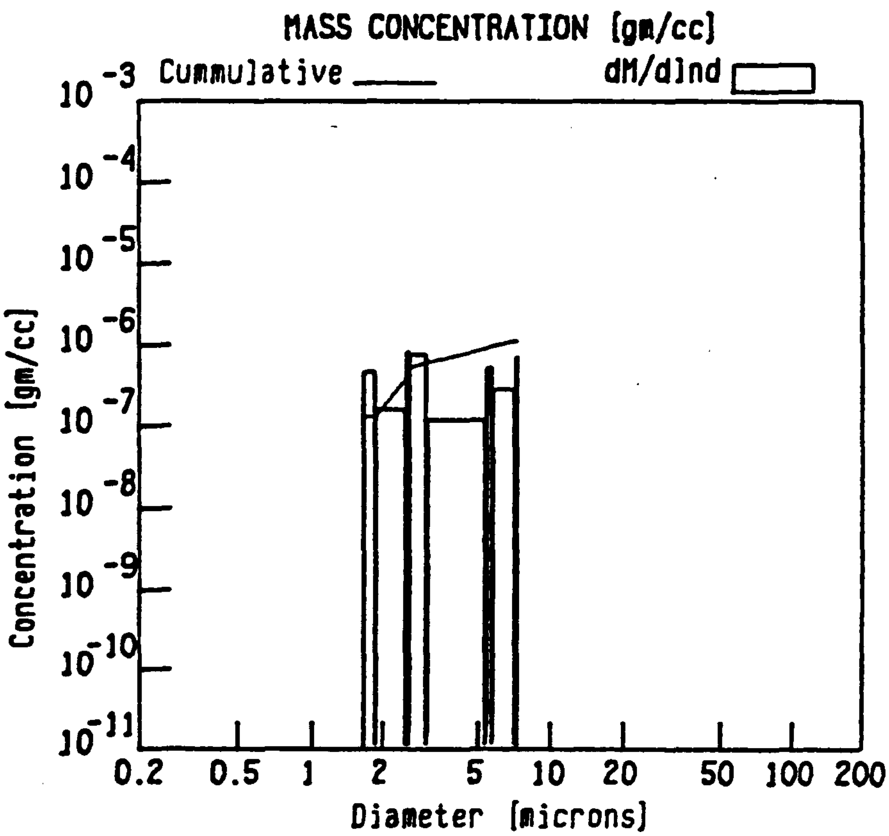
INSITEC Particle Counter Sizer Velocimeter

2' off center, downstream, AUA P=145psig T=82F, 50% RH, Water spray on



File : NTS55E.DAT
Date : 09-Sep-88
Time : 14:38:24
Trans. : 27 %
Valid : 79 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 3.31 microns

%	Diam	Cum Numb
99.9	1.70	1.01e+05
99.0	1.70	1.00e+05
90.0	1.70	9.10e+04
70.0	1.31	7.08e+04
50.0	2.54	5.05e+04
30.0	2.57	3.03e+04
10.0	1.00	1.01e+04
1.0	5.46	1.01e+03
0.1	7.24	1.01e+02

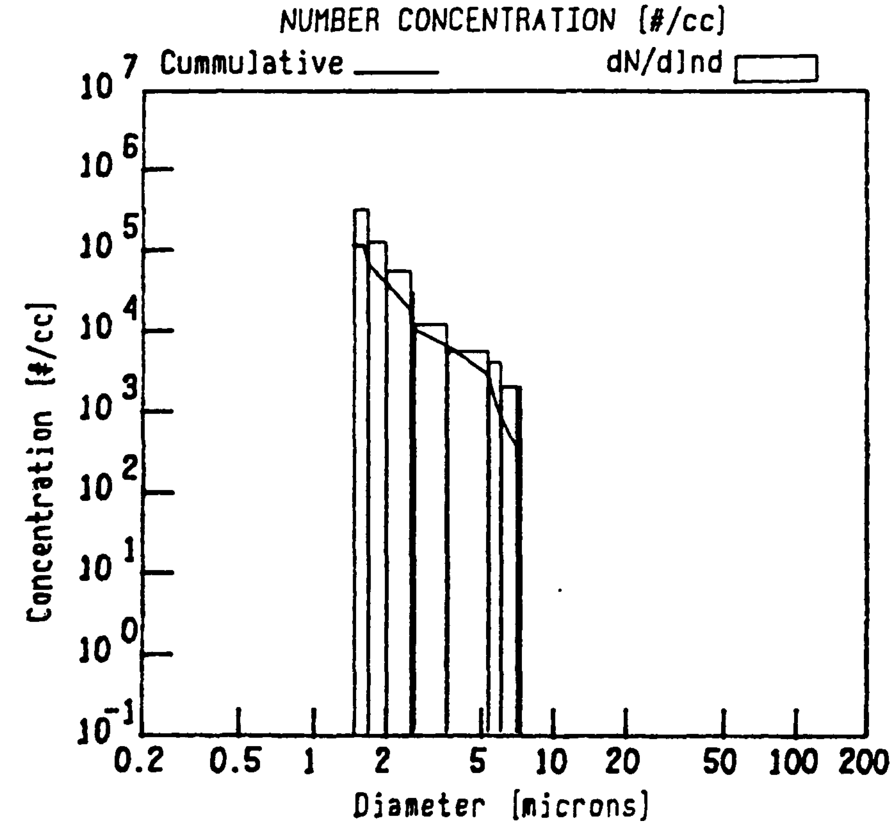


File : NTS55E.DAT
Date : 09-Sep-88
Time : 14:38:24
Trans. : 27 %
Valid : 79 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 3.31 microns

%	Diam	Cum Mass
99.9	7.29	1.16e-06
99.0	7.22	1.15e-06
90.0	6.21	1.05e-06
70.0	4.55	8.14e-07
50.0	2.86	5.82e-07
30.0	2.45	3.49e-07
10.0	1.86	1.16e-07
1.0	1.71	1.16e-08
0.1	1.70	1.16e-09

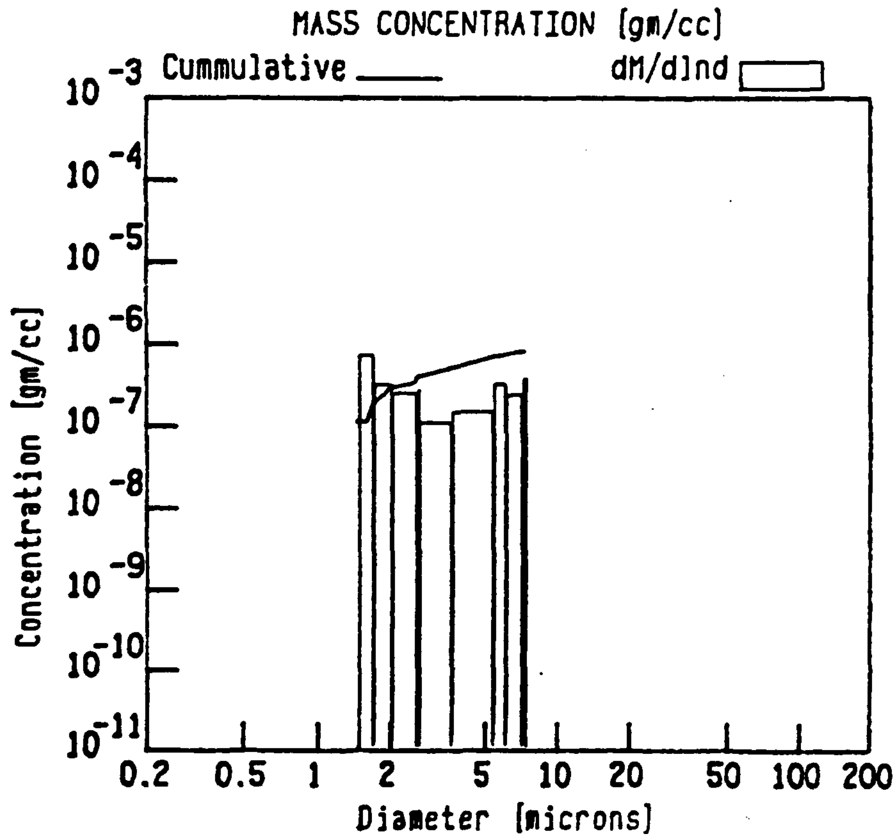
INSITEC Particle Counter Sizer Velocimeter

1' off wall, downstream, AUA P=200psig T=90F, 50% RH, Water spray off



File : NTS56B.DAT
Date : 09-Sep-88
Time : 15:28:32
Trans. : 18 %
Valid : 63 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 2.84 microns

%	Diam	Cum Numb
99.9	1.58	1.17e+05
99.0	1.58	1.16e+05
90.0	1.60	1.05e+05
70.0	1.63	8.17e+04
50.0	1.48	5.84e+04
30.0	1.65	3.50e+04
10.0	2.58	1.17e+04
1.0	5.32	1.17e+03
0.1	7.10	1.17e+02

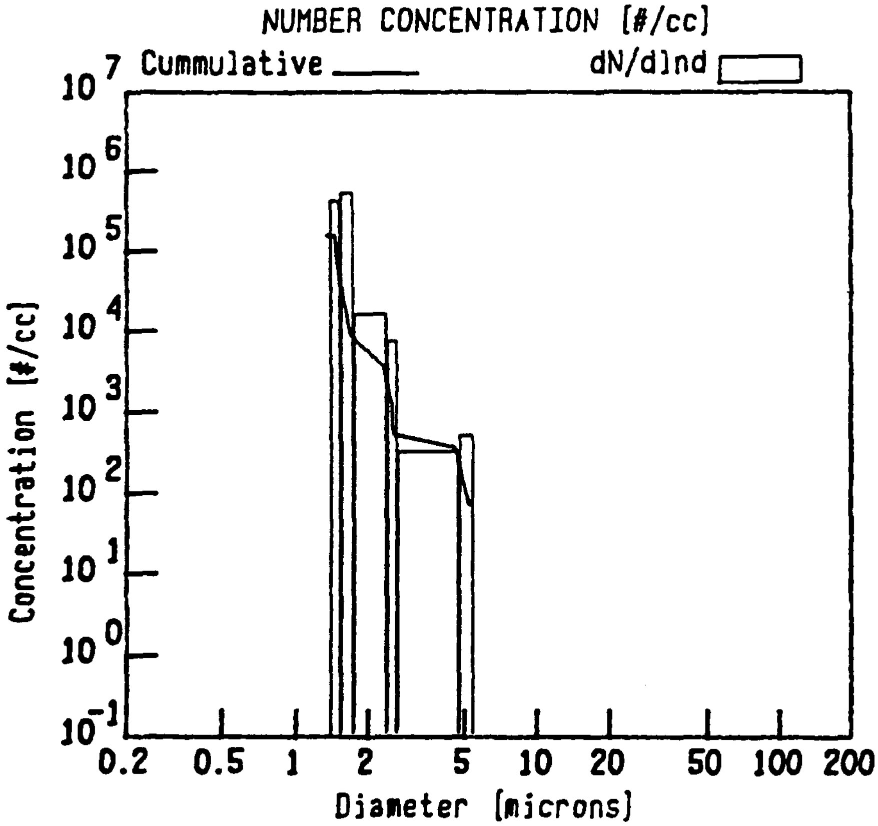


File : NTS56B.DAT
Date : 09-Sep-88
Time : 15:28:32
Trans. : 18 %
Valid : 63 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 2.84 microns

%	Diam	Cum Mass
99.9	7.31	7.94e-07
99.0	7.11	7.87e-07
90.0	5.97	7.16e-07
70.0	4.34	5.57e-07
50.0	2.71	3.98e-07
30.0	1.89	2.39e-07
10.0	1.63	7.95e-08
1.0	1.60	7.95e-09
0.1	1.60	7.95e-10

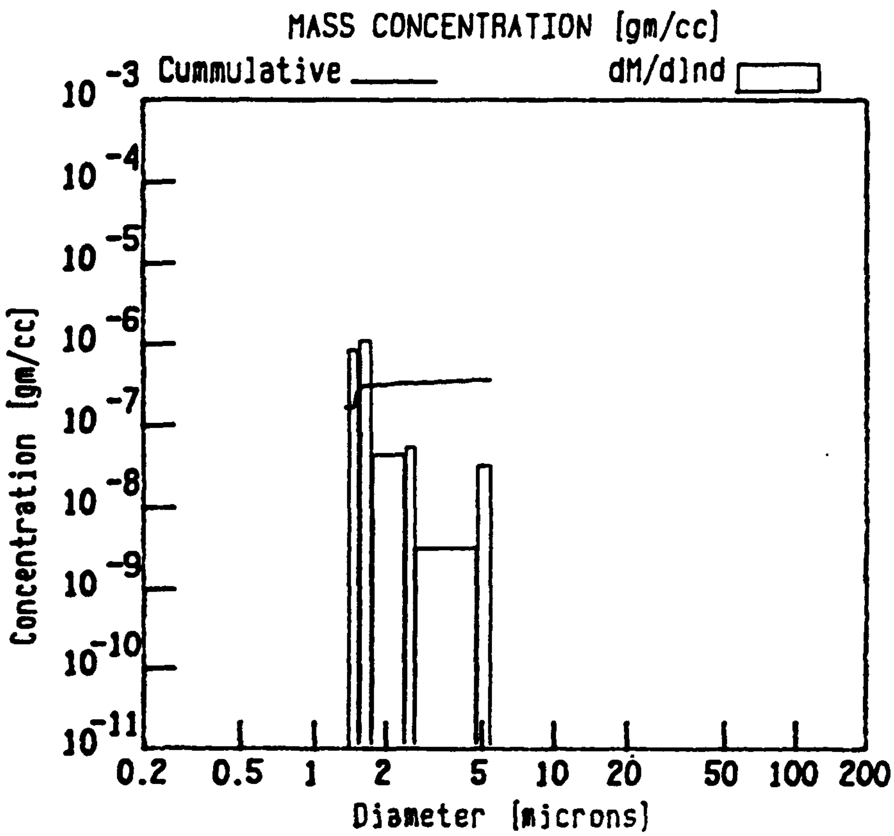
INSITEC Particle Counter Sizer Velocimeter

