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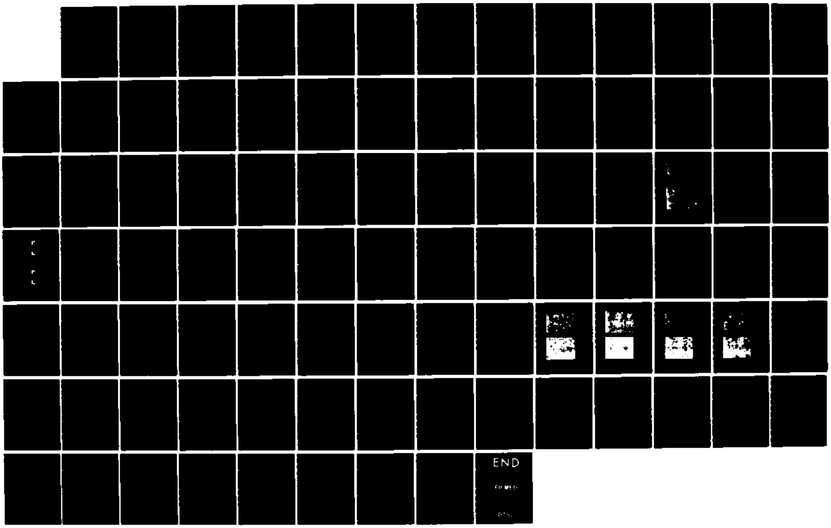

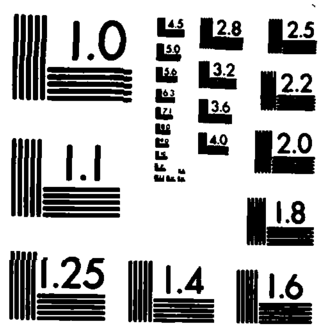

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN APPARATUS FOR SIZING PARTICULATE
MATTER IN SOLID ROCKET MOTORS

by

Robert Kelly Harris

June 1984

Thesis Advisor: D. W. Netzer

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A light scattering apparatus to measure particle size (D_{32}) in a solid rocket motor was improved. Multiple consecutive scans of two photodiode arrays were accomplished with a pacing circuit and added memory. The device was calibrated using various suspended particle samples and found to make accurate measurements. (Additional keywords: theses, data acquisition, data reduction, diffraction, polydispersion, solid propellants, computer programs.)

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An Apparatus for Sizing Particulate
Matter in Solid Rocket Motors

by

Robert Kelly Harris
B.S., Central Washington University, 1979

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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ABSTRACT

A light scattering apparatus to measure particle size (D_{32}) in a solid rocket motor was improved. Multiple consecutive scans of two photodiode arrays were accomplished with a pacing circuit and added memory. The device was calibrated using various suspended particle samples and found to make accurate measurements.

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I. INTRODUCTION

Performance prediction codes for solid rocket motors model two phase flow losses as functions of particle size. In addition, particle size within the grain port strongly affects the damping of combustion pressure oscillations. At present these models are based on particle size data from collected exhaust samples [Ref. 1]. However, particle size varies with position in the motor and other parameters (pressure, propellant formulation, nozzle design, etc.). Therefore, experiments to determine how particle size varies in the actual flow environment of the motor (i.e., across the nozzle) are needed to validate the models for two phase flow losses. Cramer [Ref. 2] and Karagounis [Ref. 3] provide a good summary of the subject and the Naval Postgraduate School Combustion Laboratory effort to obtain particle size data across the exhaust nozzle of a solid rocket motor.

The method used in this continuing effort was the diffractively scattered light technique. The diffraction patterns of light scattered by particles are analyzed to determine the volume to surface mean diameter [Refs. 4 through 11]. This method has the disadvantages that size distributions cannot be easily determined and particles larger than some threshold size will not be detected due to the exceedingly small angles as which they scatter light. However, it has the advantage that it is non-intrusive and in theory can be used in the internal motor environment.

Use of this method for particle sizing in solid rocket motors at the Naval Postgraduate School Combustion Laboratory was begun by Karagounis [Ref. 3]. The apparatus was subsequently redesigned and the data acquisition equipment upgraded with the introduction of the Hewlett Packard 3054A data acquisition system with an HP 85 as the controlling computer [Ref. 12]. The investigation by Cramer and Hansen followed and showed that propellent composition can limit the application of the technique. Large particulate combustion products in the flow made particle size data difficult to obtain. This was especially true if only one measurement of the scattering profile was made during a test firing.

To address this problem in the present study several improvements were made. A cleaner burning propellant was obtained to reduce char agglomerates in the exhaust products. A more statistically valid data sample (multiple measurements during a single test) was made possible with added momory in the data acquisition equipment and a pacing circuit which allowed full use of this memory. Data reduction was also improved with a Hewlett Packard 9836S computer combined with a more recently developed approach to particle sizing presented by Buchele [Ref. 13]. This method is discussed later in depth.

The focus of this thesis project was the following:

(1) Implement the HP 9836S as the system controller.

(2) Expand the multiprogrammer memory in order to obtain up to eight consecutive scans of the diode arrays during a test firing.

(3) Improve data reduction techniques by the method of Buchele [Ref. 13].

(4) Modify the apparatus and experimental procedures to improve the angular resolution and to reduce extraneous light.

(5) Certify the proper functioning and accuracy of the apparatus prior to actual motor testing.

II. THEORETICAL BACKGROUND

A. GENERAL DISCUSSION

The completely general theory of scattering was developed by Mie and is presented by Van de Hulst [Ref. 14]. The light scattering characteristics for spherical particles of any size are fully described in a mathematical format. The Mie scattering functions contain Legendre polynomials and spherical Bessel functions and fully treat the phenomena of reflection, refraction, diffraction, and extinction. The full theory is most often applied when particle size is approximately the same as the wavelength of the incident light. Van de Hulst [Ref. 14] calls this the regime of Anomalous Scattering.

For particle sizes much smaller than the wavelength of light the Mie equations simplify to a form which is more dependent on the index of refraction of the particles and less dependent on particle size. This is called Rayleigh Scattering.

The study of particle size behavior in solid propellant rockets mainly covers sizes much greater than the wavelength of light. Scattering by large particles such as these is described adequately by Fraunhofer diffraction.

B. APPLICATION TO LARGER PARTICLES

The ringed diffraction pattern generated by a hole in a mask, or a number of particles of the same size is described by the equation:

$$I(\theta) = \left[\frac{2J_1(\alpha\theta)}{\alpha\theta}\right]^2$$

where:

$I(\theta)$ describes the relative intensity of the scattered light at an angle theta (θ)

$J_1(\alpha\theta)$ is the Bessel function of the first kind

$\alpha = \frac{\pi D}{\lambda}$ is the particle size parameter for diameter D and wavelength of light lambda (λ).

Measuring the particle size for a monodispersion can be accomplished by measuring the angular position of a dark or bright ring in the diffraction pattern. For a dark ring the zero of the Bessel function corresponding to the ring is set equal to ($\alpha\theta$) and particle size is determined directly [Ref. 5]. For bright rings one sets ($\alpha\theta$) equal to the corresponding maximum of the Bessel function and solves for the diameter.

The above method is not used for polydispersions since the discrete rings are not observed. However, Dobbins, et al. [Ref. 5] introduced a significant improvement in the diffractively scattered light method of particle sizing. They found that although the method was not directly able to determine distributions of sizes, the volume to surface mean diameter defined by

$$D_{32} = \frac{\int_0^{D_\infty} N_r(D) D^3 dD}{\int_0^{D_\infty} N_r(D) D^2 dD} \tag{1}$$

where:

$N_r(D)$ is a distribution function describing the proportion of particles with diameter (D) in the sample, could be accurately measured.

A curve for sizing polydispersions was presented which was used by Cramer and Hansen [Refs. 2, 12].

Two phase flow losses are often calculated in terms of D_{43}. If the distribution of sizes in the polydispersion is well behaved then D_{32} and other diameters such as D_{43} can be easily related [Ref. 15]. Reference 5 reported that very small particles in the distribution have a minor influence on the scattering profile. This makes the measurement technique promising for the two phase flow loss study since very small particles do not contribute significantly to these losses and so are of less interest.

Roberts and Webb [Ref. 6] essentially confirmed the conclusions of Reference 5 and presented a similar curve for use in sizing.

More recently, Buchele [Ref. 13] gives a good summary of experimental techniques for particle sizing by measuring diffracted light. One point of interest in his report is that he represents the scattering profile of a polydispersion with a function which closely approximates the curves of References 5 and 6.

$$I_n(\theta) = EXP -(.57\alpha\theta)^2$$

This function from Reference 13 and the curve from Reference 5 were both used in the present study to evaluate the apparatus to be used with solid propellant rocket motors.

An additional detail of measuring scattering profiles is covered by Van de Hulst [Ref. 14]. The wavelength of light used in the scattering calculations depends on the index of refraction of the medium containing the particles. The wavelength used in all calculations must be:

$$\lambda = \frac{\lambda_0}{M}$$

where:

λ_0 is the wavelength of light in a vacuum and,

M is the refractive index of the medium with respect to a vacuum.

Thus, the size parameter (α) becomes:

$$\alpha = \frac{\pi DM}{\lambda_0}$$

and the beam spread parameter becomes:

$$(\alpha\theta) = \frac{\pi D M \theta}{\lambda_0}$$

Another consideration is presented by Gumprecht and Sliepcevich [Ref. 4]. Light scattered by particles in a medium is refracted as it crosses each interface of the container holding the medium. This is discussed further in the section on calibration and evaluation of the apparatus.

Additional complications arise with the full treatment of the index of refraction of the particles with respect to the medium. But, for Fraunhofer diffraction alone this aspect can be neglected.

C. RESTRICTIONS AND SOURCES OF ERROR

Some restrictions on use of the method are described by Dobbins, et al. [Ref. 5] and were satisfied as described by Cramer [Ref. 2]. These are related to the size of particles, the distance to the detector, and some phenomenon covered in the rigorous Mie theory.

One must keep in mind also that the curves developed for polydispersions are based on the Upper Limit Distribution Function of Mugele and Evans [Ref. 7]. This means that no particles with size greater than approximately ten times the mean should be in the sample [Ref. 13]. This appears to be a mild restriction. Van de Hulst [Ref. 14] describes the criteria for single scattering and a simple test to verify it. In general, as long as the scattered intensity is proportional to the number of particles the mathematics remain simple.

Sources of error of the diffractively scattered light method are covered by Buchele [Ref. 13] and are presented here.

(1) Inaccuracy of angular measurement or the limited ability to resolve small angles and,

(2) Inaccuracy of the intensity measurement due to extraneous light.

Extraneous light includes all light other than scattered light from the particles. Some examples are scattering from an aperture or dirty test section windows. Refraction of the beam due to gas density gradients and image point broadening from turbulence are others. Laser speckle is also extraneous light.

The sources of error addressed in this investigation are discussed in the related portions of the paper.

III. EXPERIMENTAL APPARATUS

A photograph of the apparatus is presented in Figure 1. A schematic is presented in Figure 2. The light scattering equipment was mounted on two optical benches. Components for measurements in the exhaust plane were mounted on one bench. The other bench held the equipment associated with the motor cavity. The light source was an eight (8) milliwatt Helium Neon laser mounted on the exhaust bench. A collimated beam was required so a spatial filter/collimator was used. A modification to this collimator is discussed later in this section. The collimated beam passed through a cube beam splitter and the second beam was diverted to a 90 degree prism on the other bench. The original beam continued through the motor exhaust plane. The other beam was routed through the nitrogen-purged glass windows in the motor housing.

Each beam was then intercepted by a physical stop located in front of its set of receiving optics. The further the stop was placed from the test section, the smaller the angle at which scattered light could be measured. In this apparatus, the stops were placed approximately 30.5 centimeters from the exit plane of the test section. This allowed a minimum angle of approximately .008 radians to be measured. Light scattered at angles greater than this was not intercepted and continued past the edges of the stop. The stop served to keep the transmitted beam out of the measuring optics and thus reduce extraneous light. The stops also improved optics alignment. This is discussed under calibration and evaluation of the apparatus.

The scattered light passed through a narrow pass filter which admitted only light of the Helium Neon frequency. This filter served to reduce extraneous light from the external surroundings.

An objective lens of 50 centimeter focal length was located behind the narrow pass filter. This lens imaged onto a photodiode array the scattering profile of the particles in the test section. The shadow of the beam stop was also imaged since the stop was between the test section and the objective lens. This was a limitation which is discussed under calibration and evaluation.

The photodiode arrays were the same units used by Cramer and Hansen [Refs. 2,12]. Each array contained 1024 silicon photodiodes on a single chip with 25 micron spacing. The accompanying circuits provided a sampled and held output which was essentially analog except for switching transients. At the end of each diode scan there was a delay before the next scan. During this delay the diodes were reset and allowed to measure the intensity of the scattering profile again. The scanning of the diode array repeated continuously. The actual sampling time of the array was about 34 milliseconds with a delay between scans of about 6 milliseconds.

The 50 centimeter focul length of the objective lens combined with the dimensions of the diode array provided a half angle field of view of about 3 degrees for mediums of refractive index near one. The effective field of view was reduced to about 2.3 degrees for calibrations when the refractive index of a Plexiglas container and water was taken into account.

The laser beam collimator mentioned previously at first produced a beam one centimeter in diameter. A lens in the collimator was changed to reduce the beam diameter for several reasons. Extraneous light would be generated if a large beam impinged on the aperture of the motor test section window. Also, if the aft beam was larger than the motor exhaust jet it would be refracted in the density (and refractive index) gradient between the exhaust and air.

The last part of the apparatus was the rocket motor itself. It was the one used by Cramer and Hansen [Refs. 2,12] and in the present study served only for aligning the optics.

IV. DATA ACQUISITION SYSTEM

A. NEW CONTROLLER

Hansen [Ref. 12] describes the major components of the Hewlett Packard 3054A data acquisition system. A list of the manuals relevant to this study is in Table 1. The HP 85 computer used by Hansen and Cramer was replaced with an HP 9836S as system controller. This newer computer has far more capability than the HP 85, including a choice of more powerful operating systems. The system used for this study was Basic Extended 2.1.

The data acquisition program written by Hansen needed minor modification to acquire multiple consecutive scans of the photodiodes. Some different I/O commands such as those which transfer data to the disk were also incorporated. The revised version of this program is listed in Appendix A. A general flow chart is presented in Figure 3.

The 9836S has two internal disk drives which were used to store the data after acquisition. The data from both diode arrays was stored in the same file. The eight (8) scans of the motor cavity were first, followed by the four (4) exhaust scans.

B. MODIFICATIONS

The memory capacity of the Multiprogrammer unit was increased so that multiple consecutive scans of the diode arrays could be recorded during a motor firing. This would provide a more statistically valid measurement of particle size. Fluctuations of scattered light intensity for a polydispersion need to be integrated over time or averaged to provide a more appropriate measurement.

In order to fully use the memory added and make data management easier the data acquisition system needed to be modified. The memory consisted of three (3) cards, each with a capacity of 4096 values. The fact that this was a multiple of 1024 (the exact number of photodiodes) meant that the idle period between scans needed to be excluded from the data. If this was not done, one (1) less scan per card would have been acquired and locating the scans in the overall block of memory would have been more difficult.

It was also necessary to chain two of the memory cards together in a way which would allow one card to be filled and then the other. A schematic of the data acquisition system is presented in Figure 4.

C. PACING AND MEMORY CONTROL CIRCUITS

The timing clock and blanking pulse of the photodiode circuitry provided the means for pacing data acquisition.

Specific results of the modifications were:

(1) Memory space was fully utilized and management of the multiple scans made easier.

(2) A/D conversions of the data were made exactly when a diode's output was on line and steady. Thus, the analog filter used in the previous study was no longer needed to suppress the switching spikes on the data line.

The following is a description of the signals and circuits used to modify the data acquisition system. All voltage levels were TTL. A timing diagram in Figure 5 shows the relations between signals. A schematic of the circuit is presented in Figure 6.

The clock pulse was a positive going spike at a frequency of about 30 KHz. This clock controlled all circuits of the photodiodes. It ran continuously, even during the blank period between scans when the diode output was clamped at zero volts.

The blanking pulse was a signal which fell to zero at the beginning of each scan. It then went positive at the end of the scan and remained high until the next scan began.

The clock pulse was used to drive a pulse shaper (monostable multivibrator). This ensured that the voltage levels through the rest of the circuit would not accidentally fall below the TTL threshold. The pulse width of the shaper was adjusted so that the negative going edge of each pulse would occur after the switching transient on the data line had decayed. This negative going edge would eventually trigger the A/D converter to store the output of each diode.

The blanking pulse was inverted and connected to an AND gate along with the pulse shaper output. The output of this AND gate is shown in Figure 5 as the pulse shaper signal held low between scans of the diode array. This was the basic signal which paced data acquisition.

This basic trigger signal was connected to an AND gate along with the output of the Multiprogrammers Timer Pacer card. In this way the trigger would not reach the A/D until the Timer Pacer output a pulse. This enabling pulse from the Timer Pacer was at least as long as the time for eight scans of a diode array.

The controller programed the Timer Pacer to produce the pulse when the Timer Pacer received a trigger from the blanking pulse. In this way, data acquisition began at the start of a scan and no data was taken during the time between scans.

The circuit to chain the memory cards together was basically an OR gate used as a negative logic AND gate. The end of conversion ($\overline{\text{EOC}}$) signal of the A/D and the ($\overline{\text{FULL}}$) signal of one memory card were connected to the gate. When both signals went low the second card was then able to store data from the A/D. This arrangement is shown in the schematic of the data acquisition system in Figure 4. The automatic lock-out feature of the memory cards when full, and the relatively slow rate of data throughput made it unnecessary to control other handshake lines [memory card manual, Table 1].

The circuit was designed to handle four (4) memory cards, so no modification will be necessary if one more card is added to the system. This would provide an additional four scans of the exhaust beam.

V. DATA REDUCTION

The data reduction programs written by Hansen were not used for this study. The new computer lended itself to another approach. Its memory capacity made it unnecessary to chain programs together and polynomial curve fitting was eliminated in favor of interactive graphics. Avoiding polynomial fits preserved the nature of the raw data so that one had a better feel for the parameters. The data reduction program "RDC" is listed in Appendix A. Figure 7 is a general flow chart for the program.

The following is a description of the program. The user was first prompted for values needed to analyze a given data set. For example, the wavelength of the laser used and the index of refraction of the medium must be known for any data set. Next, one had the choice of reducing raw data scans or reviewing a reduced data file. For raw data one chose either the exhaust or motor cavity beam data.

Raw data was plotted on the CRT and any obviously erroneous scans were excluded from further reduction. The valid scans were averaged to obtain a mean scattering profile. The mean intensity profile taken before particles were introduced was then subtracted from that taken with particles present.

This corrected for the characteristics of individual photodiodes and extraneous light which was independent of the particles.

A symmetric moving-average-type of digital filter was then applied to the profile to achieve some smoothing. This type of digital filter was chosen for simplicity and because it does not have the phase lag of analog filters [Ref. 16]. Preserving the phase of the data was necessary to retain angular resolution. Another advantage of filtering in the software rather than hardware was that raw data files remained unmolested.

The scattering profile was then analyzed using interactive graphics. If earlier, one chosen to review a reduced file, program execution began here.

One had to normalize a scattering profile in order to compare it to the theoretical curves for polydispersions. The scattered intensity on the centerline of the beam was the correct value to use for normalization but was unmeasurable due to the beam's presence.

The other unknown was, of course, the particle size. These two variables (centerline intensity for the measured profile and D_{32} for the theoretical profile of normalized intensity vs. (θ_1)) were adjusted using interactive graphics until the curve for polydispersions coincided with the data. In this way the mean diameter of particles was determined.

The second reduction technique used was the direct application of the method presented by Buchele [Ref. 13]. The equation for the polydispersion curve:

$$I_n(\theta) = EXP -(.57\ \alpha\theta)^2$$

was applied at two points of the scattering profile. This gave:

$$I2/I1 = EXP -D^2[(\theta_2^2 - \theta_1^2)(.57\ \pi/\lambda)^2]$$

Solving this for the diameter gave:

$$D = [-L_n(I2/I1)(\lambda/.57\pi)^2/(\theta_2^2 - \theta_1^2)]^{\frac{1}{2}}$$

The computer would sweep through the data using many values of theta1 (θ_1) along with several angle ratios to determine theta2 (θ_2). The results were presented graphically as particle size vs. theta1 for each angle ratio (θ_2/θ_1).

In actual practice the range of useable angles depends on the appratus, and the quality of the data. Therefore, in order to interpret the results one must have previously inspected the data. The interactive graphics routine was well suited to this and provided a hard copy for inspection.

After reducing a set of raw data the mean scattering profile was stored on disk for later review.

VI. CALIBRATION AND EVALUATION

A. IMPROVEMENTS

The geometry of the apparatus used in the investigation by Cramer and Hansen is compared with that of this study in Figure 8. In the previous study the transmitted beam was allowed to enter the receiving optics. The beam was focused off the diode array a few millimeters from the first diode. This was necessary to avoid damaging the diodes but introduced some uncertainty in angle measurements. The intense image of the beam along with scattered light from the receiving optics produced a high level of extraneous light. In the present study, stops were used to intercept the beam before reaching the receiving optics. These stops provided several advantages. A high intensity beam could be used while producing little extraneous light. Optics alignment was also improved. This reduced error in angle measurement. Alignment was accomplished using a neutral density filter to reduce beam intensity and protect the diodes. A schematic of the apparatus is in Figure 2. The laser, collimator, beam splitter and prism were positioned so that the beams passed through the appropriate measurement areas. The narrow pass filter and imaging lens were then positioned so that the beam entered on the centerline. The photodiode array was then moved using a three-axis micrometer so that the focused beam fell on the first diode. The beam stops were then put in place and the neutral density filter removed. In this way measurements commenced exactly from the optical axis of the beam.

Procedures were also refined to account for the bending of light rays as they passed through the walls of the particle container. As noted earlier, the index of refraction of the container and the medium containing particles affects scattering measurements. A Plexiglas box held the particle samples and a magnetic stirrer kept the samples suspended in water. The index of refraction of the Plexiglas and water combination was measured using a simple technique. A microscope was used to measure the ratio of actual depth to apparent depth for Plexiglas and water. The index of refraction was determined to be 1.39. This value was applied to the data to convert the measured scattering profile to that actually produced in the medium containing the particles.

B. RESULTS

Calibration results are summarized in Table 2. Initial tests were done with two samples wihch were basically mono-dispersions of large particles. Figure 9 shows the measured profile of scattered light for glass spheres ranging from

37 to 44 microns in diameter. This profile was obtained by placing the focussed beam just far enough from the first diode to avoid saturation with no particles present. The diodes located at angles less than about .01 radians saturated. The first bright ring for particles of about 40 micron diameter was visible near .02 radians. Figure 10 shows a profile for the same particles, illustrating use of the beam stops to avoid diode saturation and improve angle measurements. In this case, the first diode was located exactly on the centerline of the beam as discussed above.

Results for a sample of 53 to 63 micron glass spheres are shown in Figure 11. The center lobe was nearly completely missed but the first two bright rings were seen near .014 and .022 radians. The first two dark rings near .01 and .019 radians were also seen. The method described earlier of setting the beam spread parameter ($\alpha\theta$) equal to the zeroes and maximums of $J_1(\alpha\theta)$ was used to calculate a size of about 58 microns. Also shown in Figure 11 is the theoretical profile for a polydispersion with D_{32} = 54 microns.

Various polydispersions of either glass spheres or aluminum oxide powder were then tested. These polydispersions consisted of fairly large particles. Results are shown in Figures 12 through 17. These tests showed that the apparatus had two distinct modes of operation. If the particle concentration was very high, or if large particles dominated the polydispersion, many of the diodes at the smaller angles would saturate. This left only the data at larger angles useable. When many diodes saturated, the theoretical curve given by Dobbins, et al., was used to determine size. This was done because this curve was valid for the larger angles and lower relative intensities. The curve from Buchele [Ref. 13] was not valid for values of the beam spread parameter greater than three (3).

For low particle concentrations and/or small particles the data proved more accurate at the smaller angles. If no diodes were seen to saturate then one knew the measurement was in the higher intensity part of the center lobe. Here the curve given by Buchele was quite satisfactory for sizing.

The smallest particles tested were five, ten, and twenty micron polystyrene spheres. The bright rings for these particles occurred at angles too large for the apparatus to measure. For these samples the diodes did not saturate. Both the Gaussian curve fit and the two angle method were used to obtain D_{32}. These results were especially consistent. It should be noted that the two-angle method uses the equation for the Gaussian. If the measured profile matched the Gaussian exactly, then D_{32} would be the same for any (θ_1) and angle ratic (θ_2/θ_1) employed. Some variations in calculated D_{32} due to the imperfect fit are obvious in Figures 19, 21 and 23.

