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Computer Analysis of Cell Volume Distributions

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Computer Analysis of Cell Volume Distributions

by

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ABSTRACT

Two computer programs have been written to analyze cell volume distributions measured with a Coulter type of cell spectrometer. One of the programs, called AVØL, is used to calculate the mean cell volume of any type of distribution and to plot the data in various formats. The other program, called CELVØL, uses an iterative least-squares technique to fit either normal, log-normal, or skewed-normal distributions to the data. Either single- or double-peak distributions can be fitted. The program also converts the results of the fit to cell concentration in each peak in cells per cubic millimeter, standard deviation in cubic microns, and mean cell volume in cubic microns. For red blood cells the mean cell volume is also calculated from the hematocrit and included in the data output listing.

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CHAPTER 1

INTRODUCTION

The use of electronic particle counters to measure volume distributions of cells has brought forth a requirement for an accurate method of analyzing the volume spectra (1). To study the changes in volume distributions of various cells under different experimental conditions requires a precise knowledge of the parameters of the distribution. Some cell volume distributions can be fitted quite accurately with normal, log-normal, or skewed-normal functions. Such calculations require computer techniques. This report describes two computer programs which perform these calculations. The parameters calculated are the area (number of cells), standard deviation, mean, and, if applicable, coefficient of skewness. The CELVØL program will fit either single- or double-peak distributions. Two peaks with mean volumes of 50 and 60 cubic microns have been resolved by this program. The function chosen to fit the data is determined primarily by the type of cell being measured. Red and white blood cells appear to be fitted "best" by a skewed-normal function. Growing cell populations may have a distribution (determined by dynamics of growth) which cannot be fitted well with either function.

CHAPTER 2

AVØL COMPUTER PROGRAM

This program reads in the data, calculates the mean, standard deviation, and area for a selected band of channels, prints out the results, and then plots the data in various formats. There are options for plotting either linear or logarithmic coordinates in any combination. There are also options for excluding certain channels from the plots. All calculated data are also printed on the plot. The arithmetic mean of the distribution, μ, is calculated from the relation

$$\mu = \frac{\sum_{i=k}^{l} if_i}{\sum_{i=k}^{l} f_i} ,$$

where i is the channel number, f_i is the number of cells in channel i, and k and l are the lower and upper channel numbers that define the band of data that are to be used in the calculation to exclude debris and pulser signals. This is shown in the example. The standard deviation, σ, is calculated from the relation

$$\sigma = \frac{\sum_{i=k}^{l} f_i (i-\mu)^2}{\sum_{i=k}^{l} f_i},$$

where the variables are as described above. The area is the summation $A = \sum_{i=k}^{l} f_i$.

The format of the control card used with this program is shown in Table 1. If no lower and upper limits for the logarithmic plot are entered (columns 53 and 54), the limits are determined by the program. The program contains the option of having the entire spectrum shifted any number of channels (column 55). The plotting options can be used in any combination (columns 64 and 65). If zero, the plot will be linear only. If a logarithmic plot is called for, there will automatically be a linear plot as well. The ADD-1 value entered in columns 66-72 is the total number of pulses stored in the analyzer, obtained by counting the ADD-1 or stored pulses with an external scaler. The program will sum the counts in all channels and list this as well as the ADD-1, providing a check on accuracy of the data printout from the analyzer. The serial number is used to identify the data deck.

The control card is followed by the data cards. The data card format is shown in Table 2. For a 100-channel

Table 1. AVØL Control Card Format

Column	Information
1-52	Alpha-numeric information used to describe the data being analyzed
53	Lower limit for logarithmic plot of data; exponent of power of 10 (e.g., 2 for 100)
54	Upper limit for logarithmic plot of data; exponent of power of 10 (e.g., 4 for 10,000)
55	Number of channels spectrum is to be shifted
56	Set = 1, if only channels above 10 are to be plotted
57	Number of hundreds of channels to be read in (i.e., 1 for 100, 2 for 200, etc., up to 400)
58-59	First channel to be used in computation
60-62	Last channel to be used in computation
63	Set = 1, if printout of input and calculated data is desired
64	Set = 1 for plot of log X
65	Set = 1 for plot of log Y
66-72	ADD-1
73-80	Serial number

Table 2. AVØL Data Card Format

Column	Information
1-3	Sequence number of data card in the data deck, beginning with zero*
4-9	Channel 1
10-16	Channel 2
17-23	Channel 3
24-30	Channel 4
31-37	Channel 5
38-44	Channel 6
45-51	Channel 7
52-58	Channel 8
59-65	Channel 9
66-72	Channel 10
73-80	Serial number

*The second card would contain channels 11-20, the third channels 21-30, etc.

spectrum, there would be 10 cards. The serial number is repeated on each card.

The order of control card and data cards may be repeated as many times as desired. Figure 1 shows the card order of a problem processed by the AVØL program. Figure 2 shows the output listing. The selected area is the sum of the counts in channels 25-95. Data are printed out to channel 105, since the spectrum was shifted by 5 channels. Figure 3 is a log-log plot of the data, and Fig. 4 is a linear plot of the data. The plots also contain all computed values. A FORTRAN listing of the AVØL computer program, with the exception of the plotting subroutines, is contained in Appendix 1.

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1–6	7–12	13–18	19–24	25–30	31–36	37–42	43–48	49–54	55–60	61–66	67–72	73–80
CP-4	3 CHØ	CELLS	, SYNC	HRØNIZ	ED, PR	E DIVI	SIØN	13	51120	90111	21146	43
0			4	56	121		113	109	91	100	96	43
1	106	121	127	99	118		115	99	97	108	120	43
2	106	116	126	140	160		178	178	197	264	300	43
3	322	342	379	456	459		530	560	540	564	527	43
4	546	584	591	561	560		572	551	533	509	492	43
5	500	469	433	422	339		352	329	306	295	291	43
6	242	259	242	227	222		224	202	184	160	152	43
7	132	121	125	97	103		67	92	75	69	64	43
8	58	39	51	28	34		45	37	35	28	24	43
9	32	21	22	25	30		19	18	23	24	15	43

Fig. 1. Example of the card order required by the AVØL computer program.

CP-43 CHO CELLS, SYNCHRONIZED, PRE DIVISION   43

MEAN CELL VOLUME = 52.45 CH
STANDARD DEVIATION = 13.99 CH
SELECTED AREA = 19237. CELLS
CHANNELS USED IN COMP. = 25 TO 95

ADD-1 TOTAL = 21146.
SUM OF 105 CH = 21146.

	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	-0	-0	4	56	121
1	113	109	91	100	96	106	121	127	99	118
2	115	99	97	108	120	106	116	126	140	160
3	178	178	197	264	300	322	342	379	456	459
4	530	560	540	564	527	546	584	591	561	560
5	572	551	533	509	492	500	469	433	422	339
6	352	329	306	295	291	242	259	242	227	222
7	224	202	184	160	152	132	121	125	97	103
8	67	92	75	69	64	58	39	51	28	34
9	45	37	35	28	24	32	21	22	25	30
10	19	18	23	24	15	0	0	0	0	0

Fig. 2. AVØL output listing for the data shown in Fig. 1.

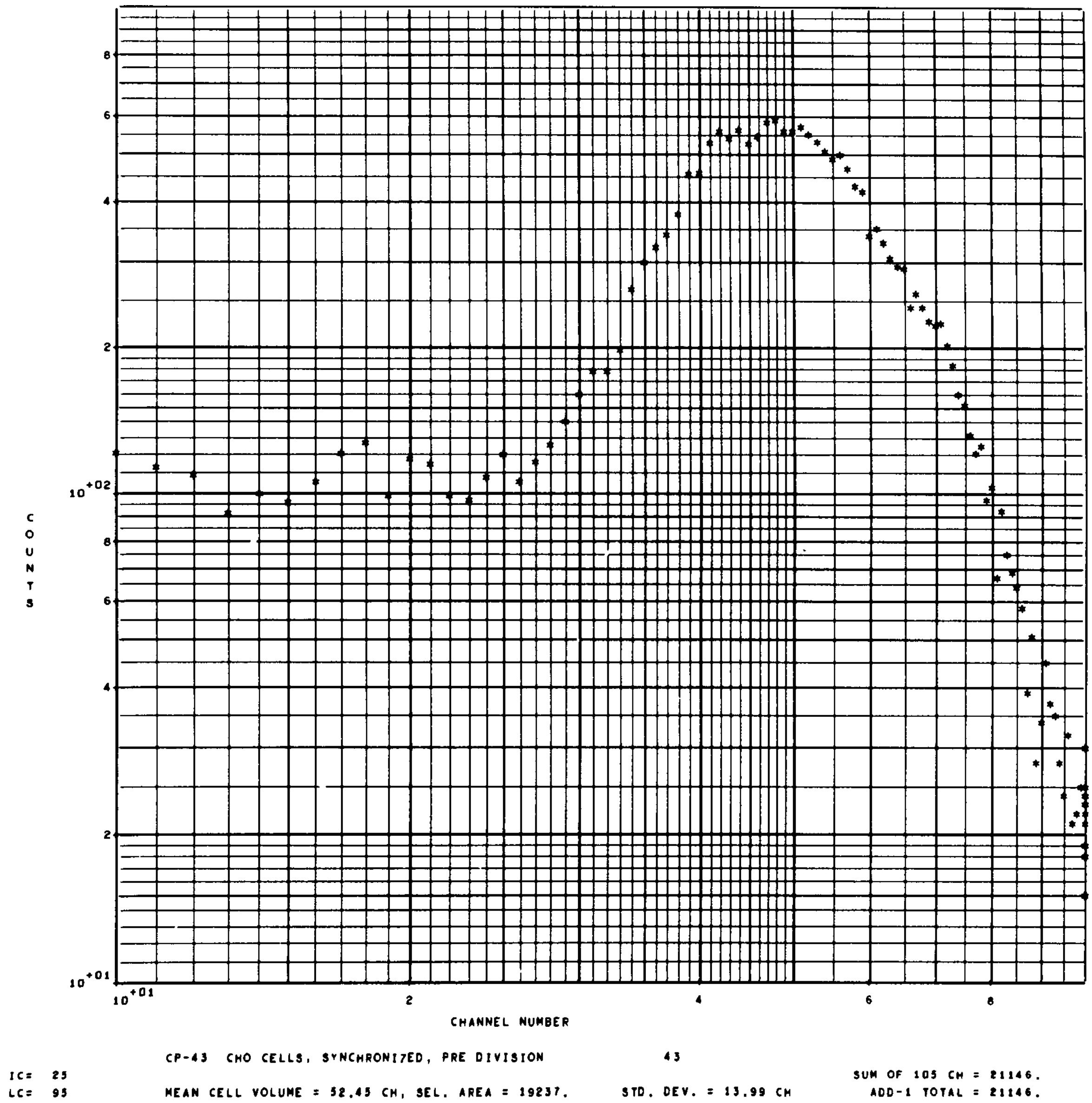

Fig. 3. A log-log plot of the count rate data of Fig. 2.