1' off center, downstream, AUA P=200psig T=90F, 50% RH, Water spray off



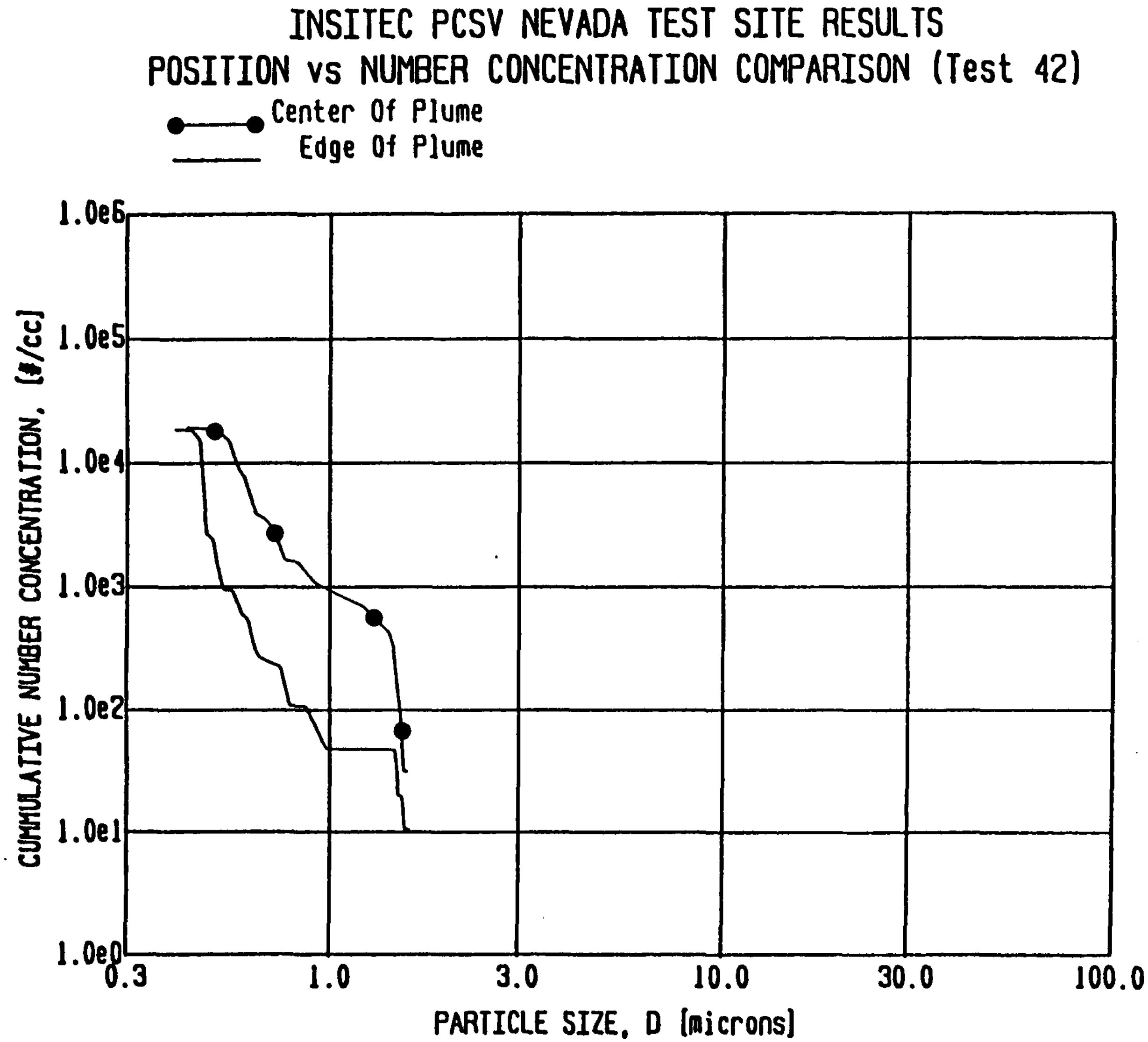
File : NTS56F.DAT
Date : 09-Sep-88
Time : 15:37:09
Trans. : 17 %
Valid : 54 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 1.68 microns

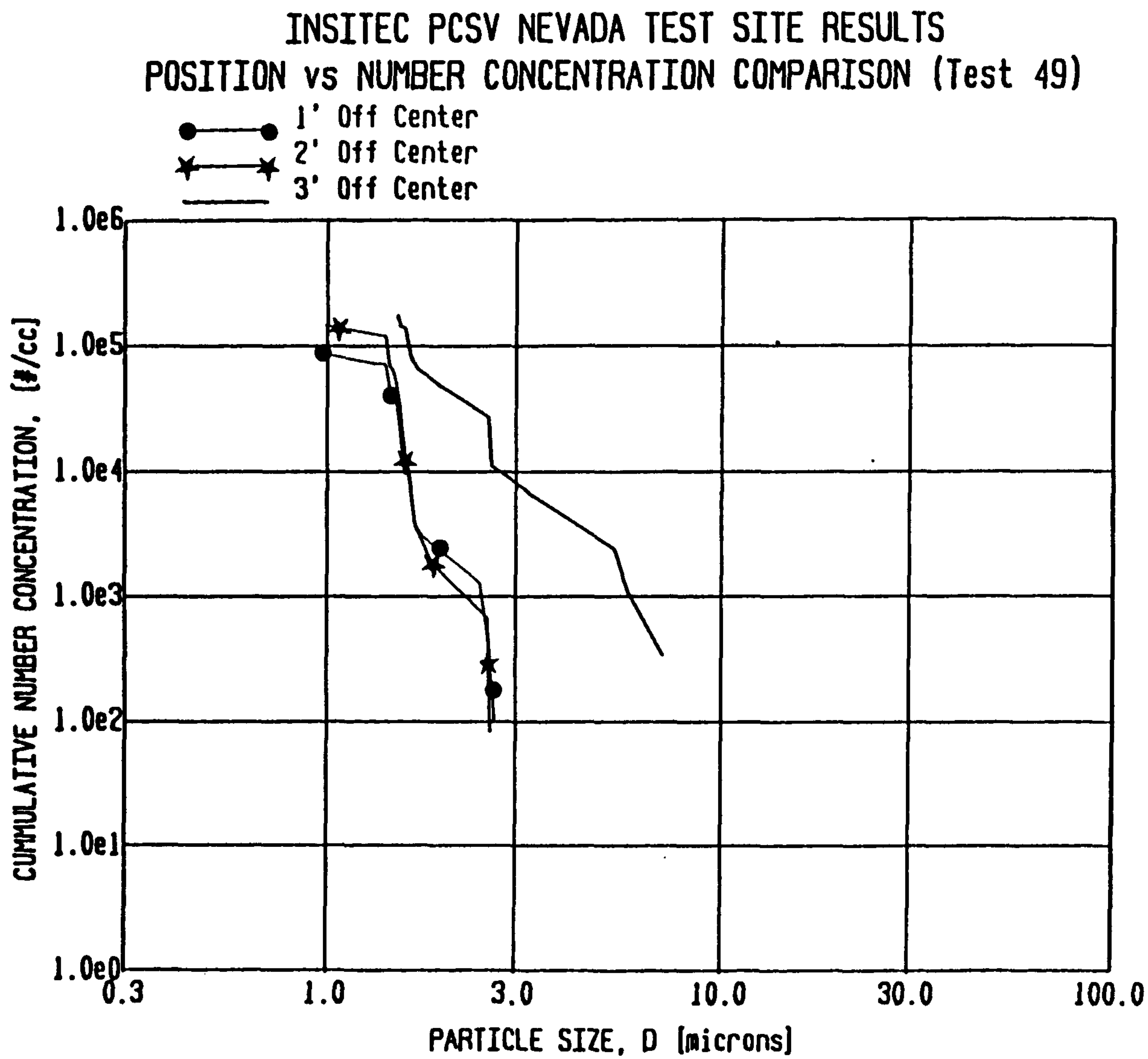
%	Diam	Cum Numb
99.9	1.50	1.63e+05
99.0	1.50	1.62e+05
90.0	1.50	1.47e+05
70.0	1.52	1.14e+05
50.0	1.53	8.16e+04
30.0	1.55	4.90e+04
10.0	1.62	1.63e+04
1.0	2.35	1.63e+03
0.1	4.52	1.63e+02



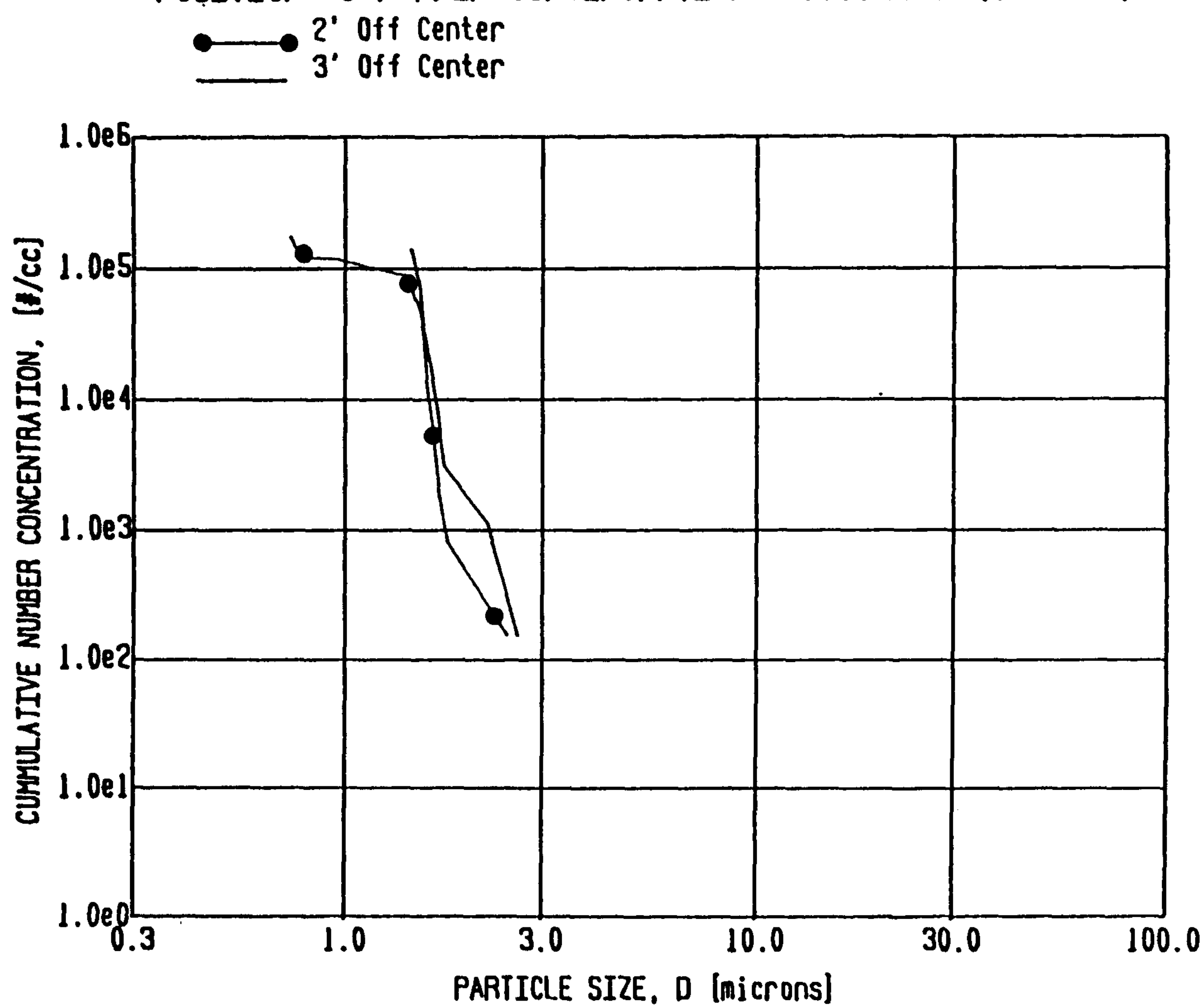
File : NTS56F.DAT
Date : 09-Sep-88
Time : 15:37:09
Trans. : 17 %
Valid : 54 %
Speed : 3.10 ± 0.00
Density: 1.00 gm/cc
D32 : 1.68 microns

%	Diam	Cum Mass
99.9	5.39	3.69e-07
99.0	5.01	3.65e-07
90.0	2.13	3.32e-07
70.0	1.58	2.58e-07
50.0	1.54	1.84e-07
30.0	1.52	1.11e-07
10.0	1.51	3.69e-08
1.0	1.50	3.69e-09
0.1	1.50	3.69e-10

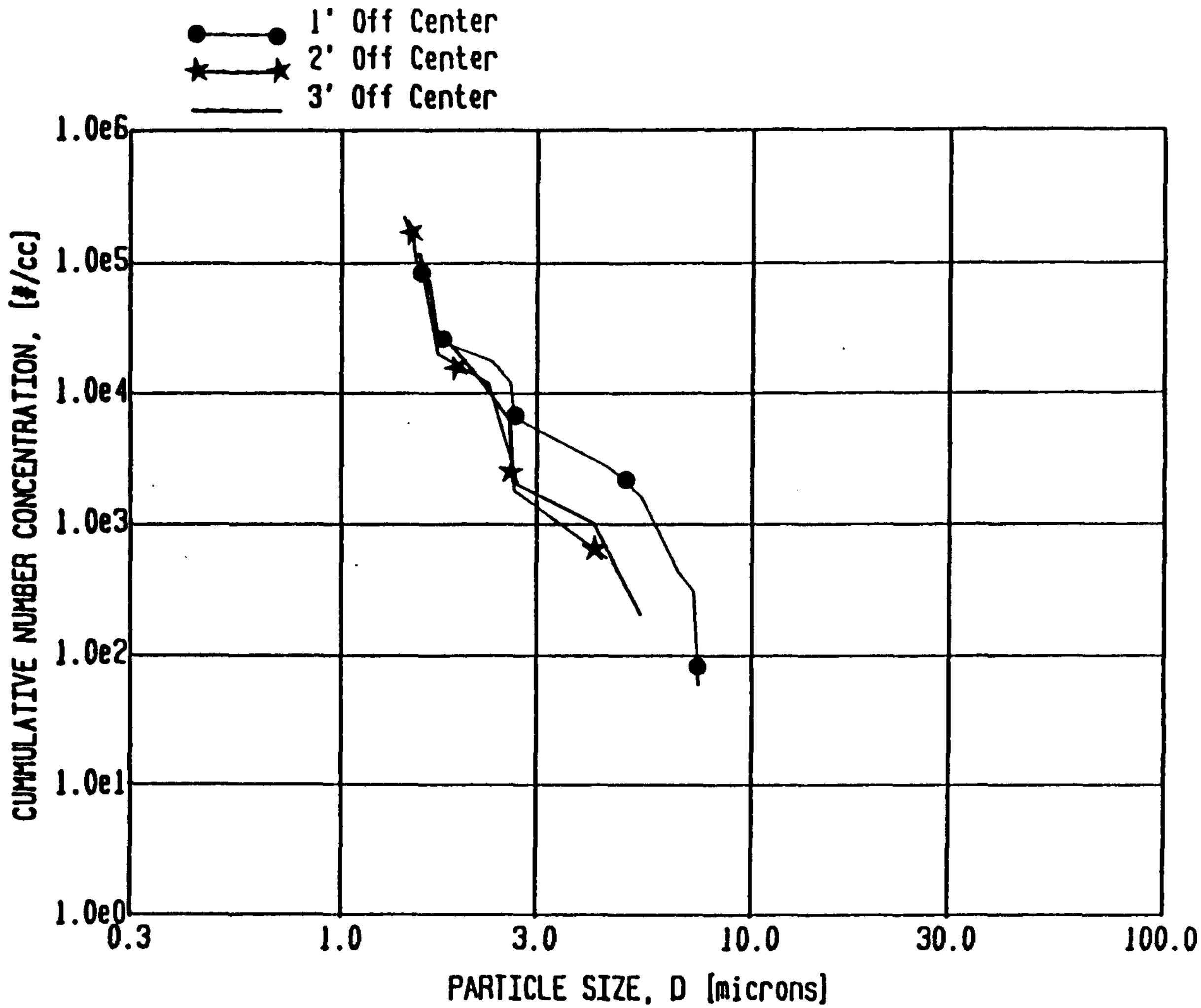

INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 42)
Center Of Plume
Edge Of Plume
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