A scanning electron microscope was used to photograph the types of particles tested. These photographs are shown in Figures 24 through 27. Equation (1) was used along with these photographs to calculate some of the values of D_{32} in Table II. Calculations of D_{32} for the polystyrene were arrived at using the manufacturers data on size distributions. The photographs generally confirm the validity of the technique.

VII. CONCLUSIONS AND RECOMMENDATIONS

The results of the calibration tests showed that the apparatus is capable of accurately measuring mean particle size for a broad range of mean diameters. It was found that the technique was most accurate if the theoretical profile fit or the two-angle method were applied at the smallest possible scattering angles.

The rocket exhaust is likely to attenuate the beam somewhat, reducing the problems related to diode saturation at small scattering angles. Thus, measurements should be possible using the high intensity part of the center lobe. This should make data reduction less ambiguous. Actual testing should begin with measurements at the exhaust plane of the motor. These should be compared with collected exhaust samples to validate the use of the apparatus in an actual motor environment. Measurements in the motor cavity would then be interpreted based on the correlation between exhaust samples and exhaust measurements.

It is also recommended that the index of refraction of the combustion gases be investigated. A literature search for an estimate of the index of refraction would probably be satisfactory.

TABLE I

ELECTRONICS MANUALS

1. HP Memory Cards Model 6970B Operating Manual
2. HP Timer Pacer Card Model 69737A Operating Manual
3. HP Analog to Digital Converter Card Model 69736A Operating Manual
4. HP Users Guide, "Using the 9826 and 9836 Computers with the 6942A Multiprogrammer"
5. Basic Language Reference Guide with Extensions 2.0 for Series 200 Computers

TABLE II. CALIBRATION RESULTS

Particle Material	Particle Size microns	Equation (1) Calculated D_{32} microns	Scattering Measurement D_{32} microns	Error microns
Polystyrene	3 to 6	4.7 **	4.5	.5
Polystyrene	6 to 16	10.2 **	7.9	2.3
Polystyrene	15 to 30	21.6 **	21	.6
Glass	37 to 44	38. *	40	2.
Glass	53 to 63	54. *	54 to 58	0 to 4
Glass	1 to 37	25. *	28 to 30	3 to 5
Aluminum Oxide	≈ 25	see Fig. 24	28	------
Aluminum Oxide	≈ 50	see Fig. 24	45	------

* From SEM Photos ** From Manufacturers Data

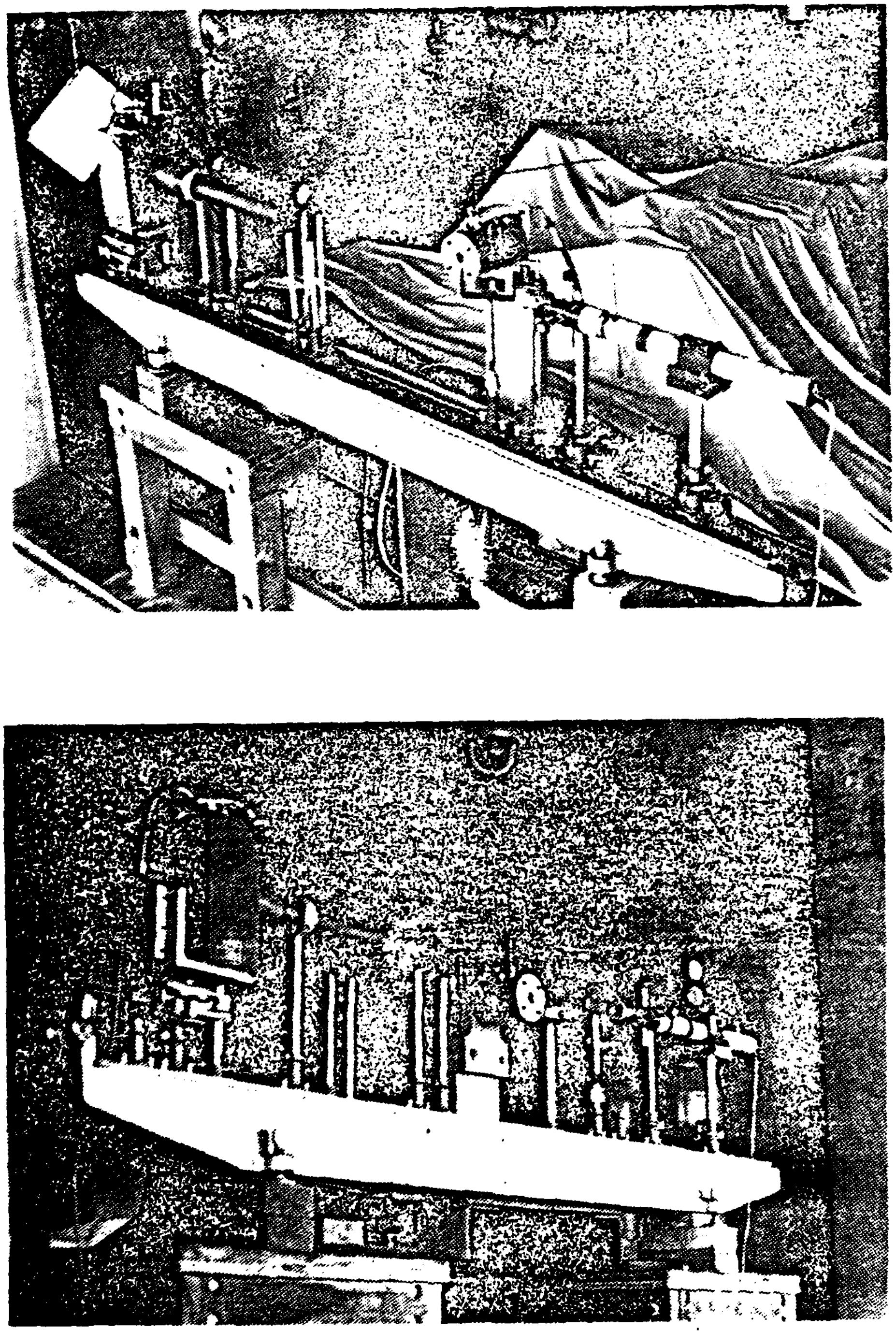


Figure 1. Photographs of Light Scattering Apparatus

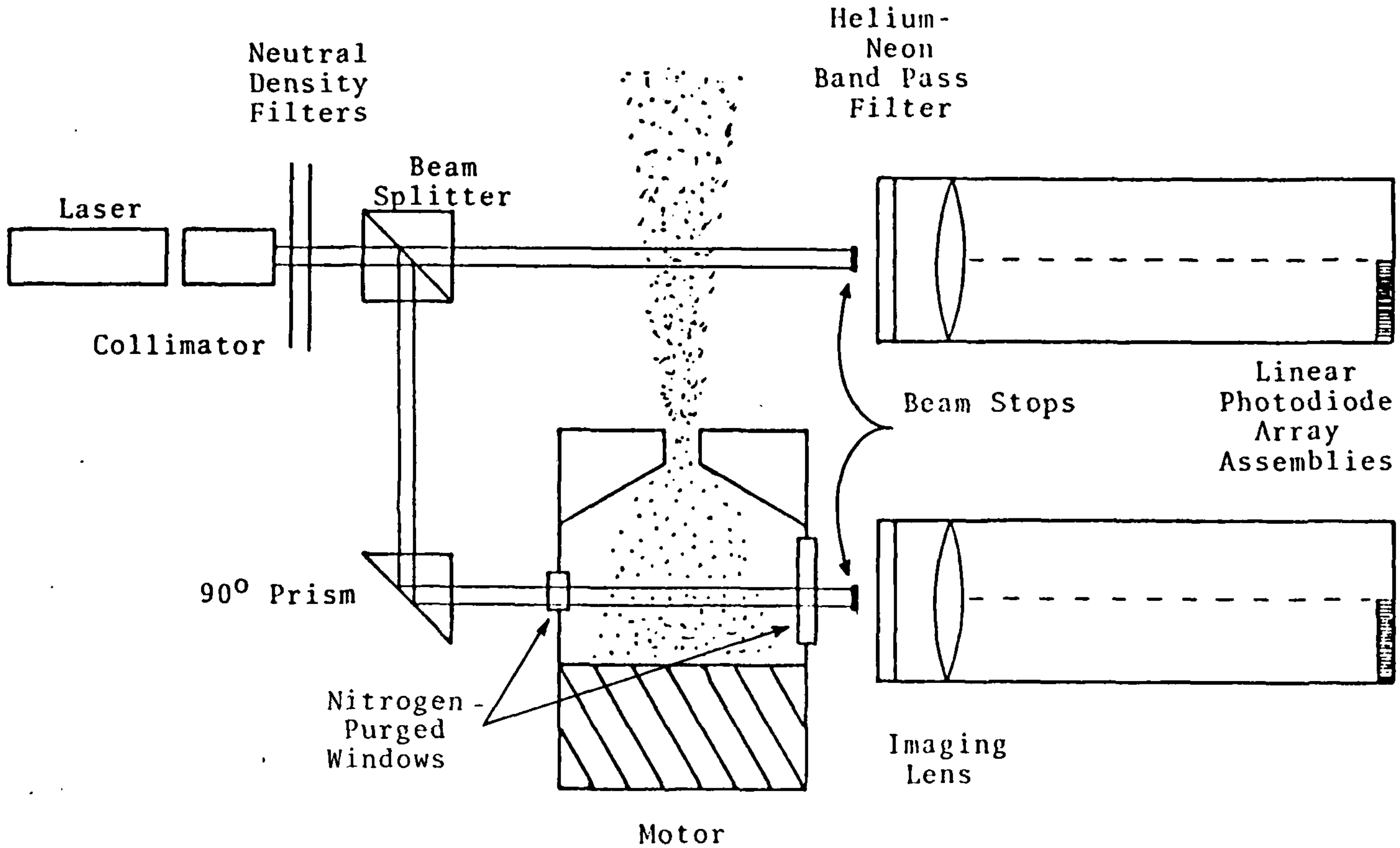


Figure 2. Schematic of Light Scattering Apparatus.

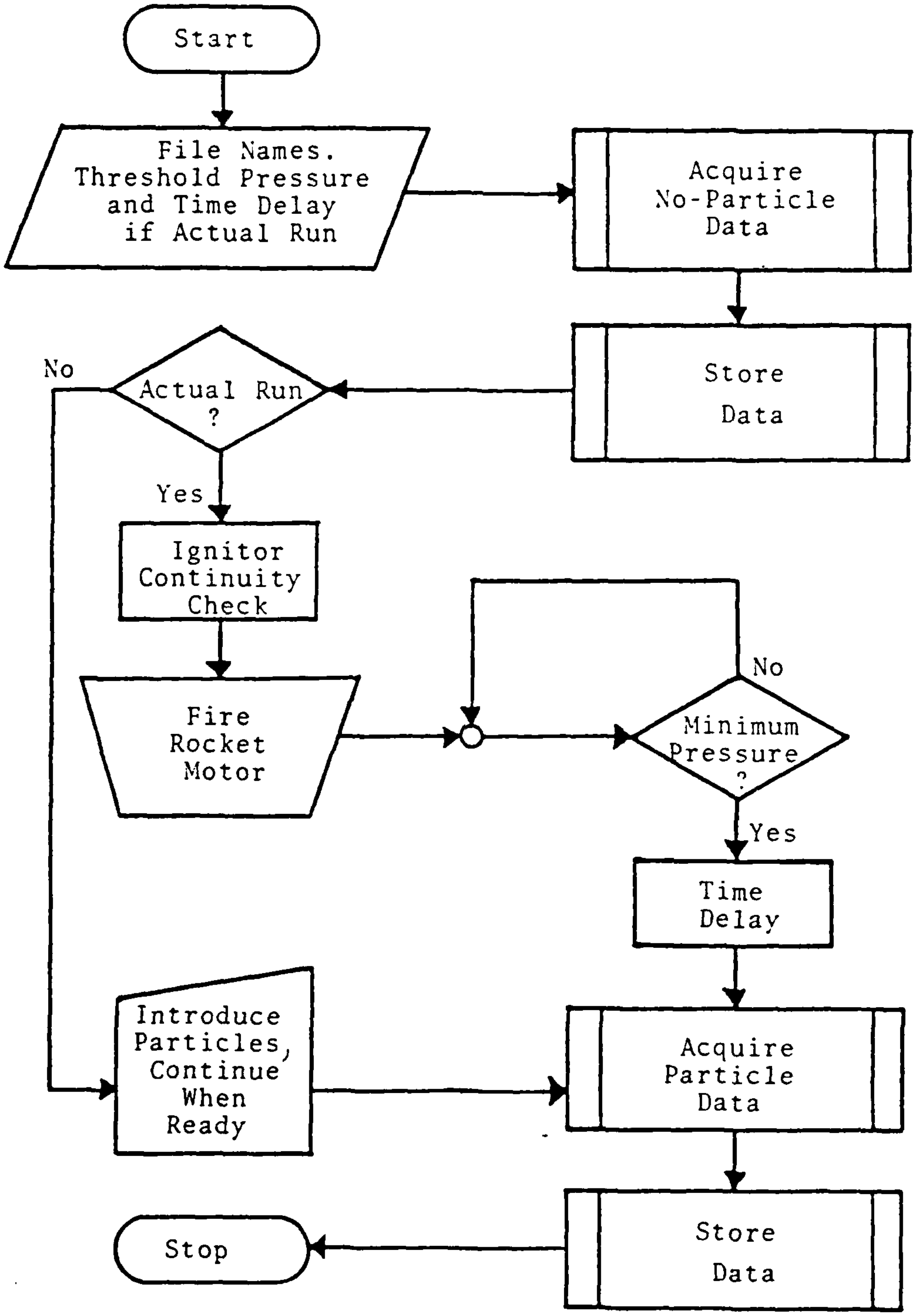


Figure 3. Flow Chart for Program "ACQDTA".

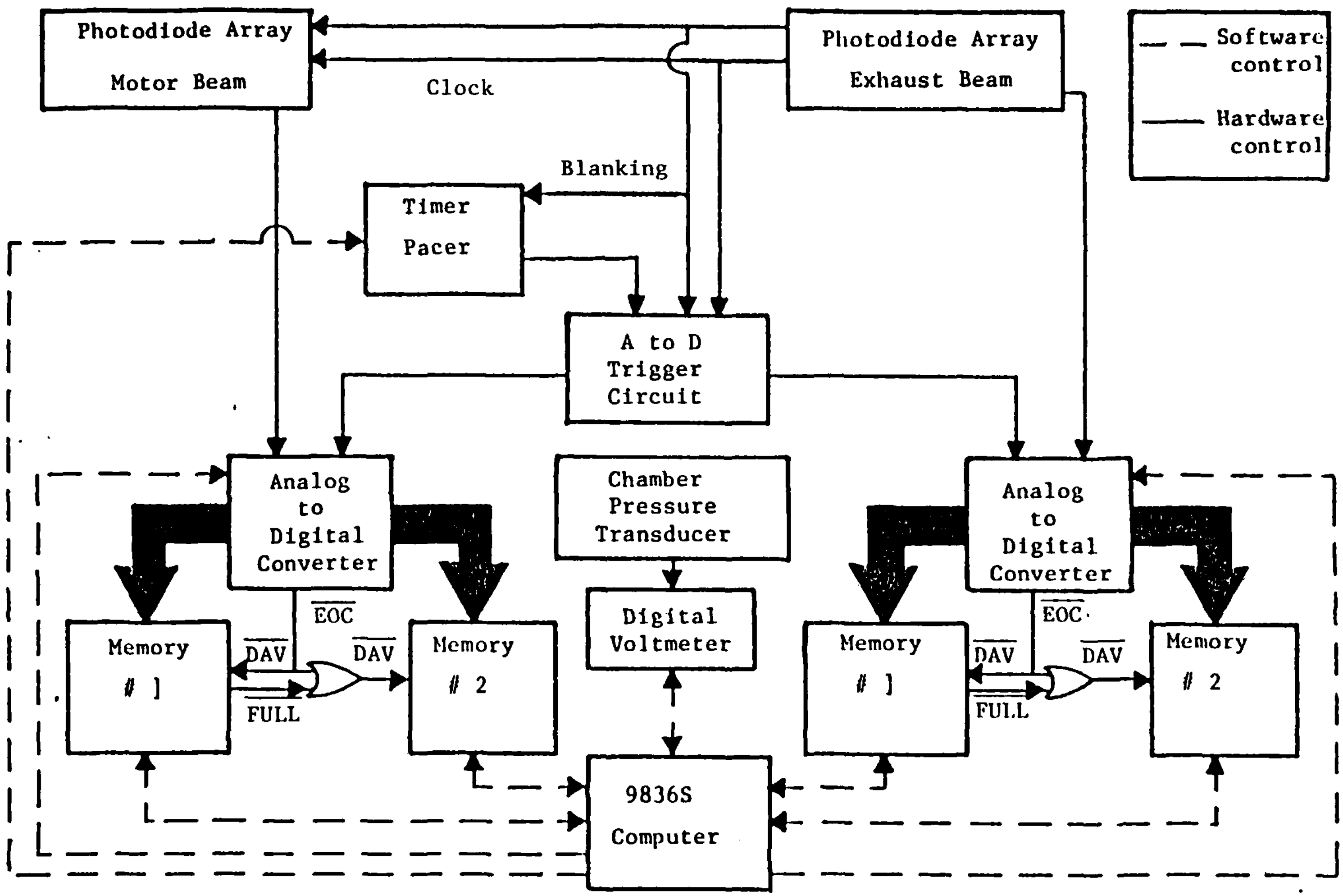


Figure 4. Schematic of Data Acquisition System.

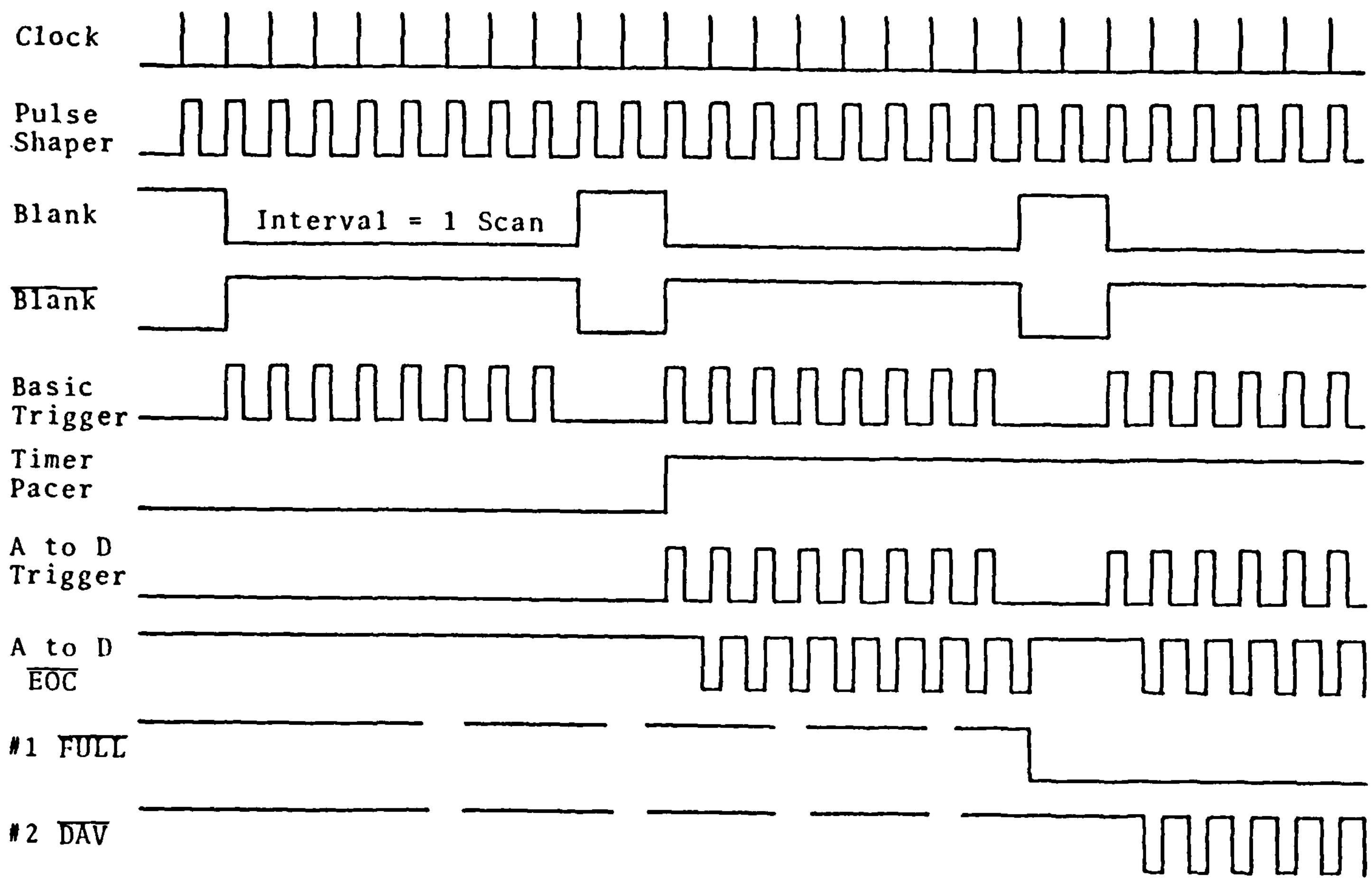


Figure 5. Timing Diagram for Data Acquisition.

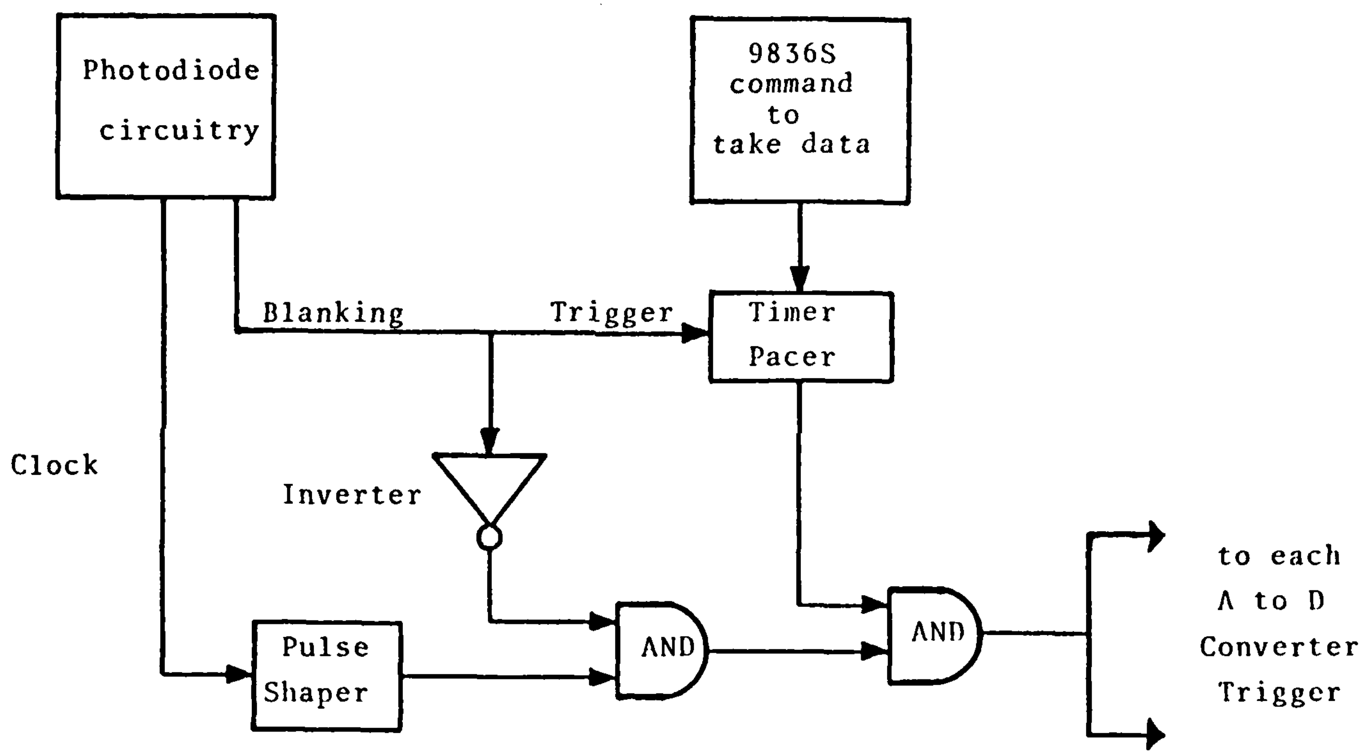


Figure 6. Schematic of Pacing Circuit for Data Acquisition.

