United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-78-226
November 1978

Cascade Impactor Data Reduction with SR-52 and TI-59 Programmable Calculators

Interagency Energy/Environment R&D Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

EPA-600/7-78-226

November 1978

Cascade Impactor Data Reduction with SR-52 and TI-59 Programmable Calculators

by

Leslie E. Sparks

Environmental Protection Agency
Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

Program Element No. EHE624A

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

ABSTRACT

This report is intended to provide useful tools for obtaining particle size distributions and graded penetration data from cascade impactor measurements. The programs calculate impactor aerodynamic cut points, total mass collected by the impactor, cumulative mass fraction less than for each stage, log-normal size distribution parameters for the data, and graded penetration. These programs are written specifically for the Texas Instruments SR-52 and TI-59 programmable calculators and the PC-100A printer. A general discussion of the program, an example problem, program listing, and user instructions are provided for each program.

CONTENTS

CONTENTS (Cont'd)

FIGURES

FIGURES (cont'd)

TABLES

NOMENCLATURE

A - Used to calculate Cunningham correction factor

A - Least-squares curve fit parameter in $y = A + Bx$

B - Least-squares curve fit parameter in $y = A + Bx$

C - Cunningham correction factor

C_i - Stage constant for ith impactor stage

C_0 -

C_1 -

C_2 - Constants for rational approximation of inverse normal function

C_3 -

C_4 -

C_5 -

D_i - Diameter of holes for ith impactor stage, cm

d - Particle diameter, μm

d_{50} - Physical impactor cut point, μm

d_{A50} - Aerodynamic impactor cut point, μmA

d_g - Mass mean diameter, μm

f_i - Cumulative mass fraction less than total mass for ith impactor stage

$f_I(d)$ - Inlet cumulative size distribution

$f_o(d)$ - Outlet cumulative size distribution

K_{50i} - Inertial impaction parameter for 50% collection efficiency on the ith impactor stage

M_i - Weight of particulate collected by ith impactor stage, mg

M_T - Total weight of particulate collected by impactor, mg

N_i - Number of holes on the ith impactor stage

P - Pressure, cm Hg

$Pt(d)$ - Penetration of particles with diameter d

NOMENCLATURE (Cont'd)

$Pt(d)_{LN}$ - Penetration of particles with diameter d calculated using linear log-normal fit

$Pt(d)_{LN^2}$ - Penetration of particles with diameter d calculated using quadratic log-normal fit

$Pt(d)_M$ - Penetration of particles with diameter d from electrostatic precipitator model

$Pt(d)_S$ - Penetration of particles with diameter d calculated using spline fit

Q - Gas flow rate through impactor, l/m

R_{ij} - Storage register ij

r^2 - Correlation coefficient

$S(x_i)$ - Spline fit function evaluated at x_i

$S'(x_i)$ - $d\,[S(x)]/dx$ evaluated at x_i

$S''(x_i)$ - $d^2[S(x)]/dx^2$ evaluated at x_i

$S'''(x_i)$ - $d^3[S(x)]/dx^3$ evaluated at x_i

T - Temperature, °C

t - Dummy variable used in inverse normal function calculation

t - Dummy variable used in spline fit program

V_i - Jet velocity for i^{th} stage, m/s

W_I - Inlet mass concentration, g/m^3

W_O - Outlet mass concentration, g/m^3

X - Inverse normal function

x - General variable

$\overline{x}$ - Average value of x

y - General variable

$\overline{y}$ - Average value of y

Z - Dummy variable

NOMENCLATURE (Cont'd)

μ - Gas viscosity, poise

λ - Gas mean free path

λ_o - Gas mean free path at 23°C

ρ - Particle density, g/cc

σ - Geometric standard deviation

σ_I - Inlet geometric standard deviation

σ_o - Outlet geometric standard deviation

INTRODUCTION

Cascade impactors are the major instrument for obtaining information on the instack particle size distribution before and after air pollution control equipment. Data reduction is tedious, time consuming, and generally requires access to a computer. Thus, there may be a long delay in obtaining reduced data after the measurements are made. Such delays can be especially troublesome in the field.

Recent advances in calculator technology make it possible to do much of the data reduction without a computer. Thus, reduced data can be available shortly after the measurements are made. The ability to examine reduced data shortly after the measurements are made is especially important in field tests. Trends and problems can be found while still in the field and corrective action can be taken to improve data taken later.

There are two sets of calculator programs in this report--one set for the Texas Instruments SR-52 calculator and a second set for the Texas Instruments TI-59 calculator. The programs in each set perform the following calculations:

1. Calculate aerodynamic cut points for each impactor stage.
2. Calculate total mass collected by the impactor.
3. Calculate the cumulative mass fraction less than for each stage.
4. Calculate the log-normal size distribution that best fits the data.
5. Calculate penetration as a function of particle diameter (graded penetration).

The methods used for the first four calculations are the same for both sets of programs. Graded penetration is calculated from the log-normal fit results in the SR-52 program set and from a spline fit to the impactor data in the TI-59 program set. A brief comparison of these two methods for calculating graded penetration is included. Two additional TI-59 programs are also provided--one to convert aerodynamic diameter to physical diameter and one to estimate the viscosity of mixtures of gases.

NOTES ON THE PROGRAMS

In the user instructions and examples, a convention of underline letters or numbers has been adopted to denote the key or keys on the SR-52 or TI-59 keyboard which should be pressed to conduct the operation discussed. For example: in the instruction Press A, the underline indicates that the A button on the keyboard should be pressed. Storage registers are indicated by R_{ij}. For example: R_{01} refers to storage register 01.

The programs all make extensive use of the indirect recall and indirect store features of the SR-52 and TI 59. Thus, it is essential that the counter for the indirect recall and indirect store registers be set at the proper initial value and advanced at the required times. Anyone who wishes to modify the programs should remember that the programs as written depend on indirect recall and indirect store instructions.

Two of the SR-52 programs store data in registers that normally are used to store program instructions. This use of the program registers can cause problems with program execution if the magnetic cards containing the programs are read improperly.

Magnetic cards are read into the SR-52 calculator by:

Step	Procedure	Press
1	Enter side A	2nd rst 2nd read
2	Enter side B	2nd read

Instructions for reading magnetic cards into the TI-59 calculator are given in the appropriate user instructions.

The programs as written are for the Meteoroloy Research, Inc. (MRI) Cascade Impactor. The programs can be modified for use with other impactors provided:

1. Calibration data for the impactor are available.
2. Number of useful stages $\leq$ 7 (including filter).

SR-52 PROGRAM SET

GENERAL DISCUSSION

The SR-52 program set is contained on six magnetic cards that must be executed in the following order: Cards 1, 2, 3, 4, 5 for inlet data; Cards 1, 2, 3, 4, 5 for outlet data; and then Card 6 for combined inlet and outlet data.

Card 1 is used to calculate and store the aerodynamic cut diameter, d_{A50}, for each impactor stage. Impactor flow rate and impactor temperature are entered before the calculation.

Card 2 is used to calculate and store the total mass collected by the impactor, M_T, and the cumulative mass fraction less than total mass collected by each stage, f_i. Mass collected by each stage, M_i, is entered and printed before the calculation is performed.

Card 3 is used to print M_T, d_{A50}, and f_i.

Card 4 is used to transform the f_i so that a log-normal fit to the data can be calculated using Card 5.

Card 5 is used to calculate a least-squares best fit to the data transformed by Card 4. The log-normal parameters, mass geometric mean diameter, d_g, and geometric standard deviation, σ, are printed along with the least-squares fit parameters, A and B for $y = A + Bx$, and the correlation coefficient, r^2.

Card 6 is used to calculate and print the graded penetration for two log-normal particle size distributions. Inlet mass concentration, W_I, outlet mass concentration, W_O, inlet geometric standard deviation, σ_I, outlet geometric standard deviation, σ_O, inlet mass mean diameter, d_{gI}, and outlet mass mean diameter, d_{gO}, are entered before the calculation is performed.

The programs on each card are discussed in detail in the next sections.

Card 1

Card 1 is used to enter the impactor flow rate, Q, in either ft^3/min or l/min and the impactor temperature, T, in either °F or °C. The program on the card then calculates d_{A50i} in μmA* for each stage. The d_{A50i} are stored in the calculator for use by other programs.

d_{A50i} is given by

$$d_{A50i} = \sqrt{\left(\frac{0.135\ \mu\pi\ D_i^{\ 3} N_i K_{50i}}{Q \times 10^{-8}}\right)} \qquad (1)$$

where μ = the viscosity of the gas in poise

D_i = the diameter of the holes on the ith stage in cm

N_i = number of holes on the ith stage

Q = gas flow rate in l/m

K_{50i} = inertial impaction parameter for 50% collection efficiency on the ith stage

K_{50i} = $d^2_{50i}\ C\rho\ V_i/9\mu\ D_i\ X\ 10^8$

d_{50i} = physical cut diameter, μm

C = Cunningham correction factor

ρ = particle density

V_i = jet velocity for ith stage, m/s

---

*The convention to denote aerodynamic diameters by μmA will be used throughout this report.

The gas viscosity used in the program is for air and is estimated by

$$\mu = 1.68 \times 10^{-4} + 2.292 \times 10^{-7} \times (1.8 T + 32) \qquad (2)$$

where μ is in poise and T is in °C.

The value for K_{50i} should be based on experimentally determined calibration curves. If such curves are not available $K_{50i} = 0.2$ can be used.

Equation 1 can be rewritten as

$$d_{A50i} = \sqrt{C_i \mu/(Q \times 10^{-8})} \qquad (3)$$

where C_i = stage constant for the i^{th} stage,

$$C_i = 0.135 \quad \pi Di^3 N_i K_{50i} \qquad (4)$$

C_i must be calculated at the time the calculator is first programmed and is stored in registers R_{91} - R_{97}. When a program with C_i stored in these registers is recorded on a magnetic card, the C_i are recorded on the card and become a permanent part of the program.

C_i for the MRI and University of Washington cascade impactors are shown in Table 1.

To use the program with an impactor other than the MRI impactor, store the appropriate stage constants in R_{91} through R_{97}.

Card 2

Card 2 is used to enter the mass collected on the i^{th} stage, M_i, and to calculate M_T and f_i. The M_i are entered in order of i = 1 to i = N where i = 1 is the stage with the largest d_{50i} and i = N is the filter.

Table 1. VALUES OF STAGE CONSTANTS FOR MRI AND UNIVERSITY OF WASHINGTON IMPACTORS

Stage	MRI Ci	University of Washington Ci	Store in
1	5.4069×10^{-2}	7.4123×10^{-2}	R_{91}
2	6.8611×10^{-2}	9.3954×10^{-2}	R_{92}
3	2.1484×10^{-2}	1.3376×10^{-2}	R_{93}
4	3.8666×10^{-3}	1.7759×10^{-3}	R_{94}
5	1.0147×10^{-3}	1.8378×10^{-3}	R_{95}
6	3.5065×10^{-4}	4.2206×10^{-4}	R_{96}
7	2.2899×10^{-4}	1.0104×10^{-4}	R_{97}

MRI stage constants for stages 4, 5, 6, and 7 are based on EPA/IERL-RTP/Particulate Technology Branch impactor calibration data. University of Washington stage constants and MRI stage constants for stages 1, 2, and 3 are based on Southern Research Institute calibration data.

The total mass collected is given by

$$M_T = \sum_{i=1}^{N} M_i \tag{5}$$

The cumulative fraction less than the total collected on the i^{th} stage, f_i, is given by

$$f_i = \left\{ \sum_{j=0}^{j=i-1} \frac{M_j}{M_T} \right. \tag{6}$$

where $j = 0$ is the filter.

The f_i are stored in the calculator for later use.

The cut points for the first two stages of the MRI impactor overlap. The masses collected by these two stages should be manually added together. The sum $M_1 + M_2$ is then entered into the calculator and is automatically attributed to the second stage in the data reduction program. The first two stages of the University of Washington impactor also overlap and must be handled in the same way as the first two stages of the MRI impactor.

The fact that the mass collected on the first two stages are added together means that there are seven masses entered. These seven M_i are used to calculate six cumulative fraction less than values which are stored for later use. The number of cumulative fraction less than values that can be stored is limited to six. If the impactor being used has more than six useful stages plus filter, the mass collected by the extra stages can be lumped with that of the top stage. For example, if there are seven useful stages 1, 2, 3, 4, 5, 6, 7, plus filter; the mass collected by stage 1 can be added to that collected by stage 2.

Card 3

Card 3 recalls M_T, f_i, and d_{A50i} from memory and prints them in the following order: M_T, d_{A501}, f_1,....d_{A506}, f_6.

Card 4*

The f_i are transformed to normal coordinates by use of the inverse normal integral, X, based on the cumulative mass fraction f_i

$$f(X) = \int_{-\infty}^{X} \frac{e^{-t^2/2}}{\sqrt{2\pi}} \, dt \qquad (7)$$

where

$$f(-\infty) = 0$$
$$f(0) = 0.5$$
$$f(+\infty) = 1.0$$

Hastings[1] gives a rational approximation that can be used to calculate X

$$X = t + \left[\frac{C_0 + C_1 + C_2 t^2}{1 + C_3 t + C_4 t^2 + C_5 t^3}\right] + \text{error of order } \varepsilon \qquad (8)$$

$$|\varepsilon| \cong 0.00045$$

$$\text{where } t = \sqrt{\ln \left(\frac{1}{1-f}\right)^2} \quad \text{for} \quad \begin{matrix} f < 1 \\ f > 0.5 \end{matrix} \qquad (9)$$

The calculator program accounts for all f_i since

$$X (f_i = m) = X (f_i = 1 - m) \text{ for } m < 0.5 \text{ by symmetry.} \qquad (10)$$

For example $X (f_i = 0.4) = - X (f_i = 0.6)$

The constants C_0 through C_5 are stored in registers R_{92} through R_{97}. The values of C_0 through C_5 are given in Table 2.

---

*Much of the original work for the program on Card 4 is due to H. F. Barbarika of Air Pollution Technology, Inc.

Table 2. VALUES OF CONSTANTS FOR INVERSE NORMAL FUNCTION

C_0 = 2.515517 stored in R_{92}
C_1 = 0.802853 stored in R_{93}
C_2 = 0.010328 stored in R_{94}
C_3 = 1.432788 stored in R_{95}
C_4 = 0.189269 stored in R_{96}
C_5 = 0.001308 stored in R_{97}

The first time the program is read onto a magnetic card with C_0 through C_5 stored in R_{92} through R_{97}, the constants become a permanent part of the program.

Card 5

Card 5 is used to determine the log-normal size distribution parameters for the data entered previously. The log-normal parameters, d_{Ag} and σ, are determined by constructing a least-squares straight line through the data transformed on Card 4. The fitted line is of the form

$$y = A + Bx \tag{11}$$

The constants A and B are determined by

$$A = \bar{y} - B\bar{x} \tag{12}$$

$$B = \frac{\Sigma(xy) - \bar{y}\,\Sigma x}{\Sigma(x^2) - (\Sigma x)^2/N} \tag{13}$$

where N = the number of data points.

$\bar{x} = \Sigma x/N$ is the average value of x and
$\bar{y} = \Sigma y/N$ is the average value of y

The log-normal parameters are given by

$$d_g = \exp\ (-\ A/B) \tag{14}$$

$$\sigma = \exp\ (1/B) \tag{15}$$

The correlation coefficient r^2 for the curve fit is given by

$$r^2 = \left(b \sqrt{\frac{\Sigma(x^2) - (\Sigma x)^2}{\Sigma(y^2) - (\Sigma y)^2/N}} \right)^2 \tag{16}$$

A, B, r^2, d_{Ag}, and σ are all printed.

Card 6

Card 6 calculates and prints penetration as a function of particle diameter (the graded penetration) for two log-normal size distributions.

