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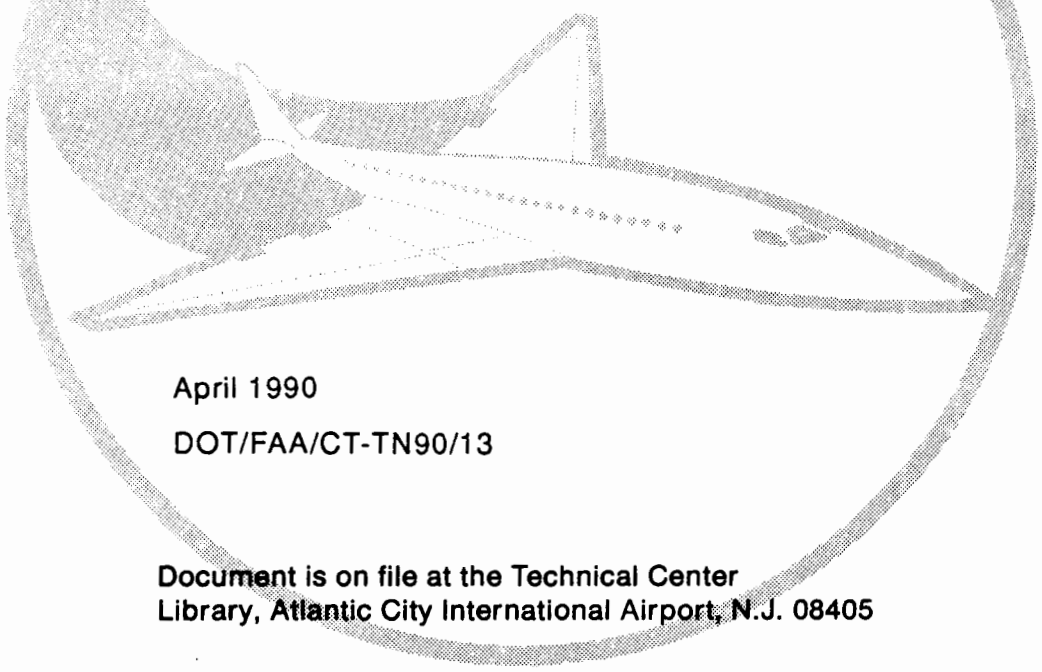

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16. Abstract

A comparison test of droplet sizing instruments used in icing research was conducted at the Arnold Engineering Development Center (AEDC) at Arnold Air Force Base, Tennessee in May 1988. Included in the test were the Fiber Optics System Particle-Sizer used at AEDC, a Forward Scattering Spectrometer Probe and Optical Array Probe provided by NASA Lewis Research Center in Cleveland, Ohio, and a Phase Doppler Particle Analyzer provided by Aerometrics, Inc. of Sunnyvale, California. The test plan encompassed systematic variation of velocity, droplet number density, droplet MVD, and droplet size distribution. This Technical Note reports on and analyzes the main results of the test.

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EXECUTIVE SUMMARY

A comparison test of droplet sizing instruments used in icing research was conducted at the Arnold Engineering Development Center (AEDC) at Arnold Air Force Base, Tennessee in May 1988. Included in the test were the Fiber Optics System (FOS) Particle-Sizer provided by AEDC, a Forward Scattering Spectrometer Probe (FOS) and Optical Array Probe (OAP) provided by NASA Lewis Research Center in Cleveland, Ohio, and a Phase Doppler Particle Analyzer (PDPA) provided by Aerometrics, Inc. of Sunnyvale, California. The test plan encompassed systematic variation of velocity, droplet number density, droplet median volume diameter, and droplet size distribution. This note reports on and analyzes the main results of the test.

The test results showed substantial variability among the instruments in their indicated values for median volume diameter, arithmetic mean diameter, number density, and liquid water content, as well as their droplet size distributions. The PDPA tended to indicate a greater proportion of large droplets than the FOS or FSSP. The indicated median volume diameter of the FOS and the FSSP differed by less than 20 percent in approximately half the tests.

INTRODUCTION

PURPOSE.

The purpose of this report is to present the results of a comparison test of droplet sizing instruments used in aircraft icing research that was conducted at the Arnold Engineering Development Center (AEDC) at Arnold Air Force Base, Tennessee, in May 1988.

The report emphasizes the median volume diameter (MVD), which is the most significant droplet size parameter for an engineer conducting icing tests and research. Arithmetic mean diameter, total number density (ND), and total liquid water content (LWC) are treated less extensively. Substantial attention is also given to two droplet distributions which can be calculated from the output of the instruments; namely, the proportion number density distribution and the proportion liquid water content distribution.

BACKGROUND.

Questions sometimes arise as to the relationship among droplet size distributions and droplet parameters which can be calculated from the output of different droplet sizing instruments. This test addressed such questions of relationship among instruments; it did not address questions concerning the accuracy of any of the instruments, since an independent standard was not available for this purpose. The data were collected over a range of conditions encompassing systematic variation of tunnel velocity, droplet number density, droplet MVD, and droplet size distribution to determine the effect of the conditions on the output of the instruments.

The test was jointly supported by AEDC, NASA Lewis Research Center, Cleveland, Ohio; the Federal Aviation Administration Technical Center, Atlantic City International Airport, New Jersey; and Aerometrics, Inc., Sunnyvale, California.

Particle sizing instruments used during the test were the Fiber-Optics System (FOS) Particle-Sizer provided by AEDC, a Forward Scattering Spectrometer Probe (FSSP) and Optical Array Probe (OAP) provided by NASA Lewis, and a Phase Doppler Particle Analyzer (PDPA) provided by Aerometrics, Inc.

OBJECTIVE.

The objective of this test was to determine the results of a comparison of instruments among themselves over a range of tunnel conditions rather than a comparison to an independent standard.

TEST FACILITY AND INSTRUMENTS

THE TEST CELL.

The test was conducted in the AEDC Icing Research Test Cell (R-1D). This test cell is described in reference 1. Figure 1 depicts the facility. The cell consists of a flow-metering venturi, plenum chamber, water spray system, bellmouth, removable connecting ducts, and a test chamber. Water droplets are sprayed into the primary air stream through atomizing spray nozzles located in the plenum chamber, upstream of the bellmouth. The bellmouth terminates in an 18-inch-diameter duct that directs the conditioned air into a 3-foot-diameter test section.

THE INSTRUMENTS.

All instruments used during the test are laser-based instruments, but they size droplets using a variety of principles. The PDPA sizes a droplet using the change in phase of rays of light scattered by the droplet (reference 2). The FOS and OAP size a droplet using the image or shadow the droplet casts upon an array of diodes (references 1 and 3). The FSSP sizes a droplet using the intensity of the light scattered by the droplet (reference 3).

Each instrument assigns individual droplets to size bins and maintains a droplet count for each bin; thus, the output of each instrument can be represented as a droplet size distribution in the form of a histogram.

PDPA. The PDPA has 50 bins; table 1 shows output for one test point for this instrument. The "value" column lists the left end points of the bins. The PDPA also provides a droplet velocity distribution and a correlation of size with velocity, as well as computing a number of parameters based on the distributions (some of which are shown in table 1); however, only the droplet size distribution is used in this report. The bin boundaries are routinely varied by the operator depending on the apparent droplet size range of the spray; table 2 shows the output for a test with much larger droplets present than for the test whose output is shown in table 1. The run time or sampling time is also controlled by the operator, who terminates the sample when in his judgement the sample distribution is "stable."

The PDPA probe volume is droplet size dependent; thus, droplet counts are corrected by the PDPA system software. It is these corrected counts, computed by a PDPA software routine, that are displayed in tables 1 and 2. Only the corrected counts are used in this study.

An Aerometrics memorandum provided to the author states:

> Due to the access constraints imposed by the AEDC tunnel, it was necessary to configure the instrument in a somewhat non-ideal manner. This led to a somewhat lower validation rate than normally expected. In particular, our probe volume was too large, with too many fringes. This gave some problems at high velocities. Overall, the PDPA worked quite well and the sizes

reported should be accurate. Number densities and volume flux may have been somewhat affected due to the lower than usual validation rate.

More information on the PDPA can be found in references 4, 5, and 6.

FSSP. The FSSP provided by NASA Lewis has four size ranges: range 0 is 5 to 95 microns, range 1 is 2 to 47 microns, range 2 is 2 to 32 microns, and range 3 is 1 to 16 microns (reference 7). For each test point in this test, the FSSP took a 30-second sample for each range. The data for a single test point are shown in table 3.

It was planned that, for each test point, the FSSP range selected for comparison would to be that with the finest resolution which encompassed essentially the entire spectrum of droplets. In practice, this would have meant that range 1 would be used unless there were so many large droplets present that it was necessary to use range 0. However, it has been determined that range 0 and range 1 were not giving compatible results during the test. This is documented in appendix D of this report. Because of this incompatibility, switching between ranges for different test points would be tantamount to switching between different instruments. Thus, only a single FSSP range has been included in this report; range 1 was the one chosen on the advice of NASA Lewis.

The FSSP, unlike the PDPA and FOS, was physically within the spray during the testing.

The FSSP probe volume is not droplet size dependent, but there is a probe volume correction based on the ratio of valid counts to total strobes (reference 3). This correction was made by software written by FAA personnel.

FOS. The FOS is described in reference 8. Table 4 shows output from the instrument at its normal magnification (80X). Table 5 shows output from the instrument at a magnification of 40X. Several points at this magnification were included in the test.

The FOS probe volume is droplet size dependent; thus, the counts were corrected for probe volume by AEDC software. Furthermore, the raw counts for bins 1 and 2 are unacceptably noisy and are not used. Instead, the counts for these two bins are fitted values based on distributional assumptions. AEDC software makes additional corrections to the counts based on empirical and/or distributional assumptions. It is these corrected counts, computed by AEDC, that are displayed in tables 4 and 5. Only the corrected counts are used in this study.

OAP. The OAP did not function properly in the spray during the test. The instrument had been carefully calibrated at NASA Lewis prior to shipment and again at AEDC prior to testing; the calibrations, using the rotating reticle developed at NASA Lewis, indicated that the instrument was in good working order. The functional problems remain unexplained and have not recurred in subsequent wet wind tunnel tests with the OAP. No data from the OAP are included in this report.

COMBINED OUTPUT. Table 6 is a printout of a file containing the combined data from the PDPA, FSSP, and FOS for a single test point. There is one such file for each test point included in this report. All comparisons in this report are

based on the data in these files and on distributions and parameters computed from these data. In the interest of uniformity, all parameters were computed by the FAA using software written by the FAA. No calculations of any participants are included in this report.

TEST PLAN AND PROCEDURES

The final test plan can be found in appendix A and the "As Tested Matrix" in appendix B. The plan encompassed systematic variation of velocity, droplet number density (as controlled by number of nozzles), droplet MVD, and droplet size distribution type (nozzle type). It was substantially modified during the two nights of testing but still guided the effort. Table 7 lists the tunnel conditions for all the test points that are included in this report. The points are listed in the order in which they were taken. "New Test Point Number" refers to the numbers based on this chronological listing and "Old Test Point Number" refers to numbers assigned during the testing, based on the original test plan where possible. The label column assigns labels to the points to indicate how they fit into the test plan. Table 8 lists instrument parameters which may be of interest. (Table C-1 in appendix C provides information on data file names and testing times.)

The test procedure called for at least 5 minutes of tunnel stability per test condition. Several data points could be taken by an instrument during the test condition. Each participant could select the data point for the test condition to be included in the instrument comparison.

TEST MATRIX SUMMARY.

I. VELOCITY TESTS: PARTICLE SIZING AS A FUNCTION OF VELOCITY. The test points for this part of the matrix fall into two groups, referred to here as the First Velocity Test (FV) and Second Velocity Test (SV). The spray was much more highly atomized for the second test. FVI denotes "First Velocity Test Point I" and SVI denotes "Second Velocity Test Point I." Following are the test points ordered by tunnel velocity:

Original Test Point Number	New Test Point Number	Label	Velocity (ft/sec)
2	1	FV1	98
8	6	FV6	100
3	2	FV2	197
7	5	FV5	198
4	3	FV3	294
5	4	FV4	314
16	21	SV6	100
10	16	SV1	101
11	17	SV2	192
15	20	SV5	198
12	18	SV3	244
13	19	SV4	307

II. NUMBER DENSITY TESTS: PARTICLE SIZING AS A FUNCTION OF NUMBER DENSITY. The number density was varied by changing the number of AEDC 2050 nozzles used. The first four points are at tunnel velocities of approximately 200 ft/sec, and the last two are at tunnel velocities of approximately 100 ft/sec. NDI denotes "Number Density Test Point I." Following are the test points ordered by number of nozzles:

Original Test Point Number	New Test Point Number	Label	Nozzles
17	24	*B1	1 AEDC 2050
18	22	ND1	2 AEDC 2050's
18'	59	ND4	3 AEDC 2050's
19	60	ND5	4 AEDC 2050's
22	25	ND3	1 AEDC 2050
21	23	ND2	2 AEDC 2050's

*Test point 24 is included in this series but is labeled B1 as the first of the baseline points. There may have been some nozzle nonuniformity present during multiple nozzle cases which could contribute to differences between measurements.

III. DISTRIBUTION TESTS: PARTICLE SIZE AS A FUNCTION OF DISTRIBUTION. The Sonicore 125-H nozzle was provided by U.S. Army Aviation Engineering Flight Activity, EAFB, CA. According to Army personnel, this nozzle has approximately 20 percent of its liquid water content in bins greater than 45 microns. ACI denotes "AEDC 2050 Nozzle Test Point I," SAI denotes "Spray System 1-A Test Point I," and SHI denotes Sonicore 125H Test Point I."

Original Test Point Number	New Test Point Number	Label
23	26	AC1
24	27	AC2
25	28	AC3
26	29	AC4
27	31	SA1
28	32	SA2
29	33	SA3
30	34	SA4
31	35	SH1
32	36	SH2
33	37	SH3

IV. ICE CRYSTAL TEST: PARTICLE SIZE AS A FUNCTION OF ICE CRYSTALS ENTRAINED IN CLOUD. ICI denotes "Ice Crystal Test Point I."

Original Test Point Number	New Test Point Number	Label	Temperature
35	61	IC1	8 Deg F
36	62	IC2	78 Deg F

VI. OAP SERIES: PARTICLE SIZE AS A FUNCTION OF PROBE OVERLAP. These test points were intended to study probe overlap between the FSSP and OAP. Points 7-15 included the OAP but not the FSSP. Points 67, 69, and 70 included the FSSP but not the OAP.

Although no OAP data are included in this report, this series is still referred to here as the OAP series as a convenient shorthand. OI denotes "OAP Series Test Point I."

Original Test Point Number	New Test Point Number	Label
56	7	01
57	8	02
58	9	03
61	10	04
62	11	05
63	12	06
64	13	07
65	14	08
66	15	09
67	38	010
69	39	011
70	40	012

VII. ATOMIZATION QUALITY STUDY. These runs were not included in the original test plan. They involve a study of atomization quality for differing air pressures and constant water flow. AI denotes "Atomization Study Test Point I."

Original Test Point Number	New Test Point Number	Label
80	42	A1
81	43	A2
82	44	A3
83	45	A4
84	46	A5
85	47	A6
86	48	A7
87	49	A8
88	50	A9
89	51	A10
90	52	A11
91	53	A12

VIII. FOS MAGNIFICATION STUDY. This series was not included in the original test plan. Under certain tunnel conditions, the PDPA was reporting significant numbers of droplets larger than 100 microns in diameter. The FOS magnification was changed to 40X in part to determine if it would also report the existence of such large droplets. MI denotes "FOS Magnification Study Test Point I."

Original Test Point Number	New Test Point Number	Label
92	54	M1
93	55	M2
94	56	M3
95	57	M4

IX. BASELINE POINTS. BI denotes "Baseline Test Point I."

Original Test Point Number	New Test Point Number	Label
17	24	B1
17'	30	B2
17''	41	B3
17'''	58	B4

FULL AND TRUNCATED DROPLET SIZE RANGES.

For most runs, the PDPA reported a significant number of droplets larger than 50 microns. The FOS also reported droplets larger than 50 microns for many runs. This makes direct comparison with the FSSP, restricted to range 1 (2-47 microns), difficult.

Therefore, it was decided to make two comparisons: All comparisons involving just the PDPA and the FOS use their full ranges. All comparisons involving the FSSP and another instrument use truncated ranges for the PDPA or FOS that approximately coincide with range 1 for the FSSP. The truncation rule can be stated as follows: For the PDPA or FOS, the last bin included in the truncated range is the bin whose midpoint is closest to 45.5 microns, since this is the midpoint of the last bin of the FSSP for range 1.

A proportion number density (ND) plot is obtained by dividing the number density for each bin by the total number density. If the plot is for a truncated range, the total number density used is over the truncated range only. A proportion LWC plot is obtained by dividing the LWC for each bin by the total LWC. If the plot is for a truncated range, the total LWC used is over the truncated range only. These definitions are illustrated in figures 2A through 2D.

Figure 2A is a full range proportion number density plot, which includes only the PDPA and FOS. Consider, for example, the first PDPA point. The abscissa of the point is the midpoint of the first PDPA bin; the ordinate is the proportion number density for that bin, i.e., the number density for that bin divided by the total number density (54, in this case) taken over all bins. The other PDPA and FOS points are determined in the same way.

Figure 2B is a full range proportion LWC plot. The points are determined just as in figure 2A; i.e, the proportion LWC for a bin is computed by dividing the LWC for that bin by the total LWC (0.1194 for the PDPA, 0.0251 for the FOS) taken over all bins.

Figure 2C is a truncated range proportion number density plot. The last point shown for the PDPA is computed for the bin with midpoint closest to 45.5 (bin 27, with a midpoint of 45.9, in this case). The proportion number density for any bin is equal to the number density for that bin divided by the total number density (53, in this case) taken over all the bins <u>in the truncated distribution</u> (bins 0 through 27, in this case). The last point shown for the FOS is computed for its bin with midpoint closest to 45.5 (bin 14, with a midpoint of exactly 45.5, in this case). The calculations are done in the same way as for the PDPA. The complete range 1 distribution of the FSSP is used.

Figure 2D is a truncated range LWC plot. The points are determined just as in figure 2C; i.e., the proportion LWC for a bin is computed by dividing the LWC for that bin by the total LWC (0.0999 for the PDPA, 0.0239 for the FOS) taken over all bins <u>in the truncated distribution</u> for the given instrument.

TEST RESULTS

The presentation of results is primarily graphical; as much as possible, the plots will speak for themselves.

The parameter MVD, of prime importance in icing calculations, is presented first and receives the most detailed treatment. Next, arithmetic mean diameter is briefly addressed. The MVD and arithmetic mean diameter can be calculated from the number density and LWC distributions, which are presented next. Finally, number density and liquid water content are discussed.

MEDIAN VOLUME DIAMETER.

Table 9 lists the MVD for the full and truncated ranges for all tests. This table, as well as tables 7 and 8, should be consulted for additional information on particular test points when examining the figures discussed below.

PDPA AND FOS: FULL RANGES. Figures 3A, 3B, and 3C are serial plots for the PDPA and FOS for test points 1-23 (first night of testing), 24-41 (includes distribution test), and 42-62 (includes atomization and FOS magnification studies). These plots show that the PDPA and FOS tended to respond in the same way to changing tunnel conditions. This is most striking for test points 31-40, when three different nozzles were used. Examination of plots reveals some exceptions to the general tendency, for example, test point 22.

Figure 4 is a serial plot of the difference between the PDPA and the FOS; figure 5 is a serial plot of the percentage difference. Figure 4 shows that for a substantial majority of the test points the PDPA exceeded the FOS by at least ten microns. Reference to figures 3A through 3C shows that most of the exceptions were test points where both instruments were measuring "small" MVD's. The average difference for all test points was more than 13 microns. Figure 5 shows that for a substantial majority of the test points the PDPA exceeded the FOS by at least 50 percent. The average percentage difference for all test points was more than 63 percent.

The baseline points are indicated with solid symbols in figures 3B and 3C. The middle two baseline points (B2 and B3) for the PDPA were about 37 microns, while the first (B1) and fourth (B4) were about 27 microns. The third baseline point for the FOS was not found, but the other three were around the level of 20 microns. The variation in the baseline MVD of the PDPA may have been due to slight changes in the nozzle centerline during the course of testing; the instrument has shown sensitivity to such changes in the past. Examination of figures 4 and 5 does not reveal that the interval from B2 to B3 is greatly different from the rest of the plot. Table 10 presents average differences between the PDPA and FOS computed over test point intervals defined using the baseline points (with the FOS magnification test points also grouped together). Average differences between the PDPA and FSSP for the truncated range are also presented. Although there is variation among the groups, perhaps the most striking aspect of the table is how little variation there is. Test points 30-41 do not show much higher average differences, either absolute or percentage, than the other groups.

Test points 54-57 were taken with the FOS magnification at 40X rather than its normal 80X. This doubles the range of the instrument. These points are indicated with stars in figures 4 and 5. Point 54 was the only point in the test for which the FOS exceeded the PDPA. Point 57 is also exceptional in that the PDPA exceeded the FOS by less than 10 percent. However, the PDPA exceeded the FOS by approximately 100 percent for point 55 and by approximately 60 percent for point 56. Interpretation of this series is further confounded by the fact that, although tunnel conditions were essentially the same for test points 51 and 54, the FOS gave an MVD for test point 51 (@ 80X) of 15.7 and for test point 54 (@ 40X) of 30.4. The PDPA and FSSP, on the other hand, varied very little between the two points.

Figure 6 is a scatter plot of PDPA versus FOS.

Figures 7 and 8 are serial plots of the first and second velocity tests. Figure 8 shows the FOS reporting decreasing MVD with increasing velocity, but figure 7 does not.

Table 11 gives the results of the number density test in which the number of nozzles used was increased between runs in order to increase number density. The first four points are at tunnel velocities of approximately 200 ft/sec. The PDPA and FOS show better agreement for the first and fourth points than the middle two. The last two points are at tunnel velocities of approximately 100 ft/sec. The agreement between the PDPA and FOS is much better than average for these two points.

PDPA, FSSP, AND FOS: TRUNCATED RANGES. The FSSP parameters valid counts (VC), total strobes (TS), VC/TS, and activity (ACT) are defined and their significance is discussed in appendix D.

Activity has been shown to be a parameter that can strongly influence the results of the FSSP (references 3, 7, and 9). High activity results in coincidence errors (two or more droplets counted and sized as one). Earlier studies (reference 7) indicate that coincidence errors start to occur at activities as low as 60 percent for the FSSP used in this test. Figure 9 is a serial plot of the activities for the FSSP for the test. There are 12 points with activities exceeding 60, which are referred to here as "high activity points." Figure 10 is a plot of the ratio of valid counts to total strobes versus activity. The figure shows that indeed this ratio begins to fall off at activities around 60. The figure can be compared with figure 4 from reference 7 (see figure 10); figure 10 has more scatter and one apparent "bad" data point (test point 26). High activity plots for the FSSP are distinguished in all plots in which they occur.

Figures 11A, 11B, and 11C are serial plots for the PDPA, FOS, and FSSP for test points 1-23, 24-41, and 42-62. These figures show that the PDPA and FSSP and the FOS and FSSP tended to respond in an analogous manner to changes in tunnel conditions. The figures reveal a number of exceptions, however.

The baseline points for the FSSP show very little variation: the MVD's are 14.0, 14.4, 14.6, and 13.5. As mentioned earlier, table 10 also presents average differences between the PDPA and FSSP computed over test point intervals defined using the baseline points (with the FOS magnification test points also grouped together). Again, it is the comparatively mild variation from group to group

that is most notable. Interpretation of this table is complicated because a group's averages are influenced by the number of FSSP high activity points that happen to fall in the group.

Figure 12 is a serial plot of the difference between the PDPA and the FSSP; figure 13 is a serial plot of the percentage difference. Figure 12 shows that for a majority of the test points the PDPA exceeded the FSSP by at least 8 microns. Reference to figures 11A through 11C shows that many of the exceptions are test points where both instruments are measuring small MVD's. The average difference for all test points was approximately 8 microns. Figure 13 shows that for a majority of the test points the PDPA exceeded the FSSP by at least 40 percent. The average percentage difference for all test points was more than 50 percent.

Figure 14 is a scatter plot of PDPA versus FSSP. Note that in general the PDPA and FSSP are in closest agreement for the FSSP high activity points.

Figures 15 and 16 are serial plots of the first and second velocity tests, corresponding to figures 7 and 8 for the full range. The plots seem to suggest a tendency of the FOS to report decreasing MVD's with increasing velocity.

Table 11 also gives the results of the number density test (in which number density was controlled by changing the number of nozzles) for the truncated ranges. Comparison of the FSSP to the other two instruments is beclouded by the fact that four of the six points are high activity points.

Figure 17 is a serial plot of the difference between the FOS and the FSSP; figure 18 is a serial plot of the percentage difference. Figures 17 and 18 show that the instruments never differed by more than 10 microns (40 percent) and that many of the differences larger than 5 microns (20 percent) are accounted for by FSSP high activity points, the FSSP "wild" point 26, and the FOS points at 40X magnification.

Figure 19 is a scatter plot of FOS versus FSSP. Figure 20 is obtained from figure 19 by excluding the FSSP high activity points and subtracting 2 microns from all FOS MVD's. Note that all but four of the points in figure 20 fall in a 10-micron band; to put it another way, the FSSP never differs by more than 5 microns from the FOS when a "bias" of 2 microns is subtracted from the latter instrument. An uncertainty of plus or minus 5 microns is sometimes quoted for MVD measurements.

MEAN DIAMETER (ARITHMETIC).

Table 12 lists the arithmetic mean diameters for the full and truncated ranges for all tests. This table, as well as tables 7 and 8, should be consulted for additional information on particular test points when examining the figures discussed below.

Comparisons among the instruments for arithmetic mean diameter tend to mirror the earlier comparisons for MVD. There are two main differences: First, the MVD is much more affected by large droplets in the distribution, since their contribution to the calculation of MVD is weighted by the cube of the droplet diameter. Second, the FOS always has very large counts in the first two bins, a

point which will be further discussed in the section on distributions; these counts have a substantial effect in reducing arithmetic mean diameter, but much less effect on MVD, again because of the weighting by the cube of the droplet diameter.

PDPA AND FOS: FULL RANGES. Figures 21A, 21B, and 21C are serial plots for the PDPA and FOS for test points 1-23, 24-41, and 42-62. Figure 22 is a scatter plot of PDPA versus FOS.

PDPA, FSSP, AND FOS: TRUNCATED RANGES. Figures 23A, 23B, and 23C are serial plots for the PDPA, FSSP, and FOS for test points 1-23, 24-41, and 42-62. Figure 24 is a scatter plot of PDPA versus FSSP. Figure 25 is a scatter plot of FOS versus FSSP.

COMPARISON OF DISTRIBUTIONS.

Several test points have been selected for presentation of distributions. These are, in the author's judgement, representative of all test points examined.

Figure 2A is a fairly "typical" full range proportion ND plot for both the PDPA and FOS. (Note: Figures 2A through 2D were discussed earlier when illustrating certain definitions; now the actual distribution shapes shown in these figures will be discussed.) The FOS shape is due to the "fitted" counts for the first two bins. These two bins, which often contain at least 70 percent of the counts, also have a profound effect on the arithmetic mean diameters for the FOS as presented in the previous section. Since they usually contain 10 percent or less of the LWC (although the percentage can exceed 20 percent for highly atomized sprays), their affect on MVD is usually modest.

Figure 2B is a fairly "typical" full range proportion LWC plot for both the PDPA and FOS. The FOS has a fairly well-defined peak from which it falls off rapidly. The PDPA has a much broader, flatter distribution with a lower, less well-defined peak.

Figure 2C is a truncated range proportion ND plot which should be compared with figure 2A. The PDPA and FOS curves are little different from those in 2A, since the percentage of droplet counts larger than 50 microns is very small. The FSSP curve is fairly typical in that it resembles the PDPA curve but with a larger proportion of droplets to the left and a smaller proportion to the right.

Figure 2D is a truncated range proportion LWC plot which should be compared with figure 2B. Note the perceptible upward shift in the PDPA curve due to dividing the bin LWC by the total LWC over the truncated rather than the full range; this is not unusual, since the percentage of LWC in droplets larger than 50 microns can be appreciable. The agreement between FOS and FSSP is unusually good. They generally have similar shapes with well-defined peaks, but it is unusual for the peaks to fall in the same place and to have almost exactly the same height.

Figures 26A-D represent a case where the truncated ranges of the PDPA and FOS contain nearly all their droplets. Thus the plots for the full and truncated ranges are virtually identical, facilitating comparison of all three instruments. This case, as well as others, indicates that the difference of the PDPA from the other two instruments is not simply a matter of the PDPA observing some large

droplets; it can be seen in the shape of the distribution that the instrument is reporting even when no large droplets are present. Note that the FOS and FSSP have much higher peaks in figure 26D than in figure 2D.

Figures 27A-D and 28A-D are for baseline points B2 and B4 respectively. Note that although the FOS and FSSP change little from one case to the next, the distribution for the PDPA changes noticeably from figures 27 and 28, most markedly in D. The agreement of the PDPA with the FOS in figures 28A-D is remarkably good.

Figures 29A-D are for test point 54, with the FOS magnification at 40X. Plots A-D should be carefully compared with A-D in figure 2, which was taken for virtually identical tunnel conditions. The curves for the FSSP and PDPA change little from 2 to 29; but there is a large change in the FOS, moving it from good agreement with FSSP to good agreement with PDPA.

Figure 30 is for test point 55, the next test point taken, also with the FOS at 40X. Note that the FOS reverts to agreeing more closely with the FSSP than with the PDPA.

Figures 31 and 32 include LWC plots only, with A and B corresponding to B and D in the earlier figures. They are for test points 56 and 57, the final two taken with the FOS at 40X. In figure 31, the FOS agrees more closely with the FSSP than with the PDPA. In figure 32, the agreement with the FSSP is not as close, while that with the PDPA is closer than before.

The points taken with the FOS at 40X are difficult to interpret and constitute a major source of uncertainty in comparing the FOS with the other two instruments. If test point 54 (@ 40X) is a "good" point for the FOS, then test point 51 (@ 80 X) is a "bad" one. But this would imply that the reasonably good agreement between the FOS and the FSSP throughout much of the test was obtained when the FOS was giving "bad" points. AEDC personnel regard this as unlikely and express little confidence in any of the 40X data.

NUMBER DENSITY.

Table 13 lists the total number densities for the full and truncated ranges for all tests. This table, as well as tables 7 and 8, should be consulted for additional information on particular test points when examining the figures discussed below.

PDPA AND FOS: FULL RANGES. Figures 33A, 33B, and 33C are serial plots for the PDPA and FOS for test points 1-23, 24-41, and 42-62. The vertical scale is 0 to 4000 for all three plots because of several very large values for the FOS. This renders comparison between the two instruments difficult for much of the data. However, the reader is referred to the corresponding plots for the truncated ranges (figures 35A-C), where the vertical range has been set to 0 to 500 (thereby excluding a few FOS points). Number density for the full and truncated ranges never differs by more than a few percent.

Figure 34 is a scatter plot of PDPA versus FOS restricted to points with ND less than 500. It shows little relationship between the two instruments.

PDPA, FSSP, AND FOS: TRUNCATED RANGES. Figures 35A, 35B, and 35C are serial plots for the PDPA and FOS for test points 1-23, 24-41, and 42-62 with the vertical scale set 0 to 500. The FSSP usually gave the highest number density of the three instruments. There are intervals (for example, 42-51) when all three instruments were responding alike to the changing conditions in the tunnel. However, there are other intervals where this is far from true. The exclusion of several FOS points with number densities larger than 500 makes interpretation of the behavior of that instrument more difficult.

Figure 36 is a scatter plot of PDPA versus FSSP. Except for a few FSSP "high activity points" (activity $>$ 60), the FSSP always gives a larger number density. This is consistent with the findings of references 3, 7, and 9: High activity entails more coincidence events and thus lower droplet counts.

Figure 37 is a scatter plot of FOS versus FSSP. This figure is similar to figure 36; it differs partly because several points with high FSSP activity are excluded since the FOS gave a number density higher than 500.

LIQUID WATER CONTENT.

Table 14 lists the LWC for the full and truncated ranges for all tests. This table, as well as tables 7 and 8, should be consulted for additional information on particular test points when examining the figures discussed below.

PDPA AND FOS: FULL RANGES. Figures 38A, 38B, and 38C are time series plots for the PDPA and FOS for test points 1-23, 24-41, and 42-62. These figures should be compared with figure 33A-C for number density. Note that the points for which the FOS gave very high number density are points for which both instruments are giving high LWC. This suggests that when there were many large droplets in the spray, both instruments observed them, but the FOS reported a very large number of small droplets as well. However, most of the droplets the FOS reported were in the first two bins, which, as already noted, are fitted values. So the very high number densities could be a "distribution-fitting effect."

Figure 39 is a scatter plot of PDPA versus FOS with both the vertical and horizontal scales set to 0 to .5. This has the effect of excluding quite a few points; however, for the points that remain, a strong relationship is revealed. Excluding the three outliers, the plot shows that a best fit line through the remaining points would have a slope of approximately 5.

PDPA, FSSP, AND FOS: TRUNCATED RANGES. Figures 40A, 40B, and 40C are time series plots for the PDPA and FOS for test points 1-23, 24-41, and 42-62. Figure 40A has a vertical scale of 0 to 2.8, 40B has a vertical scale of 0 to 2.0, and 40C has a vertical scale of 0 to 1.4. Varying the vertical scale in this way makes comparison among the plots more difficult, but it facilitates the perception of detail in the latter two plots. Note that point 39 for the FOS (LWC = 3.9) is excluded. The three instruments tend to respond alike to the changing conditions in the tunnel; this is certainly more marked than for ND (figures 35A-C) but less than for MVD (figures 11A-C). Points 44-49 are of interest since the spray was highly atomized and the distributions for the truncated ranges differ little from those for the full ranges. Note that for this highly atomized spray the FOS reports very small ND and LWC. Perhaps this is again a "distribution-fitting effect," but this time the obverse of the possible effect discussed earlier.

Figure 41 is a scatter plot of PDPA versus FSSP. The PDPA reports larger droplets, while the FSSP reports greater number densities. These two effects counteract, resulting in the remarkably good agreement for LWC shown in the plot. Apparently the fewer droplets "seen" by the PDPA were just enough larger (on average) than those "seen" by the FSSP for the two instruments to give similar LWC.

Figure 42 is a scatter plot of FOS versus FSSP, showing that the latter instrument consistently reports much larger LWC.

THRESHOLD TEST FOR PDPA.

As stated earlier, the PDPA sizes a droplet using the change in phase of rays of light scattered by the droplet. However, before a droplet is sized at all by the instrument, the intensity of its scattered light must exceed a certain threshold. The threshold is controlled by adjusting the "photomultiplier high voltage." Since intensity increases with droplet size (in fact, the relationship between the two is used by the FSSP to size droplets), increasing the threshold has the effect of eliminating smaller droplets.

Under constant tunnel conditions, the PDPA sampled a series of points with steadily increasing thresholds. Suppose some of the large droplets reported by the instrument for a low threshold were mis-sized small droplets, then increasing the threshold would cause some of these small droplets not to be sized at all, thereby decreasing the proportion of large droplets reported. Thus the series would have shown decreasing number densities in the larger bins as the threshold was increased. However, examination of the data indicates that the number densities in the larger bins were relatively steady throughout this series.

BEAD SIZING TEST.

At the conclusion of the second night of testing, in response to the apparent disparity between the sizing measurements of the PDPA and the other two instruments, a glass bead sizing test was performed. Three bottles of glass beads were used and sized by each instrument. The data file for the FOS was not found, but the results for the other two instruments are summarized below.

Nominal Size of Beads	Arithmetic Mean Diameter		Peak	
	PDPA	FSSP	PDPA	FSSP
15-37	~15.0	~18.5	~10	~20
44-53	~44.7	~33.5	~45.5	~39.5
~100	~85.5		~83	

The results for the FSSP were found by using a transfer function relating glass bead sizes to water droplet sizes; this was necessary because of the different optical properties of the two.

Unlike the other data presented in this report, the calculations for these values were not computed by the FAA. Furthermore, the values given do not reveal that the distributions for the PDPA and FSSP were quite different. The PDPA "peak" was not at all well defined, since there were several adjacent bins with approximately equal counts, meaning that the quoted "peak" could easily be shifted a bin or two to the left or right. The FSSP distributions were actually bimodal, with a small "peak" in one of the earlier bins in addition to the one quoted. It should also be noted that pouring beads through a probe volume is of course not equivalent to sizing droplets in a spray. Nonetheless, the results for the PDPA should curb any temptation to conclude that the PDPA droplet sizes are "incorrect" because they are consistently larger than those of the other two instruments.

DISCUSSION

The reader should be very careful in generalizing from the results presented here about the instruments used in the test. All participants took the greatest care, both in preparation for and during the test, to try to ensure that their instruments were operating properly. Yet the experience with the OAP illustrates that this does not guarantee proper functioning. The position of the PDPA was not optimal and the focal length had to be increased to accommodate the test facility. Furthermore, slight shifts in the spray centerline during the course of the test could have had a significant affect on this instrument. This is a matter of tunnel spray uniformity rather than simply an instrument limitation due to high spatial resolution. The FSSP was in the spray and had to be temporarily removed because of problems early on the first night.

One must be even more cautious about generalizing to other instruments of the same make. For example, the FSSP used in this test might give rather different results from another FSSP supplied and operated by another institution. The PDPA is an instrument which is being steadily enhanced and improved by Aerometrics; thus, the instrument used in this test was not identical to other PDPA's used by other institutions (as noted, the optical focal length was increased for this test). This is not to imply that another PDPA would give radically different results but only that some difference would not be surprising.

These remarks point to a need for further comparison tests using instruments of this type. Only additional tests can clarify the extent to which the results of this test are truly representative.

CONCLUSIONS

The following conclusions concern only the specific instruments used in the test.

1. The median volume diameter (MVD) of the phase doppler particle analyzer (PDPA) exceeded that of the fiber optics system particle-sizer (FOS) by at least 10 microns and at least 50 percent for most test points with an average difference of more than 13 microns and more than 63 percent. The two instruments showed no relationship for number density (ND). However, for most points with liquid water content (LWC) less than 0.5, the PDPA exceeded that for the FOS by a factor of about 5 or more.

2. Using a truncated range for the PDPA that approximately coincided with range 1 for the forward scattering spectrometer probe (FSSP), the MVD of the PDPA exceeded that of the FSSP by at least 8 microns and 40 per cent for most test points with average differences of about 8 microns and more than 50 percent. Most of the points where the two instruments were in closest agreement were high activity points for the FSSP. The number density (ND) of the FSSP exceeded that of the PDPA for all but a few high activity points. These two effects counteracted one another with the result that the LWC for the two instruments agreed surprisingly well.

3. Using a truncated range for the FOS that approximately coincided with range 1 for the FSSP, the instruments never differed by more than 10 microns or more than 40 percent, and many of the differences larger than 5 microns or 20 percent were accounted for by FSSP high activity points or FOS points at 40X magnification. If all FSSP high activity points are excluded, the FSSP rarely differed by more than 5 microns from the FOS if a "bias" of 2 microns is subtracted from the FOS. The ND and LWC of the FSSP consistently exceeded that of the FOS except for a few extremely high ND and LWC points for the latter instrument.

4. The characteristic ND distribution of the FOS was monotonically decreasing, resembling a negative exponential. The characteristic ND distributions of the PDPA and FSSP were somewhat similar to one another, each having a reasonably well-defined peak in one of the early bins. The tail of the PDPA was higher and longer, and this had a dramatic affect on the LWC distribution.

5. The characteristic LWC distribution of the PDPA was broader and flatter than those of the FOS or the FSSP. The characteristic distribution shapes of the FOS and FSSP were similar to one another, with a fairly well-defined peak, usually in the neighborhood of 10 microns.

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GLOSSARY

ACTIVITY	Percent of time the FSSP is occupied analyzing particles.
FSSP	Forward Scattering Spectrometer Probe
FOS	Fiber Optics System Particle-Sizer
LWC	Liquid water content, g/m^3
ND	Number density, $number/cm^3$
MVD	Median Volume Diameter, microns This is the value such that half of all liquid water is contained in droplets of smaller diameter and half is contained in droplets of larger diameter.
MEAN DIAMETER (ARITHMETIC)	Arithmetic mean droplet diameter, microns
OAP	Optical Array Probe
PDPA	Phase Doppler Particle Analyzer
TS	Total Strobes for FSSP
VC	Valid Counts for FSSP
VC/TS	Ratio of Valid Counts to Total Strobes for FSSP

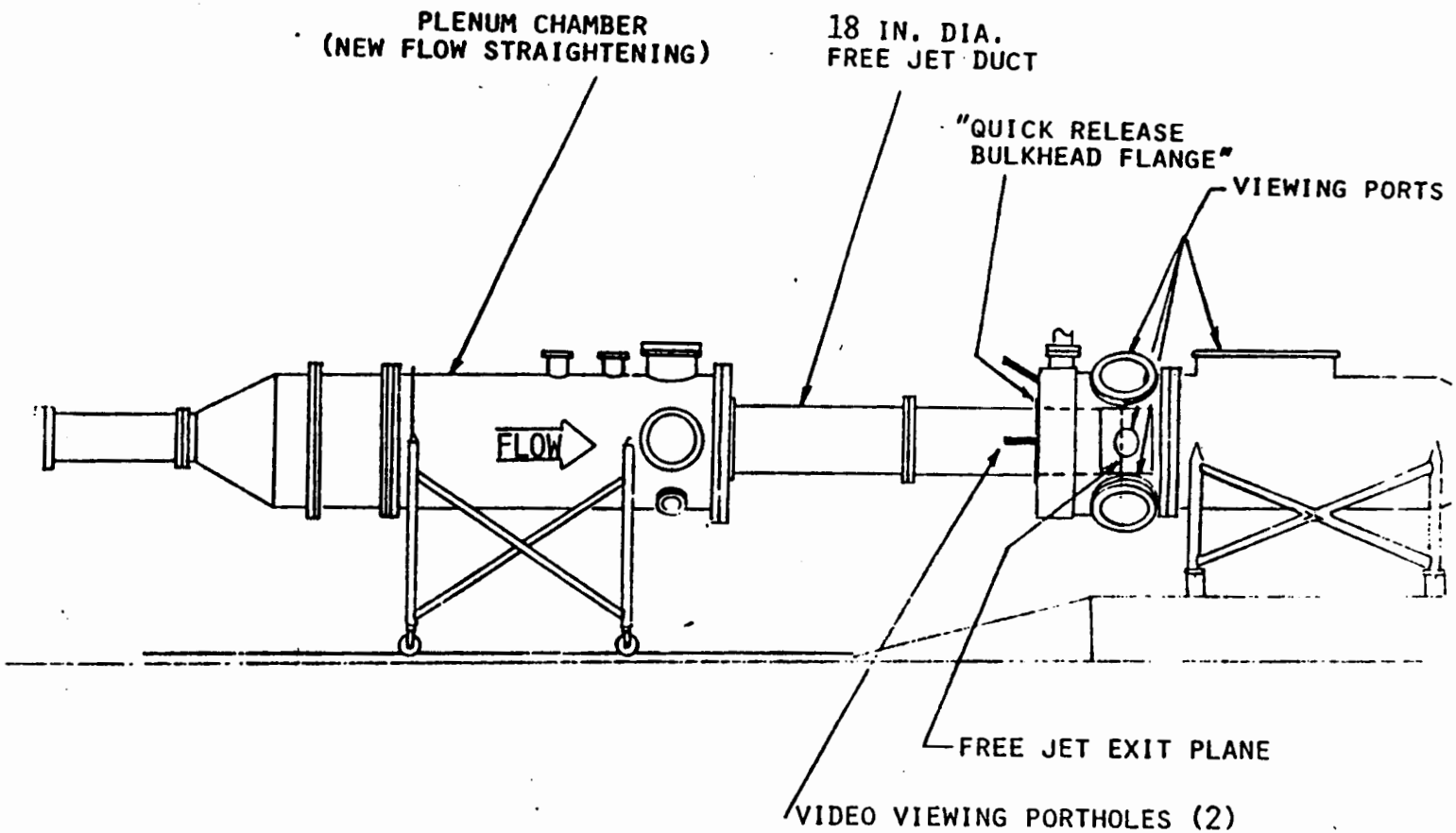


FIGURE 1. AEDC ICING RESEARCH TEST CELL (R-1D)

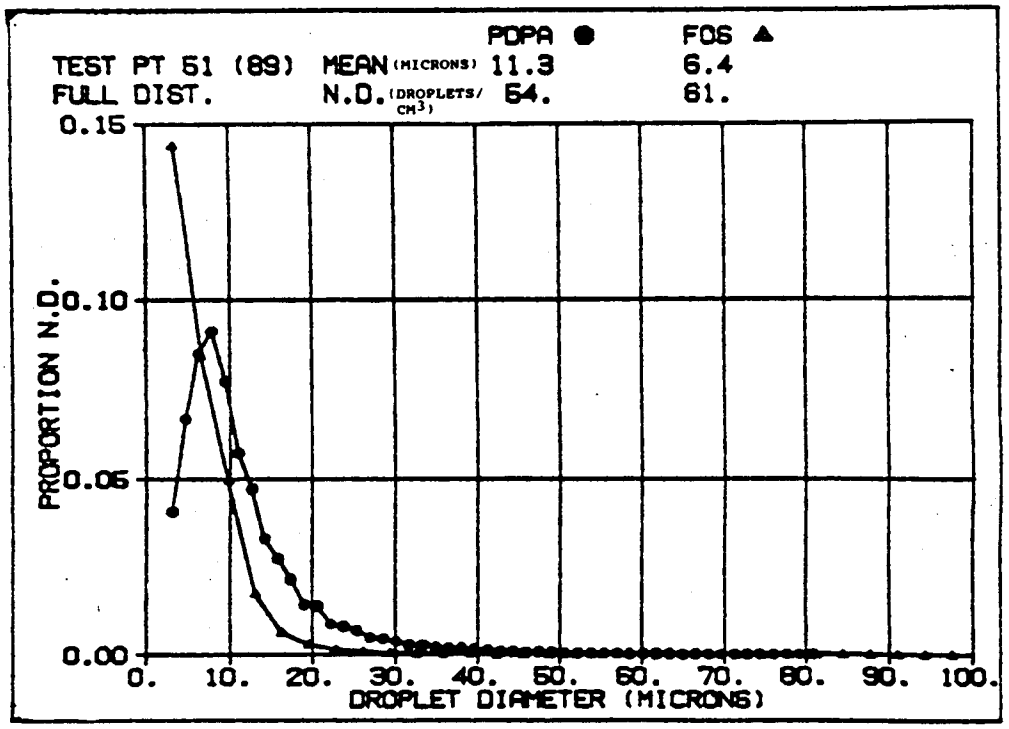


FIGURE 2A. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 51, FULL RANGE

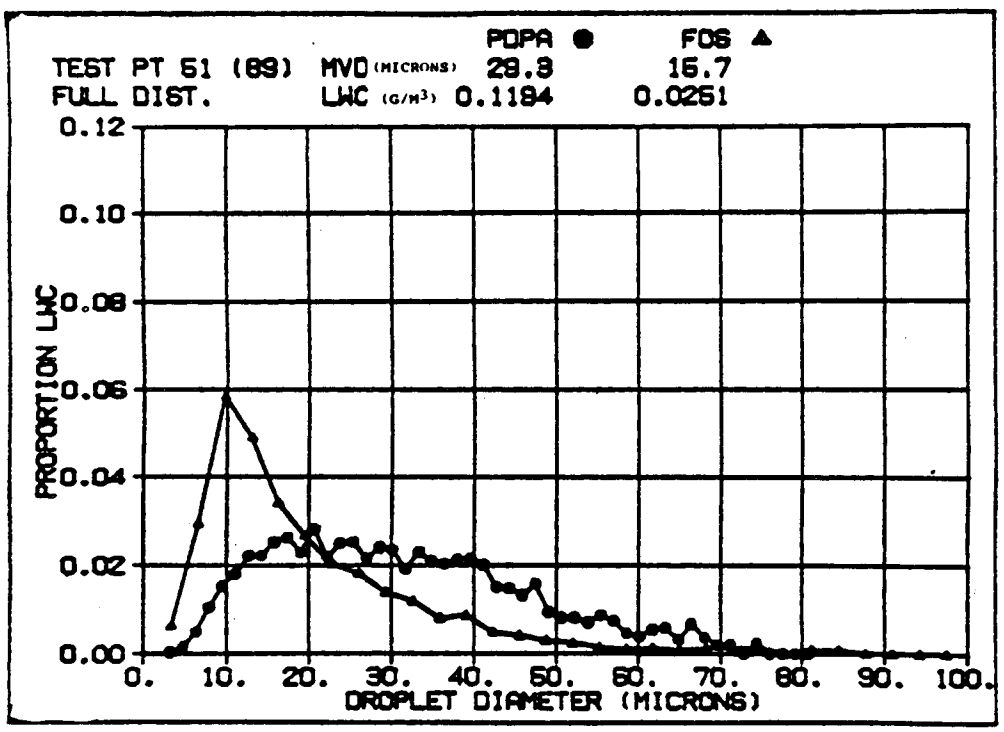


FIGURE 2B. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 51, FULL RANGE

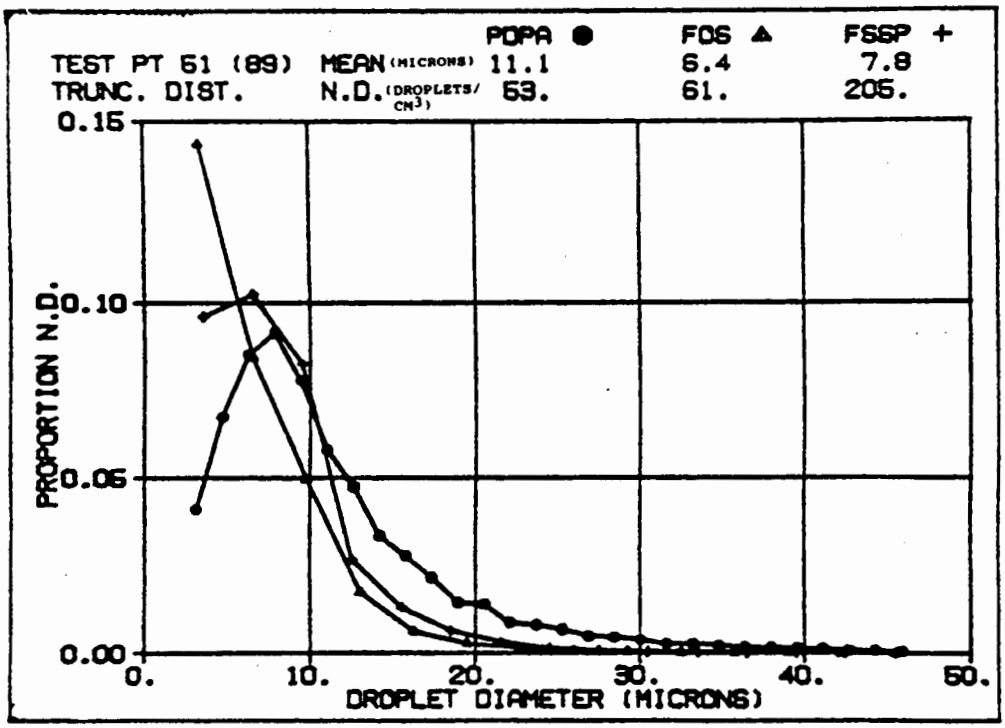


FIGURE 2C. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 51, TRUNCATED RANGE