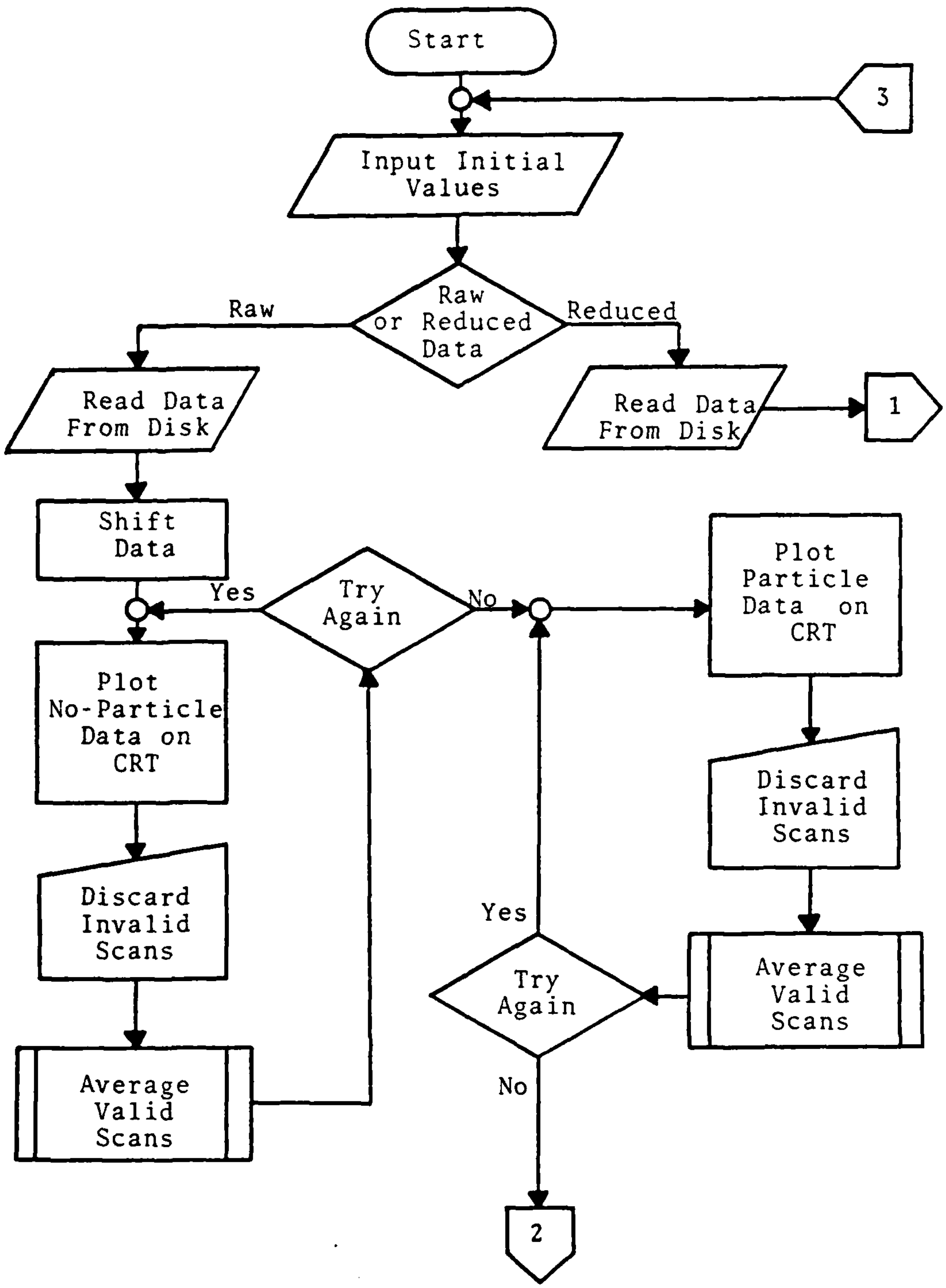


Figure 7. Flow Chart for Program "RDC".

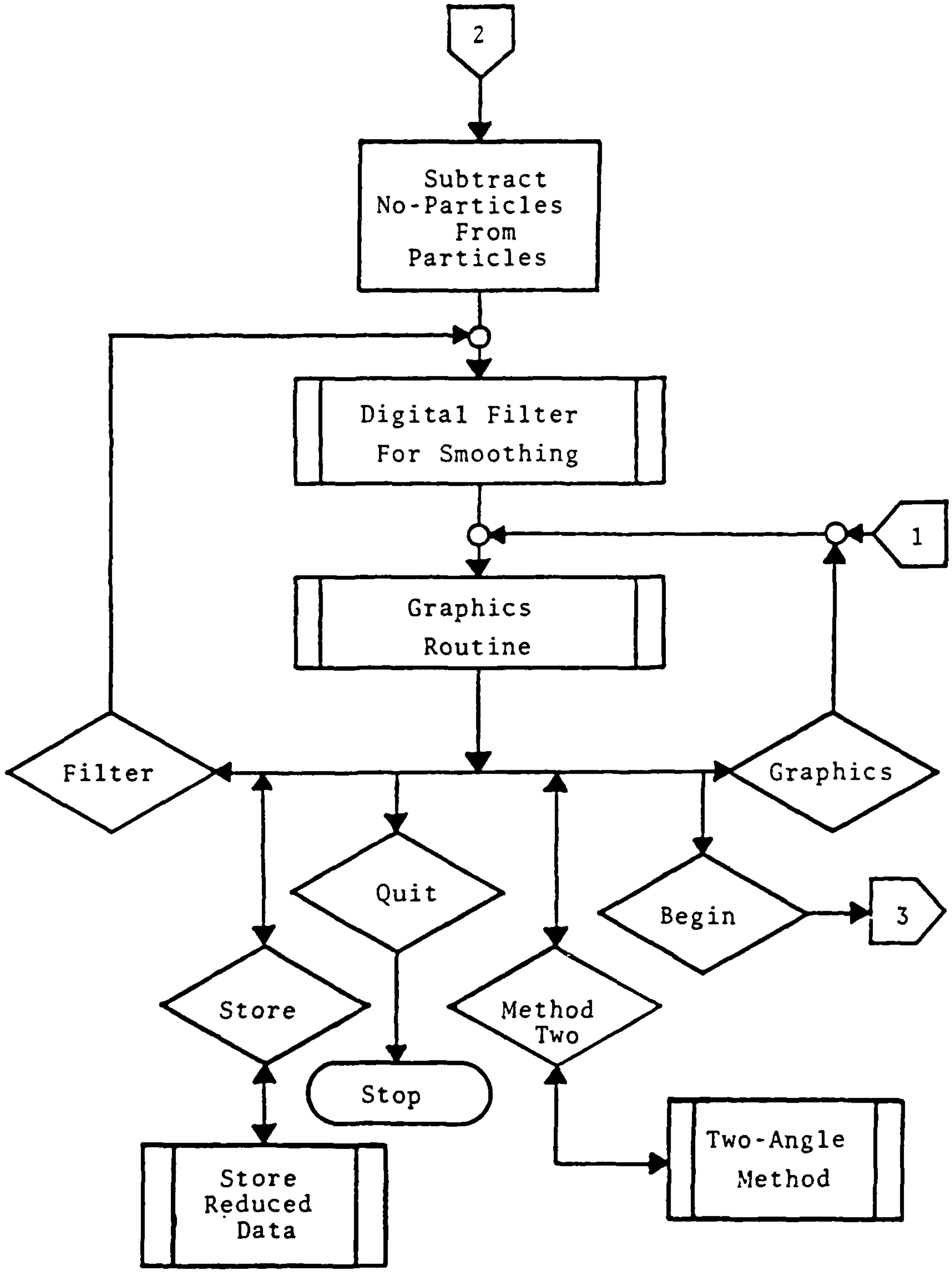


Figure 7. (Continued) Flow Chart for Program "RDC".

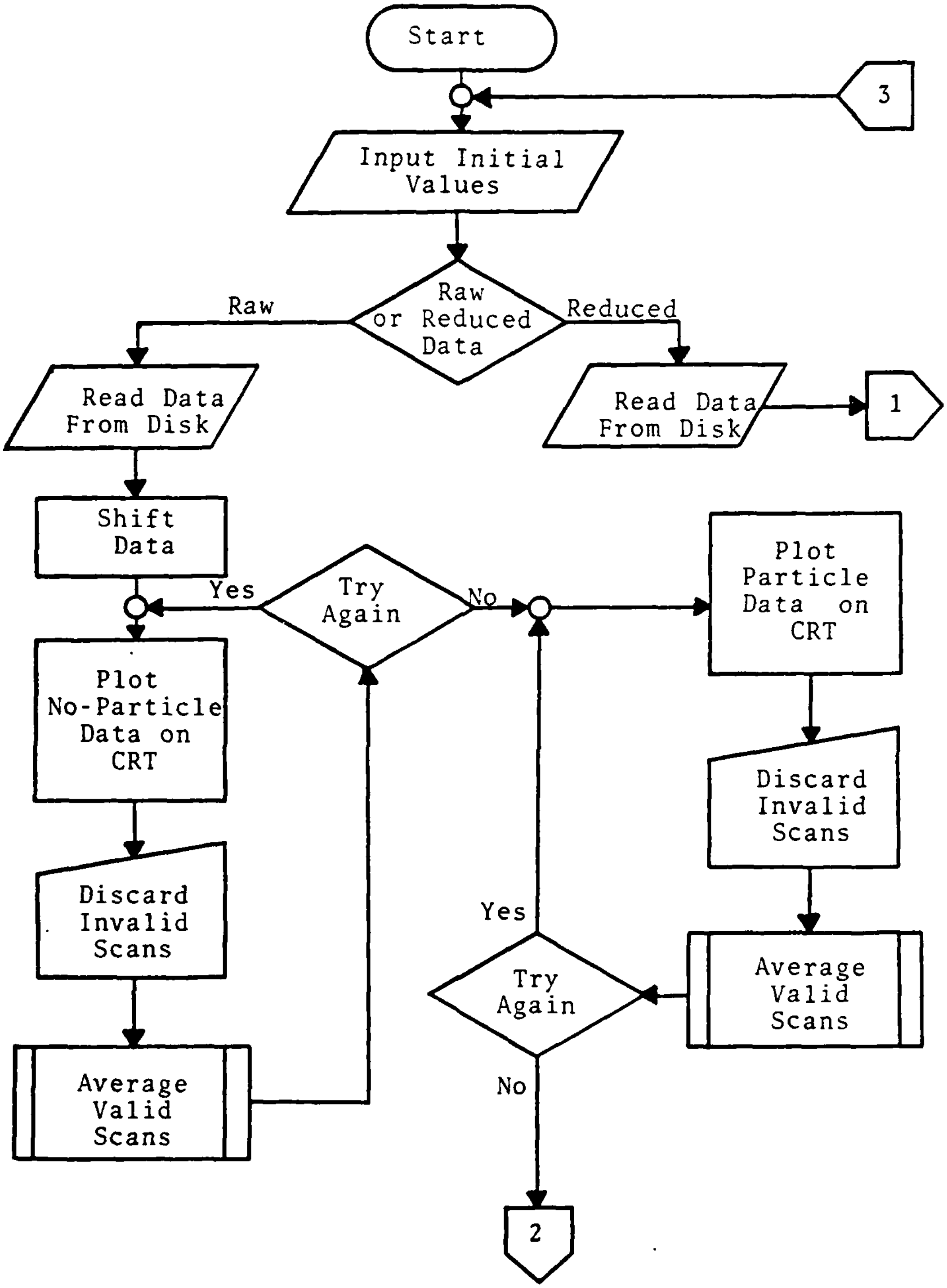


Figure 7. Flow Chart for Program "RDC".

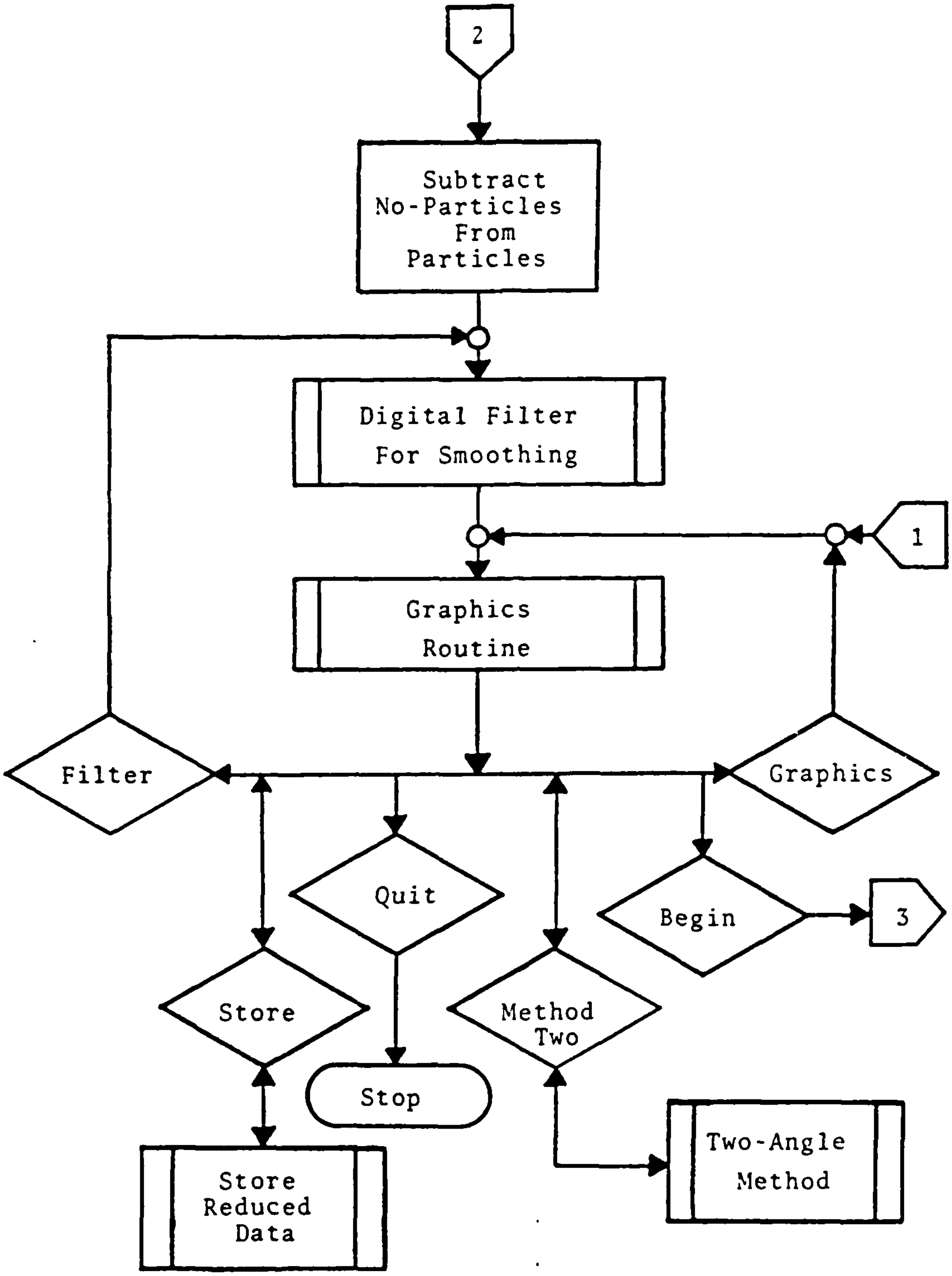


Figure 7. (Continued) Flow Chart for Program "RDC".

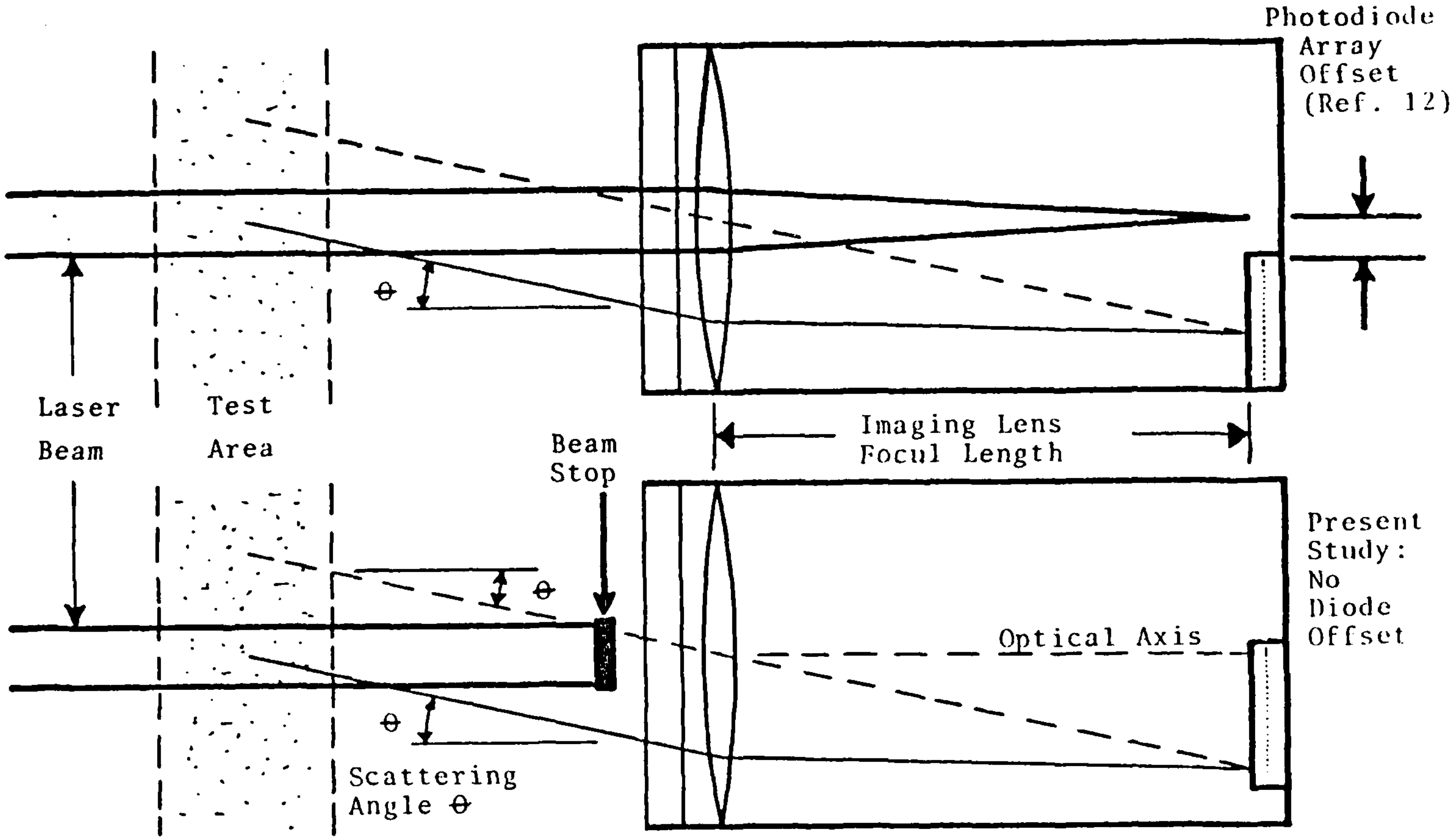


Figure 8. Comparison of Two Geometries for Light Scattering Measurements.

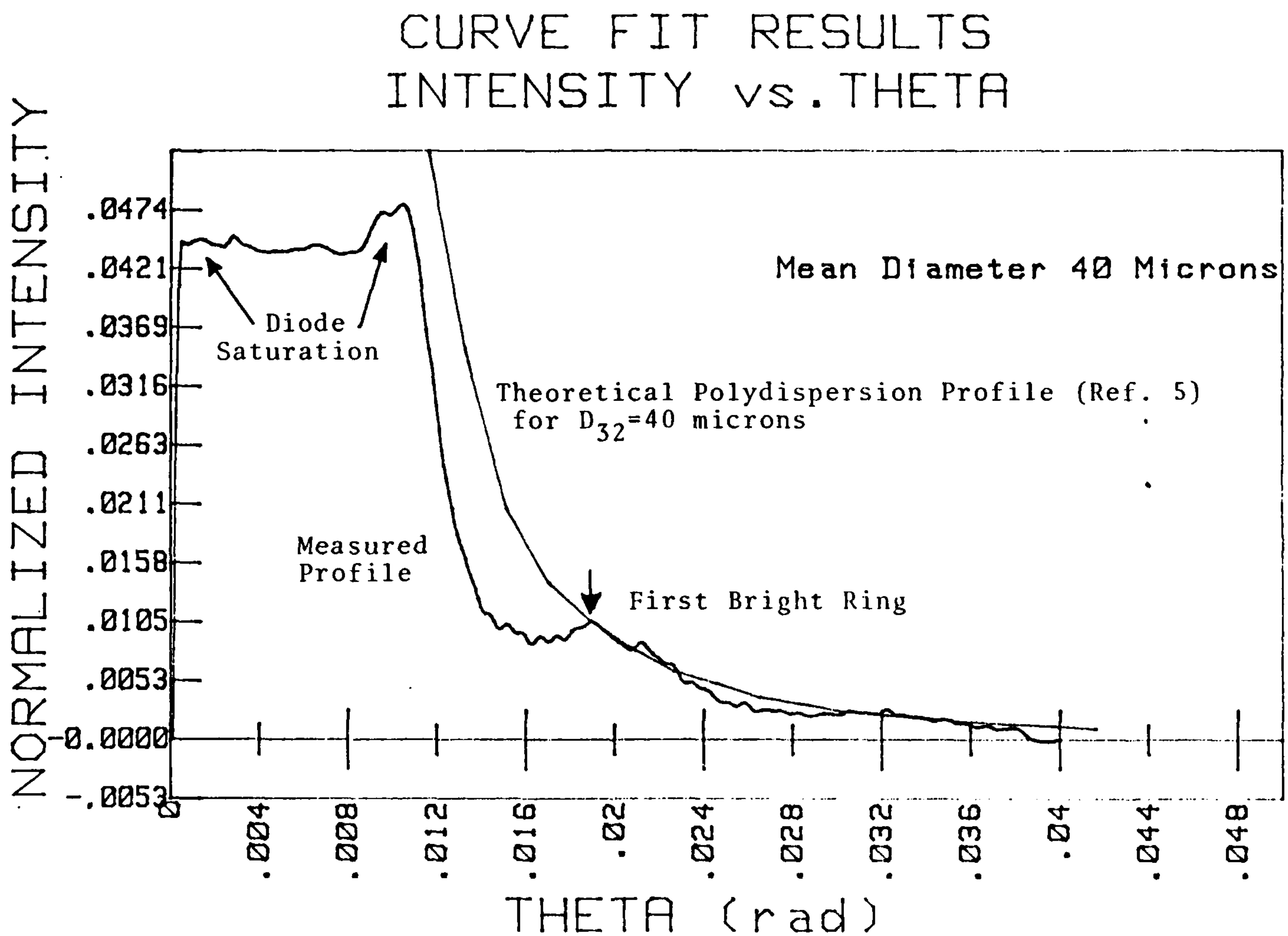


Figure 9. 37-44 Micron Glass Spheres Using No Beam Stop.