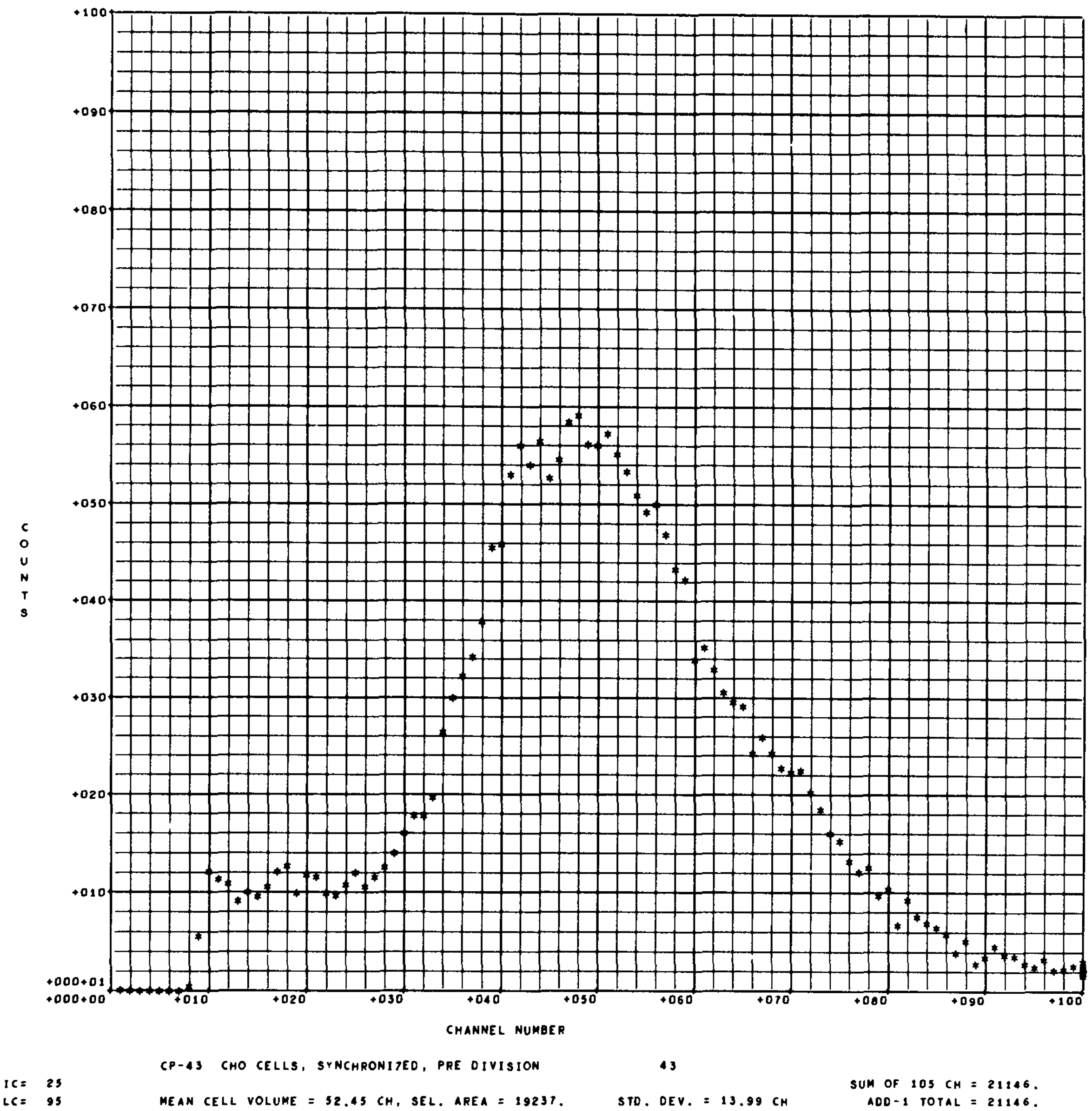

Fig. 4. A linear plot of the count rate data of Fig. 2.

CHAPTER 3

CELVØL COMPUTER PROGRAM

This program reads in the data, fits the peaks with normal, log-normal, or skewed-normal functions as specified by a control card, prints out the results, and plots the data points and computed curve. The function used in the normal fit is:

$$Y_i = \frac{Ni}{\sqrt{2\pi}\ \sigma} \exp\left[-1/2\left(\frac{X_i-\mu}{\sigma}\right)^2\right],$$

where Y_i is the frequency (number of cells) in the i^{th} channel, Ni is the area (total number of cells), σ is the standard deviation, and μ is the arithmetic mean of the distribution. A selected band of channels can be used in the fit to exclude debris and pulser signals from the computation. The function used in the log-normal fit is (2):

$$Y_i = \frac{Ni}{\sqrt{2\pi}\ \sigma_{log}\ X_i} \exp\left[-1/2\left(\frac{\log X_i-\mu_{log}}{\sigma_{log}}\right)^2\right],$$

where σ_{log} is the standard deviation and μ_{log} is the mean of the distribution of log X's. The interpretation of the results of the fit is perhaps more convenient if the parameters are given for the distribution of X's rather than the log X's. The standard deviation and mean are transformed by the following relations (3):

$$\mu = \exp\left[\left(\mu_{\log} + \frac{\sigma_{\log}^{2}}{2M}\right)\frac{1}{M}\right]$$

$$\sigma^{2} = \exp\left[\left(\mu_{\log} + \frac{\sigma_{\log}^{2}}{M}\right)\frac{2}{M} - \mu^{2}\right],$$

where $M = \log_{10} e$.

The function used in the skewed-normal fit is (2):

$$Y_i = \frac{Ni}{\sqrt{2\pi}\,\sigma}\,(1-A)\,\exp\left[-1/2\left(\frac{X_i-\mu}{\sigma}\right)^{2}\right],$$

$$A = \frac{\alpha_3}{2}\left[\frac{X_i-\mu}{\sigma} - 1/3\left(\frac{X_i-\mu}{\sigma}\right)^{3}\right],$$

where α_3 is the coefficient of skewness and the other variables are as defined above. A coefficient of skewness of zero would result in a normal distribution.

The general least-squares procedure used to fit the data has been described in detail elsewhere (4). Briefly, the Gauss method of solving the nonlinear problem is utilized.

This method consists essentially of linearizing the desired function with respect to each of the parameters by means of a truncated Taylor's series. Initial "guesstimates" of the parameters are used to evaluate the coefficients of the expansion and to obtain new parameter estimates. Until some convergence criterion is satisfied, the iterative procedure is repeated. Our particular criterion is that every parameter estimate of the function must agree with its corresponding value in the previous iteration to within one part per million. The final "best" estimates of the parameters are then substituted in the classical least-squares equation to verify their validity.

If a single peak is being fitted, the program will compute the "guesstimates" by the method described in Chapter 2. If two peaks are being fitted, the "guesstimates" must be provided for the program.

The format of the control card used with this program is shown in Table 3. Polyethylene spheres are usually used to calibrate the gain of the counter. If a 1 is punched into column 69, the spectrum is treated as a calibration measurement. The program will calculate the mean channel number and then a ratio to the mean channel number of the original calibration (channel 50.3). The computed data are then corrected by this ratio. If spheres are measured both before and after a set of measurements, both mean channel numbers

Table 3. CELVØL Control Card Format

Column	Information
1-2	Experiment number
3-8	Serial number
9-24	Animal or subject identification (alpha-numeric)
26-32	Date, as 14SEP65
35	Number of peaks
38-39	Initial channel of data to be fitted
41-42	Last channel of data to be fitted
44-47	Time sample was counted, in minutes (decimal point between columns 46 and 47)
48-54	ADD-1 count (total number of pulses stored in analyzer)
55-59	Calibration factor to convert from channel number to cubic microns
60-63	Hematocrit
68	Set = 0 to fit data with skewed-normal function = 1 to fit data with normal function = 2 to fit data with log-normal function
69	Set = 1 if spectrum is of spheres (for calibration)
70	Set = 0 for main output sheet only = 1 for complete listing of input and calculated data = 2 for plot only
71	Parameter sign control = 1 for no control = 2 for sign fixed = 0 for sign fixed for 5 iterations
72	Set = 1 if "guesstimates" are to be read in (for 2 peaks)
73-80	Repeat of experiment number and serial number

are computed and then averaged. "Guesstimates" must be provided if the program is to fit two peaks to a set of data. The format of the "guesstimate" card is shown in Table 4. The data card format is the same as for the AVØL program and is shown in Table 2. The card order required by the program is shown in Table 5. There are several features built into the program to verify that all cards contain the correct information in the proper order. All cards of a data deck must contain the same serial number in columns 73-80. The 10 cards containing the spectrum are checked to verify that the sequence numbers in column 3 are in the correct order. The control card must contain the year in columns 31 and 32. It is used to identify the card as being the control card. If any errors are found, the program skips the spectrum, searches for the next sample, and continues computation.

Figure 5 shows the card order of two problems processed by the CELVØL program. Only one peak is fitted to the first spectrum and two to the second. Figures 6, 7, and 8 are the output listings for the first spectrum fitted with a skewed-normal function. Most of the information printed on the sheets is self-explanatory, although a few of the variables should be defined. The number of iterations required to reach the convergence criterion is printed. The maximum number of iterations that the program will attempt is 26. The

Table 4. CELVØL "Guesstimate" Card Formats

Column	Information
For Normal and Log-Normal Fits	
1-6	Area of first peak (number of cells)
7-14	Standard deviation of first peak (in channels)
15-22	Mean of first peak (in channels)
37-42	Area of second peak (number of cells)
43-50	Standard deviation of second peak (in channels)
51-58	Mean of second peak (in channels)
For Skewed-Normal Fit	
1-6	Area of first peak (number of cells)
7-14	Standard deviation of first peak (in channels)
15-22	Mean of first peak (in channels)
23-29	Coefficient of skewness of first peak
37-42	Area of second peak (number of cells)
43-50	Standard deviation of second peak (in channels)
51-58	Mean of second peak (in channels)
59-65	Coefficient of skewness of second peak

Table 5. CELVØL Card Order*

Card	Information
1	Control card
2	"Guesstimate" card, if required
3	First card of data deck, containing only the serial number in channels 73-80
4	Data deck (10 cards)

*This card order can be repeated as many times as desired.

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1–6	7–12	13–18	19–24	25–30	31–36	37–42	43–48	49–54	55–60	61–66	67–72	73–80
11000085		MØUSE NØ.	3C	16ØCT	64 1	20 50	10	55197	2560	590	0 1	11000085
												1100085
0	3	5	3	8		8	10	17	17	30	37	11000085
1	33	46	58	66	64		93	90	123	159	192	11000085
2	240	335	520	749	1030	1501		2016	2560	3147	3623	11000085
3	3922	4050	4133	3883	3546	3119		2633	2187	1693	1399	11000085
4	1002	684	541	393	260		178	130	95	63	60	11000085
5	47	36	27	44	34		37	39	31	44	40	11000085
6	37	42	36	41	50		29	33	32	25	17	11000085
7	20	18	21	17	15		18	19	16	21	15	11000085
8	18	20	25	27	31		59	1533	1725	72	71	11000085
9	2	3	3	3		1	2	4	0	1	6	11000085
11000084		MØUSE NØ.	14	16ØCT	64 2	20 80	10	29827	2560	418	2 1 1	11000084
12110	4.7		30.2			13613	10.7		55.5			11000084
												11000084
0		1	6	5		1	3	8	12	14	11	11000084
1	14	12	15	25	20		33	37	64	89	108	11000084
2	158	218	339	387	583		681	852	1007	1083	1049	11000084
3	1070	992	877	809	652		580	478	388	330	308	11000084
4	314	263	307	292	316		334	344	386	420	410	11000084
5	449	507	477	505	473		546	544	492	489	504	11000084
6	454	453	376	370	371		317	265	245	210	189	11000084
7	156	143	124	120	91		91	79	54	52	58	11000084
8	53	49	39	33	39		58	1342	2101	70	27	11000084
9	17	14	13	9		9	9	8	9	10	9	11000084

Fig. 5. Two examples of the card order required by the CELVØL computer program.