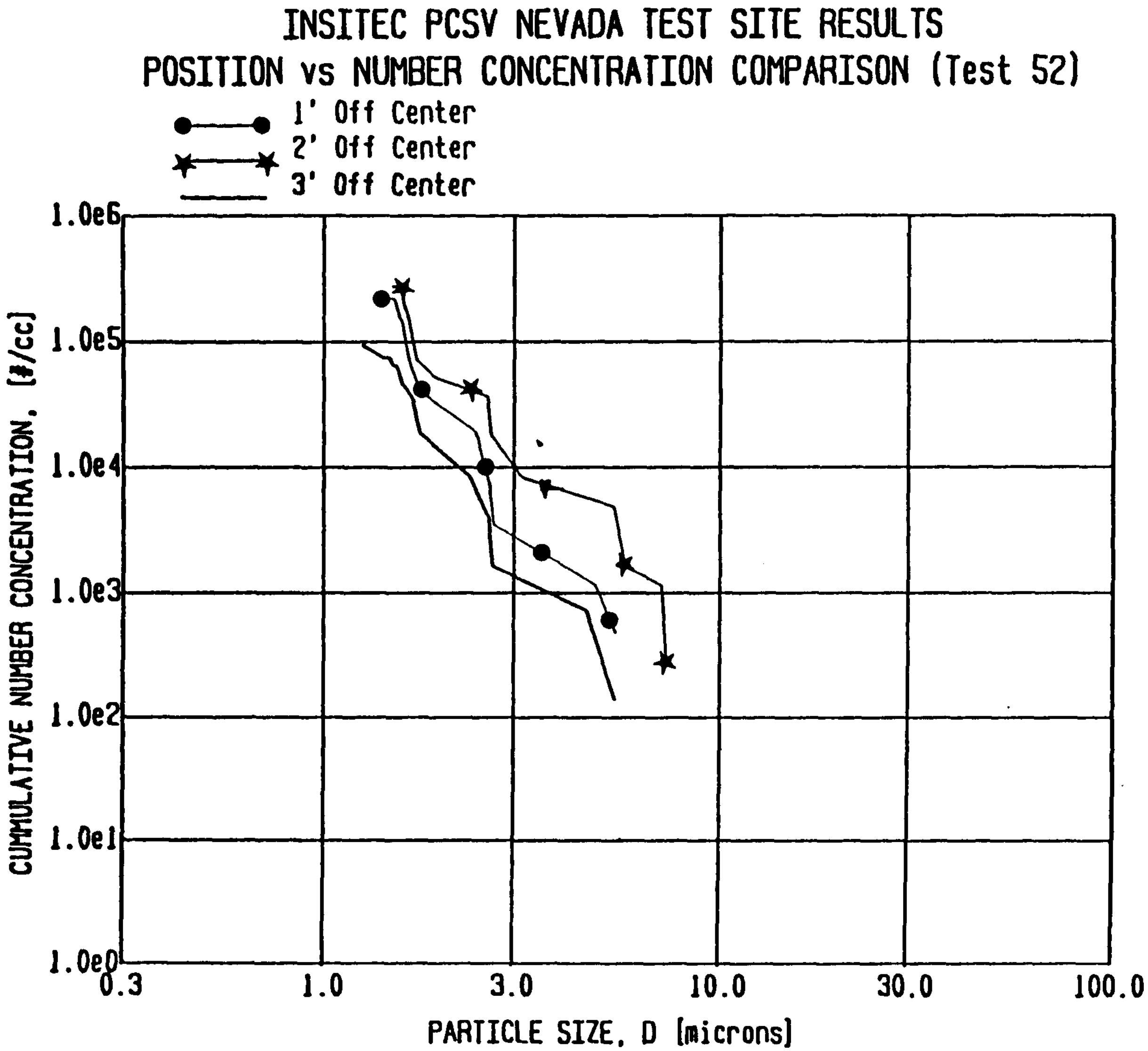

INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 49)
1' Off Center
2' Off Center
3' Off Center
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 50)

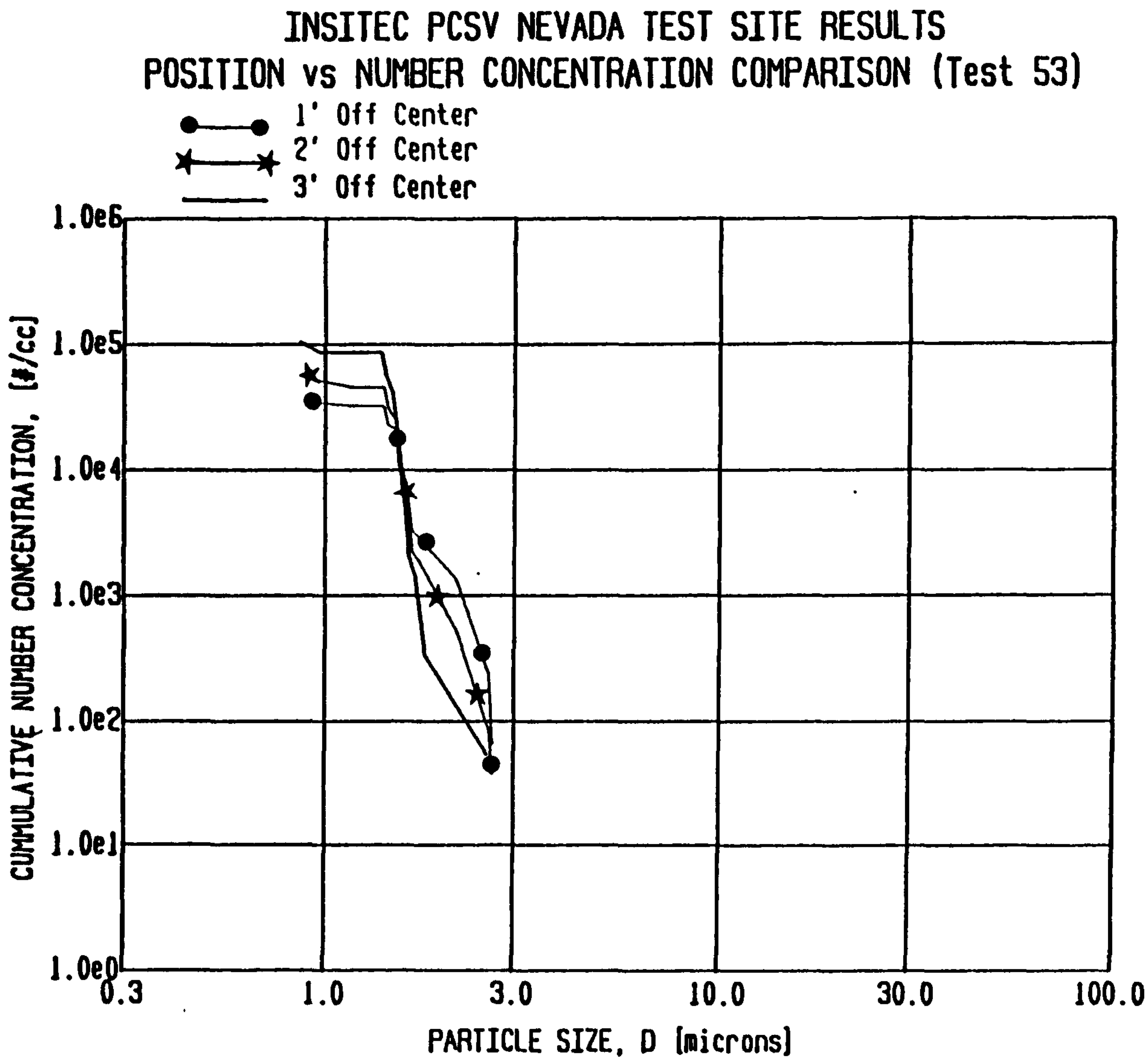


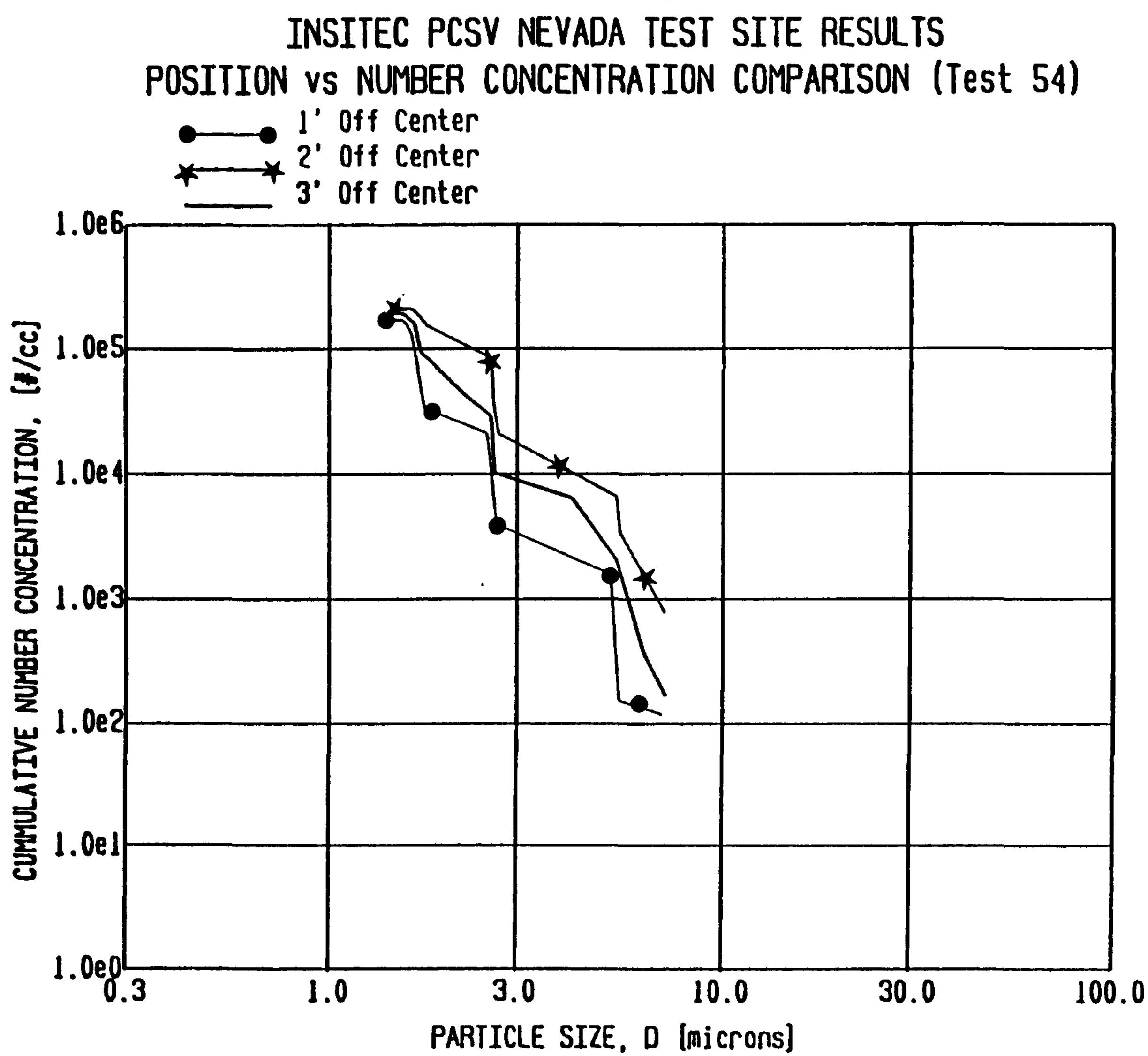
INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 51)



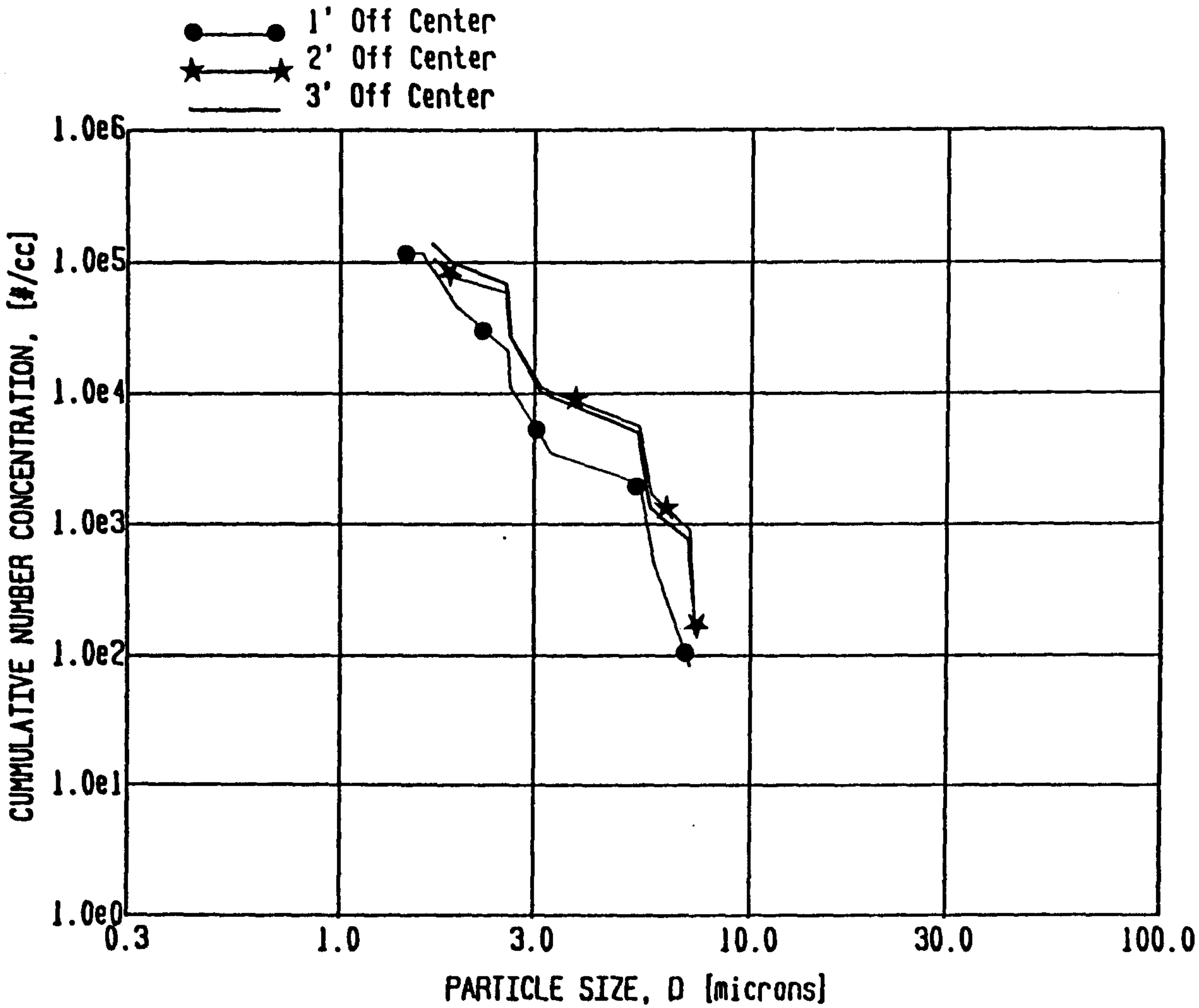


INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 52)
1' Off Center
2' Off Center
3' Off Center
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