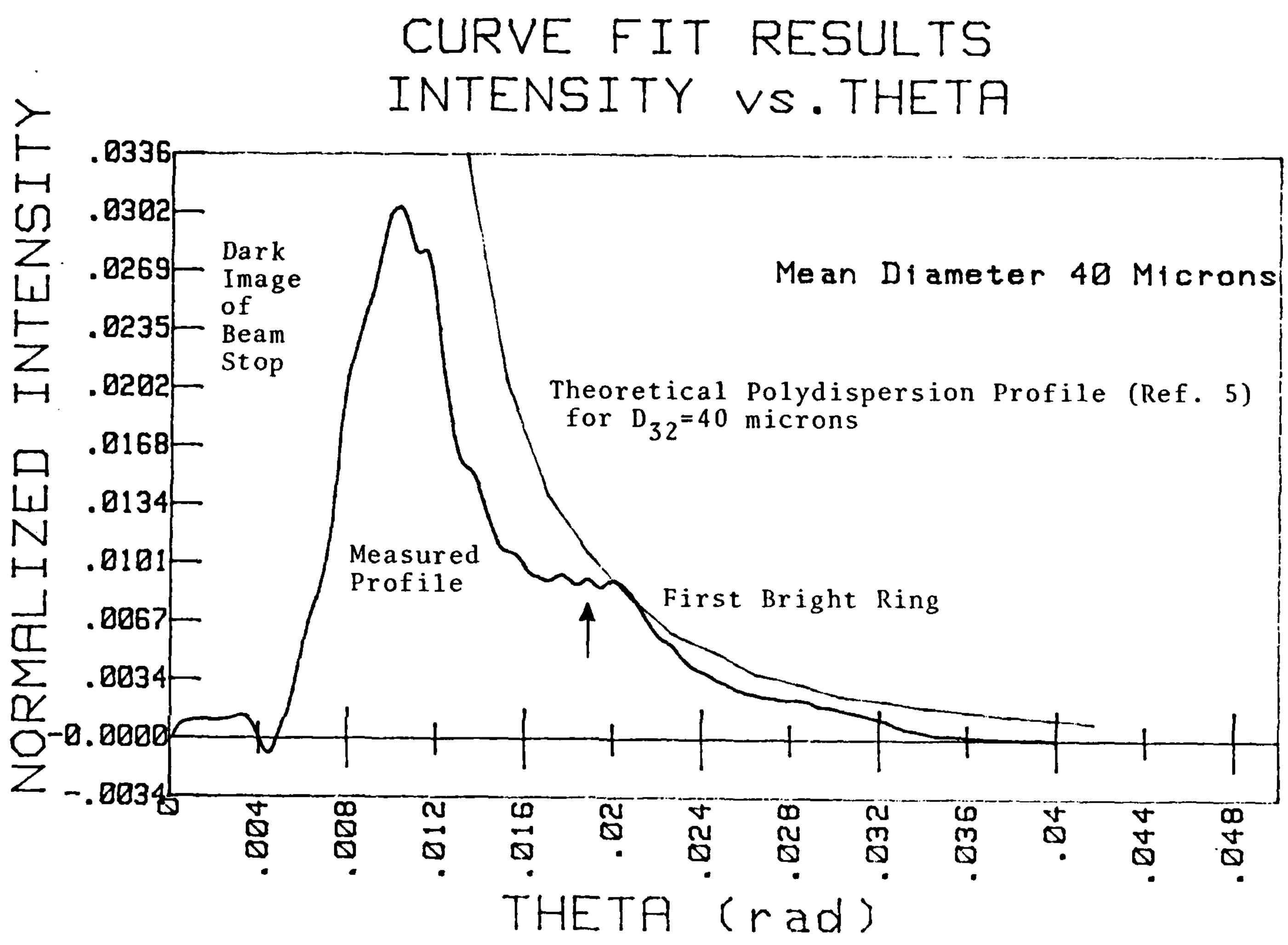


Figure 10. 37-44 Micron Glass Spheres Using Beam Stop.

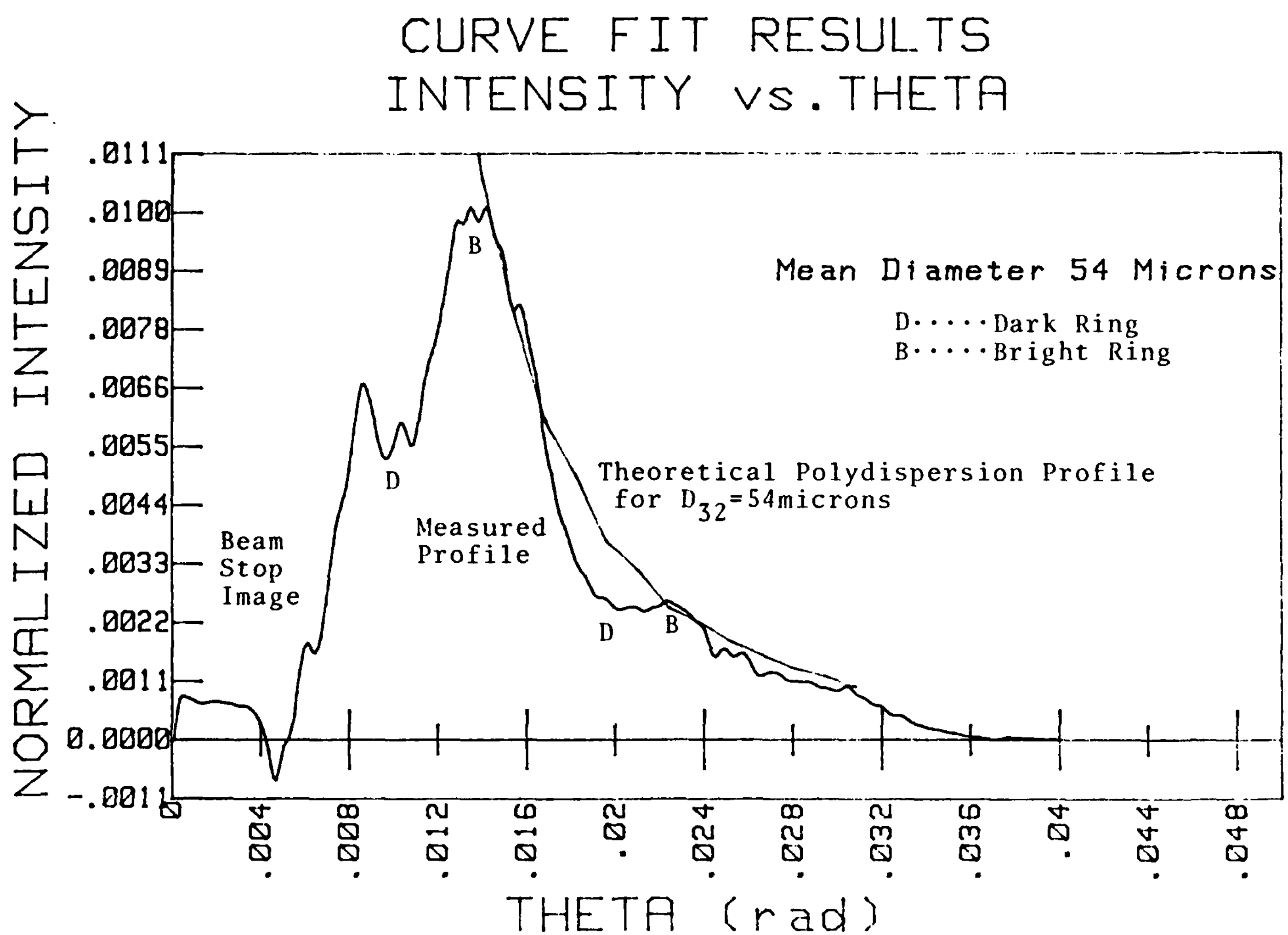


Figure 11. 53-63 Micron Glass Spheres Showing Diffraction Rings.

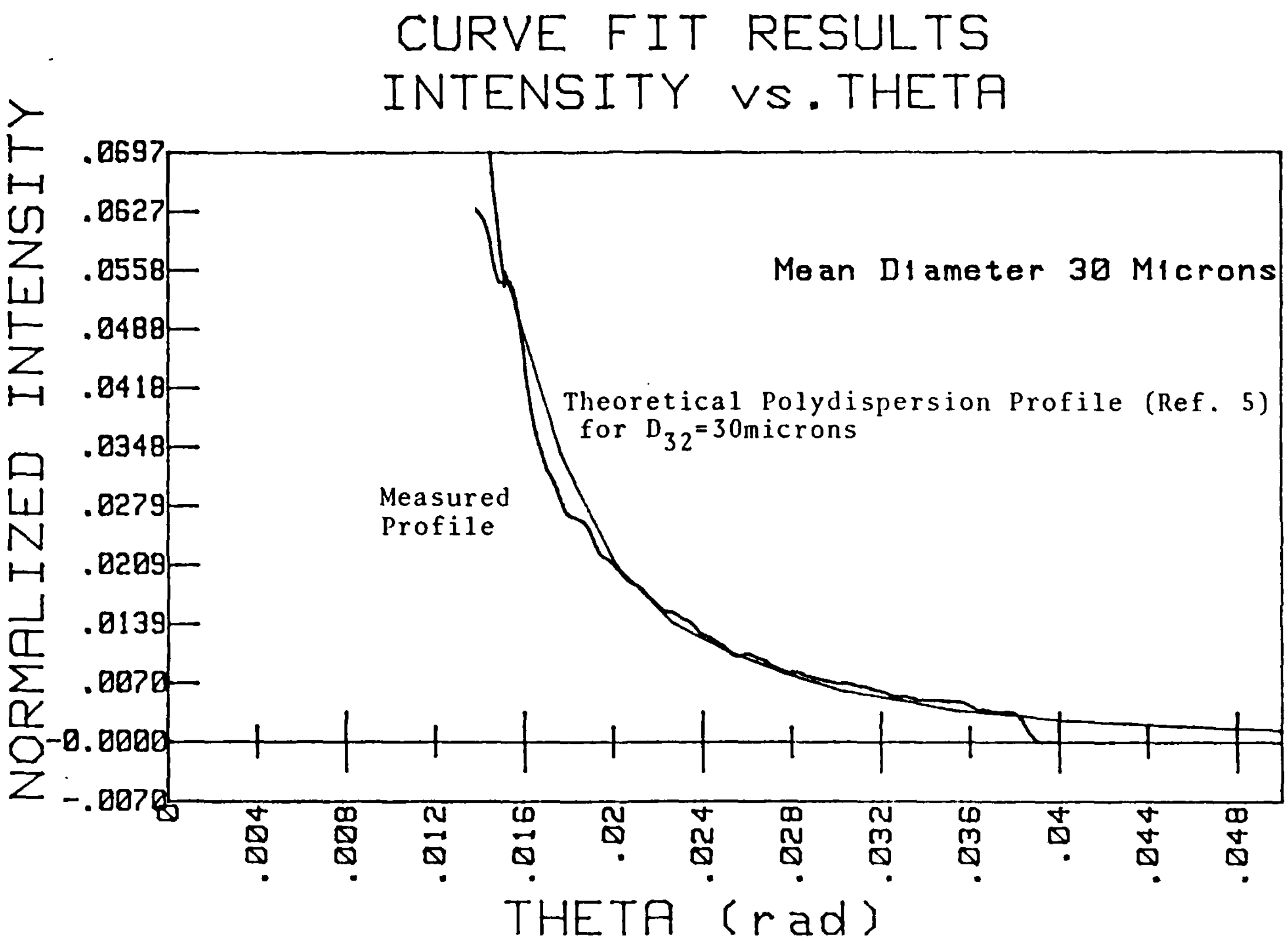


Figure 12. 1-37 Micron Glass Spheres, High Concentration.

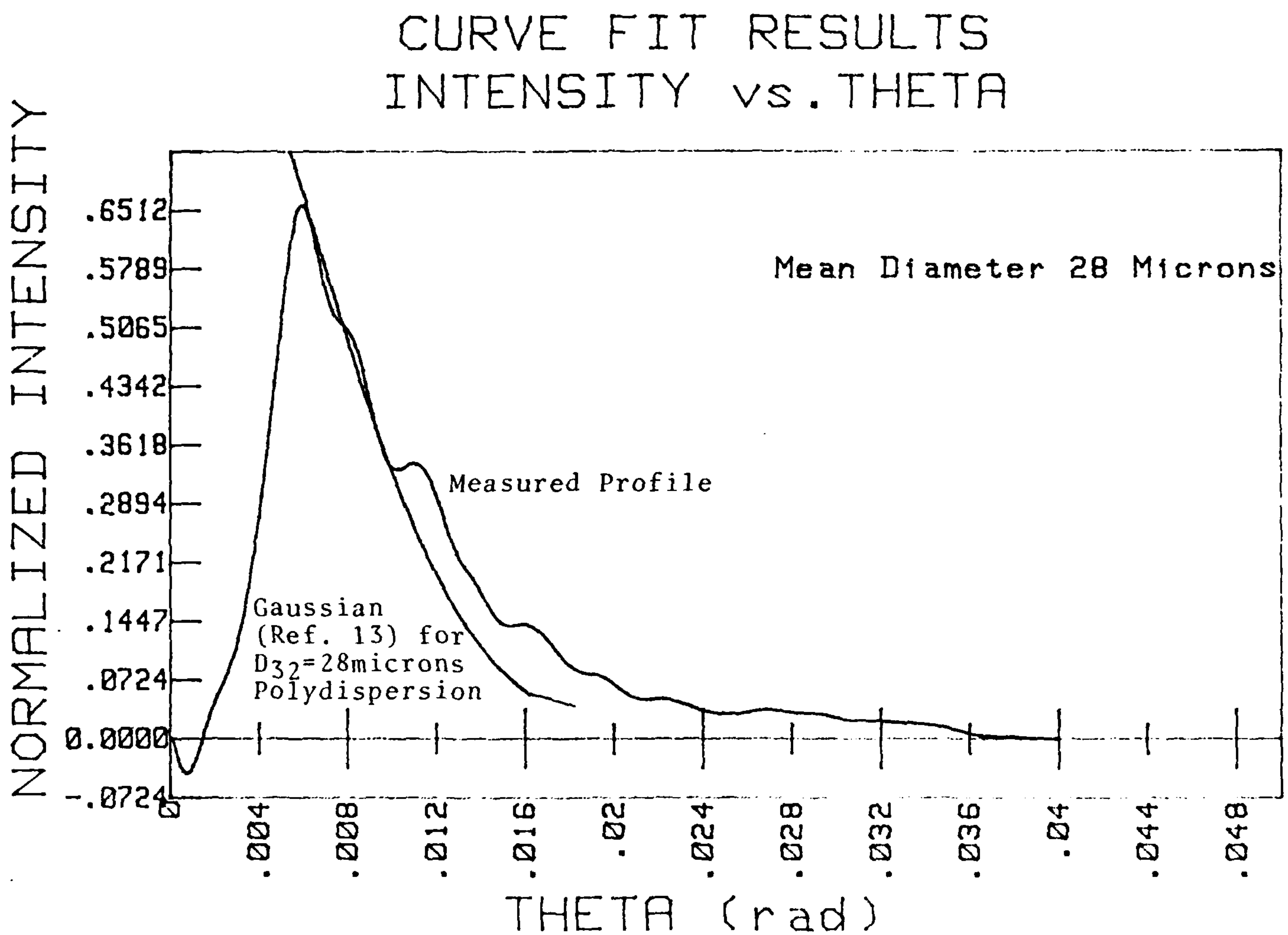


Figure 13. 1-37 Micron Glass Spheres, Low Concentration.

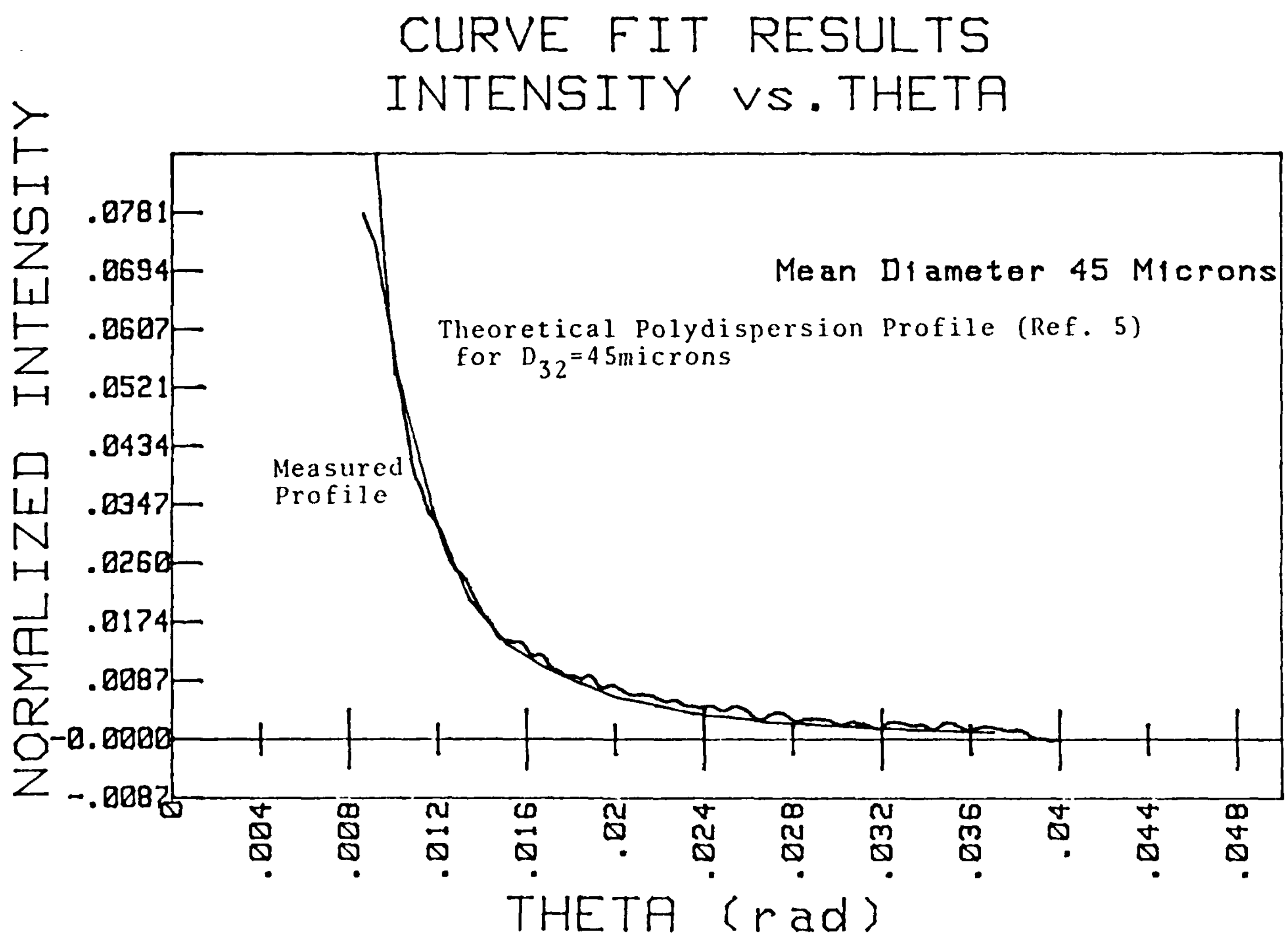


Figure 14. 50 Micron Aluminum Oxide, High Concentration.

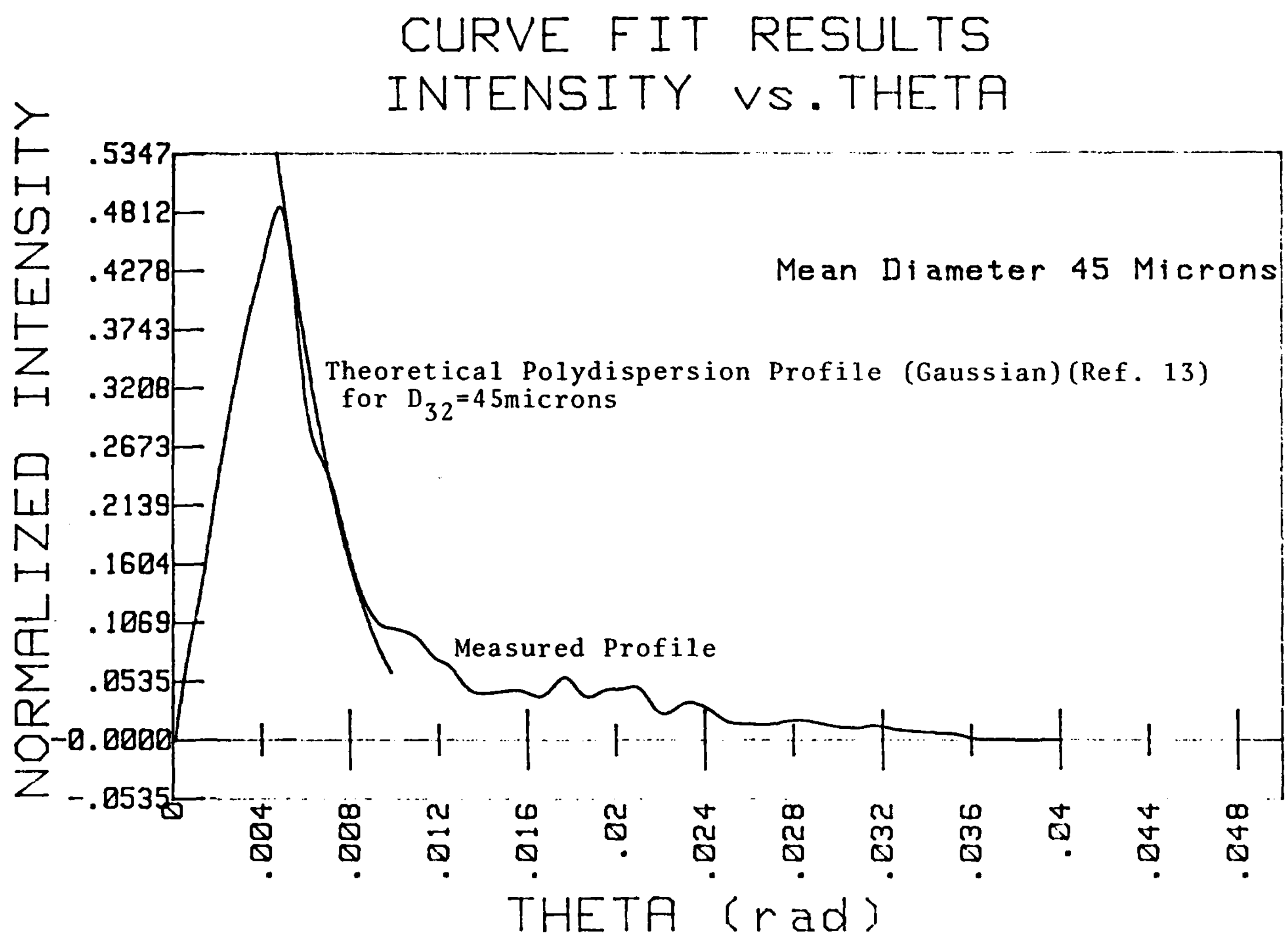


Figure 15. 50 Micron Aluminum Oxide, Low Concentration.

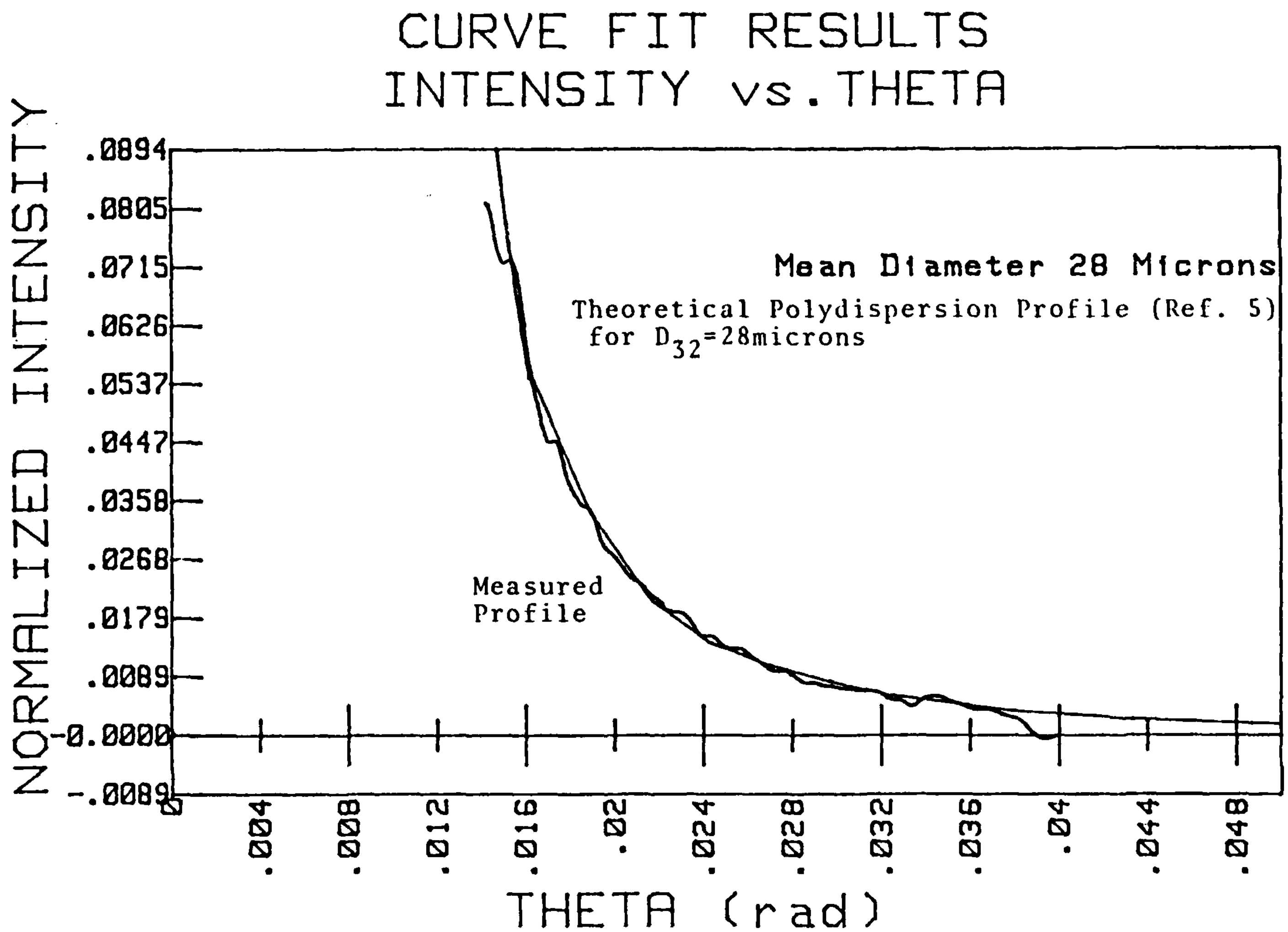


Figure 16. 25 Micron Aluminum Oxide, High Concentration.