The penetration of particles of diameter d, Pt(d), is defined as

$$Pt(d) = \frac{W_o}{W_I} \left[\frac{df_o(d)/dd}{df_I(d)/dd}\right] \tag{17}$$

where W_o = mass concentration at outlet
W_I = mass concentration at inlet
$f_o(d)$ = outlet cumulative size distribution
$f_I(d)$ = inlet cumulative size distribution

For a log-normal distribution:

$$f(d) = \int_{-\infty}^{d} \frac{1}{2\pi/d\ln\sigma} \exp \left[\frac{-\ln^2(d/d_g)}{2\ \ln^2\sigma}\right] dd \tag{18}$$

Pt(d) becomes

$$Pt(d) = \frac{W_o}{W_I} \frac{\ln\sigma_I}{\ln\sigma_o} \exp\ (Z_I^2 - Z_o^2)/2 \tag{19}$$

where $Z = \dfrac{\ln d - \ln d_g}{\ln\sigma}$

The program solves equation (19) for the range d = 0.1 to 20 μm and prints d, Pt(d), and 1-Pt(d) (the efficiency) in 0.1 μm steps for $0.1 \leq d < 1$ and in 1 μm steps for $1 \leq d \leq 20$. The printed results are <u>not</u> reliable when d is outside the range of the impactor data.

The log-normal penetrations calculated by this program are a good representation of the data when the product of the inlet and outlet correlation coefficients, $r^2_{in} \times r^2_{out}$, exceeds 0.985. When the r^2 product is less than 0.985 the calculated penetrations are still useful for determining trends.

PROGRAMMING THE SIX CARDS

Programming the cards is straightforward except for Cards 1 and 4. Data registers that normally store program instructions are used to store constants used in the calculations for Cards 1 and 4. Special care must be taken to ensure that the constants are stored in the proper registers before the magnetic cards are recorded.

Programming Card 1

Turn the calculator on. Press <u>LRN</u> to put the calculator in the learn mode. Enter the Impactor d_{A50} program as listed in the program listing. After the last instruction is entered, press <u>LRN</u> to return the calculator to calculate mode. Enter stage constants, one at a time, and store them in the appropriate registers, see Table 1. After the last stage constant is stored, record both sides of a magnetic card using following steps: press <u>2nd</u> <u>rst</u>, insert side 1, press <u>INV</u> <u>2nd</u> <u>READ</u>, insert side 2, and then press <u>INV</u> <u>2nd</u> <u>READ</u>.

Programming Card 4

Turn the calculator on. Press <u>LRN</u> to put the calculator in the learn mode. Enter the Inverse Normal Function program as listed in the program listing. After the last instruction is entered, press <u>LRN</u> to return the calculator to calculate mode. Enter C_0 through C_5, one at a time, and store them in the appropriate registers, see Table 2.

Record the program on both sides of a magnetic card by following the same procedure used for Card 1.

USE OF THE DATA REDUCTION PACKAGE

The step by step procedure for using the data reduction package is given in Table 3. Use of the package is demonstrated in Example 1.

Example 1. Use of Data Reduction Package

An MRI impactor was used to obtain the following data. Use the data reduction package to reduce the data.

Inlet		Outlet
Q	= 9.569 l/m	Q = 33.01 l/m
T	= 92°C	T = 92°C
$M_1 + M_2$	= 0.0146 mg	0.00005 mg
M_3	= 0.0199	0.0010
M_4	= 0.0273	0.0025
M_5	= 0.0080	0.0014
M_6	= 0.0021	0.0007
M_7	= 0.0005	0.0009
M_8(filter)	= 0.0003	0.0014
W_{IN}	= 0.3804 mg/l	W_o = 0.00072 mg/l

Table 3. STEPS FOR USING SR-52 DATA REDUCTION PACKAGE

Step	Procedure	Enter	Press	Display	Print
1	Read sides A and B of Card 1				
2	Check to see if card read properly		RCL 92	Constant for 1st stage	
3	Enter T	T°C	A	T°C	
	or	T°F	2nd A'	T°C	
4	Enter Q	Q l/min	B	Q l/min	
	or	cfm	2nd B	Q l/min	
5	Initialize		E	1.0000	
6	Reset		2nd rst	1.0000	
7	Calculate d_{A50i}		D	0.0000	
8	Read sides A and B of Card 2				
9	Initialize		E	0.0000	
10	Enter M_i	M_1	A	1.0000	M_1
		M_2	A	2.0000	M_2
		.		.	.
		.		.	.
		.		.	.
		M_{filter}	A	7.0000	M_8

Note: For the MRI and University of Washington impactors, M_1 = the sum of the mass collected on the first two stages. M_1 and M_2 must be added before the data are entered.

11	Calculate f_i		B	0.0000	
12	Read Side A of Card 3				
13	Print M_T, $f_i d_{A50i}$			f_6	M_T
					d_{A501}
					f_1
					.
					.
					.
					d_{A506}
					f_6

Table 3. STEPS FOR USING DATA REDUCTION PACKAGE (Cont'd)

Step	Procedure	Enter	Press	Display	Print
14	Read Card 4 sides A and B				
15	Initialize		E	8.0000	
16	Transform f_i		A		
17	Read Card 5 sides A and B				
18	Initialize		E	0.0000	
19	Calculate log-normal parameters		A	σ	A
					B
					r^2
					d_g
					σ
20	Read Card 6 sides A and B			2nd rst	
				INV READ	
				INV READ	
21	Enter W_I	W_I	A		0.10000
22	Enter W_o	W_o	2nd A'		W_o
23	Enter σ_I	σ_I	B		ln σI
24	Enter σ_o	σ_o	2nd B'		ln σ_o
25	Enter d_{gI}	d_{gI}	C		$\ln d_{gI}$
26	Enter d_{go}	d_{go}	2nd C'		ln d_{go}
27	Calculate Pt(d)		D		.
					Pt(d)
					1-Pt(d)
					0.1
					.
					.
					.
					Pt(d)
					1-Pt(d)
				9999.00000	20.0

Solution

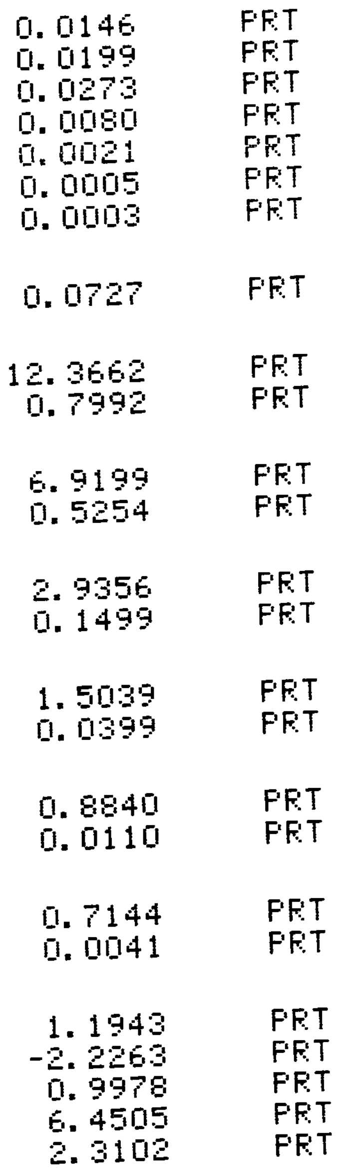
Step	Procedure	Enter	Press	Display	Print
	Do inlet calculations		2nd rst READ		
1	Read Card 1		2nd READ		
2	Check to see if read correctly		RCL 91	.054069	
3	Enter T °C	92	A	92	
4	Enter Q l/m	9.5696	B	9.5696	
5	Initialize		E	1.0000	
6	Reset		2nd rst	1.000	
7	Calculate d_{A50i}		D	0.00000	
8	Read Card 2		2nd rst 2nd READ		
9	Initialize		E	0.000000	
	Put calculator in fix display mode		INV EE	0.0000	
10	Enter $M_1 + M_2$	0.0146	A	1	0.0146
	M_3	0.0199	A	2	0.0199
	M_4	0.0273	A	3	0.0273
	M_5	0.008	A	4	0.0080
	M_6	0.0021	A	5	0.0021
	M_7	0.0005	A	6	0.0005
	M_8	0.0003	A	7	0.0003
11	Calculate f_i		B	0.0000	
12	Read Card 3 side A only		2nd rst 2nd READ		
13	Print results		A	0.0028	0.0727
					12.3662
					0.7992
					6.9199
					0.5254
					2.9356
					0.1499
					1.5039
					0.0399
					0.8840
					0.0110

Step	Procedure	Enter	Press	Display	Print
					0.7144
					0.0041
14	Read Card 4		2nd rst 2nd READ 2nd READ		
15	Initialize		E	8.0000	
16	Transform f_i		A	0.0000	
17	Read Card 5		2nd rst 2nd READ 2nd READ		
18	Initialize		E	0.0000	
19	Calculate		A	2.3102	1.1943 -2.2263 0.9978 6.4505 2.3102

A sample print out for inlet calculations is shown in Figure 1.

Repeat for Outlet

Step	Procedure	Enter	Press	Display	Print
1	Read Card 1		2nd CMS 2nd rst 2nd READ 2nd READ clr		
2	Check to see if card read correctly		RCL 91	0.054069	
3	Enter T °C	92	A	92.0000	
4	Enter Q l/m	33.01	B	33.0100	
5	Initialize		E	1.0000	
6	Reset		2nd rst	1.0000	
7	Calculate d_{A50i}		D	0.0000 00	
8	Read Card 2 and change display to fix mode		2nd rst 2nd READ 2nd READ INV EE	0.0000	



```
  0.0146      PRT
  0.0199      PRT
  0.0273      PRT
  0.0080      PRT
  0.0021      PRT
  0.0005      PRT
  0.0003      PRT

  0.0727      PRT

 12.3662      PRT
  0.7992      PRT

  6.9199      PRT
  0.5254      PRT

  2.9356      PRT
  0.1499      PRT

  1.5039      PRT
  0.0399      PRT

  0.8840      PRT
  0.0110      PRT

  0.7144      PRT
  0.0041      PRT

  1.1943      PRT
 -2.2263      PRT
  0.9978      PRT
  6.4505      PRT
  2.3102      PRT
```

Figure 1. Inlet Cascade Impactor Data for Example 1--Use of SR-52 Data Reduction Programs

Step	Procedure	Enter	Press	Display	Print
9	Enter $M_1 + M_2$	0.00005	A	1.0000	0.0001 (0.00005 rounded to 0.0001 because of printer command in Card 1)
	M_3	0.001	A	2	0.0010
	M_3	0.0025	A	3	0.0025
	M_4	0.0014	A	4	0.0014
	M_5	0.0007	A	5	0.0007
	M_6	0.0009	A	6	0.0009
	M_8(filter)	0.0014	A	7	0.0014 0.0080 . . .
10	Calculate f_i		B	0.0000	2.5213
11	Read Card 3 side A only		2nd rset 2nd READ	7	
12	Print outlet results		A		
13	Read Card 4 sides A and B		2nd rset 2nd READ 2nd READ		
14	Initialize		E	8.0000	
15	Transform		A	0.0000	
16	Read Card 5 sides A and B		2nd rset 2nd READ 2nd READ		
17	Initialize		E	0.0000	1.0813
18	Calculate		A	3.3014	0.0077 0.9384 0.9929 2.5213

Printer output for the outlet calculations is shown in Figure 2. Note that r^2 for inlet is 0.9978 and is 0.9384 for outlet.

```
0.0001      PRT
0.0010      PRT
0.0025      PRT
0.0014      PRT
0.0007      PRT
0.0009      PRT
0.0014      PRT

0.0080      PRT

6.6583      PRT
0.9937      PRT

3.7258      PRT
0.8679      PRT

1.5806      PRT
0.5535      PRT

0.8097      PRT
0.3774      PRT

0.4760      PRT
0.2893      PRT

0.3847      PRT
0.1761      PRT

1.0813      PRT
0.0077      PRT
0.9384      PRT
0.9929      PRT
2.5213      PRT
```

Figure 2. Outlet Cascade Impactor Data for Example 1 - Use of SR-52 Data Reduction Programs

Now calculate Pt(d)

Step	Procedure	Enter	Press	Display	Print
1	Read Card 6		2nd rst		
			2nd READ		
			2nd READ		
			2nd Cms		
			Clr		
			2nd Fix 5	0.00000	
2	Enter W_I	.3804	A	0.10000	
3	Enter W_o	.00072	2nd A	0.00072	
4	Enter σ_I	2.3102	B	0.83733	
5	Enter σ_o	2.5213	2nd B'	0.92477	
6	Enter d_{gI}	6.4505	C	1.86416	
7	Enter d_{go}	0.9929	2nd C'	-0.00713	
8	Calculate Pt(d)		D		18.75795*
					-17.75795
					0.10000
					.
					.
					.
					.
					0.00002
					0.99998
					20.00000
				9999.00000	

For entire printer output see Figure 3.

---

*The first five or six values of Pt(d) are unreliable because extrapolation of the data was used to calculate them.

```
 18.75795      PRT
-17.75795      PRT
  0.10000      PRT

  2.08446      PRT
 -1.08446      PRT
  0.20000      PRT

  0.61050      PRT
  0.38950      PRT
  0.30000      PRT

  0.26207      PRT
  0.73793      PRT
  0.40000      PRT

  0.13801      PRT
  0.86199      PRT
  0.50000      PRT

  0.08250      PRT
  0.91750      PRT
  0.60000      PRT

  0.05376      PRT
  0.94624      PRT
  0.70000      PRT

  0.03728      PRT
  0.96272      PRT
  0.80000      PRT

  0.02709      PRT
  0.97291      PRT
  0.90000      PRT

  0.02043      PRT
  0.97957      PRT
  1.00000      PRT
```

```
  0.00342      PRT
  0.99658      PRT
  2.00000      PRT

  0.00127      PRT
  0.99873      PRT
  3.00000      PRT

  0.00065      PRT
  0.99935      PRT
  4.00000      PRT

  0.00039      PRT
  0.99961      PRT
  5.00000      PRT

  0.00026      PRT
  0.99974      PRT
  6.00000      PRT

  0.00019      PRT
  0.99981      PRT
  7.00000      PRT

  0.00014      PRT
  0.99986      PRT
  8.00000      PRT

  0.00011      PRT
  0.99989      PRT
  9.00000      PRT

  0.00009      PRT
  0.99991      PRT
 10.00000      PRT
```

Figure 3. Penetration as a Function of Particle Diameter Printer Output for Example 1 - Use of SR-52 Data Reduction Programs

```
 0.00007       PRT
 0.99993       PRT
11.00000       PRT

 0.00006       PRT
 0.99994       PRT
12.00000       PRT

 0.00005       PRT
 0.99995       PRT
13.00000       PRT

 0.00004       PRT
 0.99996       PRT
14.00000       PRT

 0.00004       PRT
 0.99996       PRT
15.00000       PRT

 0.00003       PRT
 0.99997       PRT
16.00000       PRT

 0.00003       PRT
 0.99997       PRT
17.00000       PRT

 0.00003       PRT
 0.99997       PRT
18.00000       PRT

 0.00002       PRT
 0.99998       PRT
19.00000       PRT

 0.00002       PRT
 0.99998       PRT
20.00000       PRT
```

Figure 3. (Cont'd)

TI-59 PROGRAM SET

GENERAL DISCUSSION

The TI-59 program set is contained on five cards. Four cards are used to store program instructions and the fifth card is used to store the impactor stage constants and the constants for the log-normal transformation. The Master Library Module is used as a subroutine in the data reduction program set.

Card 1 is used to perform all the calculations performed by Cards 1, 2, 3, 4, and 5 in the SR-52 program set. The card containing the stage constants is used in conjunction with Card 1.

Cards 2, 3, and 4 are used to calculate the graded penetration curve and are used in the following order: Cards 2 and 3 for inlet data, Cards 2 and 3 for outlet data, and then Card 4.

Card 2 is used to enter d_{50i} and f_i and to set up a spline fit calculation.

Card 3 is used to complete the spline fit calculation of df_i/dd.

Card 4 is used to calculate Pt(d) from the values of df_i/dd calculated by Cards 2 and 3.

Two additional sets of programs--one to convert aerodynamic diameter to physical diameter and one to calculate the viscosity of mixtures of gases--are included.