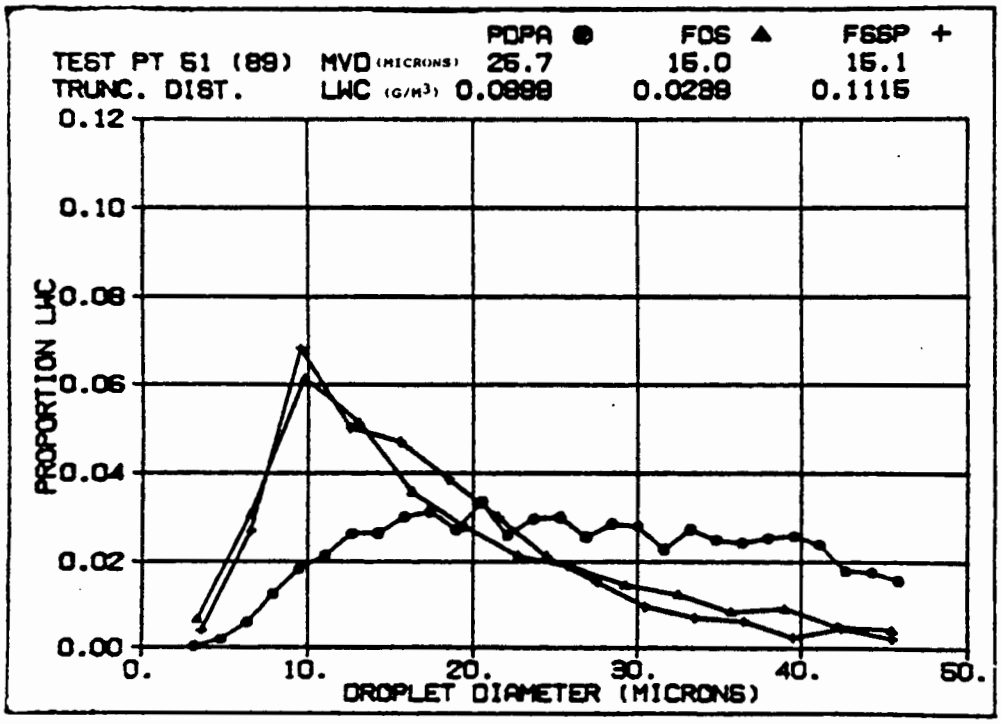


FIGURE 2D. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 51, TRUNCATED RANGE

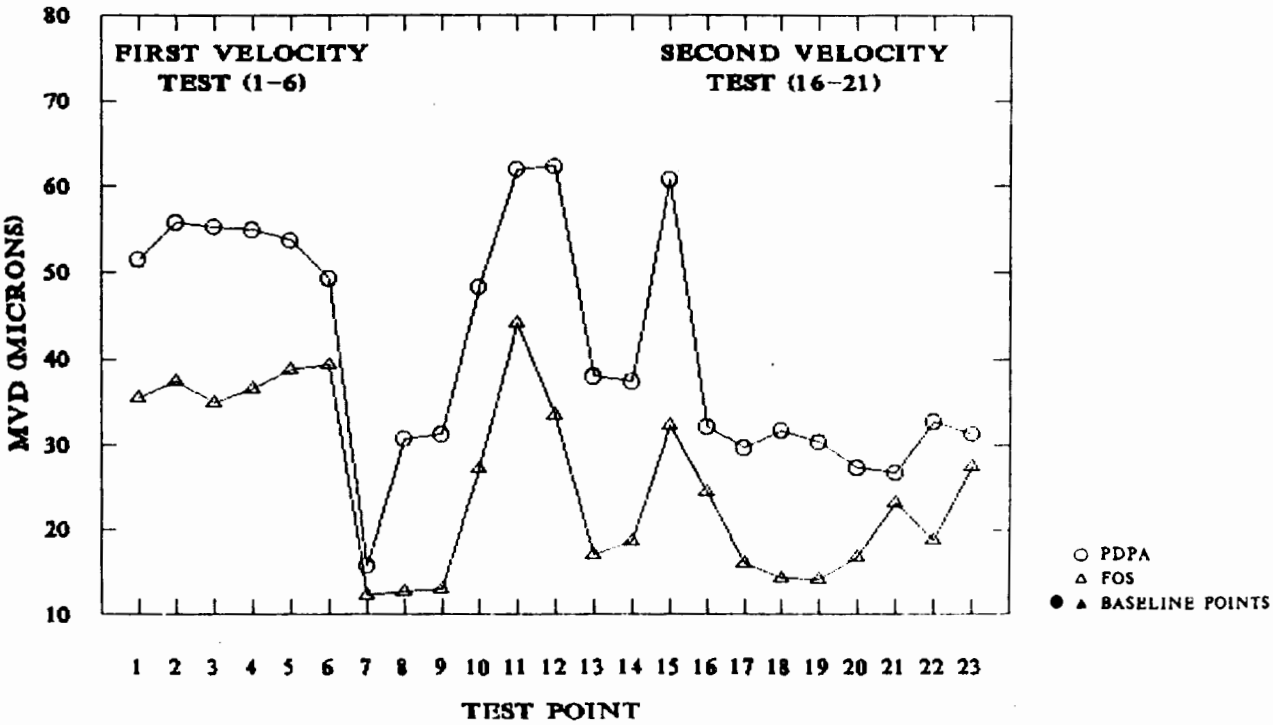


FIGURE 3A. SERIAL PLOT OF MVD FOR FULL RANGE, TEST POINTS 1-23

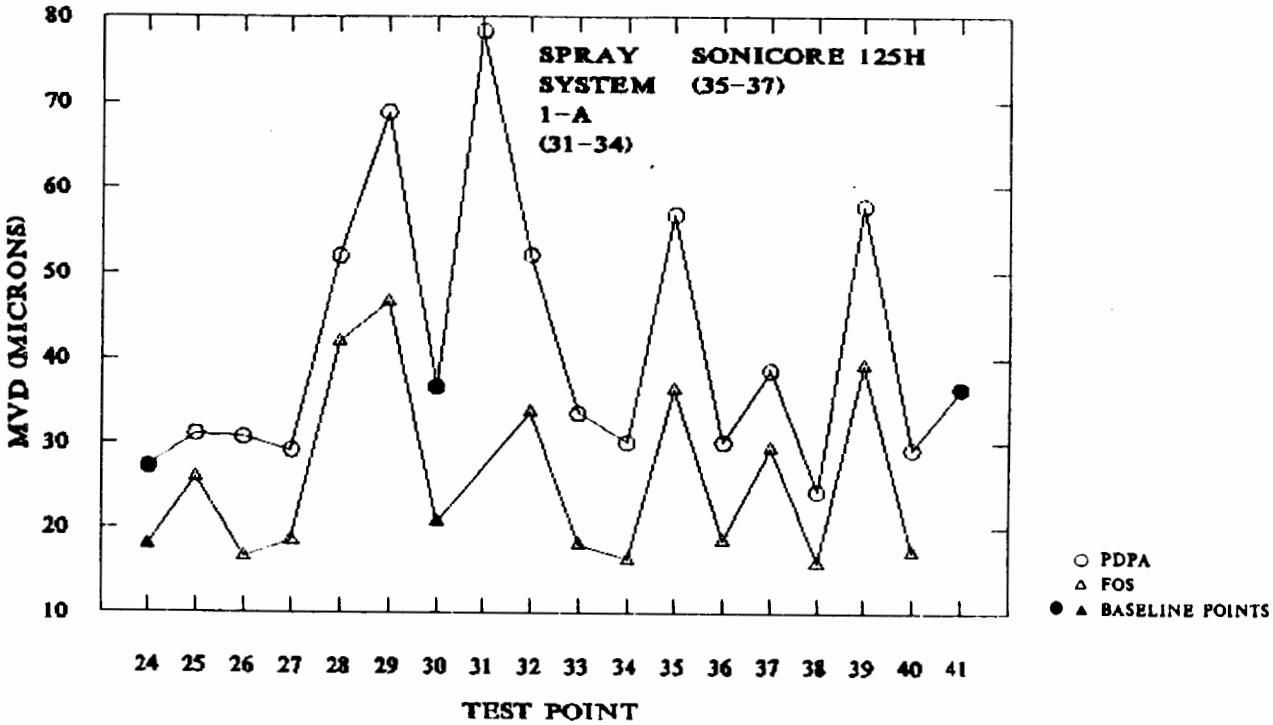


FIGURE 3B. SERIAL PLOT OF MVD FOR FULL RANGE, TEST POINTS 24-41

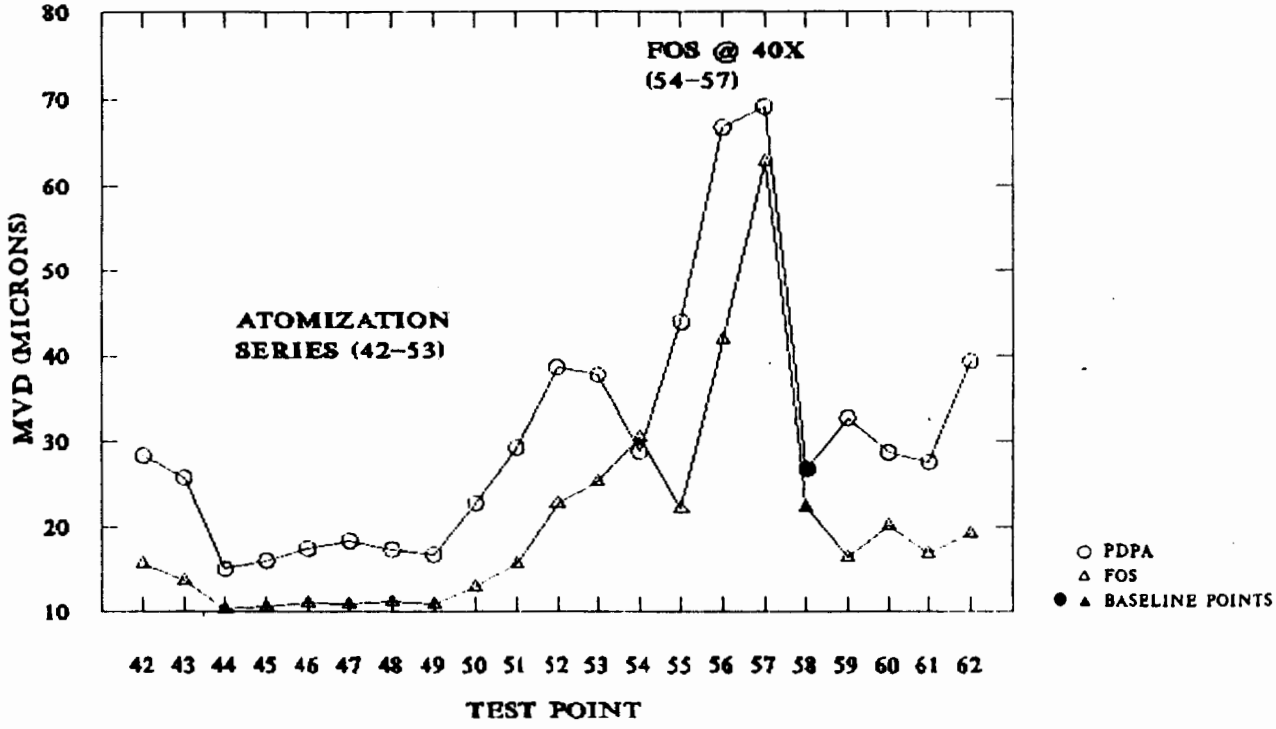


FIGURE 3C. SERIAL PLOT OF MVD FOR FULL RANGE, TEST POINTS 42-62

PDPA vs FOS

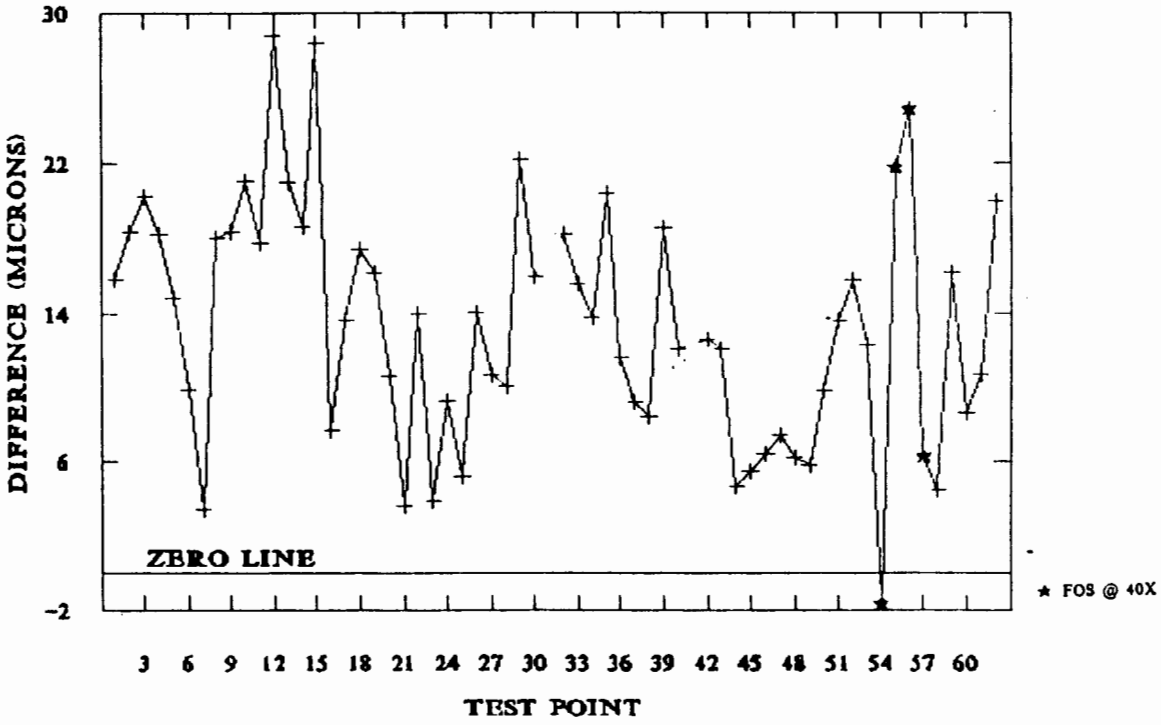


FIGURE 4. SERIAL PLOT OF MVD_{PDPA}-MVD_{FOS}, FULL RANGE

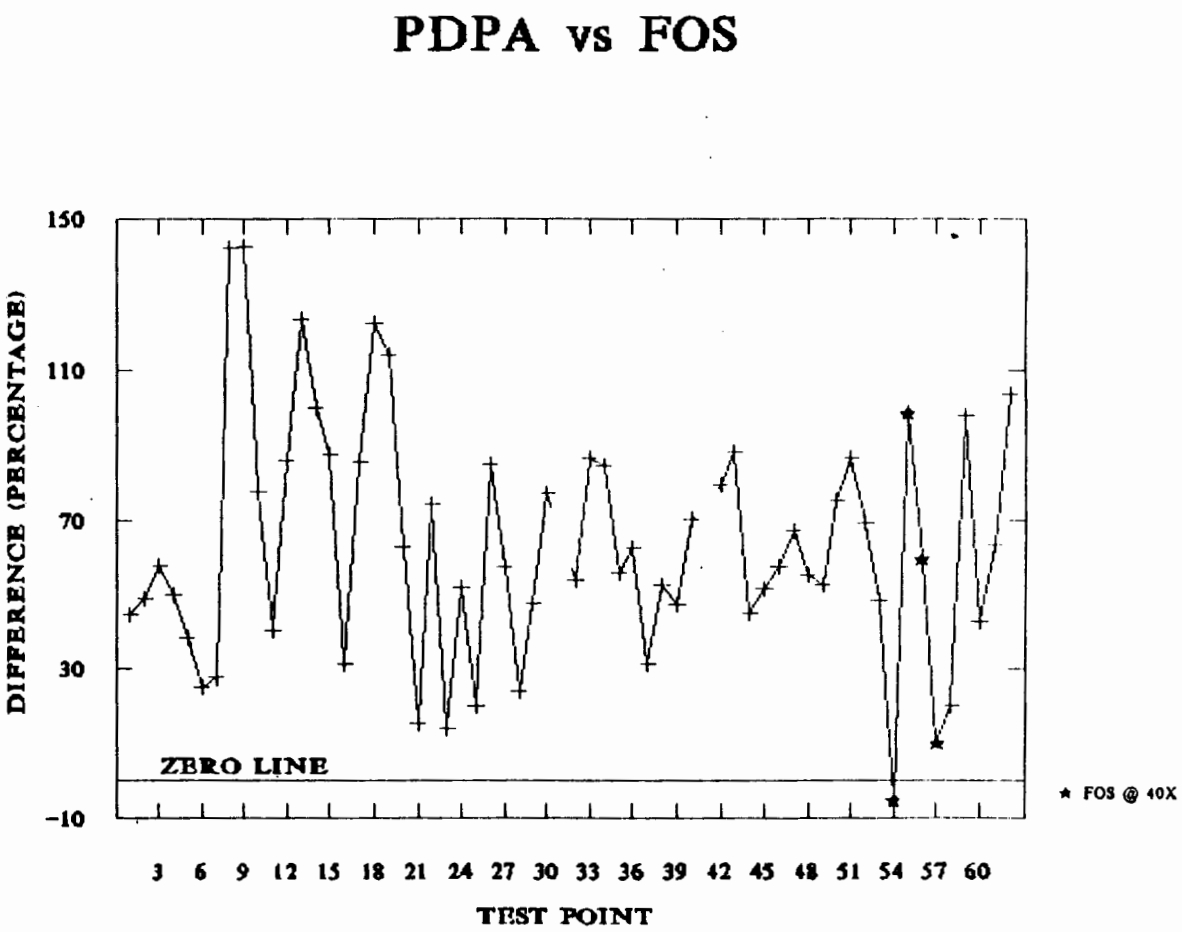


FIGURE 5. SERIAL PLOT OF 100 (MVD_{PDPA}-MVD_{FOS}) MVD_{FOS}, FULL RANGE

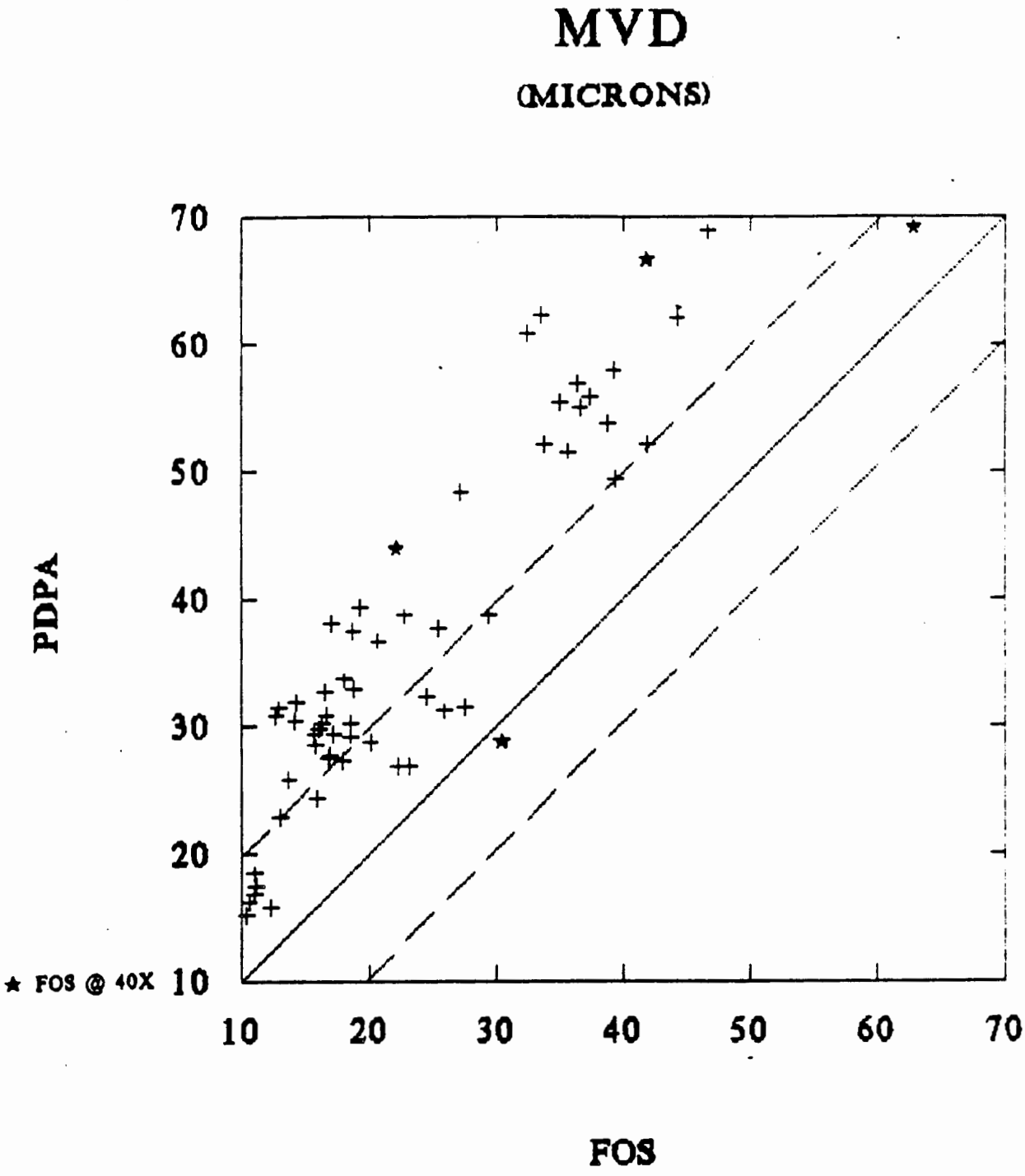


FIGURE 6. SCATTER PLOT FOR MVD OF PDPA VERSUS FOS, FULL RANGE

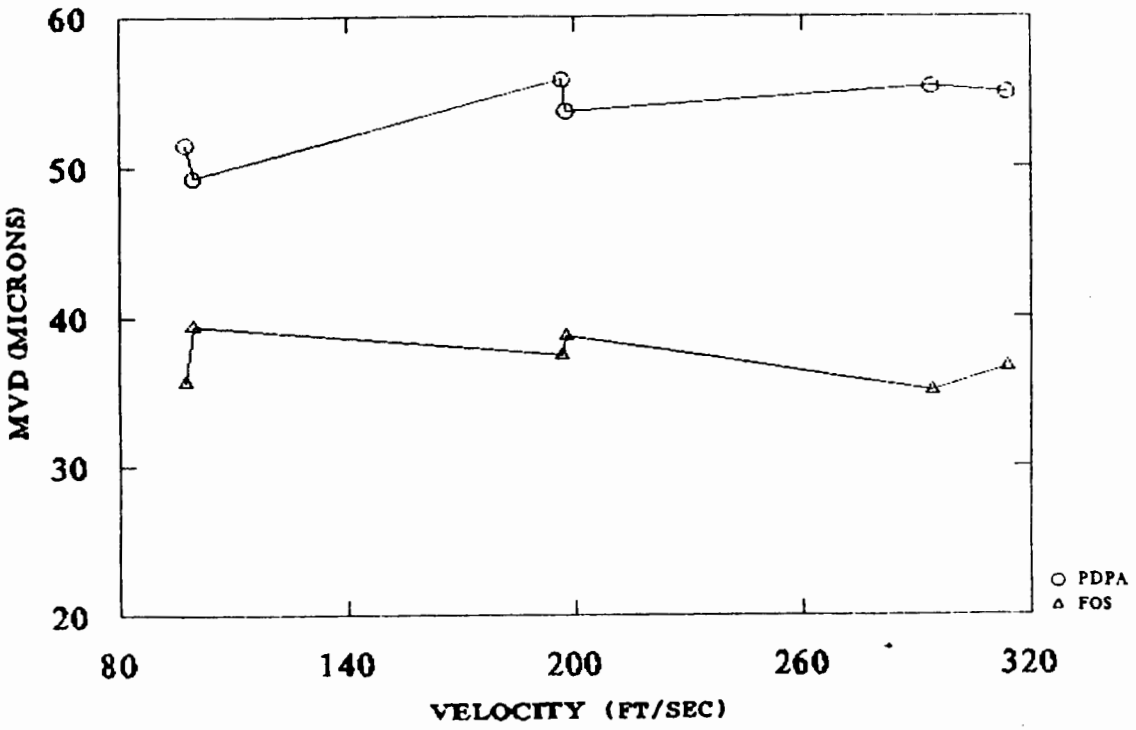


FIGURE 7. FIRST VELOCITY TEST, FULL RANGE

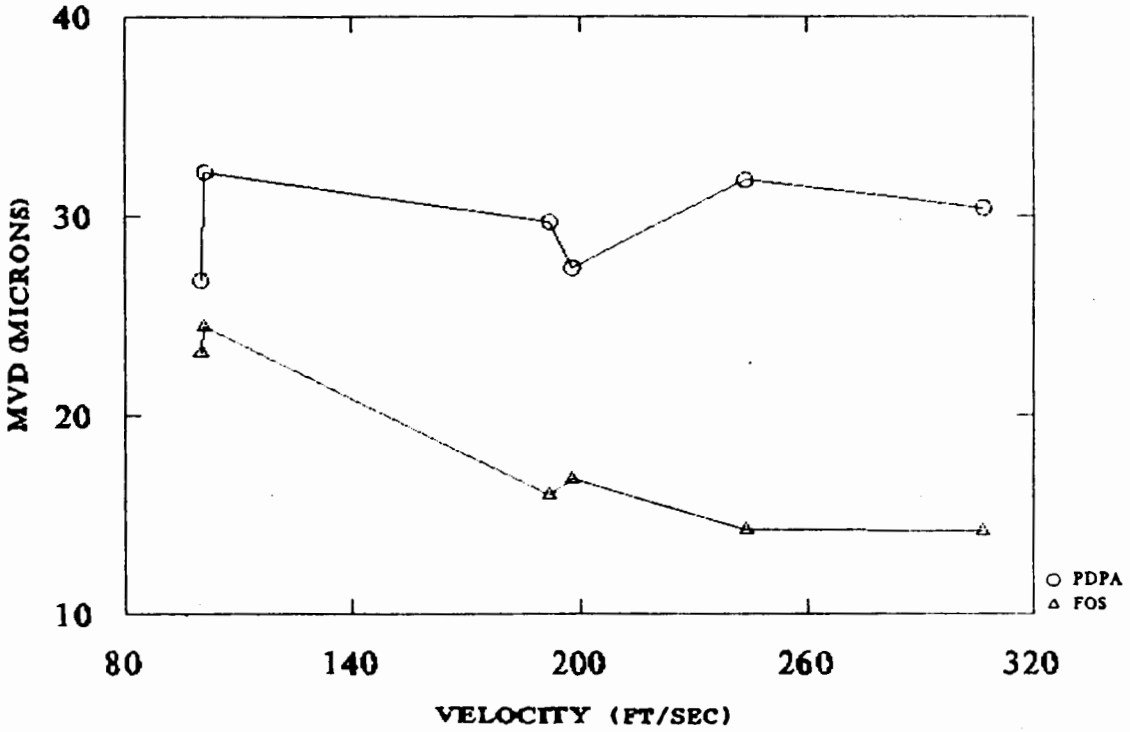


FIGURE 8. SECOND VELOCITY TEST, FULL RANGE

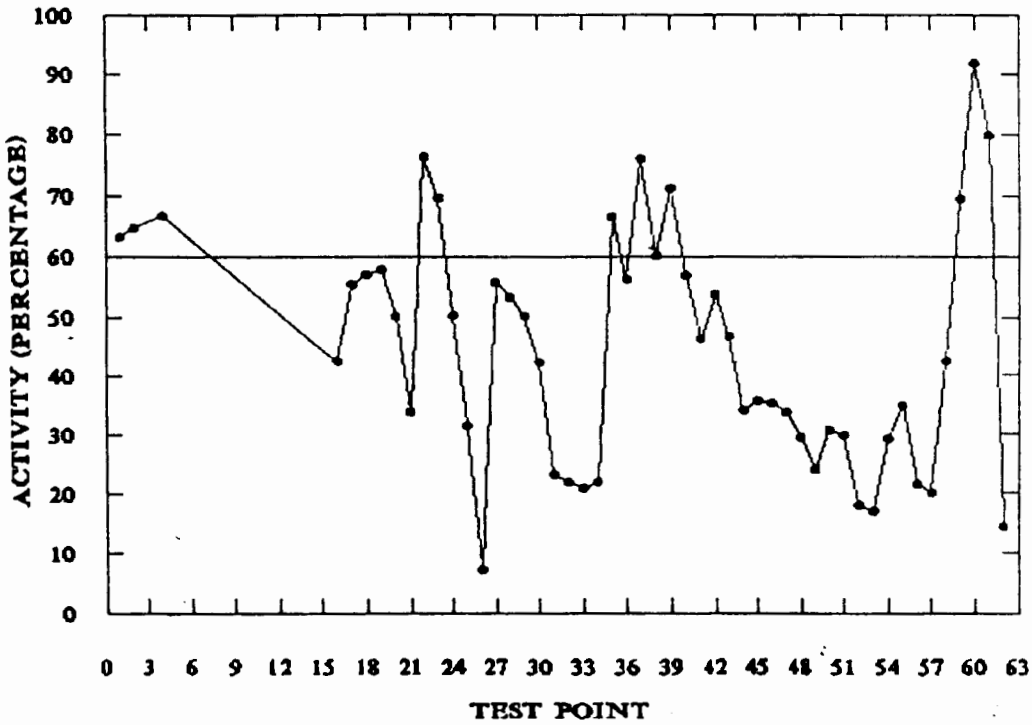


FIGURE 9. SERIAL PLOT OF FSSP ACTIVITY

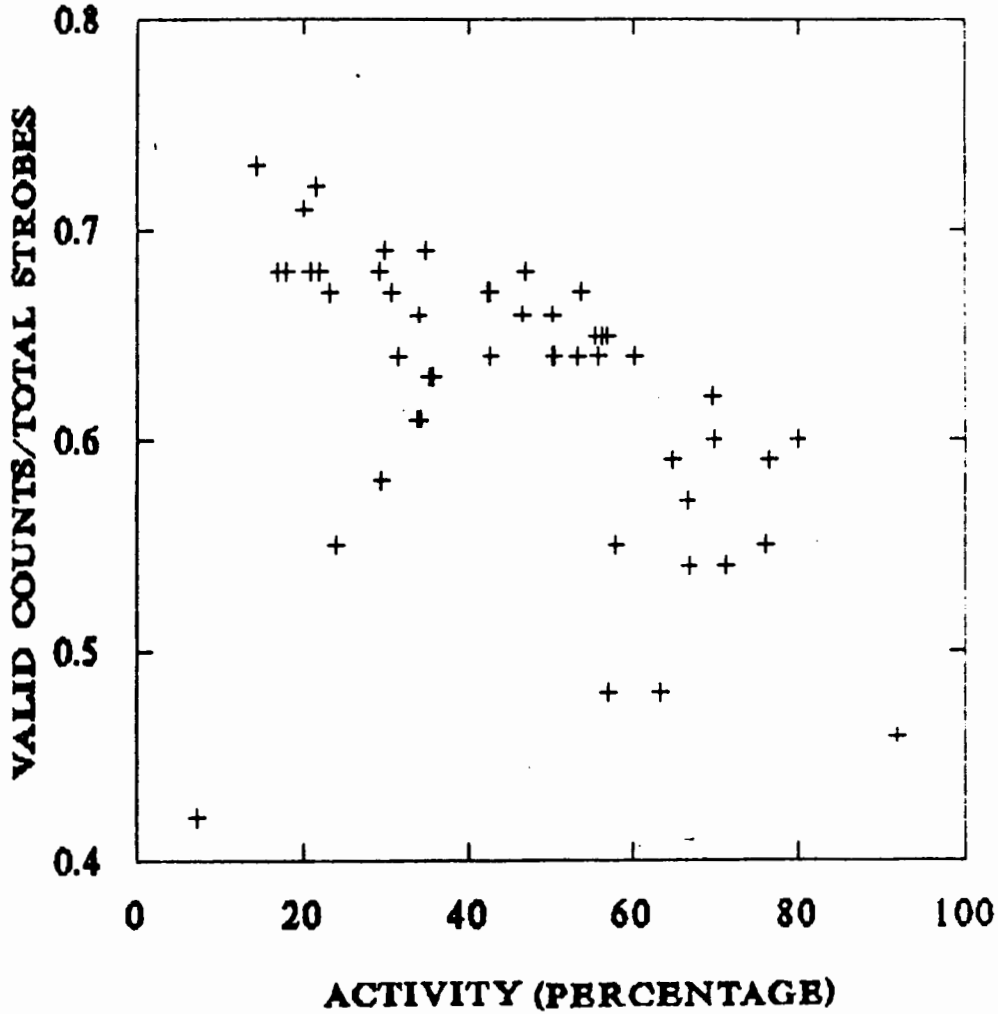
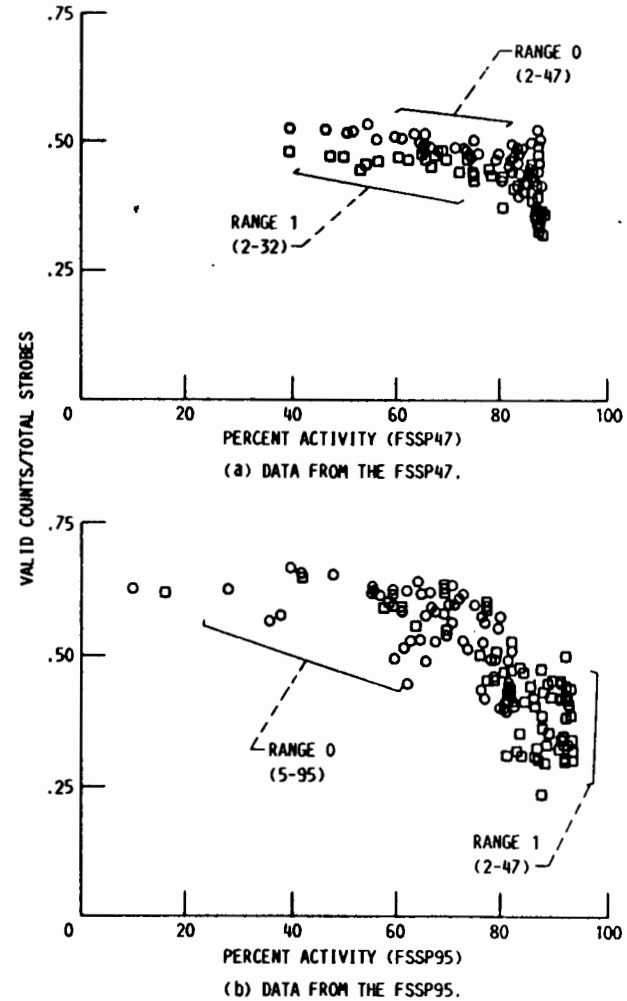


FIGURE 10. SCATTER PLOT OF VC/TS VERSUS ACTIVITY FOR FSSP



ACTIVITY IN THE FSSP'S CIRCLES ARE FOR RANGE 0. BOXES ARE FOR RANGE 1 (Reference 7)