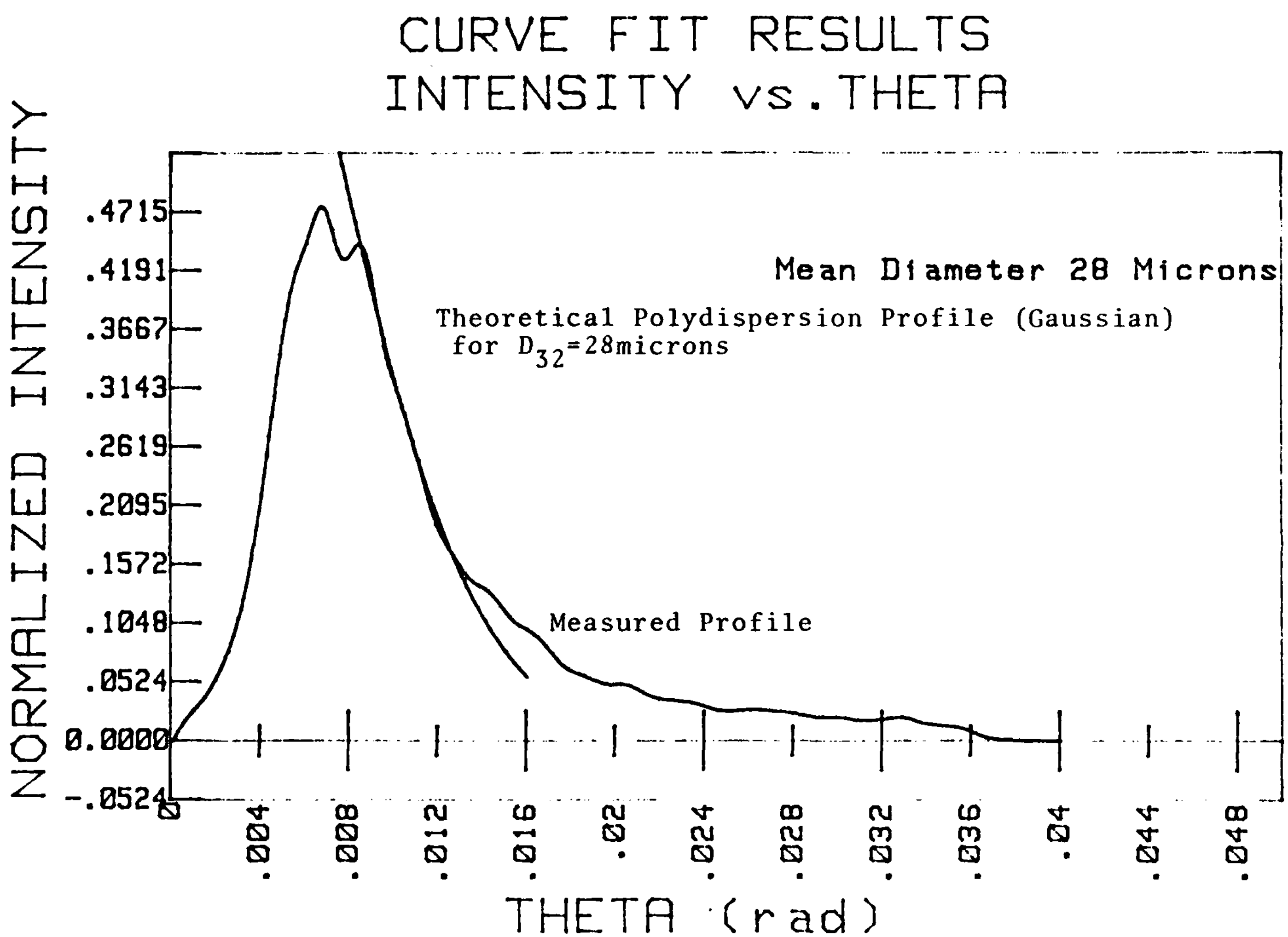


Figure 17. 25 Micron Aluminum Oxide, Low Concentration.

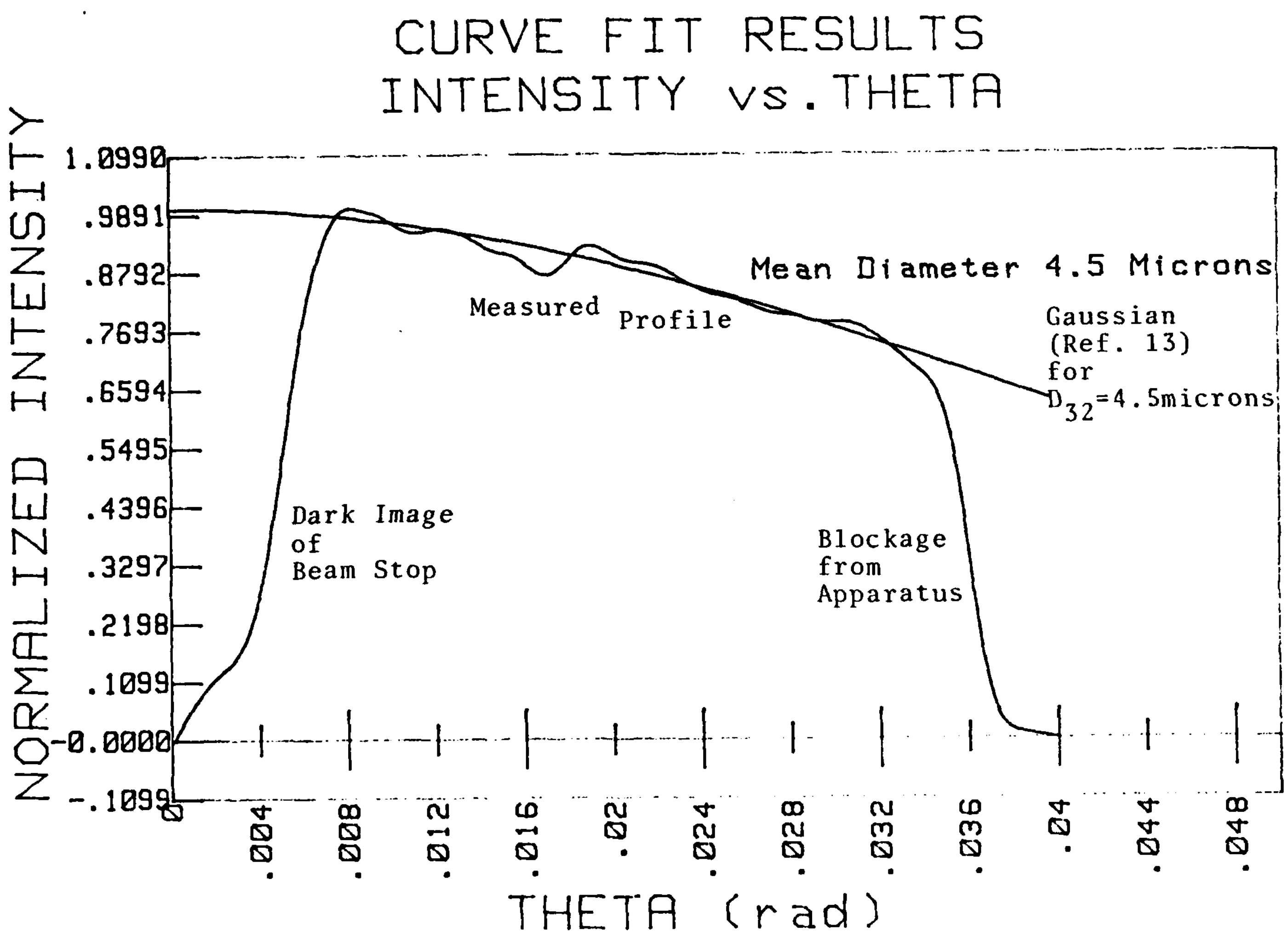


Figure 18. 5 Micron Polystyrene, Curve Fit.

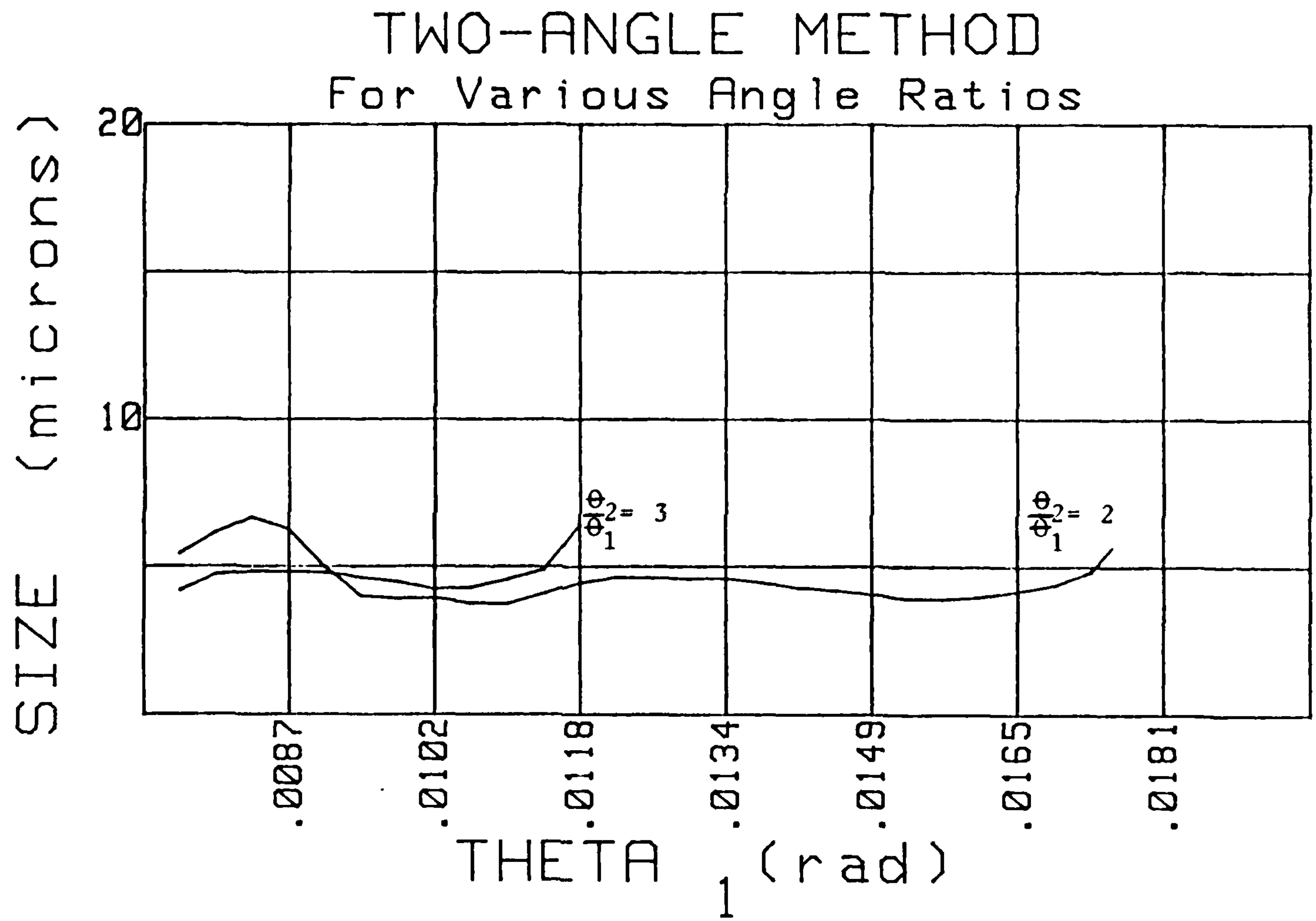


Figure 19. 5 Micron Polystyrene, Two Angle Method [Ref. 13].

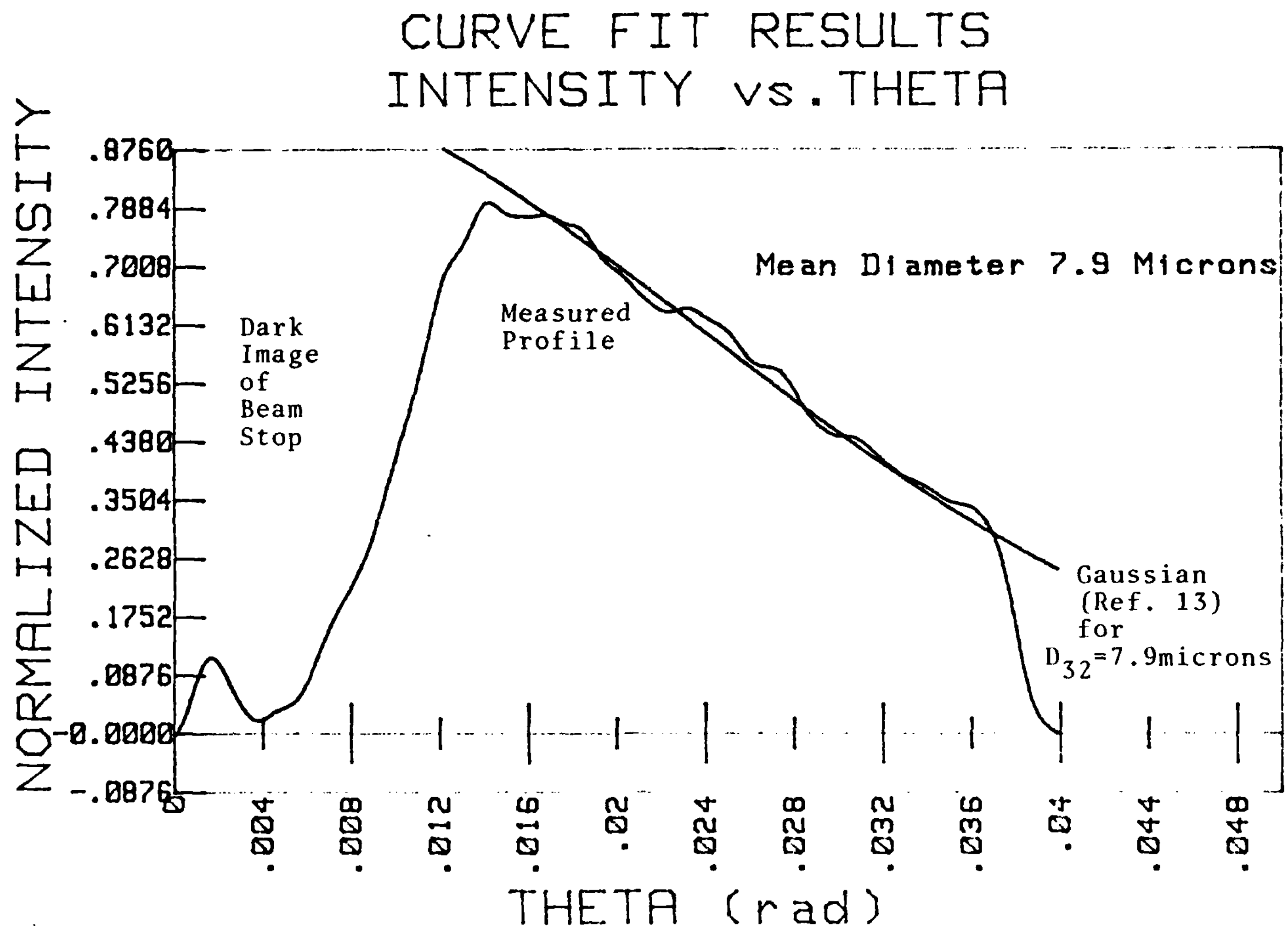


Figure 20. 10 Micron Polystyrene, Curve Fit.

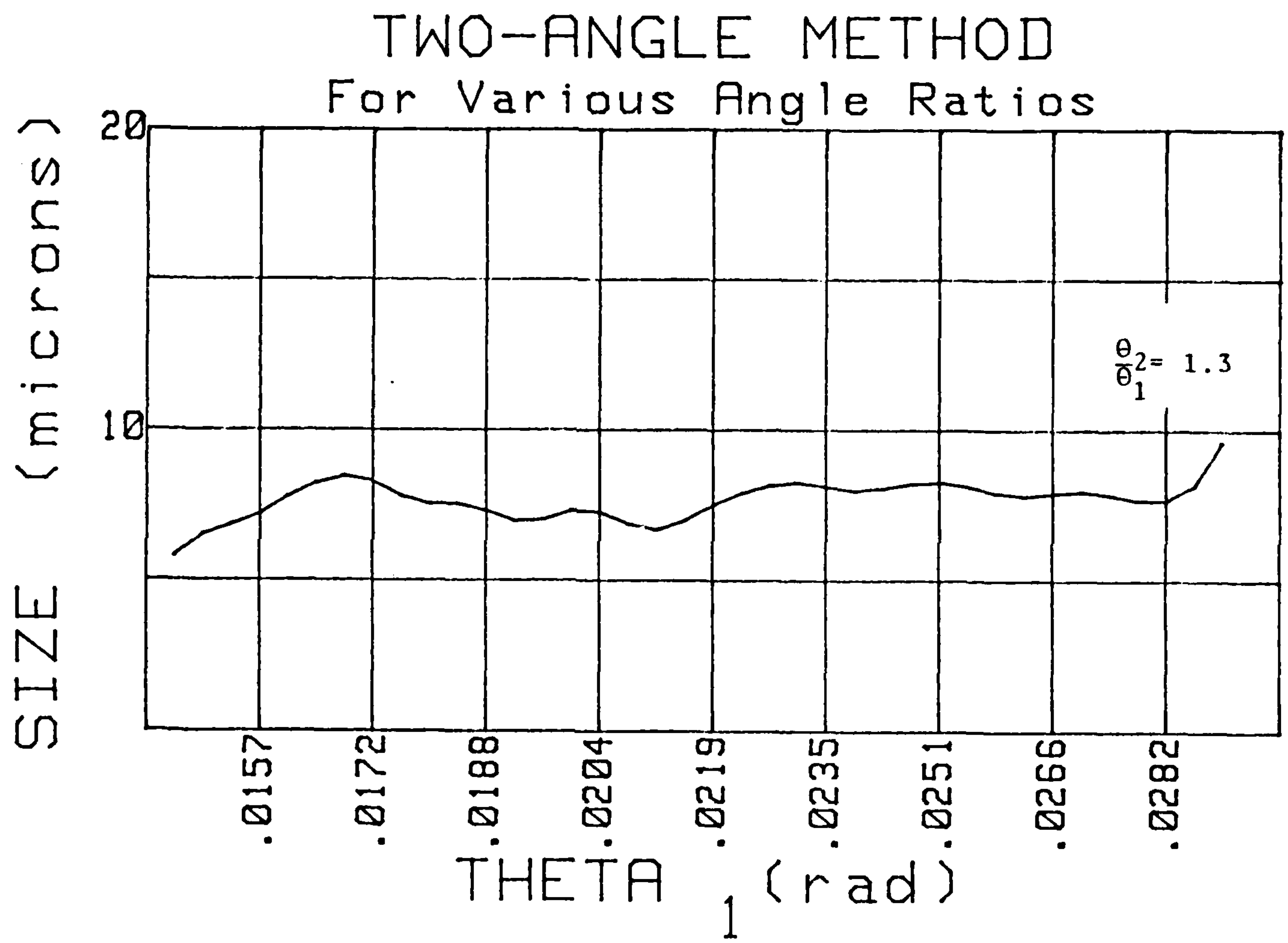


Figure 21. 10 Micron Polystyrene, Two Angle Method [Ref. 13].

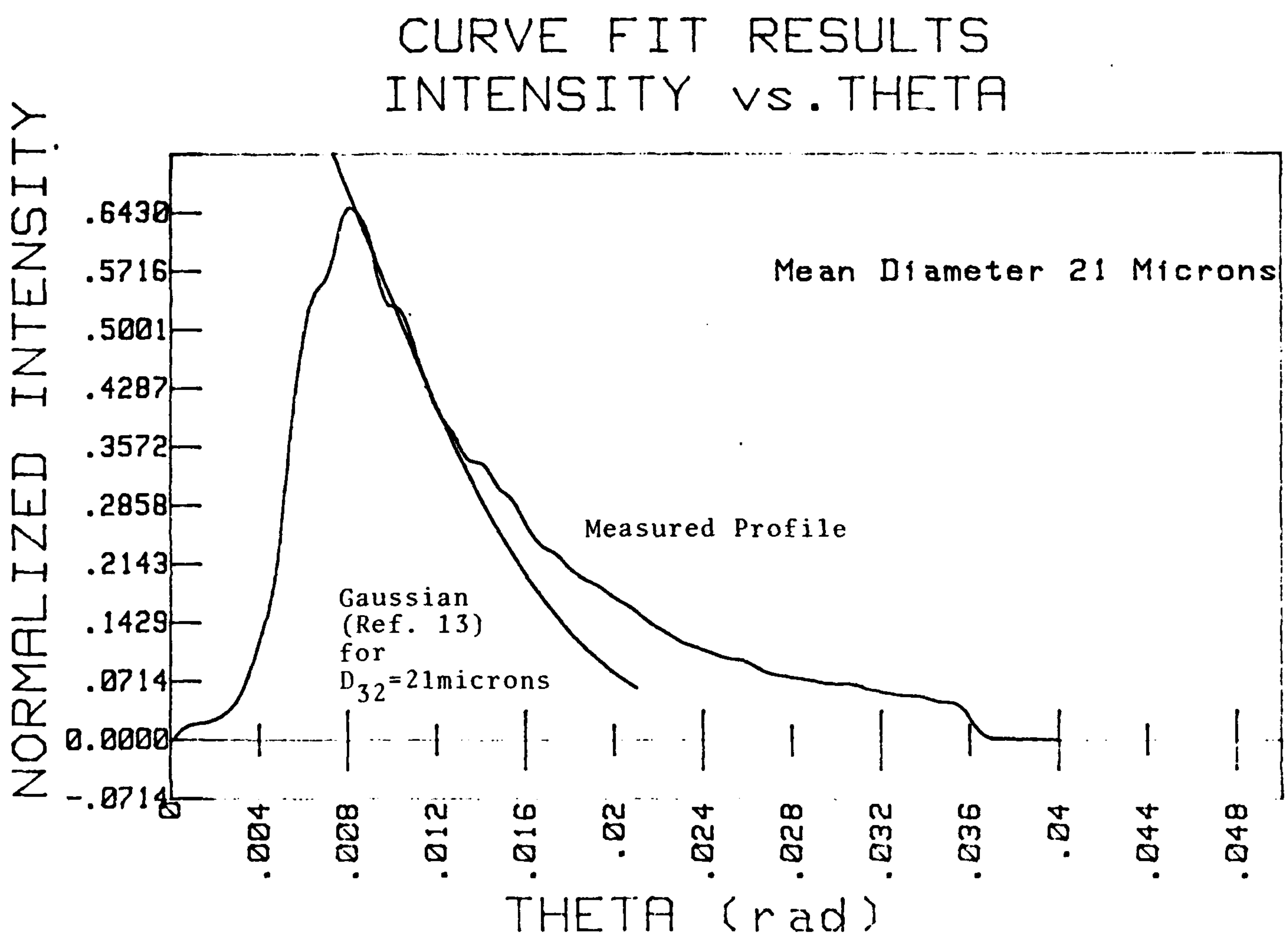


Figure 22. 20 Micron Polystyrene, Curve Fit.