The use of all cards is discussed below.

CARD 1

Card 1 in the TI-59 data reduction package replaces Cards 1, 2, 3, 4 and 5 in the SR-52 package. The programs on Card 1 solve the same equations using the same methods as are used in the SR-52 package. The discussion of equations and methods of solution will not be repeated here.

A data card which contains the impactor stage constants and the constants for the log-normal transformation are used with Card 1. This data card is recorded in advance. The steps necessary for recording the data card are:

1. Store impactor stage constants in R_{40} through R_{46}.
2. Store constants for log-normal fit in R_{47} through R_{52}.
3. Record the constants on magnetic card as follows:

   Enter 3
   Press 2nd Write
   Pass a magnetic card through the calculator.

The memory contents for the MRI Impactor are shown in Figure 4. The steps for entering the cards are shown below.

Step	Procedure	Enter	Press	Display
1	Enter side 1 of card containing program		Clr	1
2	Enter side 2 of card containing program		Clr	2
3	Enter card with constants		Clr	3

The use of the programs contained on Card 1 is demonstrated by Example 2.

Value of Constant	Register
0.054069	40
0.068611	41
0.021484	42
0.0038666	43
0.0010147	44
0.00035065	45
0.00022899	46
2.515517	47
0.802853	48
0.010328	49
1.432788	50
0.189269	51
0.001308	52

Figure 4. Contents of R_{40} through R_{52} for MRI Impactor

Example 2. Use of TI-59 Reduction Package

The following data were collected with an MRI Impactor:

T = 177°C
P = 76 cm Hg
Q = 11.64 l/m
$M_1 + 2$ = 7.1 mg
M_3 = 4.9
M_4 = 4.6
M_5 = 1.8
M_6 = 0.8
M_7 = 0.3
M_{filter} = 0.3

Use the TI-59 program to reduce the data.

Step	Procedure	Enter	Press	Display	Print
1	Enter side 1 of card containing program		Clr	1	
2	Enter side 2 of card containing program		Clr	2	
3	Enter card containing constants		Clr	3	
4	Enter data		A	370064	T=
	T °C	177	R/S		177
	P cm Hg	76			P=
					76.00
				340064	Q=
	Q l/m	11.64	R/S	3013363600	11.64
					MASS
	$M_1 + M_2$	7.1	R/S	3013363600	7.1

Step Procedure	Enter	Press	Display	Print
M_3	4.9	R/S	3013363600	MASS 4.9
M_4	4.6	R/S	3013363600	MASS 4.6
M_5	1.8	R/S	3013363600	MASS 1.8
M_6	0.8	R/S	3013363600	MASS 0.8
M_7	0.3	R/S	3013363600	MASS 0.3
M_{filter}	0.3	R/S		MASS 0.3

Program will run for 2 minutes then printing will start

```
                                    D50
                                    .6989891358
                                    FI
                                    .0151515152
             For entire Printout       .
             see Figure 5              .
                                       .
                                    SIGMA
                                    3.251912896
               3.251912896
```

Printout for this example is shown in Figure 5.

Note that the impactor data reduction program results are for aerodynamic particle diameter. The aerodynamic particle diameter is appropriate for describing the performance of devices which collect particles by inertial impaction; e.g., venturi scrubbers. However, the aerodynamic diameter is not appropriate for many situations; e.g., for describing the performance of

```
      T =
       177.
      P =
        76.
      Q =
      11.64
    MASS
         7.1
    MASS
         4.9
    MASS
         4.6
    MASS
         1.8
    MASS
         0.8
    MASS
         0.3
    MASS
         0.3
 D50
.6989891358
 FI
.0151515152
 D50
.8649661038
 FI
.0303030303
 D50
1.471400832
 FI
.0707070707
 D50
2.872280107
 FI
.1616161616
 D50
6.770484356
 FI
.3939393939
 D50
12.09926647
 FI
.6414141414
    A
-1.823399103
    B
.8480013495
R**2
0.995740151
  DG
8.586844903
SIGMA
 3.251912896
```

Figure 5. Output from Example 3--Use of TI-59 Data Reduction Package

electrostatic precipitators. In such cases the physical particle diameter is needed.

The physical particle diameter, d, is given by

$$d = d_A / \sqrt{\rho C} \qquad (20)$$

where ρ = the particle density and
C = Cunningham correction factor.

The Cunningham correction factor can be calculated from the mean free path of the gas, λ, and the particle diameter d from

$$C = 1 + 2 A \frac{\lambda}{d} \qquad (21)$$

where

$$A = 1.246 + 0.42 \exp (-0.87d/2\lambda) \qquad (22)$$

The mean free path of the gas, λ, can be calculated from

$$\lambda = \lambda_o \left(\frac{76}{P} \right) \left(\frac{T°K}{296.2} \right) \qquad (23)$$

where

λ_o = mean free path at 23°C and
76 cm Hg = 0.0653 μm for air
P = barometric pressure cm Hg
T = temperature °K

Equation (20) can be solved for d by trial and error.

The TI-59 program for calculating d is given in Appendix C. The program converts d_A to d*, prints d_A and corresponding d, prints d_i and f_i, and

---

*The tolerance for the trial and error solution of equation (20) is $|d_{i+1} - d_i|/d_i < 0.001$.

calculates and prints the log-normal fit parameters d_g, σ along with A and B for $y = A + Bx$, and the correlation coefficient r^2.

The use of this program is illustrated in Example 3.

Example 3. Use of Programs to Convert Aerodynamic Diameter to Physical Diameter

The following data were collected with an MRI impactor.

T = 100°C
P = 76 cm Hg
Q = 16 l/m
$M_1 + M_2$ = 8.0 mg
M_3 = 5.0 mg
M_4 = 4.5 mg
M_5 = 2.0 mg
M_6 = 0.9 mg
M_7 = 0.45 mg
M_8 = 0.3 mg
ρ = 2.4 g/cc

Use the TI-59 programs to reduce the data for both aerodynamic and physical particle diameters.

Step	Procedure	Enter	Press	Display	Print
1	Enter side 1 of data reduction card		Clr	1	
2	Enter side 2 of data reduction card		Clr	2	
3	Enter card containing constants		Clr	3	
4	Enter data		A	370064	T=
	T °C	100	R/S		100

Step	Procedure	Enter	Press	Display	Print
				330064	P=
	P cm Hg	76	R/S	340064	76
					Q=
	Q 1/m	16	R/S	30133663600	16
					MASS
	$M_1 + M_2$	8.0	R/S	30133663600	8.
					MASS
	M_3	5.0	R/S	30133663600	5.
					MASS
	M_4	4.5	R/S	30133663600	4.5
					MASS
	M_5	2.0	R/S	30133663600	2.
					MASS
	M_6	0.9	R/S	30133663600	0.9
					MASS
	M_7	0.45	R/S	30133663600	0.45
					MASS
	M_{filter}	0.3	R/S		0.3

Program will run for about 2 minutes then printing will start

					D50
					.5567597984
					.
					.
					.
					SIGMA
					3.372605753
				3.372605753	
5	Enter side 1 of card to calculate d from d_A		CLR	1	
6	Enter side 2 of card to calculate d from d_A		CLR	2	
7	Begin calculation		A	3745710000	Density?
	Enter	2.4	R/S		2.4

Step	Procedure	Enter	Press	Display	Print
					9.637324556 DA
					6.118139795 DP
					.
					.
					.

Printer output for this example is given in Figure 6.

As can be seen from equation (1), d_{A50} is a function of gas viscosity. The TI-59 program uses a relationship developed for air to estimate gas viscosity at impactor temperature. If the gas being sampled has a composition significantly different from that of air, the viscosity used in the program will be in error. In many cases, especially when quick data reduction at field tests is needed, the error in d_{A50} caused by using viscosity of air is not too important. However, final data reduction should be performed using the best possible estimate of the viscosity of the actual gas being sampled.

The program given in Appendix D can be used to estimate the viscosity of gas mixtures. Input data required for this program are: number of components and the viscosity, molecular weight and mole fraction of each pure component. The viscosity calculated from this program can be used in the impactor program by modifying subroutine A'of the impactor program, as follows:

1. Read TI-59 data reduction program card.
2. Press GTO 2nd A'
3. Press Learn
4. Starting at program step 339, enter the value of viscosity calculated from viscosity program
5. After last number for viscosity is entered, press INV SBR
6. Press Learn
7. Record modified program
8. Reduce data following instructions for TI-59 programs.

```
      T =
       100.
      P =
        76.
      Q =
        16.
    MASS
         8.
    MASS
         5.
    MASS
        4.5
    MASS
         2.
    MASS
        0.9
    MASS
       0.45
    MASS
        0.3
 D50
.5567597984
 FI
.0141843972
 D50
.6889640038
 FI
.0354609929
 D50
1.172002237
 FI
.0780141844
 D50
2.287832545
 FI
.1725768322
 D50
5.392835614
 FI
.3853427896
 D50
9.637324556
 FI
0.621749409
   A
-1.602678119
   B
.8225810569
R**2
0.992469079
  DG
7.017119575
SIGMA
3.372605753
```

```
        DENSITY?
           2.4

9.637324556      DA
6.118139795      DP

5.392835614      DA
3.379058333      DP

2.287832545      DA
1.376807932      DP

1.172002237      DA
.6590790717      DP

.6889640038      DA
.3488621786      DP

.5567597984      DA
0.264398662      DP

 D50
0.264398662
 FI
.0141843972
 D50
.3488621786
 FI
.0354609929
 D50
.6590790717
 FI
.0780141844
 D50
1.376807932
 FI
.1725768322
 D50
3.379058333
 FI
.3853427896
 D50
6.118139795
 FI
0.621749409
   A
-1.125663512
   B
0.749240985
R**2
.9926892225
  DG
4.492481161
SIGMA
3.798795567
```

Figure 6. Printer Output for Example 3--Use of Programs to Convert d_A to d

The use of the viscosity program is illustrated in Example 4.

Example 4. Calculation of Viscosity of Gas Mixtures

Calculate the viscosity of a mixture of hydrogen, H_2, and carbon dioxide, CO_2, at 21°C.

Component	Viscosity	Molecular Weight	Mole Fraction
H_2	0.0876 cp	2	0.413
CO_2	0.148 cp	44	0.587

Step	Procedure	Enter	Press	Display	Print
1	Read side 1 of viscosity program		CLR	1	
	Read side 2 of viscosity program		CLR	2	
2	Begin calculation		A	3171	N?
3	Enter number of components	2	R/S		2.0000
					I =
					2.0000
				42243671.00	VIS?
	Enter viscosity of H_2	0.0876	R/S		0.0876
				3043710000	MW?
	Enter molecular weight of H_2	2	R/S		2.0000
				44710000	X?
	Enter mole fraction of H_2	.413	R/S		0.4130
					I
					1.0000
				42243671.00	VIS?
	Enter viscosity of CO_2	.1480	R/S		0.1480
			3043710000		MW?

Step	Procedure	Enter	Press	Display	Print
	Enter molecular weight of CO_2	44	R/S		44.0000
				4471.0000	X?
	Enter mole fraction of CO_2	.587	R/S		0.5870
	After about 30 sec calculator will print viscosity of mixture			0.1501	0.1501 VIS

Printer output for this example is shown in Figure 7.

```
   N?
 2.0000

 I=
 2.0000
VIS?
 0.0876
MW?
 2.0000
 X?
 0.4130

 I=
 1.0000
VIS?
 0.1480
MW?
44.0000
 X?
 0.5870

 0.1501      VIS
```

Figure 7. Printer Output for Example 4--Use of Program to Estimate Viscosity

CARDS 2, 3, AND 4 (CALCULATION OF PENETRATION AS A FUNCTION OF PARTICLE DIAMETER WITH TI-59)

The derivative of the cumulative fraction less than function must be calculated in order to calculate Pt(d). The derivative can be calculated either from a curve fit to the impactor data or from differentials calculated from the tabular impactor data. The curve fit method is discussed in the SR-52 section of this report. The calculation of differentials from tabular data is discussed in this section.

A spline function gives the smoothest possible curve through data and gives the best estimate of the derivatives for the tabular data.[2] The general theory of spline functions and how to fit data with them is discussed in Reference 3 and will not be covered in this report. The Spline Function Program given in Reference 3 has been programmed for the TI-59. The program listing is given in Appendix E. Only the use of the program will be discussed in this report. This program uses numerical relaxation to solve the following system of six equations:

$$S''(X_1) = 0 \tag{24}$$

$$-S''(X_2) - b_2 S''(X_1) - (1/2 - b_2)S''(X_3) + g_2 \le \varepsilon \tag{25}$$

$$-S''(X_3) - b_3 S''(X_2) - (1/2 - b_3)S''(X_4) + g_3 \le \varepsilon \tag{26}$$

$$-S''(X_4) - b_4 S''(X_3) - (1/2 - b_4)S''(X_5) + g_4 \le \varepsilon \tag{27}$$

$$-S''(X_5) - b_5 S''(X_4) - (1/2 - b_5)S''(X_6) + g_5 \le \varepsilon \tag{28}$$

$$S''(X_6) = 0 \tag{29}$$

where

$$S''(x_i) = \frac{2}{x_{i+1} - x_{i-1}} \left[\frac{(y_{i+1} - y_i)}{(x_{i+1} - x_i)} - \frac{(y_i - y_{i-1})}{(x_i - x_{i-1})} \right] , \tag{30}$$

$$b_i = 1/2 \, \frac{(x_i - x_{i-1})}{(x_{i+1} - x_{i-1})} \tag{31}$$

$$g_i = \frac{3}{x_{i+1} - x_{i-1}} \left[\frac{(y_{i+1} - y_i)}{(x_{i+1} - x_i)} - \frac{(y_i - y_{i-1})}{(x_i - x_{i-1})} \right] \quad (32)$$

for $2 \leq i \leq 5$

and ε is a user specified tolerance (0.00001 is adequate).

After the above equations are solved, the following quantity is calculated:

$$S_i''' = \frac{S''(x_{i+1}) - S''(x_i)}{x_{i+1} - x_i} \quad , \quad i = 1, 5 \quad (33)$$

Card 2 does the following for j = 1 to 6

1. Finds i such that $x_i \leq t_j < x_{i+1}$
2. Solves the following equations:

$$S''(t_j) = S''(x_i) + (t_j - x_i)S_i''' \quad (34)$$

$$S(t_j, x_i, x_{i+1}) = 1/6 \quad [S''(x_i) + S''(x_{i+1}) + S''(t_j)] \quad (35)$$

$$S(t_j) = y_i + (t_j - x_i) \frac{(y_{i+1} - y_i)}{(x_{i+1} - x_i)} + (t_j - x_i)(t_j - x_{i+1})S(t_j,x,x_{i+1}) \quad (36)$$

$$S'(t_j) = (y_{i+1} - y_i) + (2t_j - x_i - x_{i+1})S(t_j,x_1,x_{i+1}) + 1/6 \ (t_j-x_i)(t_j-x_{i+1})S_i''') \quad (37)$$

The spline program can be used to calculate derivatives of the tabular impactor data for six values of particle diameter, d. The values of d chosen must not require extrapolation of the data. If extrapolation is attempted, an error message is printed. The program prompts the user by printing the data that should be read in. Values d should be entered when X is asked for, f_i should be entered when Y is asked for, tolerance for numerical solution should be entered when TOL is asked for, and values of d for which Pt(d) is to be calculated should be entered when T is asked for. Values d must be input in order of smallest to largest.

Output df(d)/dd is important for calculation of Pt(d) and is labelled S'(T) in the printed output.

Penetration for any particle diameter is given by

$$Pt(d) = \frac{W_O}{W_I}\left[\frac{df_O(d)/dd}{df_I(d)/dd}\right] \tag{38}$$

The use of this program is best demonstrated by an example.