EXPT. 11 MOUSE NO. 3C SERIAL 11000085 16OCT64

SKEWED NORMAL DISTRIBUTION (1) FIT TO EXPERIMENTAL DATA.

INPUT DATA CONSISTS OF 100 DATA POINTS (OR CHANNELS) OF WHICH CHANNELS 20 TO 50 ARE USED IN FIT.
COUNTING TIME = T = 1.00 MINUTES LIVE.

SUM OF 100 CHANNELS IS 55197 COUNTS.
ADD-1 SCALER RECORDED 55197 COUNTS.
DIFFERENCE IS 0 COUNTS.

SUM CHANNELS FITTED IS 49884 COUNTS.

NUMBER ITERATIONS = 7

WEIGHTED VARIANCE = 1.79

UNWGT SUM SQUARES
OF DEVIATIONS = 1.30E 05

MEAN CHANNEL NUMBER OF SPHERE SPECTRUM (11000081) IS 52.42

MEAN CHANNEL NUMBER OF SPHERE SPECTRUM (11000087) IS 51.90

RBC = CELLS PER CUBIC MILLIMETER = (K/T)(SUM 100 CHANNELS) = 14.13 MILLION, WHERE K = 256.0
HCT = 59.0
MCV = 41.8 CUBIC MICRCNS.

	PARAMETER	GUESSTIMATE		BEST ESTIMATE	STD.DEV.	CALIBRATED BEST ESTIMATE (STD.DEV.)
PEAK 1	AREA	49884.	CTS	49807.	299.	12.75 (0.077) MILLION *
	S.D.	4.99	CHS	4.99	0.024	8.27 (0.039) CU MICRONS **
	MEAN	32.93	CHS	32.92	0.031	54.60 (0.051) CU MICRONS **
	SKEW	0.200		0.189	0.020	0.189(0.020)

* FACTOR = K/T
** FACTOR = 1.72(0.964)

MEAN CHANNEL NUMBER AS CALCULATED FROM 100 EXPERIMENTAL DATA POINTS = 36.63

Fig. 6. First page of CELVØL output listing for an analysis of the first example of Fig. 5.

CHANNEL NUMBER	WEIGHT FACTOR	EXPERIMENTAL DATA	CALCULATED DATA	DIFFERENCE
1	0.	3.	-0.	0.0
2	0.	5.	-0.	0.0
3	0.	3.	-0.	0.0
4	0.	8.	-0.	0.0
5	0.	8.	-0.	0.0
6	0.	10.	-0.	0.0
7	0.	17.	-0.	0.0
8	0.	17.	-0.	0.0
9	0.	30.	-0.	0.1
10	0.	37.	-0.	0.2
11	0.	33.	-0.	0.3
12	0.	46.	-1.	0.6
13	0.	58.	-1.	0.9
14	0.	66.	-1.	1.1
15	0.	64.	-1.	0.8
16	0.	93.	1.	-1.1
17	0.	90.	7.	-6.8
18	0.	123.	20.	-19.9
19	0.	159.	47.	-46.9
20	0.00521	192.	97.	95.1
21	0.00417	240.	182.	57.7
22	0.00299	335.	318.	17.4
23	0.00192	520.	518.	1.9
24	0.00134	749.	796.	-47.0
25	0.00097	1030.	1156.	-126.4
26	0.00067	1501.	1593.	-92.4
27	0.00050	2016.	2087.	-71.3
28	0.00039	2560.	2604.	-44.1
29	0.00032	3147.	3099.	48.2
30	0.00028	3623.	3522.	101.1
31	0.00025	3922.	3828.	93.7
32	0.00025	4050.	3985.	64.9
33	0.00024	4133.	3978.	155.0
34	0.00026	3883.	3814.	69.4
35	0.00028	3546.	3517.	29.4
36	0.00032	3119.	3124.	-5.4
37	0.00038	2633.	2679.	-46.3
38	0.00046	2187.	2222.	-34.6
39	0.00059	1693.	1784.	-91.2
40	0.00071	1399.	1390.	9.2
41	0.00100	1002.	1051.	-49.3
42	0.00146	684.	773.	-88.8
43	0.00185	541.	552.	-11.0
44	0.00254	393.	383.	9.9
45	0.00385	260.	258.	1.9
46	0.00562	178.	169.	9.4
47	0.00769	130.	107.	23.3
48	0.01053	95.	65.	29.8
49	0.01587	63.	39.	24.5
50	0.01667	60.	22.	38.1
51	0.	47.	12.	-12.0
52	0.	36.	6.	-6.3
53	0.	27.	3.	-3.2
54	0.	44.	2.	-1.6
55	0.	34.	1.	-0.7
56	0.	37.	0.	-0.3
57	0.	39.	0.	-0.1
58	0.	31.	0.	-0.1
59	0.	44.	0.	-0.0
60	0.	40.	0.	-0.0

Fig. 7. Second page of CELVØL output listing for an analysis of the first example of Fig. 5.

61	0.	37.	0.	-0.0
62	0.	42.	0.	-0.0
63	0.	36.	0.	-0.0
64	0.	41.	0.	-0.0
65	0.	50.	0.	-0.0
66	0.	29.	0.	-0.0
67	0.	33.	0.	-0.0
68	0.	32.	0.	-0.0
69	0.	25.	0.	-0.0
70	0.	17.	0.	-0.0
71	0.	20.	0.	-0.0
72	0.	18.	0.	-0.0
73	0.	21.	0.	-0.0
74	0.	17.	0.	-0.0
75	0.	15.	0.	-0.0
76	0.	18.	0.	-0.0
77	0.	19.	0.	-0.0
78	0.	16.	0.	-0.0
79	0.	21.	0.	-0.0
80	0.	15.	0.	-0.0
81	0.	18.	0.	-0.0
82	0.	20.	0.	-0.0
83	0.	25.	0.	-0.0
84	0.	27.	0.	-0.0
85	0.	31.	0.	-0.0
86	0.	59.	0.	-0.0
87	0.	1533.	0.	-0.0
88	0.	1725.	0.	-0.0
89	0.	72.	0.	-0.0
90	0.	7.	0.	-0.0
91	0.	2.	0.	-0.0
92	0.	3.	0.	-0.0
93	0.	3.	0.	-0.0
94	0.	3.	0.	-0.0
95	0.	1.	0.	-0.0
96	0.	2.	0.	-0.0
97	0.	4.	0.	-0.0
98	0.	0.	0.	-0.0
99	0.	1.	0.	-0.0
100	0.	6.	-0.	0.

Fig. 8. Third page of CELVØL output listing for an analysis of the first example of Fig. 5.

"guesstimate," final value, and standard deviation (S.D.) for each parameter are printed. The final values are also multiplied by calibration factors to convert the area from counts to millions of cells and the standard deviation and mean from channels to cubic microns. The calibration factors are also listed, identified by asterisks. The number in parentheses is the ratio of 50.3 to the average mean channel number of the two sphere spectra. The last line of the printout has the mean channel number calculated by the method described in Chapter 2 for the AVØL program. The second page of the listing contains the weighting factor, the experimental and calculated spectra, and their difference channel by channel. For accurate least-squares analysis of counting data, it is important that the data be properly weighted. "Statistical" weighting is used (that is, the reciprocal of the variance of the count rate in each channel) so that the weighted variance should be 1. Figure 9 is a plot of the experimental data (open circles) and computed spectrum (solid line). The solid circles show the limits of the data used in the calculation. The peak in channel 88 is due to a pulser and is used to monitor the gain of the electronics.

Figures 10, 11, and 12 are the output listings for the two-peak problem. Two log-normal distributions were used. The results of fitting each peak are listed separately. The

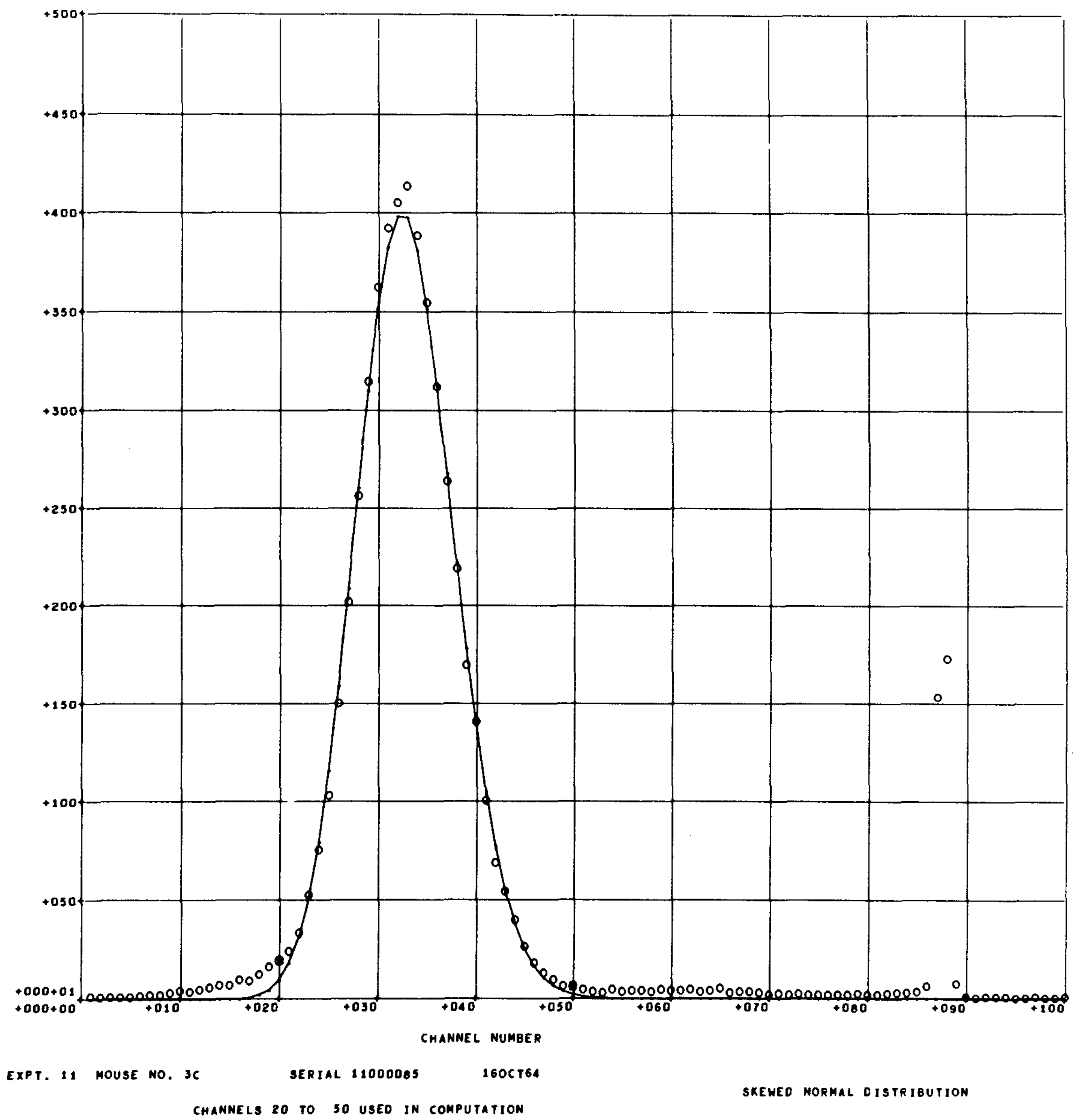

Fig. 9. A plot of the computed spectrum (solid line) and experimental data (open circles) of the example problem of Figs. 6, 7, and 8.