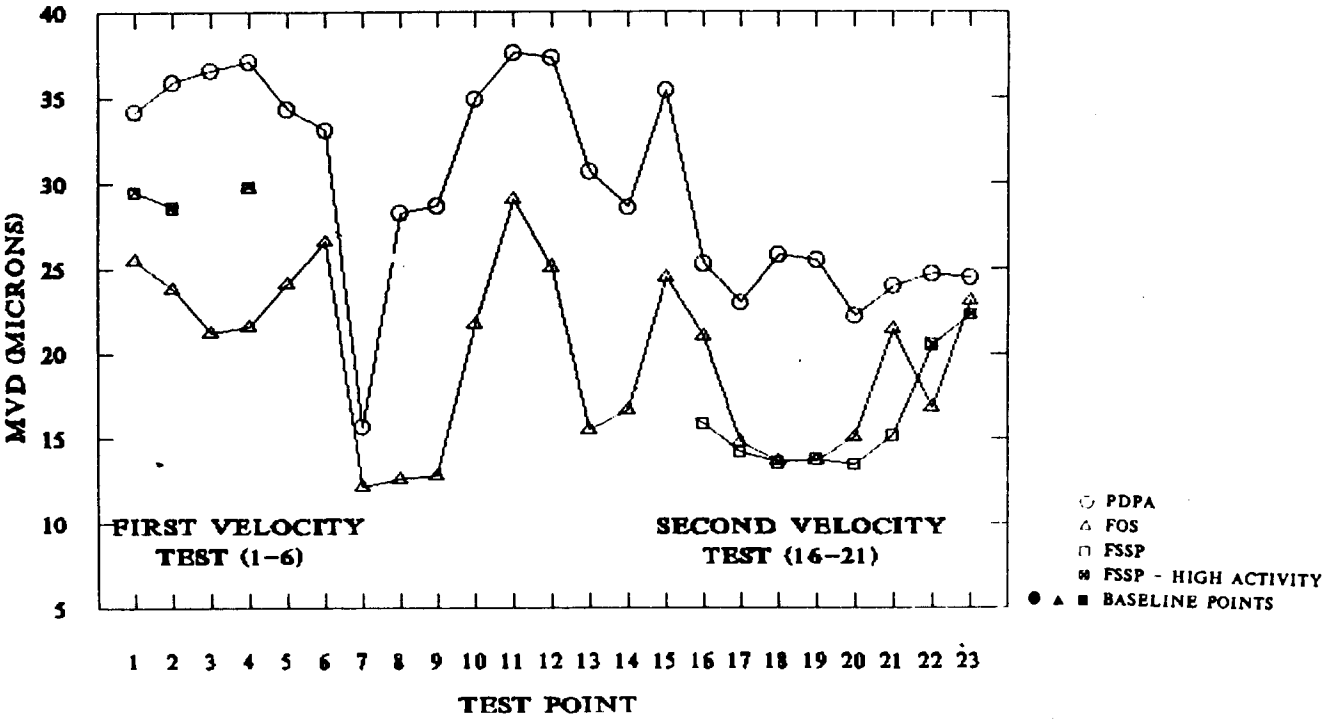


FIGURE 11A. SERIAL PLOT OF MVD FOR TRUNCATED RANGE, TEST POINTS 1-23

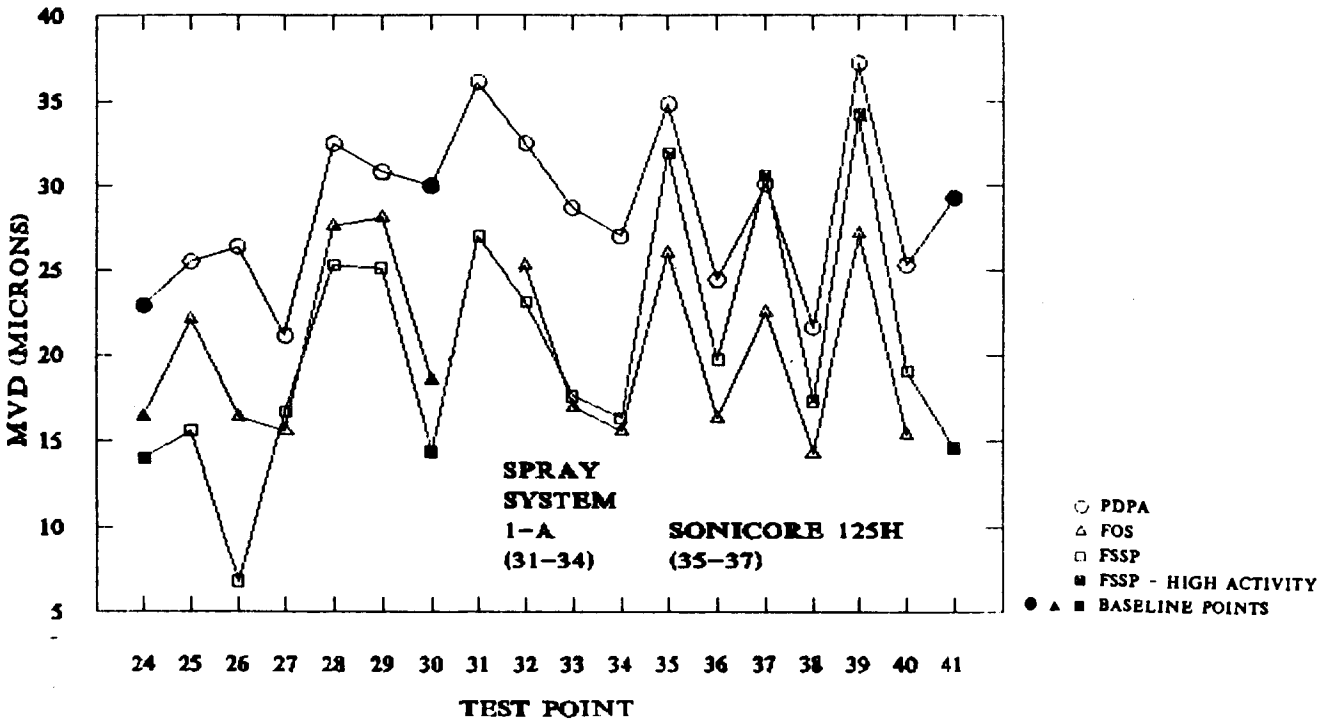


FIGURE 11B. SERIAL PLOT OF MVD FOR TRUNCATED RANGE, TEST POINTS 24-41

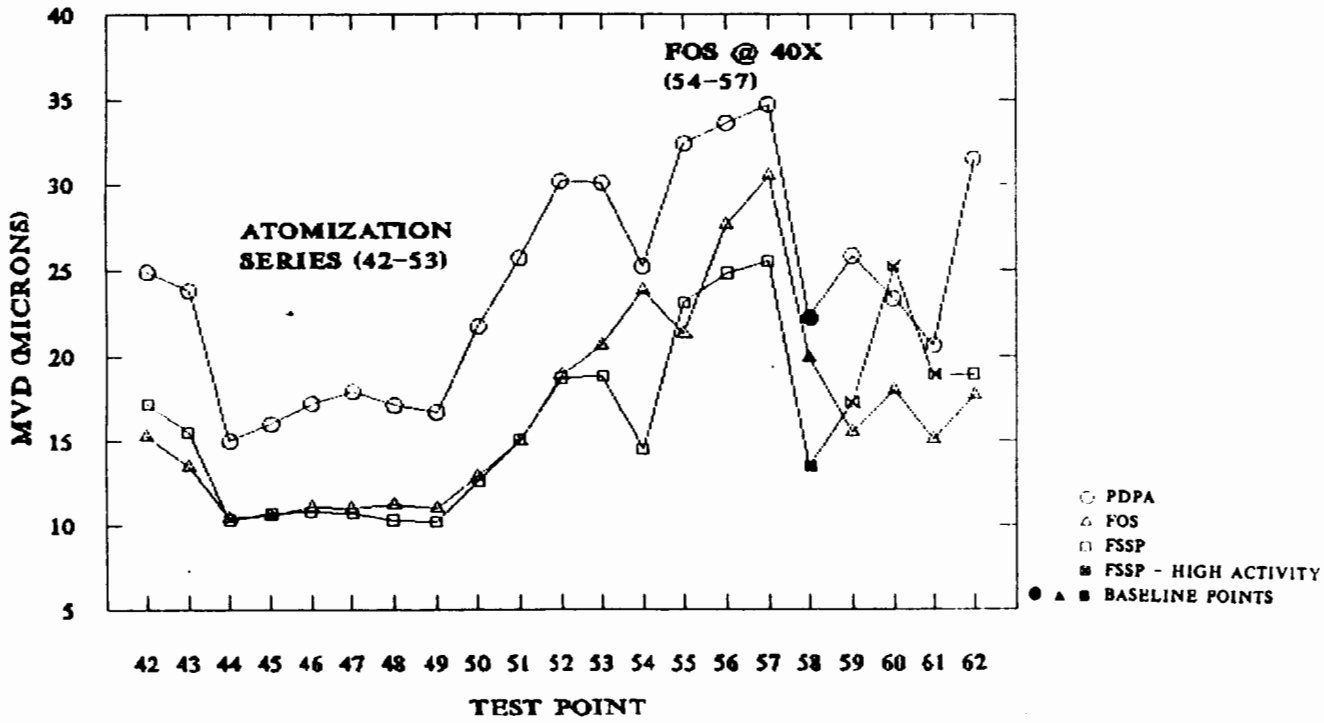


FIGURE 11C. SERIAL PLOT OF MVD FOR TRUNCATED RANGE, TEST POINTS 42-62

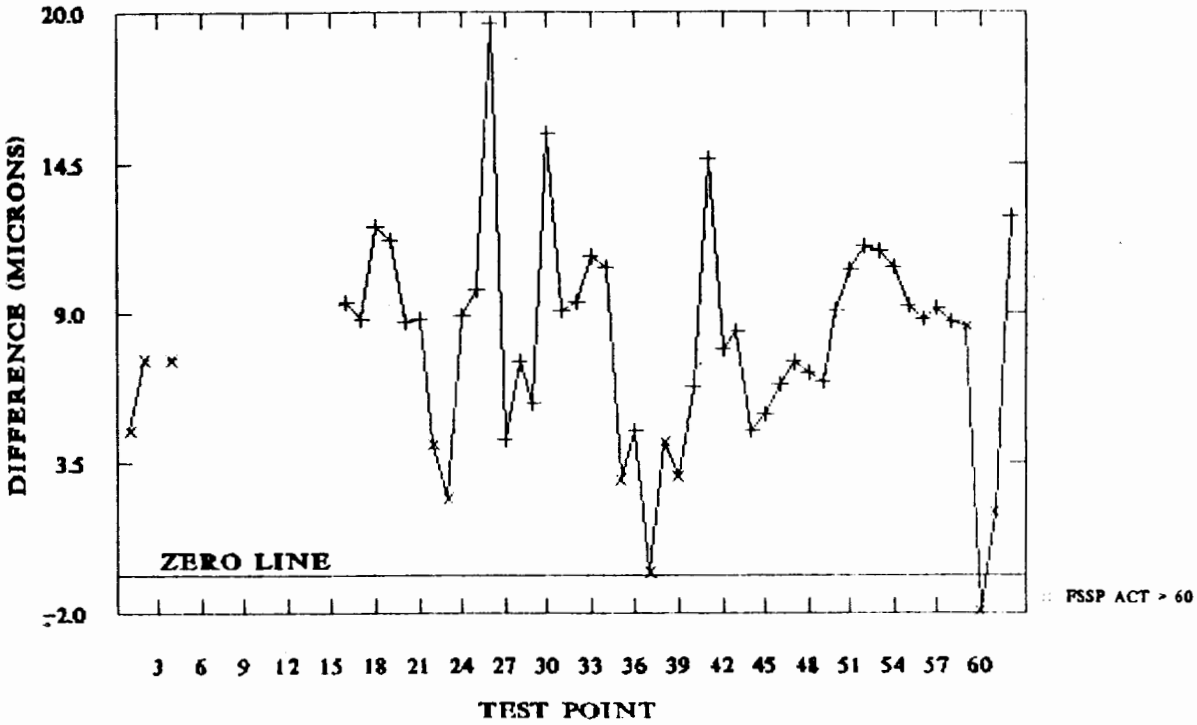


FIGURE 12. SERIAL PLOT FOR $MVD_{PDPA}-MVD_{FSSP}$, TRUNCATED RANGE

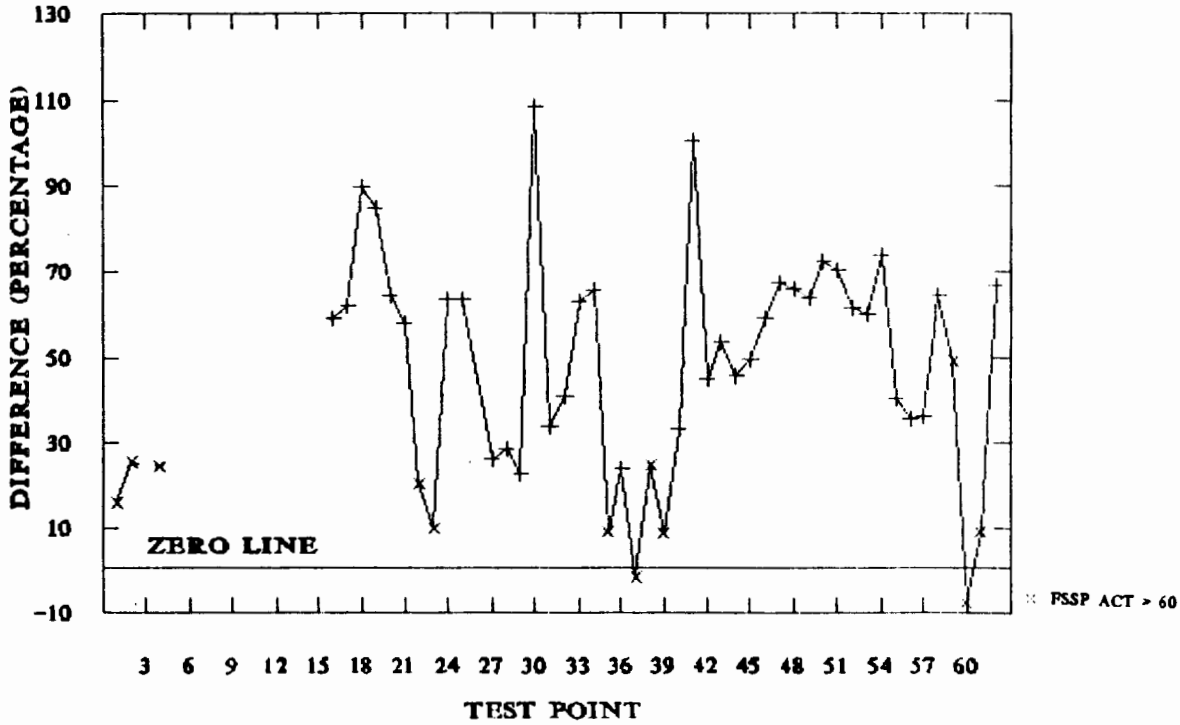


FIGURE 13. SERIAL PLOT OF 100 $(MVD_{PDPA}-MVD_{FSSP})$ $/MVD_{PSSP}$, TRUNCATED RANGE

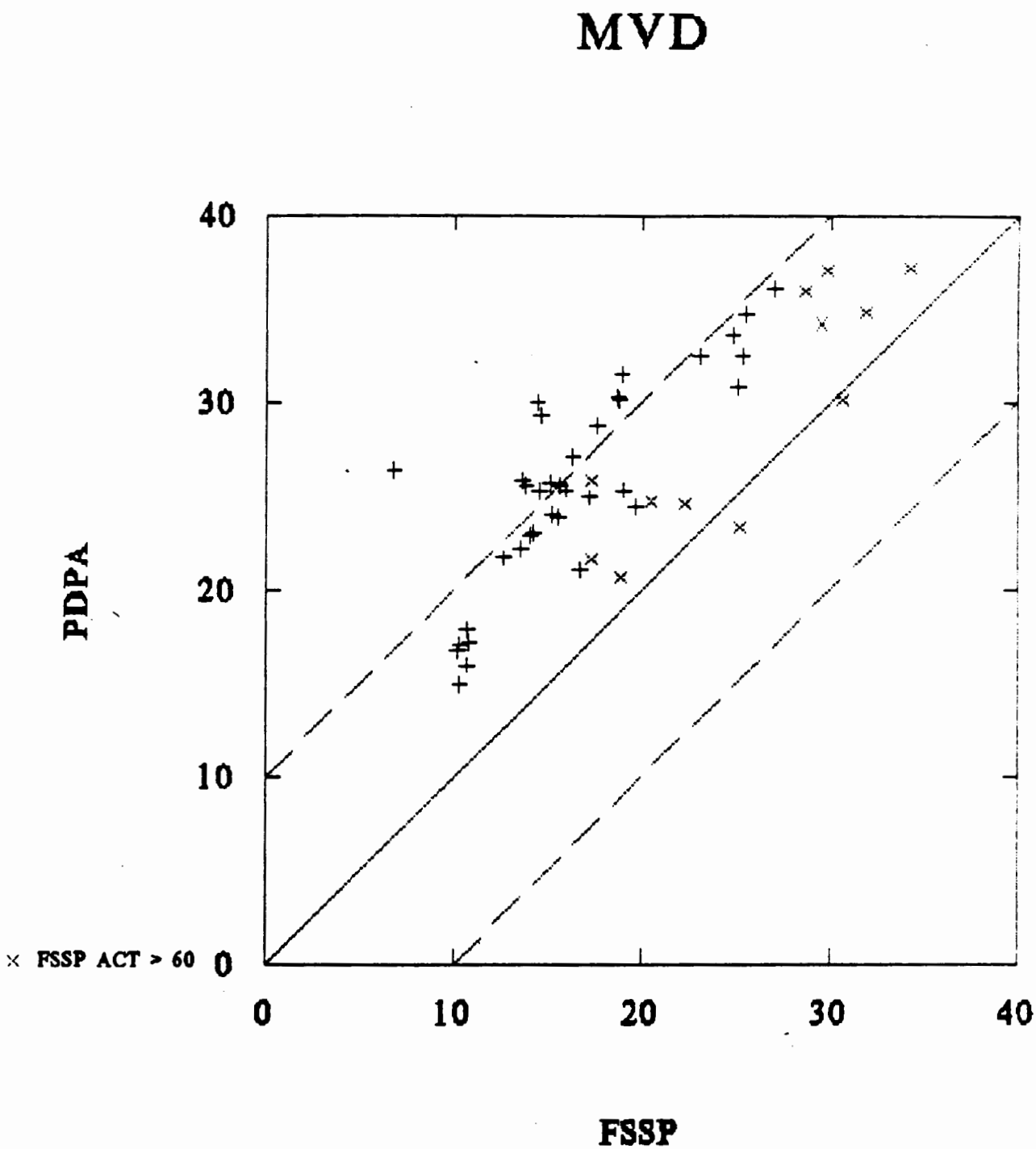


FIGURE 14. SCATTER PLOT FOR MVD OF PDPA VERSUS FSSP, TRUNCATED RANGE

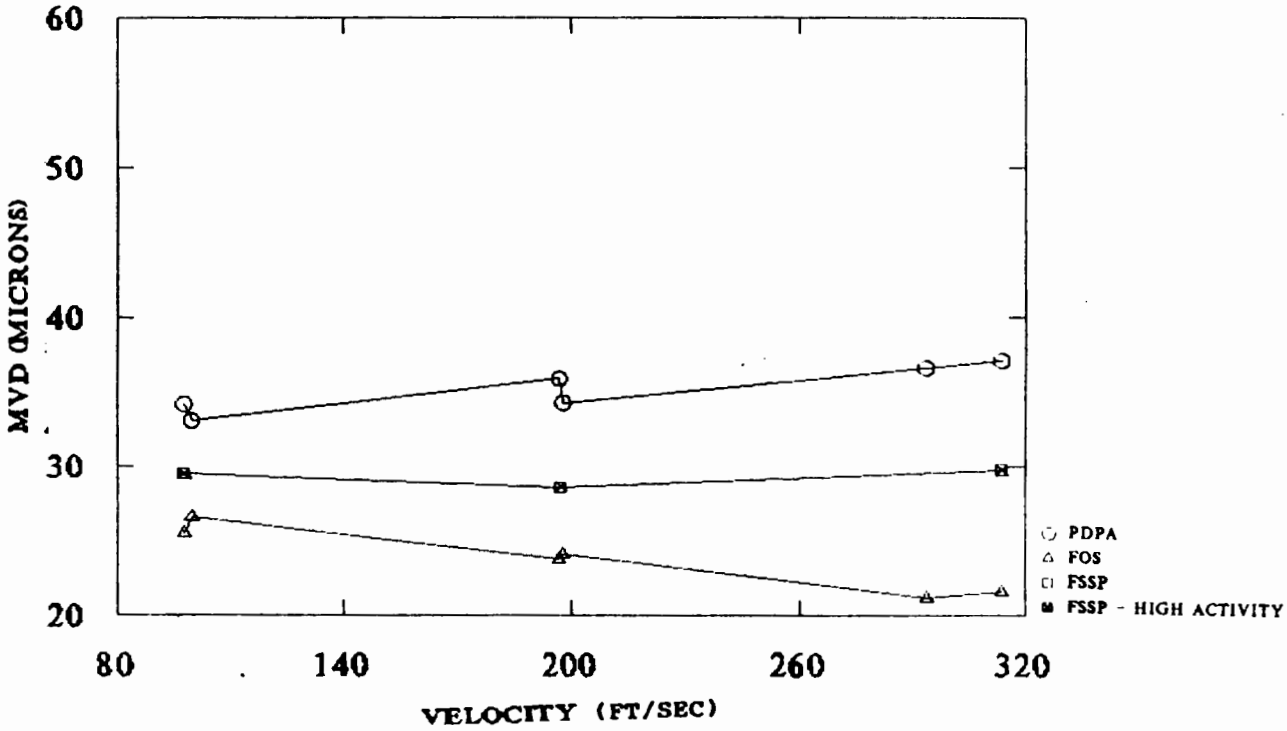


FIGURE 15. FIRST VELOCITY TEST, TRUNCATED RANGE

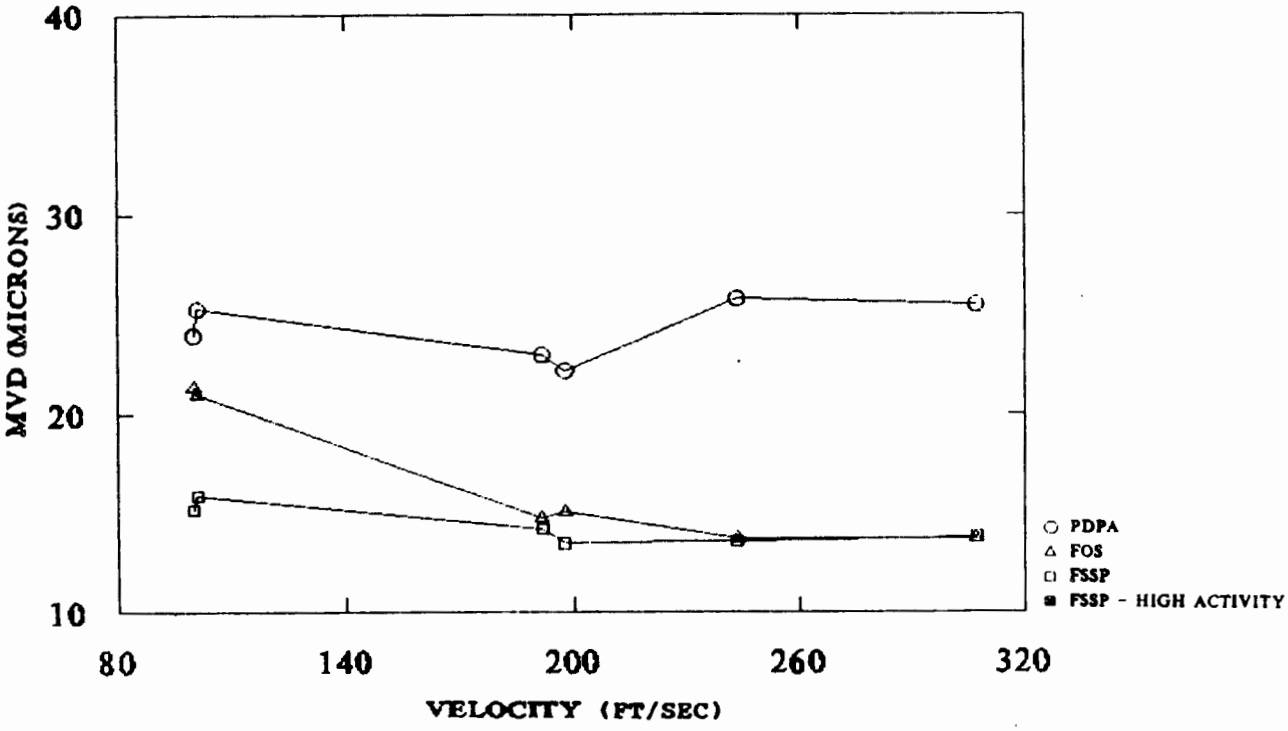


FIGURE 16. SECOND VELOCITY TEST, TRUNCATED RANGE

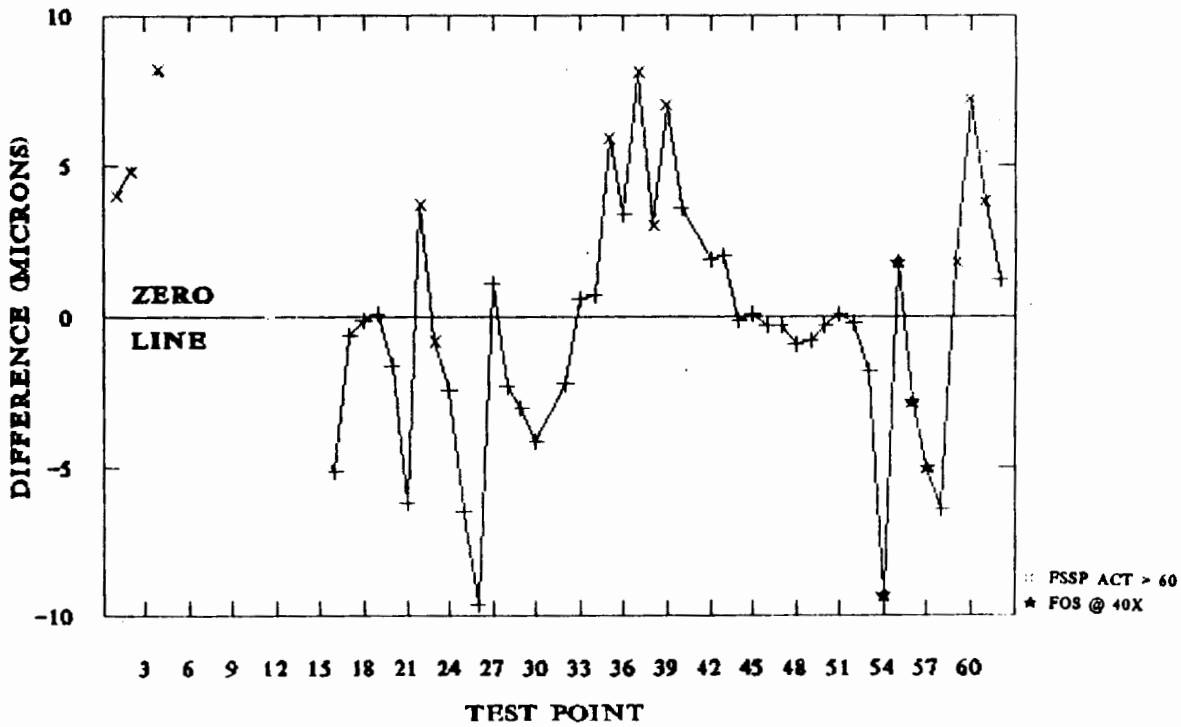


FIGURE 17. SERIAL PLOT OF $MVD_{FSSP}-MVD_{FOS}$, TRUNCATED RANGE

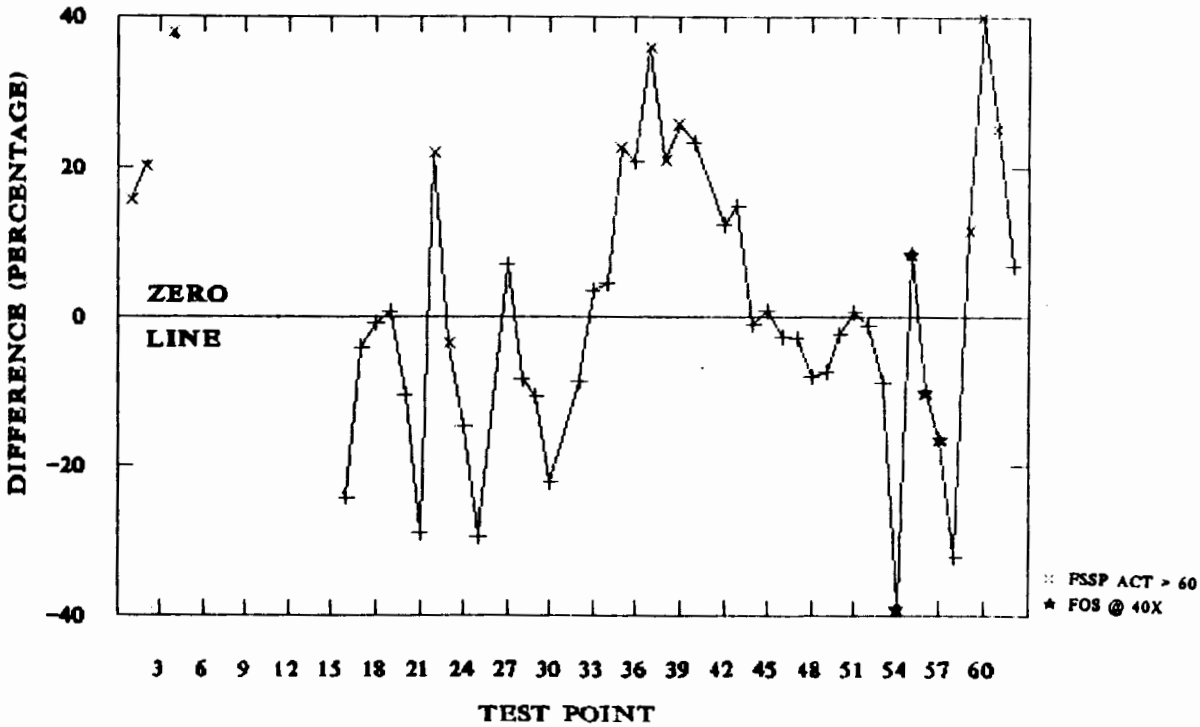


FIGURE 18. SERIAL PLOT OF 100 $(MVD_{FSSP}-MVD_{FOS})$ $/MVD_{FOS}$, TRUNCATED RANGE

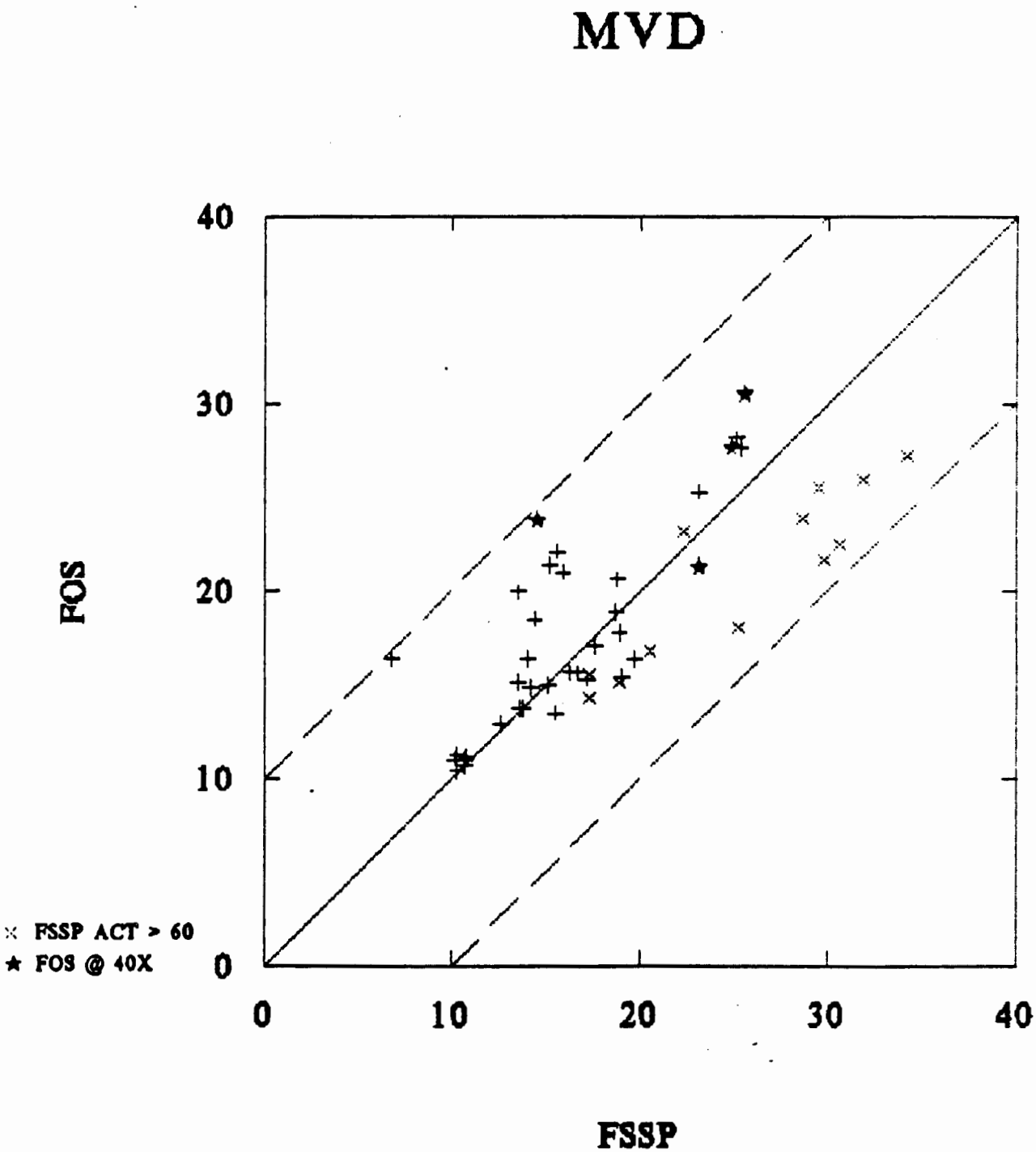


FIGURE 19. SCATTER PLOT FOR MVD OF FOS VERSUS FSSP, TRUNCATED RANGE

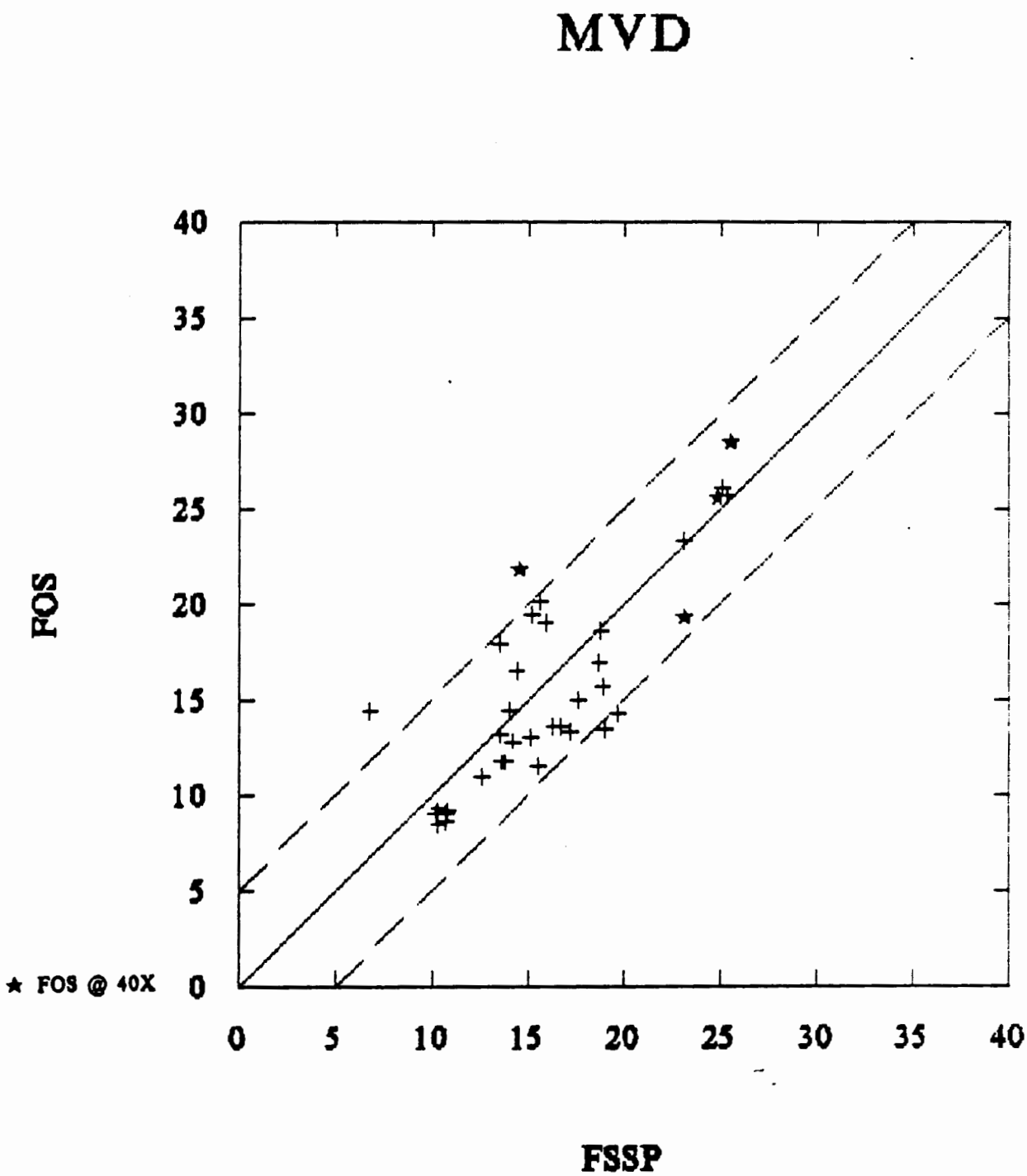


FIGURE 20. SCATTER PLOT OF MVD_{FOS}-2 VERSUS MVD_{FSSP} WITH FSSP HIGH ACTIVITY POINTS EXCLUDED, TRUNCATED RANGE

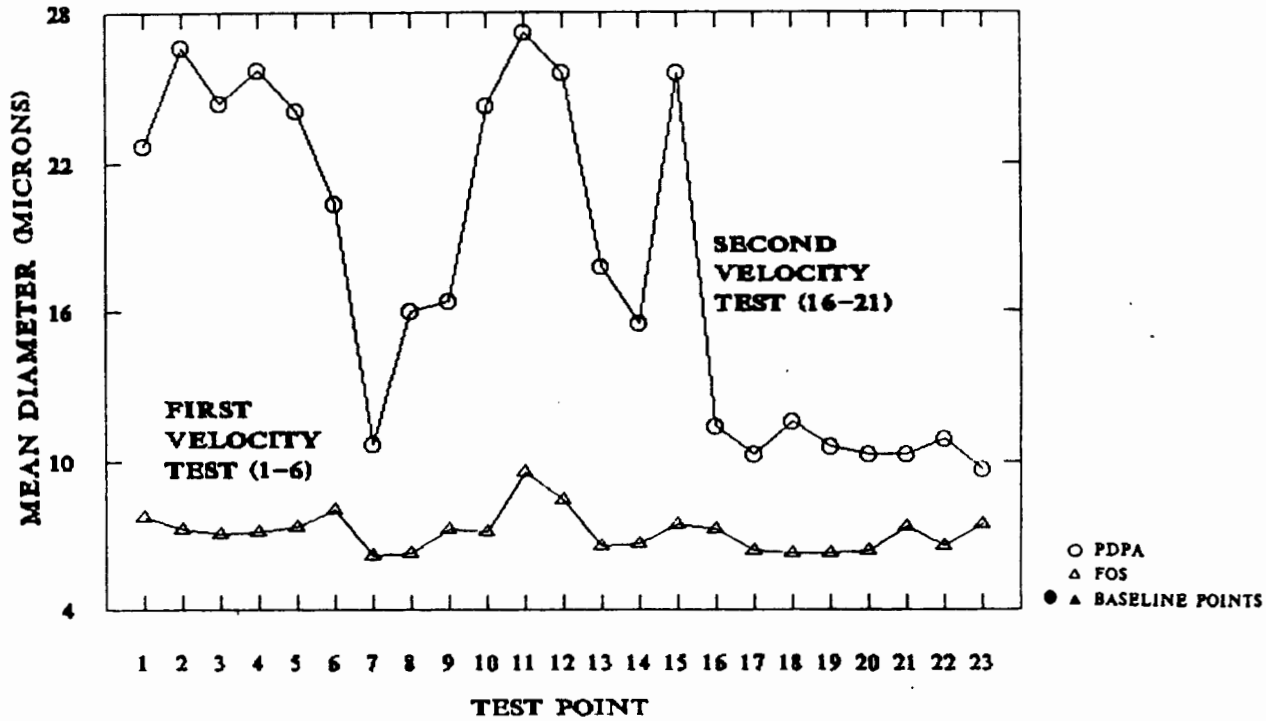


FIGURE 21A. SERIAL PLOT OF MEAN DIAMETER FOR FULL RANGE, TEST POINTS 1-23

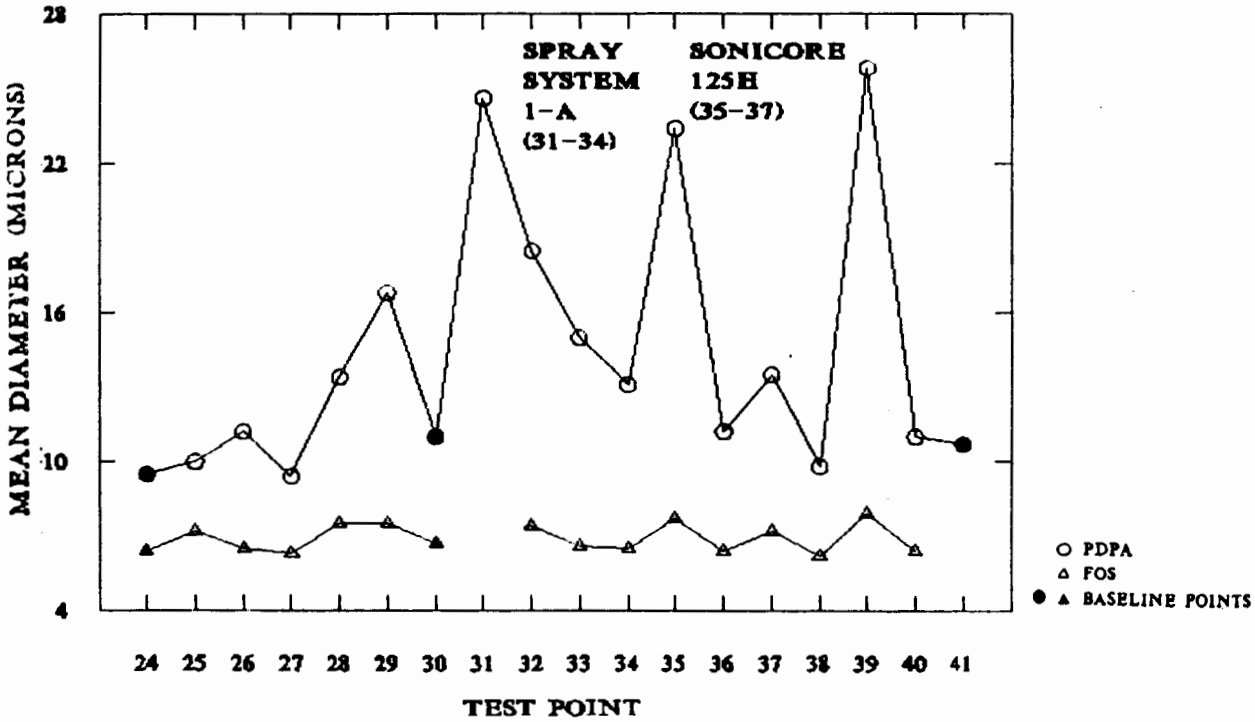


FIGURE 21B. SERIAL PLOT OF MEAN DIAMETER FOR FULL RANGE, TEST POINTS 24-41

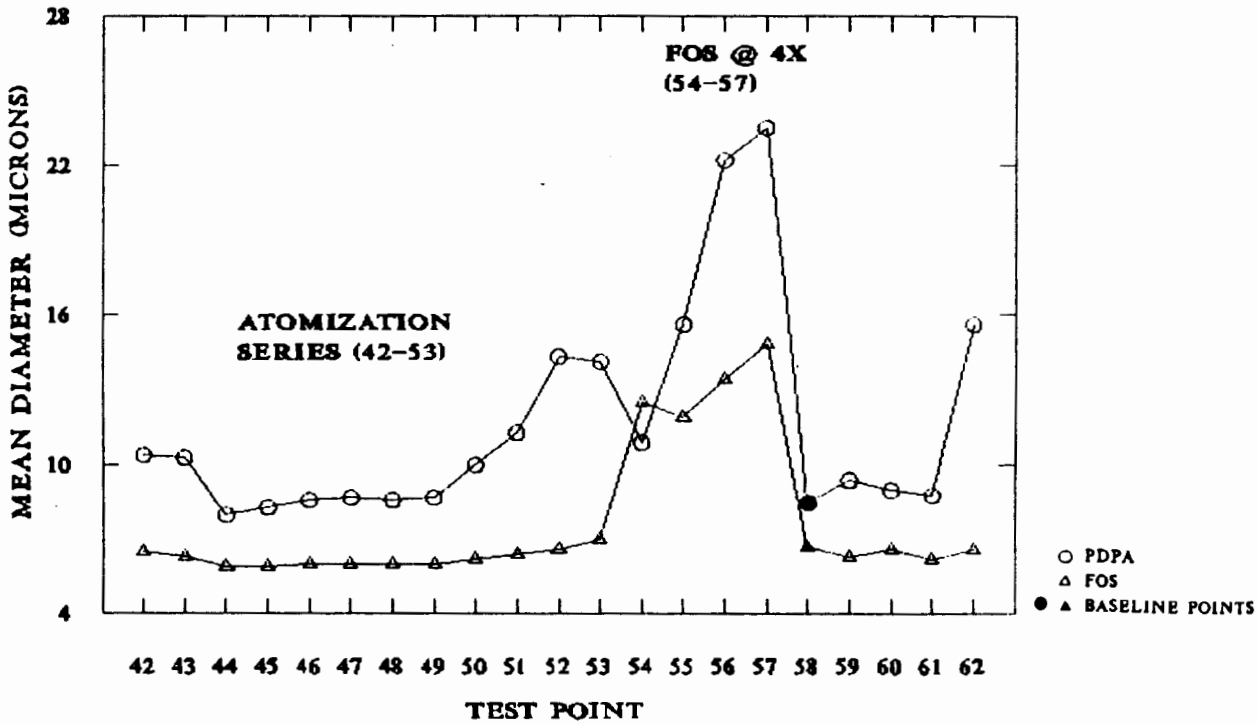


FIGURE 21C. SERIAL PLOT OF MEAN DIAMETER FOR FULL RANGE, TEST POINTS 42-62

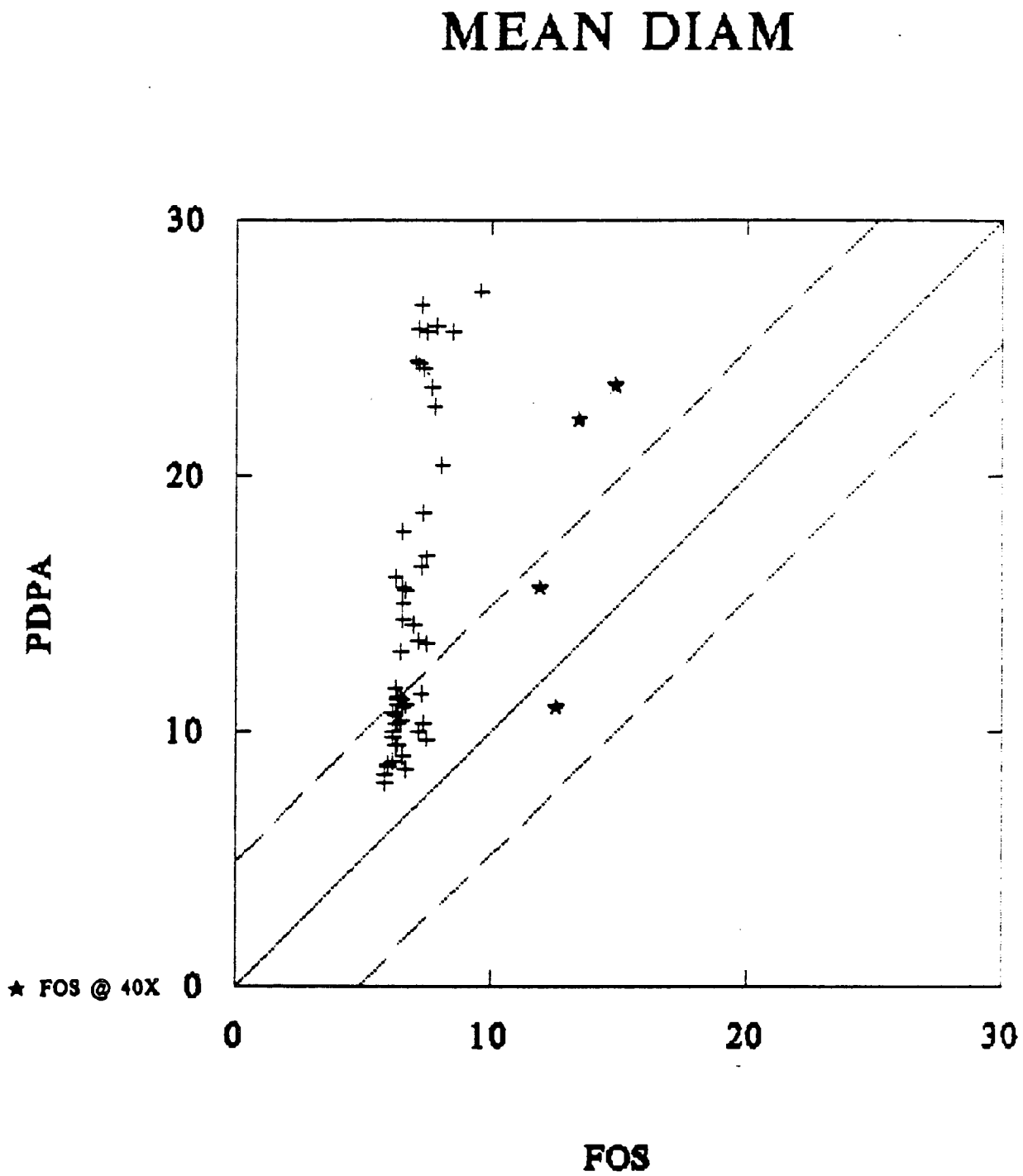


FIGURE 22. SCATTER PLOT FOR MEAN DIAMETER OF PDPA VERSUS FOS, FULL RANGE

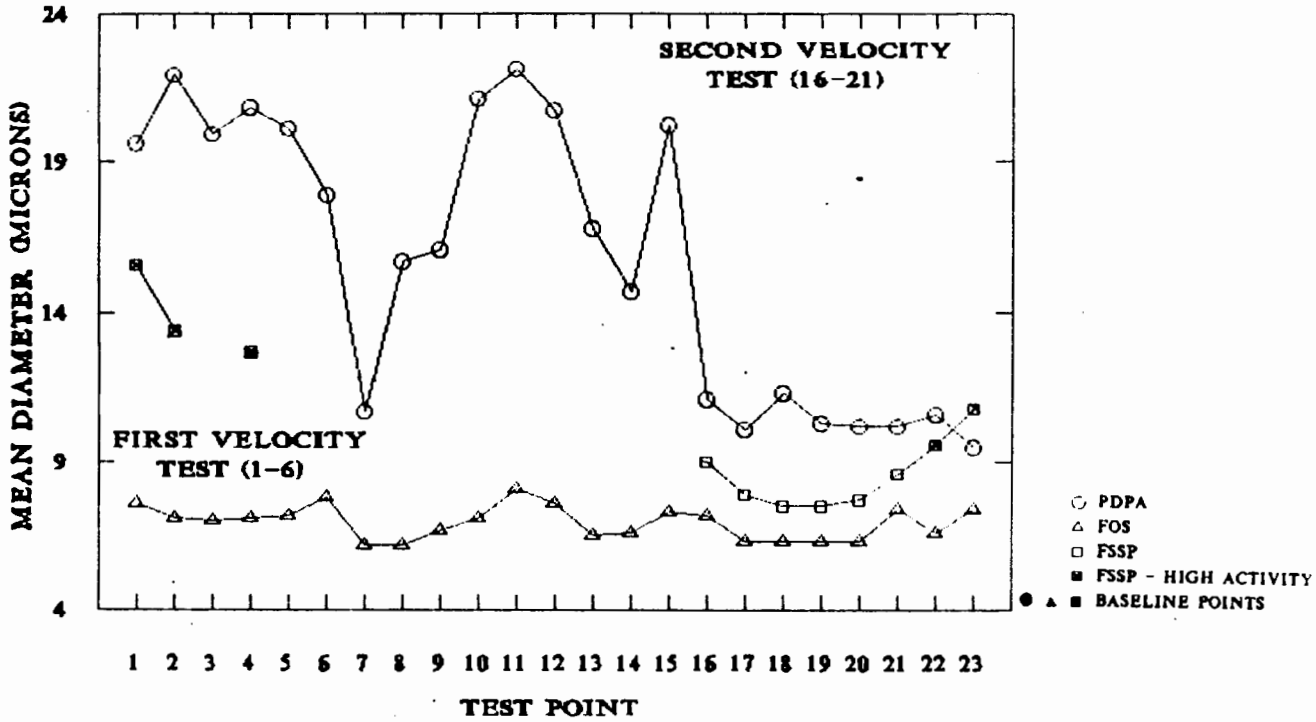


FIGURE 23A. SERIAL PLOT OF MEAN DIAMETER FOR TRUNCATED RANGE, TEST POINTS 1-23

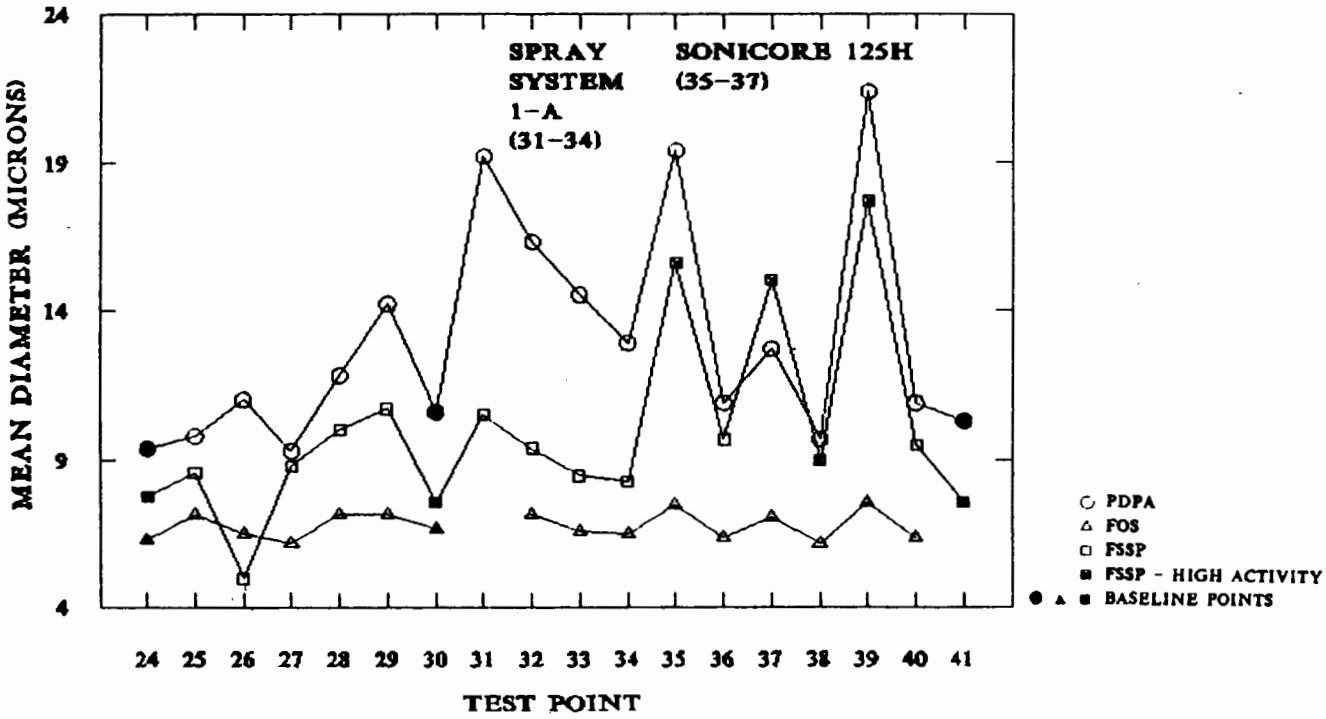


FIGURE 23B. SERIAL PLOT OF MEAN DIAMETER FOR TRUNCATED RANGE, TEST POINTS 24-41

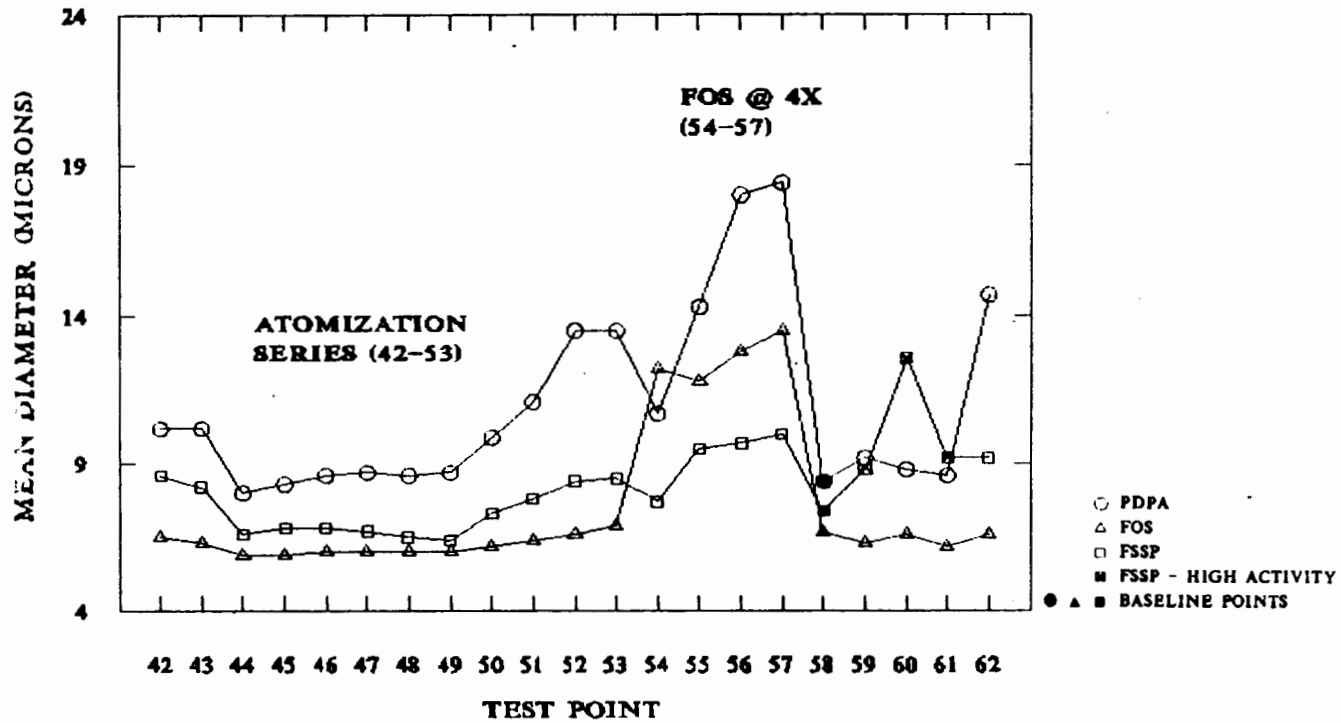


FIGURE 23C. SERIAL PLOT OF MEAN DIAMETER FOR TRUNCATED RANGE, TEST POINTS 42-62

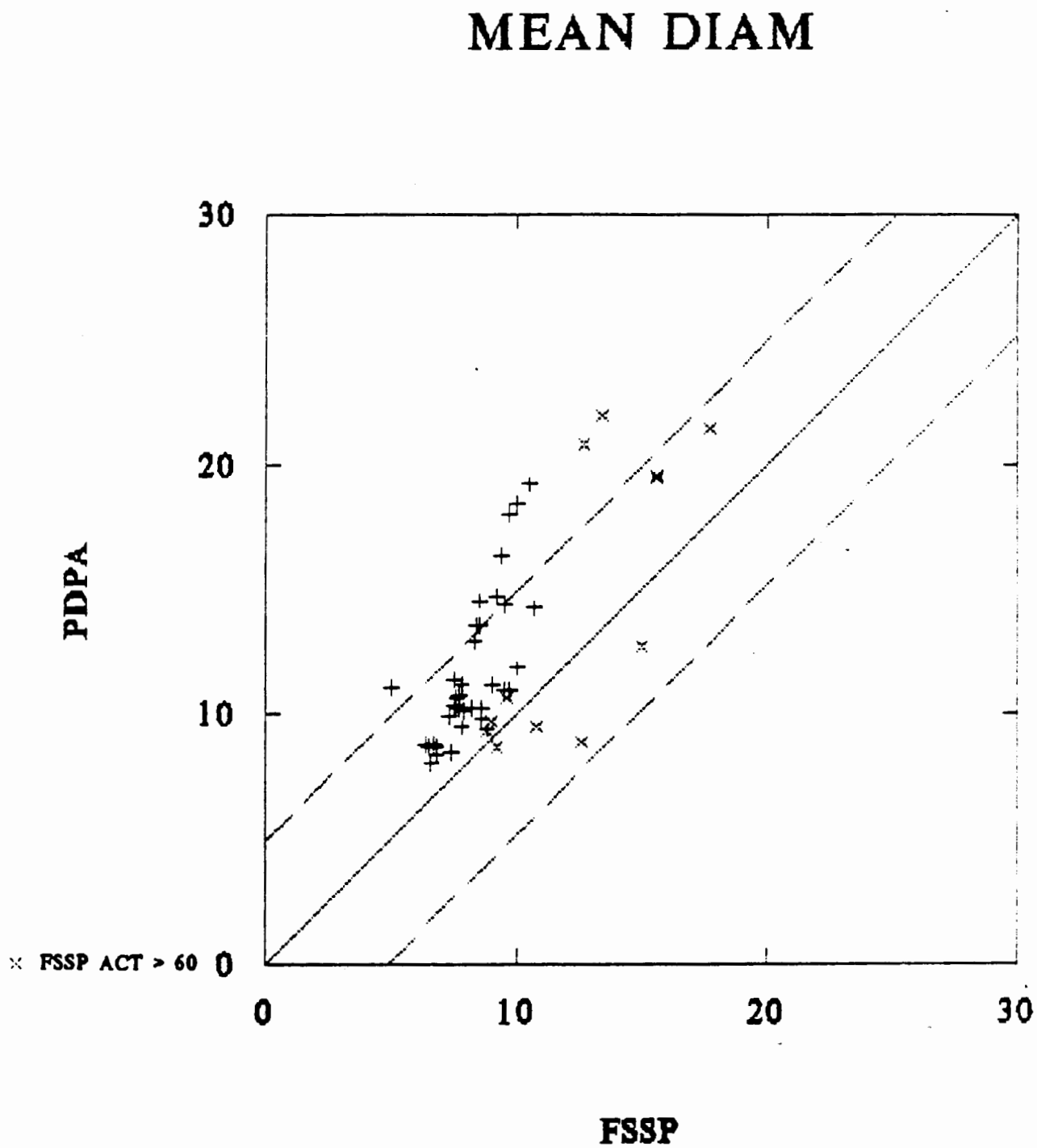


FIGURE 24. SCATTER PLOT FOR MEAN DIAMETER OF PDPA VERSUS FSSP, TRUNCATED RANGE

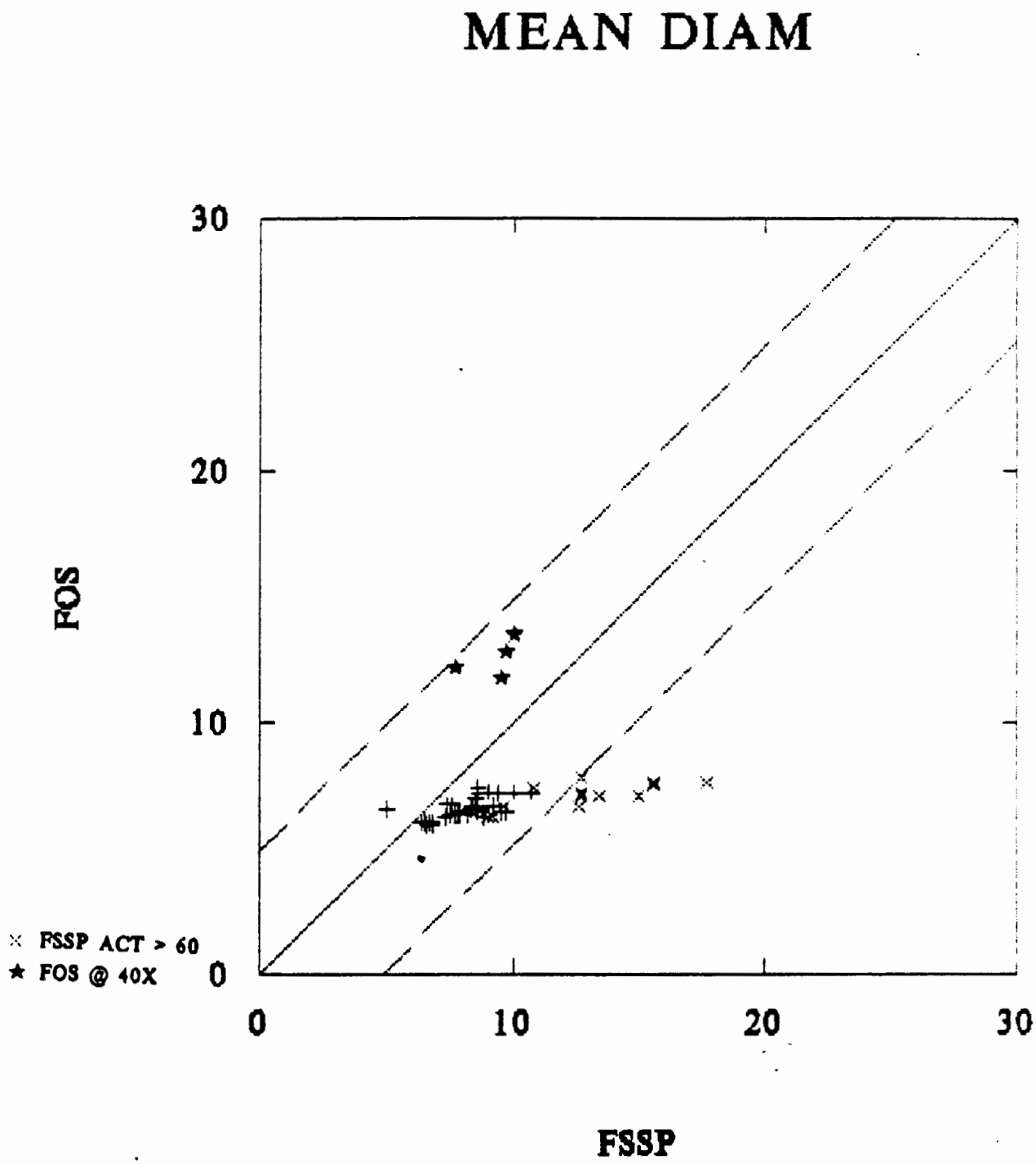


FIGURE 25. SCATTER PLOT FOR MEAN DIAMETER OF FOS VERSUS FSSP, TRUNCATED RANGE

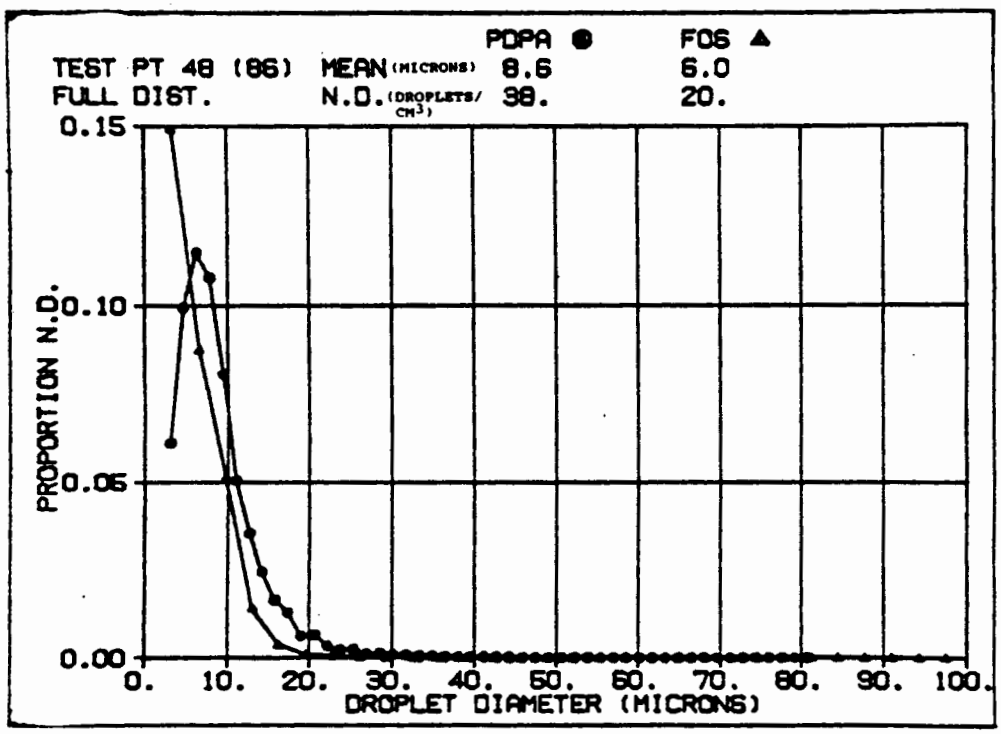