Example 5

Calculate Pt(d) from the following data:

Inlet Data $W_I = 1.305$ g/m^3		Outlet Data $W_O = 0.00492$ g/m^3	
d	f	d	f
13.826	0.8731	6.5012	0.9645
7.7369	0.53299	3.638	0.8298
3.2822	0.15228	1.5433	0.5603
1.6815	0.071066	0.7906	0.3688
0.98842	0.035533	0.4648	0.2695
0.79876	0.015228	0.3756	0.1489

Note that d's for calculation of Pt(d) must not exceed 6.5 nor be less than 0.799.

Solution

Choose values of d for calculation of Pt(d). Use 0.8, 1.0, 1.5, 2, 3, and 6. Do inlet first.

Step	Procedure	Enter	Press	Display	Print
1	Read side 1 of spline fit card	1	INV 2nd Write	1	
	Enter side 2 of spline fit card	2	INV 2nd Write	2	
2	Clear memory and initialize		2nd Cms E	-1	
3	Input data in order		A	440071	X ?
	from smallest d_{50} to	0.79876	R/S	450071	0.79876
	largest d_{50}	0.015228	R/S	440071	0.015228
					X ?
		0.98842	R/S	450071	0.98842
					Y ?
		0.035533	R/S	440071	0.035533
					X ?
		1.6815	R/S		1.6815
				450071	Y ?
		0.071066	R/S		0.071066
				.440071	X ?
		3.2822	R/S		3.2822
				450071	Y ?
		0.15228	R/S		0.15228
				440071	X ?
		7.7369	R/S		7.7369
				450071	Y ?
		0.53299	R/S		0.53299
				440071	X ?
		13.826	R/S		13.826
				450071	Y ?
		0.8731	R/S		0.8731
4	Enter tolerance for			37322771	TOL?
	numerical solution	0.0001	R/S		0.0001

The calculator will run for about 3 minutes.

Step	Procedure	Enter	Press	Display	Print
				376536	INPUT T's
5	Input d's for calculation of Pt(d)	0.8	R/S		0.8
				376536	INPUT T's
		1.0	R/S		1.
				376536	INPUT T's
		1.5	R/S		1.5
				376536	INPUT T's
		2.0	R/S		2.
				376536	INPUT T's
		3.0	R/S		3.
				376536	INPUT T's
		6.0	R/S		6.
				300000000	READ CARD 2
6	Read Card 2		CLR	1	
			CLR	2	
7	Calculate Calculator will run for about 10 seconds and then print.		A		See Figure 8 for printer output
8	Record results on magnetic card	3	2nd Write	3	
9	Repeat for outlet				
	Read Card 1 side 1	1	CLR	1	
	Read Card 1 side 2	2	CLR	2	
10	Clear memory and initialize		2nd Cms	-1	
			E		
11	Enter data		A		X ?
		0.3756	R/S		0.3756
					Y ?
		0.1489	R/S		0.1489
					X ?
		0.4648	R/S		0.4648
					Y ?
		0.2695	R/S		0.2695
					X ?

Step	Procedure	Enter	Press	Display	Print
		0.7906	R/S		0.7906
					Y ?
		0.3688	R/S		0.3688
					X ?
		1.5433	R/S		1.5433
					Y ?
		0.5603	R/S		0.5603
					X ?
		3.638	R/S		3.638
					Y ?
		0.8298	R/S		0.8298
					X ?
		6.5012	R/S		6.5012
					Y ?
		0.9645	R/S		0.9645
				376536	TOL ?
	Enter tolerance for numerical solution	0.0001	R/S		0.0001
				376536	INPUT T's
		0.8			0.8
				376536	INPUT T's
		1.0			1.
				376536	INPUT T's
		1.5			1.5
				376536	INPUT T's
		2.0			2.
				376536	INPUT T's
		3.0			3.
				376536	INPUT T's
		6.0			6.
12	Read Card 2 side 1	1	CLR	300000000	READ CARD 2
	Card 2 side 2	2	CLR		
13	Calculate		A		See Figure 8 for printer output

Step	Procedure	Enter	Press	Display	Print
14	Record data on magnetic card	3	2nd Write	3	
15	Read Pt(d) Program				
	Card side 1		CLR	1	
	side 2		CLR	2	
16	Calculate		A		
17	Read inlet card		CLR	3	READ INLET DATA
18	Read outlet card		CLR	3	READ OUTLET DATA
				2431710000	MASS IN ?
19	Enter inlet mass concentration	1.305	R/S		0.1305
				3241377100	MASS OUT ?
20	Enter outlet mass concentration	0.00492	R/S		0.000492
					D =
					0.8
					PT(D) =
					.0002409147
					D =
					1.
					PT(D) =
					.0081617673
					.
					.
					.
					D =
					6
					PT(D) =
					.0021486703
					OVERALL PT =
					.0037701149
				17311600	END

Printer output for this example is shown in Figure 8.

```
       X ?
   0.79876
       Y ?
  0.015228
       X ?
   0.98842
       Y ?
  0.035533
       X ?
    1.6815
       Y ?
  0.071066
       X ?
    3.2822
       Y ?
   0.15228
       X ?
    7.7369
       Y ?
   0.53299
       X ?
    13.826
       Y ?
    0.8731
      TOL?
    0.0001
INPUT  T'S
       0.8
INPUT  T'S
        1.
INPUT  T'S
       1.5
INPUT  T'S
        2.
INPUT  T'S
        3.
INPUT  T'S
        6.
READ CARD 2
```

```
       T =
        0.8
       S''
-.0012980732
     S(TXX1)
-.0333067433
       S(T)
 .0153685362
      S'(T)
 .1133351221
```

```
       T =
         1.
       S''
-.1948449069
     S(TXX1)
-.0617716849
       S(T)
 .0366141743
      S'(T)
 0.092230367
```

```
       T =
        1.5
       S''
-.0351955372
     S(TXX1)
-.0351634566
       S(T)
 .0650258015
      S'(T)
 .0347202559
```

```
       T =
         2.
       S''
.0219602419
     S(TXX1)
.0105782703
      S(T)
0.097705647
      S'(T)
.0407126188
```

```
       T =
         3.
       S''
.0194580689
     S(TXX1)
.0101612014
      S(T)
.1341813579
      S'(T)
.0614217742
```

```
       T =
         6.
       S''
-.0002447947
     S(TXX1)
 .0010203107
      S(T)
 .3797336807
      S'(T)
 .0919626106

      END
```

Figure 8. Printer Output for Example 5 - Use of TI-59 Program to Calculate Penetration as a Function of Particle Diameter

```
      X ?
     0.3756
      Y ?
     0.1489
      X ?
     0.4648
      Y ?
     0.2695
      X ?
     0.7906
      Y ?
     0.3688
      X ?
     1.5433
      Y ?
     0.5603
      X ?
      3.638
      Y ?
     0.8298
      X ?
     6.5012
      Y ?
     0.9645
     TOL?
     0.0001
INPUT  T'S
          0.8
INPUT  T'S
           1.
INPUT  T'S
          1.5
INPUT  T'S
           2.
INPUT  T'S
           3.
INPUT  T'S
           6.
READ CARD 2
```

```
        T =
          0.8
        S''
 1.156694357
     S(TXX1)
 0.339892683
        S(T)
 .3688166869
       S'(T)
 .0072403722


        T =
           1.
        S''
 .7667973758
     S(TXX1)
 .2749098528
        S(T)
 .3907993352
       S'(T)
 .1995895455


        T =
          1.5
        S''
-.2079450781
     S(TXX1)
 .1124527771
        S(T)
 .5458295111
       S'(T)
 .3393026199
```

```
        T =
           2.
        S''
-.2259175925
     S(TXX1)
-.0843164391
        S(T)
 .6821331141
       S'(T)
 .2101228815


        T =
           3.
        S''
-.0804387615
     S(TXX1)
-.0600699672
        S(T)
 .8035436712
       S'(T)
 .0569447045


        T =
           6.
        S''
 .0021665334
     S(TXX1)
 .0024238777
        S(T)
 .9380514439
       S'(T)
 .0524085076

        END
```

Figure 8.(Cont'd)

```
READ INLET DATA
READ OUTLET DATA
MASS IN?
      0.1305
MASS OUT?
    0.000492
       D =
         0.8
PT(D) =
 .0002408524
       D =
          1.
PT(D) =
 .0081586527
       D =
         1.5
PT(D) =
 .0368433309
       D =
          2.
PT(D) =
 .0194580314
       D =
          3.
PT(D) =
 0.003495309
       D =
          6.
PT(D) =
 .0021485482
OVERALL PT =
 .0037701149
      END
```

Figure 8. (Cont'd)

Comparison of Graded Efficiency Calculated from Curve Fit and Spline Fit

"How well does the calculated graded penetration represent the actual graded penetration?" is not a trivial question. It is as nearly impossible to answer.

The actual graded penetration for a real particulate control device is unknown. However, we can create synthetic data from mathematical models and compare data reduction results with the synthetic data. We can also compare results of various methods of calculating the graded penetration with each other when real data are available. Both types of comparisons are made in this section.

The graded penetration calculated using the spline fit, the log-normal, and a quadratic log-normal fit methods are compared in Table 4. It appears that the curve fit methods give good results when the r^2 product is greater than 0.985. This indicates that other types of distribution (such as the upper limit distribution and the Weibull distribution) could be useful. The fits for these distributions could be done by an SR-52 calculator and thus extend the useful range of the SR-52 program set.

The curve fit methods may have an advantage over the spline fit in that statistical information on goodness of fit and confidence limits of fit can be calculated for the curve fit. Such statistical information is not available from the spline fit. Also, curve fits smooth the data; spline fits do not.

Synthetic data were created with the aid of a mathematical model for electrostatic precipitation. "Perfect" impactors were used to sample the inlet particle size distribution fed into the model and the outlet particle size distribution generated by the model. The TI-59 programs were used to reduce the impactor data and calculate the graded penetration. The results of these calculations are summarized in Table 5.

Table 4. COMPARISON OF GRADED PENETRATION CALCULATED USING LINEAR LOG-NORMAL FIT, QUADRATIC LOG-NORMAL FIT AND SPLINE FIT ON ACTUAL IMPACTOR DATA

	Case 1			Case 2			Case 3		
d, μmA	$Pt(d)_{LN}$	$Pt(d)_{LN^2}$	$Pt(d)_s$	$Pt(d)_{LN}$	$Pt(d)_{LN^2}$	$Pt(d)_s$	$Pt(d)_{LN}$	$Pt(d)_{LN^2}$	$Pt(d)_s$
0.87	0.25	0.052	0.0029	0.055	0.048	0.016	0.016	0.075	0.029
1.24	0.18	0.028	0.023	0.023	0.029	0.028	0.029	0.031	0.035
1.78	0.10	0.015	0.028	0.0090	0.016	0.015	0.0099	0.014	0.015
2.53	0.069	0.0070	0.0080	0.0050	0.0081	0.0077	0.0059	0.0070	0.0070
3.62	0.050	0.0030	0.0018	0.0025	0.0038	0.0040	0.0030	0.0038	0.0032
5.16	0.037	0.0012	0.0021	0.0015	0.0016	0.0021	0.0019	0.0021	0.0022
r^2_{in} X r^2_{out}	= 0.94 linear log-normal			r^2_{in} X r^2_{out}	= 0.97 linear log-normal		r^2_{in} X r^2_{out}	= 0.985 linear log-normal	
	= 0.986 quadratic log-normal				= 0.994 quadratic log-normal			= 0.995 quadratic log-normal	

Table 5. COMPARISON OF GRADED PENETRATION CALCULATED WITH SPLINE AND LOG-NORMAL FITS WITH ACTUAL GRADED PENETRATIONS FROM ESP MODEL

d	$Pt(d)_M$	$Pt(d)_S$	Δ/M
Case 1			
0.45	0.28	0.27	0.036
0.70	0.26	0.25	0.038
1.0	0.22	0.20	0.091
1.5	0.16	0.14	0.125
2.5	0.094	0.071	0.24
4.0	0.049	0.040	0.18
Case 2			
0.45	0.28	0.28	0.0
0.70	0.27	0.25	0.074
1.0	0.23	0.21	0.087
1.5	0.17	0.15	0.12
2.5	0.10	0.082	0.18
4.0	0.060	0.052	0.13
Case 3			
0.45	0.040	0.040	0.0
0.70	0.035	0.033	0.057
1.0	0.026	0.022	0.15
1.5	0.015	0.012	0.20
2.5	0.0075	0.0052	0.31
4.0	0.0021	0.00086	0.59

$Pt(d)_m$ - Pt(d) from ESP Model

$Pt(d)_s$ - Pt(d) from spline fit

Δ_s/M - $(Pt(d)_M - Pt(d)_s)/Pt(d)_M$

The results shown in Table 5 indicate that the graded penetrations calculated from the spline fit are generally in fair agreement with the "real" graded penetrations. However, in some cases, especially when the penetrations are low, the disagreement between the calculated graded penetration and the "real" graded penetration is substantial. Work to determine ways to improve the agreement between the calculated and "real" graded penetrations and to better define the uncertainty in the calculated graded penetrations is underway and will be reported.

Lawless[4] has suggested that the cumulative size distribution data be transformed into log-normal space before the spline fit calculations are performed. Such a transformation will improve the agreement between measured and real graded penetration.

The log-normal values f_i are available in the memory of the TI-59 if one desires to perform the spline fit calculations in log-normal space. The log-normal transforms of the f_i are stored in registers 30 to 35 (transformed f_i is in R_{30}, etc.) and may be recovered by pressing 30 INV 2nd List. Value ln d_i is entered when X is asked for and the corresponding value of transformed f_i is entered when Y is asked for.

The penetration program must be modified to calculate Pt(d) from

$$Pt(d_i) = \frac{W_0 \quad \{\exp[- S(d_i)^2/2] \;\; X \;\; S'(d_i)\} \;\; \text{out}}{W_I \quad \{\exp[- S(d_i)^2/2] \;\; X \;\; S'(d_i)\} \;\; \text{in}} \qquad (39)$$

where $S(d_i)$ and $S'(d_i)$ are the output from the spline fit program for d = d_i.

Recommendations for Running Impactors

No matter what method of data reduction is used, the number of points available for calculation of the graded penetration is limited by the number of impactor stages. Also, the values of d for which Pt(d) can be calculated are limited by the range of the impactor stage d_{50}'s (extrapolation is prohibited). Data points cannot be created by the data reduction technique.

The above points lead to the following recommendations on obtaining impactor data:

1) Six or seven stages covering the range $0.5 \leq d_{A50} \leq 15$ µmA are probably adequate for most purposes.

2) The particle diameter ranges covered by the inlet and outlet impactors are the same or as close to the same as possible. Otherwise data points are lost.

3) Stages d_{A50} for the inlet and outlet impactors should be as close to each other as possible.

REFERENCES

1. Hastings, C., Jr., *Approximations for Digital Computers*. Princeton University Press, Princeton, New Jersey, 1955.

2. Walsh, J. L, Ahlberg, J. H., and Nilson, E. N., "Best Approximation Properties of the Spline Fit", J. Math. & Mech., 11, 225 (1962).

3. Greville, T. N. E., "Spline Functions, Interpolation, and Numerical Quadrature", Chapter 8 in *Mathematical Methods for Digital Computers*, Vol. II. ed. Ralston, A. and Wolf, H. S. John Wiley and Sons, New York, New York, 1967.

4. Lawless, Phil A., "Analysis of Cascade Impactor Data for Calculating Particle Penetration", Research Triangle Institute, EPA-600/7-78-189, September 1978.

APPENDIX A

USER INSTRUCTIONS AND PROGRAM LISTING FOR SR-52 DATA REDUCTION PROGRAMS

GENERAL

The data reduction programs are contained on six cards which are used in order: Cards 1, 2, 3, 4, and 5 for inlet; Cards 1, 2, 3, 4 and 5 for outlet; and Card 6 for combined inlet and outlet results. The programs use the PC-100A printer.