EXPT. 11 MOUSE NO. 14 SERIAL 11000084 16OCT64

LOG NORMAL DISTRIBUTION (2) FIT TO EXPERIMENTAL DATA.

INPUT DATA CONSISTS OF 100 DATA POINTS (OR CHANNELS) OF WHICH CHANNELS 20 TO 80 ARE USED IN FIT.
COUNTING TIME = T = 1.00 MINUTES LIVE.

SUM OF 100 CHANNELS IS 29827 COUNTS.
ADD-1 SCALER RECORDED 29827 COUNTS.
DIFFERENCE IS 0 COUNTS.

SUM CHANNELS FITTED IS 25539 COUNTS.

NUMBER ITERATIONS = 9

WEIGHTED VARIANCE = 1.17

UNWGT SUM SQUARES
OF DEVIATIONS = 5.14E 04

MEAN CHANNEL NUMBER OF SPHERE SPECTRUM (11000081) IS 52.42

MEAN CHANNEL NUMBER OF SPHERE SPECTRUM (11000087) IS 51.90

RBC = CELLS PER CUBIC MILLIMETER = (K/T)(SUM 100 CHANNELS) = 7.64 MILLION, WHERE K = 256.0
HCT = 41.8
MCV = 54.7 CUBIC MICRONS.

	PARAMETER	GUESSTIMATES		LOG NORMAL BEST ESTIMATE	STD.DEV.	TRANSFORMED BEST ESTIMATE	STD.DEV.	CALIBRATED BEST ESTIMATE (STD.DEV.)
PEAK 1	AREA	12110.	CTS	13457.	145.	13457.	145.	3.44 (0.037) MILLION *
	S.D.	0.072	CHS	0.074	0.001	5.39	0.062	8.93 (0.102) CU MICRONS **
	MEAN	1.48	CHS	1.49	0.001	31.18	0.020	51.73 (0.034) CU MICRONS **
PEAK 2	AREA	13613.	CTS	12253.	145.	12253.	145.	3.14 (0.037) MILLION *
	S.D.	0.089	CHS	0.072	0.001	9.66	0.131	16.03 (0.218) CU MICRONS **
	MEAN	1.74	CHS	1.76	0.001	57.76	0.033	95.81 (0.055) CU MICRONS **

* FACTOR = K/T
** FACTOR = 1.72(0.964)

MEAN CHANNEL NUMBER AS CALCULATED FROM 100 EXPERIMENTAL DATA POINTS = 48.94

Fig. 10. First page of CELVØL output listing for an analysis of the second example of Fig. 5.

CHANNEL NUMBER	WEIGHT FACTOR	EXPERIMENTAL DATA	CALCULATED DATA	DIFFERENCE
1	0.	-0.	0.	0.
2	0.	1.	0.	0.
3	0.	6.	0.	0.
4	0.	5.	0.	-0.0
5	0.	1.	0.	-0.0
6	0.	3.	0.	-0.0
7	0.	8.	0.	-0.0
8	0.	12.	0.	-0.0
9	0.	14.	0.	-0.0
10	0.	11.	0.	-0.0
11	0.	14.	0.	-0.0
12	0.	12.	0.	-0.0
13	0.	15.	0.	-0.0
14	0.	25.	0.	-0.1
15	0.	20.	0.	-0.3
16	0.	33.	1.	-1.4
17	0.	37.	5.	-4.7
18	0.	64.	13.	-13.4
19	0.	89.	32.	-32.3
20	0.00926	108.	68.	40.1
21	0.00633	158.	127.	31.2
22	0.00459	218.	213.	5.0
23	0.00295	339.	327.	12.4
24	0.00258	387.	462.	-74.6
25	0.00172	583.	607.	-24.2
26	0.00147	681.	749.	-68.0
27	0.00117	852.	872.	-20.5
28	0.00099	1007.	965.	41.6
29	0.00092	1083.	1020.	62.9
30	0.00095	1049.	1034.	14.9
31	0.00093	1070.	1010.	60.1
32	0.00101	992.	954.	38.2
33	0.00114	877.	874.	2.7
34	0.00124	809.	781.	28.3
35	0.00153	652.	682.	-30.1
36	0.00172	580.	586.	-5.8
37	0.00209	478.	498.	-19.9
38	0.00258	388.	422.	-34.2
39	0.00303	330.	361.	-31.3
40	0.00325	308.	316.	-8.2
41	0.00318	314.	287.	27.4
42	0.00380	263.	272.	-8.7
43	0.00326	307.	270.	37.2
44	0.00342	292.	279.	13.0
45	0.00316	316.	297.	18.9
46	0.00299	334.	322.	12.1
47	0.00291	344.	351.	-7.0
48	0.00259	386.	382.	3.7
49	0.00238	420.	414.	6.3
50	0.00244	410.	443.	-33.4
51	0.00223	449.	470.	-20.9
52	0.00197	507.	492.	15.0
53	0.00210	477.	509.	-31.9
54	0.00198	505.	520.	-15.0
55	0.00211	473.	525.	-52.0
56	0.00183	546.	524.	22.1
57	0.00184	544.	517.	26.9
58	0.00203	492.	505.	-13.0
59	0.00204	489.	488.	0.8
60	0.00198	504.	467.	36.5
61	0.00220	454.	443.	10.5

Fig. 11. Second page of CELVØL output listing for an analysis of the second example of Fig. 5.

62	0.00221	453.	417.	35.9
63	0.00266	376.	389.	-13.0
64	0.00270	370.	360.	10.1
65	0.00270	371.	330.	40.5
66	0.00315	317.	301.	15.7
67	0.00377	265.	273.	-7.8
68	0.00408	245.	245.	-0.4
69	0.00476	210.	219.	-9.4
70	0.00529	189.	195.	-5.9
71	0.00641	156.	172.	-16.2
72	0.00699	143.	151.	-8.4
73	0.00806	124.	132.	-8.4
74	0.00833	120.	115.	4.8
75	0.01099	91.	100.	-8.7
76	0.01099	91.	86.	5.0
77	0.01266	79.	74.	5.2
78	0.01852	54.	63.	-9.1
79	0.01923	52.	54.	-1.7
80	0.01724	58.	46.	12.4
81	0.	53.	39.	-38.5
82	0.	49.	32.	-32.5
83	0.	39.	27.	-27.2
84	0.	33.	23.	-22.8
85	0.	39.	19.	-19.0
86	0.	58.	16.	-15.8
87	0.	1342.	13.	-13.1
88	0.	2101.	11.	-10.9
89	0.	70.	9.	-9.0
90	0.	27.	7.	-7.4
91	0.	17.	6.	-6.1
92	0.	14.	5.	-5.0
93	0.	13.	4.	-4.1
94	0.	9.	3.	-3.3
95	0.	9.	3.	-2.7
96	0.	9.	2.	-2.2
97	0.	8.	2.	-1.8
98	0.	9.	1.	-1.5
99	0.	10.	1.	-1.2
100	0.	9.	1.	-0.9

Fig. 12. Third page of CELVØL output listing for an analysis of the second example of Fig. 5.

"guesstimates" are made and entered on the guesstimate card for the normal plane. The program then converts them to the log plane. The "best" fit values are then transformed back to the normal plane by the relations described earlier. The calibration values are as described for the first example. Figure 13 is a plot of the experimental data (open circles) and computed spectrum (solid line).

A FORTRAN listing of the CELVØL program, with the exception of the plotting and matrix inversion subroutines, is contained in Appendix 2.

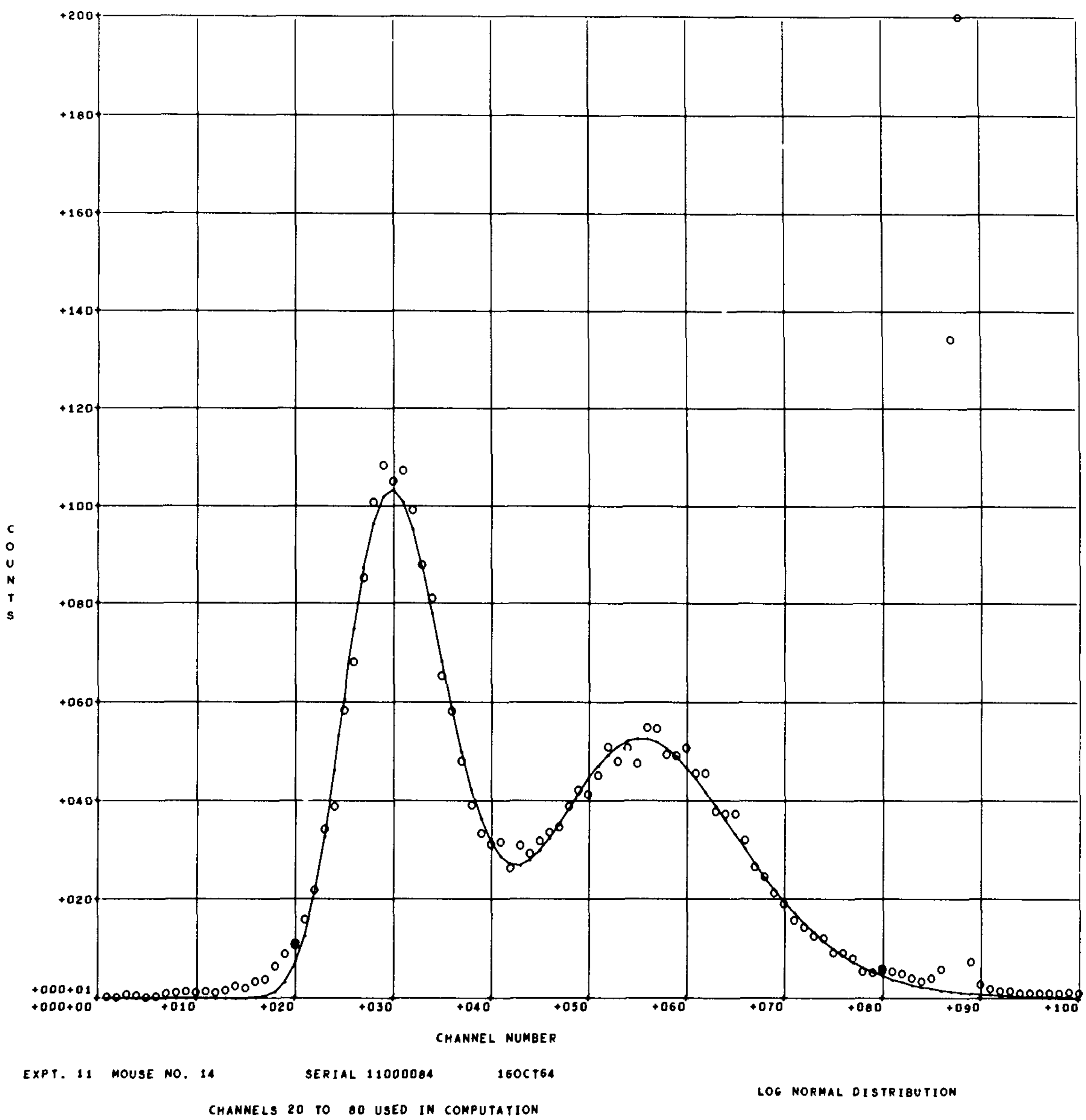

Fig. 13. A plot of the computed spectrum (solid line) and experimental data (open circles) of the example problem of Figs. 10, 11, and 12.