FIGURE 26A. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 48, FULL RANGE

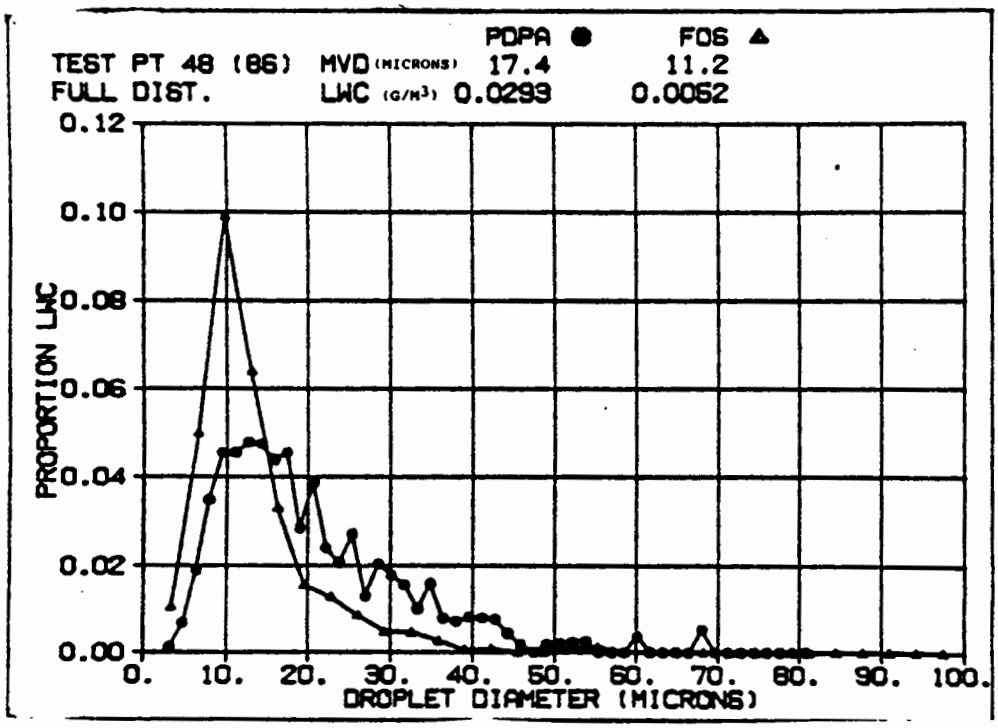


FIGURE 26B. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 48, FULL RANGE

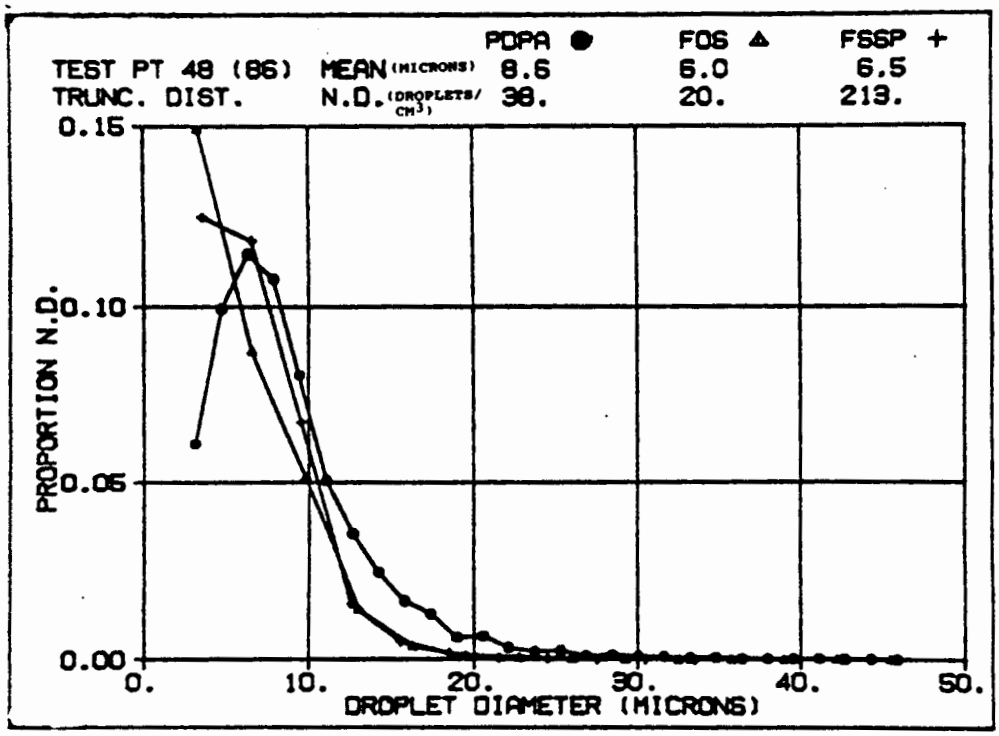


FIGURE 26C. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 48, TRUNCATED RANGE

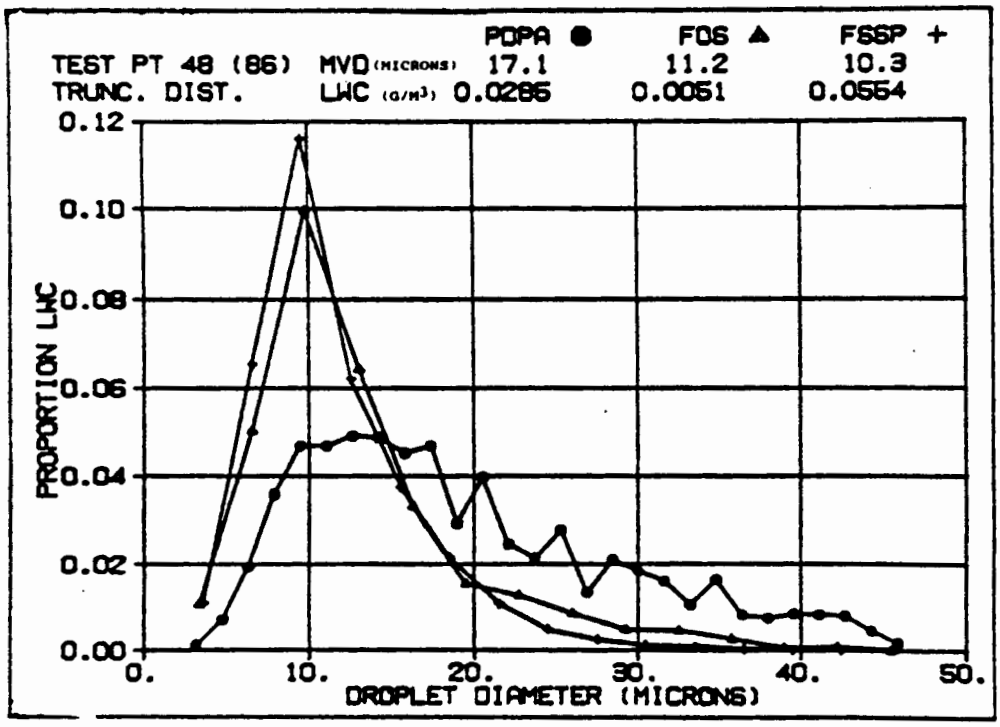


FIGURE 26D. PORPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 48, TRUNCATED RANGE

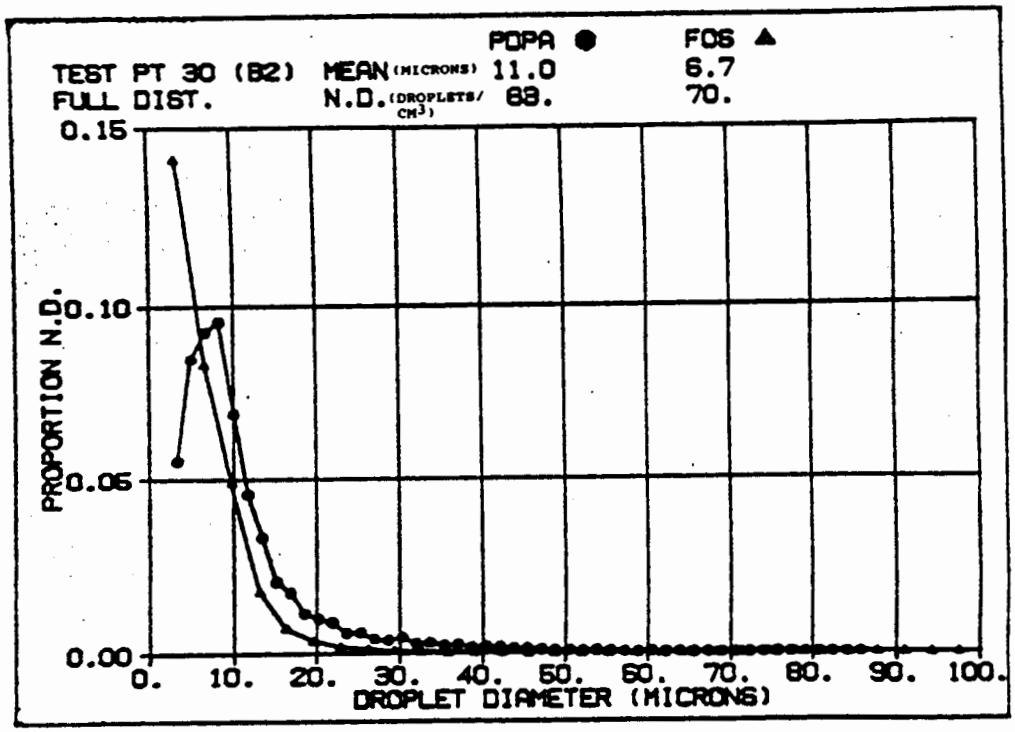


FIGURE 27A. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 30, FULL RANGE

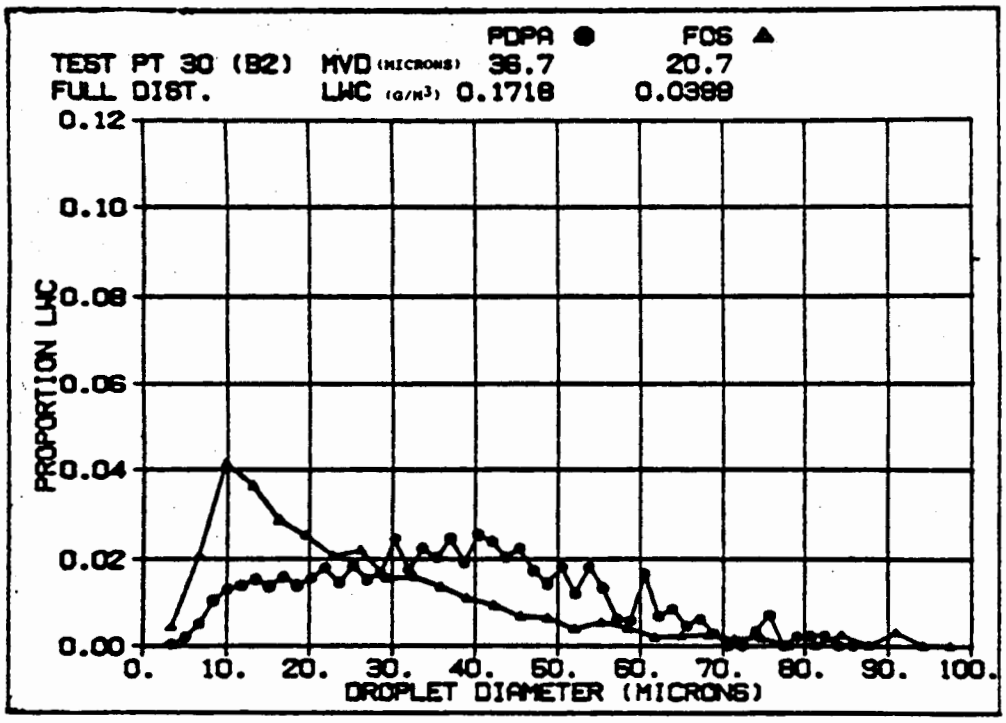


FIGURE 27B. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 30, FULL RANGE

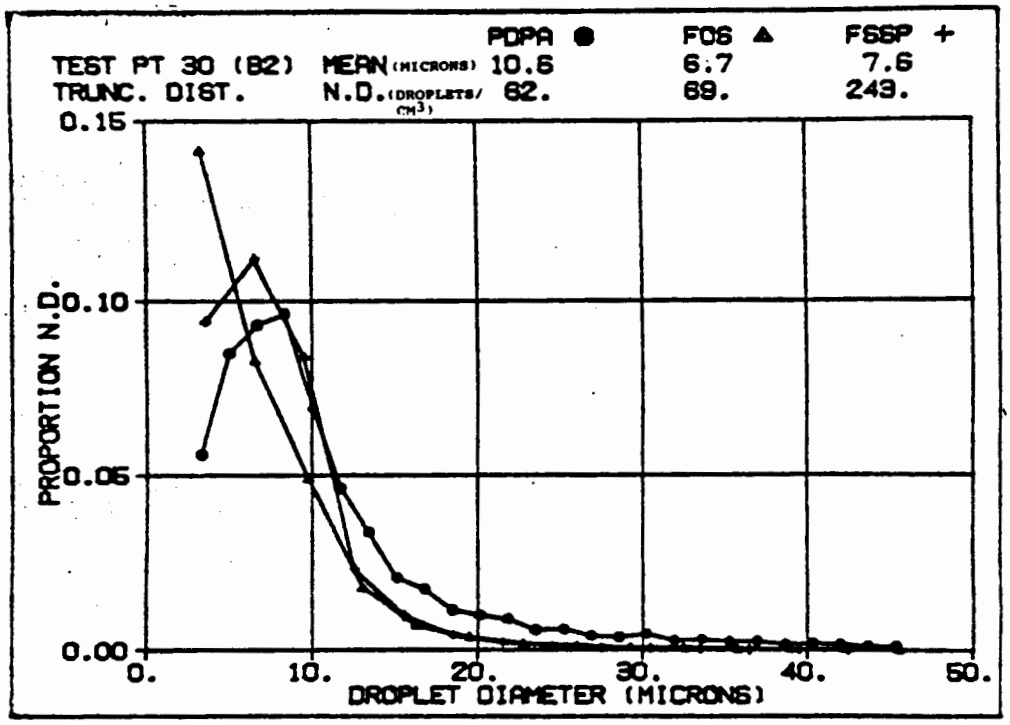


FIGURE 27C. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 30, TRUNCATED RANGE

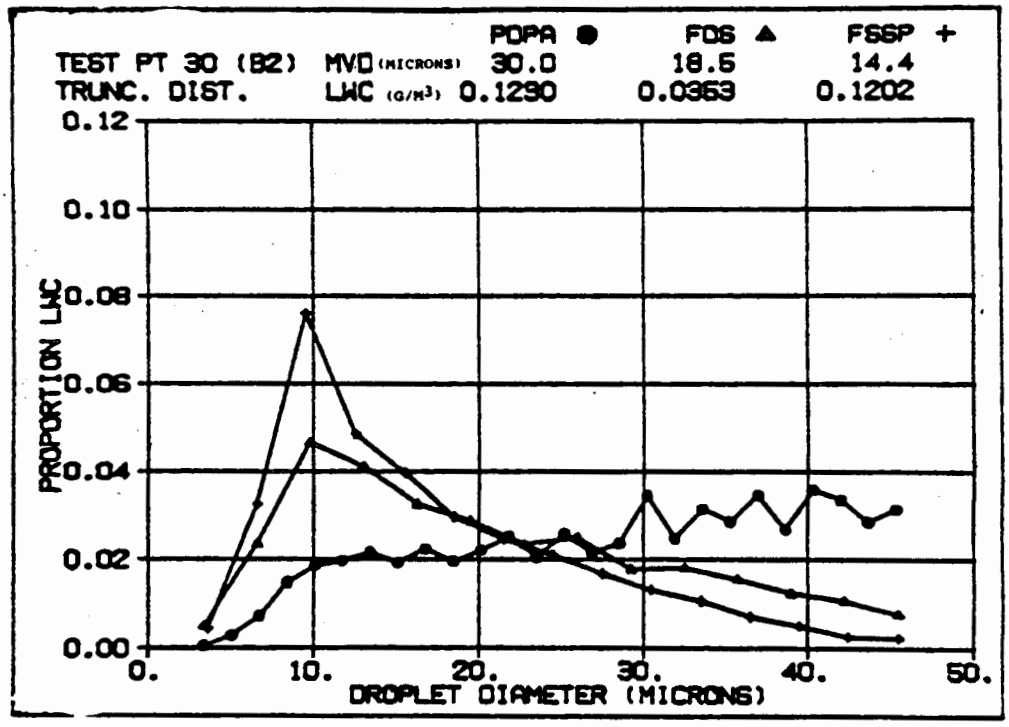


FIGURE 27D. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 30, TRUNCATED RANGE

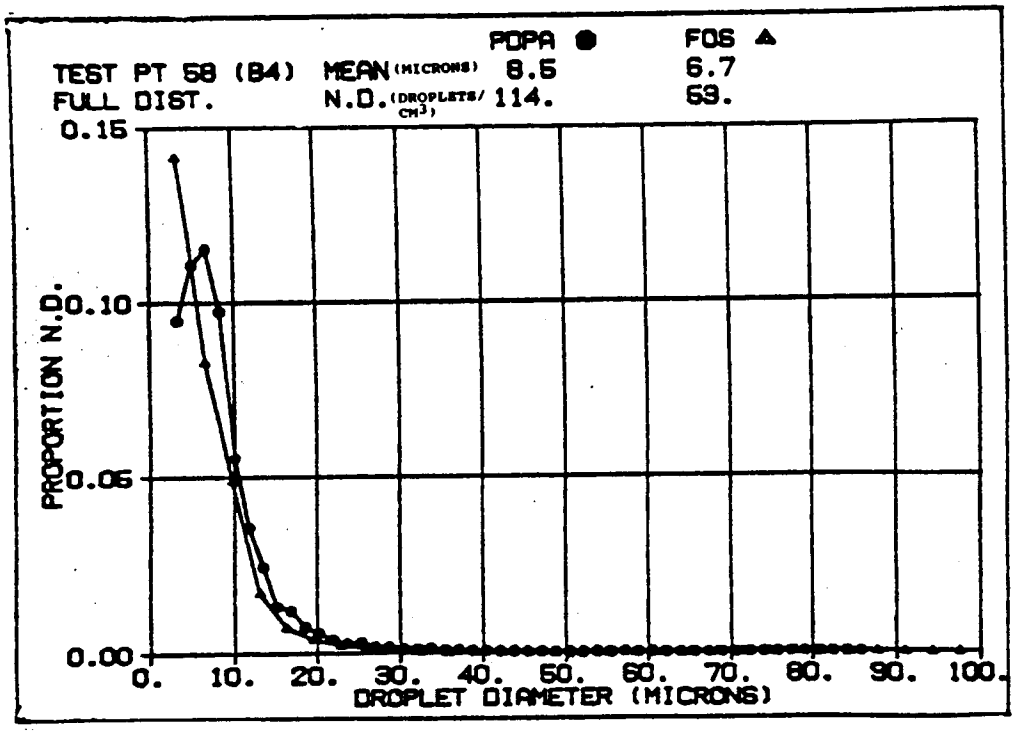


FIGURE 28A. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 58, FULL RANGE

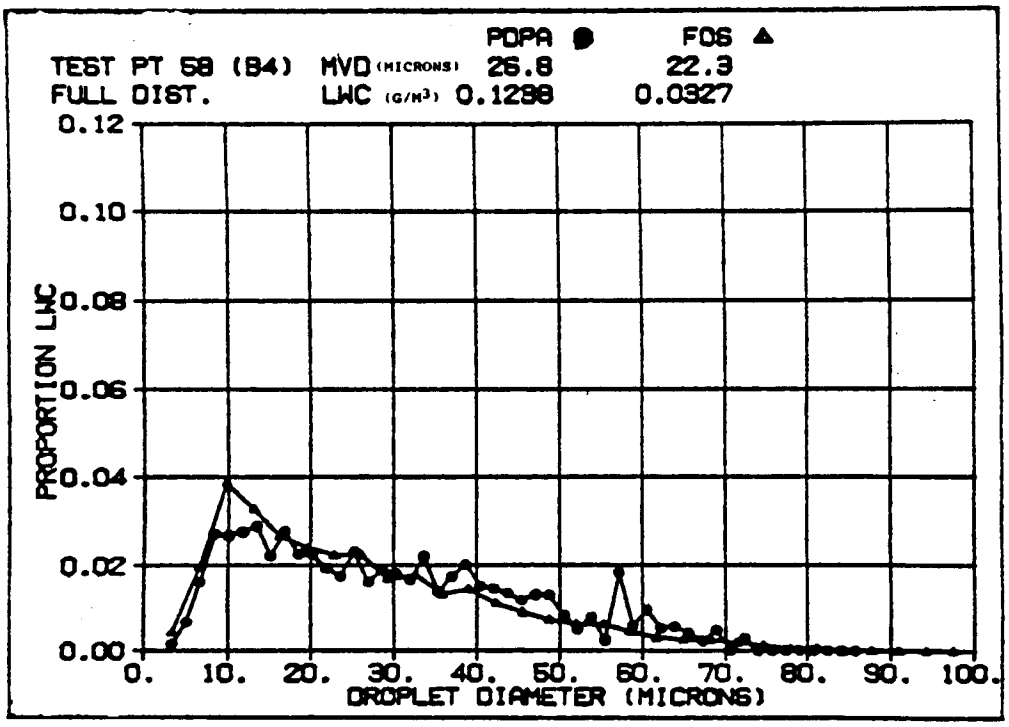


FIGURE 28B. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FPR TEST POINT 58, FULL RANGE

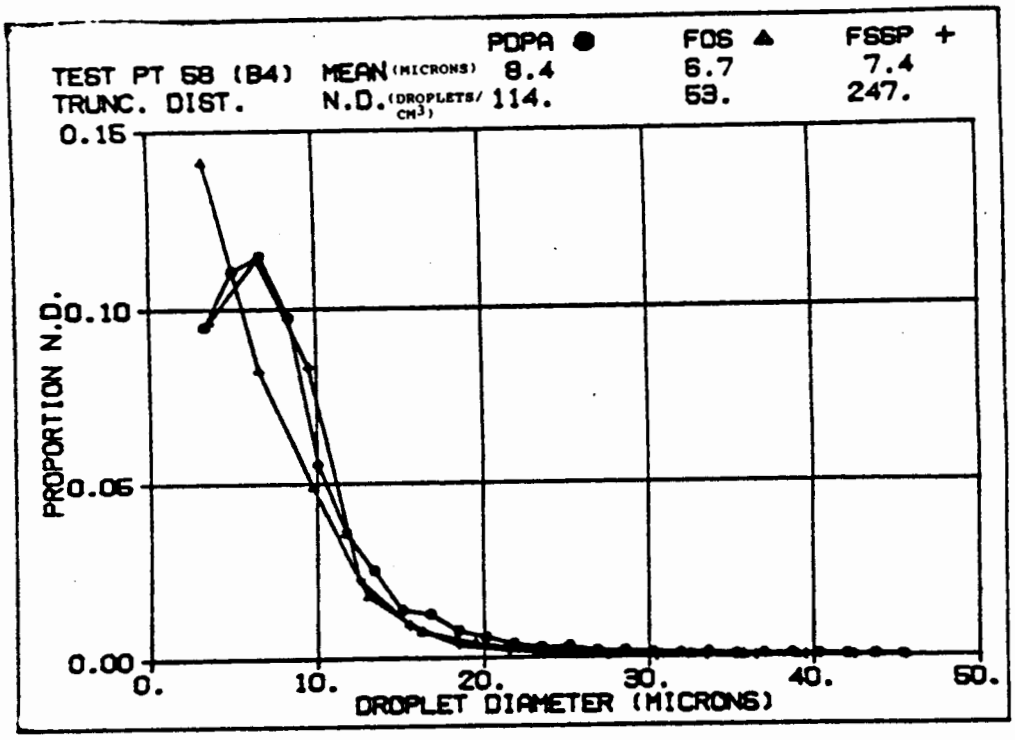


FIGURE 28C. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST PONT 58, TRUNCATED RANGE

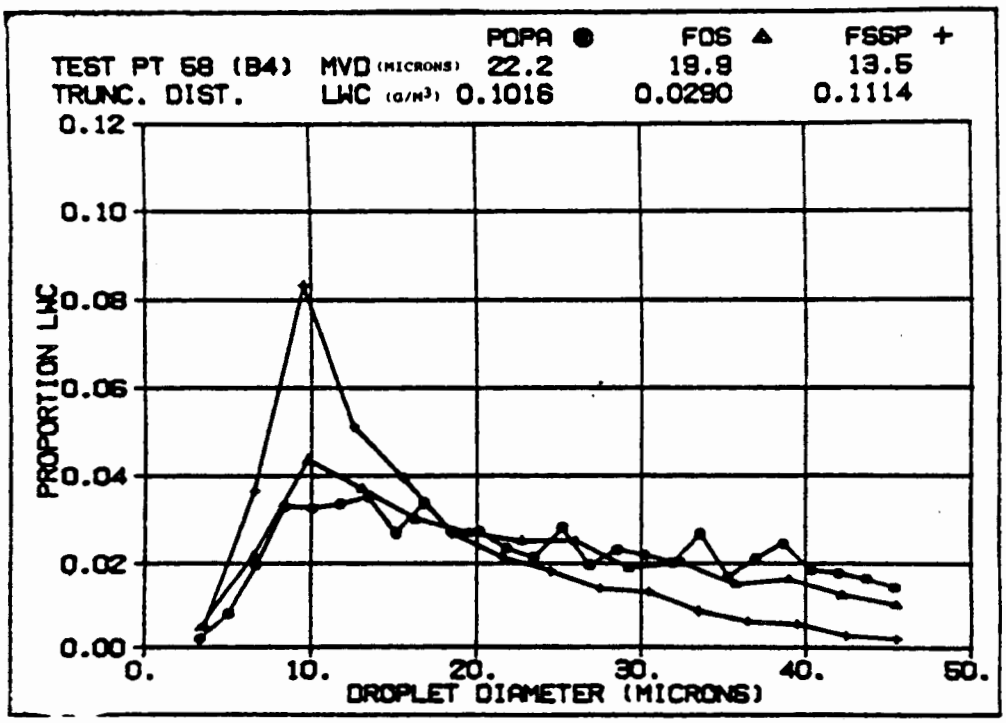


FIGURE 28D. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 58, TRUNCATED RANGE

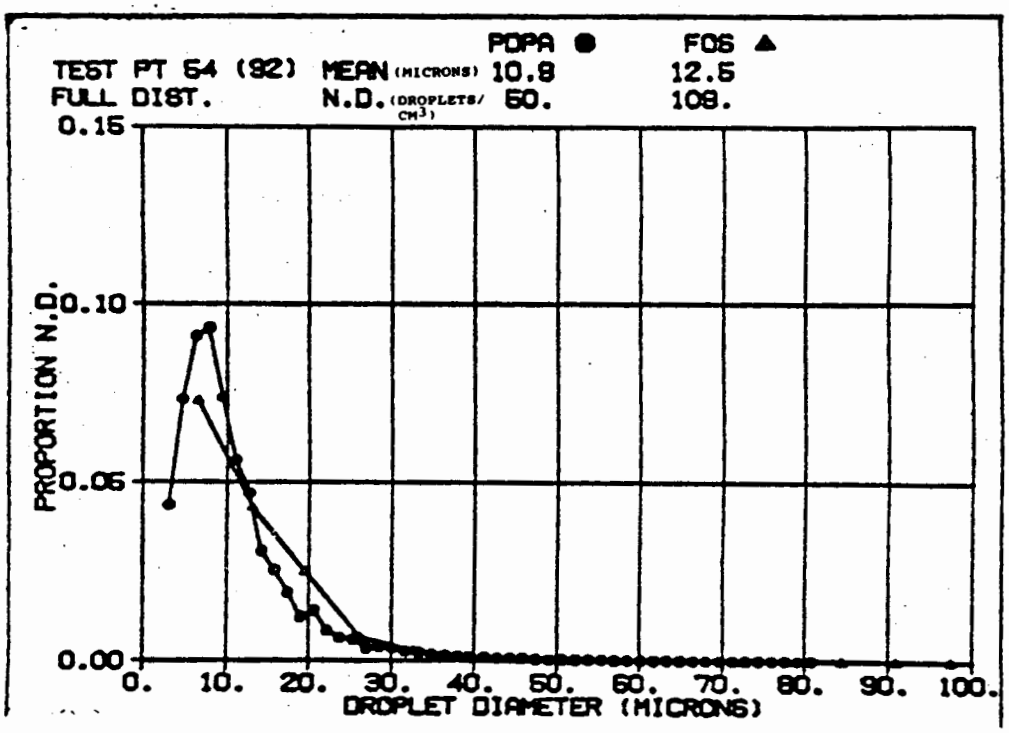


FIGURE 29A. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 54, FULL RANGE

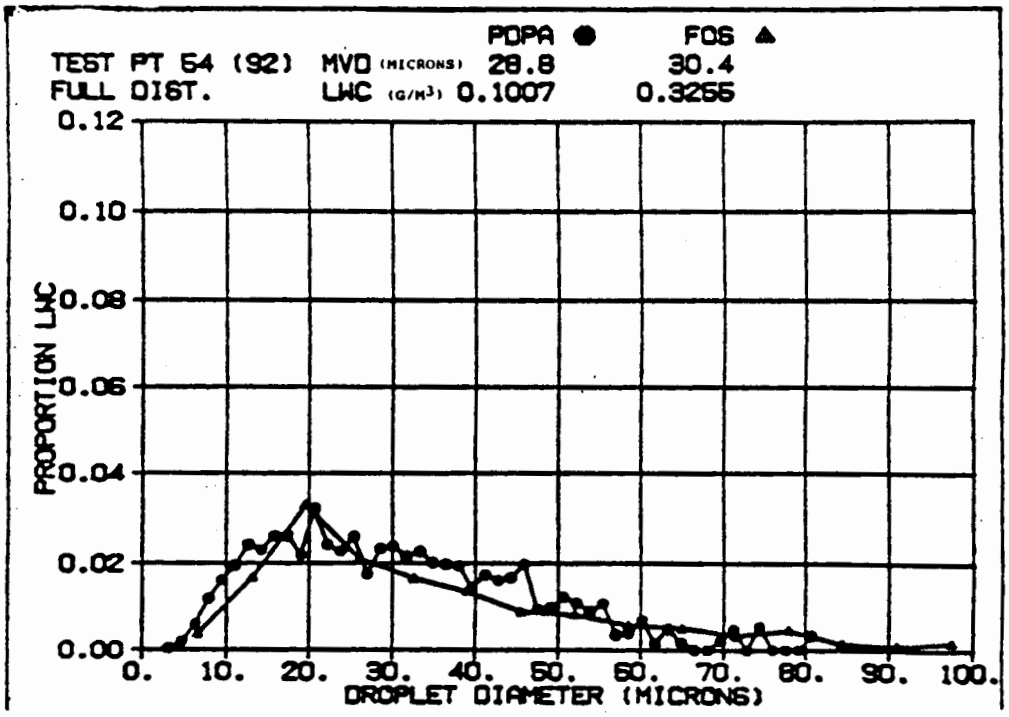


FIGURE 29B. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TESTS POINT 54, FULL RANGE

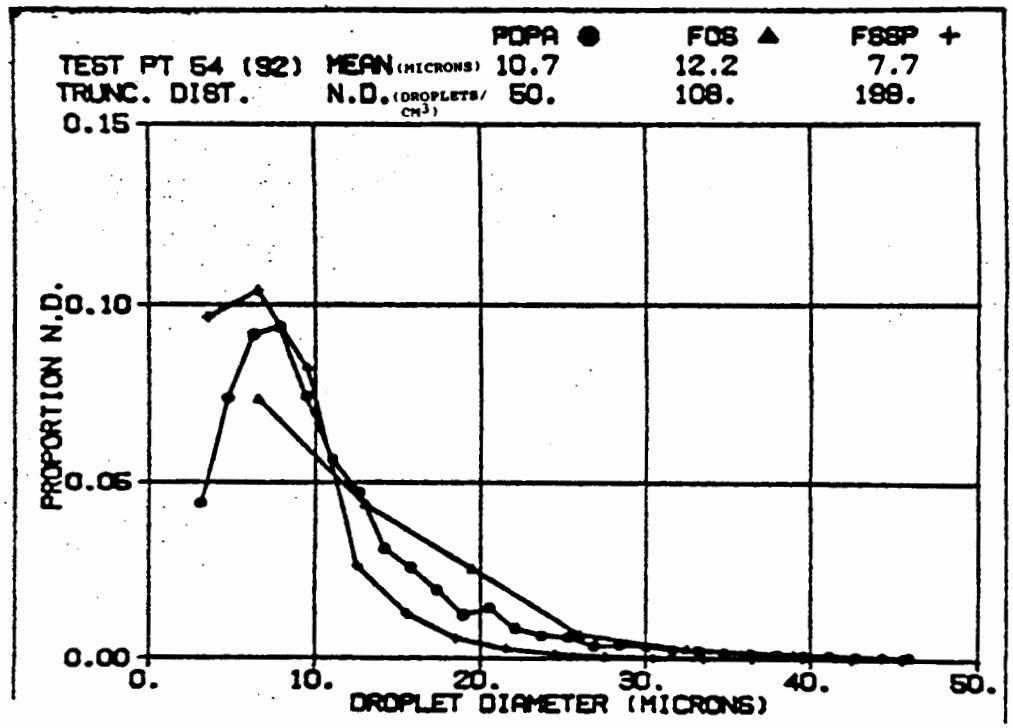


FIGURE 29C. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 54, TRUNCATED RANGE

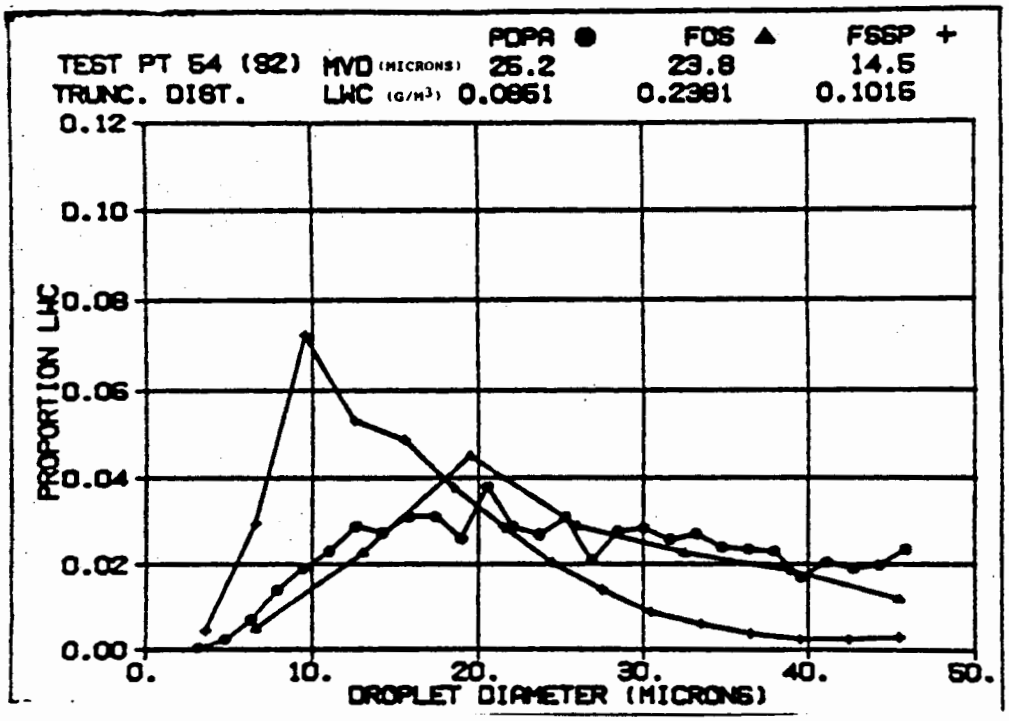


FIGURE 29D. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 54, TRUNCATED RANGE

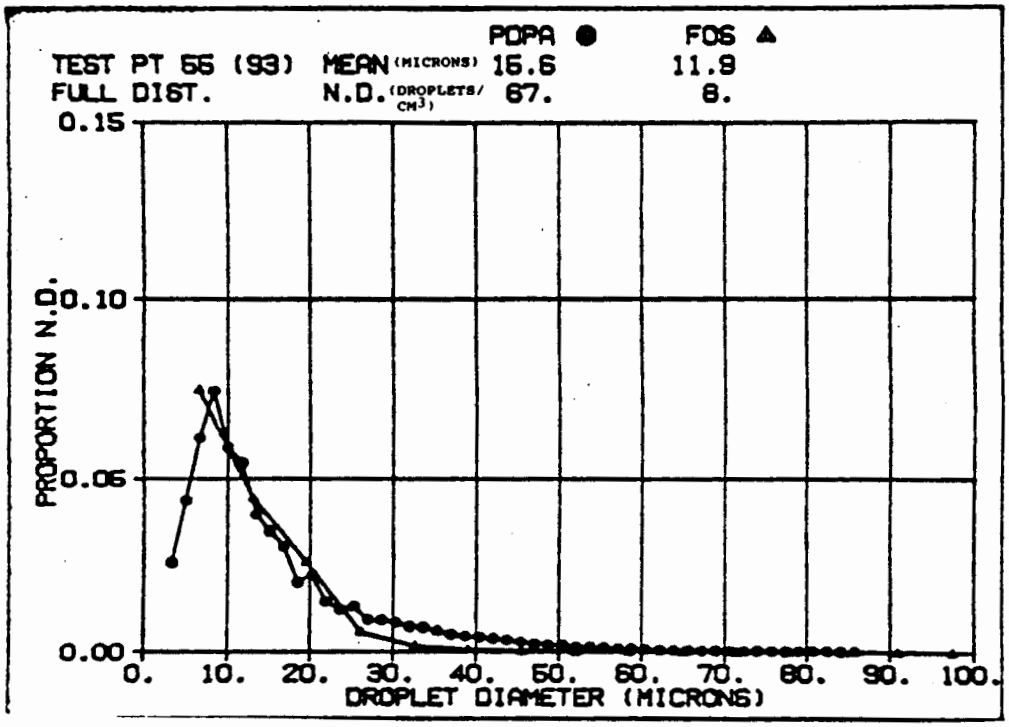


FIGURE 30A. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 55, FULL RANGE

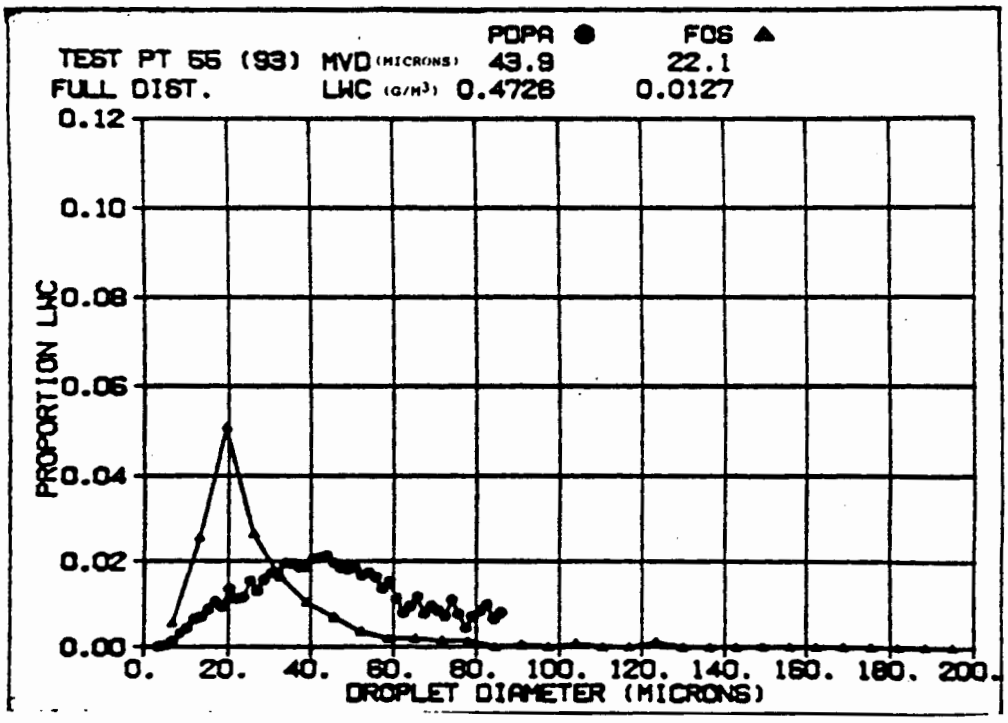


FIGURE 30B. PROPORTON LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 55, FULL RANGE

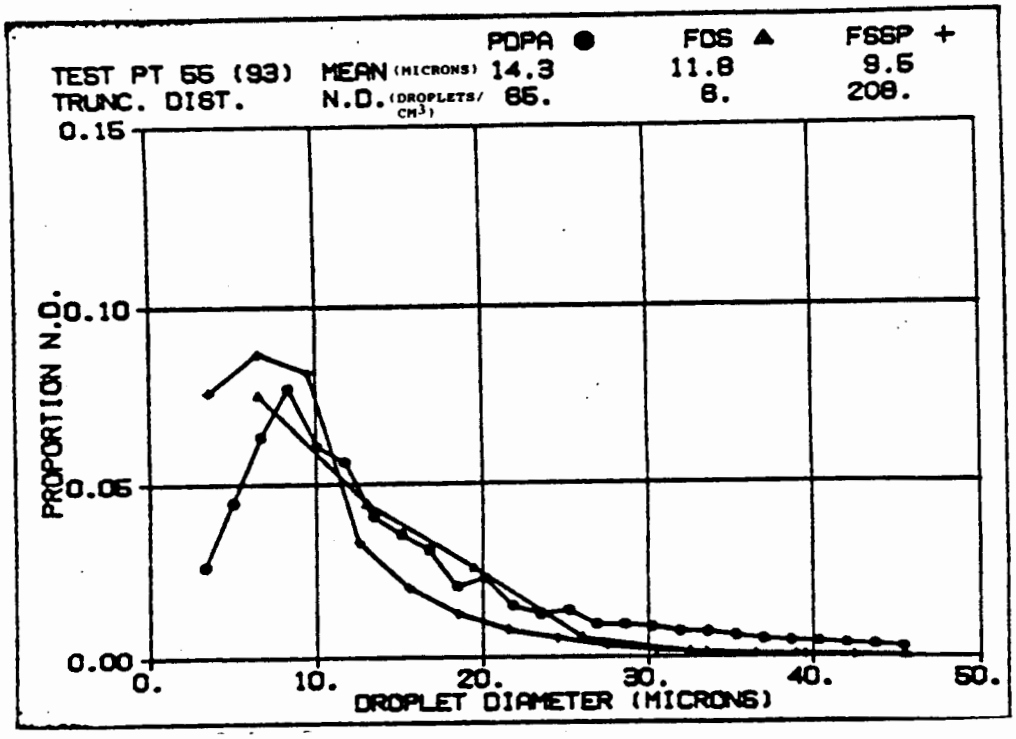


FIGURE 30C. PROPORTION NUMBER DENSITY DISTRIBUTION FOR TEST POINT 55, TRUNCATED RANGE

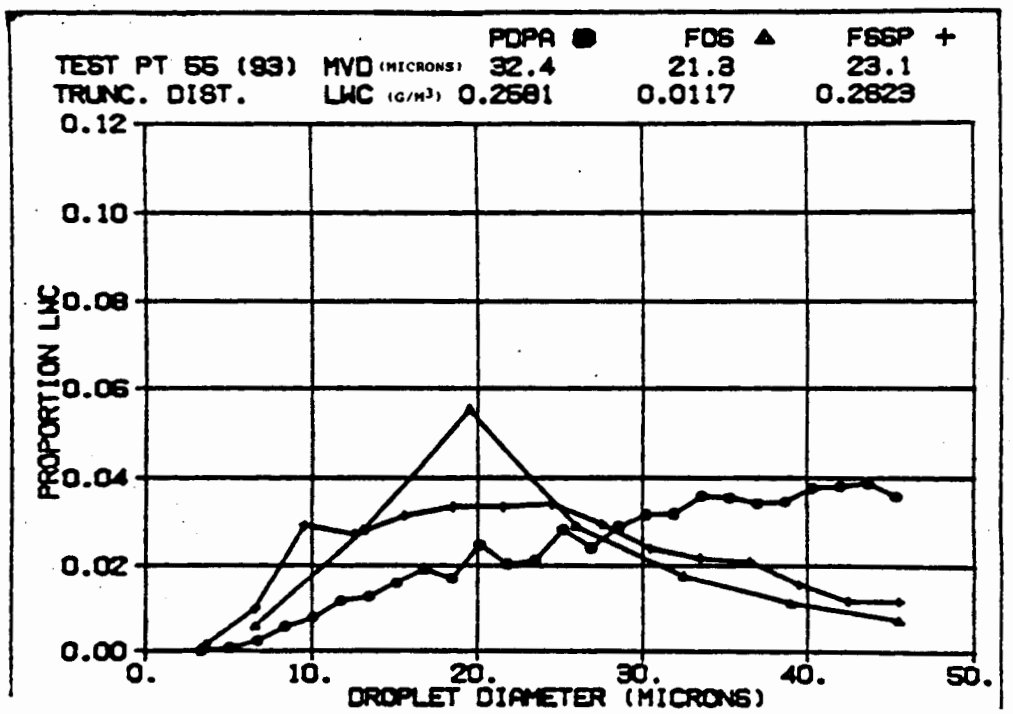


FIGURE 30D. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 55, TRUNCATED RANGE