USER INSTRUCTIONS FOR SR-52 DATA REDUCTION PACKAGE

Step	Procedure	Enter	Press	Display	Print
1	Read sides A and B of Card 1				
2	Check to see if card read properly		RCL 92	Constant for 1st stage	
3	Enter T	T°C or	A	T°C	
		T°F	2nd A'	T°C	
4	Enter Q	Q l/min or	B	Q l/min	
		cfm	2nd B	Q l/min	
5	Initialize		E	1.0000	
6	Reset		2nd rst	1.0000	
7	Calculate d_{A50i}		D	0.0000	
8	Read sides A and B of Card 2				
9	Initialize		E	0.0000	
10	Enter M_i	M_1	A	1.0000	M_1
		M_2	A	2.0000	M_2
		.		.	.
		.		.	.
		.		.	.
		M_{filter}	A	7.0000	M_8

Note: For the MRI and University of Washington impactors, M_1 = the sum of the mass collected on the first two stages. M_1 and M_2 must be added before the data are entered.

11	Read side A of Card 3				
12	Initialize		E	0.0000	
13	Print M_T, $f_i d_{A50i}$			f	M_T
					d_{A501}
					f_1
					.
					.
					.
					d_{A506}

Step	Procedure	Enter	Press	Display	Print
					f_6
14	Read Card 4 sides A and B				
15	Initialize		E	8.0000	
16	Transform f_i		A		
17	Read Card 5 sides A and B				
18	Initialize		E	0.0000	
19	Calculate log-normal parameters		A	J	A B r^2 d_g σ
20	Read Card 6 sides A and B			2nd rst INV READ INV READ	
21	Enter W_I	W_I	A		0.10000
22	Enter W_o	W_o	2nd A'		W_o
23	Enter σ_I	σ_I	B		ln σ_I
24	Enter σ_o	σ_o	2nd B'		ln σ_o
25	Enter d_{gI}	d_{gI}	C		ln d_{gI}
26	Enter d_{go}	d_{go}	2nd C'		ln d_{go}
27	Calculate Pt(D)		D		. Pt(d) 1-Pt(d) 0.1 . . . Pt(d) 1-Pt(d)
				9999.00000	20.0

```
000  46 LBL
001  19  D'
002  01  1
003  44 SUM
004  00  0
005  00  0
006  36 IND
007  43 RCL
008  00  0
009  00  0
010  56 RTN
011  46 LBL
012  10  E'
013  36 IND
014  42 STO
015  01  1
016  09  9
017  01  1
018  44 SUM
019  01  1
020  09  9
021  56 RTN
022  46 LBL
023  18  C'
024  53  (
025  01  1
026  93  .
027  06  6
028  08  8
029  52 EE
030  94 +/-
031  04  4
032  85  +
033  53  (
034  09  9
035  55  ÷
036  05  5
037  65  ×
038  43 RCL
039  00  0
040  08  8
041  85  +
042  03  3
043  02  2
044  54  )
045  65  ×
046  02  2
047  93  .
048  02  2
049  09  9
050  02  2
051  52 EE
052  94 +/-
053  07  7
054  54  )
055  56 RTN
056  46 LBL
057  13  C
058  81 HLT
059  42 STO
060  00  0
061  00  0
062  46 LBL
063  87  1'
064  19  D'
065  98 PRT
066  43 RCL
067  00  0
068  00  0
069  98 PRT
070  75  -
071  07  7
072  95  =
073  90 IFZ
074  88  2'
075  41 GTO
076  87  1'
077  46 LBL
078  88  2'
079  81 HLT
080  46 LBL
081  14  D
082  19  D'
083  65  ×
084  18  C'
085  55  ÷
086  43 RCL
087  00  0
088  09  9
089  65  ×
090  01  1
091  52 EE
092  08  8
093  95  =
094  30  √X
095  10  E'
096  43 RCL
097  01  1
098  09  9
099  75  -
```

Impactor Data Reduction Program Listing Card 1

```
101  95   =
102  90  IFZ
103  13   C
104  41  GTO
105  14   D
106  46  LBL
107  11   A
108  42  STO
109  00   0
110  08   8
111  81  HLT
112  46  LBL
113  12   B
114  42  STO
115  00   0
116  09   9
117  81  HLT
118  46  LBL
119  16   A'
120  75   -
121  03   3
122  03   3
123  95   =
124  65   ×
125  05   5
126  55   ÷
127  09   9
128  95   =
129  11   A
130  46  LBL
131  17   B'
132  55   ÷
133  93   .
134  00   0
135  03   3
136  05   5
137  03   3
138  02   2
139  95   =
140  12   B
141  46  LBL
142  15   E
143  09   9
144  01   1
145  42  STO
146  00   0
147  00   0
148  01   1
149  42  STO
150  01   1
151  09   9
152  22  INV
153  52  EE
154  57  FIX
155  04   4
156  81  HLT
```

Impactor Data Reduction Program Listing Card 1 (Cont'd)

```
000   46 LBL
001   11   A
002   98 PRT
003   36 IND
004   42 STO
005   00   0
006   00   0
007   44 SUM
008   01   1
009   09   9
010   01   1
011   44 SUM
012   00   0
013   00   0
014   43 RCL
015   00   0
016   00   0
017   75   -
018   08   8
019   09   9
020   95   =
021   81 HLT
022   46 LBL
023   15   E
024   01   1
025   03   3
026   42 STO
027   00   0
028   07   7
029   08   8
030   09   9
031   42 STO
032   00   0
033   00   0
034   00   0
035   42 STO
036   01   1
037   06   6
038   42 STO
039   01   1
040   07   7
041   42 STO
042   01   1
043   08   8
044   42 STO
045   01   1
046   09   9
047   81 HLT
048   46 LBL
049   12   B
050   43 RCL
051   00   0
052   00   0
053   75   -
054   01   1
055   95   =
056   42 STO
057   01   1
058   06   6
059   75   -
060   01   1
061   95   =
062   42 STO
063   01   1
064   08   8
065   46 LBL
066   88  2'
067   36 IND
068   43 RCL
069   01   1
070   06   6
071   44 SUM
072   01   1
073   07   7
074   01   1
075   22 INV
076   44 SUM
077   01   1
078   06   6
079   22 INV
080   44 SUM
```

Impactor Data Reduction Program Listing Card 2

```
081  01   1
082  08   8
083  43  RCL
084  01   1
085  07   7
086  55   ÷
087  43  RCL
088  01   1
089  09   9
090  95   =
091  36  IND
092  42  STO
093  00   0
094  07   7
095  01   1
096  22  INV
097  44  SUM
098  00   0
099  07   7
100  43  RCL
101  00   0
102  07   7
103  75   -
104  07   7
105  95   =
106  90  IFZ
107  77   4'
108  41  GTO
109  88   2'
110  46  LBL
111  77   4'
112  81  HLT
```

Impactor Data Reduction Progam Listing Card 2 (Cont'd)

```
000   46  LBL
001   11   A
002   99  PAP
003   43  RCL
004   01   1
005   09   9
006   22  INV
007   52  EE
008   98  PRT
009   12   B
010   81  HLT
011   46  LBL
012   12   B
013   99  PAP
014   01   1
015   42  STO
016   00   0
017   00   0
018   08   8
019   42  STO
020   01   1
021   09   9
022   46  LBL
023   87   1'
024   36  IND
025   43  RCL
026   00   0
027   00   0
028   98  PRT
029   36  IND
030   43  RCL
031   01   1
032   09   9
033   98  PRT
034   99  PAP
035   01   1
036   44  SUM
037   00   0
038   00   0
039   44  SUM
040   01   1
041   09   9
042   43  RCL
043   00   0
044   00   0
045   75   -
046   07   7
047   95   =
048   22  INV
049   90  IFZ
050   87   1'
051   56  RTN
```

Impactor Data Reduction Program Card 3

```
000   46  LBL
001   11   A
002   93   .
003   05   5
004   75   -
005  ~~36~~ IND
006   43  RCL
007   00   0
008   00   0
009   22  INV
010   50  STF
011   01   1
012   42  STO
013   01   1
014   09   9
015   95   =
016   22  INV
017   80  IF+
018   87   1'
019   46  LBL
020   88   2'
021   12   B
022   60  IFF
023   01   1
024   77   4'
025   94  +/-
026   46  LBL
027   77   4'
028   36  IND
029   42  STO
030   00   0
031   00   0
032   43  RCL
033   00   0
034   00   0
035   75   -
036   01   1
037   03   3
038   95   =
039   90  IFZ
040   79   6'
041   01   1
042   44  SUM
043   00   0
044   00   0
045   41  GTO
046   11   A
047   46  LBL
048   79   6'
049   81  HLT
```

```
050   46  LBL
051   15   E
052   08   8
053   42  STO
054   00   0
055   00   0
056   81  HLT
057   46  LBL
058   12   B
059   43  RCL
060   01   1
061   09   9
062   40   X²
063   20  1/X
064   23  LNX
065   30   √X
066   53   (
067   42  STO
068   01   1
069   08   8
070   75   -
071   53   (
072   53   (
073   43  RCL
074   09   9
075   02   2
076   85   +
077   16   A'
078   65   ×
079   43  RCL
080   09   9
081   03   3
082   85   +
083   16   A'
084   40   X²
085   65   ×
086   43  RCL
087   09   9
088   04   4
089   54   )
090   55   ÷
091   53   (
092   01   1
093   85   +
094   16   A'
095   65   ×
096   43  RCL
097   09   9
098   05   5
099   85   +
```

Impactor Data Reduction Program Listing Card 4

```
046  44 SUM
047  00  0
048  00  0
049  44 SUM
050  01  1
051  09  9
052  11  A
053  46 LBL
054  88  2'
055  43 RCL
056  01  1
057  06  6
058  75  -
059  53  (
060  43 RCL
061  01  1
062  05  5
063  55  ÷
064  06  6
065  54  )
066  65  ×
067  43 RCL
068  01  1
069  04  4
070  95  =
071  55  ÷
072  53  (
073  43 RCL
074  01  1
075  08  8
076  75  -
077  53  (
078  43 RCL
079  01  1
080  04  4
081  55  ÷
082  06  6
083  54  )
084  65  ×
085  43 RCL
086  01  1
087  04  4
088  54  )
089  95  =
090  98 PRT
```

```
000  46 LBL
001  11  A
002  36 IND
003  43 RCL
004  00  0
005  00  0
006  23 LNX
007  42 STD
008  00  0
009  07  7
010  44 SUM
011  01  1
012  04  4
013  40  X²
014  44 SUM
015  01  1
016  08  8
017  36 IND
018  43 RCL
019  01  1
020  09  9
021  49 PRD
022  00  0
023  07  7
024  44 SUM
025  01  1
026  05  5
027  40  X²
028  44 SUM
029  01  1
030  07  7
031  43 RCL
032  00  0
033  07  7
034  44 SUM
035  01  1
036  06  6
037  43 RCL
038  00  0
039  00  0
040  75  -
041  06  6
042  95  =
043  90 IFZ
044  88  2'
045  01  1
```

Impactor Data Reduction Program Listing Card 5

```
091   42  STO
092   00   0
093   00   0
094   65   ×
095   43  RCL
096   01   1
097   04   4
098   55   ÷
099   06   6
100   94  +/-
101   85   +
102   53   (
103   43  RCL
104   01   1
105   05   5
106   55   ÷
107   06   6
108   54   )
109   95   =
110   98  PRT
111   42  STO
112   01   1
113   09   9
114   53   (
115   43  RCL
116   01   1
117   06   6
118   75   -
119   53   (
120   43  RCL
121   01   1
122   05   5
123   55   ÷
124   06   6
125   54   )
126   65   ×
127   43  RCL
128   01   1
129   04   4
130   95   =
131   40   X²
132   55   ÷
133   53   (
134   53   (
135   43  RCL
```

```
136   01   1
137   08   8
138   75   -
139   53   (
140   43  RCL
141   01   1
142   04   4
143   55   ÷
144   06   6
145   54   )
146   65   ×
147   43  RCL
148   01   1
149   04   4
150   54   )
151   65   ×
152   53   (
153   43  RCL
154   01   1
155   07   7
156   75   -
157   43  RCL
158   01   1
159   05   5
160   65   ×
161   53   (
162   43  RCL
163   01   1
164   05   5
165   55   ÷
166   06   6
167   54   )
168   54   )
169   95   =
170   98  PRT
171   43  RCL
172   01   1
173   09   9
174   55   ÷
175   43  RCL
176   00   0
177   00   0
178   94  +/-
179   95   =
180   22  INV
```

Impactor Data Reduction Program Listing Card 5 (Cont'd)

```
181   23 LNX
182   98 PRT
183   43 RCL
184   00  0
185   00  0
186   20 1/X
187   22 INV
188   23 LNX
189   98 PRT
190   81 HLT
191   46 LBL
192   15  E
193   01  1
194   42 STO
195   00  0
196   00  0
197   08  8
198   42 STO
199   01  1
200   09  9
201   00  0
202   42 STO
203   00  0
204   07  7
205   42 STO
206   01  1
207   04  4
208   42 STO
209   01  1
210   05  5
211   42 STO
212   01  1
213   06  6
214   42 STO
215   01  1
216   07  7
217   42 STO
218   01  1
219   08  8
220   56 RTN
```

Impactor Data Reduction Program Listing Card 5 (Cont'd)

```
LOG NORMAL PT
      000  46 LBL
      001  11  A
      002  42 STO
      003  00  0
      004  01  1
      005  22 INV
      006  50 STF
      007  01  1
      008  93  .
      009  01  1
      010  42 STO
      011  00  0
      012  00  0
      013  81 HLT
      014  46 LBL
      015  16  A'
      016  42 STO
      017  00  0
      018  02  2
      019  81 HLT
      020  46 LBL
      021  12  B
      022  23 LNX
      023  42 STO
      024  00  0
      025  03  3
      026  81 HLT
      027  46 LBL
      028  17  B'
      029  23 LNX
      030  42 STO
      031  00  0
      032  04  4
      033  81 HLT
      034  46 LBL
      035  13  C
      036  23 LNX
      037  42 STO
      038  00  0
      039  05  5
      040  81 HLT
      041  46 LBL
      042  18  C
      043  23 LNX
      044  42 STO
      045  00  0
      046  06  6
      047  81 HLT
      048  46 LBL
      049  15  E
      050  53  (
```

```
051  53  (
052  43 RCL
053  00  0
054  00  0
055  23 LNX
056  75  -
057  43 RCL
058  00  0
059  05  5
060  54  )
061  55  ÷
062  43 RCL
063  00  0
064  03  3
065  54  )
066  40  X²
067  56 RTN
068  56 RTN
069  46 LBL
070  10  E'
071  53  (
072  53  (
073  43 RCL
074  00  0
075  00  0
076  23 LNX
077  75  -
078  43 RCL
079  00  0
080  06  6
081  54  )
082  55  ÷
083  43 RCL
084  00  0
085  04  4
086  54  )
087  40  X²
088  56 RTN
089  46 LBL
090  14  D
091  43 RCL
092  00  0
093  02  2
094  55  ÷
095  43 RCL
096  00  0
097  01  1
098  65  ×
099  43 RCL
100  00  0
```

Log-normal Penetration Program Listing

```
101  03   3
102  55   ÷
103  43  RCL
104  00   0
105  04   4
106  65   ×
107  53   (
108  53   (
109  15   E
110  75   -
111  10   E'
112  54   )
113  55   ÷
114  02   2
115  54   )
116  22  INV
117  23  LNX
118  95   =
119  57  FIX
120  05   5
121  98  PRT
122  75   -
123  01   1
124  95   =
125  94  +/-
126  98  PRT
127  43  RCL
128  00   0
129  00   0
130  98  PRT
131  99  PAP
132  75   -
133  01   1
134  95   =
135  90  IFZ
136  87   1'
137  60  IFF
138  01   1
139  87   1'
140  93   .
141  01   1
142  44  SUM
143  00   0
144  00   0
145  41  GTO
146  14   D
147  46  LBL
148  87   1'
149  50  STF
150  01   1
```

```
151  43  RCL
152  00   0
153  00   0
154  75   -
155  02   2
156  00   0
157  95   =
158  90  IFZ
159  88   2'
160  01   1
161  44  SUM
162  00   0
163  00   0
164  41  GTO
165  14   D
166  46  LBL
167  88   2'
168  09   9
169  09   9
170  09   9
171  09   9
172  09   9
173  09   9
174  81  HLT
```

Log-normal Penetration Program Listing (cont'd)

APPENDIX B

USER INSTRUCTIONS AND PROGRAM LISTING FOR TI-59 IMPACTOR DATA REDUCTION PACKAGE

INTRODUCTION

This program calculates and prints cascade impactor aerodynamic cut diameters, d_{A50}, cumulative fraction less than and the least-squares log-normal fit to the data. Input requirements are impactor temperature, °C, impactor flow rate, l/m, and mass collected by each impactor stage. The program uses the PC-100A printer and the Master Library Module.