REFERENCES

(1) Los Alamos Scientific Laboratory Report LA-3132-MS (1964), pp. 142-232.

(2) F. E. Croxton and D. J. Cowden, eds., Applied General Statistics, Prentice-Hall, Englewood Cliffs, New Jersey (1958), pp. 617-619.

(3) J. F. Kenney and E. S. Keeping, Mathematics of Statistics, 2nd edition, Van Nostrand, New York (1951), p. 122.

(4) R. H. Moore and R. K. Zeigler, Los Alamos Scientific Laboratory Report LA-2367 (1960).

APPENDIX 1

```
AVOL                                                              11/02/65        PAGE 1
C     THIS PROGRAM COMPUTES MEAN CELL VOLUME, TOTAL NUMBER OF CELLS
C     AND STANDARD DEVIATION.
C     THE SPECTRUM IS PLOTTED WITH OPTIONS OF LINEAR OR LOG SCALES.
C     DATA CARD FORMAT IS COULTER COUNTER FORMAT.
      DIMENSION ALAB(11),CH(450),S(15),BND(4),AB(450),Y(450),TEMP(450),
     1BLAB(1),CLAB(3),NM(10),ICH(450),YCH(450)
    1 READ INPUT TAPE 10,100,(ALAB(I),I=1,9),IZ3,IZ4,IZ1,IZ2,NC,
     1IC,LC,IP,IX,IY,ADD1,ALAB(10),ALAB(11)
  100 FORMAT(8A6,A4,5I1,I2,I3,3I1,F7.0,A6,A2)
      DO 200 I=1,450
      CH(I)=0.
      ICH(I)=0.
      YCH(I)=0.
      AB(I)=0.
  200 Y(I)=0.
      IF(NC-1) 2,2,3
    2 NC=1
      INC=1
    3 N=NC*100+IZ1
      M=N
      IW=IZ1+1
      READ INPUT TAPE 10,101,(CH(I),I=IW,N)
      DO 201 I=1,N
  201 AB(I)=I
      IX3=0
  101 FORMAT(3X,F6.0,9F7.0)
      BCH=0.
      DO 7 I=1,N
    7 BCH=BCH+CH(I)
C     COMPUTE MEAN CHANNEL NUMBER
      SMCN=0.
      CHS=0.
      IC=IC+IZ1
      LC=LC+IZ1
      DO 6 I=IC,LC
      A=I
      SMCN=SMCN+A*CH(I)
    6 CHS=CHS+CH(I)
      BMCN=SMCN/CHS
C     BMCN=MEAN CHANNEL NUMBER
C     CALCULATE SIGMA
      RHM=0.
      DO 8 I=IC,LC
      A=I
    8 RHM=RHM+CH(I)*(BMCN-A)**2
      SIGMA=SQRTF(RHM/CHS)
      AREA=CHS
C     PLOT ROUTINE
   58 CONTINUE
      BND(1)=0.
      BND(3)=0.
      IF(IY) 9,9,13
    9 S(1)=5.0
      S(2)=10.0
      S(3)=20.0
```

```
      DO 90 I=1,N
   90 Y(I)=CH(I)
      DO 10 I=4,15,3
      S(I)=S(I-3)*10.
      S(I+1)=S(I-2)*10.
   10 S(I+2)=S(I-1)*10.
      ISY1=10
      ISY2=6
      ILY=6
      GO TO 60
   13 DO 15 I=1,6
   15 S(I)=10.**I
      DO 30 I=1,N
   30 Y(I)=LOG10F(CH(I))
   60 CONTINUE
      CALL MAX3(CH,-1,N,IPX,CHMAX)
      DO 12 I=1,15
      IF(CHMAX-S(I)) 11,11,12
   11 BND(4)=S(I)
      J=I
      GO TO 16
   12 CONTINUE
   16 IF(IY) 18,18,17
   17 BND(4)=J
      JY=0
      DO 170 I=IW,N
      JY=JY+1
  170 YCH(JY)=CH(I)
      L=NC*100
      CALL MIN3(YCH,-1,L,IPY,CHMIN)
      CI=1.
      JI=0
      IF(CHMIN-10.) 65,64,64
   64 CI=CI*10.
      JI=JI+1
      IF(CHMIN-CI) 62,62,64
   62 BND(3)=JI-1
   65 CONTINUE
      ISY1=BND(4)-BND(3)+10.
      ISY2=0
      ILY=ISY1
   18 IF(IX) 19,19,21
   19 BND(2)=NC*100
      ISX1=10
      ISX2=6
      ILX=6
      DO 190 I=1,N
  190 AB(I)=I
      GO TO 25
   21 IF(NC-1) 23,23,22
   22 INC=2
   23 BND(2)=INC+1
      ISX1=11+INC
      ISX2=0
      ILX=11+INC
   54 IF(IZ2) 52,52,51
```

```
   51 BND(1)=1.
      ISX1=10+INC
      ILX=10+INC
      JY=0
      DO 55 I=10,N
      JY=JY+1
      AB(JY)=LOG10F(AB(I))
   55 Y(JY)=Y(I)
      GO TO 25
   52 DO 24 I=1,N
      A=I
   24 AB(I)=LOG10F(A)
   25 CONTINUE
      IF(IZ3) 251,251,250
  250 ISY1=IZ4-IZ3+10
      ILY=ISY1
      BND(3)=IZ3
      BND(4)=IZ4
  251 CONTINUE
      CALL ADV FLM(0,1)
      CALL SEL GRD(ISX1,ISY1)
      CALL SEL GRD(ISX2,ISY2)
      CALL LBL GRD(ILX,ILY,BND)
      CALL PLFILM(M,TEMP,AB,-1,Y,-1,BND,44,0)
      BLAB(1)=6HCOUNTS
      CLAB(1)=6HCHANNE
      CLAB(2)=6HL NUMB
      CLAB(3)=2HER
      CALL WFILM(1,6,BLAB,0,30.0,6.0)
      CALL WFILM(0,14,CLAB,0,59.0,55.0)
      CALL WFILM(0,66,ALAB,0,61.0,20.0)
      CALL LINCNT(62)
  105 FORMAT(5H  IC=I4,91X,6HSUM OFI4,5H CH =F7.C)
      WRITE OUTPUT TAPE 12,105,IC,N,BCH
      CALL LINCNT(63)
      WRITE OUTPUT TAPE 12,106,LC,BMCN,AREA,SIGMA,ADD1
  106 FORMAT(5H  LC=I4,11X,18HMEAN CELL VOLUME =F6.2,
     14H CH,12H SEL. AREA =F7.0,6X,11HSTD. DEV. =,
     2F6.2,3H CH9X,13HADD-1 TOTAL =F7.0)
  107 FORMAT(6X18HMEAN CELL VOLUME =F6.2,3H CH,
     121X13HADD-1 TOTAL =F8.0/
     26X20HSTANDARD DEVIATION =F6.2,3H CH,
     317X6HSUM OFI4,5H CH =F8.0/
     46X15HSELECTED AREA =F8.0,6H CELLS/
     56X24HCHANNELS USED IN COMP. =I3,3H TOI4)
  108 FORMAT(1H ,5X10I7)
  109 FORMAT(1H0I6,10I7)
  110 FORMAT(1H5,10A6,A2)
      IF(IX3) 57,57,59
   57 IF(IX) 40,40,41
   40 IF(IY) 59,59,41
   41 IX=0
      IY=0
      IZ2=0
      IX3=1
      IZ3=0
```

```
      GO TO 58
   59 CONTINUE
      IF(IP) 1,1,26
   26 WRITE OUTPUT TAPE 9,110,(ALAB(I),I=1,11)
      WRITE OUTPUT TAPE 9,111
      WRITE OUTPUT TAPE 9,107,BMCN,ADD1,SIGMA,N,BCH,AREA,IC,LC
      WRITE OUTPUT TAPE 9,111
  111 FORMAT(1H-)
      DO 27 I=1,10
   27 NM(I)=I
      WRITE OUTPUT TAPE9,108,(NM(I),I=1,10)
      M=NC*10+1
      IJ=1
      IK=10
      DO 270 I=1,N
  270 ICH(I)=CH(I)
      DO 28 I=1,M
      J=I-1
      WRITE OUTPUT TAPE 9,109,J,(ICH(K),K=IJ,IK)
      IJ=IJ+10
   28 IK=IK+10
      GO TO 1
      END(1,0,0,0,0,0,1,0,0,1,0,C,0,0,0)
```