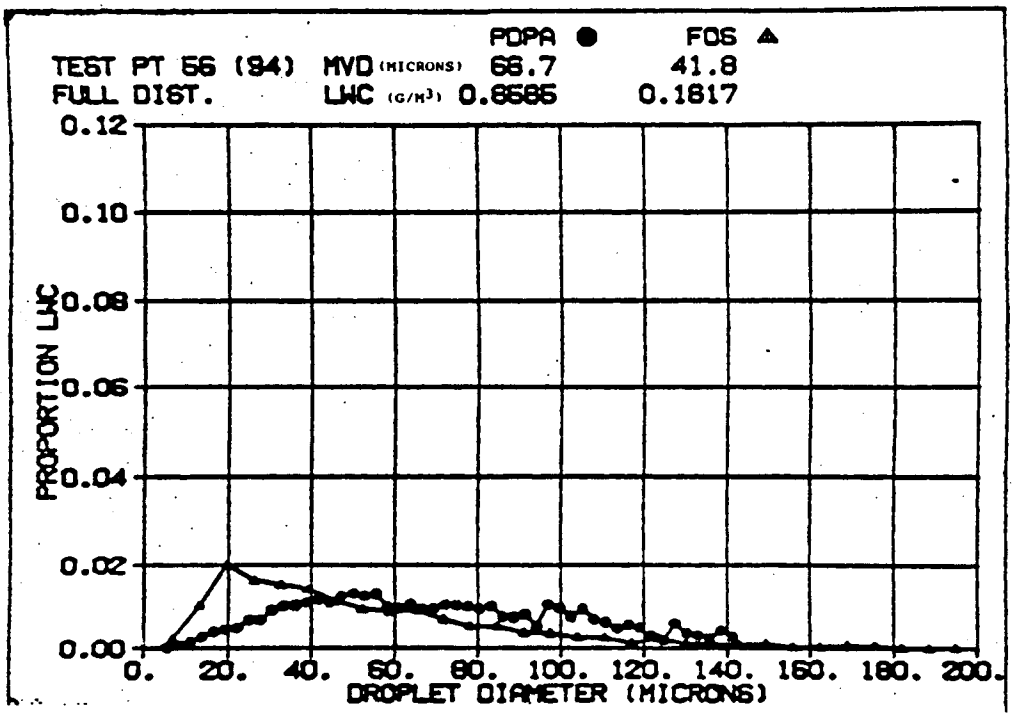


FIGURE 31A. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 56, FULL RANGE

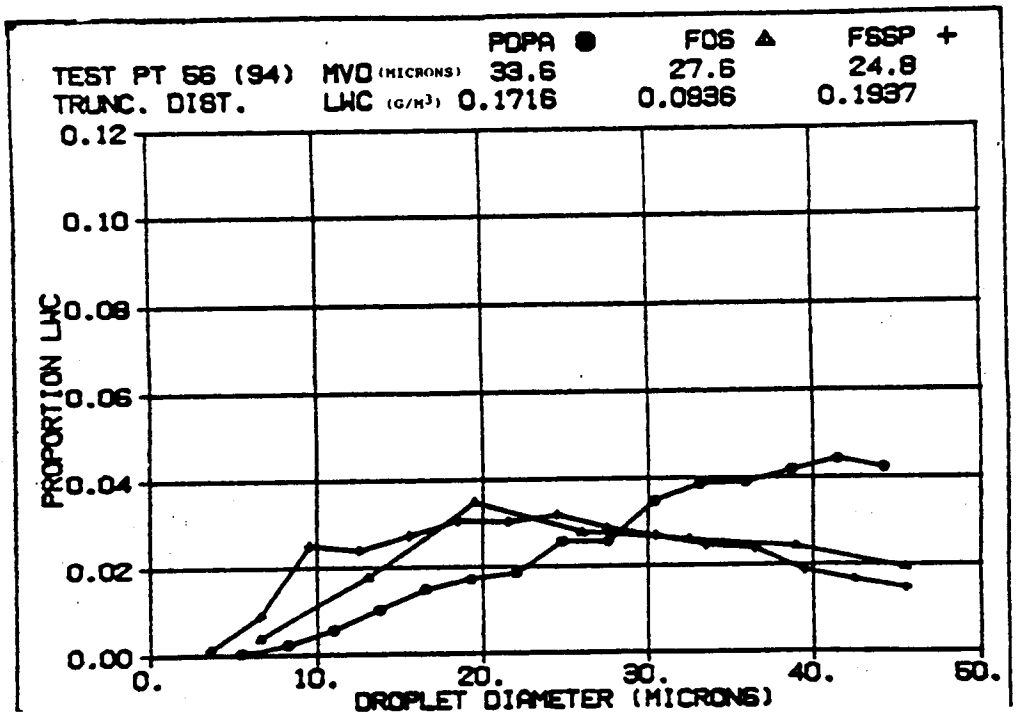


FIGURE 31B. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 56, TRUNCATED RANGE

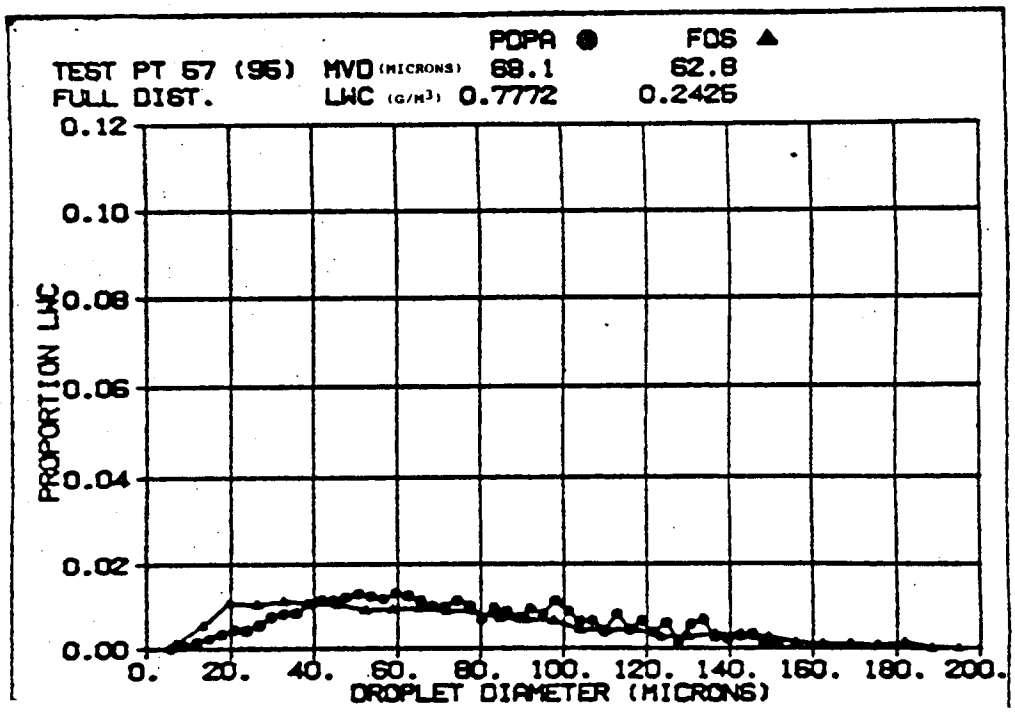


FIGURE 32A. PROPORTION LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 57, FULL RANGE

