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GLASS BEAD SIZE AND MORPHOLOGY CHARACTERISTICS

in support of

CRYSTAL MIST FIELD EXPERIMENTS

for

US Army Space and Strategic Defense Command
Lethality Division
Huntsville, Alabama
Dr. Julius Lilly, Project Manager

by

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Abstract

Soda-lime glass beads used in the Crystal Mist series of atmospheric transport and diffusion tests were characterized by scanning electron microscopy and automated image processing routines in order to fully define their size distributions and morphology. Four bead size classifications ranging from a median count diameter of 45 to 200 micrometers were found to be approximately spherical and to fall within the supplier's sizing specifications. Log-normal functions fit to the measured size distributions resulted in geometric standard deviations ranging from 1.08 to 1.12, thereby fulfilling the field trial requirements for a relatively narrow bead size distribution.

Acknowledgments

The authors would like to recognize the efforts of Ms. Bonnie McKenzie of the Electron Microscopy/Metallography Department at Sandia National Laboratories in bead sample preparation and operation of the SEM/Image Processing system.

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1.0 Introduction

One of the tasks of the Lethality Group within U.S. Army Space and Strategic Defense Command (USASSDC) is the development of a capability to simulate various missile intercept scenarios using computer codes. Currently under development within USASSDC and its various contractor organizations is a group of codes collected under a master code called PEGEM for Post Event Ground Effects Model. Among the various components of the code are modules which are used to predict atmospheric dispersion and transport of particles or droplets following release at the altitude specified in the missile intercept scenario. The atmospheric transport code takes into account various source term data from the intercept such as: initial cloud size; droplet or particle size distribution; and, total mass of agent released. Other influential factors such as meteorological conditions and local terrain are included in the simulation that is carried out to ultimately predict ground deposition of the agent in question. Other modules combine computed ground deposition data with known toxicological effects of the agents and estimates of population density to forecast morbidity or mortality in any particular intercept scenario under investigation.

An ongoing USASSDC experimental program termed Crystal Mist involved release of precision glass beads under various altitude and meteorological conditions to assist in validation and refinement of various codes that are components of PEGEM used to predict particle atmospheric transport and diffusion following a missile intercept. During these field trials, a suite of ground-based and airborne instrumentation systems were used to characterize bead cloud release position and spatial characteristics with time following release. These measurements were accompanied by extensive on-site measurements of various meteorological parameters such as atmosphere temperature and wind structure such that a reasonably comprehensive data package would be available for model improvement and validation efforts associated with the PEGEM project. As of December 1994, two field test programs were successfully completed. The first was carried out at White Sands Missile Range in December 1993 and the second at the Nevada Test Site in July 1994.

As a part of the Crystal Mist test program, researchers at Sandia were tasked with test bead selection and procurement along with a requirement to characterize the various size categories selected for test as to median size, distribution spread and morphological characteristics. This report documents information relevant to bead selection along with results of size characterization efforts utilizing scanning electron microscopy and automated image processing techniques. Since optical remote-sensing techniques such as lidar were used for cloud spatial measurements following release, a parallel effort to measure the indices of refraction of the glass beads by a Swedish university research group was arranged by the NOAA-Boulder lidar group. The NOAA research group required information on bead optical properties to assist in the interpretation of ground-based lidar data. A summary of these measurements is also given in this report.

2.0 General Bead Description

The glass beads were purchased in bulk quantity from Cataphote Inc. of Jackson, MS. Two levels of size precision were used in drop tests conducted at White Sands Missile Range in December 1993 and at the Nevada Test Site in July 1994. In general, a so-called "precision grade" category known as Class V was used for most tests. This particular category possesses fairly stringent size tolerances and sphericity requirements. On selected test days at the Nevada Test Site, a so-called "engineering grade" or Class IV category of beads was dropped. This classification possesses slightly less stringent size and sphericity requirements than the Class V category. In all test cases, 227 kg (500 lb) of beads were dropped from a below-wing hopper on a Lear jet operated by Aeromet Inc., one of the project participants.

2.1 Bead Chemical and Physical Properties

The glass beads are fabricated from soda-lime plate glass and are primarily composed of amorphous silicon dioxide. Important chemical constituents are summarized in Table 1, with relevant physical and optical properties summarized in Table 2. Reproductions of the technical data sheet produced by Cataphote Inc. for a each of the size classifications are given in Appendix A.