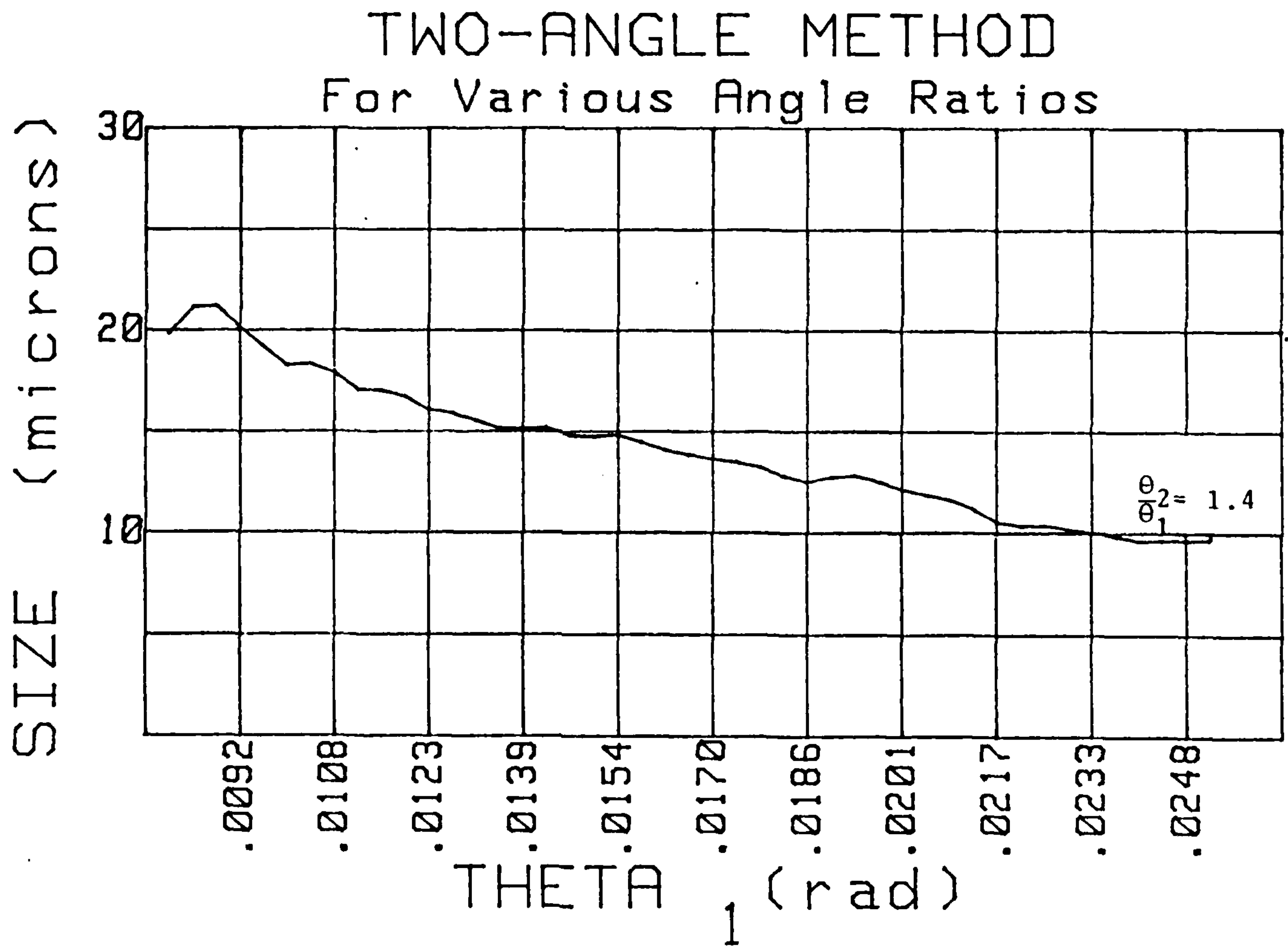
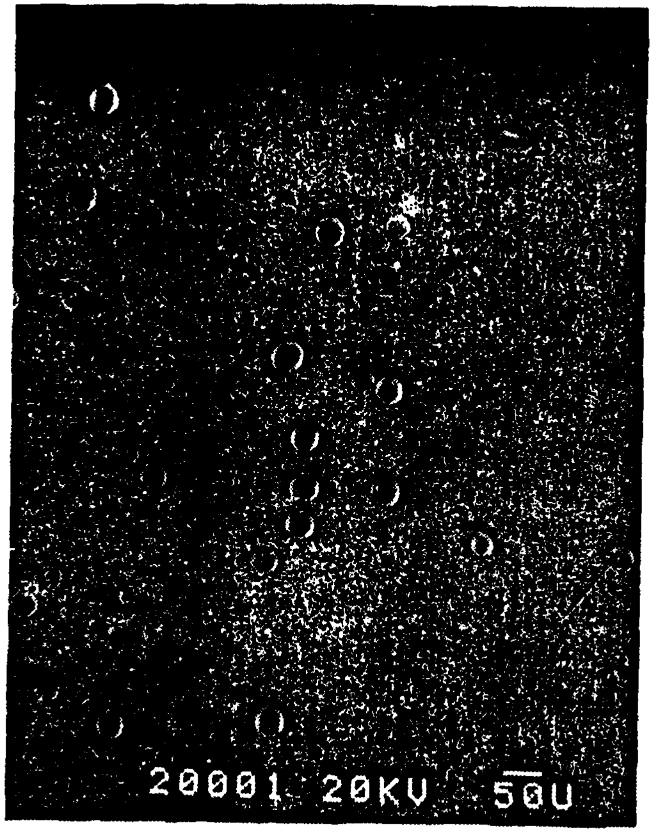


Figure 23. 20 Micron Polystyrene, Two Angle Method [Ref. 13].

25micron Aluminum Oxide

50micron Aluminum Oxide

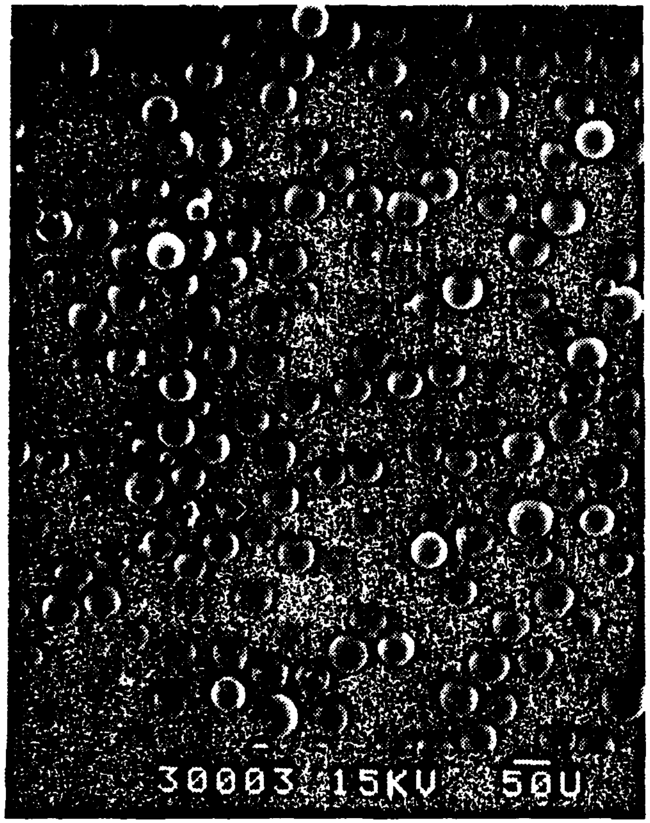
Figure 24. SEM Photographs of Aluminum Oxide.



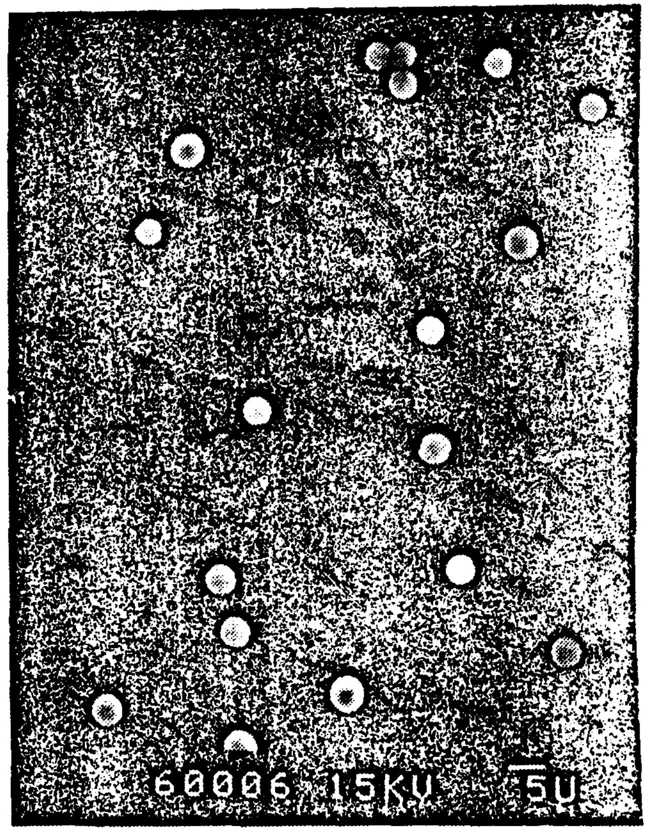
37 to 44micron Glass
D_{32} = 38

1 to 37micron Glass
D_{32} = 25

Figure 25. SEM Photographs of Glass Spheres.

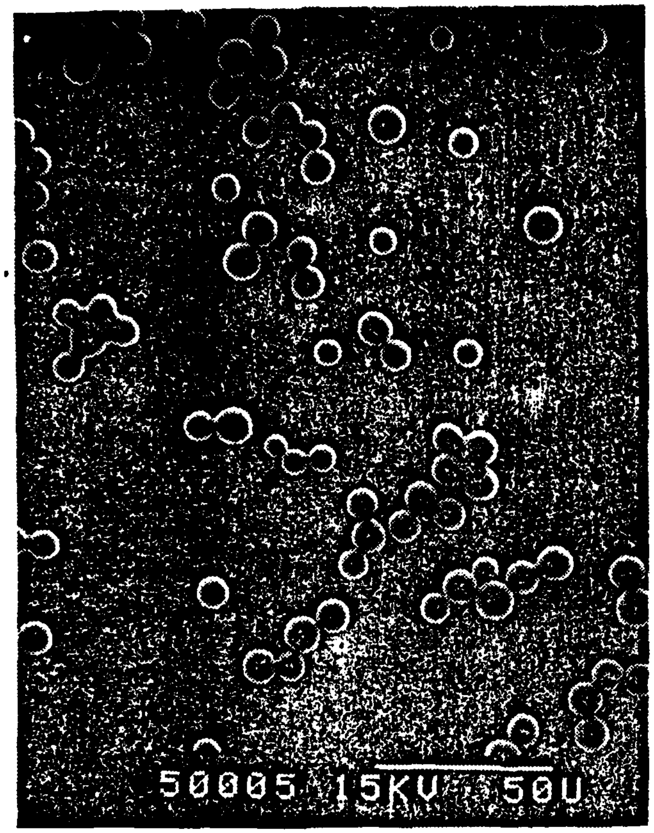


53 to 63micron Glass
D_{32} = 54

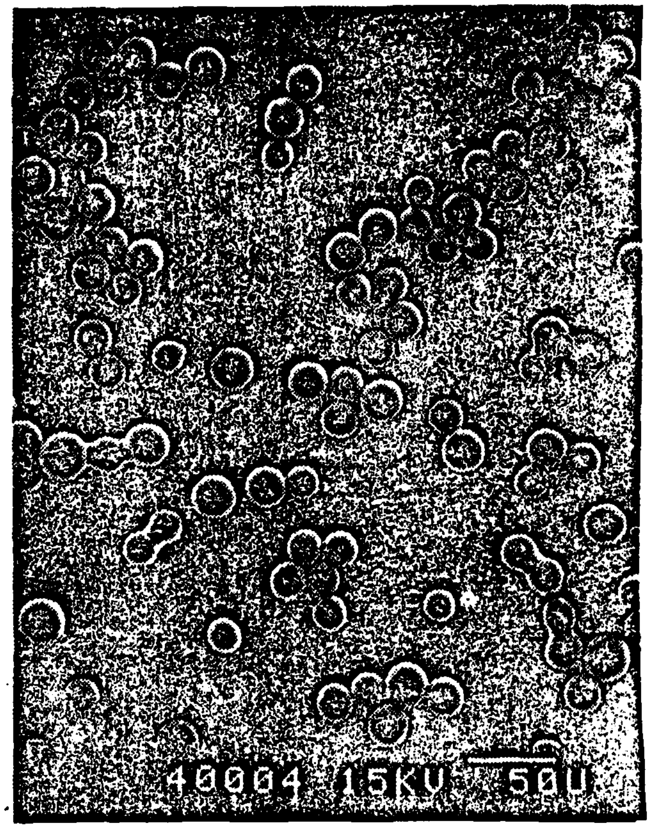


5micron Polystyrene
D_{32} = 4.7

Figure 26. SEM Photographs of Glass and Polystyrene Spheres.



10micron Polystyrene
D_{32} = 10.2



20micron Polystyrene
D_{32} = 21.6

Figure 27. SEM Photographs of Polystyrene Spheres.