APPENDIX 2


```
C     THIS PROGRAM IS WRITTEN TO FIT ONE OR MORE SKEWED GAUSSIANS TO
C     CELL VOLUME SPECTRA TAKEN WITH THE COULTER COUNTER
C     PROGRAM COMPUTES ESTIMATES FOR A SINGLE PEAK.
C     FOR TWO PEAKS THE ESTIMATES MUST BE GIVEN TO THE PROGRAM.
C     THE PROGRAM CONTAINS THE OPTION OF FITTING THE DATA WITH NORMAL,
C     SKEWED NORMAL, OR LOG NORMAL FUNCTIONS
C     WRITTEN IN JANUARY 1965
      DIMENSION ANID(3),CH(100),AH(100),AMCN(2),IEXS(2),IS1S(2),IS2S(2),
     1BB(2),TEMP(100),AB(100),S(15),BND(4)
      DIMENSION Y(100),W(100),YC(100),DY(100),PG(40),P(40),SP(40),
     1BM(40,41),X(1,100),B(100),ALAB(1),BLAB(3),AN(40),PART(40),
     2Z(40),AM(40,40),DP(40),PC(40)
      DIMENSION PCC(6),AR(2),PERS(2),PERM(2),PERA(2),SPC(6)
      COMMON Y,X,W,Z,PG,P,SP,YC,DY,BM,B,AN,WVAR,SSQ,PART,TEST,NIT,IFG
     1,IFF,NPK
C     FORMATS FOR DATA INPUT
    1 FORMAT(I2,2I3,2A6,A4,A6,I2,I3,I4,I3,F5.1,F7.0,F5.1,F4.1,4X,5I1,
     12I4)
    2 FORMAT(2X,I1,F6.0,9F7.0,2I4)
  100 READ INPUT TAPE 10,1,IEX,KS1,KS2,ANID(1),ANID(2),ANID(3),DATE,IYR,
     1NPK,ICH,LCH,CT,ADD1,FK,HCT,IFF,IS,IP,IFG,IG,IS1,IS2
      IF(IYR) 50,50,101
   50 WRITE OUTPUT TAPE 9,51,IS1,IS2
   51 FORMAT(21H1     SPECTRUM NUMBER2I4,44H IS IN DOUBT. THERE ARE TOO
     1MANY DATA CARDS.)
      GO TO 100
C     READ IN DATA CARDS (SHOULD BE 11 OF THEM)
  101 IF(IG) 102,102,103
  103 IF(IFF-1) 107,105,108
  105 READ INPUT TAPE 10,106,(PG(I),I=1,6)
  106 FORMAT(F6.0,2F8.2,14X,F6.0,2F8.2)
      GO TO 102
  107 READ INPUT TAPE 10,104,(PG(I),I=1,8)
  104 FORMAT(F6.0,2F8.2,F7.2,7X,F6.0,2F8.2,F7.2)
      GO TO 102
C     READ IN ESTIMATES FOR LOG NORMAL FIT
  108 READ INPUT TAPE 10,106,(PG(I),I=1,6)
C     CONVERT ESTIMATES
      D=PG(2)
      A=SQRTF(PG(2)**2+PG(3)**2)
      B=LOG10F(A/PG(3))
      PG(2)=SQRTF(B)
      PG(3)=LOG10F(PG(3))
      D=PG(5)
      A=SQRTF(PG(5)**2+PG(6)**2)
      B=LOG10F(A/PG(6))
      PG(5)=SQRTF(B)
      PG(6)=LOG10F(PG(6))
  102 K=-1
      READ INPUT TAPE 10,2,IEC,(AH(I),I=1,10),JS1,JS2
      IF(JS1+JS2-IS1-IS2) 37,3,37
C     IF NOT ZERO SERIAL NUMBERS DO NOT CHECK, SKIP SAMPLE
    3 I1=1
      I2=10
      DO 6 M=1,10
```

```
      K=K+1
      READINPUT TAPE 10,2,IEC,(CH(I),I=I1,I2),JS1,JS2
      IF(IEC-K) 39,4,39
C     IF NOT ZERO CARDS ARE OUT OF SEQUENCE
    4 IF(JS1+JS2-IS1-IS2) 37,5,37
    5 I1=I1+10
    6 I2=I2+10
C     IF IS =1, THIS IS SPHERE SPECTRUM, COMPUTE MCN AND STORE
    7 IF(IS) 12,12,8
    8 JS0=1
      IF(ISONE) 10,10,9
    9 JS0=2
   10 SMCN=0.
      CHS=0.
      AMCN(2)=0.
      DO 11 I=30,70
      A=I
      SMCN=SMCN+A*CH(I)
   11 CHS=CHS+CH(I)
      AMCN(JS0)=SMCN/CHS
      IEXS(JS0)=IEX
      IS1S(JS0)=KS1+1000
      IS2S(JS0)=KS2+1000
      ISONE=1
      GO TO 100
   12 ISONE =0
C     COMPUTE MEAN CHANNEL NUMBER
      SMCN=0.
      CHS=0.
      DO 13 I=ICH,LCH
      A=I
      SMCN=SMCN+A*CH(I)
   13 CHS=CHS+CH(I)
      BMCN=SMCN/CHS
      SMCN=0.
      CHS=0.
      DO 130 I=1,100
      A=I
      SMCN=SMCN+A*CH(I)
  130 CHS=CHS+CH(I)
      GMCN=SMCN/CHS
C     GMCN= MEAN CHANNEL NUMBER CALCULATED FROM ALL DATA POINTS
      NCHF=LCH-ICH+1
      N=1C0
      IF(IFF-1) 133,131,131
  133 IK=NPK*4
      GO TO 132
  131 IK=NPK*3
  132 CONTINUE
      M=1
      J=ICH-1
      DO 14 I=1,J
      W(I)=0.
   14 Y(I)=0.
      J=LCH+1
      DO 15 I=J,100
```

```
      W(I)=0.
   15 Y(I)=0.
      TCH=0.
      DO 16 I=ICH,LCH
      TCH=TCH+CH(I)
      W(I)=1./CH(I)
   16 Y(I)=CH(I)
      SCH=0.
      DO 17 I=1,100
      X(1,I)=I
   17 SCH=SCH+CH(I)
  170 IF(IG) 171,171,19
  171 IF(IP-1) 172,172,2010
 2010 DO 2011 I=1,100
      YC(I)=0.
 2011 AB(I)=I
      GO TO 2012
C     CALCULATE SIGMA
  172 RHM=0.
      DO 18 I=ICH,LCH
   18 RHM=RHM+Y(I)*(BMCN-X(1,I))**2
      SIGMA=SQRTF(RHM/TCH)
      AREA =TCH
      IF(IFF-1) 463,463,462
C     COMPUTE ESTIMATES FOR LOG NORMAL FIT
  462 D=SIGMA
      A=SQRTF(D**2+BMCN**2)
      B=LOG10F(A/BMCN)
      SIGMA=SQRTF(B)
      BMCN=LOG10F(BMCN)
  463 CONTINUE
C     ASSIGN ESTIMATES FOR COMPUTATION
C     MEAN CHANNEL NUMBER ESTIMATE, BASED ON FITTED CHANNELS
      PG(1)=AREA
      PG(2)=SIGMA
      PG(3)=BMCN
      PG(4)=0.2
   19 TEST=0.000001
      CALL CELLP(M,N,IK)
C     WRITE ROUTINE
   20 FORMAT(11H1      EXPT.I3,2A6,A4,8X,6HSERIALI5,I4 ,6X,A6,I2//)
   21 FORMAT(34H0      SKEWED NORMAL DISTRIBUTION (I1,27H) FIT TO EXPERIM
     1ENTAL DATA.//////)
      IS2=IS2+10000
      WRITE OUTPUT TAPE 9,20,IEX,ANID(1),ANID(2),ANID(3),IS1,IS2,
     1DATE,IYR
  450 IF(IFF-1) 451,452,454
  451 WRITE OUTPUT TAPE 9,21,NPK
      GO TO 457
  452 WRITE OUTPUT TAPE 9,453,NPK
  453 FORMAT(27H0      NORMAL DISTRIBUTION (I1,27H) FIT TO EXPERIMENTAL D
     1ATA.//////)
      GO TO 456
  454 WRITE OUTPUT TAPE 9,455,NPK
  455 FORMAT(31H0      LOG NORMAL DISTRIBUTION (I1,27H) FIT TO EXPERIMENT
     1AL DATA.//////)
```

```
 456 INK=NPK*3+1
     P(INK)=0.
     PG(INK)=0.
     SP(INK)=0.
 457 CONTINUE
  22 FORMAT(76H-      INPUT DATA CONSISTS OF 100 DATA POINTS (OR CHANNEL
    1S) OF WHICH CHANNELSI3,3H TOI4,17H ARE USED IN FIT./
    225H      COUNTING TIME = T =F5.2,14H MINUTES LIVE.)
     WRITE OUTPUT TAPE 9,22,ICH,LCH,CT
  23 FORMAT(34H-            SUM OF 100 CHANNELS ISI3,I4,8H COUNTS.,17X,
    119HNUMBER ITERATIONS =I3/34H            ADC-1 SCALER  RECORDEDI3,
    2I4,8H COUNTS./34H                  DIFFERENCE ISI7,8H COUNTS.,
    317X,19HWEIGHTED VARIANCE =F6.2//34H            SUM CHANNELS FITTED
    4 ISI3,I4,8H COUNTS.17X 17HUNWGT SUM SQUARES/1H ,65X,13HOF DEVIATIO
    5NS5X1H=1PE9.2)
     ID=TCH*0.0001
     D=ID*10000
     JD=TCH-D+10000.
     IE=SCH*0.0001
     D=IE*10000
     JE=SCH-D+10000.
     IF=ADD1*0.0001
     D=IF*10000
     JF=ADD1-D+10000.
     JG=SCH-ADD1
     WRITE OUTPUT TAPE 9,23,IE,JE,NIT,IF,JF,JG,WVAR,ID,JD,SSQ
     IF(JSO) 29,29,24
  24 DO 25 I=1,JSO
  25 WRITE OUTPUT TAPE 9,26,IEXS(I),IS1S(I),IS2S(I),AMCN(I)
  26 FORMAT(46H-      MEAN CHANNEL NUMBER OF SPHERE SPECTRUM (I2,2I3,4H)
    1 ISF6.2)
  27 FORMAT(1H0)
     K=(14-JSO*2)/2
     DO 28 I=1,K
  28 WRITE OUTPUT TAPE 9,27
     GO TO 310
  29 DO 30 I=1,7
  30 WRITE OUTPUT TAPE 9,27
  31 FORMAT(68H      RBC = CELLS PER CUBIC MILLIMETER  =  (K/T)(SUM 100
    1 CHANNELS) =F6.2,19H MILLION, WHERE K =F6.1/11H      HCT =F5.1/
    211H      MCV =F5.1,15H CUBIC MICRONS.//)
 310 RBC=FK/CT*SCH*0.000001
     VCM=10.*HCT/RBC
     WRITE OUTPUT TAPE 9,31,RBC,FK,HCT,VCM
  34 FORMAT(1H 71X14H* FACTOR = K/T/
    11H 70X16H** FACTOR = 1.721H(F6.3,1H))
  35 FORMAT(75H-      MEAN CHANNEL NUMBER AS CALCULATED FROM 100 EXPERIM
    1ENTAL DATA POINTS =F6.2)
     IF(IFF-1) 338,337,336
 336 WRITE OUTPUT TAPE 9,330
C      FORMATS FOR PRINTING LOG NORMAL FITS
 330 FORMAT(1H041X10HLOG NORMAL16X11HTRANSFORMED20X10HCALIBRATED/
    11H 11X9HPARAMETER4X12HGUESSTIMATES3X13HBEST ESTIMATE,
    23X8HSTD.DEV.3X13HBEST ESTIMATE3X8HSTD.DEV.2X,
    313HBEST ESTIMATE11H (STD.DEV.))
     GO TO 339
```

```
  337 WRITE OUTPUT TAPE 9,32
      GO TO 339
  338 WRITE OUTPUT TAPE 9,32
   32 FORMAT(1H0,77X,10HCALIBRATED/1H 12X9HPARAMETER4X,11HGUESSTIMATE,
     15X,26HBEST  ESTIMATE    STD.DEV.4X24HBEST ESTIMATE (STD.DEV.))
  339 CONTINUE
      I=1
      NPKL=NPK
      DO 36 K=1,NPKL
      IF(IFF-1) 424,424,420
C     CONVERT LOG NORMAL PARAMETERS TO LINEAR PLANE
C     STD. DEV. CONVERTED ON PERCENT BASIS
  420 CONTINUE
      PCC(I)=P(I)
      SPC(I)=SP(I)
      PCC(I+1)=P(I+1)
      SPC(I+1)=SP(I+1)
      PCC(I+2)=P(I+2)
      SPC(I+2)=SP(I+2)
      PERA(K)=SP(I)/P(I)
      PERS(K)=SP(I+1)/P(I+1)
      PERM(K)=SP(I+2)/P(I+2)
      P(I+2)=EXPF((P(I+2)+0.5/0.434294*P(I+1)**2)/0.434294)
      SP(I+2)=P(I+2)*PERM(K)
      AY=2.0*PCC(I+2)+2.0/0.434294*P(I+1)**2
      P(I+1)=EXPF(AY/0.434294)-P(I+2)**2
      P(I+1)=SQRTF(P(I+1))
      SP(I+1)=P(I+1)*PERS(K)
  424 CONTINUE
      BEA=P(I)*FK/CT*0.000001
      BEAE=SP(I)/P(I)*BEA
      IF(JSO) 352,352,351
  351 ASO=JSO
      SAVG=(AMCN(1)+AMCN(2))/ASO
      COF=50.3/SAVG
      GO TO 353
  352 COF=1.
  353 BESD=P(I+1)*1.72*COF
      BEM=P(I+2)*1.72*COF
      BESDE=SP(I+1)/P(I+1)*BESD
      BEME=SP(I+2)/P(I+2)*BEM
      BEC=P(I+3)
      BECE=SP(I+3)
      IF(IFF-1) 333,334,335
  333 CONTINUE
      WRITE OUTPUT TAPE 9,33,K,PG(I),P(I),SP(I),BEA,BEAE,PG(I+1),P(I+1),
     1SP(I+1),BESD,BESDE,PG(I+2),P(I+2),SP(I+2),BEM,BEME,PG(I+3),P(I+3),
     2SP(I+3),BEC,BECE
   33 FORMAT(1OHO     PEAKI2,7H   AREA6XF7.0,4X3HCTS5XF7.0,9XF5.0,7XF5.2
     1,2H (F5.3,14H) MILLION    */1H 14X4HS.D.10XF5.2,5H  CHS9XF5.2,10X,
     2F5.3,4XF5.2,2H (F5.3,15H) CU MICRONS **/
     31H 14X4HMEAN10XF5.2,5H  CHS9XF5.2,10XF5.3,3XF6.2,2H (F5.3,15H) CU
     4MICRONS **/
     51H 14X4HSKEW11XF5.3,14XF5.3,9XF5.3,5XF5.3,1H(F5.3,1H)//)
      GO TO 340
  334 WRITE OUTPUT TAPE 9,332,K,PG(I),P(I),SP(I),BEA,BEAE,PG(I+1),P(I+1),
```

```
     1,SP(I+1),BESD,BESDE,PG(I+2),P(I+2),SP(I+2),BEM,BEME
 332 FORMAT(10H0      PEAKI2,7H   AREA6XF7.0,4X3HCTS5XF7.0,9XF5.0,7XF5.2
     1,2H (F5.3,14H) MILLION    */1H 14X4HS.D.10XF5.2,5H  CHS9XF5.2,10X,
     2F5.3,4XF5.2,2H (F5.3,15H) CU MICRONS **/
     31H 14X4HMEAN10XF5.2,5H  CHS9XF5.2,10XF5.3,3XF6.2,2H (F5.3,15H) CU
     4MICRONS **//)
      GO TO 340
 335 WRITE OUTPUT TAPE 9,331,K,PG(I),PCC(I),SPC(I),P(I),SP(I),
     1BEA,BEAE,PG(I+1),PCC(I+1),SPC(I+1),P(I+1),SP(I+1),BESD,BESDE,
     2PG(I+2),PCC(I+2),SPC(I+2),P(I+2),SP(I+2),BEM,BEME
 331 FORMAT(10H0      PEAKI2,6H  AREA6XF7.0,4X3HCTS3XF7.0,
     18XF5.0,7XF7.0,8XF5.0,5XF5.2,2H (F5.3,14H) MILLION    */
     21H 13X4HS.D.10XF6.3,4H CHS7XF6.3,8XF5.3,8XF5.2,