Table 1
Glass Bead Chemical Properties

Chemical	Mass Fraction (%)
SiO_2	71-74
Na_2O	12-15
CaO	8-10
MgO	1.5-3.8
Al_2O_3	0.2-1.5
K_2O	0-0.2
Fe_2O_3	trace

Source: Cataphote Inc. Technical Data Sheet

Table 2
Glass Bead Physical and Optical Properties

Bead Physical Property	Value
Bulk Density	1.36 g/cm^3 Low 1.55 g/cm^3 High 1.48 g/cm^3 Average
Bead Density	2.42 g/cm^3 Low 2.50 g/cm^3 High
Coefficient of Thermal Expansion	$8.6 \times 10^{-6}/°C$
Complex Index of Refraction[1] $\lambda = 10.59\ \mu m$	2.25 (±2.7%) - 0.99 (±4.1%)i

Source: Cataphote Technical Data Sheet

[1] The index of refraction information is summarized from measurements made by investigators at the University of Uppsala, School of Engineering in Sweden through arrangements made by Dr. Wynn Eberhard of the NOAA-Boulder Lidar Group [Andersson et al, 1994].

2.2 Bead Size Characteristics

Size specifications for Class IV, Engineering Grade and Class V, Precision Grade beads as listed by the manufacturer are given in Table 3. Differences between Class IV and Class V occur in both the number of beads within the specified size range and the number of true spheres in the batch.

Table 3
Glass Bead Classification Criteria

Bead Classification	Sizing Restrictions
Class IV, Engineering Grade	80% in specified size range 85% true spheres
Class V, Precision Grade	90% in specified size range 90% true spheres

Source: Cataphote Inc.

3.0 Glass Bead Size Selections

Four distinct bead sizes were selected for test drops at both White Sands Missile Range and the Nevada Test site as shown in Table 4. Three of these size categories were Class V, Precision Grade, denoted as "Class V - Small", "Class V - Medium" and "Class V - Large". The fourth category was an "engineering grade" and is denoted as "Class IV - Medium." The approximate number of beads in a typical 227 kg (500 lb) load as deployed in the test program is given in the last column of Table 4 for each of the bead size categories of interest. These data were calculated by assuming a nominal bead density of 2.46 g/cm^3 with all beads at a diameter corresponding to the arithmetic mean of the size range shown in column 4 of Table 4.

Table 4
Test Bead Description

Size	Batch No.	U.S. Sieve Size	Micron Range	Approx No. per 227 kg Drop
Class V Small	1527/1798*	-325+400	44-37	2.7×10^{12}
Class V Medium	1617/1757	-200+230	74-63	5.9×10^{10}
Class V Large	1619/1756	-70+80	210-177	2.6×10^{10}
Class IV Medium	30812	-230+325	62-44	1.5×10^{12}

*Note: Two separate procurement actions resulted in two different batch numbers for each of the Class V size categories.

4.0 Bead Size Characterization Methods

In order to verify the size classification specifications given by Cataphote Inc., samples of each bead size were analyzed by a scanning electron microscope with an automated image processing system. Sizing data from this apparatus was then further processed to determine various size distribution parameters, such as number median diameter and geometric standard deviation, for each of the four size categories selected for use in the field tests. Additional details on imaging and analysis methodology are given in the following paragraphs.

4.1 Scanning Electron Microscope and Image Processing Software

The glass beads were analyzed on an Amary 1645 Scanning Electron Microscope (SEM) equipped with a Noran 8502 Image Analyzer and associated software. A digital image describing the perimeter of a particular bead is determined by detecting the edge of the bead against the background in the SEM image. The image processing software then determines the maximum particle projection (or diameter) through iterative searching across the perimeter of the bead image. The minimum image projection is also determined in a similar manner. The mean of the maximum and minimum bead projection is then calculated for an estimate of the bead diameter. A parameter known as circularity is also calculated from a measure of the projected area and perimeter of the object. Circularity is defined as follows.

$$Circularity = \frac{Perimeter^2}{4\pi \cdot Area} \qquad (1)$$

For a true circle, the circularity parameter would be equal to unity. The degree to which the images are not true circles, and the beads non-spherical by inference, is indicated by the extent to which the circularity parameter for each bead departs from a value of unity. The automated image processing software typically detects and sizes about 600-900 bead images in each size classification run so that statistically significant parameters can be used to describe the bead size distribution.