APPENDIX A

PROGRAM LISTINGS

```
10   !**********          ACQDTA : FOR 9836S             ******************
20   !********** ACQUIRES MULTIPLE SCANS OF BOTH DIODE ARRAYS ****************
30   !**********          AND STORES THEM ON DISK        *****************
40   !**********  BERT HANSEN, KEN GRAHAM,KELLY HARRIS 1984   ****************
50    OPTION BASE 1
60    COM Q1$[12],Q2$[12],T1$[20],D1$[12],D2$[12],Address(4),E(4096)
70    COM A(1024) BUFFER,B(4096) BUFFER,C(4096) BUFFER,D(4096) BUFFER
80    OUTPUT 709;"AR"                                         !ANALOG RESET
90   ASSIGN @Multi10 TO 72310             !CLEARS THE WAKE-UP SERVICE REQUEST
100  ENTER @Multi10;Qq1,Qq2,Qq3,Qq4,Qq5,Qq6            !OF THE MULTIPROGRAMMER
110  MAT Address= (0)
120  ENABLE INTR 7
130   CLEAR 722
140   PRINT USING "3/"
150   PRINT "ENTER THE FILENAMES OF THE DATA FILES TO BE CREATED (e.g. RAW1,RAW2
)"
160   PRINT "                              12 CHARACTERS MAXIMUM, EACH"
170   PRINT USING "/"
180   PRINT "           AN  EMPTY  DISK  MUST  BE  IN  THE  LEFT  DISK  DRIVE "
190   PRINT ""
200   PRINT "                   THE DATA FILES WILL NEARLY FILL A DISK"
210   PRINT USING "/"
220   MASS STORAGE IS ":INTERNAL,4,0"          ! CHANGE THIS LATER IF NECESSARY
230   INPUT "           INPUT FILE NAMES NOW - (FILENAME1,FILENAME2) ",D1$,D2$
240   M5=1024
250   Zz$=":INTERNAL,4,1"                            ! STRING INDICATES MASS STORAGE
260   CREATE BDAT D1$&Zz$,6144,16    ! 12 SCANS OF 1024  @ 2*8 BYTES PER RECORD
270   CREATE BDAT D2$&Zz$,6144,16    ! 1024*12/2=NUMBER OF RECORDS=6144)
280   PRINT USING "@"
290   PRINT "       DATA WILL BE STORED ON DISKETTE WITH FOLLOWING FILE NAMES:"
300   PRINT USING "///"
310   PRINT "                    NO PARTICLES ---- FILENAME = ";D1$
320   PRINT "                    PARTICLES ------- FILENAME = ";D2$
330   PRINT USING "//"
340   PRINT "             IS THIS A CALIBRATION ?   ENTER ' Y ' IF YES "
350   PRINT "                             ANYTHING ELSE IF NO "
360   INPUT R$
370   PRINT USING "//"
380   PRINT "                               BE SURE LASER IS ON"
390   PRINT "                          PRESS [CONTINUE] WHEN READY"
400   PAUSE
```

```
410   IF R$="Y" THEN 470
420   PRINT USING "@"
430   INPUT "ENTER THE THRESHOLD PRESSURE TO TRIGGER THE DEVICES (psi)",S8
440   INPUT "ENTER TIME DELAY FROM THRESHOLD PRESSURE (sec)",T8
450   !           TIMES ARE INTERPRETED BY THE COMPUTER IN SECONDS DOWN TO .001
460   V0=S8/151.5                       ! CALIBRATION OF PRESSURE TRANSDUCER
470   D3$=D1$                           ! NO-PARTICLES STRING NAME
480   GOSUB Multiprog
490   GOSUB Storedata
500   IF R$="Y" THEN 1000
510   !*****************************************************************
520 Contcheck:                                           !Continuity checking
530   OUTPUT 709;"AC20"           !CONNECT 3456A DVM TO IGNITION FIRING LINE
540   LOCAL LOCKOUT 7         !KEEPS OPR. FROM SWITCHING FRONT PANEL TO LOCAL
550   R7=225                                         ! IN THOUSANDS OF OHMS
560   OUTPUT 722;"HSM002SW2SO1L1SOF4R1T3QX1"          !RESISTANCE MEASUREMENT
570   !   H RESETS DVM;SM002 SETS SERVICE REQUEST MASK WHERE 002 IS OCTAL REP. OF
580   !   THE SERIAL POLL MASK BYTE;SW2 TELLS WHICH TERMINAL SWITCH IS USED;SO1
590   !   SYSTEM OUTPUT MODE ON - WAITS FOR CONTROLLER TO HANDSHAKE;L1 LOAD
600   !   INTERNAL MEMORY ON;S0-FUNCTION SHIFT OFF:F4-TWO WIRE CONNECTION TO DVM
610   !   R1-AUTORANGING;T3-SINGLE TRIGGER;Q-LOAD INTERNAL MEMORY OFF;X1-EXECUTE
620   !   STORED PROGRAM.
630   GOSUB Reading
640   R8=V
650   IF R8<R7 THEN GOTO Ok
660  !*********************CONTINUITY CHECK*******************************
670   PRINT USING "@"
680   PRINT "C O N T I N U I T Y   C H E C K   B A D!!!!"
690   PRINT "RECHECK BEFORE PROCEEDING.  WHEN CHECKED, PRESS [CONTINUE]"
700   BEEP 3000,.3
710   WAIT .1
720   BEEP 100,1.0
730   PAUSE
740   GOTO Contcheck
750 Ok:PRINT USING "@"
760   DISP "                  C O N T I N U I T Y   C H E C K   IS   O.K."
770   PRINT "                             BE SURE NITROGEN IS ON"
780   OUTPUT 709;"AC21"          !CONNECT DVM FOR IGNITOR VOLTAGE MEASUREMENT
790   PRINT "                          DVM CONNECTED TO FIRE SWITCH"
800   PRINT USING "/"
810   PRINT "BE SURE VISICORDER IS SET UP TO RUN ON PROPER SCALE WITH LAMP ON."
820   PRINT USING "/"
830   OUTPUT 722;"HSM002SW2Z0SO1L1FL0.01STISOF1R1T3Q"      ! VOLTAGE ON IGNITER
840   DISP "                          STANDING BY FOR IGNITION"
850   PRINT "                         STANDING BY FOR IGNITION"
860   BEEP 2000,.1
870   OUTPUT 722;"X1"                                    !VOLTMETER TRIGGER
880   GOSUB Reading                                      !READS VOLTMETER
890   R9=ABS(V)
900   IF R9<10 THEN GOTO 870                           ! 12 VOLTS ON IGNITOR
```

```
910  O0=TIMEDATE                     ! USES COMPUTER CLOCK TO GET ELAPSED TIMES
920  OUTPUT 709;"AC22"                        ! CONNECT PRESSURE XDUCER TO DVM
930  OUTPUT 722;"X1"                          ! TRIGGER VOLTMETER
940  GOSUB Reading
950  R9=ABS(V)
960  IF R9<V0 THEN GOTO 930                                 ! THRESHOLD PRESSURE
970  WAIT T8                                                ! TIME DELAY
980  O1=TIMEDATE
990  IF R$<>"Y" THEN 1060                   !IF ACTUAL RUN THEN SKIP SOME LINES
1000 !                 FOR CALIBRATIONS INTRODUCE PARTICLES AND THEN CONTINUE
1010 PRINT CHR$(12)
1020 PRINT USING "////////"
1030 PRINT "                 INTRODUCE PARTICLES THEN PRESS KEY # 9 TO TAKE DATA"
1040 ON KEY 9 LABEL "  TAKE DATA" GOTO 1060
1050 Standby: GOTO Standby
1060 GOSUB Multiprog                                       ! TAKE PARTICLE DATA
1070 LOCAL 7
1080 D3$=D2$                                             !PARTICLE DATA FILE NAME
1090 GOSUB Storedata
1100 PRINT "          ELAPSED TIME:      FIRE TO MULTIPROGRAMMER CALL = ";O1-O0
1110 PRINT "          ELAPSED TIME:      FIRE TO MEMORY INTERRUPT     = ";O2-O0
1120 PRINT "        DATA STORED ON DISK WITH FILENAMES (";D1$;") AND (";D2$;")"
1130 GOTO End
1140 Multiprog: !
1150 OUTPUT 723;"CC,2,3,12,13T"
1160 OUTPUT 723;"CC,5,6,9,10T"  !CLEARS THE ARM,BUSY AND EOP OF MEMORY CARDS
1170 OUTPUT 723;"CC,1,4,11T"    !CLEARS SAME FOR A TO D'S AND TIMER PACER
1180 OUTPUT 723;"SF,2,3,1,.001,12,T"      ! THE (1) IS 2'S COMPLIMENT BINARY
1190 OUTPUT 723;"SF,5,3,1,.001,12,T"  ! THE .001 IS THE LEAST SIGNIFICANT BIT
1200 OUTPUT 723;"SF,9,3,1,.001,12,T"  ! THE 12 IS FOR 12 BIT WORD SIZE
1210 OUTPUT 723;"SF,12,3,1,.001,12,T" ! SINCE THE A TO D IS 12 BIT
1220 OUTPUT 723;"WF,3,1023T,WF,6,4095T"
1230 OUTPUT 723;"WF,10,4095T,WF,13,4095T"
1240 !  SETS REFERENCE WORD FOR WHEN TO STOP TAKING DATA AND GENERATE INTERRUPT
1250 OUTPUT 723;"WF,2.1,1T,WF,5.1,1T,WF,9.1,1T,WF,12.1,1T"      !SETS FIFO MODE
1260 OUTPUT 723;"WF,3.1,0T,WF,3.2,0T,WF,3.3,0T,WF,13.1,0T,WF,13.2,0T,WF,13.3,0T
"

1270 OUTPUT 723;"WF,6.1,0T,WF,6.2,0T,WF,6.3,0T,WF,10.1,0T,WF,10.2,0T,WF,10.3,0T
"

1280           ! SETS COUNTER AND POINTERS OF 2ND MEMORY CARD IN EACH PAIR TO 0
1290 OUTPUT 723;"AC,3T,AC,6T,AC,10T,AC,13T"!ARMS CARDS WHICH GENERATE INTERRUPT
1300 OUTPUT 723;"WF,4.2,0T,WF,4,1ST"  ! TIMER PACER GIVES 1 PULSE OF 1 SEC WHEN
1310           ! TRIGGERED  BY THE BLANKING PULSE (PLENTY OF TIME FOR 8 SCANS)
1320 WAIT 2
1330 K=SPOLL(723)                                      !WAIT FOR MEM INTERRUPT
1340 IF K<>64 THEN GOTO 1330
1350 OUTPUT 723;"WF,4.2,1T"    ! MAY BE UNNECESSARY TO ALTER TIMER  PACER SINCE
1360 !          MEMORY CARDS HAVE AUTOMATIC LOCKOUT BUT FOR NOW WE WILL DO IT
1370 O2=TIMEDATE
1380 ON ERROR GOTO Err_trap          ! NEEDED TO READ ARMED CARD INTERRUPT LIST
1390 SEND 7;UNL MLA TALK 23 SEC 12   ! SPECIFICALLY ASKS FOR INTERRUPT LIST
```

```
1400 Var_read:   ENTER 7,Address(*)                  !READ WHICH CARDS INTERRUPTED
1410 Memcards:  PRINT "            MEMORY CARDS WHICH GENERATED INTERRUPTS ARE "
1420  PRINT "                             SLOTS$ = ";Address(*)
1430  MAT Address= (0)
1440  OFF ERROR
1450  OUTPUT 723;"DC,3,6,13,10T"                              !DISSARM MEM CARDS
1460  OUTPUT 723;"MI,2,1024T"                           ! SET UP CARD TO BE READ
1470  ENTER 72305;A(*)                          ! GETS DATA FROM 1024 MEMORY BOARD
1480  OUTPUT 723;"MI,5,4096T"
1490  ENTER 72305;B(*)                          ! GETS DATA FROM 4096 MEMORY BOARD
1500  PRINT "                   EXHAUST   DATA ENTERED"
1510  OUTPUT 723;"MI,12,4096T"
1520  ENTER 72305;C(*)
1530  OUTPUT 723;"MI,9,4096T"
1540  ENTER 72305;D(*)
1550  ENABLE INTR 7;8
1560  PRINT "                   MOTOR     DATA ENTERED"
1570  MAT A= (-1)*A        ! THE 1024 CARD IS INCLUDED BUT NOT SAVED. IT DIDN'T
1580  MAT B= (-1)*B        ! PERFORM WELL. COULD BE REPLACED BY A 4096 CARD.
1590  MAT C= (-1)*C
1600  MAT D= (-1)*D        ! DIODE VOLTAGES ARE NEGATIVE SO SIGNS ARE CHANGED
1610  RETURN
1620 Storedata:!
1630  ASSIGN @Diskfile TO D3$&Zz$
1640  ASSIGN @Buff1 TO BUFFER C(*)                      ! MOTOR CAVITY 4 SCANS
1650  ASSIGN @Buff2 TO BUFFER D(*)                      ! MOTOR CAVITY 4 SCANS
1660  ASSIGN @Buff3 TO BUFFER B(*)                      ! EXHAUST      4 SCANS
1670  CONTROL @Buff1,3;1,32768,1                 !SETS BUFFER POINTERS TO FULL
1680  CONTROL @Buff2,3;1,32767,1                !INTERFACE REGISTERS SECTION OF
1690  CONTROL @Buff3,3;1,32767,1                               !LANGUAGE MANUAL
1700  TRANSFER @Buff1 TO @Diskfile               ! ORDER OF DATA ON THE DISK IS
1710  WAIT FOR EOT @Diskfile                            ! MOTOR CAVITY--8 SCANS
1720  TRANSFER @Buff2 TO @Diskfile                      ! EXHAUST    -- 4 SCANS
1730  WAIT FOR EOT @Diskfile                         !WAIT BECAUSE OVERLAPPING
1740  TRANSFER @Buff3 TO @Diskfile                     !TRANSFERS ARE NOT WANTED
1750  WAIT FOR EOT @Diskfile
1760  ASSIGN @Diskfile TO *                                  !CLOSE I / O PATHS
1770  ASSIGN @Buff1 TO *
1780  ASSIGN @Buff2 TO *
1790  ASSIGN @Buff3 TO *
1800  RETURN
1810 Reading:!
1820  STATUS 7,1;A0                           !CHECKING STATUS BEFORE READING
1830  ENTER 722;V                             !VOLTMETER IS A FORMALITY TO
1840  ENABLE INTR 7;8                         !CLEAR THE SERVICE REQUEST
1850  RETURN
1860 Err_trap:  IF ERRN=159 AND ERRL(Var_read) THEN Memcards
1870  PRINT ERRM$                     !EVEN IF THE ERROR WAS NOT THE ONE PLANNED
1880  GOTO Memcards                   !FOR PROGRAM EXECUTION CONTINUES
1890 End: END
```

```
10    !*****************************************************************
20    !******************         RDC            ******************
30    !******************      PLOTS RAW DATA     ******************
40    !******************        AVERAGES         ******************
50    !******************         FILTERS         ******************
60    !****************** DETERMINES MEAN DIAMETER ******************
70    !****************** BY INTERACTIVE GRAPHICS ******************
80    !****************** AND THE TWO-ANGLE METHOD ******************
90    !******************   Robert Kelly Harris   ******************
100   !******************          1984           ******************
110   !*****************************************************************
120   OPTION BASE 1
130   COM /Hrdgaus/ Av2(1024)
140   COM /Gauss/ T1(1024),G(1024),L
150   COM /Max/ M7,M5,Xt,Yt,Xm,Ym
160   COM /Readata/ B,P,H,Q3$[20],Q4$[20],Zz$[20],Y1(8192) BUFFER,Y2(8192) BUFFE
R
170   COM /Two/ Av1(1024),M,M1,F
180   DIM Scans(8),X(1024)
190   COM /Plots/ P1$[20],P2$[20],P3$[20],P4$[20]
200   INTEGER Graf(1:12480) BUFFER
210 Choose:  PRINT CHR$(12)
220   Old=0
230   PRINT " TO LOOK AT ANY DATA FILE THE PROGRAM NEEDS SOME STARTING INFORMATI
ON"
240   PRINT ""
250   PRINT "       TO ACCOUNT FOR THE CHANGE IN WAVELENGTH IN THE MEDIUM"
260   PRINT ""
270   PRINT "            ENTER THE INDEX OF REFRACTION OF THE MEDIUM"
280   PRINT ""
290   PRINT "                          WATER = 1.33"
300   PRINT "                            AIR = 1.0"
310   PRINT "               ESTIMATE OF EXHAUST = 1.1"
320   BEEP
330   INPUT "       THIS VALUE ADJUSTS THE COMPARISON CURVE TO THE MEDIUM",M1
340   PRINT CHR$(12)
350   PRINT "    TO ACCOUNT FOR REFRACTION OF LIGHT AT BOUNDARIES BETWEEN"
360   PRINT ""
370   PRINT " THE MEDIUM AND AIR YOU MUST ENTER THE INDEX OF REFRACTION    "
380   PRINT ""
```

```
390  PRINT "     OF THE COMBINATION OF THE MEDIUM AND ITS BOUNDARY"
400  PRINT ""
410  PRINT "          THIS VALUE IS APPLIED DIRECTLY TO THE DATA"
420  PRINT ""
430  PRINT "            AIR=1.0              PLEXIGLASS & WATER = 1.39"
440  PRINT ""
450  PRINT "ESTIMATE OF  MOTOR CAVITY COMBUSTION PRODUCTS & WINDOW = 1.22"
460  PRINT ""
470  PRINT "                  ESTIMATE OF ROCKET EXHAUST  = 1.1 OR 1.0"
480  INPUT M
490  PRINT CHR$(12)
500  INPUT "               ENTER LASER WAVELENGTH (HeNe=.6328,Ar=.488)",L
510  INPUT "ENTER THE DESIRED PLOTTING INTERVAL OF DIODE ARRAY (2,4,6)",H
520  F=460                               !mm  FOCUL LENGTH OF OBJECTIVE LENS
530  Diod=.025                           !mm  DIODE SPACING MAY BE .03
540      FOR I=0 TO 1023
550      X(I+1)=I+1                       !CREATE AN ARRAY OF DIODE NUMBERS
560      T1(I+1)=(I*Diod)/(F*M)           !CREATE AN ARRAY OF THETA
570      NEXT I
580  PRINT CHR$(12)
590  CALL Display1(Old)                  !JUST PRINTS INITIAL REMARKS ON CRT
600  IF Old THEN CALL Review(Av1(*))     !THESE TWO LINES ALLOW FOR
610  IF Old THEN GOTO Gauss              !REVIEWING REDUCED DATA FILES
620  BEEP
630  INPUT "            INPUT TWO FILENAMES NOW (NO-PART ,PART)",Q3$,Q4$
640  INPUT "       ENTER '1' FOR MOTOR      '2' FOR EXHAUST",P
650  Zz$=":INTERNAL,4,1"            ! USES LEFT DISK DRIVE FOR RAW DATA FILES
660  CALL Readata
670  CALL Shift
680  BEEP
690 Screen:  !
700  PRINT CHR$(12)                       !CLEARS SCREEN
710  P1$="VOLTAGE"
720  P2$="DIODE NUMBER"                   ! STRINGS FOR PLOTS
730  P3$="VOLTAGE vs. DIODE"
740  P4$="RAW  DATA"
750  M5=1024
760  Xt=64                                ! SET UP VALUES FOR PLOTS
770  Yt=.04
780  Xm=4
790  Ym=5
800  CALL Plot(Y2(*))                     ! DRAWS AXES ,ETC...
810  GSTORE Graf(*)                       ! STORES GRAPHICS DISLAY JUST MADE
820  CALL Dataplot(B,Y1(*),H)            !PLOT NO-PARTICLES DATA
830  PRINT "                                NO-PARTICLES PLOTTED"
840  PRINT ""
850  PRINT "                                  HOW MANY SCANS SEEM TO BE GOOD ?"
860  INPUT J
```

```
870  PRINT ""
880  PRINT "          WHICH SCANS ARE GOOD ?...ie...1,2,4,5,7,INCLUDE LAST CO
MMA"                  !LAST COMMA IS REQUIRED OR YOU HAVE TO HIT CONT.. TWICE
890  INPUT Scans(*)
900  PRINT CHR$(12)
910  PRINT USING "/////////"
920  PRINT "                         AVERAGING THE SELECTED SCANS"
930  GRAPHICS OFF
940  CALL Average(J,Scans(*),Y1(*),Av1(*))
950  PRINT USING "@"
960  GLOAD Graf(*)     !LOADS GRAPHICS ARRAY RATHER THAN WASTE TIME RE-DRAWING
970  GRAPHICS ON
980  CALL Result(Av1(*),X(*),H)                    ! PLOTS 1024 ELEMENT ARRAYS
990  PRINT USING "//"
1000 PRINT "                         Average Intensity No-Particles"
1010 ON KEY 0 LABEL "AVERAGE1" GOTO Screen
1020 ON KEY 1 LABEL "PLOT-PARTICLES" GOTO 1060
1030 PRINT "               PRESS KEY # 0 TO RE-AVERAGE OR # 1 TO CONTINUE"
1040 Standby:             ! MANUAL CALLS THIS INTERRUPT DRIVEN PROGRAMMING
1050      GOTO Standby                  ! LOOPS, WAITING FOR USER TO DECIDE
1060 PRINT USING "@"
1070 OFF KEY 1                   !HELPS AVOID CONFUSION BY CLEARING THAT BOX
1080 CALL Dataplot(B,Y2(*),H)                           !PLOT PARTICLES DATA
1090 PRINT USING "/"
1100 PRINT "                                       PARTICLE DATA PLOTTED"
1110 PRINT "       FOR A HARD COPY OF THIS RAW DATA PRESS KEY # 6"
1120 PRINT " "
1130 PRINT "                     OR    TO CONTINUE PRESS KEY # 1"
1140 ON KEY 6 LABEL "HARD & RAW" GOTO Raw
1150 ON KEY 1 LABEL "CONTINUE " GOTO Select
1160 GOTO Standby
1170 Raw:  CALL Plot(Y2(*),1)          ! THE ONE (1) IS AN OPTIONAL PARAMETER
1180       CALL Dataplot(B,Y2(*),H)     ! WHICH IS USED TO GET HARD COPIES
1190 Select:!
1200       OFF KEY 6
1210       OFF KEY 1
1220 PRINT CHR$(12)
1230 PRINT USING "////"
1240 PRINT "                              HOW MANY SCANS SEEM TO BE GOOD ?"
1250 INPUT J
1260 PRINT "               WHICH SCANS ARE GOOD ?...ie...1,2,4,5,7,INCLUDE
 LAST COMMA"
1270 INPUT Scans(*)
1280 PRINT CHR$(12)
1290 PRINT USING "/////////"
1300 GRAPHICS OFF
1310 PRINT "                         AVERAGING THE SELECTED SCANS"
1320 CALL Average(J,Scans(*),Y2(*),Av2(*))
1330 PRINT USING "@"
1340 P4$="AVERAGED SCANS"
```

```
1350  CALL Plot(Av2(*))
1360  GRAPHICS ON
1370  GSTORE Graf(*)
1380  CALL Result(Av2(*),X(*),H)
1390  PRINT USING "//"
1400  PRINT "                              Average Scattered Intensity"
1410  ON KEY 2 LABEL "AVERAGE2" GOTO 1080
1420  ON KEY 3 LABEL "SUBTRACT" GOTO 1450
1430  PRINT "                    HIT KEY # 2 TO RE-AVERAGE OR KEY # 3 TO
CONTINUE"
1440  GOTO Standby
1450  PRINT USING "@"
1460  OFF KEY 3
1470  MAT Av1= Av2-Av1                  !SUBTRACTS NO-PARTICLES FROM PARTICLES
1480  GLOAD Graf(*)
1490  CALL Result(Av1(*),X(*),H)
1500  PRINT USING "///"
1510  PRINT "                Plot of the Difference Between Particles and N
o-Particles"
1520  PRINT "                                    KEY # 6 FOR HARD COPY"
1530  PRINT "                                    KEY # 1 TO CONTINUE "
1540  ON KEY 6 LABEL "  HARD AVERAGE" GOTO 1570
1550  ON KEY 1 LABEL "    FILTER   " GOTO 1600
1560  GOTO Standby
1570  CALL Plot(Av1(*),1)
1580  CALL Result(Av1(*),X(*),H)
1590  PLOTTER IS 3,"INTERNAL"
1600  PRINT USING "//"
1610  PRINT "                 ENTER THE NUMBER OF TIMES YOU WISH TO APPLY"
1620  PRINT "                     THE DIGITAL FILTER FOR SMOOTHING"
1630  PRINT "                          EXAMPLE******** 10"
1640  PRINT "                        TAKES ABOUT 1.5 MINUTES"
1650  INPUT "                        ZERO IS ALSO ACCEPTABLE",Fil
1660  IF Fil=0 THEN Gauss
1670  P4$="FILTERED DATA"
1680  CALL Filter(Av1(*),Fil)
1690  PRINT CHR$(12)
1700  CALL Plot(Av1(*))
1710  IF Old THEN MAT X= T1
1720  CALL Result(Av1(*),X(*),H)
1730  PRINT "                Plot of the Difference Between Particles and N
o-Particles"
1740  PRINT "                         AFTER APPLICATION OF A DIGITAL FIL
TER"
1750  PRINT "                                   for a HARD COPY  "
1760  PRINT "                                 PREPARE the PLOTTER and"
1770  PRINT "                                     PRESS KEY # 8"
1780  PRINT "                                          OR"
1790  PRINT "                               PRESS KEY # 9 TO NORMALIZE"
1800  ON KEY 8 LABEL "HARD FILTERED" GOTO 1830
1810  ON KEY 9 LABEL "  NORMALIZE  " GOTO Gauss
```

```
1820  GOTO Standby
1830  CALL Plot(Av1(*),1)                              ! The 1 is for hard copy
1840  CALL Result(Av1(*),X(*),H)
1850  OFF KEY 8
1860 Gauss: OFF KEY 2                          !KEY 1 OPTION IS STILL VALID
1870        OFF KEY 8
1880  ON KEY 1 LABEL "    FILTER  " GOTO 1600 ! ALLOWS ONE TO SMOOTH OLD DATA
1890                                          ! WHEN REVIEWING REDUCED FILES
1900        PRINT CHR$(12)
1910  !Av2 Array is Normalized BUT  Av1(*) is Still Saved For Re-work if Needed
1920  MAT Av2= Av1   ! TO BEGIN WITH THE ARRAY IS ASSUMED TO BE NORMALIZED
1930                 ! AND THE USER CHANGES THIS WITH INTERACTIVE GRAPHICS
1940                 ! IN THE SUBROUTINE "Compare"
1950  P1$="NORMALIZED INTENSITY"
1960  P2$="THETA (rad)"                                 !STRINGS FOR PLOTS
1970  P3$="INTENSITY vs.THETA"
1980  P4$="CURVE FIT RESULTS"
1990  M5=.05                                           !SET UP VALUES
2000  Xt=.004                                          !FOR PLOTS
2010  Yt=.1
2020  Xm=2
2030  Ym=2
2040  CALL Plot(Av2(*))
2050  CALL Result(Av2(*),T1(*),H)       !PLOT OF NORMALIZED INTENSITY vs. THETA
2060  GSTORE Graf(*)                    ! SAVES THE SCREEN IMAGE
2070  CALL Compare(Av1(*),H,M,M1,Graf(*))
2080   GRAPHICS OFF
2090   ON KEY 4 LABEL "OTHER  ARRAY" GOTO Choose
2100   ON KEY 5 LABEL " TWO-ANGLE" GOTO Buchele
2110   ON KEY 9 LABEL " NORMALIZE" GOTO Gauss
2120   ON KEY 6 LABEL "STORE DATA" GOTO Storedata
2130   ON KEY 7 LABEL "   QUIT   " GOTO Quit
2140   CALL Menue1                              ! PRINTS OPTIONS ON THE SCREEN
2150   GOTO Standby
2160 Buchele:  !
2170   CALL Twoangle
2180   CALL Menue1
2190   GOTO Standby
2200 Storedata:!
2210   CALL Store
2220   CALL Menue1
2230   GOTO Standby
2240 Quit:  !
2250  END
2260       SUB Average(J,Scans(*),Y(*),Av(*))  !AVERAGES SELECTED SCANS
2270       MAT Av= (0)          !INITIALIZES THE ARRAY LOCAL TO THIS ROUTINE
2280            FOR I=1 TO J STEP 1
2290            K=(Scans(I)-1)*1024+1         ! THIS COUNTER IS THE BEGINNING
2300            L=Scans(I)*1024               ! AND THIS ONE THE END OF BLOCKS
2310                 FOR I1=K TO L            ! OF 1024 IN THE OVERALL DATA
```

```
2320              I2=I1-K+1                  ! THIS COUNTER IS ALWAYS BETWEEN
2330              Av(I2)=Av(I2)+Y(I1)        ! 1 AND 1024
2340              NEXT I1
2350          NEXT I
2360      MAT Av= Av/(J)                     !*****THE AVERAGE*****!
2370      SUBEND
2380  SUB Dataplot(B,Y(*),H)                 !B IS 4 OR 8(THE NUMBER OF SCANS)
2390  COM /Max/ M7,M5,Xt,Yt,Xm,Ym
2400  LDIR 0
2410  LORG 4
2420      FOR J=1 TO B                       !EACH SCAN
2430      MOVE 500+J*50,M7-.05               ! SEE NEXT LINE
2440      LABEL J;               ! HELPS KEEP TRACK OF EACH SCAN AS IT APPEARS
2450      LINE TYPE 1
2460      K=(J-1)*1024+1                     !BEGINNING OF EACH SCAN AND
2470      L=J*1024                           !THE END WITHIN THE TOTAL BLOCK
2480      MOVE 1,Y(K)                        ! MOVE TO THE FIRST POINT
2490           FOR I=K TO L STEP H
2500           X=I-K+1                       ! THIS GIVES 1 TO 1024 FOR ABSCISSA
2510           PLOT X,Y(I)
2520           NEXT I
2530      NEXT J
2540      PENUP
2550  SUBEND
2560     SUB Result(Iav(*),D(*),H)           !THE AVERAGE INTENSITY IS PLOTTED
2570     CLIP ON
2580     MOVE D(1),Iav(1)
2590          FOR I=1 TO 1024 STEP H
2600          DRAW D(I),Iav(I)
2610          NEXT I
2620          PENUP
2630     SUBEND
2640  SUB Plot(Y(*),OPTIONAL Hard)           !IF THE OPTIONAL(Hard)IS RECEIVED
2650  COM /Max/ M7,M5,Xt,Yt,Xm,Ym            !THE FIGURE GOES TO THE PLOTTER
2660  COM /Plots/ P1$[20],P2$[20],P3$[20],P4$[20]
2670  M7=MAX(Y(*))*1.1                       ! A SCALING VARIABLE
2680  M6=.1*M7                               ! ANOTHER SCALING VARIABLE
2690  PRINT ""
2700  GINIT                          !GINIT IS JUST GOOD PRACTICE SO YOU KNOW
2710                                 !WHERE YOU ARE BEGINNING
2720  SELECT NPAR                    !THIS DETECTS IF THE HARD COPY IS DESIRED
2730  CASE 1                         !IT COULD BE DONE WITH IF THEN LOGIC
2740     PLOTTER IS 3,"INTERNAL"     !BUT IS PRESENTED FOR FAMILIARIZATION
2750  CASE 2                         !SINCE IT IS MORE POWERFUL IN COMPLEX