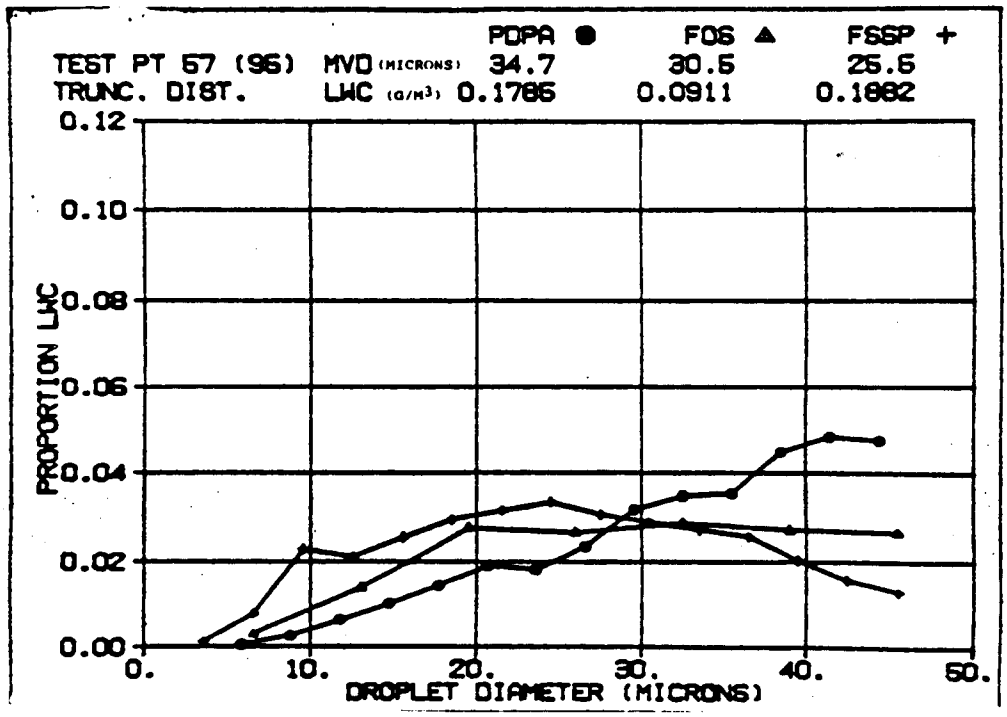


FIGURE 32B. PROPORTON LIQUID WATER CONTENT DISTRIBUTION FOR TEST POINT 57, TRUNCATED RANGE

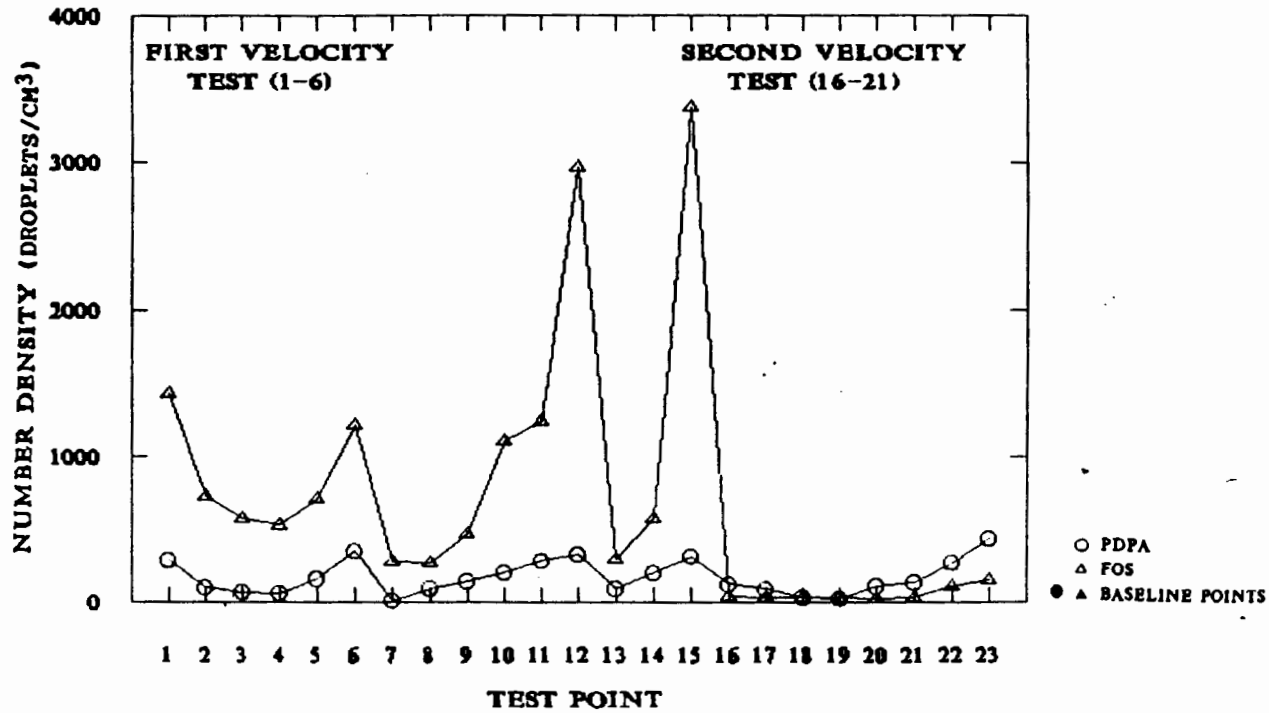


FIGURE 33A. SERIAL PLOT OF ND FOR FULL RANGE, TEST POINTS 1-23

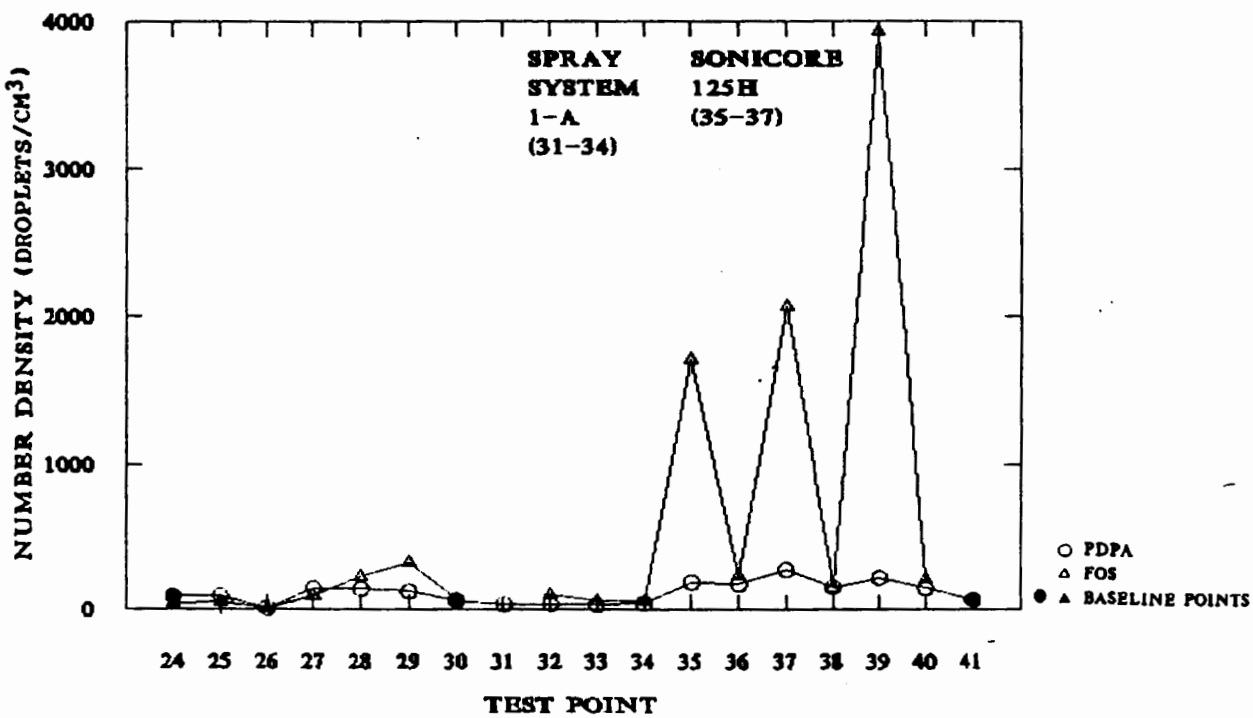


FIGURE 33B. SERIAL PLOT OF ND FOR FULL RANGE, TEST POINTS 24-41

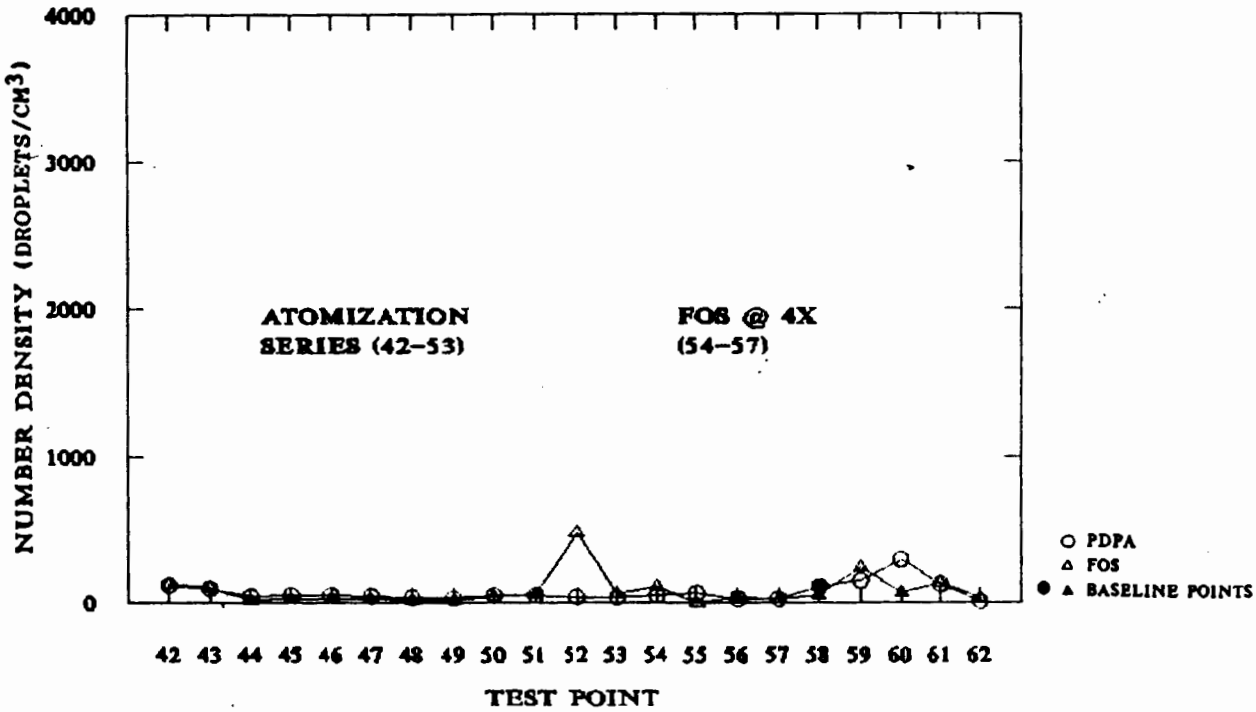


FIGURE 33C. SERIAL PLOT OF ND FOR FULL RANGE, TEST POINTS 42-62

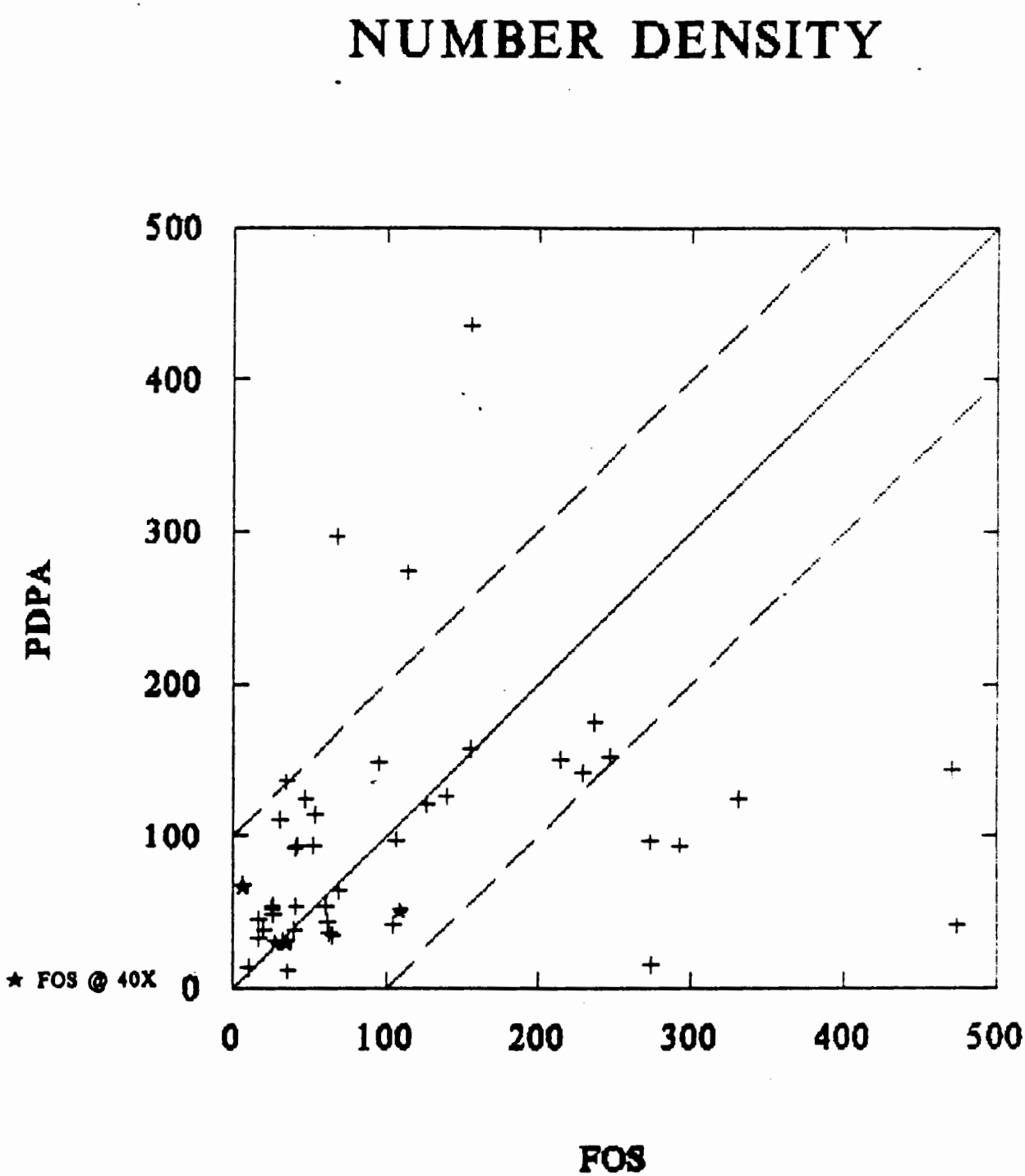


FIGURE 34. SCATTER PLOT FOR ND OF PDPA VERSUS FOS, FULL RANGE

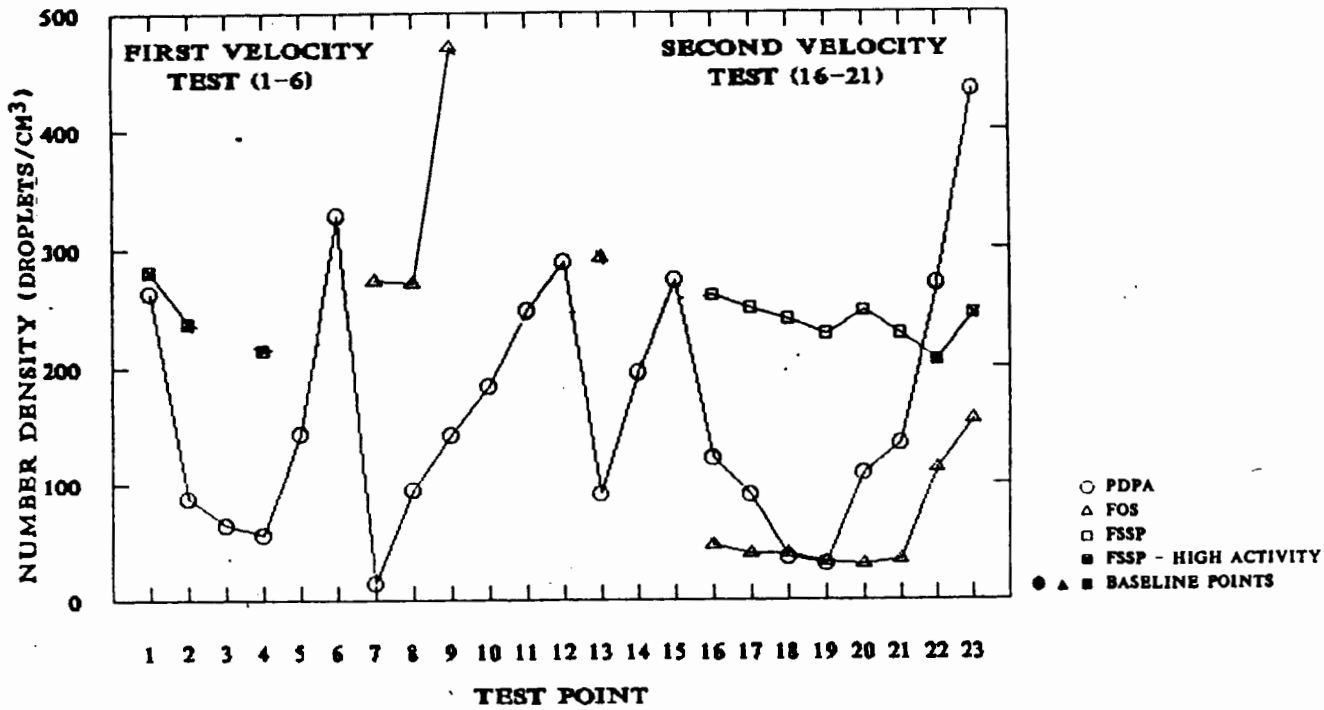


FIGURE 35A. SERIAL PLOT OF ND FOR TRUNCATED RANGE, TEST POINTS 1-23

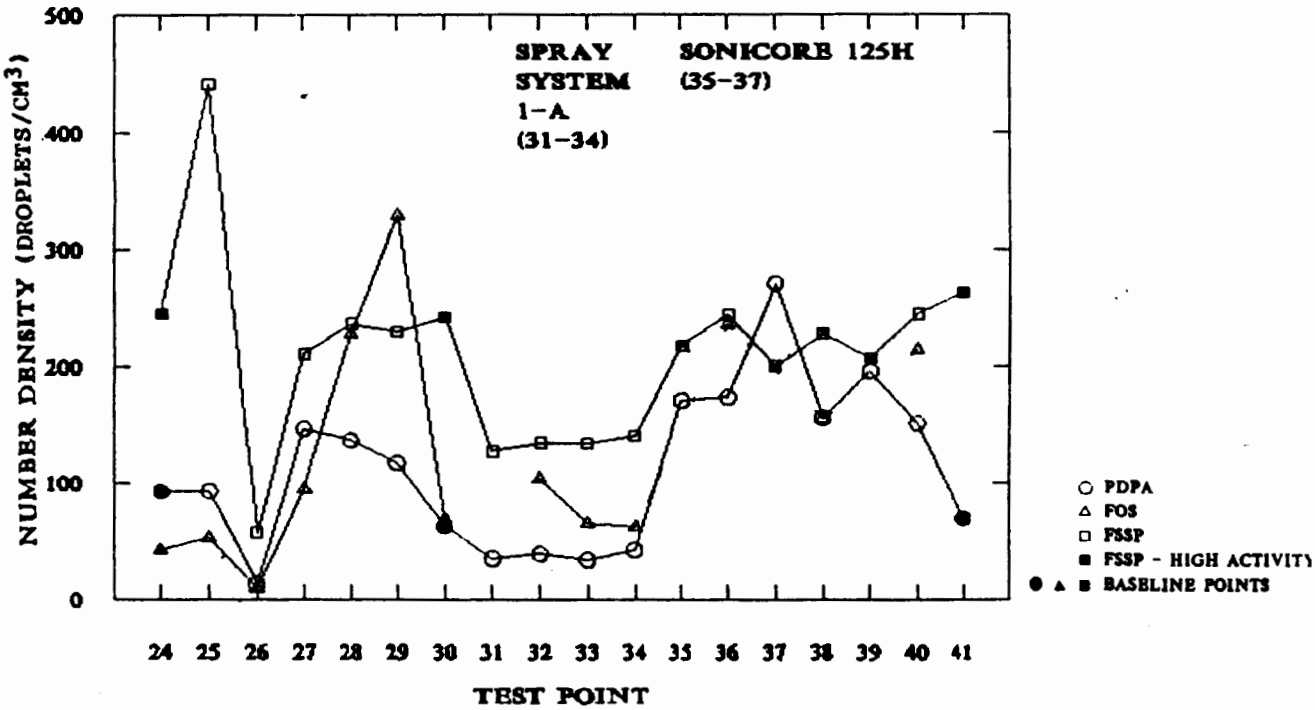


FIGURE 35B. SERIAL PLOT OF ND FOR TRUNCATED RANGE, TEST POINTS 24-41

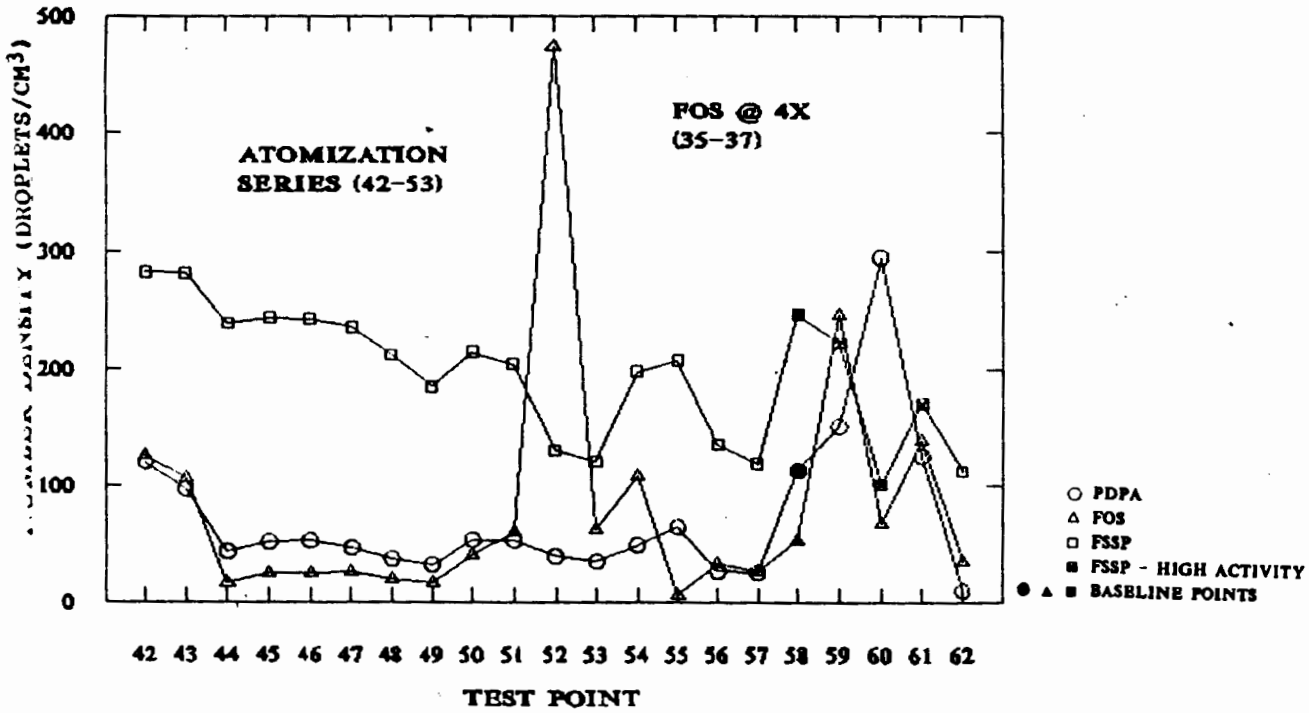


FIGURE 35C. SERIAL PLOT OF ND FOR TRUNCATED RANGE, TEST POINTS 42-62

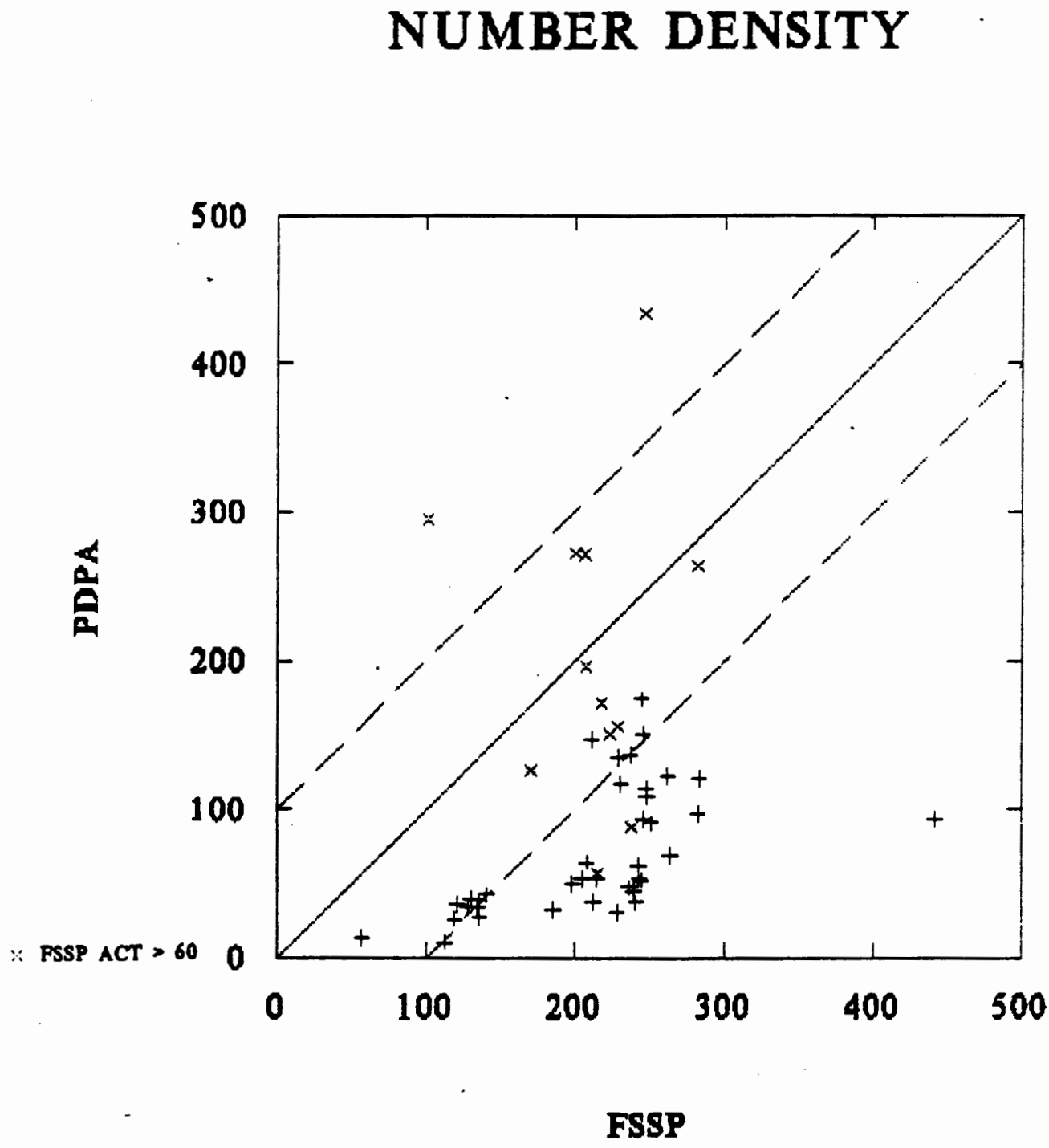


FIGURE 36. SCATTER PLOT FOR ND OF PDPA VERSUS FSSP, TRUNCATED RANGE

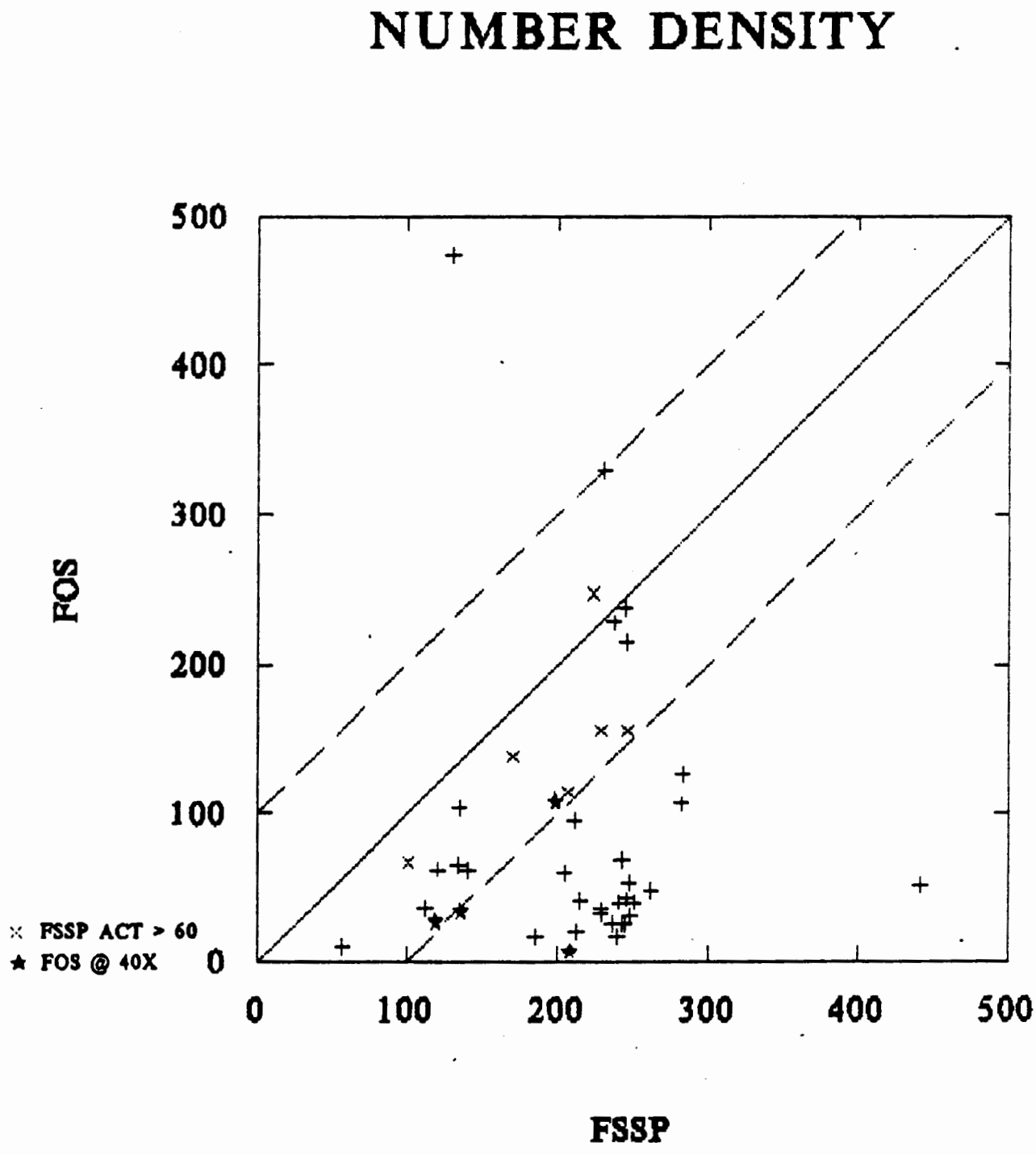


FIGURE 37. SCATTER PLOT FOR ND OF FOS VERSUS FSSP, TRUNCATED RANGE

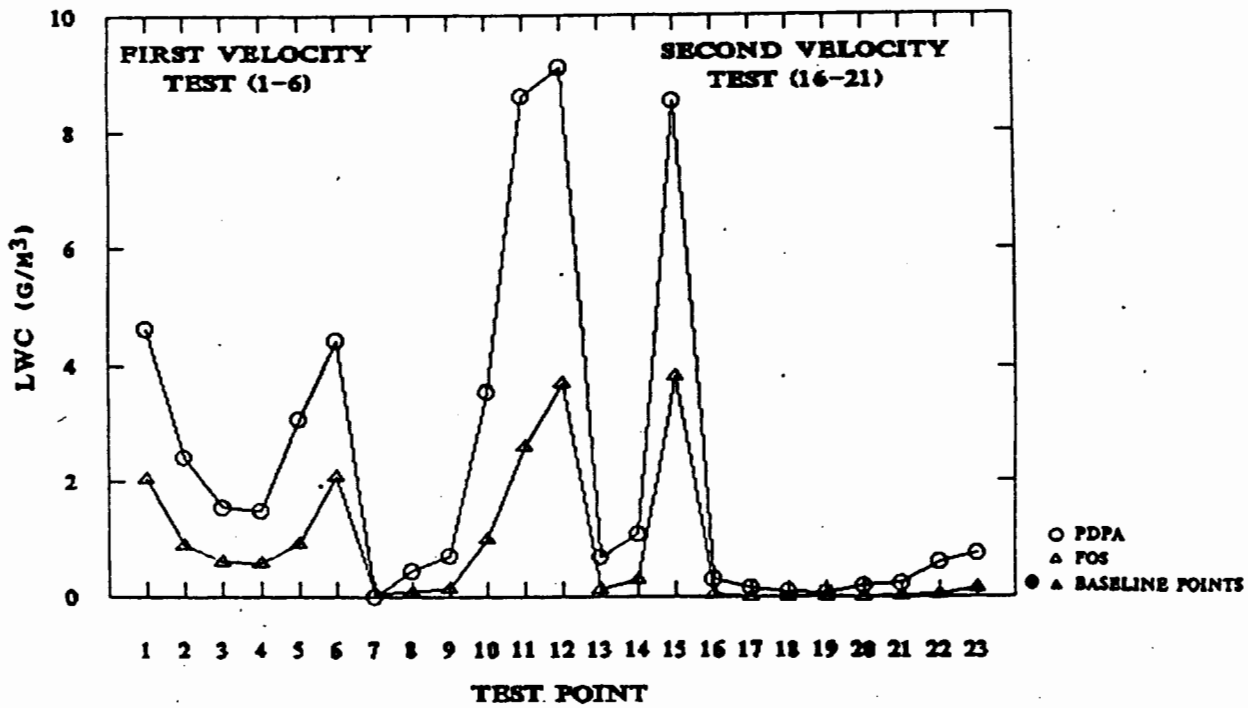


FIGURE 38A. SERIAL PLOT OF LWC FOR FULL RANGE, TEST POINTS 1-23

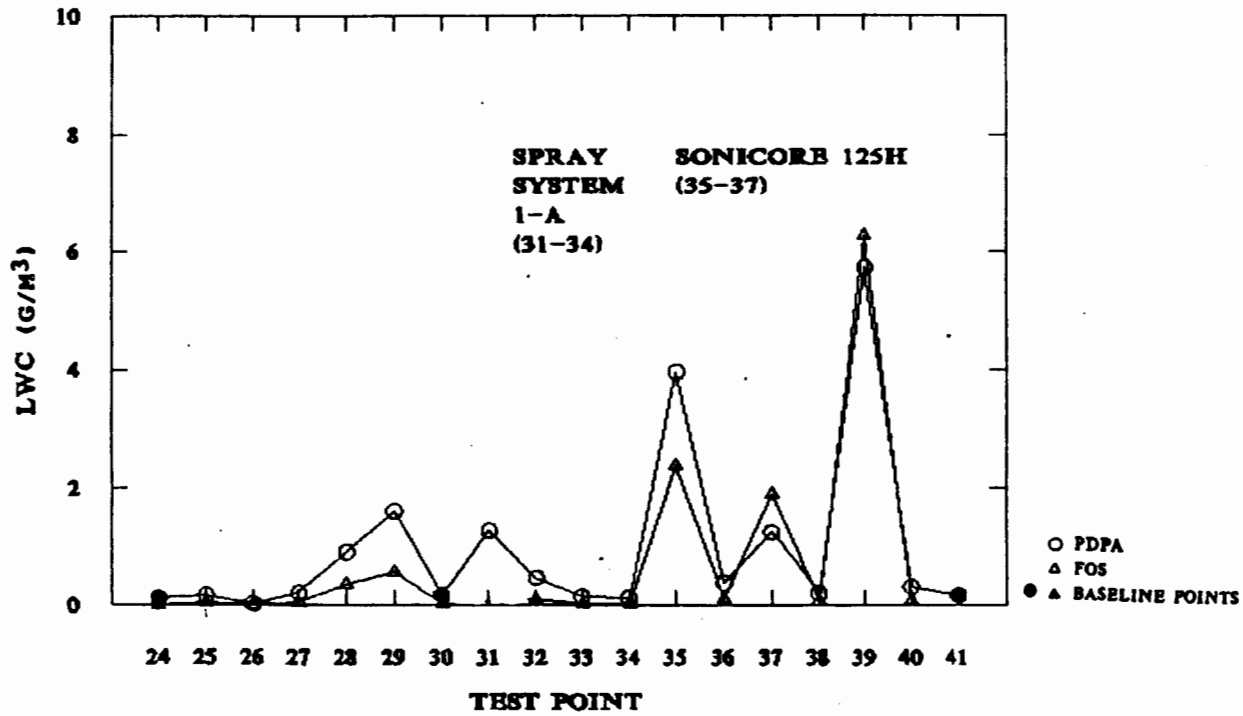


FIGURE 38B. SERIAL PLOT OF LWC FOR FULL RANGE, TEST POINTS 24-41

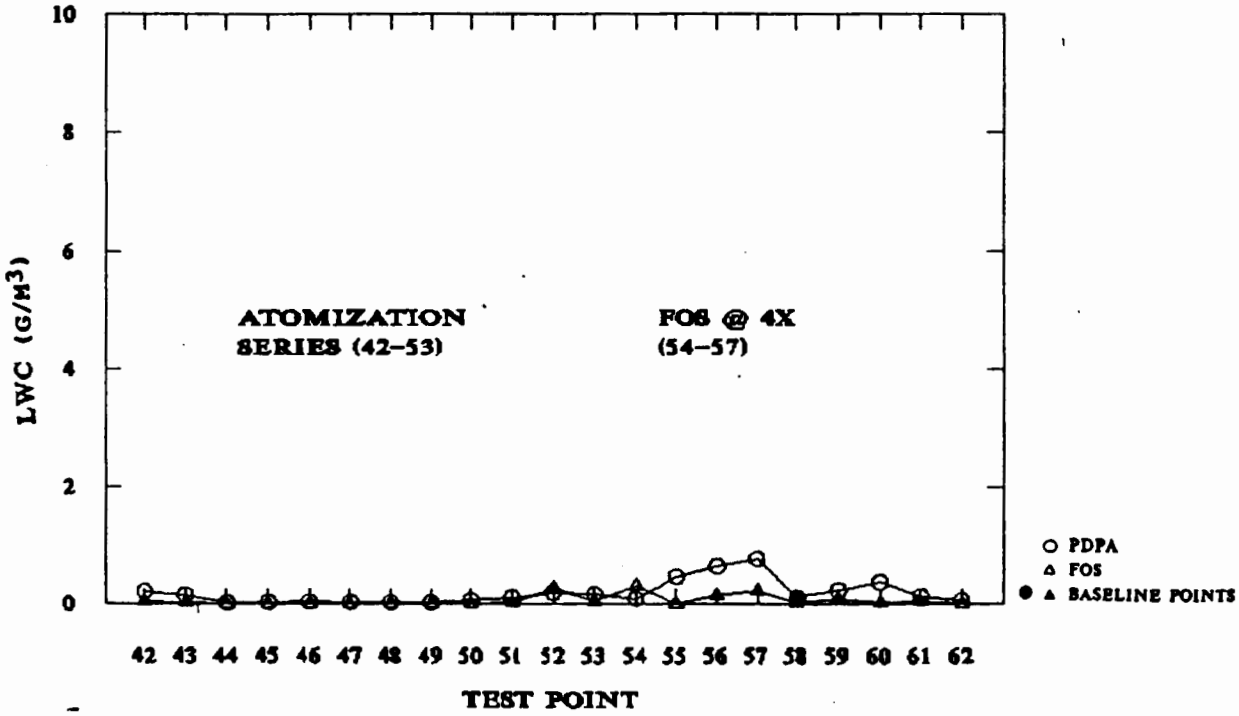


FIGURE 38C. SERIAL PLOT OF LWC FOR FULL RANGE, TEST POINTS 42-62

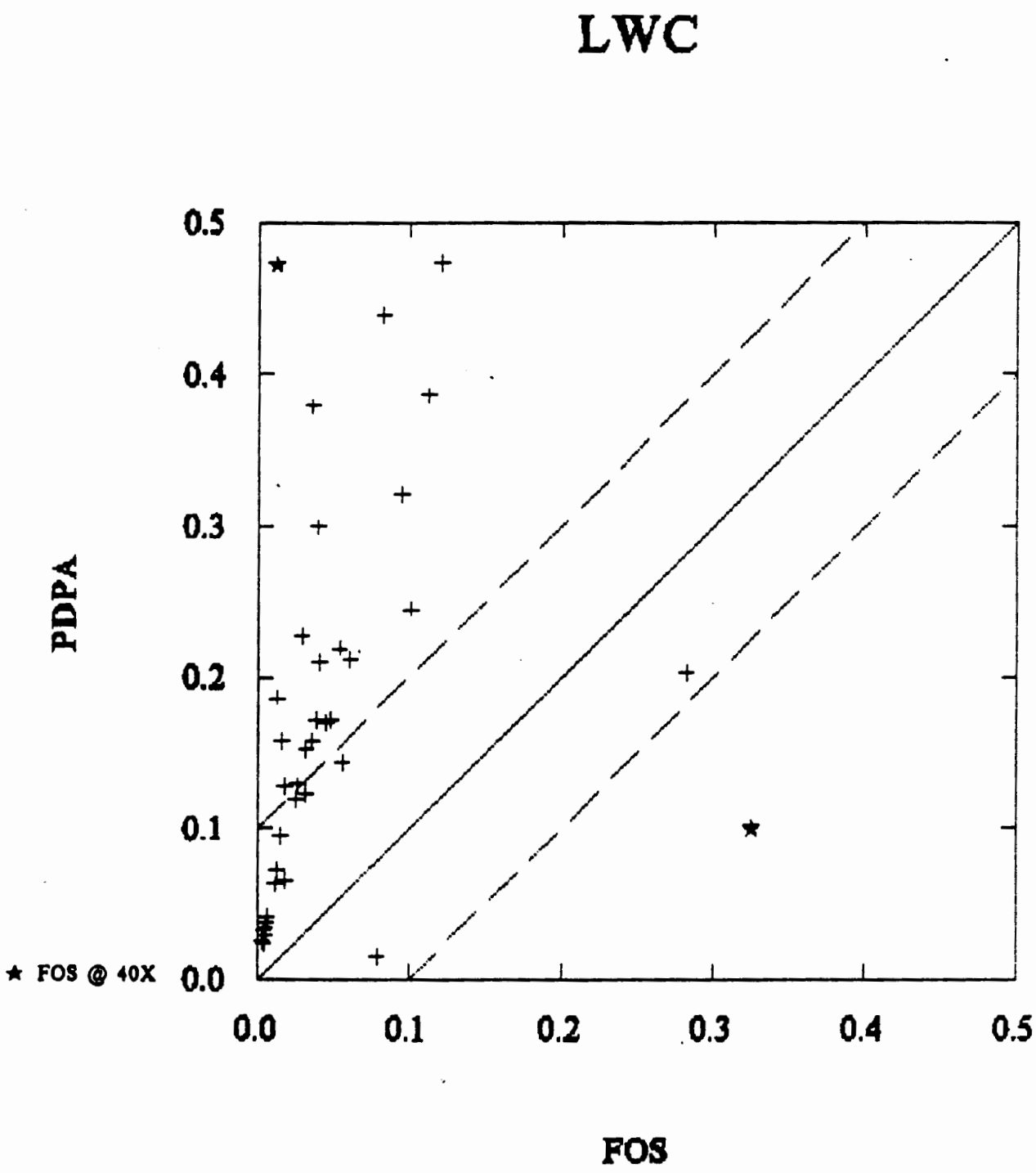


FIGURE 39. SCATTER PLOT FOR LWC OF PDPA VERSUS FOS, FULL RANGE

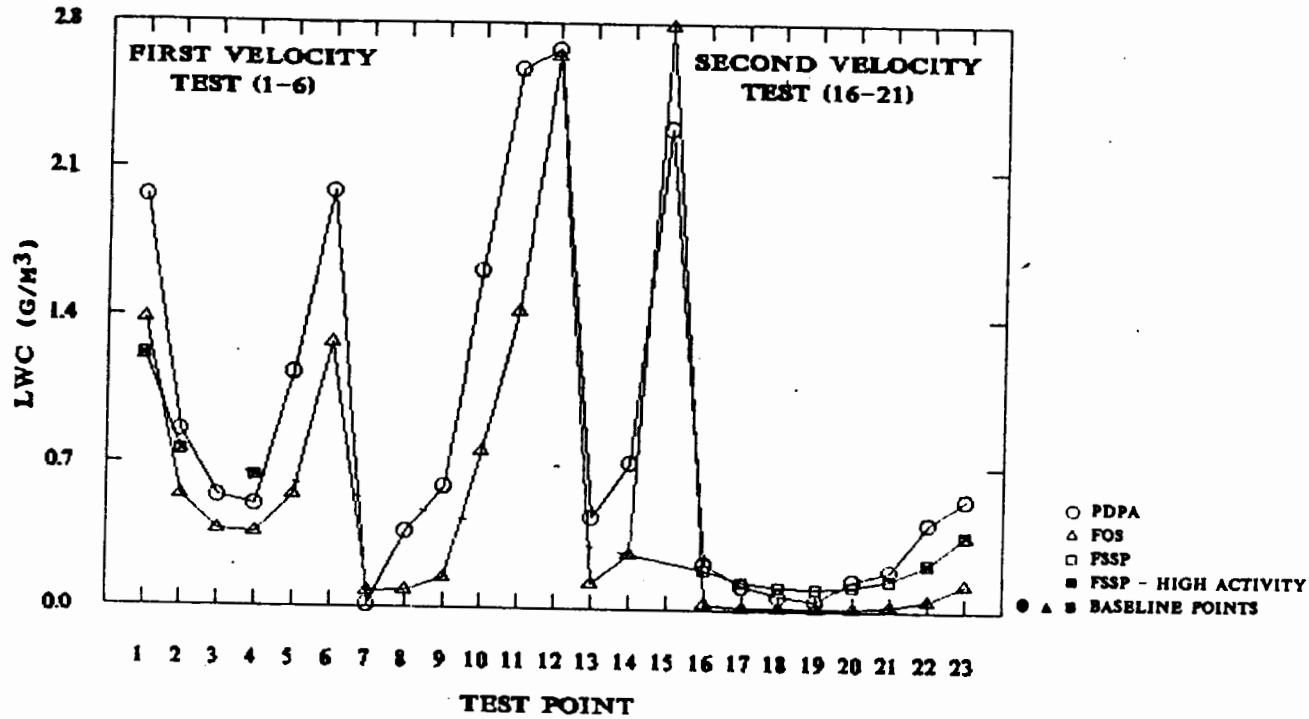


FIGURE 40A. SERIAL PLOT OF LWC FOR TRUNCATED RANGE, TEST POINTS 1-23

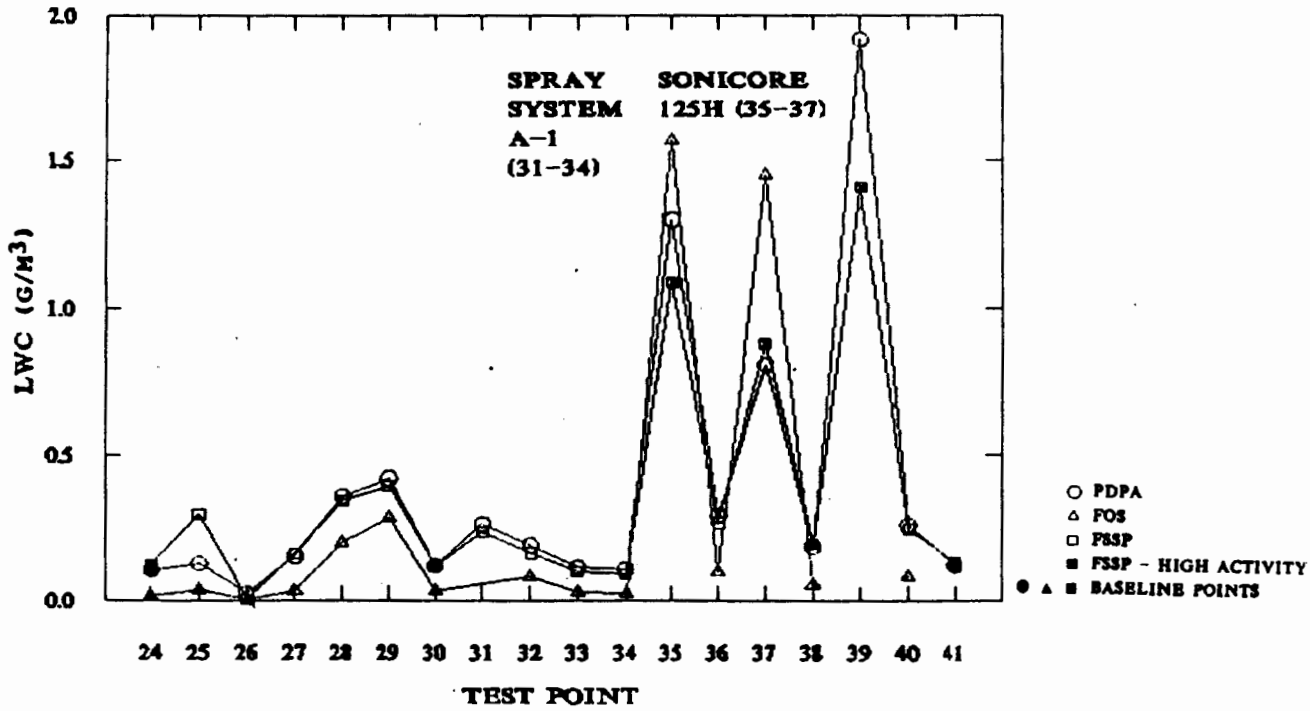


FIGURE 40B. SERIAL PLOT OF LWC FOR TRUNCATED RANGE, TEST POINTS 24-41

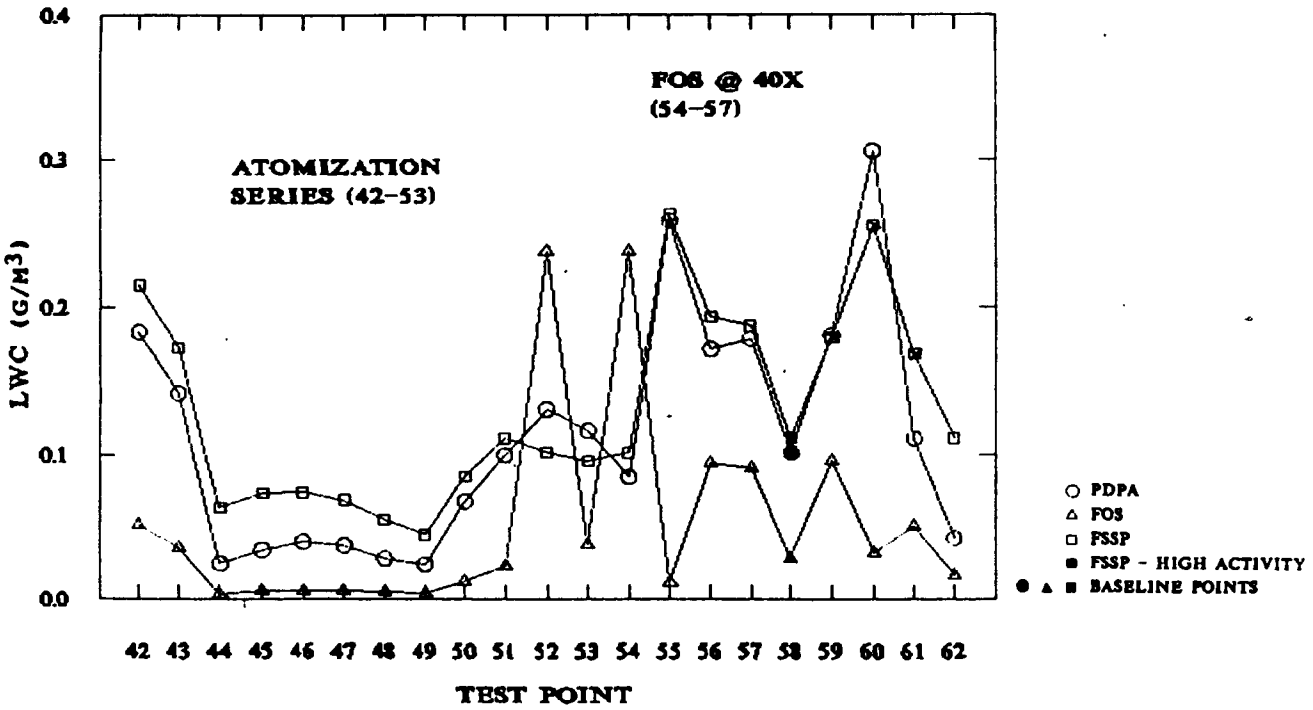


FIGURE 40C. SERIAL PLOT OF LWC FOR TRUNCATED RANGE, TEST POINTS 42-62

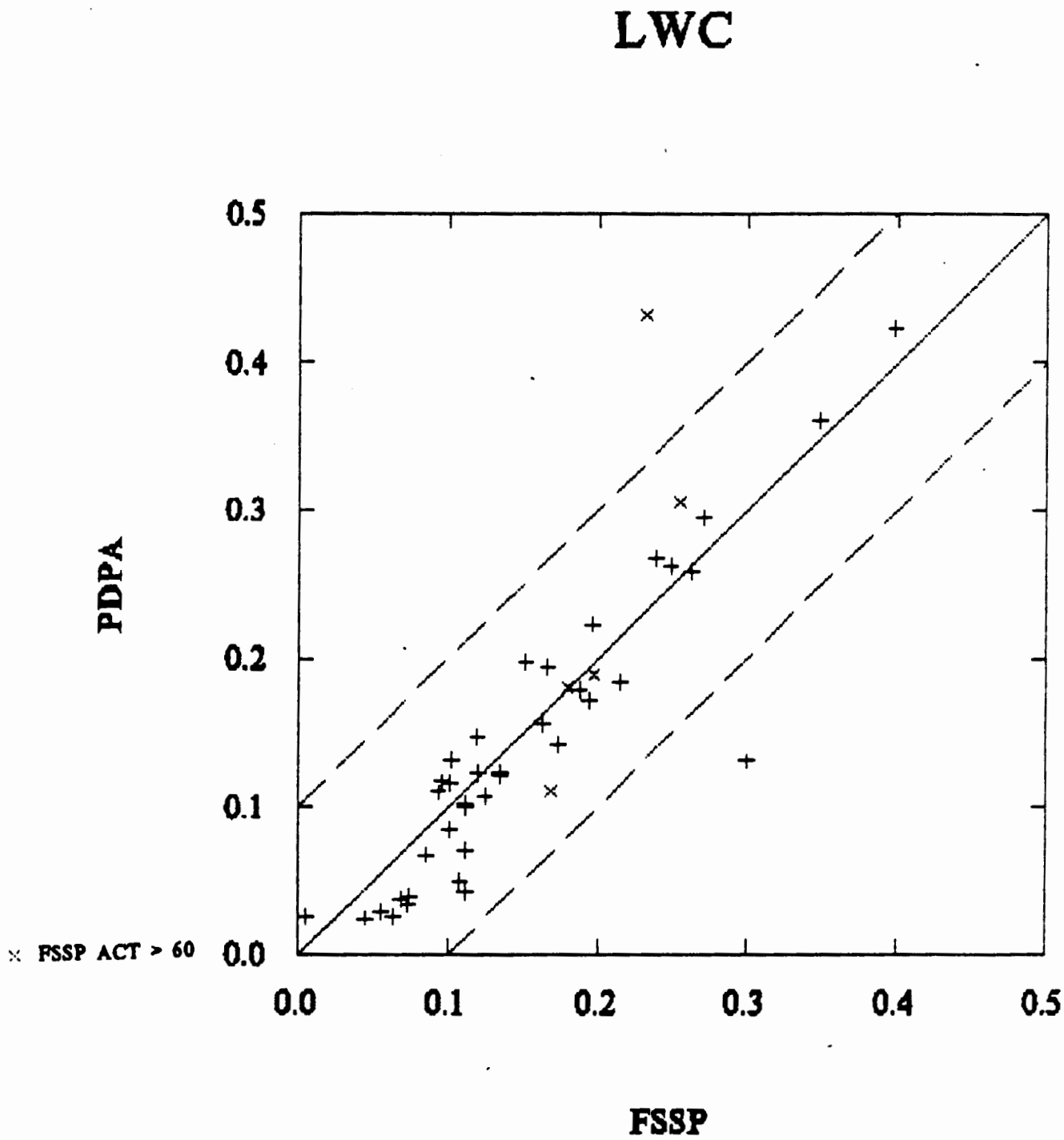


FIGURE 41. SCATTER PLOT FOR LWC OF PDPA VERSUS FSSP, TRUNCATED RANGE

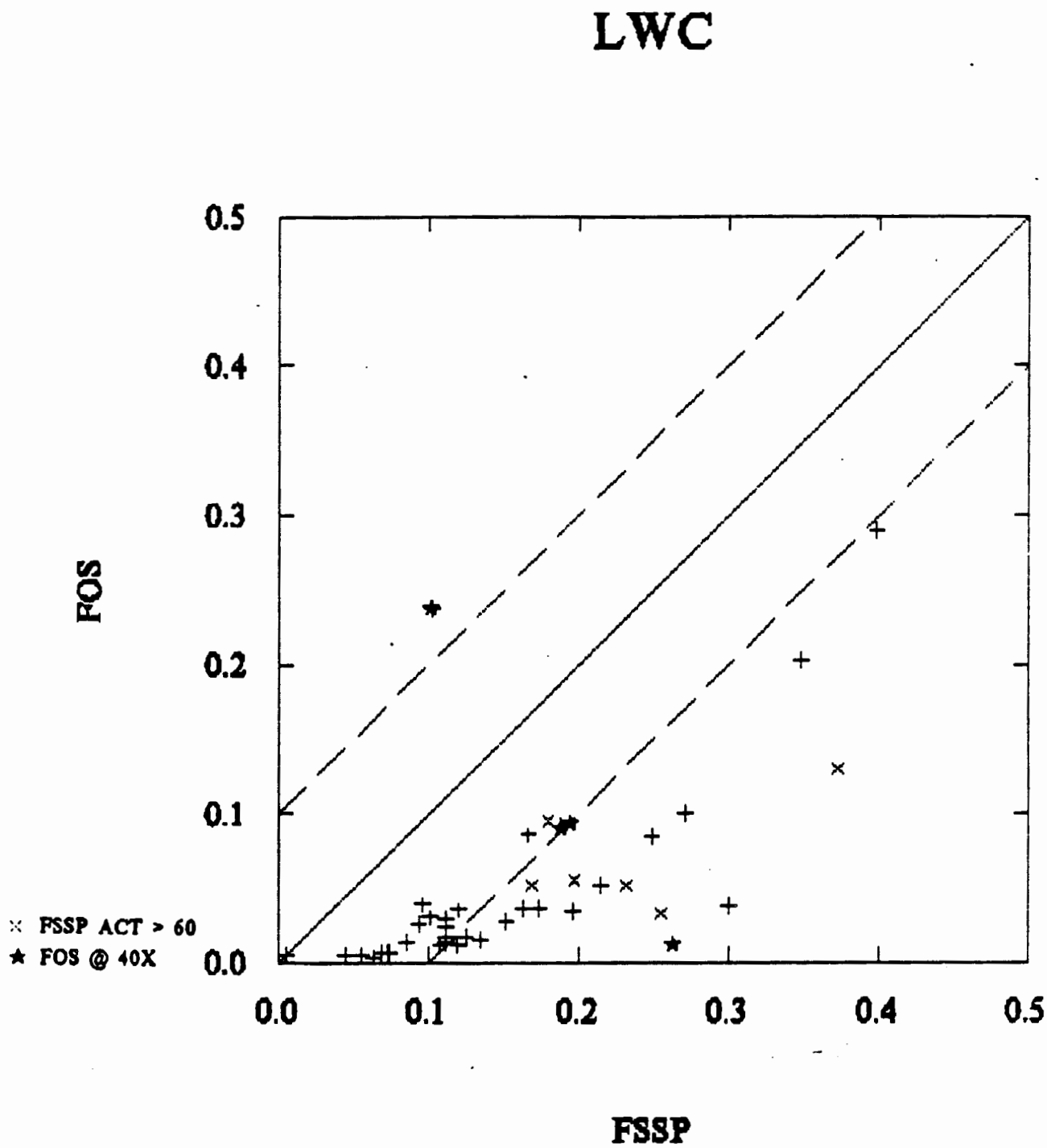


FIGURE 42. SCATTER PLOT FOR LWC OF FOS, VERSUS FSSP, TRUNCATED RANGE

TABLE 1. PDPA OUTPUT FOR TEST POINT 51

Experiment: AEDC
Test: VIII Test Pt: 89
Run Number: 42
27 MAY 1988 3:46:16
Attempted Samples: 37817
Valid Samples: 20003
Corrected Count: 26288
Run Time: 11.76 seconds

Diameter Data - MVD:	28.6 uM
Arithmetic Mean (D10):	10.5 uM
Area Mean (D20):	12.9 uM
Volume Mean (D30):	15.7 uM
Sauter Mean (D32):	23.1 uM
Number Density:	5.36E+001 /cc
Probe Area:	7.66E-003 cm^2
Volume Flow Rate:	4.49E-006 cc/s
Volume Flux:	5.87E-004 cc/s/cm^2

CDIAHST

Bin	Value	Count
0	2.28571	1703
1	3.87172	2794
2	5.45773	3545
3	7.04373	3803
4	8.62974	3229
5	10.21574	2390
6	11.80175	1966
7	13.38776	1383
8	14.97376	1143
9	16.55977	892
10	18.14577	598
11	19.73178	575
12	21.31778	359
13	22.90379	333
14	24.48980	277
15	26.07580	197
16	27.66181	185
17	29.24781	154
18	30.83382	107
19	32.41983	111
20	34.00583	88
21	35.59184	75
22	37.17784	69
23	38.76385	62
24	40.34985	51
25	41.93586	34
26	43.52187	30
27	45.10787	24
28	46.69388	26
29	48.27988	14
30	49.86589	11
31	51.45190	10
32	53.03790	8
33	54.62391	9
34	56.20991	7
35	57.79592	4
36	59.38192	3
37	60.96793	4
38	62.55394	4
39	64.13994	2
40	65.72595	4
41	67.31195	2
42	68.89796	1
43	70.48397	1
44	72.06997	0
45	73.65598	1
46	75.24198	0
47	76.82799	0
48	78.41399	0
49	80.00000	0

TABLE 2. PDPA OUTPUT FOR TEST POINT 57

Experiment: AEDC
Test: VIII Test Pt: 95
Run Number: 49
27 MAY 1988 5:26:22
Attempted Samples: 31712
Valid Samples: 20014
Corrected Count: 27198
Run Time: 19.90 seconds

Diameter Data - MVD:	67.9 uM
Arithmetic Mean (D10):	22.0 uM
Area Mean (D20):	28.8 uM
Volume Mean (D30):	36.0 uM
Sauter Mean (D32):	56.0 uM
Number Density:	2.95E+001 /cc
Probe Area:	7.99E-003 cm^2
Volume Flow Rate:	3.32E-005 cc/s
Volume Flux:	4.16E-003 cc/s/cm^2

CDIAHST

Bin	Value	Count
0	4.28571	2484
1	7.25948	3525
2	10.23324	3641
3	13.20700	2962
4	16.18076	2422
5	19.15452	2014
6	22.12828	1290
7	25.10204	1163
8	28.07580	1145
9	31.04956	944
10	34.02332	738
11	36.99708	734
12	39.97085	633
13	42.94461	505
14	45.91837	448
15	48.89213	401
16	51.86589	317
17	54.83965	258
18	57.81341	249
19	60.78717	203
20	63.76093	159
21	66.73469	124
22	69.70845	105
23	72.68222	109
24	75.65598	86
25	78.62974	53
26	81.60350	65
27	84.57726	53
28	87.55102	40
29	90.52478	47
30	93.49854	37
31	96.47230	47
32	99.44606	33
33	102.41983	22
34	105.39359	21
35	108.36735	12
36	111.34111	22
37	114.31487	11
38	117.28863	15
39	120.26239	8
40	123.23615	12
41	126.20991	3
42	129.18367	10
43	132.15743	11
44	135.13120	4
45	138.10496	3
46	141.07872	4
47	144.05248	4
48	147.02624	1
49	150.00000	1

TABLE 3. FSSP OUTPUT FOR TEST POINT 51

```
Test Pt: 89
DATE 88/05/27                    TIME 03:49:33
AEDC INST COMPARE TEST           ELT  00:00:30.0
FSSP-100(95)                     RAW COUNTS N

      0 A 0          0 B 0          0 C 0          0 D 0
  61673 A 1  5   40206 B 1  2   20759 C 1  2   13791 D 1  1
  18893 A 2 11   42864 B 2  5   19735 C 2  4    3388 D 2  2
   1557 A 3 17   34545 B 3  8   32546 C 3  6    8175 D 3  3
     67 A 4 23   11168 B 4 11   21938 C 4  8    7161 D 4  4
     11 A 5 29    5482 B 5 14   14070 C 5 10    9062 D 5  5
      0 A 6 35    2646 B 6 17    8087 C 6 12   12401 D 6  6
      1 A 7 41    1323 B 7 20    4469 C 7 14   13837 D 7  7
      6 A 8 47     625 B 8 23    2948 C 8 16   13253 D 8  8
      4 A 9 53     320 B 9 26    1760 C 9 18   10225 D 9  9
      4 A10 59     145 B10 29    1135 C10 20    7712 D10 10
      0 A11 65      81 B11 32     656 C11 22    5412 D11 11
      1 A12 71      56 B12 35     424 C12 24    4611 D12 12
      0 A13 77      17 B13 38     230 C13 26    3117 D13 13
      0 A14 83      26 B14 41     128 C14 28    2327 D14 14
      0 A15 89      10 B15 44      80 C15 30    1948 D15 15
            95              47              32              16

DATE 88/05/27                    TIME 03:49:33
AEDC INST COMPARE TEST           ELT  00:00:30.0
FSSP-100(95)                     TOTAL STROBES

    143793     201151     204562     201576
      19.6       29.8       30.0       39.2

         1          0          0          0
       0.0        0.0        0.0        0.0

03:50:18
60 M/S
60 PSIA
15 PSIA
ATOMIZATION TEST
```

TABLE 4. FOS OUTPUT FOR TEST POINT 51
(Magnification is 80x)

Velocity =	57.0	m/sec
Sample Time =	127.3	sec
Test Point =	89	
Single End Rejects =	4359	

Bin Number	Ctr. Diam.	#-Density (#/cm^3)
1	3.25	28.3903
2	6.50	16.7002
3	9.75	9.8236
4	13.00	3.4620
5	16.25	1.2343
6	19.50	0.5591
7	22.75	0.2684
8	26.00	0.1594
9	29.25	0.0862
10	32.50	0.0535
11	35.75	0.0270
12	39.00	0.0227
13	42.25	0.0098
14	45.50	0.0067
15	48.75	0.0039
16	52.00	0.0026
17	55.25	0.0012
18	58.50	0.0008
19	61.75	0.0008
20	65.00	0.0004
21	68.25	0.0006
22	71.50	0.0006
23	74.75	0.0004
24	78.00	0.0000
25	81.25	0.0002
26	84.50	0.0002
27	87.75	0.0000
28	91.00	0.0000
29	94.25	0.0000
30	97.50	0.0000

TABLE 5. FOS OUTPUT FOR TEST POINT 57
(Magnification is 40x)

Velocity =	59.1	m/sec
Sample Time =	24.23	sec
Test Point =	95	
Single End Rejects =	9925	

Bin Number	Ctr. Diam.	#-Density (#/cm^3)
1	6.5	12.2013
2	13.0	7.1772
3	19.5	4.2219
4	26.0	1.7145
5	32.5	0.9472
6	39.0	0.5184
7	45.5	0.3198
8	52.0	0.1866
9	58.5	0.1350
10	65.0	0.1011
11	71.5	0.0707
12	78.0	0.0543
13	84.5	0.0340
14	91.0	0.0268
15	97.5	0.0203
16	104.0	0.0114
17	110.5	0.0093
18	117.0	0.0082
19	123.5	0.0041
20	130.0	0.0037
21	136.5	0.0039
22	143.0	0.0031
23	149.5	0.0023
24	156.0	0.0010
25	162.5	0.0007
26	169.0	0.0006
27	175.5	0.0004
28	182.0	0.0007
29	188.5	0.0000
30	195.0	0.0000

TABLE 6. COMBINED OUTPUT FOR TEST POINT 51

Test Pt: 89
Tunnel conditions: V: 187 ft/s WF: .011 gpm Ts: 33 F

VIII/42	RUN89.FSP	1044.DAT
27 03:46:16	27 03:49:33	
Aerometrics	NASA Lewis	AEDC
PDPA	FSSP	FOS

AS: 37817
VS: 20003
CC: 26288
RT: 11.76 sec
ND: 5.36E+001 /cc B
PA: 7.66E-003 cm^2 TS 201151
VFR: 4.49E-006 cc/s Act 29.8 ST: 127.3 sec
VF: 5.87E-004 cc/s/cm^2 SER: 4359

Bin	Value	Count	Count	Bin	Val	Bin	Value	ND/cc
0	2.28571	1703	40206	B 1	2	1	1.625	28.3903
1	3.87172	2794	42864	B 2	5	2	4.875	16.7002
2	5.45773	3545	34545	B 3	8	3	8.125	9.8236
3	7.04373	3803	11168	B 4	11	4	11.375	3.4620
4	8.62974	3229	5482	B 5	14	5	14.625	1.2343
5	10.21574	2390	2646	B 6	17	6	17.875	0.5591
6	11.80175	1966	1323	B 7	20	7	21.125	0.2684
7	13.38776	1383	625	B 8	23	8	24.375	0.1594
8	14.97376	1143	320	B 9	26	9	27.625	0.0862
9	16.55977	892	145	B10	29	10	30.875	0.0535
10	18.14577	598	81	B11	32	11	34.125	0.0270
11	19.73178	575	56	B12	35	12	37.375	0.0227
12	21.31778	359	17	B13	38	13	40.625	0.0098
13	22.90379	333	26	B14	41	14	43.875	0.0067
14	24.48980	277	10	B15	44	15	47.125	0.0039
15	26.07580	197			47	16	50.375	0.0026
16	27.66181	185				17	53.625	0.0012
17	29.24781	154				18	56.875	0.0008
18	30.83382	107				19	60.125	0.0008
19	32.41983	111				20	63.375	0.0004
20	34.00583	88				21	66.625	0.0006
21	35.59184	75				22	69.875	0.0006
22	37.17784	69				23	73.125	0.0004
23	38.76385	62				24	76.375	0.0000
24	40.34985	51				25	79.625	0.0002
25	41.93586	34				26	82.875	0.0002
26	43.52187	30				27	86.125	0.0000
27	45.10787	24				28	89.375	0.0000
28	46.69388	26				29	92.625	0.0000
29	48.27988	14				30	95.875	0.0000
30	49.86589	11					99.125	
31	51.45190	10						
32	53.03790	8						
33	54.62391	9						
34	56.20991	7						
35	57.79592	4						
36	59.38192	3						
37	60.96793	4						
38	62.55394	4						
39	64.13994	2						
40	65.72595	4						
41	67.31195	2						
42	68.89796	1						
43	70.48397	1						
44	72.06997	0						
45	73.65598	1						
46	75.24198	0						
47	76.82799	0						
48	78.41399	0						
49	80.00000	0						

TABLE 7. TUNNEL CONDITIONS SUMMARY

NEW TEST PT NUMBER	OLD TEST PT NUMBER	LABEL*	TUNNEL VELOCITY (ft/s)	WATER FLOW RATE (GPM)	TEMP (Deg F)	PRESSURES AIR (psia)	PRESSURES WATER (psia)
1	2	FV1	98	0.107	58	85	105.0
2	3	FV2	197	0.114	56	85	105.0
3	4	FV3	294	0.113	52	85	105.0
4	5	FV4	314	0.114	52	85	105.0
5	7	FV5	198	0.114	58	85	105.0
6	8	FV6	100	0.115	58	85	105.0
7	56	O1	196	0.019	57	85	45.0
8	57	O2	195	0.040	54	85	55.0
9	58	O3	196	0.072	55	125	95.0
10	61	O4	195	0.124	56	70	19.0
11	62	O5	195	0.219	53	40	26.0
12	63	O6	194	0.252	55	40	28.0
13	64	O7	193	0.062	55	43	14.5
14	65	O8	195	0.092	56	43	16.0
15	66	O9	197	0.244	55	43	27.0
16	10	SV1	101	0.037	60	100	100.0
17	11	SV2	192	0.037	53	100	100.0
18	12	SV3	244	0.036	51	100	100.0
19	13	SV4	307	0.035	50	100	100.0
20	15	SV5	198	0.036	58	100	100.0
21	16	SV6	100	0.037	60	100	100.0
22	18	ND1	198	0.083	57	100	100.0
23	21	ND2	98	0.082	60	100	100.0
24	17	B1	199	0.037	56	100	100.0
25	22	ND3	100	0.037	63	100	100.0
26	23	AC1	199	0.011	59	100	80.0
27	24	AC2	199	0.052	57	80	95.0
28	25	AC3	197	0.062	59	50	75.0
29	26	AC4	195	0.073	59	40	75.0
30	17'	B2	203	0.033	58	100	100.0
31	27	SA1	196	0.068	60	120	145.0
32	28	SA2	194	0.029	57	120	35.0
33	29	SA3	195	0.017	58	120	20.0
34	30	SA4	195	0.019	60	150	20.0
35	31	SH1	198	0.172	59	35	20.0
36	32	SH2	197	0.043	58	40	14.0
37	33	SH3	194	0.168	58	50	21.0
38	67	O10	196	0.052	57	40	19.0
39	69	O11	195	0.242	58	43	27.0
40	70	O12	197	0.043	58	43	14.0
41	17''	B3	203	0.033	58	100	100.0
42	80	A1	184	0.019	22	120	20.0
43	81	A2	185	0.020	32	180	20.0
44	82	A3	187	0.008	34	180	14.6
45	83	A4	186	0.010	33	165	14.5
46	84	A5	185	0.010	32	150	14.5
47	85	A6	184	0.009	29	135	14.6
48	86	A7	186	0.000	32	120	14.6
49	87	A8	187	0.000	33	90	14.0
50	88	A9	186	0.010	34	90	16.0
51	89	A10	187	0.011	33	60	16.7
52	90	A11	187	0.011	34	30	17.3
53	91	A12	190	0.010	31	30	17.3
54	92	M1	190	0.009	33	60	16.7
55	93	M2	190	0.027	33	60	30.0
56	94	M3	187	0.037	50	60	50.0
57	95	M4	194	0.042	57	60	70.0
58	17'''	B4	197	0.032	57	100	100.0
59	18'	ND4	194	0.112	57	100	100.0
60	19	ND5	177	0.170	41	95	100.0
61	35	IC1	165	0.032	8	100	100.0
62	36	IC2	203	0.031	78	100	100.0

* FV - FIRST VELOCITY TEST, O - OAP SERIES, SV - SECOND VELOCITY TEST
ND - NUMBER DENSITY TEST, B - BASELINE PT
DIST TEST: AC - AEDC 2050, SA - SPRAY SYSTEM 1-A, SH - SONICORE 125H
A - ATOMIZATION SERIES, M - FOS MAG @ 40X, IC - ICE CRYSTAL

TABLE 8. INSTRUMENT PARAMETERS SUMMARY

NEW TP NO	OLD TP NO	LA-BEL	PDPA RUN TIME	FSSP VALID COUNTS (VC)	FSSP TOTAL STROBES (TS)	FSSP VC/TS	FSSP ACTIVITY	FOS SAMPLE TIME	FOS SINGLE END REJECTS
1	2	FV1	5.51	69894	145045	0.48	63.3	4.2	9294
2	3	FV2	8.20	144755	246624	0.59	64.8	5.9	9654
3	4	FV3	7.38					6.3	9456
4	5	FV4	7.85	191944	355001	0.54	66.8	6.7	9408
5	7	FV5	5.00					6.9	9639
6	8	FV6	4.38					6.0	9631
7	56	O1	62.48					22.7	2444
8	57	O2	8.36					25.6	2619
9	58	O3	5.56					15.6	2782
10	61	O4	3.57					7.7	9581
11	62	O5	2.46					2.1	9475
12	63	O6	2.06					1.0	922
13	64	O7	9.05					25.5	4396
14	65	O8	3.77					13.0	5270
15	66	O9	2.11					1.7	9748
16	10	SV1	12.96	88704	138864	0.64	42.6	82.3	2130
17	11	SV2	8.47	163621	252694	0.65	55.5	82.0	2040
18	12	SV3	16.67	147888	309032	0.48	57.1	76.3	1912
19	13	SV4	16.66	201699	368761	0.55	58.0	56.5	1366
20	15	SV5	7.09	170354	257740	0.66	50.2	89.1	1628
21	16	SV6	10.96	78711	120145	0.66	33.9	90.0	1762
22	18	ND1	2.84	126012	214758	0.59	76.4	29.8	2354
23	21	ND2	3.25	75744	126756	0.60	69.7	47.6	4758
24	17	B1	7.65	164293	256952	0.64	50.4	117.0	3223
25	22	ND3	14.80	149204	232026	0.64	31.5	95.3	2435
26	23	AC1	46.15	24983	59537	0.42	7.3	268.1	1758
27	24	AC2	4.56	140718	220722	0.64	55.8	40.9	2549
28	25	AC3	4.67	156384	245193	0.64	53.3	12.6	9778
29	26	AC4	5.30	150524	236161	0.64	50.3	12.6	9778
30	17'	B2	11.50	173596	258595	0.67	42.4	86.8	4368
31	27	SA1	15.39	87723	131867	0.67	23.2		
32	28	SA2	15.88	93219	137598	0.68	21.9	66.2	9873
33	29	SA3	19.84	94038	137749	0.68	20.9	121.2	5462
34	30	SA4	14.90	97840	144450	0.68	22.0	110.9	4210
35	31	SH1	3.09	129485	226564	0.57	66.6	910.0	0
36	32	SH2	3.72	163216	252915	0.65	56.3	31.0	4943
37	33	SH3	1.83	112729	204416	0.55	76.1	3.7	8288
38	67	O10	4.15	150489	235443	0.64	60.2	35.7	2414
39	69	O11	2.79	114901	212348	0.54	71.3	1.4	9135
40	70	O12	4.20	164477	254063	0.65	56.9	32.8	4217
41	17''	B3	9.79	186703	280921	0.66	46.5		
42	80	A1	5.65	182635	273429	0.67	53.8	54.6	3616
43	81	A2	6.88	187258	273955	0.68	46.9	43.6	2093
44	82	A3	15.38	143926	235622	0.61	34.1	29.7	790
45	83	A4	12.92	150612	238696	0.63	35.7	81.9	703
46	84	A5	12.53	148254	236326	0.63	35.2	77.7	747
47	85	A6	13.99	139617	228239	0.61	33.7	76.3	715
48	86	A7	17.52	119536	207797	0.58	29.5	119.6	960
49	87	A8	20.22	100060	183306	0.55	24.0	28.2	854
50	88	A9	11.90	139983	210134	0.67	30.7	84.1	1592
51	89	A10	11.76	139514	201151	0.69	29.8	127.3	4359
52	90	A11	15.13	87302	128453	0.68	18.0	1.1	4416
53	91	A12	16.74	82140	120963	0.68	17.0	9.7	6717
54	92	M1	12.71	135560	198066	0.68	29.2	43.1	3158
55	93	M2	10.18	143549	207520	0.69	34.8	47.5	1624
56	94	M3	20.77	95602	133566	0.72	21.5	24.3	6246
57	95	M4	19.90	86405	122254	0.71	20.0	24.2	9925
58	17'''	B4	14.46	171269	255963	0.67	42.5	113.9	5090
59	18'	ND4	4.77	140710	227427	0.62	69.6	15.6	2608
60	19	ND5	2.14	43270	93910	0.46	91.8	89.4	4170
61	35	IC1	5.69	88159	147891	0.60	79.9	30.5	2508
62	36	IC2	56.08	88159	120360	0.73	14.4	72.3	1949

TABLE 9. MVD SUMMARY

NEW TP NO	OLD TP NO	LA-BEL	FSSP ACTIV-ITY	FULL RANGE PDPA	FULL RANGE FOS	FULL RANGE PDPA-FOS	TRUNCATED RANGE PDPA	TRUNCATED RANGE FSSP	TRUNCATED RANGE FOS	TRUNCATED RANGE PDPA-FSSP	TRUNCATED RANGE FOS-FSSP
1	2	FV1	63.3	51.5	35.6	15.9	34.2	29.5	25.5	4.7	-4.0
2	3	FV2	64.8	55.8	37.4	18.4	35.9	28.6	23.8	7.3	-4.8
3	4	FV3		55.3	35.0	20.3	36.6		21.2		
4	5	FV4	66.8	54.9	36.6	18.3	37.1	29.8	21.6	7.3	-8.2
5	7	FV5		53.7	38.8	14.9	34.3		24.1		
6	8	FV6		49.3	39.4	9.9	33.1		26.6		
7	56	O1		15.7	12.3	3.4	15.7		12.2		
8	57	O2		30.8	12.7	18.1	28.3		12.6		
9	58	O3		31.3	12.9	18.4	28.7		12.8		
10	61	O4		48.3	27.2	21.1	34.9		21.7		
11	62	O5		62.0	44.2	17.8	37.6		29.1		
12	63	O6		62.3	33.5	28.8	37.3		25.1		
13	64	O7		38.0	17.0	21.0	30.7		15.5		
14	65	O8		37.4	18.7	18.7	28.6		16.7		
15	66	O9		60.8	32.4	28.4	35.4		24.5		
16	10	SV1	42.6	32.2	24.5	7.7	25.3	15.9	21.0	9.4	5.1
17	11	SV2	55.5	29.7	16.0	13.7	23.0	14.2	14.8	8.8	0.6
18	12	SV3	57.1	31.8	14.3	17.5	25.8	13.6	13.7	12.2	0.1
19	13	SV4	58.0	30.4	14.2	16.2	25.5	13.8	13.7	11.7	-0.1
20	15	SV5	50.2	27.4	16.8	10.6	22.2	13.5	15.1	8.7	1.6
21	16	SV6	33.9	26.8	23.2	3.6	24.0	15.2	21.4	8.8	6.2
22	18	ND1	76.4	32.8	18.8	14.0	24.7	20.5	16.8	4.2	-3.7
23	21	ND2	69.7	31.4	27.5	3.9	24.5	22.3	23.1	2.2	0.8
24	17	B1	50.4	27.2	17.9	9.3	22.9	14.0	16.4	8.9	2.4
25	22	ND3	31.5	31.1	25.9	5.2	25.5	15.6	22.1	9.9	6.5
26	23	AC1	7.3	30.7	16.6	14.1	26.4	6.8	16.4	19.6	9.6
27	24	AC2	55.8	29.2	18.5	10.7	21.1	16.7	15.6	4.4	-1.1
28	25	AC3	53.3	52.0	41.9	10.1	32.5	25.3	27.6	7.2	2.3
29	26	AC4	50.3	68.8	46.6	22.2	30.8	25.1	28.1	5.7	3.0
30	17'	B2	42.4	36.7	20.7	16.0	30.0	14.4	18.5	15.6	4.1
31	27	SA1	23.2	78.3			36.1	27.0		9.1	
32	28	SA2	21.9	52.1	33.8	18.3	32.5	23.1	25.3	9.4	2.2
33	29	SA3	20.9	33.6	18.0	15.6	28.7	17.6	17.0	11.1	-0.6
34	30	SA4	22.0	30.1	16.3	13.8	27.0	16.3	15.6	10.7	-0.7
35	31	SH1	66.6	56.8	36.4	20.4	34.8	31.9	26.0	2.9	-5.9
36	32	SH2	56.3	30.1	18.5	11.6	24.4	19.7	16.3	4.7	-3.4
37	33	SH3	76.1	38.6	29.4	9.2	30.1	30.6	22.5	-0.5	-8.1
38	67	O10	60.2	24.3	15.9	8.4	21.6	17.3	14.3	4.3	-3.0
39	69	O11	71.3	57.8	39.2	18.6	37.2	34.2	27.2	3.0	-7.0
40	70	O12	56.9	29.3	17.2	12.1	25.3	19.0	15.4	6.3	-3.6
41	17''	B3	46.5	36.5			29.3	14.6		14.7	
42	80	A1	53.8	28.4	15.8	12.6	24.9	17.2	15.3	7.7	-1.9
43	81	A2	46.9	25.8	13.7	12.1	23.8	15.5	13.5	8.3	-2.0
44	82	A3	34.1	15.1	10.4	4.7	15.0	10.3	10.4	4.7	0.1
45	83	A4	35.7	16.1	10.6	5.5	16.0	10.7	10.6	5.3	-0.1
46	84	A5	35.2	17.5	11.1	6.4	17.2	10.8	11.1	6.4	0.3
47	85	A6	33.7	18.4	11.0	7.4	17.9	10.7	11.0	7.2	0.3
48	86	A7	29.5	17.4	11.2	6.2	17.1	10.3	11.2	6.8	0.9
49	87	A8	24.0	16.8	11.0	5.8	16.7	10.2	11.0	6.5	0.8
50	88	A9	30.7	22.8	13.0	9.8	21.7	12.6	12.9	9.1	0.3
51	89	A10	29.8	29.3	15.7	13.6	25.7	15.1	15.0	10.6	-0.1
52	90	A11	18.0	38.6	22.8	15.8	30.2	18.7	18.9	11.5	0.2
53	91	A12	17.0	37.7	25.4	12.3	30.1	18.8	20.6	11.3	1.8
54	92	M1	29.2	28.8	30.4	-1.6	25.2	14.5	23.8	10.7	9.3
55	93	M2	34.8	43.9	22.1	21.8	32.4	23.1	21.3	9.3	-1.8
56	94	M3	21.5	66.7	41.8	24.9	33.6	24.8	27.6	8.8	2.8
57	95	M4	20.0	69.1	62.8	6.3	34.7	25.5	30.5	9.2	5.0
58	17'''	B4	42.5	26.8	22.3	4.5	22.2	13.5	19.9	8.7	6.4
59	18'	ND4	69.6	32.7	16.5	16.2	25.8	17.3	15.5	8.5	-1.8
60	19	ND5	91.8	28.7	20.1	8.6	23.3	25.2	18.0	-1.9	-7.2
61	35	IC1	79.9	27.6	16.9	10.7	20.6	18.9	15.1	1.7	-3.8
62	36	IC2	14.4	39.3	19.3	20.0	31.5	18.9	17.7	12.6	-1.2

TABLE 10. MVD - SELECTED INTERVALS

POINTS	PDPA VS. FOS FULL RANGE MEAN NUMERICAL DIFFERENCE	PDPA VS. FOS FULL RANGE MEAN PERCENTAGE DIFFERENCE	PDPA VS. FSSP TRUNCATED RANGE MEAN NUMERICAL DIFFERENCE	PDPA VS. FSSP TRUNCATED RANGE MEAN PERCENTAGE DIFFERENCE
ALL	13.3	63.2	7.7	50.6
1-23	15.7	70.2	7.8	46.7
24-29	11.9	47.8	9.3	82.1
30-41	14.4	62.3	8.3	46.4
42-53	9.4	64.8	8.0	59.5
54-57	12.9	40.7	9.5	46.4
58-62	12.0	65.6	5.9	36.3

TABLE 11. COMPARISON OF MVD'S FOR NUMBER DENSITY TEST

			FULL RANGE					TRUNCATED RANGE						
						PDPA-FOS				PDPA-FSSP			FOS-FSSP	
NEW TP NO	NO OF NOZ	VEL (ft /s)	FSSP ACT	PDPA	FOS	DIF	% DIF	PDPA	FSSP	DIF	% DIF	FOS	DIF	% DIF
24	1	199	50.4	27.2	17.9	9.3	52	22.9	14.0	8.9	64	16.4	-2.4	-0
22	2	198	76.4	32.8	18.8	14.0	74	24.7	20.5	4.2	20	16.8	3.7	22
59	3	194	69.6	32.7	16.5	16.2	98	25.8	17.3	8.5	49	15.5	1.8	12
60	4	177	91.8	28.7	20.1	8.6	43	23.3	25.2	-1.9	-8	18.0	7.2	40
25	1	100	31.5	31.1	25.9	5.2	20	25.5	15.6	9.9	63	22.1	-6.5	-29
23	2	98	69.7	31.4	27.5	3.9	14	24.5	22.3	2.2	10	23.1	-0.8	-3