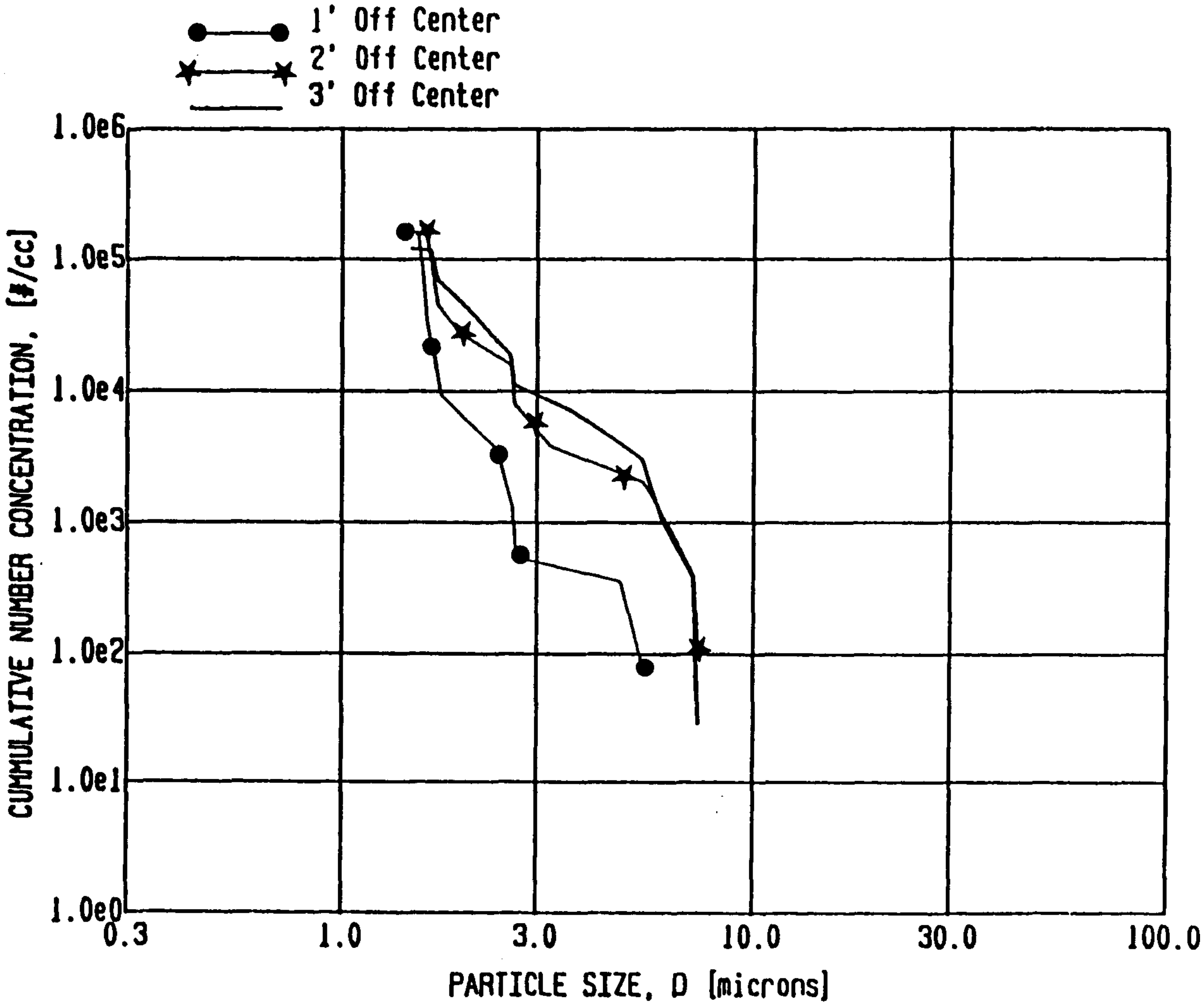

INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 53)
1' Off Center
2' Off Center
3' Off Center
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]


INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 54)
1' Off Center
2' Off Center
3' Off Center
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

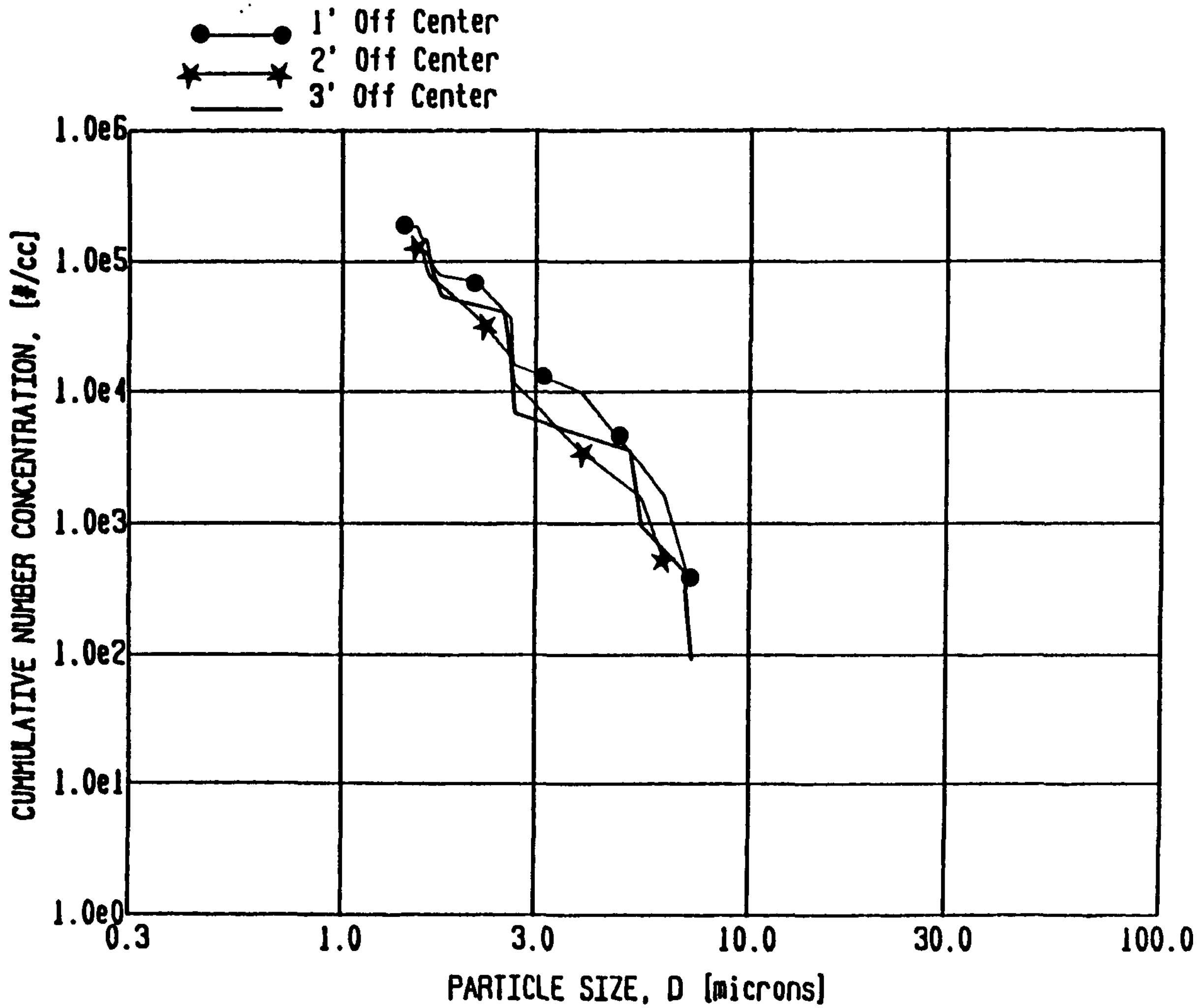
INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 55)

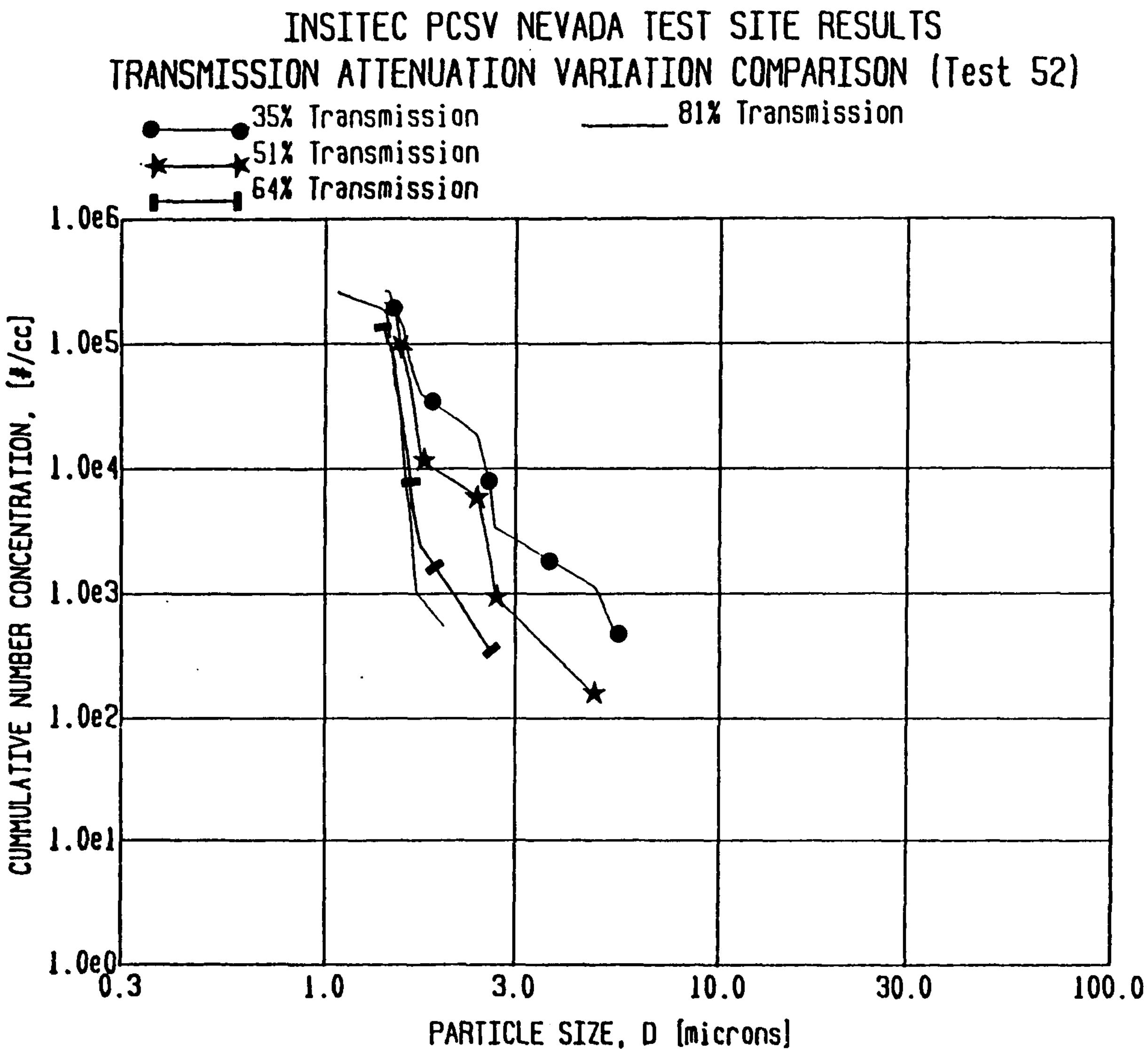


INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 56)