2760     PLOTTER IS 705,"HPGL"       !SITUATIONS
2770 END SELECT
2780 GRAPHICS ON                                 ! TO BE ABLE TO SEE THE PLOT
2790 CSIZE 5,.6
2800 DEG
2810 LDIR 0
```

```
2820 LORG 5
2830 MOVE 75,95
2840 LABEL USING "K";P4$
2850 MOVE 75,90
2860 LABEL P3$
2870 MOVE 75,20
2880 LABEL P2$
2890 LDIR 90
2900 MOVE 18,60
2910 LABEL P1$
2920 VIEWPORT 30,125,30,85                         ! SCREEN UNITS FOR MARGINS
2930 FRAME                                         ! DRAWS A BOX
2940 WINDOW 0,M5,-M6,M7                            ! EXTENT OF X AND Y
2950 AXES Xt,M6,0,0,Xm,1,5
2960 LDIR 0
2970 CSIZE 3,.5
2980 LORG 8
2990 CLIP OFF
3000      FOR I=-M6 TO M7 STEP M7/10               !NUMBER THE Y AXIS
3010      MOVE 0,I
3020      LABEL USING "#,MD.DDDD";I
3030      NEXT I
3040 CSIZE 3,.6
3050 LDIR 90
3060      LORG 8
3070      FOR I=0 TO M5 STEP Xt                    !NUMBER THE X AXIS
3080      MOVE I,-M6
3090      LABEL USING "#,K";I
3100      NEXT I
3110      PENUP
3120 SUBEND
3130      SUB Compare(Av1(*),H,M,M1,INTEGER Graf(*))
3140      COM /Gauss/ T1(*),G(*),L
3150      COM /Hrdgaus/ Av2(*)
3160      COM /Max/ M7,M5,Xt,Yt,Xm,Ym
3170      DIM T(1:1024),At(1:17),Dobbins(1:17),T1d(1:17)
3180      DATA 3.,3.5,4.,4.5,5.,5.5,6.,6.5,7.,7.5,8.,8.5,9.,9.5,10.,10.5,11.
3190      DATA .0556,.035,.0206,.014,.0106,.0081,.00605,.005,.00374,.0032,.00248,
.0022,.00185,.0016,.00135,.0012,.001
3200      READ At(*)
3210      READ Dobbins(*)
3220           OFF KEY                       !GETS RID OF ALL LABELS ON KEYS
3230           ON KEY 3 LABEL "MENUE" GOTO Subexit
3240           PLOTTER IS 3,"INTERNAL"      ! IN CASE A HARD COPY WAS JUST MADE
3250           Hard=0                      ! (0) SO ONE DOESN'T EXIT TOO SOON
3260           Centerline=1                    ! THE INITIAL NORMALIZING VALUE
3270           D=20.               ! INITIAL PATICLE MEAN DIAMETER IN MICRONS
3280 Change:  CSIZE 4,.6
3290           PRINT USING "//////"
```

```
3300         PRINT "                                        STAND BY FOR CURVE"
3310         MOVE 0,1
3320         CLIP ON
3330         Con=PI*D*M1/L                  !A CONSTANT
3340         FOR I=1 TO 1024 STEP H
3350         T(I)=T1(I)*Con                 !Theta-bar for some Dbar(note M1)
3360         G(I)=EXP(-((.57*T(I))^2))         !Gaussian curve for this Dbar
3370         IF T(I)>3.0 THEN 3400          !GAUSSIAN NO GOOD FOR Theta-bar>3
3380         DRAW T1(I),G(I)                   !Gaussian curve vs. theta
3390         NEXT I
3400         MAT T1d= At/(Con)               !THETA FOR POINTS ON DOBBINS'CUR
VE
3410         FOR I=1 TO 17
3420         DRAW T1d(I),Dobbins(I)
3430         NEXT I
3440         PENUP
3450     IF Hard THEN SUBEXIT       !EXITS ROUTINE IF A HARD COPY WAS JUST MADE
3460     PRINT USING "/////////"
3470     PRINT "                              USE THE KNOB TO VARY THE PARTICLE
SIZE"
3480     PRINT "                                  OR HIT KEY # 6 FOR HARD COPY"
3490     PRINT " "
3500     PRINT "                                     KEY # 9 ALLOWS YOU TO"
3510     PRINT "                                         RE-NORMALIZE"
3520     PRINT " "
3530     PRINT "                                     HIT KEY # 3 TO GET OUT"
3540     PRINT USING "//////"
3550     ON KEY 6 LABEL "HARD COPY" GOTO Hardgauss
3560     ON KEY 9 LABEL "NORMALIZE" GOTO Divide
3570     ON KNOB .05 GOTO Pulse              !(.05) IS TIME INTERVAL IN WHICH
3580 Wait:  GOTO Wait                        ! PULSES FROM THE KNOB ARE
3590 Pulse: PRINT USING "@"                  ! COUNTED AND THIS NUMBER IS
3600       Strng1$="Mean Diameter "          ! USED BY THE INTERRACTIVE
3610       Strng2$=" Microns"                ! GRAPHICS TO VARY THE PARTICLE
3620     Count=KNOBX                         ! SIZE AND PLOT THE ASSOCIATED
3630     D=DROUND(D+Count/15,2)              ! GAUSSIAN APPROXIMATIONS OF
3640     GLOAD Graf(*)                       ! SCATTERING PROFILES
3650     LDIR 0
3660     LORG 8
3670     MOVE M5,.8*M7
3680     LABEL Strng1$&VAL$(D)&Strng2$
3690     GOTO Change
3700 Hardgauss:!
3710     PRINT "                                        PREPARE the PLOTTER"
3720     PRINT "                                        PRESS CONTINUE for"
3730     PRINT "                                           HARD COPY"
3740     PAUSE
3750     Hard=1                        ! SO THAT SUBEXIT OCCURS AFTER HARD COPY
3760     CALL Plot(Av2(*),1)           ! 1**HARD COPY
3770     CALL Result(Av2(*),T1(*),H)
```

```
3780      PRINT USING "@"
3790      LORG 8
3800      MOVE M5,.8*M7
3810      LDIR 0
3820      LABEL Strng1$&VAL$(D)&Strng2$
3830      MOVE 0,1
3840      GOTO Change
3850 Divide:!
3860      PEN -1                                            !ERASES LAST PLOT
3870      MOVE 0,0
3880      FOR I=1 TO 1024 STEP H
3890      DRAW T1(I),Av2(I)
3900      NEXT I
3910      PRINT CHR$(12)
3920      PRINT USING "//////"
3930      PRINT "                                    USE THE KNOB TO RE-NORMALIZE"
3940      PRINT "                                     KEY # 4 WILL RE-PLOT USING"
3950      PRINT "                                             UPDATED SCALE"
3960      ON KEY 4 LABEL "   RE-PLOT" GOTO Replot
3970      ON KNOB .05 GOTO Vary
3980      GOTO Wait
3990 Vary:PRINT CHR$(12)
4000      PEN -1                                               !ERASES LAST PLOT
4010      MOVE 0,0
4020      FOR I=1 TO 1024 STEP H
4030      DRAW T1(I),Av2(I)
4040      NEXT I
4050      PEN 1
4060      C2=KNOBX
4070      Centerline=Centerline+C2/120      !KNOB USED TO VARY NORMALIZING VALUE
4080      MAT Av2= Av1/(Centerline)                   !NEW NORMALIZED DATA ARRAY
4090      GOTO 3870                              !PLOTS THE NEW NORMALIZED ARRAY
4100 Replot:    !
4110      PRINT CHR$(12)
4120      CALL Plot(Av2(*))
4130      CALL Result(Av2(*),T1(*),H)
4140      GSTORE Graf(*)
4150      GOTO Change
4160 Subexit:    !
4170      SUBEND
4180       SUB Menue1
4190         PRINT USING "@"
4200         PRINT "                        YOU CAN RE-NORMALIZE"
4210         PRINT "***********************************************************"
4220         PRINT "                         YOU CAN RE-AVERAGE (New Data Only)"
4230         PRINT "***********************************************************"
4240         PRINT "                    PRESS KEY # 4 TO LOOK AT OTHER DATA"
4250         PRINT "                                 OLD OR NEW "
4260         PRINT "                               MOTOR / EXHAUST"
4270         PRINT "***********************************************************"
```

```
4280        PRINT "                              PRESS KEY # 5 "
4290        PRINT "                        FOR THE ' TWO-ANGLE ' METHOD"
4300        PRINT "                            OF PARTICLE SIZING"
4310        PRINT "*********************************************************"
4320        PRINT "                TO STORE THE REDUCED DATA PRESS KEY # 6      "
4330        PRINT "*********************************************************"
4340        PRINT "                   TO END THIS SESSION PRESS KEY # 7"
4350      SUBEND
4360      SUB Display1(Old)
4370  PRINT "                       TO REDUCE NEW DATA PRESS KEY # 1"
4380  PRINT ""
4390  PRINT "                TO REVIEW PREVIOUSLY REDUCED DATA PRESS KEY # 2"
4400  PRINT "   "
4410  ON KEY 1 LABEL "  NEW DATA" GOTO New
4420  ON KEY 2 LABEL "  OLD DATA" GOTO Review
4430 Wait: GOTO Wait
4440 New: PRINT CHR$(12)
4450  PRINT "          PUT THE DISK IN THE LEFT DRIVE IF IT IS NOT ALREADY"
4460  PRINT ""
4470  PRINT "             ENTER THE NAMES OF THE FIRST AND SECOND FILES."
4480  PRINT ""
4490  PRINT "              EACH FILE HAS  DATA FROM BOTH DIODE ARRAYS."
4500  PRINT ""
4510  PRINT "          FIRST IS NO-PARTICLES & NEXT IS PARTICLES ----D1$,D2$"
4520  PRINT ""
4530  Old=0
4540  SUBEXIT
4550 Review:  Old=1     !THIS VARIABLE IS PASSED TO THE MAIN PROGRAM TO INDICATE
4560                    !THAT THE DATA TO BE READ IS ONE (1) SCAN AND THAT
4570                    !THE AVERAGING ROUTINES WILL NOT BE USED
4580           SUBEND
4590  SUB Readata
4600  COM /Readata/ B,P,H,Q3$[20],Q4$[20],Zz$[20],Y1(*) BUFFER,Y2(*) BUFFER
4610  Xyz=1                                               ! FILE POINTER VARIABLE
4620  B=8                                         ! NUMBER OF SCANS IN MOTOR DATA
4630  R1=65536                                    !NUMBER OF BYTES   OF MOTOR DATA
4640  IF P=2 THEN Xyz=4097                      !RECORD # WHERE EXHAUST DATA BEGINS
4650  IF P=2 THEN R1=32768                       !NUMBER OF BYTES   OF EXHAUST DATA
4660  IF P=2 THEN B=4                           !NUMBER OF SCANS IN EXHAUST DATA
4670  PRINT " "
4680  PRINT "                     READING DATA FROM FILE ON DISK"
4690       ASSIGN @Disk1 TO Q3$&Zz$
4700       ASSIGN @Disk2 TO Q4$&Zz$                             !OPEN I/O PATHS
4710       ASSIGN @Buff1 TO BUFFER Y1(*)
4720       ASSIGN @Buff2 TO BUFFER Y2(*)
4730       CONTROL @Disk1,5;Xyz
4740       TRANSFER @Disk1 TO @Buff1;COUNT R1           !READS NO-PARTICLE DATA
4750       WAIT FOR EOT @Disk1                      ! NOT AN OVERLAPPING TRANSFER
4760       CONTROL @Disk2,5;Xyz                    !Xyz SETS DISK FILE POINTER TO
4770                                               !EITHER MOTOR OR EXHAUST DATA
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```
4780        TRANSFER @Disk2 TO @Buff2;COUNT R1              !READS PARTICLE DATA
4790        WAIT FOR EOT @Disk2
4800        ASSIGN @Disk1 TO *
4810        ASSIGN @Disk2 TO *                      !JUST GOOD PRACTICE TO CLOSE
4820        ASSIGN @Buff1 TO *                      !I/O PATHS
4830        ASSIGN @Buff2 TO *
4840  SUBEND
4850 SUB Plot2(E,D(*),X)
4860      DIM Title1$[25],Theta$[20]
4870      GINIT
4880      IF X=1 THEN PLOTTER IS 705,"HPGL"
4890      DEG                                       !DEGREES for LABEL DIRECTION
4900      GRAPHICS ON
4910      VIEWPORT 35,125,30,85
4920      Max=10*INT((MAX(D(*))+10)/10)
4930      WINDOW D(1,2),D(E,2),0,Max
4940      G=(D(E,2)-D(1,2))/(E-1)*4           !AN X GRID LINE EVERY 4th POINT
4950      F=(INT(E/4)-1)*4
4960      IF F=0 THEN F=4
4970      CLIP D(4,2)-G,D(F,2)+2*G,0,Max      !MAKES GRID UNIFORM
4980      GRID G,5,D(4,2)-G,0
4990      CLIP OFF
5000      LORG 8
5010      LDIR 90
5020      CSIZE 4,.5
5030      FOR I=4 TO E STEP 4                          !PUTS NUMBERS ON X AXIS
5040           MOVE D(I,2),0
5050           LABEL USING ".DDDD";D(I,2)
5060      NEXT I
5070      LDIR 0
5080      LORG 8
5090      FOR I=10 TO Max STEP 10                           !NUMBER Y AXIS
5100           MOVE D(4,2)-G,I
5110           LABEL USING "#,K";I
5120      NEXT I
5130      CSIZE 6,.6
5140      Title$="TWO-ANGLE METHOD"
5150      Title1$="For Various Angle Ratios"                !STRINGS FOR PLOTS
5160      Size$="SIZE  (microns)"
5170      Thta$="THETA  (rad)"
5180      Sub$="1"
5190      LDIR 90
5200      LORG 5
5210      B=D(4,2)-G-(D(E,2)-D(1,2))/10
5220      MOVE B,Max/2
5230      LABEL Size$
5240      LDIR 0
5250      A=(D(E,2)+D(1,2))/2
5260      MOVE A,-Max/4
5270      LABEL Thta$
```

```
5280    LORG 3
5290    MOVE A,-Max/4
5300    LABEL Sub$
5310    LORG 5
5320    MOVE A,Max*1.15
5330    LABEL Title$
5340    CSIZE 4.5
5350    MOVE A,Max*1.05
5360    LABEL Title1$
5370    PENUP
5380 SUBEND
5390 SUB Distribution(D(*),Tratio,E)
5400    LINE TYPE 1
5410    CLIP ON
5420    Tratio$=VAL$(Tratio)                         ! ANGLE RATIO
5430    MOVE D(1,2),D(1,1)
5440    FOR I=1 TO E                       !THIS SUBROUTINE PLOTS THE
5450        DRAW D(I,2),D(I,1)             !PARTICLE SIZES DERIVED USING
5460    NEXT I                             !VARIOUS ANGLE RATIOS APPLIED
5470    LORG 4                             !TO THE DATA OVER A RANGE OF
5480    LINE TYPE 1                        !ANGLES
5490    CSIZE 4,.3
5500    MOVE D(I-1,2),D(I-1,1)+2
5510    LABEL Tratio$
5520    PENUP
5530 SUBEND
5540 SUB Twoangle
5550 !*****************************************************************
5560 !***************    SUBPROGRAM 'TWOANGLE'    ******************
5570 !***************     PARTICLE SIZING BY      ******************
5580 !***************     MEASURING THE RATIO     ******************
5590 !***************       OF INTENSITY AT       ******************
5600 !***************         TWO ANGLES          ******************
5610 !*****************************************************************
5620 OPTION BASE 1
5630 COM /Two/ Av1(1024),M,M1,F
5640 COM /Gauss/ T1(1024),G(1024),L          !THE GAUSS IS NOT USED HERE
5650                                         !BUT THE COM BLOCK HAS THETA
5660 DIM D(200,2)                            !AND WAVELENGTH
5670 PRINT CHR$(12)
5680 PRINT USING "///////"
5690 PRINT "    THIS SUBPROGRAM USES THE TWO-ANGLE METHOD DESCRIBED BY BUCHELE"
5700 PRINT " "
5710 PRINT "    TO CALCULATE PATICLE SIZE FOR VARIOUS ANGLE RATIOS AND ANGLES."
5720 PRINT " "
5730 PRINT "         IT IS HOPED THAT THE CURVES WHICH RESULT WILL SHOW "
5740 PRINT " "
5750 PRINT "                   WHICH SIZE IS THE MOST PROBABLE."
5760 PRINT " "
5770 PRINT "AFTER NOTING FROM THE RAW DATA WHICH ANGLES CONTAIN THE CENTER LOBE"
```

```
5780 PRINT ""
5790 PRINT "       ENTER*************THE SMALLEST USEABLE ANGLE,"
5800 PRINT "                            THE SMALLEST ANGLE RATIO,AND"
5810 PRINT "                         THE STEP SIZE BETWEEN ANGLE RAIOS"
5820 PRINT "                                YOU WISH TO EXPLORE"
5830 PRINT "     EXAMPLE*************         .012,1.2,.4"
5840 INPUT " ENTER           theta1,theta-ratio,theta-step",Q,A,B
5850     OFF KEY
5860     X=0                                    !GRAPH WILL APPEAR ON SCREEN
5870 Begin:                !RUNNING CONTINUES HERE WHEN A HARD COPY IS DESIRED
5880          !Van De Hulst and Gumprech & Sleepevich explain that the change in
5890          !wavelength of the beam is accounted for by dividing by the index
5900          !of refraction of the medium. *********L=L/M1 **********
5910 C=(L/M1/.57/PI)^2          !------------see page 15 of nasa tech paper 2156
5920 FOR N=1 TO 1024                        !to see this is a convenient constant
5930      IF Q<T1(N) THEN 5950                  !FINDS POSITION OF MINIMUN ANLGE
5940 NEXT N
5950 FOR Tratio=A TO 3 STEP B                       !VARIOUS ANGLE RATIOS
5960     FOR J=N TO 1010/Tratio STEP 10            !SETS THE RANGE OF POSSIBLE
5970                                               ! ANGLES (THETA 1)
5980          Thta1=T1(J)
5990          Thta2=T1(J*Tratio)                   ! THETA 2
6000          Deltatheta=Thta2^2-Thta1^2
6010          I1=0
6020          I2=0
6030          FOR I=J-5 TO J+5                     !THESE 2 LOOPS AVERAGE A FEW
6040               I1=I1+Av1(I)                    !INTENSITIES IN THE HOPE
6050          NEXT I                               !OF A STEADIER CALCULATION
6060               I1=I1/11
6070          FOR I=INT(J*Tratio-5) TO INT(J*Tratio+5)
6080               I2=I2+Av1(I)                    ! DONE HERE FOR THETA2 FOR
6090          NEXT I                               ! THE GIVEN ANGLE RATIO
6100               I2=I2/11
6110          E=(J-N)/10+1          !THIS IS A COUNTER FOR THE ARRAY CONTAINING
6120                                !PARTICLE SIZE AND THETA1 FOR THE GIVEN
6130                                !ANGLE RATIO
6140          IF I1<I2 OR I1=0 OR I2<=0 THEN D(E,1)=0 !ALLOWANCE FOR IF THE DATA
6150          IF I1<I2 OR I1=0 OR I2<=0 THEN GOTO Xcomp  !IS NOT WELL BEHAVED
6160          D(E,1)=SQR(-C/Deltatheta*LOG(I2/I1))           !TWO ANGLE METHOD
6170                                !VALUE OF DIAMETER based on INTENSITY RATIO
6180                                !For a given ANGLE RATIO and ANGLE THETA1
6190 Xcomp:   D(E,2)=Thta1
6200         Spar=PI*D(E,1)*M1/L     !THIS IS PI*D/LAMBDA  -- THE SIZE PARAMETER
6210         Tbar=Spar*Thta2                    !THETA BAR FOR THE LARGER ANGLE
6220         IF Tbar>3 THEN J=1010/Tratio       !THIS ENDS THE DO LOOP FOR THIS
6230         IF E=1 AND Tbar>3 THEN 6330        !ANGLE RATIO SINCE THE GAUSSIAN
6240  !the above line ends all calculation if     !IS NOT VALID WHEN Tbar > 3
6250  !the first element (E=1)failed the test
6260     NEXT J
6270             !   FIRST TIME THROUGH-- D HAS THE MOST ELEMENTS IT WILL HAVE
```

```
6280             !  SO SET UP THE GRAPH USING D's PRESENT PARAMETERS
6290 PRINT CHR$(12)
6300     IF Tratio=A THEN CALL Plot2(E,D(*),X)
6310     CALL Distribution(D(*),Tratio,E)
6320 NEXT Tratio
6330     ON KEY 2 LABEL "HARD COPY" GOTO Hard
6340     ON KEY 3 LABEL "MENUE " GOTO Subexit
6350 PRINT USING "/////"
6360 PRINT "                      YOU CAN GET A HARD COPY BY PRESSING KEY # 2"
6370 PRINT "                         OR EXIT THIS ROUTINE BY PRESSING KEY # 3"
6380 Standby:GOTO Standby
6390 Hard:X=1                                !A VARIABLE TO CONTROL PLOTTER
6400      GOTO Begin
6410 Subexit: GINIT
6420          GRAPHICS OFF
6430 SUBEND
6440  SUB Shift
6450  COM /Readata/ B,P,H,Q3$[20],Q4$[20],Z:$[20],Y1(*) BUFFER,Y2(*) BUFFER
6460  DIM E(1:8192)
6470  PRINT CHR$(12)
6480  PRINT USING "///////"
6490  PRINT " RAW DATA IS BEING SHIFTED TO CORRECT FOR SMALL GAPS BETWEEN SCANS"
6500  PRINT ""
6510  PRINT "                BE PATIENT, IT'S A LONG SET OF DO-LOOPS"
6520        !      THERE ARE SOME SMALL GAPS BETWEEN SCANS AND THIS SUBROUTINE
6530        !      SHIFTS THE DATA SO THAT THE FIRST DIODE DATA POINT IS MOVED
6540        !      TO THE VERY BEGINNING OF ITS 1024 BLOCK IN THE OVERALL ARRAY
6550        !      .THE FIRST SET IS RIGHT ON, THE NEXT IS ONE OFF,THE THIRD IS
6560        !      TWO OFF ,,SO FORTH.  THIS MAY NOT MATTER WITH OUR RESOLUTION
6570        !      AND IS PROBABLY DUE TO THE MEMORY CARD CYCLING AT THE END OF
6580        !      SOME SCANS. SEE THE CIRCUIT TIMING DIAGRAM IN THE THESIS.
6590      SELECT B
6600      CASE 4                   !EXHAUST DATA HAS 4 SCANS
6610          M=3
6620      CASE 8                   !MOTOR DATA HAS 8 SCANS
6630          M=7
6640      END SELECT
6650   FOR K=1 TO 2
6660   IF K=1 THEN MAT E= Y1       !OPPERATES ON NO-PARTICLE AND PARTICLE SETS
6670   IF K=2 THEN MAT E= Y2
6680          FOR J=0 TO M
6690          IF M=7 AND J(=3 THEN 6800  !One 4096 Block Doesn't Need Shifting
6700              FOR I=(J)*1024+1 TO (J+1)*1024          !BLOCKS OF 1024
6710                  IF M=3 THEN L=I+J       !Array B Has the worst
6720                                          !Problem With Shifting Data
6730                  IF M=7 THEN L=I+1       !Array D is Allways off by one
6740                  IF ' .J+1)*1024 THEN L=(J+1)*1024
6750             !JUST TO AVUID PROGRAMMING ERROR AT THE END OF THE ARRAY
6760                  E(I)=E(L)                 !THIS SHIFTS THE DATA
6770                                            !DEPENDING ON 'L',ARRIVED AT
```

```
6780                                                !BY OBSERVING RAW DATA
6790              NEXT I
6800          NEXT J
6810      IF K=1 THEN MAT Y1= E
6820      IF K=2 THEN MAT Y2= E
6830 NEXT K
6840 SUBEND
6850 SUB Store    ! THE LARGE ARRAY CONTAINING MULTIPLE SCANS HAS BEEN REDUCED
6860              ! TO A MEAN SCATTERING PROFILE BY AVERAGING AND FILTERING. IF
6870              ! YOU FEEL THAT STORING THIS DATA IS NECESSARY THIS ROUTINE
6880              ! DOES IT. IT SAVES DISK SPACE TO STORE THE RESULTS THEN
6890              ! ELIMINATE THE RAW DATA IF YOU FEEL CONFIDENT THAT THE
6900              ! REDUCTION IS THE BEST THAT CAN BE.  IN OTHER WORDS,
6910              ! DO NOT PURGE A RAW DATA FILE UNLESS YOU ARE ABSOLUTELY SURE
6920              ! YOU WON'T WANT TO REDUCE IT AGAIN.
6930 COM /Hrdgaus/ Av2(*)                          !Av2(*) IS THE REDUCED DATA
6940 DIM Data(1:1024) BUFFER                   !BUFFER USED TO TRANSFER TO DISK
6950 MAT Data= Av2
6960 PRINT CHR$(12)
6970 PRINT USING "//////"
6980 PRINT "   A  SUGGESTED METHOD OF NAMING REDUCED DATA FILES IS AS FOLLOWS"
6990 PRINT "  M-------MOTOR BEAM"
7000 PRINT "  X-------EXHAUST BEAM"
7010 PRINT "  C-------CALIBRATION , IF NO 'C' THEN AN ACTUAL FIRING IS ASSUMED"
7020 PRINT "  G-------GLASS BEADS "
7030 PRINT "                    IF NO 'C' THEN 'G' STANDS FOR 'GAP' PROPELLANT"
7040 PRINT "  A-------ALUMINUM OXIDE"
7050 PRINT "  PPP-----CHAMBER PRESSURE FOR RUN OR OTHER....(NOZZLE TYPE)"
7060 PRINT "          PARTICLE SIZE FOR CALIBRATION"
7070 PRINT "  MMDD----MONTH,DAY OF RUN OR CALIBRATION"
7080 PRINT ""
7090 PRINT "                         EXAMPLE:    MCA125JN12"
7100 PRINT ""
7110 PRINT "  MOTOR BEAM CALIBRATION USING ALUMINUM OXIDE FROM 1 TO 25 MICRONS"
7120 PRINT "  ON JUNE 12"
7130 PRINT "                         EXAMPLE:    XG550AU10"
7140 PRINT ""
7150 PRINT "  EXHAUST BEAM DATA FOR GAP PROPELLANT AT 550 psi ON AUGUST 10"
7160 PRINT "              PLACE A DISK IN THE RIGHT HAND DRIVE"
7170 PRINT "  ENTER THE FILENAME YOU WISH TO USE FOR THIS REDUCED DATA"
7180 INPUT A$
7190 CREATE BDAT A$,512,16
7200 ASSIGN @Disk TO A$
7210 ASSIGN @Buff TO BUFFER Data(*)
7220 CONTROL @Buff,3;1,8192,1                           !BUFFER IS FULL
7230 TRANSFER @Buff TO @Disk;COUNT 8192
7240 WAIT FOR EOT @Disk
7250 ASSIGN @Buff TO *
7260 ASSIGN @Disk TO *
7270 SUBEND
```

```
7280 SUB Review(Av1(*))
7290 DIM Data(1:1024) BUFFER
7300 PRINT " EACH REDUCED FILE CONTAINS ONE SCAN ONLY.  YOU MUST KNOW IF IT"
7310 PRINT "       IS EXHAUST , MOTOR CAVITY , OR CALIBRATION DATA."
7320 PRINT ""
7330 PRINT " THE DISK WITH THE REDUCED FILE SHOULD BE IN THE RIGHT-HAND DRIVE"
7340 PRINT ""
7350 PRINT "            ENTER THE FILENAME OF THE REDUCED DATA"
7360 PRINT "                           TO BE REVIEWED"
7370 PRINT ""
7380 INPUT A$
7390 ASSIGN @Disk TO A$
7400 ASSIGN @Buff TO BUFFER Data(*)
7410 CONTROL @Disk,5;1
7420 CONTROL @Buff,3;1,0,1                         !THIS IS AN EMPTY BUFFER
7430 TRANSFER @Disk TO @Buff;COUNT 8192            !1024*8=NUMBER OF BYTES
7440 WAIT FOR EOT @Disk
7450 ASSIGN @Disk TO *
7460 ASSIGN @Buff TO *
7470 MAT Av1= Data
7480 SUBEND
7490 SUB Filter(A(*),Fil)
7500 DIM E(1:1024)
7510 PRINT CHR$(12)
7520 PRINT USING "////////"
7530 PRINT "                                 FILTERING THE SCATTERING PROFILE"
7540     FOR J=1 TO Fil
7550             FOR I=1 TO 1014
7560                  B=I+1              !THIS IS A Symetric Moving Average
7570                  C=I+2              !TYPE OF DIGITAL FILTER. EACH
7580                  D=I+3              !DATA POINT IS EQUALLY WEIGHTED
7590                  F=I+4              !IN THIS CASE BUT THIS CAN BE
7600                  G=I+5              !CHANGED IF ONE DETERMINES THAT
7610                  H=I+6              !FEWER POINTS WITH UNEQUAL WEIGHTS
7620                  K=I+7              !WOULD BE FASTER OR GIVE BETTER
7630                  L=I+8              !RESULTS.  THIS TYPE OF FILTER WAS
7640                  N=I+9              !USED SINCE IT INTRODUCES NO PHASE
7650                  P=I+10             !LAG       (Angular Resolution).
7660  E(G)=(A(I)+A(B)+A(C)+A(D)+A(F)+A(G)+A(H)+A(K)+A(L)+A(N)+A(P))/11
7670             NEXT I
7680         MAT A= E
7690     NEXT J
7700 SUBEND
```

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