     39XF5.3,F7.2,2H (F5.3,15H) CU MICRONS **/
     41H 13X4HMEAN10XF5.2,5H  CHS7XF5.2,9XF5.3,8XF5.2,
     59XF5.3,F7.2,2H (F5.3,15H) CU MICRONS **//)
 340 IF(IFF-1) 360,361,361
 360 I=I+4
     GO TO 36
 361 I=I+3
  36 CONTINUE
     WRITE OUTPUT TAPE 9,34,COF
     WRITE OUTPUT TAPE 9,35,GMCN
     GO TO 200
  37 WRITE OUTPUT TAPE 9,38,IS1,IS2
  38 FORMAT(     66H1SERIAL NUMBER ON FIRST CARD DOES NOT AGREE WITH I.
     1D. CARD, SERIALI5,I4,43H, SPECTRUM SKIPPED AND COMPUTATION RESUMED
     2.)
      GO TO 41
  39 WRITE OUTPUT TAPE 9,40,IS1,IS2,IEC
  40 FORMAT(19H1      SERIAL NUMBER 2I4,28H , CARD OUT OF ORDER, NUMBERI
     12,42H,SPECTRUM SKIPPED AND COMPUTATION RESUMED.)
  41 READ INPUT TAPE 10,1,IEX,KS1,KS2,ANID(1),ANID(2),ANID(3),DATE,IYR,
     1NPK,ICH,LCH,CT,ADD1,FK,HCT,IFF,IS,IP,IFG,IG,IS1,IS2
      IF(IYR) 41,41,101
C     PLOT ROUTINE
 200 DO 201 I=1,N
     Z(1)=X(1,I)
     IF(IFF-1) 403,404,405
 403 CALL YP1(YT,IK)
     GO TO 407
 404 CALL YP2 (YT,IK)
     GO TO 407
 405 DO 406 ICI=1,NPK
     P(3*ICI-2)=PCC(3*ICI-2)
     P(3*ICI-1)=PCC(3*ICI-1)
 406 P(3*ICI)=PCC(3*ICI)
     CALL YP3(YT,IK)
 407 CONTINUE
     YC(I)=YT
 201 AB(I)=I
2012 S(1)=5.0
     S(2)=10.0
     S(3)=20.0
     DO 202 I=4,13,3
     S(I)=S(I-3)*10.
```

```
      S(I+1)=S(I-2)*10.
  202 S(I+2)=S(I-1)*10.
      BND(1)=0.
      BND(2)=100.
      BND(3)=0.
      CALL MAX3(Y,-1,100,IPX,CHMAX)
      DO 205 I=1,15
      IF(CHMAX-S(I)) 204,204,205
  204 BND(4)=S(I)
      GO TO 206
  205 CONTINUE
  206 CALL ADV FLM(0,1)
      CALL SEL GRD (6,6)
      CALL LBL GRD (6,6,BND)
      CALL PLFILM(100,TEMP,AB,-1,CH,-1,BND,38,0)
      CALL PLFILM(100,TEMP,AB,-1,YC,-1,BND,42,1)
      AB(1)=ICH
      AB(2)=LCH
      BB(1)=CH(ICH)
      BB(2)=CH(LCH)
      CALL PLFILM(2,TEMP,AB,-1,BB,-1,BND,44,0)
      CALL PLFILM(2,TEMP,AB,-1,BB,-1,BND,63,0)
      ALAB(1)=6HCOUNTS
      BLAB(1)=6HCHANNE
      BLAB(2)=6HL NUMB
      BLAB(3)=2HER
      CALL WFILM(1,6,ALAB,0,30.0,6.0)
      CALL WFILM(0,14,BLAB,0,59.0,55.0)
      CALL LINCNT(61)
      WRITE OUTPUT TAPE 12,212,IEX,ANID(1),ANID(2),ANID(3),IS1,IS2,
     1DATE,IYR
      CALL LIN CNT (62)
      IF(IFF-1) 341,342,343
  341 WRITE OUTPUT TAPE 12,344
  344 FORMAT(90X,26HSKEWED NORMAL DISTRIBUTION)
      GO TO 347
  342 WRITE OUTPUT TAPE 12,345
  345 FORMAT(90X,19HNORMAL DISTRIBUTION)
      GO TO 347
  343 WRITE OUTPUT TAPE 12,346
  346 FORMAT(90X,23HLOG NORMAL DISTRIBUTION)
  347 CONTINUE
      CALL LINCNT(63)
      WRITE OUTPUT TAPE 12,207,ICH,LCH
      CALL ADV FLM(0,1)
  207 FORMAT(27X,8HCHANNELSI3,3H TOI4,20H USED IN COMPUTATION)
  208 CONTINUE
C     PRINT ROUTINE
      IF(IP-1) 100,209,100
  209 WRITE OUTPUT TAPE 9,210
  210 FORMAT(61H1      CHANNEL   WEIGHT   EXPERIMENTAL  CALCULATED   DIFFE
     1RENCE/45H        NUMBER  FACTOR       DATA         DATA//)
      WRITE OUTPUT TAPE 9,211,((I,W(I),CH(I),YC(I),DY(I)),I=1,100)
  211 FORMAT(I10,F11.5,F12.0,F13.0,F13.1)
  212 FORMAT(11H      EXPT.I3,2A6,A4,8X,6HSERIALI5,I4,6X,A6,I2//)
      GO TO 100
```

```
END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)
```

```
      SUBRØUTINE CELLP(M,N,IK)
      DIMENSIØN Y(100),W(100),YC(100),DY(100),PG(40),P(40),SP(40),
     1BM(40,41),X(1,100),B(100),ALAB(1),BLAB(3),AN(40),PART(40),
     2Z(40),AM(40,40),DP(40),PC(40)
      CØMMØN Y,X,W,Z,PG,P,SP,YC,DY,BM,B,AN,WVAR,SSQ,PART,TEST,NIT,IFG
     1,IFF,NPK
      IM=0
      ITS=0                                                            PPAK026
      IHSP=0                                                           PPAK027
      M25C=0                                                           PPAK028
 1125 CØNTINUE
      SENSELIGHT 0                                                     PPAK033
      VAR = 0.0                                                        PPAK034
       SS = 0.0                                                        PPAK035
      LIES=0                                                           PPAK036
 1100 DØ 1101 I=1,IK                                                   PPAK037
      DP(I)=0.0                                                        PPAK038
      PC(I)=PG(I)                                                      PPAK039
      BM(I,1) = 0.0                                                    PPAK040
      SP(I)=0.0                                                        PPAK041
 1101 P(I)=PG(I)                                                       PPAK042
      LIT = 0                                                          PPAK043
      LIE = 0                                                          PPAK044
   51 LICK = 0                                                         PPAK057
      K=IK-IM                                                          PPAK058
 1103 IT=0                                                             PPAK059
      KP=K+1                                                           PPAK060
      IF(K) 1102, 11011,11032                                          PPAK061
11011 LIES = 1                                                         PPAK062
      GØ TØ 11087                                                      PPAK063
11032 DØ1108I=1,K                                                      PPAK064
      DØ1108J=1,KP                                                     PPAK065
      IF(J-KP)1104,1105,1105                                           PPAK066
 1104 AM(I,J)=0.0                                                      PPAK067
 1105 IF(I+1-J)1106,1107,1106                                          PPAK068
 1106 BM(I,J)=0.0                                                      PPAK069
      GØTØ1108                                                         PPAK070
 1107 BM(I,J)=1.0                                                      PPAK071
 1108 CØNTINUE                                                         PPAK072
      H = 1.0                                                          PPAK073
      IT=IT+1                                                          PPAK074
11087 DØ21122L=1,N                                                     PPAK075
      DØ 11084 J = 1, M                                                PPAK076
11084 Z(J) = X(J,L)                                                    PPAK077
   66 IF(IFF-1) 407,408,409
  407 CALL YP1(YT,IK)
      GØ TØ 410
  408 CALL YP2(YT,IK)
      GØ TØ 410
  409 CALL YP3(YT,IK)
  410 CØNTINUE
11085 IF(LIES)11086,11086,1115                                         PPAK079
11086 JACK=0                                                           PPAK080
      DØ9003JUK=1,IK                                                   PPAK081
 9002 JAKE=JUK-JACK                                                    PPAK086
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      AN(JAKE) = PART(JUK)                                              PPAK087
 9003 CONTINUE                                                          PPAK090
 1115 YC(L) = YT                                                        PPAK091
      DY(L) = Y(L) - YC(L)                                              PPAK092
      IF(LIES)21116,21116,31117                                         PPAK093
31117 VAR=VAR+W(L)*DY(L)**2                                             PPAK094
      SS=SS+DY(L)**2                                                    PPAK095
      GO TO 21122                                                       PPAK096
21116 IF(K)1102,21122,1117                                              PPAK097
 1117 DO1122I=1,K                                                       PPAK098
      DO 1122 J=I,KP                                                    PPAK099
      IF(J-KP)1118,1119,1119                                            PPAK100
 1118 AM(I,J)=AM(I,J)+AN(I)*AN(J)*W(L)                                  PPAK101
      GO TO 1122                                                        PPAK102
 1119 BM(I,1)=BM(I,1)+AN(I)*DY(L)*W(L)                                  PPAK103
 1122 CONTINUE                                                          PPAK104
21122 CONTINUE                                                          PPAK105
      V = 0.0                                                           PPAK106
      DO 60 L = 1,N                                                     PPAK107
   60 V = V + W(L) *DY(L) **2                                           PPAK108
      IF (LIES) 21128, 21128, 1153                                      PPAK109
21128 IF (K - 1) 21129, 21129, 31123                                    PPAK110
31123 DO31124 J=2,K                                                     PPAK111
      JIG = J - 1                                                       PPAK112
      DO 31124 I=1,JIG                                                  PPAK113
31124 AM(J,I) = AM(I,J)                                                 PPAK114
21129 IF (K) 1102, 1123, 11221                                          PPAK115
11221 IF(SENSELIGHT1)1123,11251                                         PPAK116
 1123 SENSELIGHT1                                                       PPAK117
      IF (K) 1102, 1152, 21123                                          PPAK119
21123 CONTINUE
11251 IF(LIE) 1102, 6000,7000                                           PPAK126
 6000 KT = 1                                                            PPAK127
      GO TO 8000                                                        PPAK128
 7000 KT=KP                                                             PPAK129