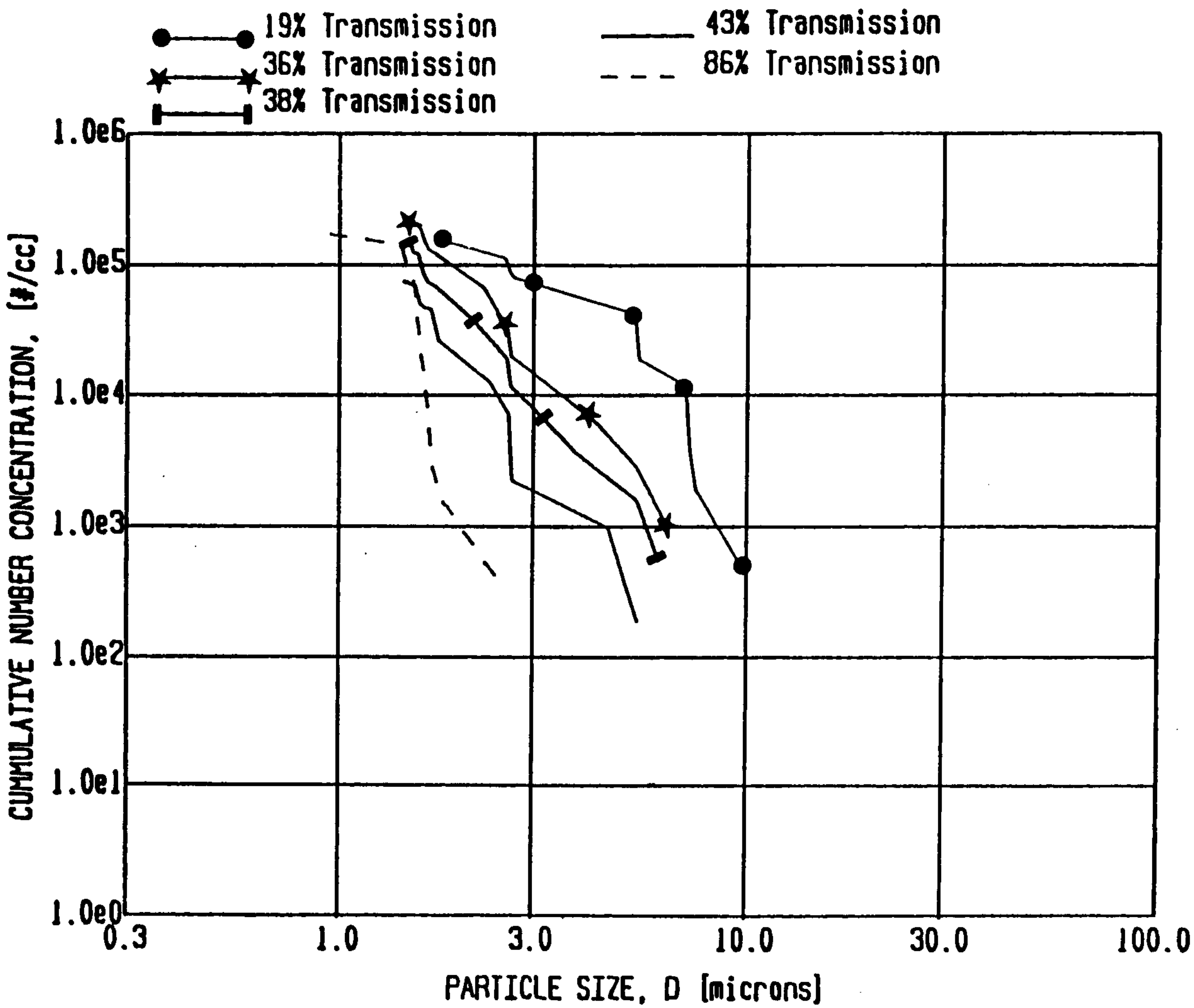


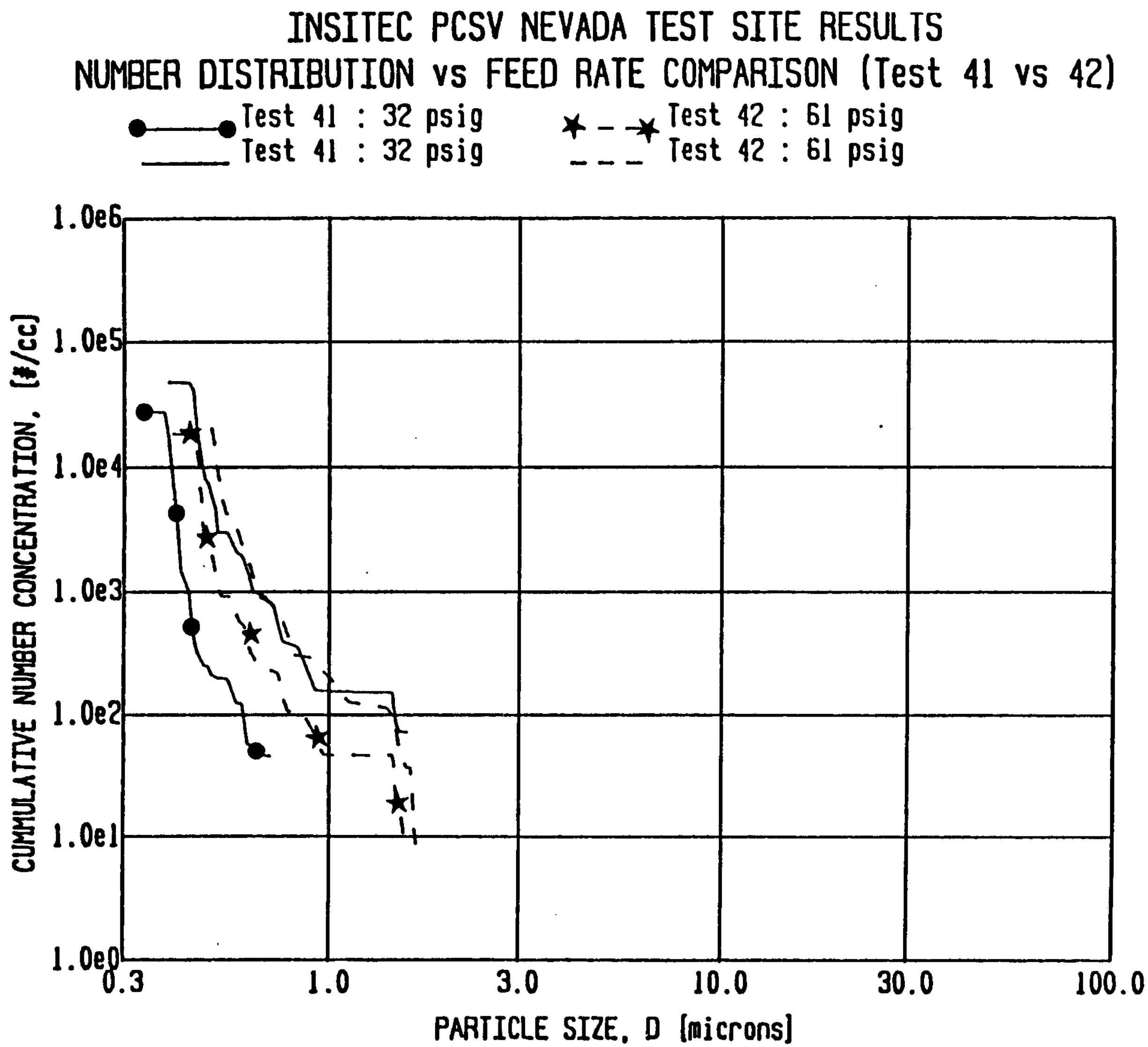
INSITEC PCSV NEVADA TEST SITE RESULTS
POSITION vs NUMBER CONCENTRATION COMPARISON (Test 57)



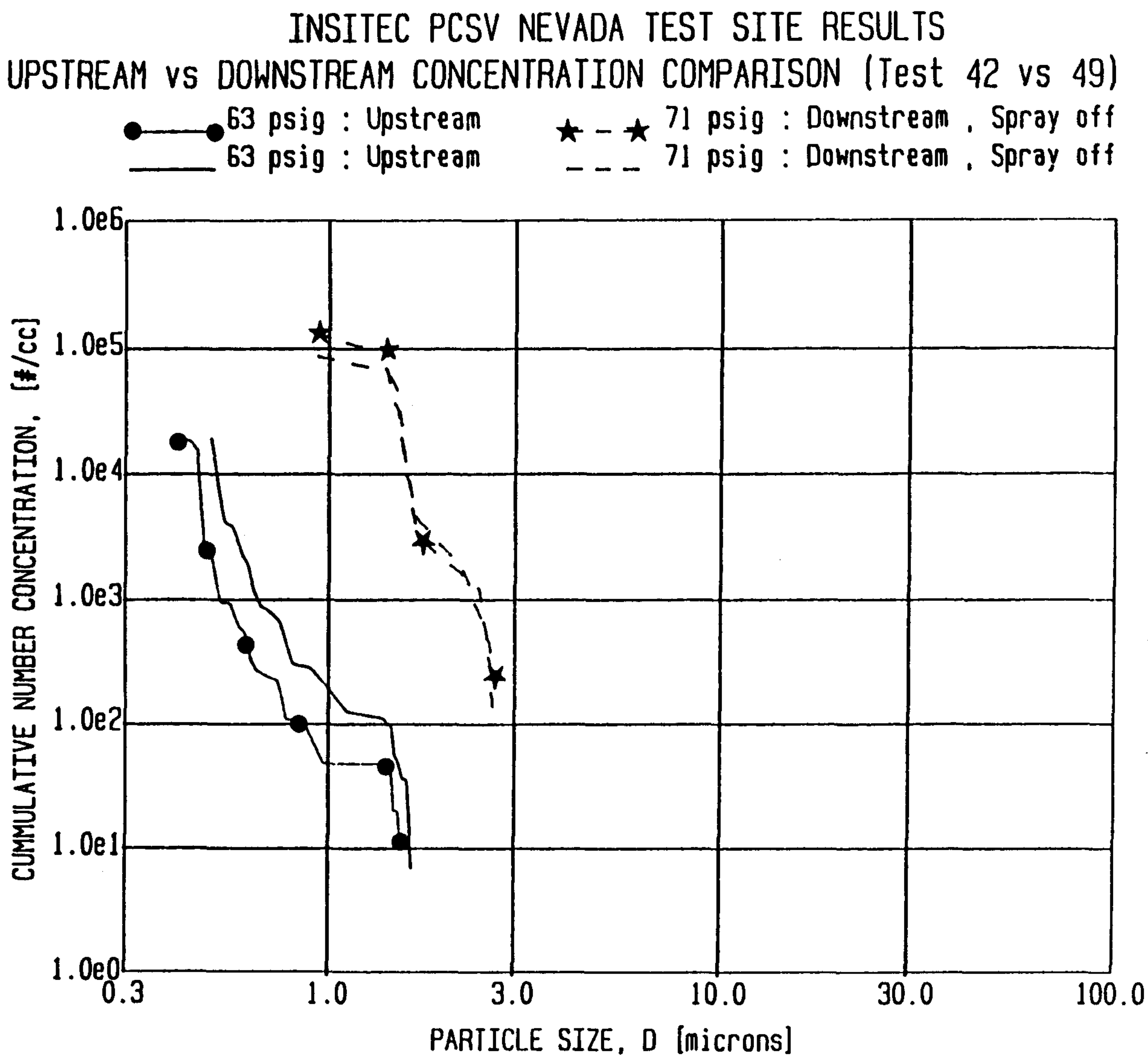

INSITEC PCSV NEVADA TEST SITE RESULTS
TRANSMISSION ATTENUATION VARIATION COMPARISON (Test 52)
35% Transmission
51% Transmission
64% Transmission
81% Transmission
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

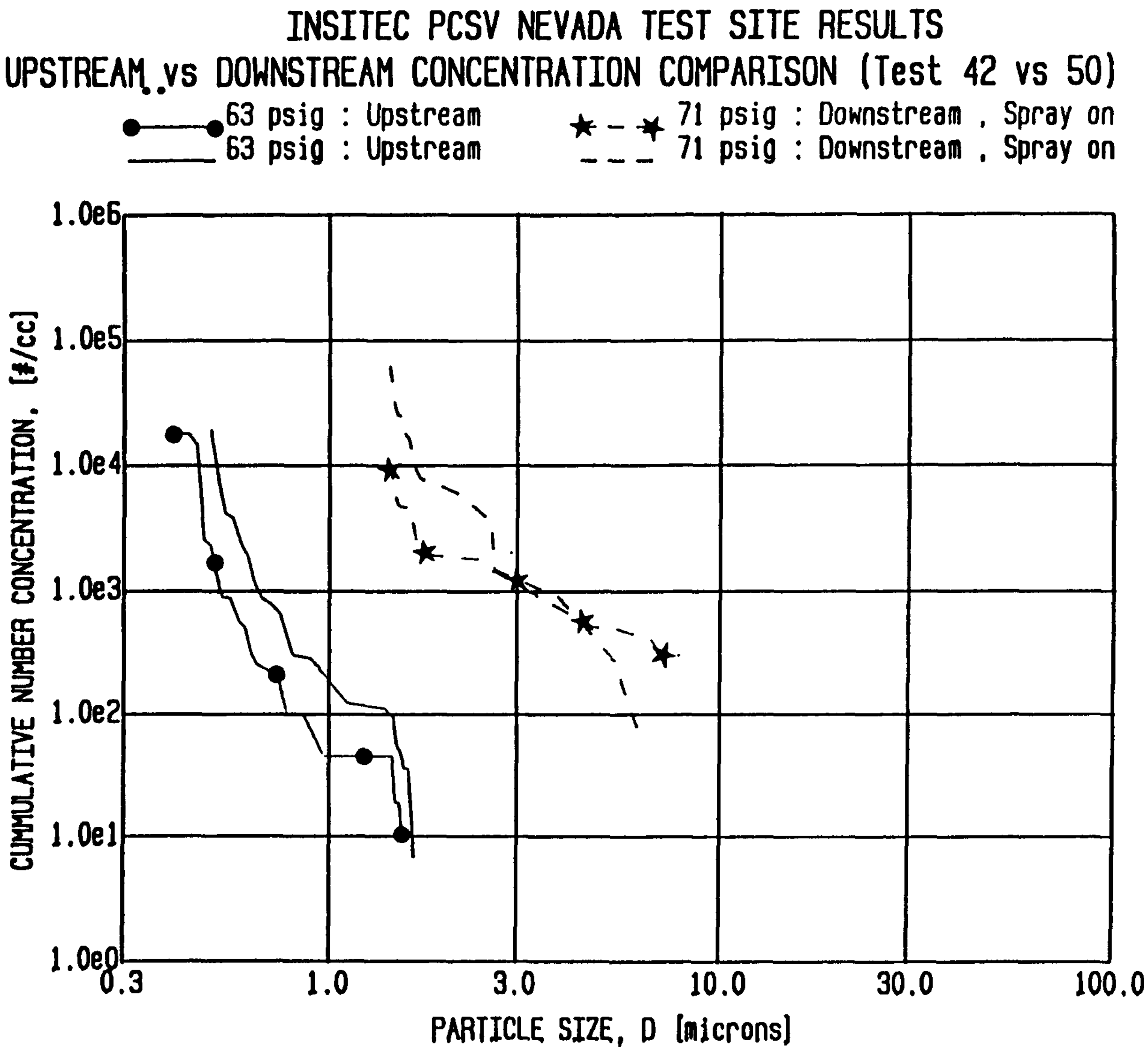
INSITEC PCSV NEVADA TEST SITE RESULTS
TRANSMISSION ATTENUATION VARIATION COMPARISON (Test 57)