Nomenclature, in order used by program:

T = impactor temperature, °C
P = impactor pressure, cm Hg
Q = impactor flow rate, l/m
Mass = mass of particulate collected per stage
D50 = aerodynamic impactor cut diameter, μmA
FI = cumulative fraction less than
A = least-squares fit constant, A, in $y = A + Bx$
B = least-squares fit constant, B, in $y = A + Bx$
R** = correlation coefficient, r^2
DG = Aerodynamic mass mean particle diameter of log-normal size distribution, μmA
SIGMA = geometric standard deviation of log-normal size distribution

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Read side 1 of card		Clr	1	
	Read side 2 of Card		Clr	2	
	Read card with stage constants		Clr	3	

Step	Procedure	Enter	Press	Display	Print
2	Start calculation		A	370064	T =
	Enter temperature °C	T°C	R/S		
	Enter pressure cm Hg	P cm Hg	R/S	330064	P =
	Enter flow rate	1/m	R/S	340064	Q =
				3013363600	MASS
	Enter mass collected per stage	M	R/S		
					.
					.
					.
				3013363600	MASS
		M_n	R/S		
					D50
					F_I
					.
					.
					FI
					A
					B
					R**2
					DG
					SIGMA
					σ

```
000  76 LBL
001  11  A
002  00  0
003  42 STO
004  58  58
005  69 OP
006  00  00
007  03  3
008  07  7
009  00  0
010  00  0
011  06  6
012  04  4
013  69 OP
014  02  02
015  69 OP
016  05  05
017  91 R/S
018  42 STO
019  01  01
020  42 STO
021  59  59
022  99 PRT
023  03  3
024  03  3
025  00  0
026  00  0
027  06  6
028  04  4
029  69 OP
030  02  02
031  69 OP
032  05  05
033  91 R/S
034  42 STO
035  36  36
036  99 PRT
037  69 OP
038  00  00
039  03  3
040  04  4
041  00  0
042  00  0
043  06  6
044  04  4
045  69 OP
046  02  02
047  69 OP
048  05  05
049  91 R/S
050  99 PRT
```

°F convert to °C

(F-32)÷1.8

2nd Pgm $\boxed{25}$

A

" Hg convert to cm Hg.

× 2.54 =

2nd Pgm $\boxed{24}$

A

acfm X 28.317

```
051  42 STO
052  02  02
053  00  0
054  42 STO
055  53  53
056  42 STO
057  58  58
058  07  7
059  42 STO
060  00  00
061  01  1
062  07  7
063  42 STO
064  54  54
065  76 LBL
066  87 IFF
067  69 OP
068  00  00
069  03  3
070  00  0
071  01  1
072  03  3
073  03  3
074  06  6
075  03  3
076  06  6
077  00  0
078  00  0
079  69 OP
080  02  02
081  69 OP
082  05  05
083  91 R/S
084  99 PRT
085  72 ST*
086  54  54
087  44 SUM
088  53  53
089  01  1
090  44 SUM
091  54  54
092  97 DSZ
093  00  00
094  87 IFF
095  07  7
096  42 STO
097  00  00
098  00  0
099  04  4
100  00  0
```

17	91	R/S
2ns 18	PRT 36	2nd Pgm
19	25	25
20	A	11

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1

```
101  42  STO
102  54   54
103  01   1
104  00   0
105  42  STO
106  55   55
107  76  LBL
108  88  DMS
109  73  RC*
110  54   54
111  55   ÷
112  43  RCL
113  02   02
114  65   X
115  16  A'
116  65   X
117  01   1
118  52  EE
119  08   8
120  95   =
121  34  ΓX
122  72  ST*
123  55   55
124  01   1
125  44  SUM
126  54   54
127  44  SUM
128  55   55
129  97  DSZ
130  00   00
131  88  DMS
132  03   3
133  05   5
134  42  STO
135  55   55
136  06   6
137  42  STO
138  00   00
139  02   2
140  03   3
141  42  STO
142  54   54
143  03   3
144  05   5
145  42  STO
146  57   57
147  02   2
148  09   9
149  42  STO
150  56   56
151  76  LBL
152  89   π
153  73  RC*
154  54   54
155  44  SUM
156  58   58
157  43  RCL
158  58   58
159  55   ÷
160  43  RCL
161  53   53
162  95   =
163  72  ST*
164  56   56
165  12   B
166  72  ST*
167  57   57
168  01   1
169  94  +/-
170  44  SUM
171  54   54
172  44  SUM
173  56   56
174  44  SUM
175  57   57
176  44  SUM
177  55   55
178  25  CLR
179  97  DSZ
180  00   00
181  89   π
182  36  PGM
183  01   01
184  71  SBR
185  25  CLR
186  01   1
187  06   6
188  42  STO
189  54   54
190  03   3
191  05   5
192  42  STO
193  55   55
194  06   6
195  42  STO
196  00   00
197  76  LBL
198  77   GE
199  73  RC*
200  54   54
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1 (Cont'd)

```
201   23 LNX
202   32 X↕T
203   73 RC*
204   55  55
205   78 Σ+
206   01  1
207   94 +/-
208   44 SUM
209   54  54
210   44 SUM
211   55  55
212   25 CLR
213   97 DSZ
214   00  00
215   77  GE
216   01  1
217   06  6
218   42 STO
219   54  54
220   02  2
221   09  9
222   42 STO
223   55  55
224   06  6
225   42 STO
226   00  00
227   76 LBL
228   78 Σ+
229   69 OP
230   00  00
231   01  1
232   06  6
233   00  0
234   06  6
235   00  0
236   01  1
237   69 OP
238   01  01
239   69 OP
240   05  05
241   73 RC*
242   54  54
243   99 PRT
244   02  2
245   01  1
246   02  2
247   04  4
248   00  0
249   00  0
250   69 OP
```

```
251   01  01
252   69 OP
253   05  05
254   73 RC*
255   55  55
256   99 PRT
257   01  1
258   94 +/-
259   44 SUM
260   54  54
261   44 SUM
262   55  55
263   25 CLR
264   97 DSZ
265   00  00
266   78 Σ+
267   69 OP
268   00  00
269   01  1
270   03  3
271   69 OP
272   01  01
273   69 OP
274   05  05
275   69 OP
276   12  12
277   99 PRT
278   69 OP
279   00  00
280   01  1
281   04  4
282   69 OP
283   01  01
284   69 OP
285   05  05
286   69 OP
287   12  12
288   32 X↕T
289   99 PRT
290   69 OP
291   00  00
292   03  3
293   05  5
294   05  5
295   01  1
296   05  5
297   01  1
298   00  0
299   03  3
300   69 OP
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1 (Cont'd)

```
301  01  01
302  69 OP
303  05  05
304  69 OP
305  13  13
306  33 X²
307  99 PRT
308  69 OP
309  00  00
310  01  1
311  06  6
312  02  2
313  02  2
314  69 OP
315  01  01
316  69 OP
317  05  05
318  69 OP
319  12  12
320  55  ÷
321  32 X:T
322  95  =
323  94 +/-
324  22 INV
325  23 LNX
326  99 PRT
327  69 OP
328  00  00
329  03  3
330  06  6
331  02  2
332  04  4
333  02  2
334  02  2
335  03  3
336  00  0
337  01  1
338  03  3
339  69 OP
340  01  01
341  69 OP
342  05  05
343  69 OP
344  12  12
345  32 X:T
346  35 1/X
347  22 INV
348  23 LNX
349  99 PRT
350  92 RTN
```

```
351  76 LBL
352  16 A'
353  53  (
354  53  (
355  43 RCL
356  01  01
357  65  ×
358  09  9
359  55  ÷
360  05  5
361  85  +
362  03  3
363  02  2
364  54  )
365  65  ×
366  02  2
367  93  .
368  02  2
369  09  9
370  02  2
371  52 EE
372  94 +/-
373  07  7
374  85  +
375  01  1
376  93  .
377  06  6
378  08  8
379  52 EE
380  94 +/-
381  04  4
382  54  )
383  92 RTN
384  76 LBL
385  12  B
386  93  .
387  05  5
388  32 X:T
389  73 RC*
390  56  56
391  42 STO
392  09  09
393  77  GE
394  69 OP
395  86 STF
396  01  01
397  53  (
398  01  1
399  75  -
400  73 RC*
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1 (Cont'd)

```
401  56  56
402  54  )
403  42 STO
404  09  09
405  76 LBL
406  69 OP
407  53  (
408  01  1
409  75  -
410  43 RCL
411  09  09
412  54  )
413  35 1/X
414  33 X²
415  23 LNX
416  34 ΓX
417  42 STO
418  09  09
419  53  (
420  43 RCL
421  09  09
422  75  -
423  53  (
424  53  (
425  43 RCL
426  47  47
427  85  +
428  43 RCL
429  09  09
430  65  ×
431  43 RCL
432  48  48
433  85  +
434  43 RCL
435  09  09
436  33 X²
437  65  ×
438  43 RCL
439  49  49
440  54  )
441  55  ÷
442  53  (
443  01  1
444  85  +
445  43 RCL
446  09  09
447  65  ×
448  43 RCL
449  50  50
450  85  +
```

```
451  43 RCL
452  09  09
453  33 X²
454  65  ×
455  43 RCL
456  51  51
457  85  +
458  43 RCL
459  52  52
460  65  ×
461  43 RCL
462  09  09
463  45 Yˣ
464  03  3
465  54  )
466  54  )
467  54  )
468  87 IFF
469  01  01
470  38 SIN
471  92 RTN
472  76 LBL
473  38 SIN
474  22 INV
475  86 STF
476  01  01
477  94 +/-
478  92 RTN
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1 (Cont'd)

APPENDIX C

USER INSTRUCTIONS AND PROGRAM LISTING FOR TI-59 PROGRAM TO CONVERT AERODYNAMIC DIAMETER TO PHYSICAL DIAMETER

GENERAL

This program converts aerodynamic diameter to physical diameter. Aerodynamic diameter, d_A, and physical diameter are printed. The program then calculates and prints cumulative fraction less than for each stage, and the log-normal fit to the data. Input requirements are particle density, g/cc. The program uses the PC-100A printer and the Master Library Module.

Nomenclature, in order used by program:

DENSITY = particle density, g/cc
DA = aerodynamic particle diameter, μmA
DP = physical particle diameter, μm
D_{50} = physical impactor cut diameter, μm
F_I = cumulative fraction less than
A = least-squares fit constant, A, in $y = A + Bx$
B = least-squares fit constant, B, in $y = A + Bx$
R** = correlation coefficient, r^2
D_G = physical mass mean particle diameter of log-normal size distribution, μm
SIGMA = geometric standard deviation of log-normal size distribution

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Enter Side 1 of card		CLR	1	
	Enter Side 2 of card		CLR	2	
	Begin calculation		A		DENSITY
	Enter density	ρ	R/S		

Step	Procedure	Enter	Press	Display	Print
					d_A DA
					D DP
					.
					.
					.
					SIGMA
					σ

```
000  76  LBL
001  14   D
002  73  RC*
003  54   54
004  92  RTN
005  76  LBL
006  13   C
007  53   (
008  01   1
009  85   +
010  02   2
011  65   X
012  43  RCL
013  42   42
014  55   ÷
015  43  RCL
016  40   40
017  65   X
018  53   (
019  01   1
020  93   .
021  02   2
022  06   6
023  85   +
024  93   .
025  04   4
026  02   2
027  65   X
028  53   (
029  93   .
030  08   8
031  07   7
032  65   X
033  43  RCL
034  40   40
035  55   ÷
036  53   (
037  02   2
038  65   X
039  43  RCL
040  42   42
041  54   )
042  54   )
043  94  +/-
044  22  INV
045  23  LNX
046  54   )
047  54   )
048  92  RTN
049  76  LBL
050  11   A
051  01   1
052  06   6
053  01   1
054  07   7
055  03   3
056  01   1
057  03   3
058  06   6
059  02   2
060  04   4
061  69  OP
062  00   00
063  69  OP
064  02   02
065  03   3
066  07   7
067  04   4
068  05   5
069  07   7
070  01   1
071  00   0
072  00   0
073  00   0
074  00   0
075  69  OP
076  03   03
077  69  OP
078  05   05
079  91  R/S
080  99  PRT
081  42  STO
082  43   43
083  93   .
084  00   0
085  06   6
086  05   5
087  03   3
088  65   X
089  07   7
090  06   6
091  55   ÷
092  02   2
093  09   9
094  06   6
095  93   .
096  02   2
097  65   X
098  53   (
099  43  RCL
100  59   59
```

Program Listing Program to Convert Aerodynamic Diameter to Physical Diameter

```
101   85   +
102   02   2
103   07   7
104   03   3
105   54   )
106   55   ÷
107   43  RCL
108   36   36
109   95   =
110   42  STO
111   42   42
112   01   1
113   01   1
114   42  STO
115   54   54
116   06   6
117   42  STO
118   00   00
119   69  OP
120   00   00
121   93   .
122   00   0
123   00   0
124   01   1
125   32  X:T
126   76  LBL
127   87  IFF
128   98  ADV
129   01   1
130   06   6
131   01   1
132   03   3
133   69  OP
134   04   04
135   73  RC*
136   54   54
137   69  OP
138   06   06
139   55   ÷
140   43  RCL
141   42   42
142   34  ΓX
143   95   =
144   42  STO
145   40   40
146   42  STO
147   41   41
148   76  LBL
149   88  DMS
150   43  RCL
```

```
151   41   41
152   42  STO
153   40   40
154   14   D
155   55   ÷
156   53   (
157   13   C
158   65   ×
159   43  RCL
160   43   43
161   54   )
162   34  ΓX
163   95   =
164   42  STO
165   41   41
166   75   -
167   43  RCL
168   40   40
169   95   =
170   50  I×I
171   55   ÷
172   43  RCL
173   40   40
174   95   =
175   77   GE
176   88  DMS
177   01   1
178   06   6
179   03   3
180   03   3
181   69  OP
182   04   04
183   43  RCL
184   41   41
185   69  OP
186   06   06
187   72  ST*
188   54   54
189   01   1
190   44  SUM
191   54   54
192   97  DSZ
193   00   00
194   87  IFF
195   36  PGM
196   01   01
197   71  SBR
198   25  CLR
199   01   1
200   06   6
```

rogram Listing Program to Convert Aerodynamic Diameter to Physical Diameter (Cont'd)

```
201  42  STO
202  54   54
203  03   3
204  05   5
205  42  STO
206  55   55
207  06   6
208  42  STO
209  00   00
210  98  ADV
211  76  LBL
212  77   GE
213  73  RC*
214  54   54
215  23  LNX
216  32  X:T
217  73  RC*
218  55   55
219  78  Σ+
220  01   1
221  94  +/-
222  44  SUM
223  54   54
224  44  SUM
225  55   55
226  25  CLR
227  97  DSZ
228  00   00
229  77   GE
230  01   1
231  06   6
232  42  STO
233  54   54
234  02   2
235  09   9
236  42  STO
237  55   55
238  06   6
239  42  STO
240  00   00
241  76  LBL
242  78  Σ+
243  69  OP
244  00   00
245  00   0
246  01   1
247  06   6
248  00   0
249  06   6
250  00   0
```

```
251  01   1
252  69  OP
253  01   01
254  69  OP
255  05   05
256  73  RC*
257  54   54
258  99  PRT
259  69  OP
260  00   00
261  02   2
262  01   1
263  02   2
264  04   4
265  00   0
266  00   0
267  69  OP
268  01   01
269  69  OP
270  05   05
271  73  RC*
272  55   55
273  99  PRT
274  01   1
275  94  +/-
276  44  SUM
277  54   54
278  44  SUM
279  55   55
280  25  CLR
281  97  DSZ
282  00   00
283  78  Σ+
284  69  OP
285  00   00
286  01   1
287  03   3
288  69  OP
289  01   01
290  69  OP
291  05   05
292  69  OP
293  12   12
294  99  PRT
295  69  OP
296  00   00
297  01   1
298  04   4
299  69  OP
300  01   01
```

Program Listing Program to Convert Aerodynamic Diameter to Physical Diameter (Cont'd)

```
301   69 OP
302   05  05
303   69 OP
304   12  12
305   32 X:T
306   99 PRT
307   03  3
308   05  5
309   05  5
310   01  1
311   05  5
312   01  1
313   00  0
314   03  3
315   69 OP
316   01  01
317   69 OP
318   05  05
319   69 OP
320   13  13
321   33 X²
322   99 PRT
323   69 OP
324   00  00
325   01  1
326   06  6
327   02  2
328   02  2
329   69 OP
330   01  01
331   69 OP
332   05  05
333   69 OP
334   12  12
335   55  ÷
336   32 X:T
337   95  =
338   94 +/-
339   22 INV
340   23 LNX
341   99 PRT
342   03  3
343   06  6
344   02  2
345   04  4
346   02  2
347   02  2
348   03  3
349   00  0
350   01  1
351   03  3
352   69 OP
353   01  01
354   69 OP
355   05  05
356   69 OP
357   12  12
358   32 X:T
359   35 1/X
360   22 INV
361   23 LNX
362   99 PRT
363   92 RTN
```

Program listing Program to Convert Aerodynamic Diameter to Physical Diameter (Cont'd)

APPENDIX D

USER INSTRUCTIONS AND PROGRAM LISTING FOR PROGRAM TO ESTIMATE VISCOSITY OF MIXTURES

GENERAL

This program estimates the viscosity of mixtures of gases. The input data requirements are: number of components (10 maximum), and the viscosity, molecular weight and mole fraction of each pure component.