TABLE 12. MEAN DIAMETER SUMMARY

NEW TP NO	OLD TP NO	LA-BEL	FSSP ACTIV-ITY	FULL RANGE PDPA	FULL RANGE FOS	FULL RANGE PDPA-FOS	TRUNCATED RANGE PDPA	TRUNCATED RANGE FSSP	TRUNCATED RANGE FOS	TRUNCATED RANGE PDPA-FSSP	TRUNCATED RANGE FOS-FSSP
1	2	FV1	63.3	22.7	7.8	14.9	19.6	15.6	7.6	4.0	-8.0
2	3	FV2	64.8	26.6	7.3	19.3	21.9	13.4	7.1	8.5	-6.3
3	4	FV3		24.4	7.1	17.3	19.9		7.0		
4	5	FV4	66.8	25.7	7.2	18.5	20.8	12.7	7.1	8.1	-5.6
5	7	FV5		24.1	7.4	16.7	20.1		7.2		
6	8	FV6		20.4	8.1	12.3	17.9		7.8		
7	56	O1		10.7	6.2	4.5	10.7		6.2		
8	57	O2		16.0	6.3	9.7	15.7		6.2		
9	58	O3		16.4	7.3	9.1	16.1		6.7		
10	61	O4		24.3	7.2	17.1	21.1		7.1		
11	62	O5		27.2	9.6	17.6	22.1		8.1		
12	63	O6		25.6	8.5	17.1	20.7		7.6		
13	64	O7		17.8	6.6	11.2	16.8		6.5		
14	65	O8		15.5	6.7	8.8	14.7		6.6		
15	66	O9		25.6	7.5	18.1	20.2		7.3		
16	10	SV1	42.6	11.4	7.3	4.1	11.1	9.0	7.2	2.1	-1.8
17	11	SV2	55.5	10.3	6.4	3.9	10.1	7.9	6.3	2.2	-1.6
18	12	SV3	57.1	11.6	6.3	5.3	11.3	7.5	6.3	3.8	-1.2
19	13	SV4	58.0	10.6	6.3	4.3	10.3	7.5	6.3	2.8	-1.2
20	15	SV5	50.2	10.3	6.4	3.9	10.2	7.7	6.3	2.5	-1.4
21	16	SV6	33.9	10.3	7.4	2.9	10.2	8.6	7.4	1.6	-1.2
22	18	ND1	76.4	10.9	6.6	4.3	10.6	9.6	6.6	1.0	-3.0
23	21	ND2	69.7	9.7	7.5	2.2	9.5	10.8	7.4	-1.3	-3.4
24	17	B1	50.4	9.5	6.4	3.1	9.4	7.8	6.3	1.6	-1.5
25	22	ND3	31.5	10.0	7.2	2.8	9.8	8.6	7.2	1.2	-1.4
26	23	AC1	7.3	11.2	6.5	4.7	11.0	5.0	6.5	6.0	1.5
27	24	AC2	55.8	9.4	6.3	3.1	9.3	8.8	6.2	0.5	-2.6
28	25	AC3	53.3	13.4	7.5	5.9	11.8	10.0	7.2	1.8	-2.8
29	26	AC4	50.3	16.8	7.5	9.3	14.2	10.7	7.2	3.5	-3.5
30	17'	B2	42.4	11.0	6.7	4.3	10.6	7.6	6.7	3.0	-0.9
31	27	SA1	23.2	24.6			19.2	10.5		8.7	
32	28	SA2	21.9	18.5	7.4	11.1	16.3	9.4	7.2	6.9	-2.2
33	29	SA3	20.9	15.0	6.6	8.4	14.5	8.5	6.6	6.0	-1.9
34	30	SA4	22.0	13.1	6.5	6.6	12.9	8.3	6.5	4.6	-1.8
35	31	SH1	66.6	23.4	7.7	15.7	19.4	15.6	7.5	3.8	-8.1
36	32	SH2	56.3	11.2	6.4	4.8	10.9	9.7	6.4	1.2	-3.3
37	33	SH3	76.1	13.5	7.2	6.3	12.7	15.0	7.1	-2.3	-7.9
38	67	O10	60.2	9.8	6.2	3.6	9.7	9.0	6.2	0.7	-2.8
39	69	O11	71.3	25.8	7.9	17.9	21.4	17.7	7.6	3.7	-10.1
40	70	O12	56.9	11.0	6.4	4.6	10.9	9.5	6.4	1.4	-3.1
41	17''	B3	46.5	10.7			10.3	7.6		2.7	
42	80	A1	53.8	10.4	6.5	3.9	10.2	8.6	6.5	1.6	-2.1
43	81	A2	46.9	10.3	6.3	4.0	10.2	8.2	6.3	2.0	-1.9
44	82	A3	34.1	8.0	5.9	2.1	8.0	6.6	5.9	1.4	-0.7
45	83	A4	35.7	8.3	5.9	2.4	8.3	6.8	5.9	1.5	-0.9
46	84	A5	35.2	8.6	6.0	2.6	8.6	6.8	6.0	1.8	-0.8
47	85	A6	33.7	8.7	6.0	2.7	8.7	6.7	6.0	2.0	-0.7
48	86	A7	29.5	8.6	6.0	2.6	8.6	6.5	6.0	2.1	-0.5
49	87	A8	24.0	8.7	6.0	2.7	8.7	6.4	6.0	2.3	-0.4
50	88	A9	30.7	10.0	6.2	3.8	9.9	7.3	6.2	2.6	-1.1
51	89	A10	29.8	11.3	6.4	4.9	11.1	7.8	6.4	3.3	-1.4
52	90	A11	18.0	14.3	6.6	7.7	13.5	8.4	6.6	5.1	-1.8
53	91	A12	17.0	14.1	7.0	7.1	13.5	8.5	6.9	5.0	-1.6
54	92	M1	29.2	10.9	12.5	-1.6	10.7	7.7	12.2	3.0	4.5
55	93	M2	34.8	15.6	11.9	3.7	14.3	9.5	11.8	4.8	2.3
56	94	M3	21.5	22.2	13.4	8.8	18.0	9.7	12.8	8.3	3.1
57	95	M4	20.0	23.5	14.8	8.7	18.4	10.0	13.5	8.4	3.5
58	17'''	B4	42.5	8.5	6.7	1.8	8.4	7.4	6.7	1.0	-0.7
59	18'	ND4	69.6	9.4	6.3	3.1	9.2	8.8	6.3	0.4	-2.5
60	19	ND5	91.8	9.0	6.6	2.4	8.8	12.6	6.6	-3.8	-6.0
61	35	IC1	79.9	8.8	6.2	2.6	8.6	9.2	6.2	-0.6	-3.0
62	36	IC2	14.4	15.6	6.6	9.0	14.7	9.2	6.6	5.5	-2.6

TABLE 13. NUMBER DENSITY SUMMARY

NEW TP NO	OLD TP NO	LA-BEL	FSSP ACTIV-ITY	FULL RANGE PDPA	FULL RANGE FOS	FULL RANGE PDPA-FOS	TRUNCATED RANGE PDPA	TRUNCATED RANGE FSSP	TRUNCATED RANGE FOS	TRUNCATED RANGE PDPA-FSSP	TRUNCATED RANGE FOS-FSSP
1	2	FV1	63.3	286	1433	-1147	264	282	1428	-18	1146
2	3	FV2	64.8	100	724	-624	88	238	722	-150	483
3	4	FV3		73	578	-505	65		576		
4	5	FV4	66.8	65	532	-468	56	215	530	-159	315
5	7	FV5		160	714	-554	144		711		
6	8	FV6		350	1219	-869	329		1212		
7	56	O1		15	274	-260	15		274		
8	57	O2		96	273	-176	95		273		
9	58	O3		144	471	-327	143		471		
10	61	O4		203	1111	-908	185		1109		
11	62	O5		283	1248	-965	249		1238		
12	63	O6		326	2968	-2642	289		2957		
13	64	O7		94	293	-199	92		293		
14	65	O8		200	579	-379	196		579		
15	66	O9		315	3379	-3064	275		3369		
16	10	SV1	42.6	124	48	77	123	262	48	-139	-214
17	11	SV2	55.5	91	40	51	91	251	40	-160	-210
18	12	SV3	57.1	37	40	-3	37	241	40	-204	-201
19	13	SV4	58.0	32	33	-2	31	229	33	-198	-196
20	15	SV5	50.2	110	31	79	110	248	31	-138	-217
21	16	SV6	33.9	136	35	101	135	229	35	-93	-194
22	18	ND1	76.4	273	114	159	271	207	114	65	-93
23	21	ND2	69.7	436	156	280	434	246	155	188	-91
24	17	B1	50.4	93	42	51	93	246	42	-153	-204
25	22	ND3	31.5	94	52	42	93	442	52	-349	-390
26	23	AC1	7.3	14	10	4	14	57	10	-43	-47
27	24	AC2	55.8	148	95	53	147	211	95	-64	-116
28	25	AC3	53.3	142	229	-87	137	237	228	-100	-9
29	26	AC4	50.3	124	331	-207	118	231	329	-113	98
30	17'	B2	42.4	63	70	-7	63	243	70	-180	-173
31	27	SA1	23.2	39			35	128		-93	
32	28	SA2	21.9	41	104	-64	39	135	104	-96	-31
33	29	SA3	20.9	34	65	-31	34	135	65	-101	-69
34	30	SA4	22.0	42	62	-19	42	141	62	-99	-80
35	31	SH1	66.6	189	1707	-1518	171	218	1700	-47	1482
36	32	SH2	56.3	175	237	-62	174	245	237	-71	-8
37	33	SH3	76.1	276	2069	-1793	271	201	2065	71	1864
38	67	O10	60.2	157	155	2	157	229	155	-72	-74
39	69	O11	71.3	219	3930	-3711	196	207	3910	-11	3703
40	70	O12	56.9	151	215	-64	151	246	215	-94	-31
41	17''	B3	46.5	70			69	264		-194	
42	80	A1	53.8	121	126	-5	121	283	126	-162	-157
43	81	A2	46.9	97	106	-9	97	282	106	-185	-176
44	82	A3	34.1	44	17	27	44	240	17	-196	-223
45	83	A4	35.7	52	26	27	52	244	26	-192	-219
46	84	A5	35.2	53	26	27	53	243	26	-190	-218
47	85	A6	33.7	47	26	21	47	236	26	-189	-210
48	86	A7	29.5	38	21	17	38	213	21	-175	-192
49	87	A8	24.0	33	17	16	33	185	17	-153	-168
50	88	A9	30.7	54	41	13	54	215	41	-161	-174
51	89	A10	29.8	54	61	-7	53	205	61	-152	-144
52	90	A11	18.0	40	474	-434	40	131	474	-91	343
53	91	A12	17.0	36	63	-27	36	121	63	-86	-58
54	92	M1	29.2	50	109	-59	50	199	108	-149	-90
55	93	M2	34.8	67	6	60	65	208	6	-143	-202
56	94	M3	21.5	30	34	-5	27	136	34	-109	-102
57	95	M4	20.0	30	28	2	26	119	27	-93	-92
58	17'''	B4	42.5	114	53	61	114	248	53	-134	-194
59	18'	ND4	69.6	152	247	-95	151	223	247	-72	24
60	19	ND5	91.8	296	68	228	295	101	68	194	-34
61	35	IC1	79.9	126	139	-13	126	171	139	-45	-32
62	36	IC2	14.4	11	36	-25	11	113	36	-102	-77

TABLE 14. LWC SUMMARY

NEW TP NO	OLD TP NO	LA-BEL	FSSP ACTIV-ITY	FULL RANGE PDPA	FULL RANGE FOS	FULL RANGE PDPA-FOS	TRUNCATED RANGE PDPA	TRUNCATED RANGE FSSP	TRUNCATED RANGE FOS	TRUNCATED RANGE PDPA-FSSP	TRUNCATED RANGE FOS-FSSP
1	2	FV1	63.3	4.635	2.058	2.577	1.965	1.218	1.383	0.747	0.165
2	3	FV2	64.8	2.430	0.873	1.556	0.855	0.760	0.545	0.095	-0.215
3	4	FV3		1.546	0.586	0.960	0.542		0.374	0.542	
4	5	FV4	66.8	1.489	0.577	0.912	0.503	0.645	0.363	-0.142	-0.282
5	7	FV5		3.097	0.896	2.201	1.139		0.552	1.139	
6	8	FV6		4.444	2.098	2.345	1.993		1.281	1.993	
7	56	O1		0.015	0.079	-0.064	0.015		0.079	0.015	
8	57	O2		0.439	0.083	0.356	0.375		0.082	0.375	
9	58	O3		0.701	0.149	0.552	0.598		0.148	0.598	
10	61	O4		3.562	0.984	2.578	1.625		0.763	1.625	
11	62	O5		8.599	2.605	5.994	2.580		1.431	2.580	
12	63	O6		9.108	3.717	5.392	2.675		2.643	2.675	
13	64	O7		0.681	0.134	0.547	0.451		0.122	0.451	
14	65	O8		1.084	0.307	0.777	0.716		0.270	0.716	
15	66	O9		8.522	3.831	4.691	2.298		2.788	2.298	
16	10	SV1	42.6	0.299	0.040	0.259	0.222	0.196	0.034	0.026	-0.162
17	11	SV2	55.5	0.158	0.016	0.142	0.120	0.135	0.016	-0.014	-0.119
18	12	SV3	57.1	0.095	0.015	0.080	0.070	0.112	0.014	-0.041	-0.098
19	13	SV4	58.0	0.063	0.012	0.051	0.050	0.108	0.011	-0.058	-0.097
20	15	SV5	50.2	0.186	0.013	0.173	0.147	0.119	0.012	0.028	-0.108
21	16	SV6	33.9	0.227	0.029	0.197	0.197	0.152	0.027	0.045	-0.125
22	18	ND1	76.4	0.592	0.059	0.533	0.431	0.232	0.052	0.199	-0.180
23	21	ND2	69.7	0.733	0.157	0.577	0.548	0.372	0.130	0.175	-0.243
24	17	B1	50.4	0.128	0.018	0.110	0.108	0.125	0.017	-0.017	-0.108
25	22	ND3	31.5	0.170	0.045	0.125	0.131	0.300	0.038	-0.170	-0.263
26	23	AC1	7.3	0.032	0.004	0.028	0.026	0.006	0.004	0.020	-0.001
27	24	AC2	55.8	0.209	0.041	0.168	0.156	0.163	0.036	-0.007	-0.127
28	25	AC3	53.3	0.906	0.353	0.553	0.361	0.348	0.203	0.013	-0.145
29	26	AC4	50.3	1.608	0.570	1.038	0.423	0.398	0.289	0.024	-0.109
30	17'	B2	42.4	0.171	0.039	0.132	0.123	0.120	0.035	0.003	-0.085
31	27	SA1	23.2	1.272			0.266	0.238		0.028	
32	28	SA2	21.9	0.474	0.121	0.353	0.194	0.166	0.086	0.027	-0.081
33	29	SA3	20.9	0.152	0.032	0.121	0.116	0.101	0.030	0.015	-0.071
34	30	SA4	22.0	0.129	0.026	0.103	0.110	0.094	0.025	0.016	-0.068
35	31	SH1	66.6	3.969	2.385	1.585	1.301	1.087	1.567	0.214	0.480
36	32	SH2	56.3	0.386	0.113	0.273	0.295	0.271	0.100	0.024	-0.171
37	33	SH3	76.1	1.247	1.908	-0.661	0.806	0.879	1.452	-0.074	0.573
38	67	O10	60.2	0.211	0.061	0.150	0.188	0.197	0.056	-0.009	-0.142
39	69	O11	71.3	5.725	6.278	-0.552	1.915	1.409	3.964	0.506	2.555
40	70	O12	56.9	0.321	0.095	0.227	0.262	0.249	0.085	0.014	-0.164
41	17''	B3	46.5	0.176			0.124	0.135		-0.011	
42	80	A1	53.8	0.219	0.054	0.166	0.183	0.215	0.052	-0.031	-0.163
43	81	A2	46.9	0.158	0.036	0.122	0.142	0.173	0.036	-0.031	-0.137
44	82	A3	34.1	0.025	0.003	0.022	0.025	0.064	0.004	-0.039	-0.060
45	83	A4	35.7	0.035	0.005	0.029	0.035	0.074	0.006	-0.039	-0.068
46	84	A5	35.2	0.041	0.006	0.035	0.040	0.074	0.006	-0.034	-0.068
47	85	A6	33.7	0.038	0.006	0.032	0.038	0.069	0.006	-0.031	-0.063
48	86	A7	29.5	0.029	0.005	0.024	0.029	0.055	0.005	-0.027	-0.050
49	87	A8	24.0	0.024	0.004	0.021	0.025	0.045	0.004	-0.020	-0.041
50	88	A9	30.7	0.072	0.013	0.060	0.068	0.086	0.013	-0.018	-0.072
51	89	A10	29.8	0.119	0.025	0.094	0.100	0.112	0.024	-0.012	-0.088
52	90	A11	18.0	0.203	0.282	-0.078	0.131	0.102	0.237	0.029	0.135
53	91	A12	17.0	0.171	0.048	0.124	0.117	0.096	0.039	0.020	-0.058
54	92	M1	29.2	0.100	0.325	-0.225	0.085	0.102	0.238	-0.016	0.136
55	93	M2	34.8	0.472	0.012	0.460	0.258	0.262	0.012	-0.004	-0.250
56	94	M3	21.5	0.656	0.161	0.495	0.172	0.194	0.094	-0.022	-0.100
57	95	M4	20.0	0.777	0.242	0.535	0.179	0.187	0.091	-0.009	-0.096
58	17'''	B4	42.5	0.123	0.032	0.091	0.102	0.111	0.029	-0.010	-0.082
59	18'	ND4	69.6	0.245	0.101	0.144	0.181	0.179	0.096	0.002	-0.083
60	19	ND5	91.8	0.379	0.036	0.343	0.306	0.255	0.033	0.051	-0.222
61	35	IC1	79.9	0.143	0.056	0.087	0.111	0.169	0.051	-0.057	-0.117
62	36	IC2	14.4	0.066	0.018	0.047	0.043	0.112	0.017	-0.069	-0.094

APPENDIX A

TEST PLAN

Revision B
5/25/88

Test Plan

Particle Sizing Instrument Comparison Test

Sponsored By:

Federal Aviation Administration (FAA)
FAA Technical Center, Atlantic City, NJ

National Aeronautics and Space Administration (NASA)
Lewis Research Center, Cleveland, Ohio

Arnold Engineering and Development Center
Arnold Air Force Base, TN

Background: Previous studies have shown that ice accretions on aircraft components are extremely sensitive to cloud droplet median volumetric diameter (MVD) and spectrum. Hence, the cloud droplet size and size distribution are parameters which must be controlled and monitored during aircraft engine and component certification testing in simulated and natural icing environments. It has also been shown that the particle measuring instruments currently used by the icing test community are inconsistent and many times do not agree with the rotating cylinder measuring technique which was used to establish the criterion for aircraft icing certification (Federal Aviation Regulation (FAR) Part 25). To enhance the knowledge base for the modern particle measuring instruments and to establish a common basis of comparison among various icing facilities, a direct particle size instrument comparison test is necessary.

The specific requirements for this study are two-fold; (1) to aid the FAA engine and component icing certification process, and (2) to reduce facility-to-facility test result variations due to droplet sizing inconsistencies. The study will consist of gathering sufficient particle sizing data to be analyzed for instrument sizing characteristics under varying test cell conditions.

Objectives: The objectives of this study are as follows;

(1) Directly compare the following particle sizing techniques:

A. Particle Imaging,
B. Laser Phase/Doppler Velocimetry,
C. Forward Scatter Spectrometry.

(2) Directly compare instrument sizing capability as a function of velocity, particle size distribution, number density, and the presence of ice particles.

(3) Compare the outputs of expanded range instruments with the interpolated and merged outputs of limited range instruments.

Approach: The instruments will be installed in the R1D test cell of the Arnold Engineering Development Center's Engine Test Facility. A simulated icing cloud will be generated utilizing one to four air atomizing nozzles (NASA Icing Research Tunnel (IRT) nozzles will be used for all tests except that portion investigating droplet distribution effects, which will utilize a modified NASA nozzle and a Sonicore 125-H nozzle under separate tests). Each instrument to be evaluated will be installed to measure the same portion of the cloud. The non-intrusive devices will be mounted so as to monitor continuously and simultaneously with the other intrusive devices. These non-intrusive instruments will provide a reference for all other instruments and ensure tunnel condition repeatability for testing the intrusive devices individually. The intrusive devices will be installed in the test chamber of the tunnel in such a manner as to minimize the disruption of the flow field which may sort the particles based upon size and affect the instrument readings.

The tunnel conditions will be varied over wide ranges to exercise the instruments as appropriate. Each instrument sponsor has defined the test conditions appropriate for that instrument consistent with the objectives of the test. A combined test table has been developed dependent upon these inputs which maximizes test efficiency without significantly affecting the range of the test. It should be pointed out that this test is not intended to calibrate nozzles or the test

cell. Each instrument shall be compared on a point-for-point basis. Therefore, test cell variations and nozzle variations will have little effect on the test.

The general variations of test parameters are as follows:

Parameter	Purpose of Variation	Expected Range
Velocity	Observe velocity effects on sizing.	50 - 400 ft/sec
Number density	Observe cloud optical density effects.	Up to 4x ref. (see note 1)
Droplet MVD	(1) Observe the sizing capability of the instruments as a function of where the MVD lies in the instrument's range. (2) Observe the sizing capability of multiple instrument systems which merge probe outputs to arrive at an overall MVD as MVD varies within the probe overlap region.	10 - 40 Microns
Drop size distribution	Observe the effect of varying and skewing the drop size distribution.	TBD (see note 2)
Temperature	Observe the effect of ice crystals on sizing and to quantify the sampling capability/degradation due to ice buildup on the isokinetic probe area of the intrusive devices.	10°F - Ambient (see note 3)

Notes:

1. The "reference" has been defined to be a single NASA-Lewis IRT Std. nozzle operating at P_{an} = 85 psia, P_{wn} = 105 psia, with a nominal flow rate of .054 GPM and a nominal drop size of 15 micron MVD in an airstream of 60 m/s (200 ft/s). (Note: P_{an} and P_{wn} are the nozzle air and water pressures, respectively.)

2. A different nozzle will be used which will have a distinctly different drop size distribution (e.g., NASA-LeRC Model II vs. Sonicore #125-H at 21-24 microns, based upon existing calibration curves).

3. Atomizing air temperature will be reduced to approximately 100°F at 10°F static temperature to create ice particles.

Test Matrix: The Test Matrix identified as an appendix to this test plan defines the specific test conditions to be performed. These test points are listed in the order of priority. The intent is to perform each test point listed only once. It is, therefore, the responsibility of the instrument operators to ensure their data has stabilized before proceeding to the next test point. However, (on the first day of testing) each test point should last no longer than five (5) minutes. It should be noted that all reference to dropsize (MVD) is based upon existing calibration curves and are

considered estimates only for this test. No attempt will be made to exactly set a given MVD, but to merely be consistent in nozzle flow and pressure settings.

The first day's testing will be performed with all particle measurement instruments installed (FOS, PDPA, and FSSP set for auto ranging or sizing through 95 microns). The second day of testing will be used to evaluate observed phenomena of the first day of testing, LWC Comparison with an accretion rod, and OAP Probe sizing characteristics for a limited test matrix.

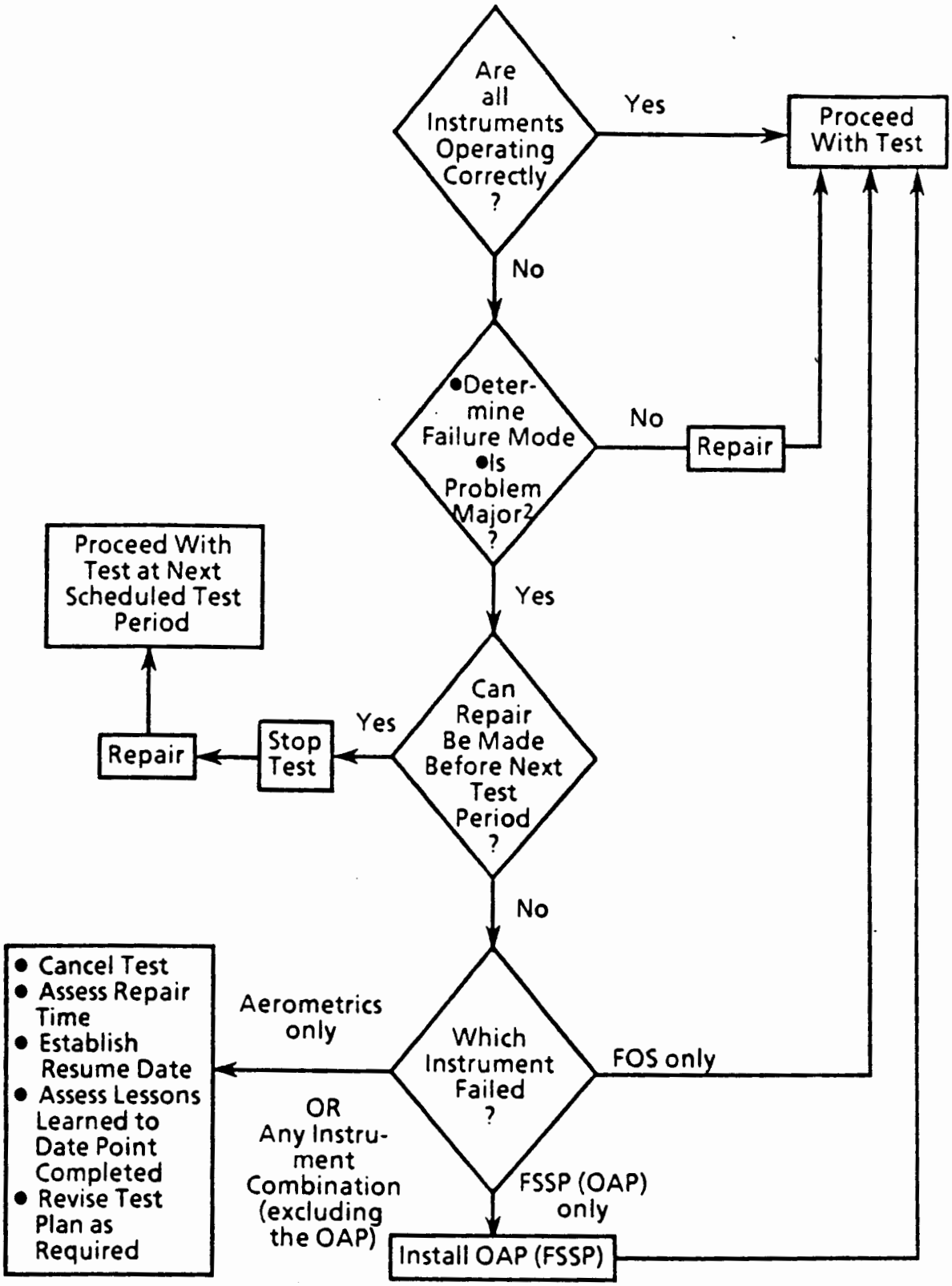
Particle Sizing Instrumentation Failure Contingency Plan: In the event of a particle sizing instrumentation system failure, the decision to proceed with the test or to stop testing will be made based upon the attached Instrumentation Failure Mode Decision Diagram. This contingency plan is based upon an attempt to maximize the gathering of data which can be compared with at least one other instrument of comparable range and resolution during the test. To manage the risk of losing an instrument unnoticeably, the test matrix includes several baseline (or reference) points to substantiate the operation of the instruments at regular intervals and after critical or harsh data points during the test.

Schedule: The tentative schedule is to test within the time frame of 2 May 88 to 16 May 88.

Contacts: The U.S. Air Force contact for all official communication regarding this test project is Mr. Carlos Tirres (615-454-6514). The Sverdrup Technology (operating contractor for the ETF) project manager is Mr. C. Scott Bartlett (615-454-6873). Technical contact for Sverdrup Technology is Mr. Tom F. Tibbals (615-454-6605).

Attachment: Instrumentation Failure Mode Decision Diagram
Estimate of Elapsed Time for Test Matrix
Appendix -- Test Matrix

Instrumentation[1] Failure Mode Decision Diagram



Notes: 1. Particle Measurement Instrumentation Systems ONLY -- all other instrument failures handled per general AEDC procedures.

2. "Minor" is defined as a problem which takes less than two (2) hours to repair. In the case of the FSSP (or OAP) which failed at a point in the test matrix where data is still needed for the OAP (or FSSP), then "Minor" is defined as a problem which takes less time to repair than the time to switch probes.

Test Matrix

I. Particle Sizing as a function of Velocity.

a.) Nozzle Conditions

Type -- NASA-Lewis IRT Std (1)
Air Pressure -- 85 psia
Water Pressure -- 105 psia
Nominal Flow Rate -- .054 GPM
Nominal Drop Size -- 15 micron MVD

Test Point		
1	Velocities:	15 M/S (50 ft/s)
2		30 M/S (100 ft/s)
3*		60 M/S (200 ft/s) -- (Reference Condition = TP17)
4		90 M/S (300 ft/s)
5		120 M/S (400 ft/s)
6		150 M/S (500 ft/s)
7**		60 M/S (200 ft/s)
8**		30 M/S (100 ft/s)

***b.) Nozzle Conditions:

Type -- NASA-Lewis IRT Std (1)
Air Pressure -- 55 psia
Water Pressure -- 115 psia
Nominal Flow Rate -- .093 GPM
Nominal Drop Size -- 30 micron MVD

Test Point		
9 - 16	Velocities:	same as (I a.)

* At this test point, each instrument should perform multiple data sets to establish cloud uniformity with time and for the various acquisition times of the instruments.

** Test points 7 & 8 (15 & 16) are repeats so as to establish a baseline for the remainder of the test.

*** Test points 9-16 of Test Plan Phase I b. is performed to examine the effect of MVD on the velocity characteristics of the particle measurement instruments.

II. Particle Sizing as a function of particle number density. {1,2}

NOTE: At the beginning, of this test, operate each nozzle independently to verify the individual nozzle spectrums.

(TP 17) a.)* Velocity: 60 M/S (200 ft/s)

Nozzle Conditions:

Type -- NASA-Lewis IRT Std (1)**
Air Pressure -- 85 psia
Water Pressure -- 105 psia
Nominal Flow Rate -- .054 GPM/nozzle
Nominal Drop Size -- 15 micron MVD

(TP 18) b.) Same conditions except
Type -- NASA-Lewis IRT Std (2)

-------- c.) Repeat Reference Condition (TP17)

(TP 19) d.) Same conditions except
Type -- NASA-Lewis IRT Std (4)

-------- e.) Repeat Reference Condition (TP17)

(TP 20) f.)*** Same conditions except
Type -- NASA-Lewis IRT Std (4)
Velocity: 30 M/S (100 ft/s)

-------- g.) Repeat Reference Condition (TP17) @ 30 m/s (100 ft/s)

(TP 21) h.) Same conditions except
Type -- NASA-Lewis IRT Std (2)
Velocity: 30 M/S (100 ft/s)

(TP 22) i.) Same conditions except
Type -- NASA-Lewis IRT Std (1)
Velocity: 30 M/S (100 ft/s)

-------- j.) Repeat Reference Condition (TP17) @ 60 m/s (200 ft/s)

* Reference condition.

** Number in parentheses is the number of nozzles activated.

*** Velocity changes are to evaluate the velocity effects on particle sizing with different number densities.

NOTES:
1. Due to the possibility of flooding the FSSP, this test will be at the end of the day, regardless of position within Test Plan.
2. It is desirable that laser extinction measurements be performed on these test points.

III. Particle Size as a function of Distribution.

a.) Velocity: 60 M/S (200 ft/s)

Nozzle Conditions:

Test Point	Nozzle Type	Air Pressure PSIA	Water Pressure PSIA	Nominal Drop Size Microns	Flow Rate GPM
23	IRT-std.	85	90	10	.027
24		55	95	25	.054
25		55	115	30	.093
26		35	85	40	.085
Repeat Reference Condition (TP17)					
27	IRT-Mod 1	45	125	20	.009
28		35	115	25	.036
29		35	135	30	.041
30		35	155	35	.044
31	Sonicore 125-H*	35	6	20	.040
32		40	12	25	.080
33		50	21	30	.200
34		40	28	40	.275
Repeat Reference Condition (TP17)					

* Per Dumants Belte, U.S.Army Aviation Engineering Flight Activity, EAFB, CA, this nozzle has approximately 20% of its water in bins greater than 45 microns. The conditions specified are from AEDC calibration curves.

IV. Particle Size as a function of ice crystals entrained in cloud.

a.) Velocity: 60 M/S (200 ft/s)
Tunnel Temperature: 10°F Static

Nozzle Conditions:

Atomizing Air Temperature: ≈ 100°F
Type -- NASA-Lewis IRT Std (1)

Test Point	Air Pressure PSIA	Water Pressure PSIA	Nominal Drop Size Microns	Flow Rate GPM
Repeat Reference Condition *(@T_s = 10°F)				
35	85	90	10	.027
36	55	95	20	.076
37	55	115	30	.093
38	35	85	40	.085
Repeat Reference Condition *(@T_s = 10°F)				

*Atomization N_2 Temperature at ≥ 175°F

V. Baseline for cloud without disturbances due to FSSP (or OAP), which will also establish if the FSSP is naturally sorting out particles and thereby affecting the MVD determined.

Test Point	Velocity M/S(Ft/s)	Nozzle Type	Air Pressure PSIA	Water Pressure PSIA	Nominal Drop Size Microns	Flow Rate GPM
39	15	IRT-Std(1)	85	105	15	.054
40	30					
41	60	----------(Reference Condition)----------				
42	90					
43	120					
44	30		55	115	30	.093
45	60					
46	60	IRT-Std(2)	85	105	15	.066
47	30					
----------Repeat Reference Condition (TP17)----------						
48	60	IRT-Mod1(1)	45	50	10	.009
49	60		35	155	35	.044
50	60	Sonicore 125-H(1)	40	12	25	.080
51	60		40	28	40	.275
52*	60	IRT-Std(1)	65	95	20	.066
53*	----------		same	----------		
54*	----------		same	----------		
55**	----------		same	----------		
----------Repeat Reference Condition (TP17)----------						

* Reduce tunnel temperature (Ts = 10°F) to obtain LWC/Rod ice thickness measurements.

** Reduce atomizing air temperature to 100°F to generate ice particles, also obtain LWC/Rod ice thickness measurements.

Note: No intrusive devices will be installed, except a rod for ice accretion.

VI. Particle size as a function of probe overlap (PMS, FSSP, & OAP). {1,2}

a.) Velocity: 60 M/S (200ft/s)

Conditions:

Test Point	Probe Type	Nozzle Type	Air Pressure PSIA	Water Pressure PSIA	Nominal Drop Size Microns	Flow Rate GPM
----------Repeat Reference Condition (TP17)----------						
56	OAP	IRT-Std	85	90	10	.027
57	@10-600		85	135	20	.085
58			35	65	30	.066
59			35	75	35	.076
60			35	85	40	.085
61		Sonicore	70	5	13	.030
62		125-H	40	12	25	.080
63			40	28	40	.275
64			43	15	21	.093
65			43	16	35	.113
66			43	27	55	.251
67	FSSP		70	5	13	.030
68	@2-47		40	12	25	.080
69			40	28	40	.275
70			43	15	21	.093
71			43	16	35	.113
72			43	27	55	.251
73		IRT-Std	85	90	10	.027
74			85	135	20	.085
75			35	65	30	.066
76			35	75	35	.076
77			35	85	40	.085
----------Repeat Reference Condition (TP17)----------						

Notes: 1) Sampling times for each probe must be noted such that LWC per probe bin can be determined and reported.

2) Sonicore 125-H is the nozzle used on the U.S. Army HISS. It has a large tail with approximately 20% of the water in bins greater than 45 microns. The first three points for this nozzle are per AEDC calibration curves. The second three points are per U.S. Army HISS data.

VII. Particle size as a function of degraded aperature due to ice on FSSP isokinetic sampling probe.

(TP 78) a.) Velocity: 60 M/S (200 ft/s)
Tunnel Temperature: 25°F Total
Nozzle Conditions:
Type -- NASA-Lewis IRT Std (1)
Air Pressure -- 65 PSIA
Water Pressure -- 95 PSIA
Nominal Flow Rate -- .066 GPM
Nominal Drop Size -- 20 Micron MVD.

(TP 79) B. Same, except Tunnel Temperature: 10°F Total

Note: This test will be performed for academic reasons only as time permits. This is considered low priority.

-- ESTIMATE OF ELAPSED TIME --
FOR TEST MATRIX

Test Point	Description	Nozzle(s)[1] Installed	Probes[2] Installed	Test Day	Elapsed[3] Time
--	Test Cell Start	2A, 1B, 1C	FSSP	1	To
--	Instr. checks	2A, 1B, 1C	FSSP	1	To + 0:45
1-8	Velocity Test (MVD = 15μ)	2A, 1B, 1C	FSSP	1	To + 1:50
9-16	Velocity Test (MVD = 30μ)	2A, 1B, 1C	FSSP	1	To + 2:40
23-26	Distribution Test (IRT-Std)	2A, 1B, 1C	FSSP	1	To + 3:10
27-30	Distribution Test (IRT-Mod.1)	2A, 1B, 1C	FSSP	1	To + 3:40
31-34	Distribution Test (Sonicore)	2A, 1B, 1C	FSSP	1	To + 4:10
--	Cool Test Cell & N_2	2A, 1B, 1C	FSSP	1	To + 4:40
35-38	Ice Crystal Test	2A, 1B, 1C	FSSP	1	To + 5:10
--	Warm Test Cell[4] & N_2	2A, 1B, 1C	FSSP	1	To + 5:40
--	Shutdown Test Cell	2A, 1B, 1C	FSSP	1	To + 5:45
--	Change Nozzles and Cal FSSP	4A	FSSP	1	To + 7:00
--	Test Cell Restart	4A	FSSP	1	To + 7:10
17-19	Number Density Test (60m/s)	4A	FSSP	1	To + 7:40
20-22	Number Density Test (30m/s)	4A	FSSP	1	To + 8:10
--	Shutdown Test Cell	4A	FSSP	1	To + 8:20
--	Remove FSSP & Install Nozzles	2A, 1B, 1C	None	1	To + 9:00
--	Test Cell Restart	2A, 1B, 1C	None	1	To + 9:10
39-45	Baseline Test (IRT-Std[1])	2A, 1B, 1C	None	1	To + 9:45

Notes:

1. A = IRT-Std, B = IRT-Mod1, C = Sonicore 125-H. Each nozzle must be installed in the same arm for each test, and each arm always positioned at the same location for each test.
2. Probes installed inside the R1D Test Cell, Aerometrics and FOS probes always active.
3. Referenced to end of described item from test cell air-on time in Hr:min.
4. Warm test cell slowly and allow to stabilize at approximately ambient for 5 min. to prevent FSSP fogging and condensation when opening test cell. Obtain a data point at reference condition (TP17) prior to shutdown.

46-47	Baseline Test (IRT-Std[2])	2A, 1B, 1C	None	1	To + 9:55
48-49	Baseline Test (IRT-Mod.1[1])	2A, 1B, 1C	None	1	To + 10:10
50-51	Baseline Test (Sonicore [1])	2A, 1B, 1C	None	1	To + 10:25
52-54	Baseline & Acretion Test	2A, 1B, 1C	None	1	To + 11:00
55	Baseline w/Crystals & Acretion Test	2A, 1B, 1C	None	1	To + 11:15
--	Shutdown Test Cell	2A, 1B, 1C	None	1	To + 11:20
--	Test Cell Start	2A, 1B, 1C	OAP	2	To
--	Instr. Checks	2A, 1B, 1C	OAP	2	To + 0:15
56-60	Probe Overlap (IRT-Std)	2A, 1B, 1C	OAP	2	To + 0:45
61-66	Probe Overlap (Sonicore)	2A, 1B, 1C	OAP	2	To + 1:15
--	Shutdown Test Cell	2A, 1B, 1C	OAP	2	To + 1:20
--	Remove OAP & Install FSSP	2A, 1B, 1C	FSSP	2	To + 2:30
--	Test Cell Restart	2A, 1B, 1C	FSSP	2	To + 2:40
67-72	Probe Overlap (Sonicore)	2A, 1B, 1C	FSSP	2	To + 3:15
73-77	Probe Overlap (IRT-Std)	2A, 1B, 1C	FSSP	2	To + 3:45
--	Cool Test Cell	2A, 1B, 1C	FSSP	2	To + 4:00
78	Degraded FSSP Aperature	2A, 1B, 1C	FSSP	2	To + 4:15
--	Warm Test Cell (Remove Ice)	2A, 1B, 1C	FSSP	2	To + 4:30
--	Cool Test Cell	2A, 1B, 1C	FSSP	2	To + 4:45
79	Degraded FSSP Aperature	2A, 1B, 1C	FSSP	2	To + 5:00

APPENDIX B

AS TESTED MATRIX

As Tested Matrix

I. Particle Sizing as a function of Velocity.

a.) Nozzle Conditions

Type -- NASA-Lewis IRT Std (1)
Air Pressure -- 85 psia
Water Pressure -- 105 psia
Nominal Flow Rate -- .114 GPM

Test Point			
2	Velocities	30 M/S (100 ft/s)	
3		60 M/S (200 ft/s)	-- (Reference Condition = TP17)
4		90 M/S (300 ft/s)	
4'		95 M/S (315 ft/s)	
7		60 M/S (200 ft/s)	
8		30 M/S (100 ft/s)	

b.) Nozzle Conditions:

Type -- AEDC 2050
Air Pressure -- 100 psia
Water Pressure -- 100 psia
Nominal Flow Rate -- .037 GPM

Test Point	
10 - 16	Velocities:same as (I a.)

II. Particle Sizing as a function of particle number density.

(TP 17) a.) Velocity: 60 M/S (200 ft/s)

Nozzle Conditions:

Type -- AEDC 2050 (1)**
Air Pressure -- 100 psia
Water Pressure -- 100 psia
Nominal Flow Rate -- .037 GPM/nozzle

(TP 18) b.) Same conditions except
Type -- AEDC 2050 (2)

(TP 18') c.) Same conditions except
Type -- AEDC 2050 (3)

(TP 19) d.) Same conditions except
Type -- AEDC 2050 (4)

(TP 21) h.) Same conditions except
Type -- AEDC 2050 (2)
Velocity: 30 M/S (100 ft/s)

(TP 22) i.) Same conditions except
Type -- AEDC 2050 (1)
Velocity: 30 M/S (100 ft/s)

** Number in parentheses is the number of nozzles activated.

III. Particle Size as a function of Distribution.

a.) Velocity: 60 M/S (200 ft/s)

Nozzle Conditions:

Test Point	Nozzle Type	Air Pressure PSIA	Water Pressure PSIA	Flow Rate GPM
23	AEDC 2050	100	80	.011
24		80	95	.052
25		50	75	.062
26		40	75	.073
----------Repeat Reference Condition (TP17)----------				
27	Spray Sys. 1-A	120	145	.068
28		120	35	.029
29		120	20	.017
30		150	20	.019
31	Sonicore 125-H*	35	20	.172
32		40	14	.043
33		50	21	.168
----------Repeat Reference Condition (TP17)----------				

* Per Dumants Belte, U.S.Army Aviation Engineering Flight Activity, EAFB, CA, this nozzle has approximately 20% of its water in bins greater than 45 microns. The conditions specified are from AEDC calibration curves.

80-95, Spray Sys. 1-A at various conditions, see test logs.

particle Size as a function of ice crystals entrained in cloud.

a.) Velocity: 60 M/S (200 ft/s)
Tunnel Temperature: 8°F Static (35), 78°F (35')

Nozzle Conditions:

Type -- AEDC 2050

Test Point	Air Pressure PSIA	Water Pressure PSIA	Flow Rate GPM
35	100	100	.032
35'	100	100	.031

VI. Particle size as a function of probe overlap (PMS, FSSP, & OAP). {1,2}

a.) Velocity: 60 M/S (200ft/s)

Conditions:

Test Point	Probe Type	Nozzle Type	Air Pressure PSIA	Water Pressure PSIA	Flow Rate GPM
----------Repeat Reference Condition (TP17)----------					
56	OAP	IRT-Std	85	45	.019
57	@10-600		85	55	.040
58			125	95	.072
61		Sonicore	70	19	.124
62		125-H	40	26	.219
63			40	28	.252
64			43	14.5	.062
65			43	16	.092
66			43	27	.244
67	FSSP		70	19	.052
69			43	27	.242
70			43	14	.043

Notes: 1) Sampling times for each probe must be noted such that LWC per probe bin can be determined and reported.

2) Sonicore 125-H is the nozzle used on the U.S. Army HISS. It has a large tail with approximately 20% of the water in bins greater than 45 microns. The first three points for this nozzle are per AEDC calibration curves. The second three points are per U.S. Army HISS data.

APPENDIX C

DATA FILES

TABLE C-1. FILE DESIGNATIONS, DATES AND TIMES

NEW TP NO	OLD TP NO	LA-BEL*	AEROMETRICS FILE	AEROMETRICS DATE/TIME	NASA LEWIS FILE	NASA LEWIS DATE/TIME	AEDC FILE
1	2	FV1	I(A)/03	MAY 25/22:40:01	RUN2.FSP	MAY 25/22:47:55	91.DAT
2	3	FV2	I(A)/08	MAY 25/22:57:12	RUN3.FSP	MAY 25/22:56:55	92.DAT
3	4	FV3	I(A)/09	MAY 25/23:12:20	NO DATA		93.DAT
4	5	FV4	I(A)/12	MAY 25/23:29:25	RUN5.FSP	MAY 25/23:33:32	94.DAT
5	7	FV5	I(A)/18	MAY 25/23:49:08	RUN7.FSP	MAY 26/00:08:35	95.DAT
6	8	FV6	I(A)/21	MAY 26/00:05:12	NO DATA		96.DAT
7	56	O1	VI/02	MAY 26/01:51:44	NO DATA		97.DAT
8	57	O2	VI/04	MAY 26/02:02:20	RUN57.OAP	MAY 26/02:03:51	98.DAT
9	58	O3	VI/06	MAY 26/02:12:48	RUN58.OAP	MAY 26/02:32:42	99.DAT
10	61	O4	VI/08	MAY 26/02:29:14	NO DATA		910.DAT
11	62	O5	VI/12	MAY 26/03:03:19	RUN62.OAP	MAY 26/03:03:29	911.DAT
12	63	O6	VI/13	MAY 26/03:20:22	RUN63.OAP	MAY 26/03:20:40	9103.DAT
13	64	O7	VI/16	MAY 26/03:29:26	RUN64.OAP	MAY 26/03:31:16	9104.DAT
14	65	O8	VI/18	MAY 26/03:36:22	NO DATA		9105.DAT
15	66	O9	VI/20	MAY 26/03:41:32	NO DATA		9106.DAT
16	10	SV1	I(A)/23	MAY 26/07:01:45	RUN10.FSP	MAY 26/07:02:40	9107.DAT
17	11	SV2	I(A)/25	MAY 26/07:15:42	RUN11.FSP	MAY 26/07:14:10	9108.DAT
18	12	SV3	I(A)/28	MAY 26/07:20:19	RUN12.FSP	MAY 26/07:21:21	9109.DAT
19	13	SV4	I(A)/30	MAY 26/07:31:05	RUN13.FSP	MAY 26/07:30:23	9110.DAT
20	15	SV5	I(A)/33	MAY 26/07:37:44	RUN15.FSP	MAY 26/07:40:17	9111.DAT
21	16	SV6	I(A)/35	MAY 26/07:46:18	RUN16.FSP	MAY 26/07:48:24	9112.DAT
22	18	ND1	II/03	MAY 26/07:59:22	RUN18.FSP	MAY 26/08:02:39	1028.DAT
23	21	ND2	II/04	MAY 26/08:04:25?	RUN21.FSP	MAY 26/07:58:09	9115.DAT
24	17	B1	II/07	MAY 26/21:49:44	RUN17.FSP	MAY 26/21:49:39	1017.DAT
25	22	ND3	II/09	MAY 26/21:57:35	RUN22.FSP	MAY 26/21:58:16	1018.DAT
26	23	AC1	III/02	MAY 26/22:16:49	RUN23A.FSP	MAY 26/22:18:53	1019.DAT
27	24	AC2	III/05	MAY 26/22:29:44	RUN24A.FSP	MAY 26/22:32:33	1020.DAT
28	25	AC3	III/08	MAY 26/22:45:54	RUN25.FSP	MAY 26/22:48:42	1021.DAT
29	26	AC4	III/11	MAY 26/22:56:35	RUN26.FSP	MAY 26/22:57:32	1022.DAT
30	17'	B2	III/13	MAY 26/23:06:07	RUN17A.FSP	MAY 26/23:06:13	1034.DAT
31	27	SA1	III/15	MAY 26/23:20:53	RUN27.FSP	MAY 26/23:21:59	1024.DAT
32	28	SA2	III/16	MAY 26/23:30:28	RUN28.FSP	MAY 26/23:33:12	1025.DAT
33	29	SA3	III/18	MAY 26/23:39:18	RUN29.FSP	MAY 26/23:41:46	1026.DAT
34	30	SA4	III/21	MAY 26/23:49:00	RUN30.FSP	MAY 26/23:49:56	1027.DAT
35	31	SH1	III/22	MAY 27/00:11:53	RUN31.FSP	MAY 27/00:19:49	1028.DAT
36	32	SH2	III/25	MAY 27/00:30:14	RUN32.FSP	MAY 27/00:32:22	1029.DAT
37	33	SH3	III/27	MAY 27/00:40:06	RUN33.FSP	MAY 27/00:43:56	1030.DAT
38	67	O10	VI/22	MAY 27/00:49:08	RUN67.FSP	MAY 27/00:51:54	1031.DAT
39	69	O11	VI/24	MAY 27/01:01:11	RUN69.FSP	MAY 27/01:03:59	1032.DAT
40	70	O12	VI/26	MAY 27/01:07:45	RUN70A.FSP	MAY 27/01:14:31	1033.DAT
41	17''	B3	VI/29	MAY 27/01:29:37	RUN17C.FSP	MAY 27/01:28:51	NOT FOUND
42	80	A1	VIII/31	MAY 27/02:39:28	RUN80.FSP	MAY 27/02:39:02	1035.DAT
43	81	A2	VIII/33	MAY 27/02:48:10	RUN81.FSP	MAY 27/02:49:46	1036.DAT
44	82	A3	VIII/35	MAY 27/02:53:09	RUN82.FSP	MAY 27/02:54:09	1037.DAT
45	83	A4	VIII/36	MAY 27/03:04:14	RUN83.FSP	MAY 27/03:07:25	1038.DAT
46	84	A5	VIII/37	MAY 27/03:09:36	RUN84.FSP	MAY 27/03:12:24	1039.DAT
47	85	A6	VIII/38	MAY 27/03:17:35	RUN85.FSP	MAY 27/03:20:30	1040.DAT
48	86	A7	VIII/39	MAY 27/03:27:32	RUN86.FSP	MAY 27/03:30:53	1041.DAT
49	87	A8	VIII/40	MAY 27/03:32:35	RUN87.FSP	MAY 27/03:36:03	1042.DAT
50	88	A9	VIII/41	MAY 27/03:38:35	RUN88.FSP	MAY 27/03:41:27	1043.DAT
51	89	A10	VIII/42	MAY 27/03:46:16	RUN89.FSP	MAY 27/03:49:33	1044.DAT
52	90	A11	VIII/43	MAY 27/03:54:33	RUN90.FSP	MAY 27/03:57:24	1260.DAT
53	91	A12	VIII/44	MAY 27/04:43:12	RUN91.FSP	MAY 27/04:46:18	1045.DAT
54	92	M1	VIII/45	MAY 27/04:54:15	RUN92.FSP	MAY 27/04:57:12	1046.DAT
55	93	M2	VIII/46	MAY 27/05:03:24	RUN93.FSP	MAY 27/05:05:54	1048.dat
56	94	M3	VIII/47	MAY 27/05:13:46	RUN94.FSP	MAY 27/05:15:47	1049.dat
57	95	M4	VIII/49	MAY 27/05:26:22	RUN95.FSP	MAY 27/05:29:06	1050.dat
58	17'''	B4	II/13	MAY 27/06:09:57	RUN17D.FSP	MAY 27/06:13:04	1023.DAT
59	18'	ND4	II/15	MAY 27/06:18:50	RUN18A.FSP	MAY 27/06:21:48	1054.DAT
60	19	ND5	II/17	MAY 27/06:33:32	RUN18C.FSP	MAY 27/06:36:14	1052.DAT
61	35	IC1	IV/01	MAY 27/07:12:41	RUN35.FSP	MAY 27/07:15:04	1058.DAT
62	36	IC2	IV/03	MAY 27/07:22:33	RUN36.FSP	MAY 27/07:24:36	1059.DAT

APPENDIX D

COMPARISON OF RANGES 0 AND 1 FOR FORWARD SCATTERING SPECTROMETER PROBE

Results for ranges 0 and 1 of the FSSP during the AEDC instrument comparison test are compared in this appendix. It is demonstrated that they did not give compatible results during the test.