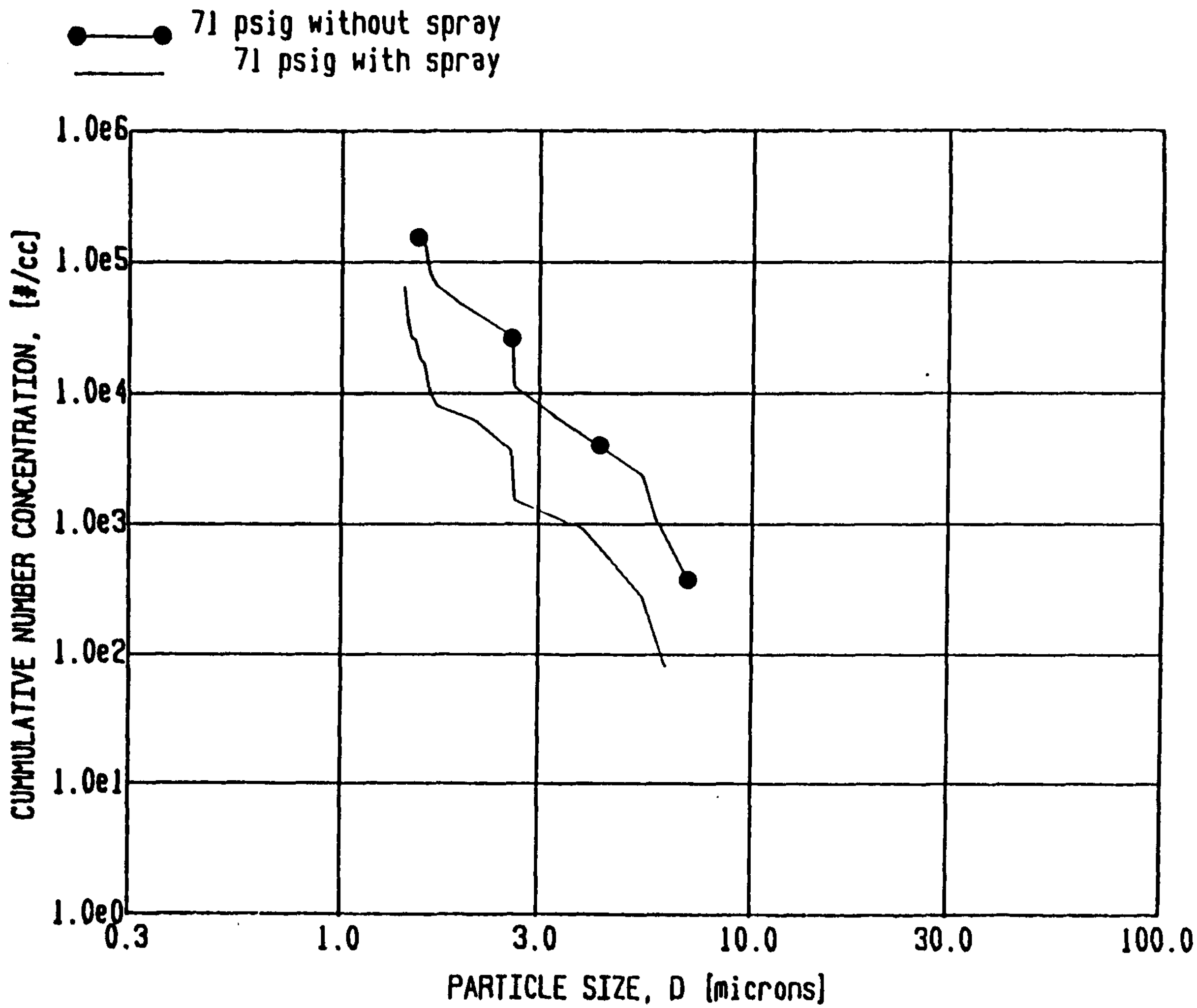
INSITEC PCSV NEVADA TEST SITE RESULTS
NUMBER DISTRIBUTION vs FEED RATE COMPARISON (Test 41 vs 42)
Test 41 : 32 psig
Test 41 : 32 psig
Test 42 : 61 psig
Test 42 : 61 psig
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

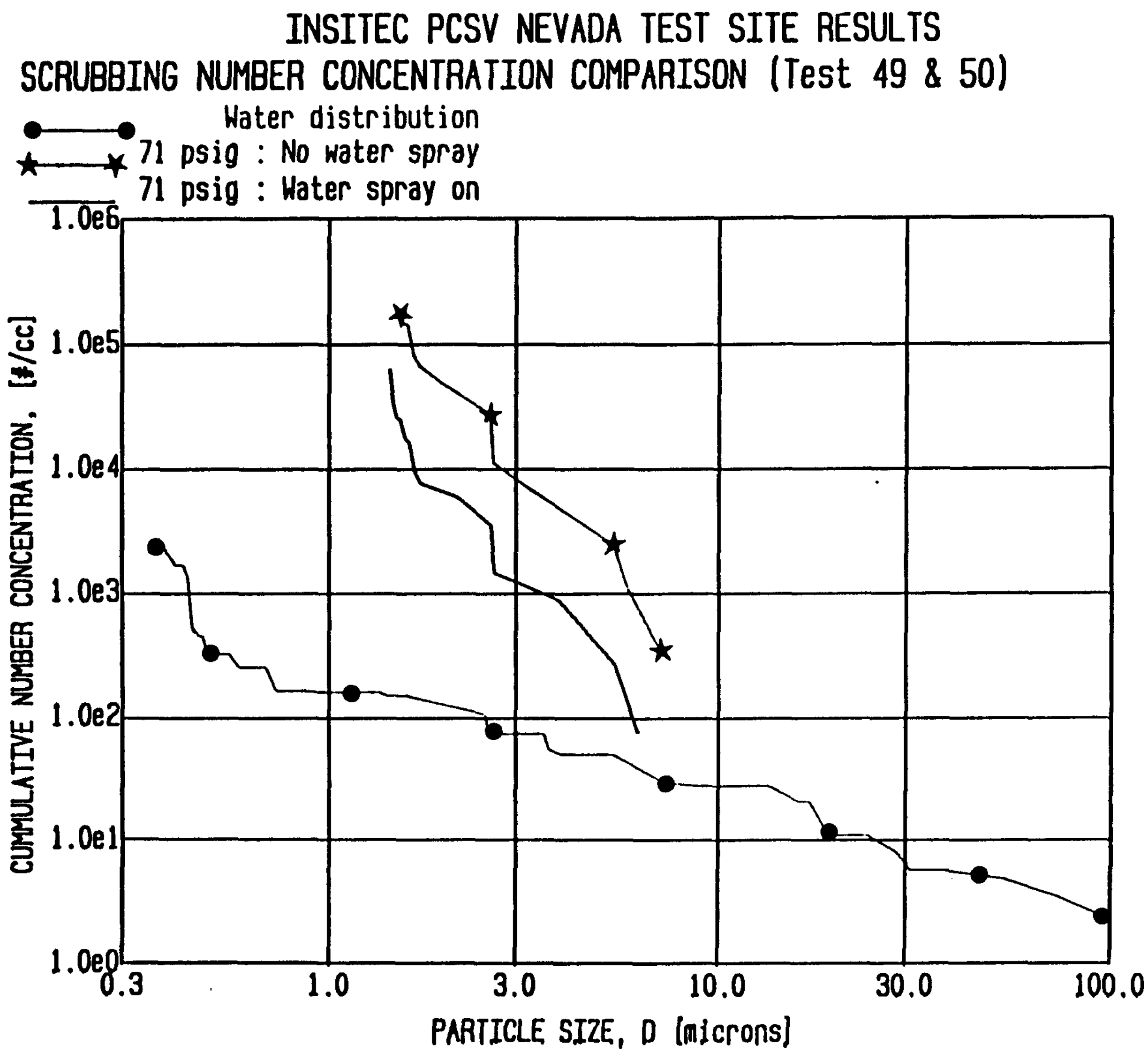

INSITEC PCSV NEVADA TEST SITE RESULTS
UPSTREAM vs DOWNSTREAM CONCENTRATION COMPARISON (Test 42 vs 49)
63 psig : Upstream
63 psig : Upstream
71 psig : Downstream , Spray off
71 psig : Downstream , Spray off
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
PARTICLE SIZE, D [microns]

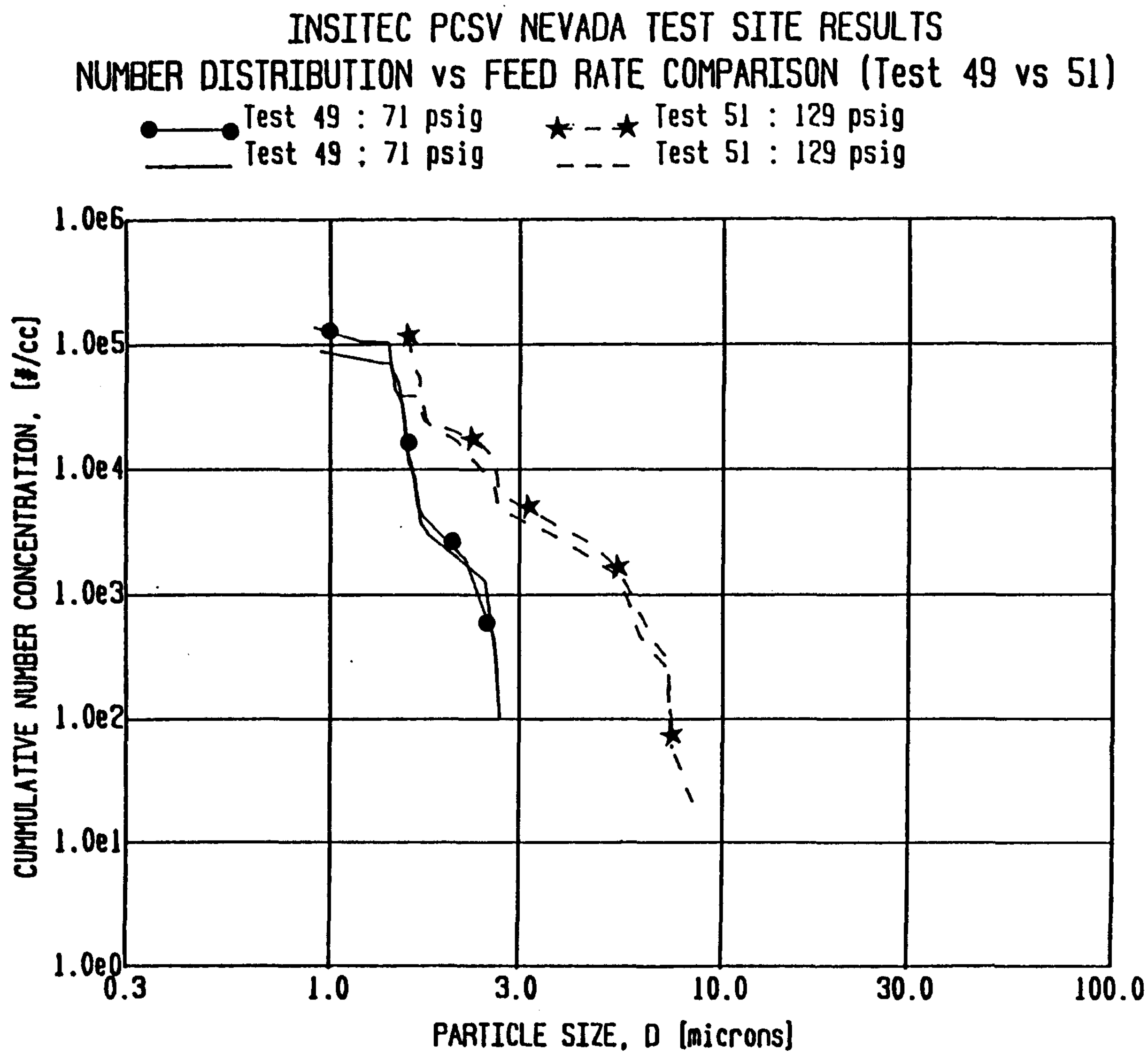


INSITEC PCSV NEVADA TEST SITE RESULTS
UPSTREAM vs DOWNSTREAM CONCENTRATION COMPARISON (Test 42 vs 50)
63 psig : Upstream
63 psig : Upstream
71 psig : Downstream , Spray on
71 psig : Downstream , Spray on
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]

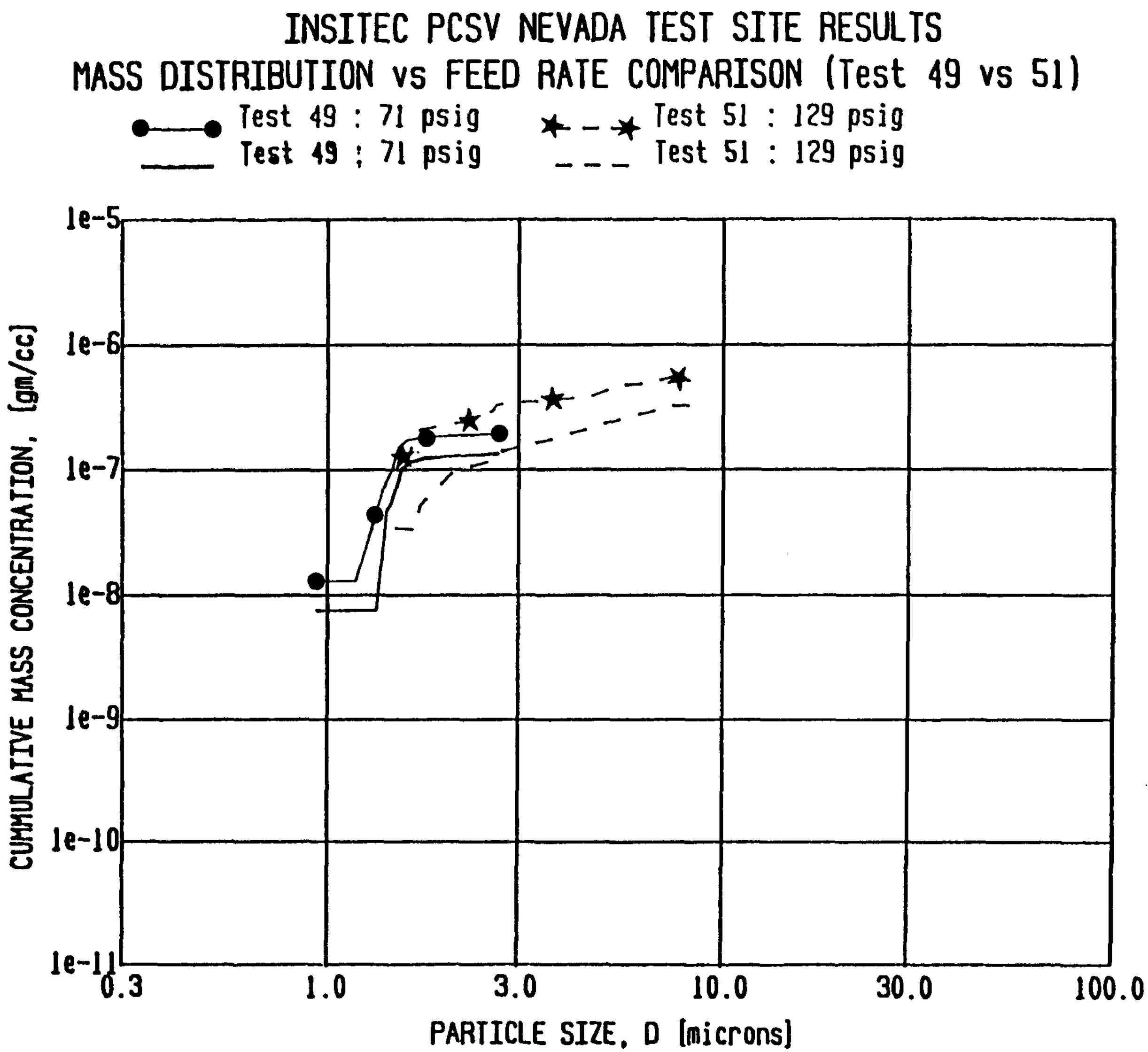
INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUNBER CONCENTRATION COMPARISON (Test 49 & 50)