Nomenclature in order used by program:

N = Total number of components
I = Number identifying component for which input data are required
VIS = Viscosity of component number I
MW = Molecular weight of component number I
X = Mole fraction of component number I

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Enter side 1 of card		Clr	1	
	Enter side 2 of card		Clr	2	
2	Start calculation		A	3171	N?
	Enter number of components	n	R/S		n
					I =
					n
				42243671.00	VIS?
3	Enter μ_n	μ_n	R/S		μ_n
				3043710000	MIN?
4	Enter MW_n	MW_n	R/S		MIN_n
				4471.0000	X?

Step	Procedure	Enter	Press	Display	Print
5	Enter X_i	X_i			X_i
					I =
					n-1
	Repeat steps 3, 4 and 5 for all components				
				$\mu_{mixture}$	$\mu_{mixture}^{VIS}$

```
000   76  LBL
001   87  IFF
002   12   B
003   43  RCL
004   00   00
005   94  +/-
006   44  SUM
007   50   50
008   44  SUM
009   51   51
010   44  SUM
011   52   52
012   25  CLR
013   73  RC*
014   50   50
015   42  STO
016   40   40
017   73  RC*
018   51   51
019   42  STO
020   41   41
021   73  RC*
022   52   52
023   42  STO
024   42   42
025   00   0
026   42  STO
027   53   53
028   43  RCL
029   00   00
030   32  X:T
031   76  LBL
032   88  DMS
033   12   B
034   43  RCL
035   59   59
036   67   EQ
037   89   π
038   94  +/-
039   44  SUM
040   50   50
041   44  SUM
042   51   51
043   44  SUM
044   52   52
045   25  CLR
046   53   (
047   01   1
048   85   +
049   53   (
050   43  RCL
051   40   40
052   55   ÷
053   73  RC*
054   50   50
055   54   )
056   34  √X
057   65   ×
058   53   (
059   73  RC*
060   51   51
061   55   ÷
062   43  RCL
063   41   41
064   54   )
065   45  YX
066   93   .
067   02   2
068   05   5
069   54   )
070   33  X²
071   55   ÷
072   53   (
073   08   8
074   34  √X
075   65   ×
076   53   (
077   01   1
078   85   +
079   43  RCL
080   41   41
081   55   ÷
082   73  RC*
083   51   51
084   54   )
085   34  √X
086   54   )
087   65   ×
088   73  RC*
089   52   52
090   55   ÷
091   43  RCL
092   42   42
093   95   =
094   44  SUM
095   53   53
096   76  LBL
097   89   π
098   12   B
099   97  DSZ
100   59   59
```

Program Listing Viscosity Program

```
101   88  DMS
102   43  RCL
103   40   40
104   55   ÷
105   53   (
106   43  RCL
107   53   53
108   85   +
109   01   1
110   54   )
111   95   =
112   44  SUM
113   54   54
114   43  RCL
115   58   58
116   42  STO
117   59   59
118   12   B
119   97  DSZ
120   00   00
121   87  IFF
122   13   C
123   91  R/S
124   76  LBL
125   12   B
126   43  RCL
127   58   58
128   85   +
129   01   1
130   95   =
131   42  STO
132   50   50
133   43  RCL
134   58   58
135   85   +
136   01   1
137   01   1
138   95   =
139   42  STO
140   51   51
141   43  RCL
142   58   58
143   85   +
144   02   2
145   01   1
146   95   =
147   42  STO
148   52   52
149   92  RTN
150   76  LBL
```

```
151   11   A
152   69  OP
153   00   00
154   03   3
155   01   1
156   07   7
157   01   1
158   69  OP
159   02   02
160   69  OP
161   05   05
162   91  R/S
163   58  FIX
164   04   04
165   99  PRT
166   42  STO
167   58   58
168   42  STO
169   00   00
170   42  STO
171   59   59
172   00   0
173   12   B
174   76  LBL
175   38  SIN
176   12   B
177   98  ADV
178   69  OP
179   00   00
180   02   2
181   04   4
182   06   6
183   04   4
184   69  OP
185   02   02
186   69  OP
187   05   05
188   43  RCL
189   00   00
190   99  PRT
191   94  +/-
192   44  SUM
193   50   50
194   44  SUM
195   51   51
196   44  SUM
197   52   52
198   04   4
199   02   2
200   02   2
```

Program Listing Viscosity Program (Cont'd)

```
201   04   4
202   03   3
203   06   6
204   07   7
205   01   1
206   69  OP
207   02   02
208   69  OP
209   05   05
210   91  R/S
211   99  PRT
212   72  ST*
213   50   50
214   03   3
215   00   0
216   04   4
217   03   3
218   07   7
219   01   1
220   00   0
221   00   0
222   00   0
223   00   0
224   69  OP
225   02   02
226   69  OP
227   05   05
228   91  R/S
229   99  PRT
230   72  ST*
231   51   51
232   69  OP
233   00   00
234   04   4
235   04   4
236   07   7
237   01   1
238   69  OP
239   02   02
240   69  OP
241   05   05
242   91  R/S
243   99  PRT
244   72  ST*
245   52   52
246   97  DSZ
247   00   00
248   38  SIN
249   43  RCL
250   58   58
```

```
251   42  STO
252   00   00
253   42  STO
254   59   59
255   12   B
256   61  GTO
257   87  IFF
258   76  LBL
259   13   C
260   98  ADV
261   22  INV
262   58  FIX
263   04   4
264   02   2
265   02   2
266   04   4
267   03   3
268   06   6
269   69  OP
270   04   04
271   58  FIX
272   04   04
273   43  RCL
274   54   54
275   69  OP
276   06   06
277   91  R/S
```

Program Listing Viscosity Program (Cont'd)

APPENDIX E

USER INSTRUCTIONS AND PROGRAM LISTING FOR SPLINE FIT PROGRAM

GENERAL

The spline fit program fits a spline function between six data points, x and y_i i = 1 to 6. The function can be used to interpolate values of y between the data points. The spline function also can be used to estimate the derivative dy/dx anywhere in the interval x_i to x_N. The program uses the PC-100A printer.

Nomenclature, in order used by program:

X = x variable
Y = y variable
TOL = Tolerance for numerical solution (0.0001 is adequate)
T = Value of x for which interpolated values of y are desired
S"(T) = d^2y/dx at x = T
S(T) = Value of y at x = T
S'(T) = dy/dx at x = T

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Enter side 1 of Card 1		Clr	1	
	Enter side 2 of Card 1		Clr	2	
2	Clear memory and initialize		2nd Cms E	-1	
3	Enter data		A		X?
	X must be	x_1			x_1
	entered in order				Y?
	from smallest to	y_1			y_1
	largest				
					.
					.
					.

Step	Procedure	Enter	Press	Display	Print
		x_n			x_n
					Y?
		y_n			y_n
					TOL?
		TOL			TOL
4	Program calculates for about 2 minutes				INPUT T's
5	Enter T	T_1			T_1
		.			.
		.			.
		.			.
		T_N			T_N
6	Finish Card 1				READ Card 2
7	Read side 1 of card 2		Clr	1	
	Read side 2 of Card 1		Clr	2	
8	Calculate		A		T =
					T_1
					S"
					Numbers
					S(TXX1)
					Numbers
					S(T)
					Numbers
					S'(T)
					Numbers
					.
					.
					.
					.
					END
9	Save T_i and $S'(T_i)$ by recording on magnetic card for later use	3	2nd Write	3	

```
SPLINE FIT CARD 1
     000  76 LBL
     001  15  E
     002  00  0
     003  42 STO
     004  27  27
     005  42 STO
     006  32  32
     007  01  1
     008  94 +/-
     009  42 STO
     010  49  49
     011  76 LBL
     012  10 E'
     013  01  1
     014  42 STO
     015  50  50
     016  07  7
     017  42 STO
     018  51  51
     019  01  1
     020  03  3
     021  42 STO
     022  52  52
     023  01  1
     024  08  8
     025  42 STO
     026  53  53
     027  02  2
     028  03  3
     029  42 STO
     030  54  54
     031  02  2
     032  08  8
     033  42 STO
     034  55  55
     035  03  3
     036  03  3
     037  42 STO
     038  56  56
     039  43 RCL
     040  49  49
     041  42 STO
     042  00  00
     043  92 RTN
     044  76 LBL
     045  11  A
     046  06  6
     047  42 STO
     048  00  00
     049  76 LBL
     050  60 DEG
     051  69 OP
     052  00  00
     053  04  4
     054  04  4
     055  00  0
     056  00  0
     057  07  7
     058  01  1
     059  69 OP
     060  02  02
     061  69 OP
     062  05  05
     063  91 R/S
     064  99 PRT
     065  72 ST*
     066  50  50
     067  69 OP
     068  00  00
     069  04  4
     070  05  5
     071  00  0
     072  00  0
     073  07  7
     074  01  1
     075  69 OP
     076  02  02
     077  69 OP
     078  05  05
     079  91 R/S
     080  99 PRT
     081  72 ST*
     082  51  51
     083  01  1
     084  44 SUM
     085  50  50
     086  44 SUM
     087  51  51
     088  44 SUM
     089  49  49
     090  97 DSZ
     091  00  00
     092  60 DEG
     093  76 LBL
     094  12  B
     095  69 OP
     096  00  00
     097  03  3
     098  07  7
     099  03  3
     100  02  2
```

```
101  02   2
102  07   7
103  07   7
104  01   1
105  69  OP
106  02   02
107  69  OP
108  05   05
109  91  R/S
110  99  PRT
111  42  STO
112  37   37
113  76  LBL
114  13   C
115  10  E'
116  76  LBL
117  38  SIN
118  43  RCL
119  50   50
120  85   +
121  01   1
122  95   =
123  42  STO
124  40   40
125  43  RCL
126  51   51
127  85   +
128  01   1
129  95   =
130  42  STO
131  41   41
132  73  RC*
133  40   40
134  75   -
135  73  RC*
136  50   50
137  95   =
138  72  ST*
139  52   52
140  35  1/X
141  65   X
142  53   (
143  73  RC*
144  41   41
145  75   -
146  73  RC*
147  51   51
148  54   )
149  95   =
150  72  ST*
151  53   53
```

```
152  01   1
153  44  SUM
154  50   50
155  44  SUM
156  51   51
157  44  SUM
158  52   52
159  44  SUM
160  53   53
161  97  DSZ
162  00   00
163  38  SIN
164  76  LBL
165  14   D
166  10  E'
167  04   4
168  42  STO
169  00   00
170  76  LBL
171  39  COS
172  43  RCL
173  53   53
174  85   +
175  01   1
176  95   =
177  42  STO
178  40   40
179  43  RCL
180  52   52
181  85   +
182  01   1
183  95   =
184  42  STO
185  41   41
186  73  RC*
187  52   52
188  85   +
189  73  RC*
190  41   41
191  95   =
192  42  STO
193  38   38
194  35  1/X
195  65   X
196  93   .
197  05   5
198  65   X
199  73  RC*
200  52   52
201  95   =
```

Spline Fit Card 1 (Cont'd)

```
202   72  ST*
203   54   54
204   02   2
205   65   ×
206   53   (
207   73  RC*
208   40   40
209   75   -
210   73  RC*
211   53   53
212   54   )
213   55   ÷
214   43  RCL
215   38   38
216   95   =
217   72  ST*
218   55   55
219   65   ×
220   03   3
221   55   ÷
222   02   2
223   95   =
224   72  ST*
225   56   56
226   01   1
227   44  SUM
228   53   53
229   44  SUM
230   52   52
231   44  SUM
232   54   54
233   44  SUM
234   55   55
235   44  SUM
236   56   56
237   97  DSZ
238   00   00
239   39  COS
240   76  LBL
241   16  A'
242   00   0
243   32  X:T
244   10  E'
245   04   4
246   42  STO
247   00   00
248   76  LBL
249   70  RAD
250   43  RCL
251   55   55
```

```
252   85   +
253   01   1
254   95   =
255   42  STO
256   40   40
257   75   -
258   02   2
259   95   =
260   42  STO
261   41   41
262   01   1
263   93   .
264   00   0
265   07   7
266   01   1
267   07   7
268   09   9
269   06   6
270   08   8
271   65   ×
272   53   (
273   73  RC*
274   55   55
275   94  +/-
276   75   -
277   73  RC*
278   54   54
279   65   ×
280   73  RC*
281   41   41
282   75   -
283   53   (
284   93   .
285   05   5
286   75   -
287   73  RC*
288   54   54
289   54   )
290   65   ×
291   73  RC*
292   40   40
293   85   +
294   73  RC*
295   56   56
296   54   )
297   95   =
298   42  STO
299   44   44
300   50  I×I
```

Spline Fit Card 1 (Cont'd)

```
301   22  INV
302   77   GE
303   87  IFF
304   32  X:T
305   76  LBL
306   87  IFF
307   43  RCL
308   44   44
309   74  SM*
310   55   55
311   01    1
312   44  SUM
313   55   55
314   44  SUM
315   54   54
316   44  SUM
317   56   56
318   97  DSZ
319   00   00
320   70  RAD
321   43  RCL
322   37   37
323   22  INV
324   77   GE
325   16  A'
326   76  LBL
327   17  B'
328   10  E'
329   03    3
330   03    3
331   42  STO
332   40   40
333   05    5
334   42  STO
335   00   00
336   76  LBL
337   80  GRD
338   43  RCL
339   55   55
340   75    -
341   01    1
342   95    =
343   42  STO
344   41   41
345   53    (
346   73  RC*
347   55   55
348   75    -
349   73  RC*
350   41   41
351   54    )
352   55    ÷
353   73  RC*
354   52   52
355   95    =
356   72  ST*
357   40   40
358   01    1
359   44  SUM
360   55   55
361   44  SUM
362   40   40
363   44  SUM
364   52   52
365   97  DSZ
366   00   00
367   80  GRD
368   03    3
369   09    9
370   42  STO
371   50   50
372   06    6
373   42  STO
374   00   00
375   76  LBL
376   18  C'
377   69  OP
378   00   00
379   02    2
380   04    4
381   03    3
382   01    1
383   03    3
384   03    3
385   04    4
386   01    1
387   03    3
388   07    7
389   69  OP
390   01   01
391   03    3
392   07    7
393   06    6
394   05    5
395   03    3
396   06    6
397   69  OP
398   02   02
399   69  OP
400   05   05
401   91  R/S
```