 8000 IF (K - 1) 1152, 3000, 4000                                       PPAK130
 3000 DET = AM(1,1)                                                     PPAK131
      BM(1,1) = BM(1,1)/AM(1,1)                                         PPAK132
      BM(1,2) = 1.0/AM(1,1)                                             PPAK133
      GOTO1131                                                          PPAK134
 4000 CALLLEQD(AM,BM,K,KT,40,40,DET)                                    PPAK135
C     CHANGES FOR 7090...                                               PPAK136
 1131 IF(SENSELIGHT1)1132,1133                                          PPAK137
 1132 CONTINUE
      SENSELIGHT1                                                       PPAK139
 1133 JUK = 0                                                           PPAK140
      DO 11351 I=1,IK                                                   PPAK141
14332 CONTINUE
11343 JAKE = I - JUK                                                    PPAK146
      IF(IFG-1)27002,22353,6661                                         PPAK147
27002 IF(IT-5)6661,6661,22353                                           PPAK148
 6661 DP(I) = BM(JAKE,    1)                                            PPAK149
16666 PC(I) = P(I) + H*     DP(I)                                       PPAK150
C     CHANGES FOR 7090...                                               PPAK151
      IF(SENSELIGHT1)7777,26666                                         PPAK152
26666 IF(IFG-1)27000,11351,6667                                         PPAK153
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27000 IF(IT-5)6667,6667,11351                                         PPAK154
 7777 SENSELIGHT1                                                     PPAK155
      GOTO11351                                                       PPAK156
 6667 IF(P(I)*PC(I))6668,11351, 11351                                 PPAK157
 6668 H = H/2.0                                                       PPAK158
      IF (H - 0.0000000001) 12352,  16666, 16666                      PPAK159
11351 CONTINUE                                                        PPAK161
      GO TO 1139                                                      PPAK162
22353 IF(IT-25)6661,6661,13000                                        PPAK163
13000 ITS=IT                                                          PPAK164
11341 IF(ABSF(DP(I)) - ABSF(BM(JAKE,1)))11342, 11342, 6661            PPAK165
11342 H = H/2.0                                                       PPAK166
      IF(H-.0000000001)12352,6661,6661                                PPAK167
12352 IHSP=1                                                          PPAK168
      GOTO1102                                                        PPAK169
 1139 IF(SENSELIGHT1)1147,1140                                        PPAK170
 1140 GOTO1142                                                        PPAK171
 1142 NIT=IT
 1145 JERK = 0                                                        PPAK178
      DO 1146 I = 1,IK                                                PPAK179
      IF (P(I)) 11451, 11452, 11451                                   PPAK180
11451 IF(ABSF((PC(I)-P(I))/P(I))- TEST   ) 1146, 1146, 1148           PPAK181
11452 JERK = JERK + 1                                                 PPAK182
 1146 CONTINUE                                                        PPAK183
      IF (JERK - IK) 1147, 1148, 1148                                 PPAK184
 1147 SENSELIGHT1                                                     PPAK185
      LIE = 1                                                         PPAK186
      M25C=1                                                          PPAK187
 1148 DO1149I=1,IK                                                    PPAK188
 1149 P(I)=PC(I)                                                      PPAK189
      IF (LICK) 1102, 1150, 1152                                      PPAK190
 1150 IF(SENSELIGHT1)11501,1151                                       PPAK191
11501 SENSELIGHT1                                                     PPAK192
      LICK = 1                                                        PPAK193
 1151 IF(M25C)29768,29768,11032                                       PPAK194
29768 IF(IT-25)11032,11512,11032                                      PPAK195
11512 SENSELIGHT 1                                                    PPAK196
      IT=0                                                            PPAK197
      ITS=26                                                          PPAK198
      GO TO 1147                                                      PPAK199
 1152 VAR=0.0                                                         PPAK200
      SS=0.0                                                          PPAK201
      LIES = 1                                                        PPAK202
       GO TO 11087                                                    PPAK203
 1153 DF=N-K                                                          PPAK204
      IDF=N-K                                                         PPAK205
      IF(K) 1102, 21155, 21154                                        PPAK206
21154 CONTINUE
21998 IF(ITS)13002,13004,13002                                        PPAK213
13002 IT=ITS                                                          PPAK214
13004 NIT=IT
21155 WVAR = VAR/DF                                                   PPAK216
      SSQ = SS                                                        PPAK217
       JACK = 0                                                       PPAK218
      DO 21160 I = 1,IK                                               PPAK219
 1158 JAKE = I - JACK                                                 PPAK224
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      J = JAKE + 1                                                      PPAK225
 1159 SP(I) = SQRTF(BM(JAKE,J)*WVAR)                                    PPAK226
21160 CONTINUE                                                          PPAK229
 1102 SENSELIGHT 0                                                      PPAK230
      IF(IHSP)22100,22108,22100                                         PPAK231
22100 WRITEOUTPUTTAPE9,22102                                            PPAK232
22102 FORMAT(75H1THE PROGRAM QUIT ITERATING SINCE THE PARAMETER(S) INSIS
     XT ON CHANGING SIGNS)                                              PPAK234
22108 RETURN                                                            PPAK235
      END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)
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```
      SUBROUTINE YP1(YT,IK)
C     SUBROUTINE YP1 IS FOR SKEWED NORMAL CURVE
      DIMENSION Y(100),W(100),YC(100),DY(100),PG(40),P(40),SP(40),
     1BM(40,41),X(1,100),B(100),ALAB(1),BLAB(3),AN(40),PART(40),
     2Z(40),AM(40,40),DP(40),PC(40)
      COMMON Y,X,W,Z,PG,P,SP,YC,DY,BM,B,AN,WVAR,SSQ,PART,TEST,NIT,IFG
     1,IFF,NPK
    3 YT=0.
C     P(4I-3)= AREA, P(4I-2) = STANDARD DEVIATION,
C     P(4I-1) = MEAN, P(4I) = COEFF OF SKEWNESS
      XX=1./SQRTF(2.*3.1415926)
    6 IND=IK/4
   10 DO16J1=1,IND
      T1=P(4*J1-3)*XX/P(4*J1-2)*EXPF(-0.5*
     X(Z-P(4*J1-1))**2/(P(4*J1-2)**2))
      T2=(Z-P(4*J1-1))/P(4*J1-2)
      T3=(Z-P(4*J1-1))**3/(P(4*J1-2)**3)
      T4=T2**2
      YT=YT+T1*(1.-P(4*J1)*0.5*T2*(1.-(T4/3.)))
      PART(4*J1-3)=T1/P(4*J1-3)*(1.-P(4*J1)*0.5*
     X(T2-T3/3.))
      PART(4*J1-2)=T1*((-1./P(4*J1-2))*(1.-P(4*J1)*0.5
     X*T2+P(4*J1)*T3/6.)+T2**2/P(4*J1-2)*(1.-P(4*J1)
     X*.5*T2+T3*P(4*J1)/6.)+P(4*J1)*0.5*T2/
     XP(4*J1-2)-P(4*J1)*0.5*T3/P(4*J1-2))
      PART(4*J1-1)=T1*(T2/P(4*J1-2)*(1.-0.5*P(4*J1)
     X*(T2-T3/3.))+0.5*P(4*J1)/P(4*J1-2)-0.5*
     XP(4*J1)*(Z-P(4*J1-1))**2/P(4*J1-2)**3)
   16 PART(4*J1)=T1*(-0.5*(T2-T3/3.))
    4 RETURN                                                        YPG017
      END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE YP2(YT,IK)
C     SUBROUTINE YP2 IS FOR NORMAL CURVE
      DIMENSION Y(100),W(100),YC(100),DY(100),PG(40),P(40),SP(40),
     1BM(40,41),X(1,100),B(100),ALAB(1),BLAB(3),AN(40),PART(40),
     2Z(40),AM(40,40),DP(40),PC(40)
      DIMENSION G(4)
      COMMON Y,X,W,Z,PG,P,SP,YC,DY,BM,B,AN,WVAR,SSQ,PART,TEST,NIT,IFG
     1,IFF,NPK
      YT=0.
      DO 4 I=1,NPK
      G(I)=(0.3989423*P(3*I-2)/P(3*I-1))*EXPF(-0.5*((Z(1)-P(3*I))
     1/P(3*I-1))**2)
      YT=YT+G(I)
      PART(3*I-2)=G(I)/P(3*I-2)
      PART(3*I-1)=(((Z(1)-P(3*I))**2/(P(3*I-1))**3)
     1-(1.0/P(3*I-1)))*G(I)
    4 PART(3*I)=(((Z(1)-P(3*I))/(P(3*I-1))**2))*G(I)
      RETURN
      END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)
```

```
      SUBROUTINE YP3(YT,IK)
C     SUBROUTINE YP3 IS FOR LOG NORMAL CURVE
      DIMENSION Y(100),W(100),YC(100),DY(100),PG(40),P(40),SP(40),
     1BM(40,41),X(1,100),B(100),ALAB(1),BLAB(3),AN(40),PART(40),
     2Z(40),AM(40,40),DP(40),PC(40)
      DIMENSION G(4)
      COMMON Y,X,W,Z,PG,P,SP,YC,DY,BM,B,AN,WVAR,SSQ,PART,TEST,NIT,IFG
     1,IFF,NPK
      YT=0.
      DO 4 I=1,NPK
      ZLOG=LOG10F(Z(1))
      G(I)= 0.3989423*0.4342945*P(3*I-2)/P(3*I-1)/Z(1)*
     1EXPF(-0.5*((ZLOG-P(3*I))/P(3*I-1))**2)
      YT=YT+G(I)
      PART(3*I-2)=G(I)/P(3*I-2)
      PART(3*I-1)=(((ZLOG-P(3*I))**2/(P(3*I-1))**3)
     1-(1.0/P(3*I-1)))*G(I)
    4 PART(3*I)=(((ZLOG-P(3*I))/(P(3*I-1))**2))*G(I)
      RETURN
      END(1,0,0,0,0,0,1,0,0,1,0,0,0,0,0)
```