The test point numbers used in this appendix are those assigned by NASA during the testing. Suffixes have not been retained: For example, test points 18 and 18A are both simply listed as test point 18.

Table D1 lists information on valid counts (VC), total strobes (TS), VC/TS, and activity (ACT) for all test points discussed in this appendix. These terms are defined and their significance discussed on page 4 of Reference 7:

> The valid counts are the sum of all the counts in the 15 size bins in the FSSP. Droplets that go through the radially central region of the laser beam generate valid counts and total strobes. The ratio of VC/TS is a measure of the fractional part of the beam diameter (or the effective beam diameter) that is used for measuring the droplets. This is used for determining the probe volume in the FSSP.
>
> The FSSP measures a quantity called activity. It is defined as the percent of the time the instrument is busy analyzing particles. An equation describing activity is given as:
>
> $$\text{Activity} = 100 * (T_t + D_t) / E_t.$$
>
> T_t is the sum of the transit time of all particles through the probe volume. D_t is the sum of all the periods of dead time when the instrument is analyzing a particle and is insensitive to other particles in the sample volume. And E_t is the total elapsed time the FSSP is running.

Many, but not all, of the test points are listed in the order in which they were taken. For example, test points 80-95 are listed in the order, but all the baseline points are simply labeled 17 and listed together.

Table D2 lists information on MVD, ND, and number density over the interval from 35 to 47 microns (ND(35-47)). Also listed are percentage differences in these parameters when ranges 0 and 1 are compared. Note that range 0 and 1 are taken in reverse order for ND.

Table D3 repeats columns from the previous tables for ease of reference when examining the plots.

Table D4 shows the output for Test Point 94 for ranges 0 and 1. Note that these two ranges have a common interval of 5 to 47 microns over which they are directly comparable. This interval can also be subdivided into subintervals where direct comparison is possible. For example, combining bins 2 and 3 in range 1 gives an interval from 5 to 11 microns which is directly comparable to bin 1 in range 0. Table D5 illustrates these remarks, also for Test Point 94. Results for the interval from 35 to 47 microns are examined later in a plot.

Figure D1 is a scatter plot of MVD's for range 0 versus range 1 computed over the common interval of 5 to 47 microns. The MVD's for range 0 were computed using the counts for bins 1 through 7 as shown in Table D1 while those for range 1 were computed using the counts for bins 2 through 14. A curve has been "faired in" which exhibits a trend for most of the data. When the range 1 MVD is very small (around 10 microns), it is just slightly exceeded by the range 0 MVD. As the range 1 MVD increases, it also increases relative to the range 0 MVD. The difference between the two MVD's is relatively constant for the larger MVD's. Seven "outlier points" which do not follow the pattern just described have been circled. (Test point 94 of Tables D4 and D5 is one of these points.)

Figure D2 is a scatter plot of ND's for range 0 versus range 1 computed over the common interval of 5 to 47 microns. Again, a curve has been "faired in" which exhibits the trend for most of the data. When the range 1 ND is less than about 150, it agrees very well with the range 0 ND. As the range 1 ND increases beyond 150, the amount by which it is exceeded by the range 0 ND steadily increases. Three "outlier points" are circled.

Sixteen test points are listed in table D5 for which the range 1 MVD exceeded 20 microns. These test points are listed in table D6 for ease of reference. The 7 MVD outlier points from figure D1 appear in this table. The most striking way in which they differ from the other points is that they are the <u>only</u> points for which the range 1 activity is less than 60; to use the phrase employed in the main body of the report, they are the only ones which are <u>not</u> "high activity points."

Figure D3 is a plot of percentage difference in MVD versus percentage difference in VC/TS for the data of table D3. Figure D4 is the same plot using only the data of table D6. The 7 MVD outliers are not distinguished in the first plot, but in the second they are the only ones except for one additional one such that the percentage difference in VC/TS exceeds 20.

Figure D5 is a plot of percentage difference in MVD versus percentage difference in ND for the data of table D3. Figure D6 is the same plot using only the data of table D6. The 7 MVD outliers are not distinguished in the first plot, but in the second they are the only ones such that the percentage difference in ND is less than 20. In light of figure D2, this means that they are among the points with relatively low number densities, which is consistent with their having lower activity values.

Figure D7 is a plot of percentage difference in MVD versus the ratio of range 1 to range 0 for number density over the interval 35 to 47 microns. The plot is only for the points in Table D6, since for many of the points in Table D3 the ratio is either undefined or potentially misleading because the counts for the interval are so low. The 7 MVD outlier points are again easily distinguished from the rest of the data.

TABLE D-1.

TEST PT	RNG 0 VC	RNG 1 VC	RNG 0 TS	RNG 1 TS	RNG 0 VC/TS	RNG 1 VC/TS	PERCENT DIFF: VC/TS	RNG 0 ACT	RNG 1 ACT	PERCENT DIFF: ACT
2	92334	69894	181301	145045	0.51	0.48	-5.3	42.9	63.3	47.6
3	173580	144755	281279	246624	0.62	0.59	-4.9	45.0	64.8	44.0
5	178223	191944	386882	355001	0.46	0.54	17.4	48.6	66.8	37.4
10	56028	88704	124903	138864	0.45	0.64	42.3	26.9	42.6	58.4
11	121273	163621	231569	252694	0.52	0.65	23.7	36.2	55.5	53.3
12	180288	147888	273659	309032	0.66	0.48	-27.3	38.3	57.1	49.1
13	179003	201699	318641	368761	0.56	0.55	-2.7	39.3	58.0	47.6
15	120453	170354	223629	257740	0.54	0.66	22.6	33.8	50.2	48.5
16	50007	78711	99601	120145	0.50	0.66	30.5	21.0	33.9	61.4
18	173128	126012	282800	214758	0.61	0.59	-4.1	55.4	76.4	37.9
18	85374	43270	193674	93910	0.44	0.46	4.5	76.8	91.8	19.5
21	67565	75744	173925	126756	0.39	0.60	54.1	49.9	69.7	39.7
23	19336	24983	33983	59537	0.57	0.42	-26.2	3.5	7.3	108.6
24	121238	140718	227800	220722	0.53	0.64	19.9	39.1	55.8	42.7
25	122322	156384	235683	245193	0.52	0.64	22.9	35.8	53.3	48.9
26	116775	150524	227113	236161	0.51	0.64	23.9	34.2	50.3	47.1
27	52893	87723	105140	131867	0.50	0.67	32.2	14.0	23.2	65.7
28	55812	93219	103393	137598	0.54	0.68	25.4	13.3	21.9	64.7
29	58280	94038	102139	137749	0.57	0.68	19.6	12.8	20.9	63.3
30	62630	97840	110289	144450	0.57	0.68	19.2	13.8	22.0	59.4
31	171415	129485	275459	226564	0.62	0.57	-8.0	47.8	66.6	39.3
32	130128	163216	248029	252915	0.53	0.65	22.9	39.5	56.3	42.5
33	176933	112729	286953	204416	0.62	0.55	-10.7	56.8	76.1	34.0
35	95106	88159	242468	147891	0.39	0.60	52.0	64.2	79.9	24.5
36	51585	76277	82178	120360	0.63	0.63	1.0	9.7	14.4	48.5
17	113059	164293	213103	256952	0.53	0.64	20.3	29.9	50.4	68.6
17	104774	173596	197947	258595	0.53	0.67	26.8	26.1	42.4	62.5
17	117782	186703	214849	280921	0.55	0.67	21.4	28.8	46.5	61.5
17	100486	171269	190073	255963	0.53	0.67	26.5	25.1	42.5	69.3
18	151211	140710	265268	227427	0.57	0.62	8.6	50.0	69.6	39.2
67	135886	150489	250391	235443	0.54	0.64	17.7	43.7	60.2	37.8
69	177734	114901	283658	212348	0.63	0.54	-13.7	51.9	71.3	37.4
70	129281	164477	246041	254063	0.53	0.65	23.2	39.3	56.9	44.8
80	118507	182635	241381	273429	0.49	0.67	36.0	37.7	53.8	42.7
81	112877	187258	219835	273955	0.51	0.68	33.3	33.3	46.9	40.8
82	89093	143926	155438	235622	0.57	0.61	6.6	20.6	34.1	65.5
83	94933	150612	169005	238696	0.56	0.63	12.3	23.0	35.7	55.2
84	94501	148254	168056	236326	0.56	0.63	11.6	22.8	35.2	54.4
85	90929	139617	160413	228239	0.57	0.61	7.9	21.5	33.7	56.7
86	82754	119536	138945	207797	0.60	0.58	-3.5	18.2	29.5	62.1
87	70363	100060	116051	183306	0.61	0.55	-9.9	14.7	24.9	69.4
88	85563	139983	150515	210134	0.57	0.67	17.3	20.3	30.7	51.2
89	82217	139514	143793	201151	0.57	0.69	21.3	19.6	29.8	52.0
90	58536	87302	93842	128453	0.62	0.68	9.0	12.6	18.8	49.2
91	54233	82140	88481	120963	0.61	0.68	10.8	11.2	17.7	58.0
92	83073	135560	143527	198066	0.58	0.68	18.1	18.8	29.2	55.3
93	86698	143549	164006	207520	0.53	0.69	30.8	23.5	34.8	48.1
94	59111	95062	103580	133566	0.57	0.71	24.7	14.5	21.5	48.3
95	49568	86405	90712	122254	0.55	0.71	29.5	12.1	20.2	66.9

TABLE D-2.

TEST PT	RNG 0 MVD	RNG 1 MVD	PERCENT DIFF: MVD	RNG 1 ND	RNG 0 ND	PERCENT DIFF: ND	RNG 0 ND(35-47)	RNG 1 ND(35-47)	RATIO ND(35-47)
2	26.6	29.5	10.9	266.1	349.1	31.2	8.4	11.4	1.4
3	24.5	28.7	17.1	211.4	270.1	27.8	3.78	6.55	1.7
5	23.6	29.8	26.3	186.8	234.2	25.4	2.74	6.01	2.2
10	15.0	15.9	6.0	220.1	235.5	7.0	0.14	0.28	2.0
11	12.4	14.3	15.3	188	229.7	22.2	0.04	0.15	3.8
12	13.0	13.8	6.2	170.6	213.6	25.2	0.17	0.2	1.2
13	11.7	13.9	18.8	163.7	197.7	20.8	0.15	0.28	1.9
15	12.2	13.7	12.3	182.6	215.1	17.8	0.02	0.12	6.0
16	14.8	15.3	3.4	188.1	189.7	0.9	0.1	0.24	2.4
18	16.9	20.6	21.9	167.8	271.8	62.0	0.58	0.87	1.5
18	21.2	25.2	18.9	86.4	207.8	140.5	1.55	1.75	1.1
21	18.6	22.3	19.9	218.7	337.8	54.5	1.16	1.59	1.4
23	12.2	7.1	-41.8	25.7	32.5	26.5	0	0	-
24	13.9	16.8	20.9	168.1	217.9	29.6	0.13	0.38	2.9
25	15.5	25.3	63.2	193.3	227.6	17.7	0.41	2.57	6.3
26	16.0	25.1	56.9	192.4	221.5	15.1	0.47	2.84	6.0
27	14.2	27.0	90.1	102.1	102	-0.1	0.16	1.84	11.5
28	13.8	23.2	68.1	104	101.5	-2.4	0.08	0.9	11.3
29	13.3	17.7	33.1	101.4	99.8	-1.6	0.01	0.15	15.0
30	13.0	16.4	26.2	105.6	107.7	2.0	0.01	0.1	10.0
31	29.6	31.9	7.8	194.5	261.5	34.4	8.79	12.27	1.4
32	15.1	19.7	30.5	200.1	239.7	19.8	0.15	0.74	4.9
33	27.8	30.6	10.1	179.1	279.6	56.1	6.9	8.79	1.3
35	14.9	19.0	27.5	134.3	279.8	108.3	0.21	0.54	2.6
36	12.1	11.0	-9.1	67.9	77.1	13.5	0	0.01	-
17	11.8	14.1	19.5	181.9	203.9	12.1	0.03	0.16	5.3
17	11.8	14.6	23.7	174	185.7	6.7	0.02	0.2	10.0
17	11.8	14.8	25.4	190.8	201.6	5.7	0.02	0.25	12.5
17	11.5	13.6	18.3	176.1	183.8	4.4	0.01	0.17	17.0
18	14.8	17.4	17.6	176.6	260.3	47.4	0.28	0.45	1.6
67	14.6	17.4	19.2	182.1	243.2	33.6	0.13	0.43	3.3
69	32.2	34.2	6.2	188.4	269.9	43.3	15.24	19.05	1.3
70	14.7	19.1	29.9	198.7	237.8	19.7	0.11	0.66	6.0
80	13.7	17.3	26.3	214.3	249.8	16.6	0.05	0.3	6.0
81	13.3	15.6	17.3	209.7	226.3	7.9	0.01	0.14	14.0
82	10.9	10.4	-4.6	154	158.3	2.8	0	0	-
83	11.5	10.9	-5.2	160.9	173.1	7.6	0	0	-
84	11.6	10.9	-6.0	159.8	173	8.3	0	0	-
85	11.4	10.8	-5.3	153.5	166	8.1	0	0.01	-
86	11.3	10.5	-7.1	133.2	142.3	6.8	0	0	-
87	11.2	10.3	-8.0	114.3	118.2	3.4	0	0	-
88	12.5	12.7	1.6	147.5	154.1	4.5	0	0.03	-
89	13.0	15.2	16.9	145.8	146.4	0.4	0	0.16	-
90	13.7	18.8	37.2	94.9	95.5	0.6	0.01	0.25	25.0
91	13.5	18.9	40.0	88.6	88.7	0.1	0.01	0.21	21.0
92	12.8	14.6	14.1	141	143.9	2.1	0	0.11	-
93	14.0	23.2	65.7	160.7	164.3	2.2	0.09	1.43	15.9
94	14.2	24.8	74.6	105	105.4	0.4	0.09	1.28	14.2
95	13.7	25.5	86.1	93.5	89	-4.8	0.06	1.29	21.5

TABLE D-3.

TEST PT	PER DIFF: VC/TS	RNG 0 ACT	RNG 1 ACT	PER DIFF: ACT	RNG 0 MVD	RNG 1 MVD	PER DIFF: MVD	PER DIFF: ND	RATIO ND(35-47)
2	-5.3	42.9	63.3	47.6	26.6	29.5	10.9	31.2	1.4
3	-4.9	45.0	64.8	44.0	24.5	28.7	17.1	27.8	1.7
5	17.4	48.6	66.8	37.4	23.6	29.8	26.3	25.4	2.2
10	42.3	26.9	42.6	58.4	15.0	15.9	6.0	7.0	2.0
11	23.7	36.2	55.5	53.3	12.4	14.3	15.3	22.2	3.8
12	-27.3	38.3	57.1	49.1	13.0	13.8	6.2	25.2	1.2
13	-2.7	39.3	58.0	47.6	11.7	13.9	18.8	20.8	1.9
15	22.6	33.8	50.2	48.5	12.2	13.7	12.3	17.8	6.0
16	30.5	21.0	33.9	61.4	14.8	15.3	3.4	0.9	2.4
18	-4.1	55.4	76.4	37.9	16.9	20.6	21.9	62.0	1.5
18	4.5	76.8	91.8	19.5	21.2	25.2	18.9	140.5	1.1
21	54.1	49.9	69.7	39.7	18.6	22.3	19.9	54.5	1.4
23	-26.2	3.5	7.3	108.6	12.2	7.1	-41.8	26.5	-
24	19.9	39.1	55.8	42.7	13.9	16.8	20.9	29.6	2.9
25	22.9	35.8	53.3	48.9	15.5	25.3	63.2	17.7	6.3
26	23.9	34.2	50.3	47.1	16.0	25.1	56.9	15.1	6.0
27	32.2	14.0	23.2	65.7	14.2	27.0	90.1	-0.1	11.5
28	25.4	13.3	21.9	64.7	13.8	23.2	68.1	-2.4	11.3
29	19.6	12.8	20.9	63.3	13.3	17.7	33.1	-1.6	15.0
30	19.2	13.8	22.0	59.4	13.0	16.4	26.2	2.0	10.0
31	-8.0	47.8	66.6	39.3	29.6	31.9	7.8	34.4	1.4
32	22.9	39.5	56.3	42.5	15.1	19.7	30.5	19.8	4.9
33	-10.7	56.8	76.1	34.0	27.8	30.6	10.1	56.1	1.3
35	52.0	64.2	79.9	24.5	14.9	19.0	27.5	108.3	2.6
36	1.0	9.7	14.4	48.5	12.1	11.0	-9.1	13.5	-
17	20.3	29.9	50.4	68.6	11.8	14.1	19.5	12.1	5.3
17	26.8	26.1	42.4	62.5	11.8	14.6	23.7	6.7	10.0
17	21.4	28.8	46.5	61.5	11.8	14.8	25.4	5.7	12.5
17	26.5	25.1	42.5	69.3	11.5	13.6	18.3	4.4	17.0
18	8.6	50.0	69.6	39.2	14.8	17.4	17.6	47.4	1.6
67	17.7	43.7	60.2	37.8	14.6	17.4	19.2	33.6	3.3
69	-13.7	51.9	71.3	37.4	32.2	34.2	6.2	43.3	1.3
70	23.2	39.3	56.9	44.8	14.7	19.1	29.9	19.7	6.0
80	36.0	37.7	53.8	42.7	13.7	17.3	26.3	16.6	6.0
81	33.3	33.3	46.9	40.8	13.3	15.6	17.3	7.9	14.0
82	6.6	20.6	34.1	65.5	10.9	10.4	-4.6	2.8	-
83	12.3	23.0	35.7	55.2	11.5	10.9	-5.2	7.6	-
84	11.6	22.8	35.2	54.4	11.6	10.9	-6.0	8.3	-
85	7.9	21.5	33.7	56.7	11.4	10.8	-5.3	8.1	-
86	-3.5	18.2	29.5	62.1	11.3	10.5	-7.1	6.8	-
87	-9.9	14.7	24.9	69.4	11.2	10.3	-8.0	3.4	-
88	17.3	20.3	30.7	51.2	12.5	12.7	1.6	4.5	-
89	21.3	19.6	29.8	52.0	13.0	15.2	16.9	0.4	-
90	9.0	12.6	18.8	49.2	13.7	18.8	37.2	0.6	25.0
91	10.8	11.2	17.7	58.0	13.5	18.9	40.0	0.1	21.0
92	18.1	18.8	29.2	55.3	12.8	14.6	14.1	2.1	-
93	30.8	23.5	34.8	48.1	14.0	23.2	65.7	2.2	15.9
94	24.7	14.5	21.5	48.3	14.2	24.8	74.6	0.4	14.2
95	29.5	12.1	20.2	66.9	13.7	25.5	86.1	-4.8	21.5

TABLE D-4.

TEST POINT 94

RANGE 0

Bin	Interval	Count	n.d.
1	5-11	39115	69.81
2	11-17	17793	31.76
3	17-23	1895	3.38
4	23-29	164	0.29
5	29-35	59	0.11
6	35-41	27	0.05
7	41-47	22	0.04
8	47-53	15	0.03
9	53-59	13	0.02
10	59-65	0	0.00
11	65-71	6	0.01
12	71-77	2	0.00
13	77-83	0	0.00
14	83-89	0	0.00
15	89-95	0	0.00

VC= 59111 ND= 105.50
TS= 103580
VC/TS= 0.57
Activity= 14.5

RANGE 1

Bin	Interval	Count	n.d.
1	2-5	21708	31.06
2	5-8	24102	34.49
3	8-11	22919	32.80
4	11-14	9579	13.71
5	14-17	5708	8.17
6	17-20	3772	5.40
7	20-23	2374	3.40
8	23-26	1681	2.41
9	26-29	1075	1.54
10	29-32	740	1.06
11	32-35	507	0.73
12	35-38	380	0.54
13	38-41	234	0.33
14	41-44	165	0.24
15	44-47	118	0.17

VC= 95062 ND= 136.04
TS= 133566
VC/TS= 0.71
Activity= 21.5

TABLE D-5.

TEST POINT 94

Comparison over Common Interval: 5 - 47 microns

RANGE 0					RANGE 1				
Bin	Interval	Count	n.d.		Bins	Interval	Count	n.d.	
1	5-11	39115	69.81	66.21%	2&3	5-11	45810	67.29	64.10%
2	11-17	17793	31.76	30.12%	4&5	11-17	32498	21.88	20.84%
3	17-23	1895	3.38	3.21%	6&7	17-23	9480	8.80	8.38%
4	23-29	164	0.29	0.28%	8&9	23-29	4055	3.94	3.76%
5	29-35	59	0.11	0.10%	10&11	29-35	1815	1.78	1.70%
6	35-41	27	0.05	0.05%	12&13	35-41	887	0.88	0.84%
7	41-47	22	0.04	0.04%	14&15	41-47	399	0.40	0.39%
	TOTALS:	59075	105.43	100%			94944	104.97	100%
	35-47	49	0.09	0.08%		35-47	1286	1.28	1.22%

Ratios for Interval 35-47

	Range 1		Range 0		
Counts	1286	/	49	=	26.24
n.d.	1.28	/	0.09	=	14.68
%	1.22	/	0.08	=	14.74

TABLE D-6.

TEST PT	PER DIFF: VC/TS	RNG 0 ACT	RNG 1 ACT	PER DIFF: ACT	RNG 0 MVD	RNG 1 MVD	PER DIFF: MVD	PER DIFF: ND	RATIO ND(35-47)
2	-5.3	42.9	63.3	47.6	26.6	29.5	10.9	31.2	1.4
3	-4.9	45.0	64.8	44.0	24.5	28.7	17.1	27.8	1.7
5	17.4	48.6	66.8	37.4	23.6	29.8	26.3	25.4	2.2
18	-4.1	55.4	76.4	37.9	16.9	20.6	21.9	62.0	1.5
18	4.5	76.8	91.8	19.5	21.2	25.2	18.9	140.5	1.1
21	54.1	49.9	69.7	39.7	18.6	22.3	19.9	54.5	1.4
25	22.9	35.8	53.3	48.9	15.5	25.3	63.2	17.7	6.3
26	23.9	34.2	50.3	47.1	16.0	25.1	56.9	15.1	6.0
27	32.2	14.0	23.2	65.7	14.2	27.0	90.1	-0.1	11.5
28	25.4	13.3	21.9	64.7	13.8	23.2	68.1	-2.4	11.3
31	-8.0	47.8	66.6	39.3	29.6	31.9	7.8	34.4	1.4
33	-10.7	56.8	76.1	34.0	27.8	30.6	10.1	56.1	1.3
69	-13.7	51.9	71.3	37.4	32.2	34.2	6.2	43.3	1.3
93	30.8	23.5	34.8	48.1	14.0	23.2	65.7	2.2	15.9
94	24.7	14.5	21.5	48.3	14.2	24.8	74.6	0.4	14.2
95	29.5	12.1	20.2	66.9	13.7	25.5	86.1	-4.8	21.5

FSSP RANGE COMPARISON

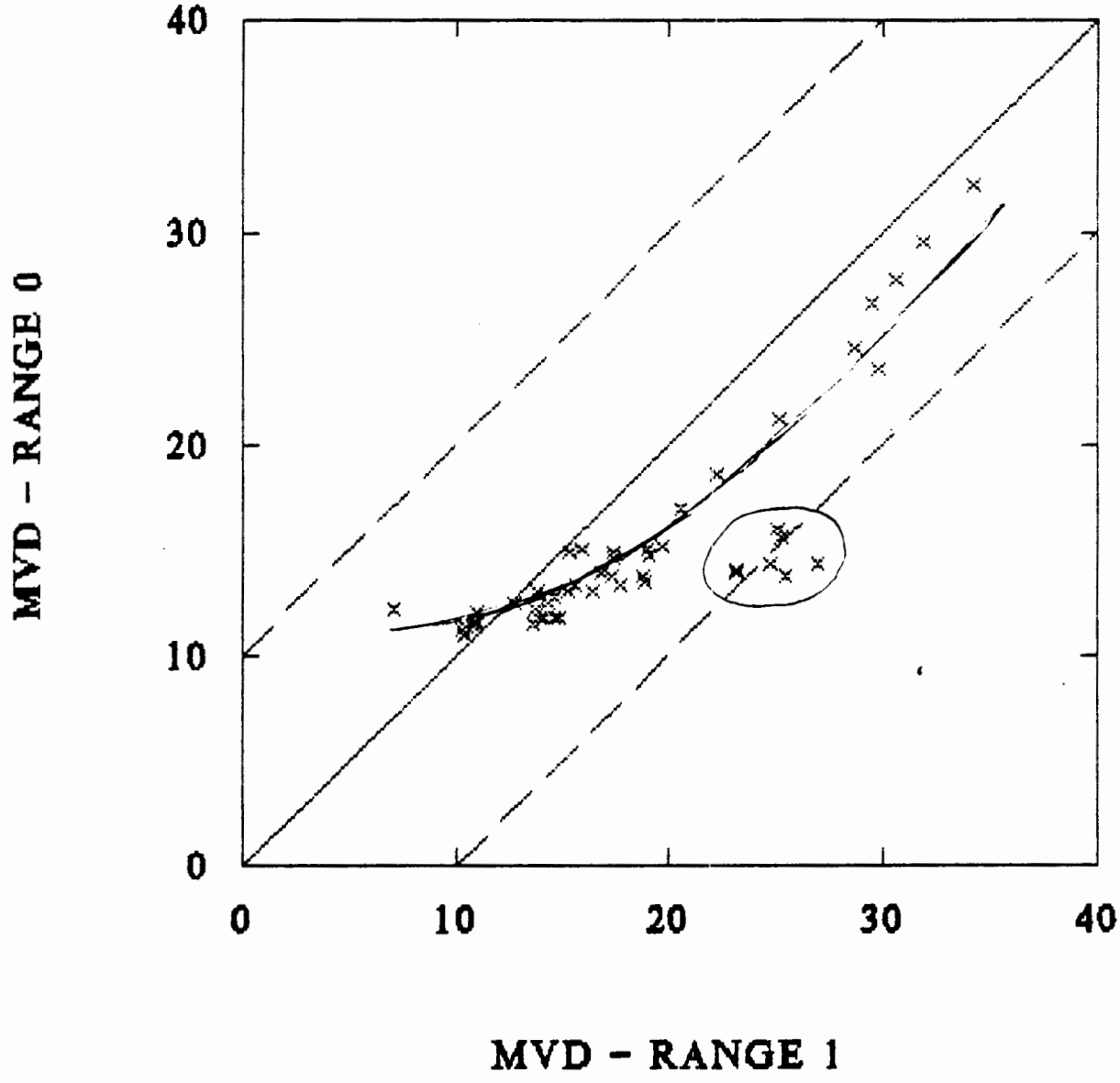


FIGURE D-1.

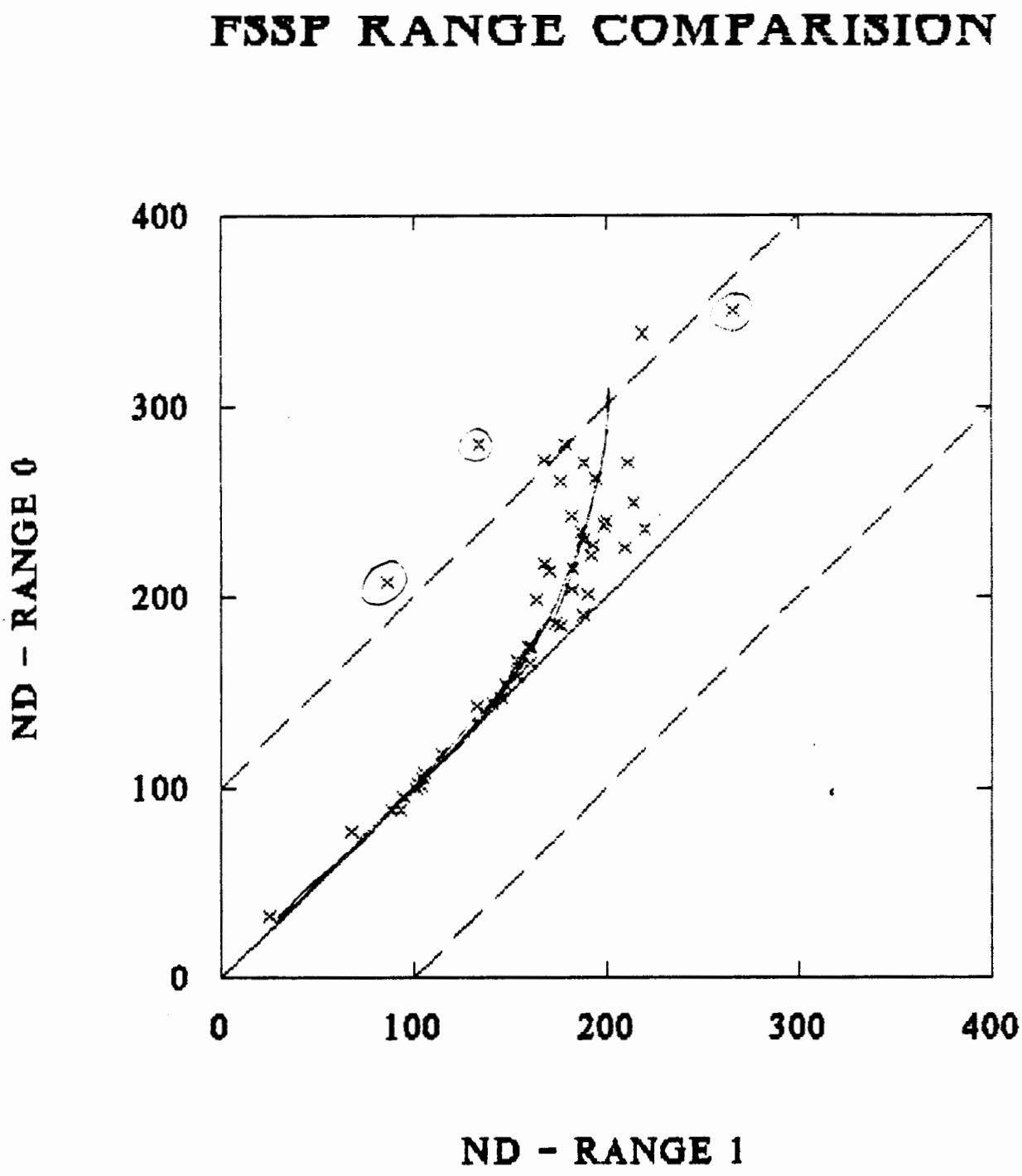

FSSP RANGE COMPARISION
400
300
200
100
0
0
100
200
300
400
ND - RANGE 0
ND - RANGE 1

FIGURE D-2.

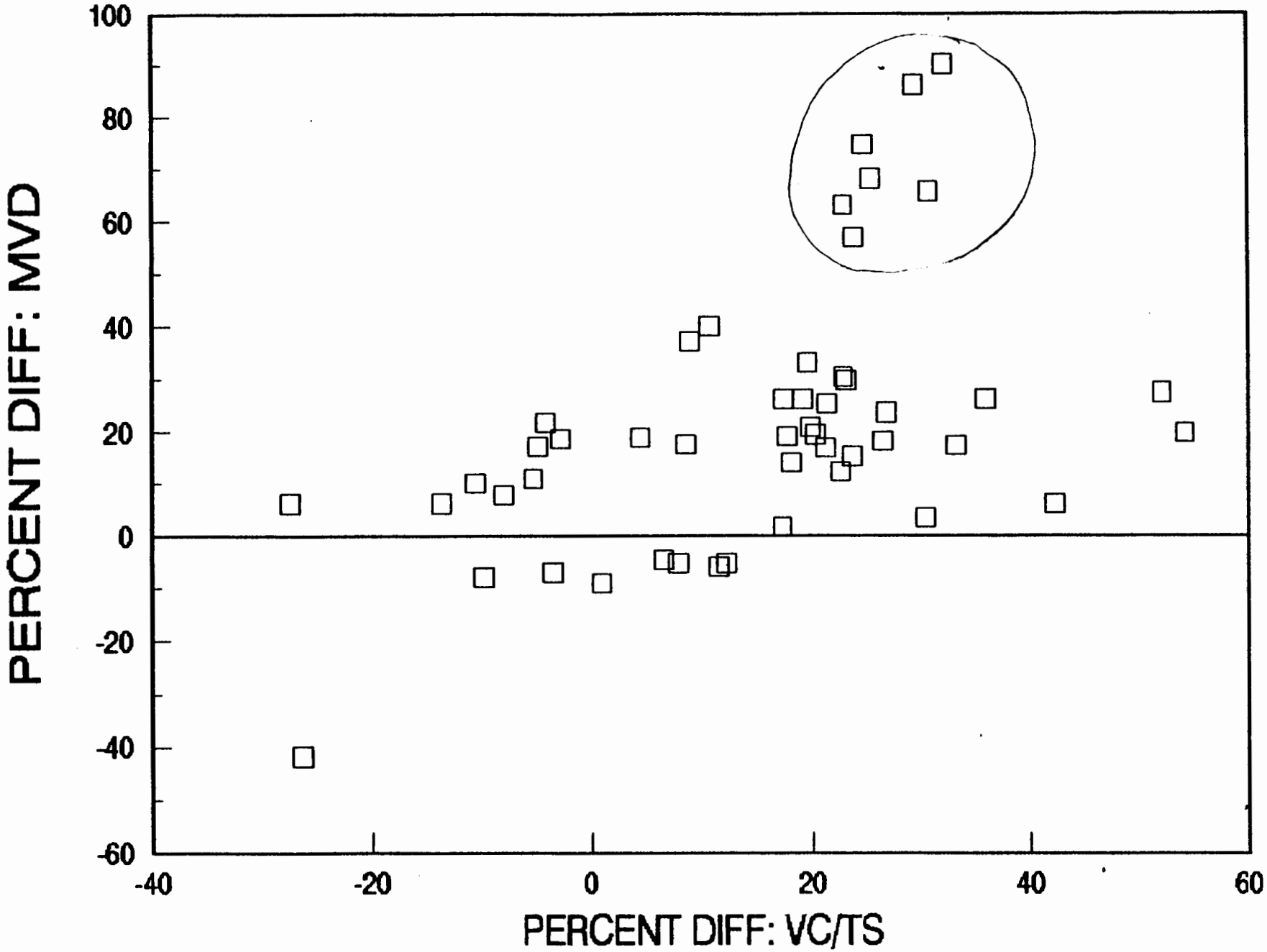

PERCENT DIFF: MVD
100
80
60
40
20
0
-20
-40
-60
-40
-20
0
20
40
60
PERCENT DIFF: VC/TS

FIGURE D-3.

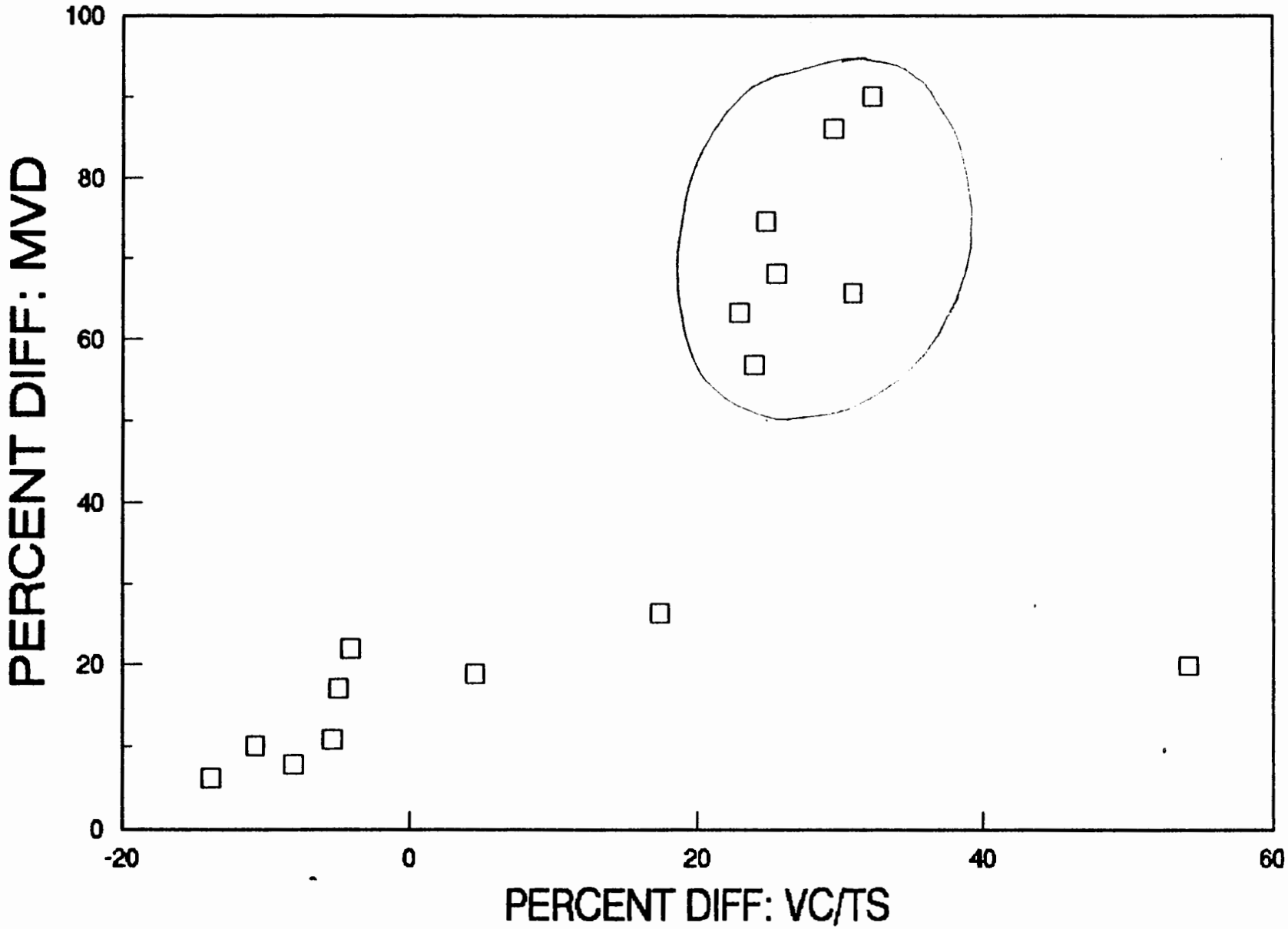

PERCENT DIFF: MVD
100
80
60
40
20
0
-20
0
20
40
60
PERCENT DIFF: VC/TS

FIGURE D-4.

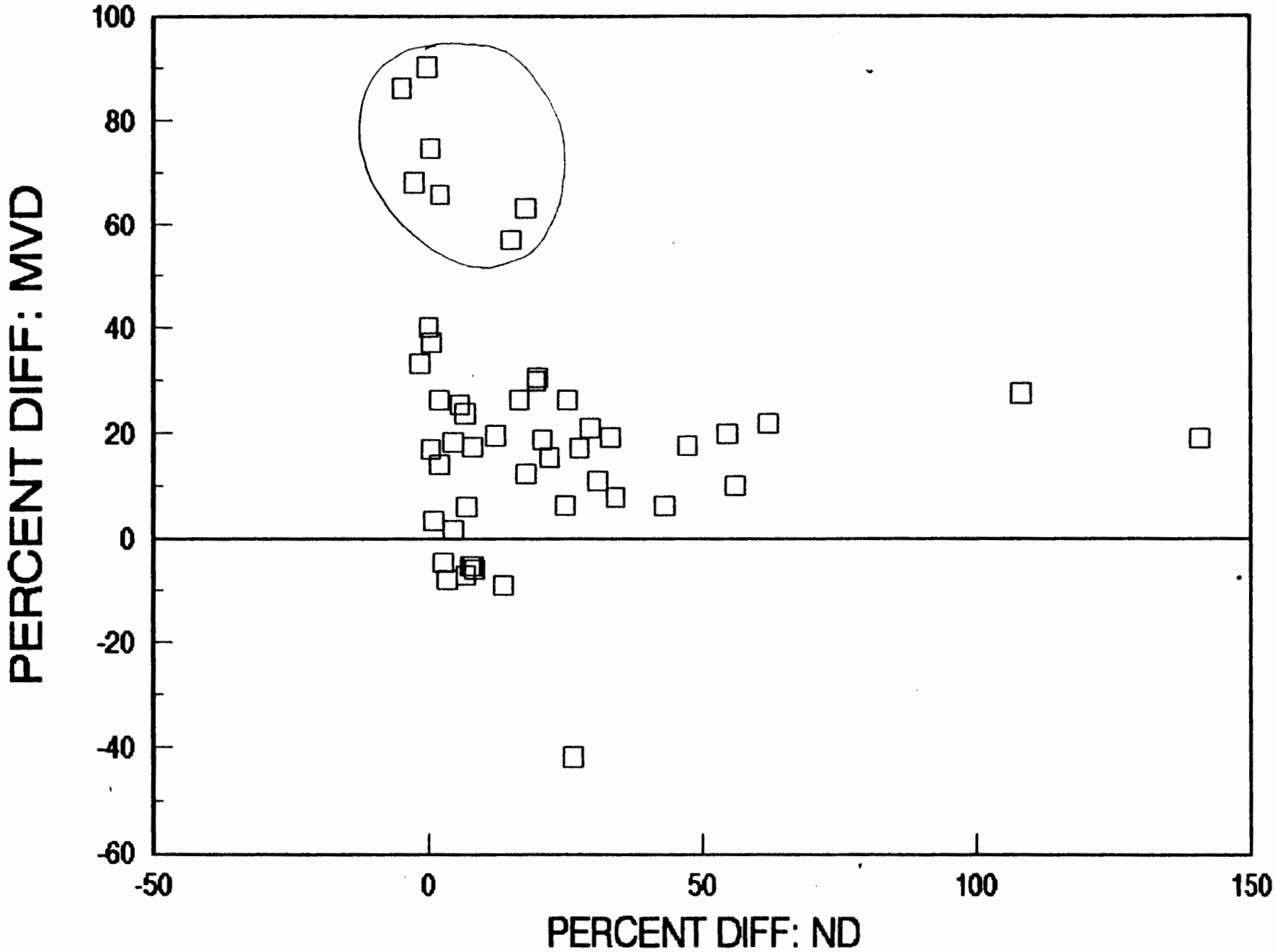

PERCENT DIFF: MVD
100
80
60
40
20
0
-20
-40
-60
-50
0
50
100
150
PERCENT DIFF: ND

FIGURE D-5.

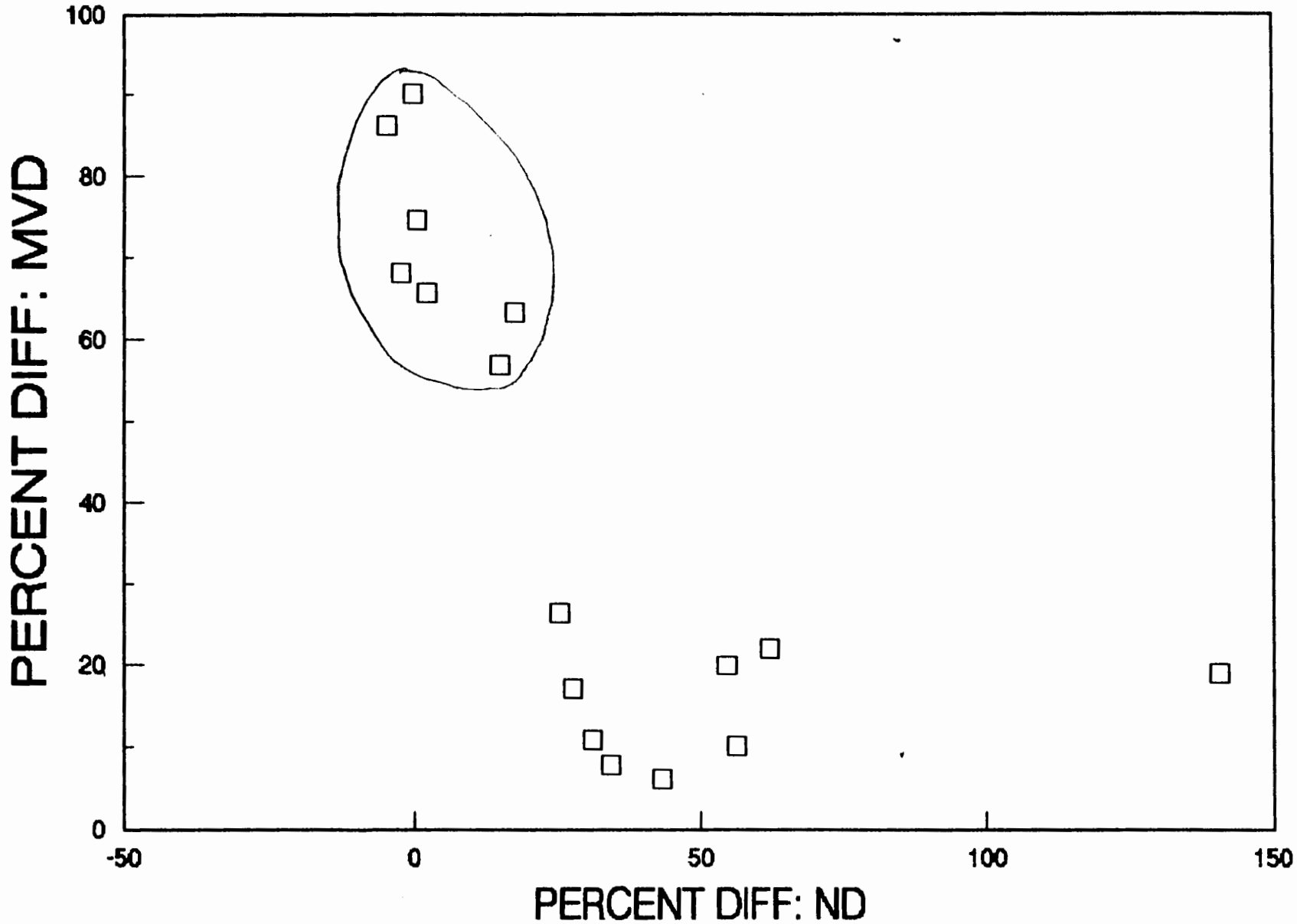

PERCENT DIFF: MVD
100
80
60
40
20
0
-50
0
50
100
150
PERCENT DIFF: ND

FIGURE D-6.

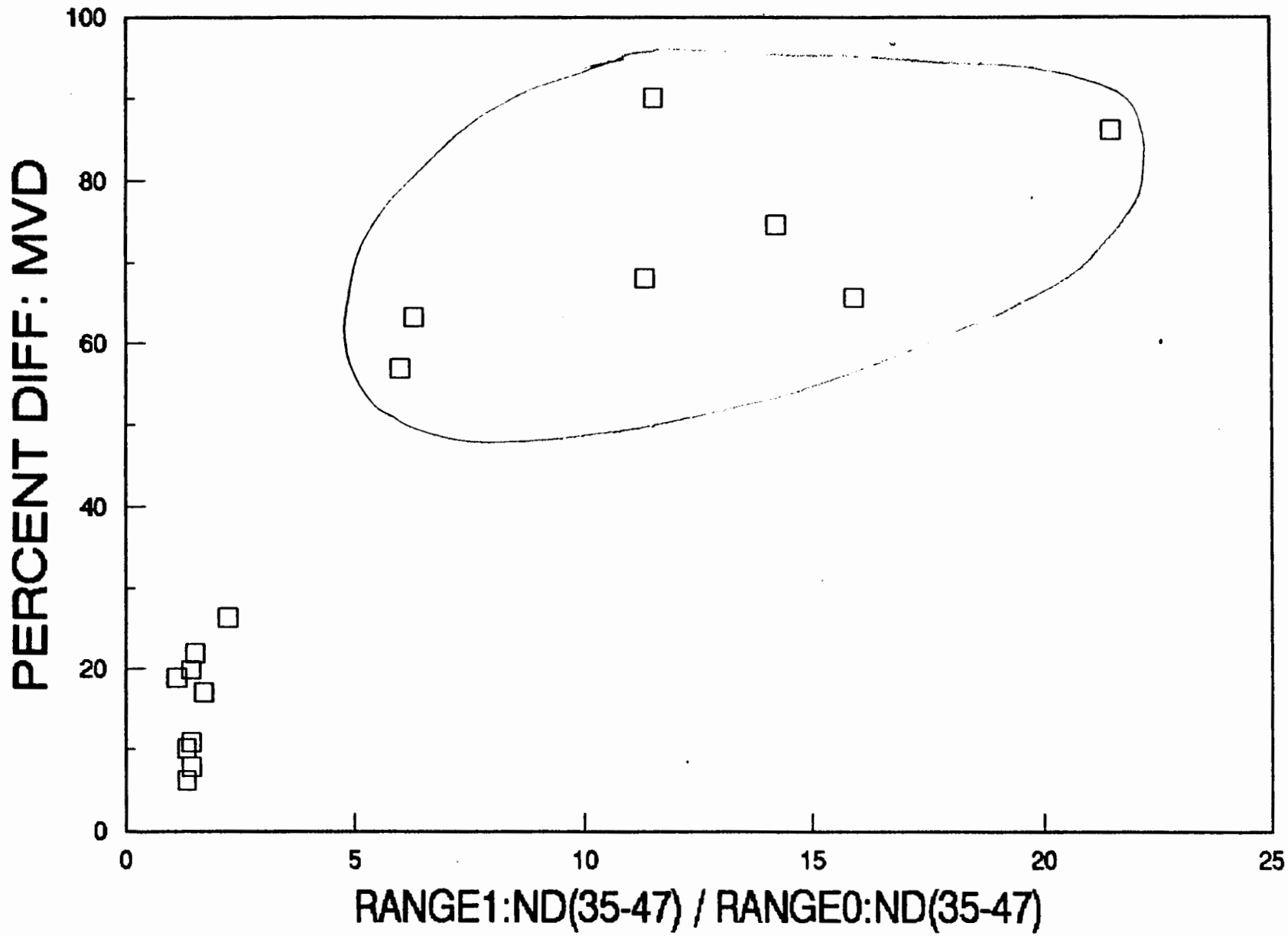

PERCENT DIFF: MVD
100
80
60
40
20
0
0
5
10
15
20
25
RANGE1:ND(35-47) / RANGE0:ND(35-47)

FIGURE D-7.