4.2 Bead Distribution Numerical Analysis

Raw data from the imaging processing system consisted of the maximum, minimum and mean image diameter along with the circularity parameter for each bead image randomly selected by the image processing system. These data were then imported into a spreadsheet so the distribution could be plotted and appropriate log-normal distributions could be overlaid for comparison. The particle sizing data was also imported into a distribution analysis and fitting software package called DISTFIT™ (Chimera Software, Golden Valley, MN) such that additional bead distribution characterization and log-normal function fitting routines could be carried out.

5.0 Bead Size Distribution Analysis Results

5.1 SEM/Image Analysis Descriptive Statistics

A summary of SEM/Image Analysis data from each of the bead sizes is given in Table 5. Mean bead sizes are in expected ranges according to the Cataphote Inc. specifications. In all cases the circularity parameters associated with the beads were in excess of unity--indicating that the beads are in fact not perfect spheres, but rather slightly elongated (See Section 5.4 for additional discussion). The mean diameter and associated standard deviation summary statistics given in Table 5 for the raw SEM data are of limited utility however since the none of the data was log transformed and the expectations were that the distribution would be log-normally distributed. The raw data from the SEM/Image processing system is given in Appendix B for the four size classifications that were examined.

Table 5
Summary SEM/Image Analysis Sizing Statistics

Size Category	Mean Image Diameter µm	Circularity	No. of Beads
Class V - Small	42.5 ± 8.3	1.09 ± 0.18	606
Class V - Medium	68.8 ± 13.9	1.14 ± 0.27	596
Class V - Large	187.2 ± 55.2	1.13 ± 0.42	608
Class IV - Medium	48.2 ± 10.0	1.14 ± 0.34	977

5.2 SEM Photo Images

Photo images of each of the bead samples are given in Figures 1 through 4. These images reveal several features. First, to the unaided eye the beads appear more or less spherical. Second, a small number of bead fragments can be observed in some of the fields of view. The fragments are typically much smaller than the average bead size such that their gravitational settling rate would be significantly less than that of the whole beads. Third, in selected cases, a few doublets or significantly undersized singlets can be observed. These outliers should be adequately represented in the tabulated size distributions since numerous (600-1,000) randomly selected images were used the compilation of the distribution.

5.3 Bead Distributions

Frequency plots of average bead diameter for each of the measured size categories are given in Figures 5-8. The median diameter for all size categories falls within the range called out in the Cataphote Inc. specifications (Table 4, Column 4). A limited number of outliers can be observed in all of the bead distributions usually a result of either bead fragments or occasional bead doublets encountered by the imaging system.

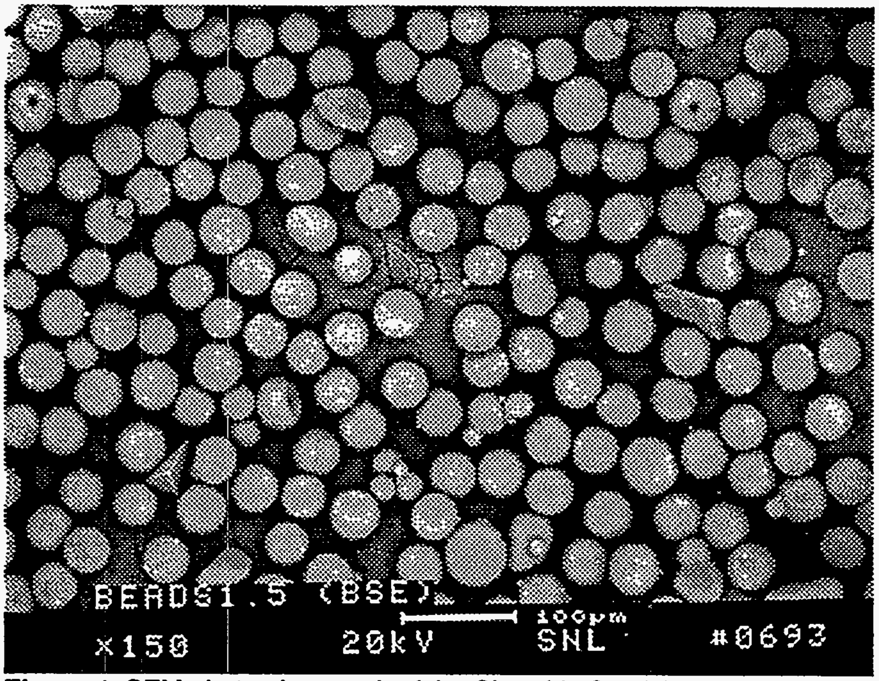

Figure 1 SEM photomicrograph of the Class V - Small beads. A 100 μm reference sizing bar is included at the bottom of the photograph.