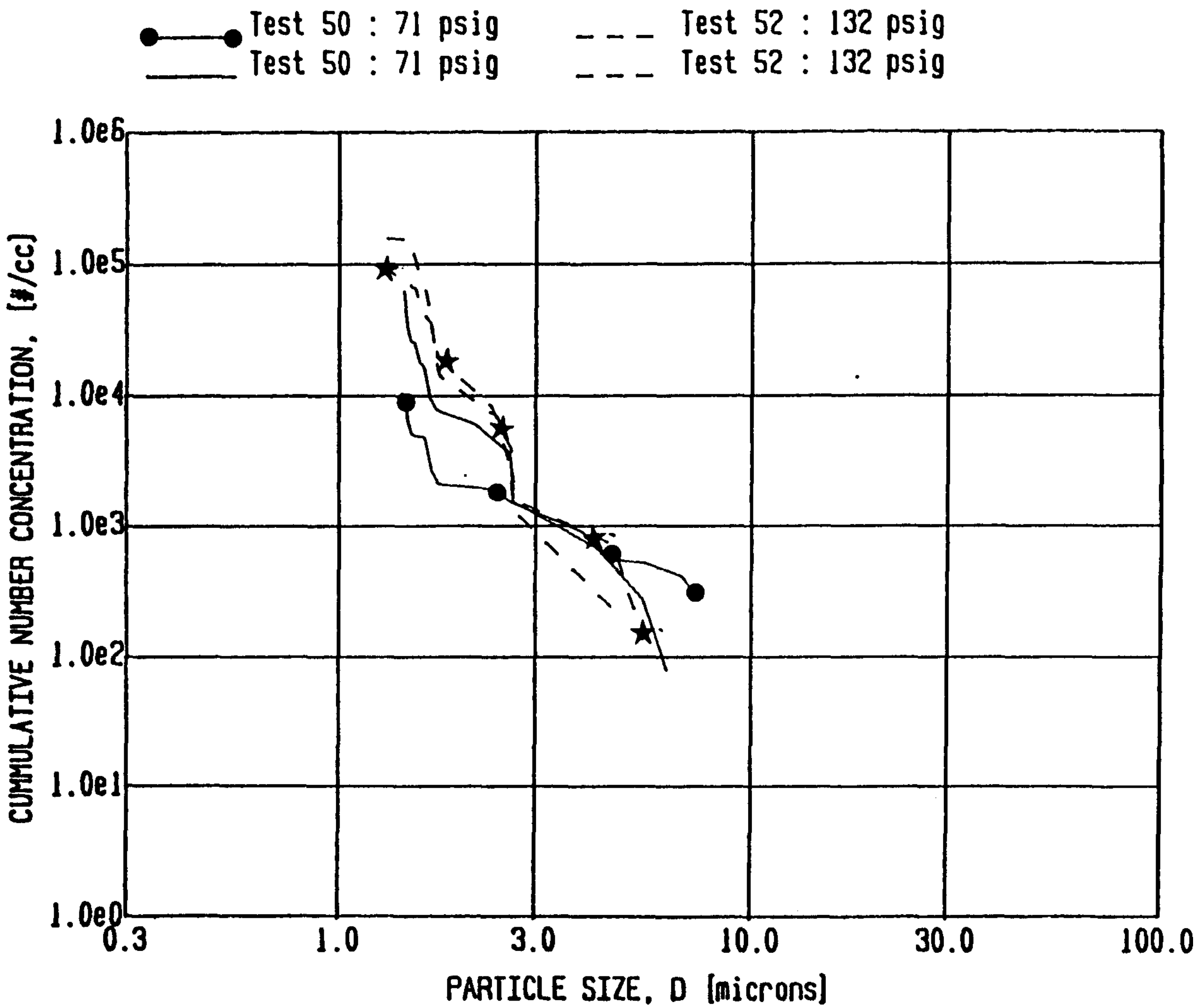

INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUMBER CONCENTRATION COMPARISON (Test 49 & 50)
Water distribution
71 psig : No water spray
71 psig : Water spray on
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]



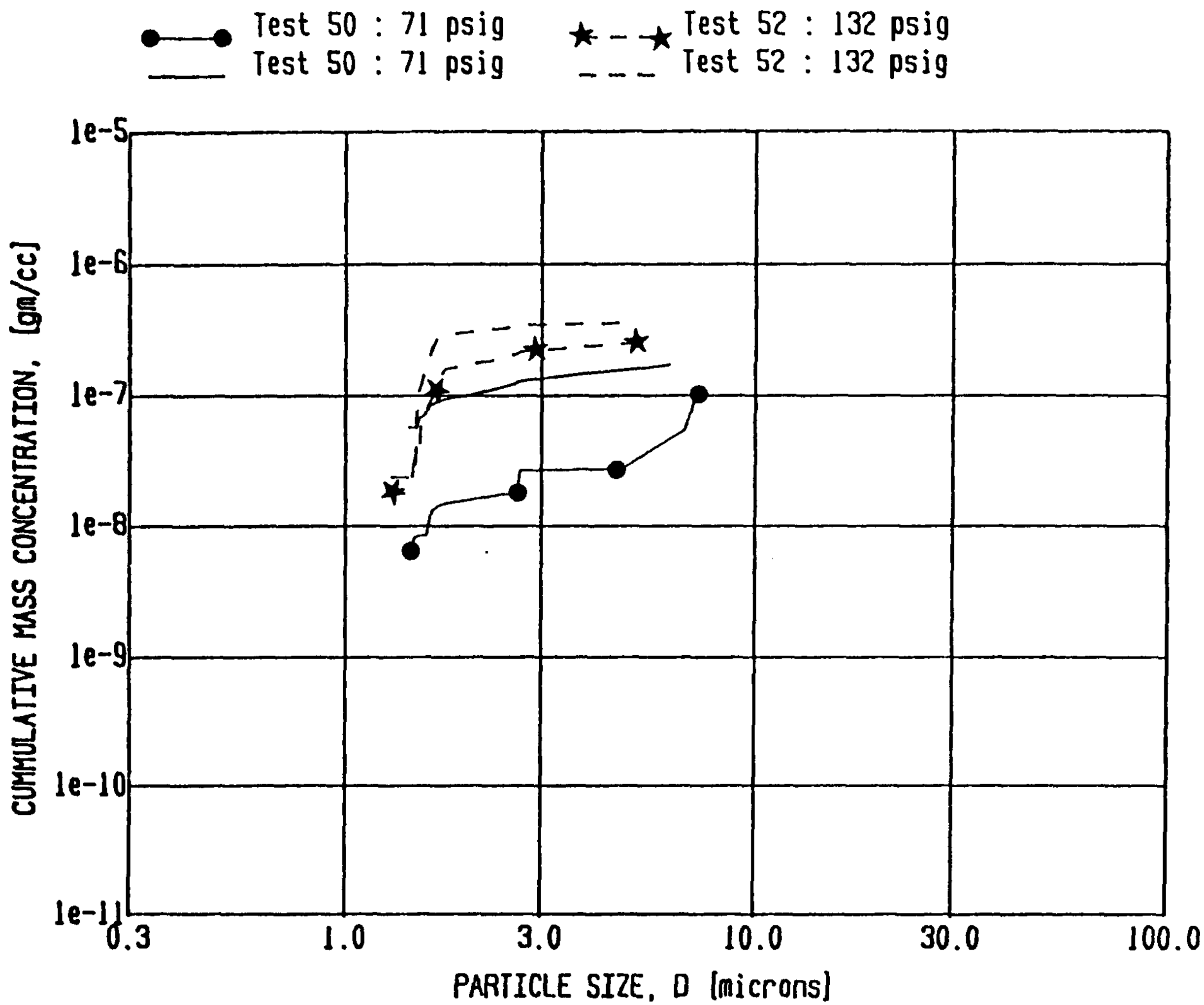
INSITEC PCSV NEVADA TEST SITE RESULTS
NUMBER DISTRIBUTION vs FEED RATE COMPARISON (Test 49 vs 51)
Test 49 : 71 psig
Test 49 ; 71 psig
Test 51 : 129 psig
Test 51 : 129 psig
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]


INSITEC PCSV NEVADA TEST SITE RESULTS
MASS DISTRIBUTION vs FEED RATE COMPARISON (Test 49 vs 51)
Test 49 : 71 psig
Test 51 : 129 psig
Test 49 ; 71 psig
Test 51 : 129 psig
1e-5
1e-6
1e-7
1e-8
1e-9
1e-10
1e-11
0.3
1.0
3.0
10.0
30.0
100.0
CUMMULATIVE MASS CONCENTRATION, [gm/cc]
PARTICLE SIZE, D [microns]

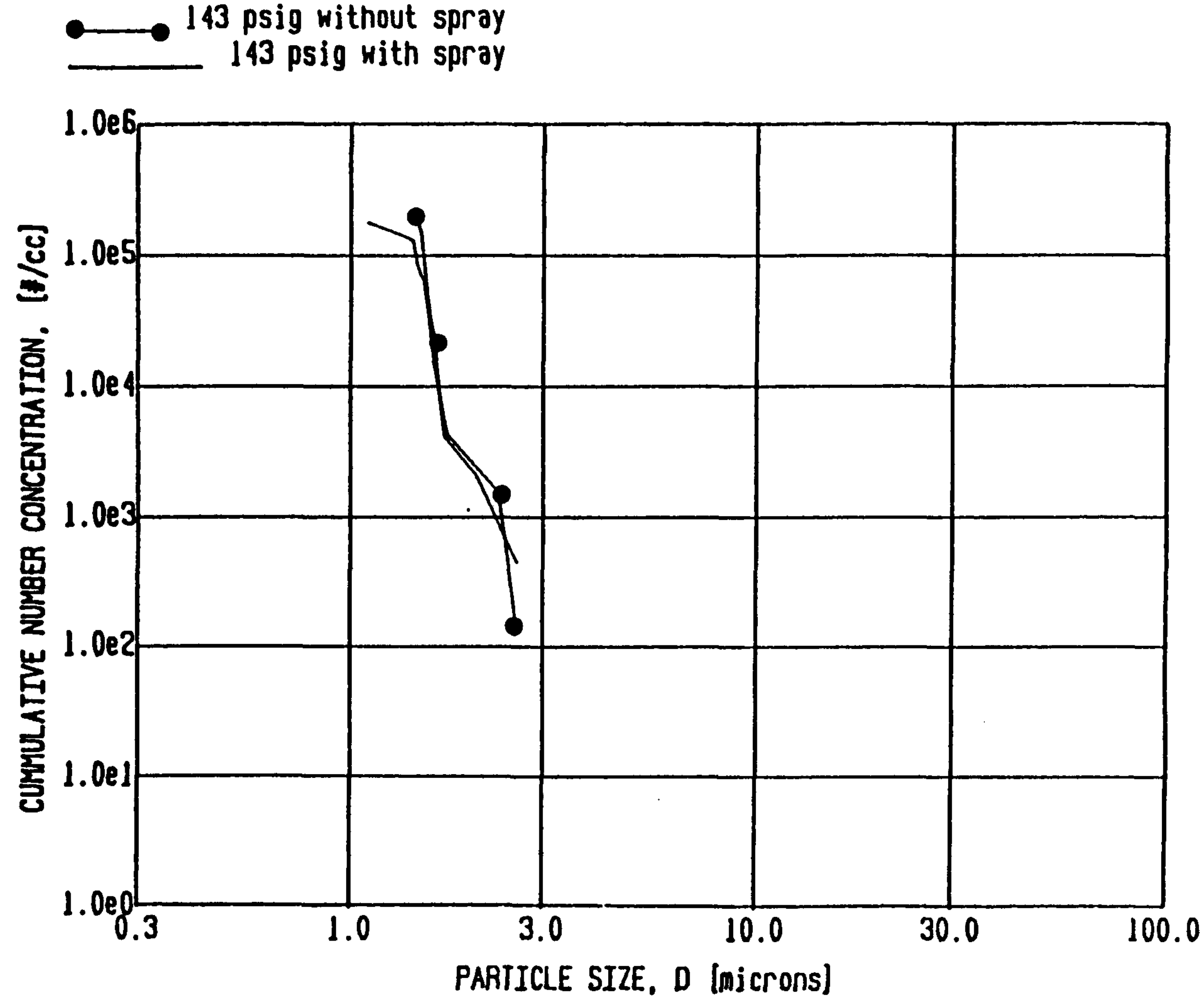
INSITEC PCSV NEVADA TEST SITE RESULTS
NUMBER DISTRIBUTION vs FEED RATE COMPARISON (Test 50 vs 52)