Spline Fit Card 1 (Cont'd)

```
402  72 ST*
403  50  50
404  99 PRT
405  01  1
406  44 SUM
407  50  50
408  97 DSZ
409  00  00
410  18 C'
411  69 OP
412  00  00
413  03  3
414  05  5
415  01  1
416  07  7
417  01  1
418  03  3
419  01  1
420  06  6
421  00  0
422  00  0
423  69 OP
424  01  01
425  01  1
426  05  5
427  01  1
428  03  3
429  03  3
430  05  5
431  01  1
432  06  6
433  00  0
434  00  0
435  69 OP
436  02  02
437  00  0
438  03  3
439  00  0
440  00  0
441  00  0
442  00  0
443  00  0
444  00  0
445  00  0
446  00  0
447  69 OP
448  03  03
449  69 OP
450  05  05
451  01  1
452  91 R/S
```

Spline Fit Card 1 (Cont'd)

```
SPLINE FIT CARD 2
        000  76 LBL
        001  11  A
        002  04  4
        003  04  4
        004  42 STO
        005  58  58
        006  03  3
        007  09  9
        008  42 STO
        009  56  56
        010  06  6
        011  42 STO
        012  00  00
        013  01  1
        014  42 STO
        015  51  51
        016  00  0
        017  32 X:T
        018  76 LBL
        019  87 IFF
        020  43 RCL
        021  00  00
        022  73 RC*
        023  56  56
        024  42 STO
        025  59  59
        026  43 RCL
        027  59  59
        028  75  -
        029  43 RCL
        030  01  01
        031  95  =
        032  67  EQ
        033  79  x̄
        034  22 INV
        035  77  GE
        036  88 DMS
        037  43 RCL
        038  59  59
        039  75  -
        040  43 RCL
        041  06  06
        042  95  =
        043  67  EQ
        044  78 Σ+
        045  77  GE
        046  88 DMS
        047  43 RCL
        048  59  59
        049  75  -
        050  73 RC*
        051  51  51
        052  95  =
        053  67  EQ
        054  79  x̄
        055  22 INV
        056  77  GE
        057  67  EQ
        058  01  1
        059  44 SUM
        060  51  51
        061  97 DSZ
        062  00  00
        063  87 IFF
        064  76 LBL
        065  88 DMS
        066  69 OP
        067  00  00
        068  01  1
        069  07  7
        070  03  3
        071  05  5
        072  03  3
        073  05  5
        074  03  3
        075  02  2
        076  03  3
        077  05  5
        078  69 OP
        079  02  02
        080  69 OP
        081  05  05
        082  61 GTO
        083  69 OP
        084  76 LBL
        085  78 Σ+
        086  06  6
        087  42 STO
        088  51  51
        089  76 LBL
        090  67  EQ
        091  01  1
        092  22 INV
        093  44 SUM
        094  51  51
        095  76 LBL
        096  79  x̄
        097  12  B
        098  76 LBL
        099  69 OP
        100  01  1
```

Spline Fit Card 2

```
101   44 SUM
102   56  56
103   01  1
104   42 STO
105   51  51
106   06  6
107   42 STO
108   00  00
109   43 RCL
110   56  56
111   75  -
112   04  4
113   05  5
114   95  =
115   22 INV
116   67  EQ
117   87 IFF
118   69 OP
119   00  00
120   01  1
121   07  7
122   03  3
123   01  1
124   01  1
125   06  6
126   69 OP
127   02  02
128   69 OP
129   05  05
130   92 RTN
131   76 LBL
132   12  B
133   01  1
134   44 SUM
135   58  58
136   43 RCL
137   51  51
138   85  +
139   06  6
140   95  =
141   42 STO
142   52  52
143   85  +
144   01  1
145   01  1
146   95  =
147   42 STO
148   53  53
149   85  +
150   09  9
151   95  =
152   42 STO
153   54  54
154   85  +
155   06  6
156   95  =
157   42 STO
158   55  55
159   43 RCL
160   59  59
161   75  -
162   73 RC*
163   51  51
164   95  =
165   42 STO
166   23  23
167   01  1
168   44 SUM
169   51  51
170   43 RCL
171   59  59
172   75  -
173   73 RC*
174   51  51
175   95  =
176   42 STO
177   24  24
178   65  ×
179   43 RCL
180   23  23
181   95  =
182   42 STO
183   25  25
184   98 ADV
185   69 OP
186   00  00
187   03  3
188   07  7
189   00  0
190   00  0
191   06  6
192   04  4
193   69 OP
194   02  02
195   69 OP
196   05  05
197   43 RCL
198   59  59
199   99 PRT
200   69 OP
```

Spline Fit Card 2 (Cont'd)

```
201  00  00
202  03  3
203  06  6
204  06  6
205  05  5
206  06  6
207  05  5
208  69  OP
209  02  02
210  69  OP
211  05  05
212  73  RC*
213  54  54
214  42  STO
215  51  51
216  85  +
217  43  RCL
218  23  23
219  65  ×
220  73  RC*
221  55  55
222  95  =
223  99  PRT
224  42  STO
225  26  26
226  69  OP
227  00  00
228  03  3
229  06  6
230  05  5
231  05  5
232  03  3
233  07  7
234  04  4
235  04  4
236  04  4
237  04  4
238  69  OP
239  02  02
240  00  0
241  02  2
242  05  5
243  06  6
244  00  0
245  00  0
246  00  0
247  00  0
248  00  0
249  00  0
250  69  OP
251  03  03
252  69  OP
253  05  05
254  01  1
255  44  SUM
256  54  54
257  53  (
258  73  RC*
259  54  54
260  85  +
261  43  RCL
262  51  51
263  85  +
264  43  RCL
265  26  26
266  54  )
267  55  ÷
268  06  6
269  95  =
270  99  PRT
271  42  STO
272  57  57
273  69  OP
274  00  00
275  03  3
276  06  6
277  05  5
278  05  5
279  03  3
280  07  7
281  05  5
282  06  6
283  69  OP
284  02  02
285  69  OP
286  05  05
287  73  RC*
288  52  52
289  85  +
290  43  RCL
291  23  23
292  65  ×
293  73  RC*
294  53  53
295  85  +
296  53  (
297  43  RCL
298  25  25
299  65  ×
300  43  RCL
```

Spline Fit Card 2 (Cont'd)

```
301  57  57
302  54  )
303  95  =
304  99 PRT
305  69 OP
306  00  00
307  03  3
308  06  6
309  06  6
310  05  5
311  05  5
312  05  5
313  03  3
314  07  7
315  05  5
316  06  6
317  69 OP
318  02  02
319  69 OP
320  05  05
321  73 RC*
322  53  53
323  85  +
324  53  (
325  43 RCL
326  23  23
327  85  +
328  43 RCL
329  24  24
330  54  )
331  65  ×
332  43 RCL
333  57  57
334  85  +
335  53  (
336  43 RCL
337  25  25
338  65  ×
339  73 RC*
340  55  55
341  55  ÷
342  06  6
343  54  )
344  95  =
345  99 PRT
346  72 ST*
347  58  58
348  98 ADV
349  92 RTN
```

Spline Fit Card 2 (Cont'd)

APPENDIX F

USER INSTRUCTIONS AND PROGRAM LISTING FOR CALCULATION OF PENETRATION AS A FUNCTION OF PARTICLE DIAMETER PROGRAM FOR TI-59

GENERAL

This program is used in conjunction with the spline fit program to calculate penetration as a function of particle diameter. Magnetic cards are used to input the results from the spline fit program needed in this program. Particle diameter, penetration for that diameter, and overall penetration are printed on the PC-100A printer.

Nomenclature, in order used by program:

Mass In = Particulate mass concentration at inlet
Mass Out = Particulate mass concentration at outlet
D = Particle diameter, μm
PT(D) = Penetration for particle diameter, d, fraction
Overall PT = Overall penetration, $\frac{\text{Mass (out)}}{\text{Mass (in)}}$

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Read side 1 of card		Clr	1	
	Read side 2 of card		Clr	2	
2	Begin calculation		A	3	READ INLET DATA
	Read magnetic card with results from spline fit for inlet		Clr R/S		
				3	READ OUTLET DATA
	Read magnetic card with results from spline fit for outlet		Clr R/S		
					MASS IN?
	Enter inlet mass concentration, M_I		R/S		MASS OUT?
	Enter outlet mass concentration, M_O		R/S		D = number

Step	Procedure	Enter	Press	Display	Print
					PT(D) =
					.
					.
					.
					D =
					number
					PT(D) =
					number
					Overall PT
					number
					END

```
000  76  LBL
001  12   B
002  69  OP
003  00   00
004  03   3
005  00   0
006  01   1
007  03   3
008  03   3
009  06   6
010  03   3
011  06   6
012  00   0
013  00   0
014  69  OP
015  01   01
016  02   2
017  04   4
018  03   3
019  01   1
020  07   7
021  01   1
022  00   0
023  00   0
024  00   0
025  00   0
026  69  OP
027  02   02
028  69  OP
029  05   05
030  91  R/S
031  99  PRT
032  42  STO
033  25   25
034  03   3
035  02   2
036  04   4
037  01   1
038  03   3
039  07   7
040  07   7
041  01   1
042  00   0
043  00   0
044  69  OP
045  02   02
046  69  OP
047  05   05
048  91  R/S
049  99  PRT
050  42  STO
051  26   26
052  92  RTN
053  76  LBL
054  11   A
055  69  OP
056  00   00
057  03   3
058  05   5
059  01   1
060  07   7
061  01   1
062  03   3
063  01   1
064  06   6
065  00   0
066  00   0
067  69  OP
068  01   01
069  02   2
070  04   4
071  03   3
072  01   1
073  02   2
074  07   7
075  01   1
076  07   7
077  03   3
078  07   7
079  69  OP
080  02   02
081  00   0
082  00   0
083  01   1
084  06   6
085  01   1
086  03   3
087  03   3
088  07   7
089  01   1
090  03   3
091  69  OP
092  03   03
093  69  OP
094  05   05
095  03   3
096  91  R/S
097  03   3
098  09   9
099  42  STO
100  20   20
101  01   1
102  42  STO
103  21   21
104  04   4
105  05   5
106  42  STO
107  22   22
108  07   7
109  42  STO
110  23   23
111  06   6
112  42  STO
113  00   00
114  76  LBL
115  60  DEG
116  73  RC*
117  20   20
118  72  ST*
119  21   21
120  73  RC*
121  22   22
122  72  ST*
123  23   23
124  01   1
125  44  SUM
126  20   20
127  44  SUM
128  21   21
129  44  SUM
130  22   22
131  44  SUM
132  23   23
133  97  DSZ
134  00   00
135  60  DEG
136  03   3
137  02   2
138  04   4
139  01   1
140  03   3
141  07   7
142  02   2
143  07   7
144  01   1
145  07   7
146  69  OP
147  02   02
148  03   3
149  07   7
150  00   0
```

Program Listing Pt(d) Program for TI-59

```
151   00   0
152   01   1
153   06   6
154   01   1
155   03   3
156   03   3
157   07   7
158   69  OP
159   03   03
160   01   1
161   03   3
162   00   0
163   00   0
164   00   0
165   00   0
166   00   0
167   00   0
168   00   0
169   00   0
170   69  OP
171   04   04
172   69  OP
173   05   05
174   03   3
175   91  R/S
176   04   4
177   05   5
178   42  STO
179   22   22
180   01   1
181   03   3
182   42  STO
183   23   23
184   06   6
185   42  STO
186   00   00
187   76  LBL
188   70  RAD
189   73  RC*
190   22   22
191   72  ST*
192   23   23
193   01   1
194   44  SUM
195   22   22
196   44  SUM
197   23   23
198   97  DSZ
199   00   00
200   70  RAD
201   12   B
202   43  RCL
203   26   26
204   55   ÷
205   43  RCL
206   25   25
207   95   =
208   42  STO
209   27   27
210   01   1
211   42  STO
212   20   20
213   07   7
214   42  STO
215   21   21
216   01   1
217   03   3
218   42  STO
219   22   22
220   06   6
221   42  STO
222   00   00
223   76  LBL
224   80  GRD
225   73  RC*
226   22   22
227   55   ÷
228   73  RC*
229   21   21
230   65   ×
231   43  RCL
232   27   27
233   95   =
234   42  STO
235   30   30
236   69  OP
237   00   00
238   01   1
239   06   6
240   00   0
241   00   0
242   06   6
243   04   4
244   69  OP
245   02   02
246   69  OP
247   05   05
248   73  RC*
249   20   20
250   99  PRT
251   69  OP
252   00   00
253   03   3
254   03   3
255   03   3
256   07   7
257   05   5
258   05   5
259   01   1
260   06   6
261   05   5
262   06   6
263   69  OP
264   01   01
265   00   0
266   00   0
267   06   6
268   04   4
269   00   0
270   00   0
271   00   0
272   00   0
273   00   0
274   00   0
275   69  OP
276   02   02
277   69  OP
278   05   05
279   43  RCL
280   30   30
281   99  PRT
282   01   1
283   44  SUM
284   20   20
285   44  SUM
286   21   21
287   44  SUM
288   22   22
289   97  DSZ
290   00   00
291   80  GRD
292   69  OP
293   00   00
294   03   3
295   02   2
296   04   4
297   02   2
298   01   1
299   07   7
300   03   3
```

Program Listing Pt(d) Program for TI-59 (Cont'd)

```
301  05   5
302  01   1
303  03   3
304  69  OP
305  01   01
306  02   2
307  07   7
308  02   2
309  07   7
310  00   0
311  00   0
312  03   3
313  03   3
314  03   3
315  07   7
316  69  OP
317  02   02
318  00   0
319  00   0
320  06   6
321  04   4
322  00   0
323  00   0
324  00   0
325  00   0
326  00   0
327  00   0
328  69  OP
329  03   03
330  69  OP
331  05   05
332  43  RCL
333  27   27
334  99  PRT
335  69  OP
336  00   00
337  01   1
338  07   7
339  03   3
340  01   1
341  01   1
342  06   6
343  00   0
344  00   0
345  69  OP
346  02   02
347  69  OP
348  05   05
349  92  RTN
```

Program Listing Pt(d) Program for TI-59 (Cont'd)

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-78-226

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE Cascade Impactor Data Reduction with SR-52 and TI-59 Programmable Calculators

5. REPORT DATE November 1978

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S) Leslie E. Sparks

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

10. PROGRAM ELEMENT NO. EHE624A

11. CONTRACT/GRANT NO. NA (Inhouse)

12. SPONSORING AGENCY NAME AND ADDRESS
EPA, Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

13. TYPE OF REPORT AND PERIOD COVERED User Manual; 5-6/78

14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES Author Sparks' mail drop is 61; his phone is 919/541-2925.

16. ABSTRACT
The report provides useful tools for obtaining particle size distributions and graded penetration data from cascade impactor measurements. The programs calculate impactor aerodynamic cut points, total mass collected by the impactor, cumulative mass fraction less than for each stage, log-normal size distribution parameters for the data, and graded penetration. These programs are written for the Texas Instruments SR-52 and TI-59 programmable calculators and the PC-100A printer. A general discussion of the program, an example problem, program listing, and user instructions are provided for each program.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Data Reduction	Cascade Impactors	09B
Impactors	Graded Penetration	13I
Particle Size Distribution	Particulate	14B
Measurement		
Dust		11G
Computer Programs		

18. DISTRIBUTION STATEMENT Unlimited

19. SECURITY CLASS *(This Report)* Unclassified

20. SECURITY CLASS *(This page)* Unclassified

21. NO. OF PAGES 111

22. PRICE

EPA Form 2220-1 (9-73)