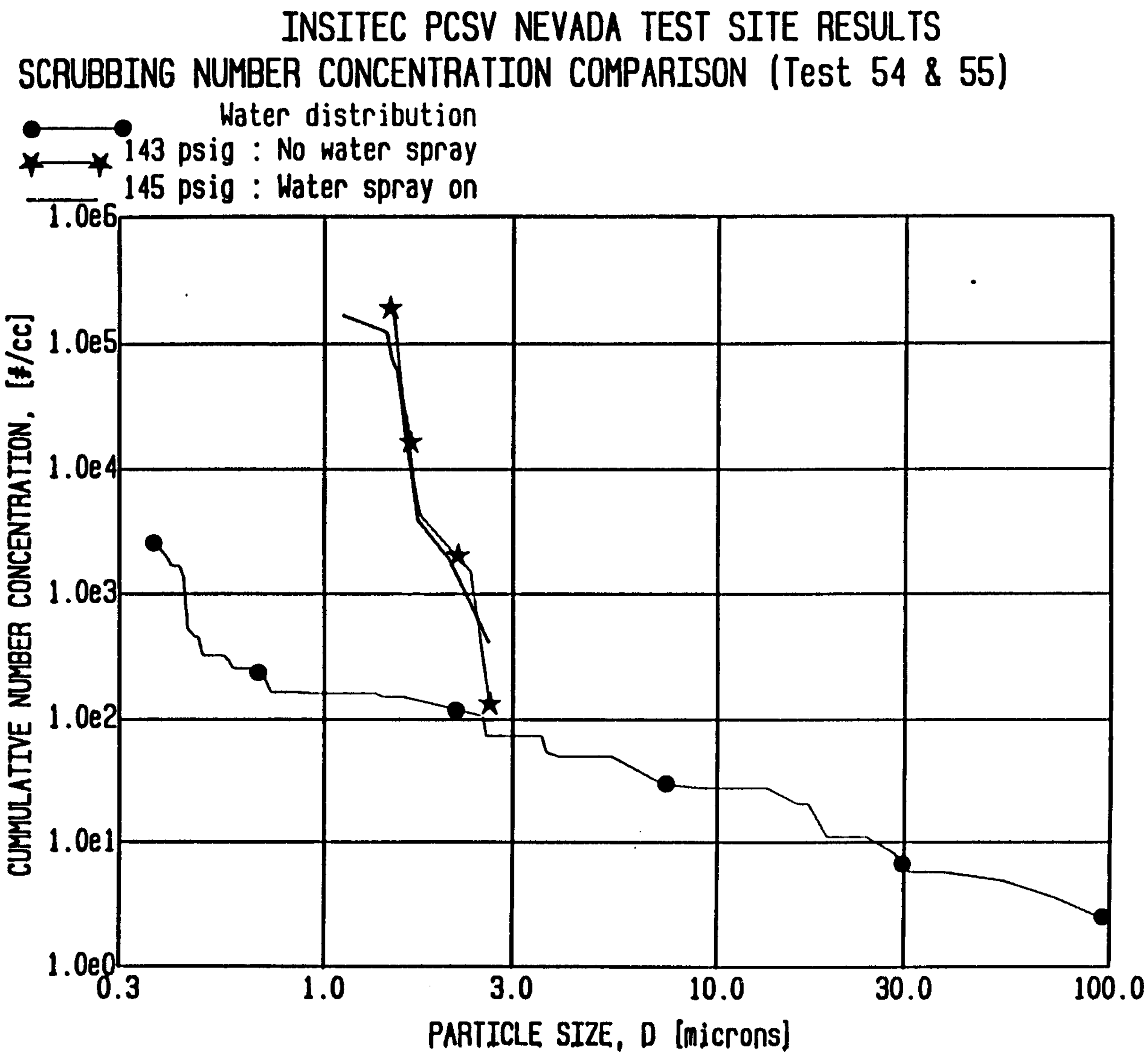


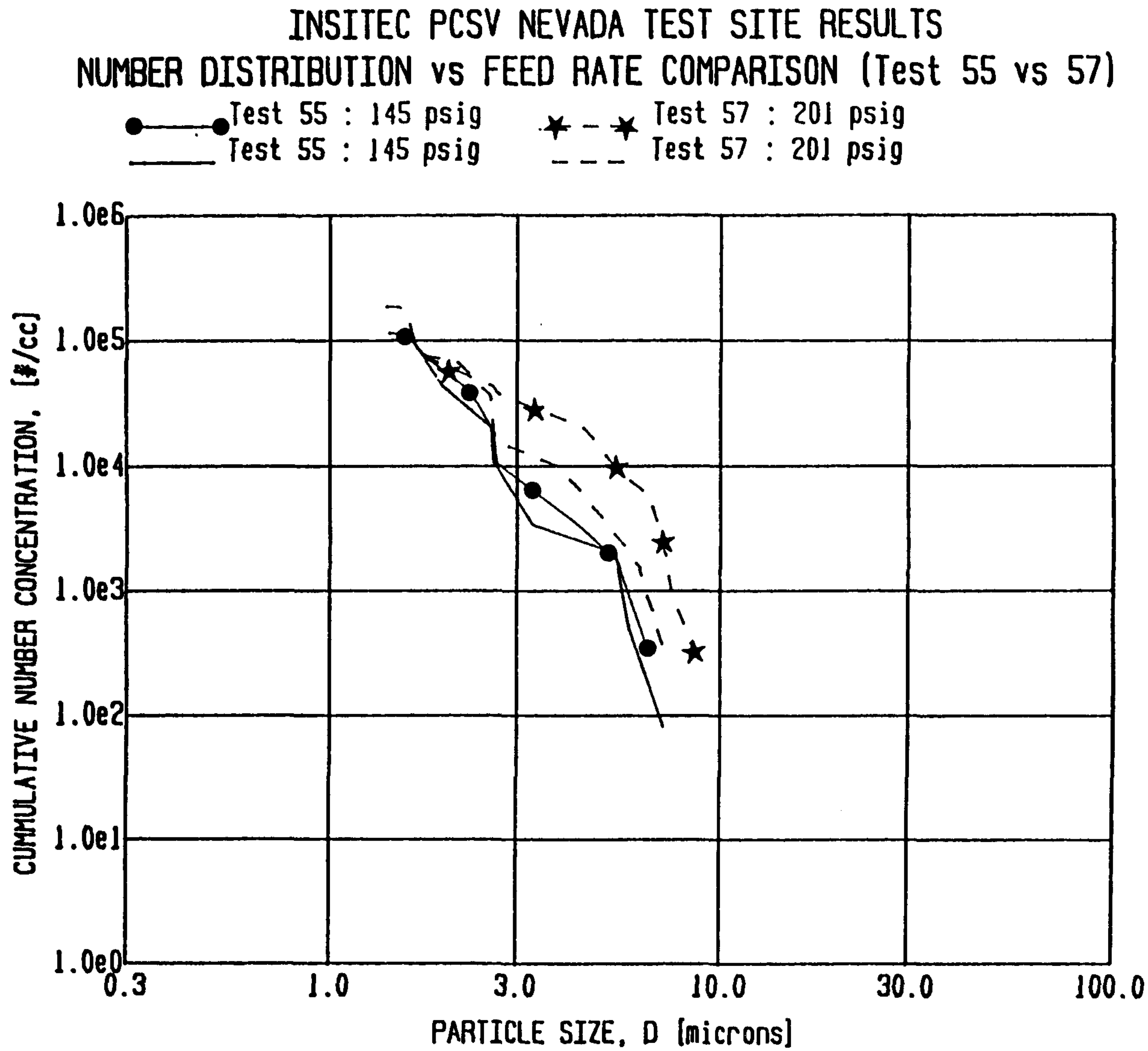
INSITEC PCSV NEVADA TEST SITE RESULTS
MASS DISTRIBUTION vs FEED RATE COMPARISON (Test 50 vs 52)

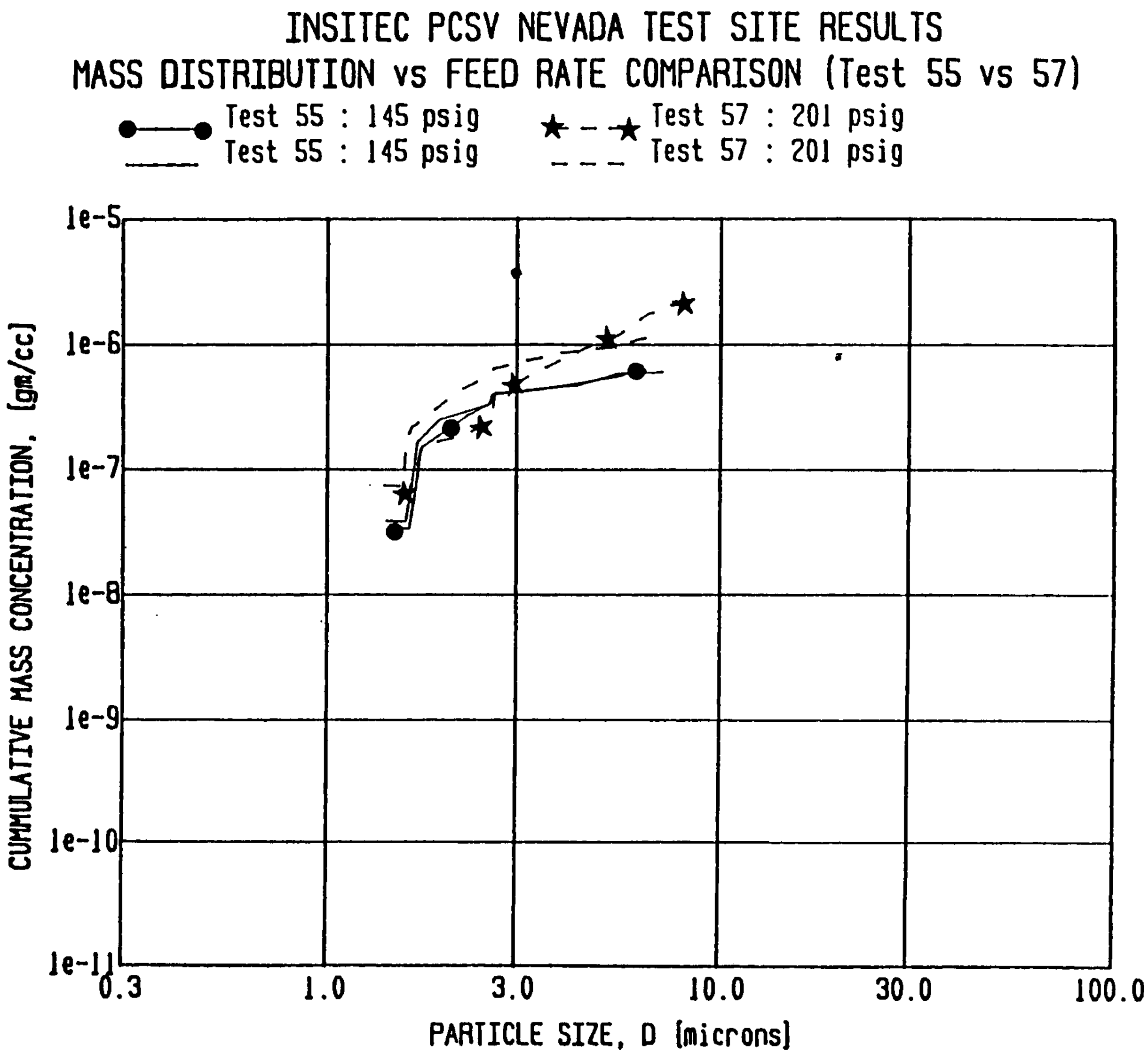


INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUMBER CONCENTRATION COMPARISON (Test 54 & 55)

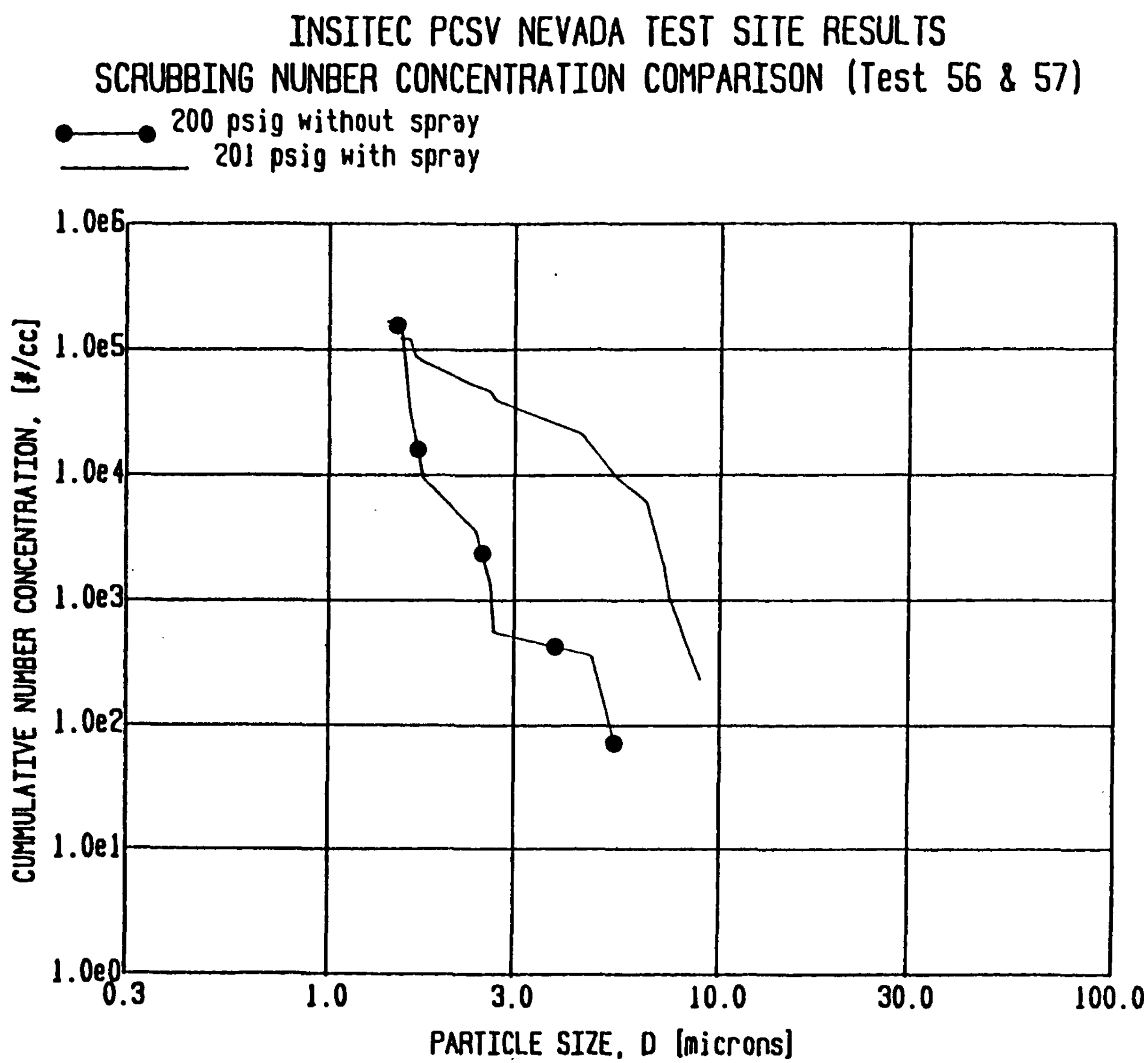



INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUMBER CONCENTRATION COMPARISON (Test 54 & 55)
Water distribution
143 psig : No water spray
145 psig : Water spray on
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]


INSITEC PCSV NEVADA TEST SITE RESULTS
NUMBER DISTRIBUTION vs FEED RATE COMPARISON (Test 55 vs 57)
Test 55 : 145 psig
Test 55 : 145 psig
Test 57 : 201 psig
Test 57 : 201 psig
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
0.3
1.0
3.0
10.0
30.0
100.0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
PARTICLE SIZE, D [microns]



INSITEC PCSV NEVADA TEST SITE RESULTS
MASS DISTRIBUTION vs FEED RATE COMPARISON (Test 55 vs 57)
Test 55 : 145 psig
Test 55 : 145 psig
Test 57 : 201 psig
Test 57 : 201 psig
1e-5
1e-6
1e-7
1e-8
1e-9
1e-10
1e-11
0.3
1.0
3.0
10.0
30.0
100.0
CUMMULATIVE MASS CONCENTRATION, [gm/cc]
PARTICLE SIZE, D [microns]


INSITEC PCSV NEVADA TEST SITE RESULTS
SCRUBBING NUNBER CONCENTRATION COMPARISON (Test 56 & 57)
200 psig without spray
201 psig with spray
1.0e6
1.0e5
1.0e4
1.0e3
1.0e2
1.0e1
1.0e0
CUMMULATIVE NUMBER CONCENTRATION, [#/cc]
0.3
1.0
3.0
10.0
30.0
100.0
PARTICLE SIZE, D [microns]