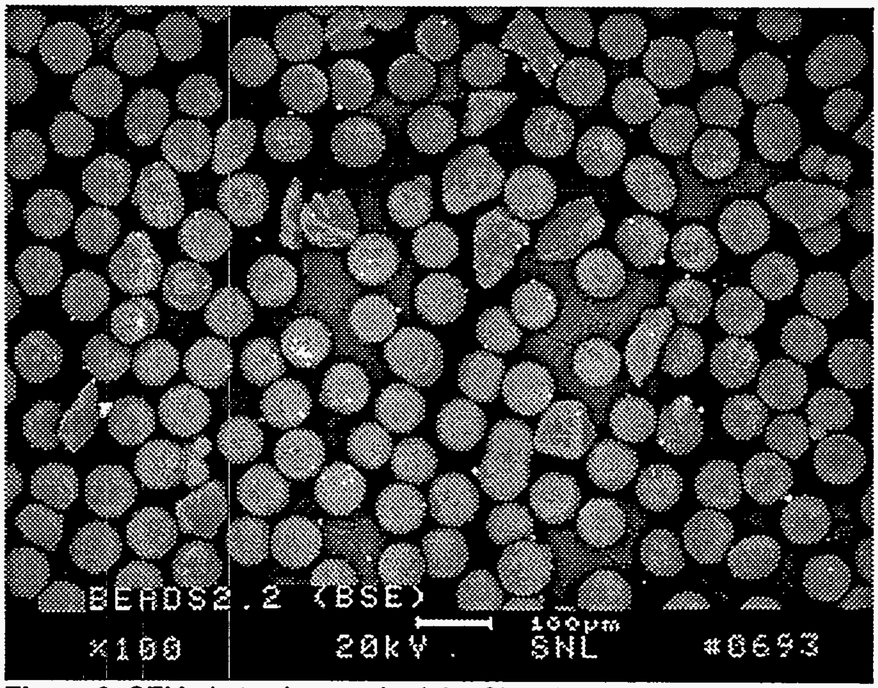

Figure 2 SEM photomicrograph of the Class V - Medium beads. A 100 μm reference sizing bar is included at the bottom of the photograph.

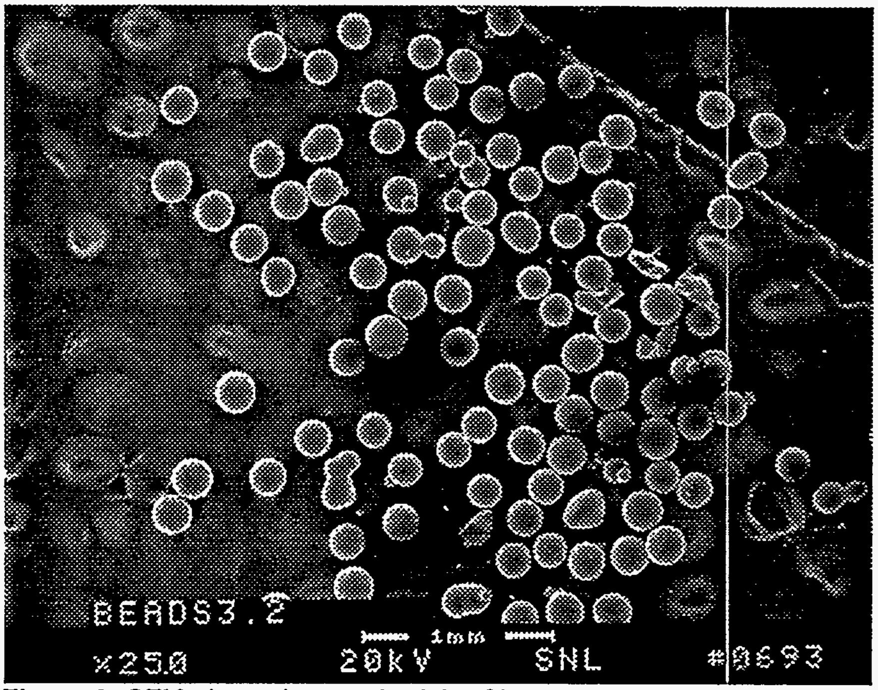

Figure 3 SEM photomicrograph of the Class V - Large beads. A 1 mm reference sizing bar is included at the bottom of the photograph.

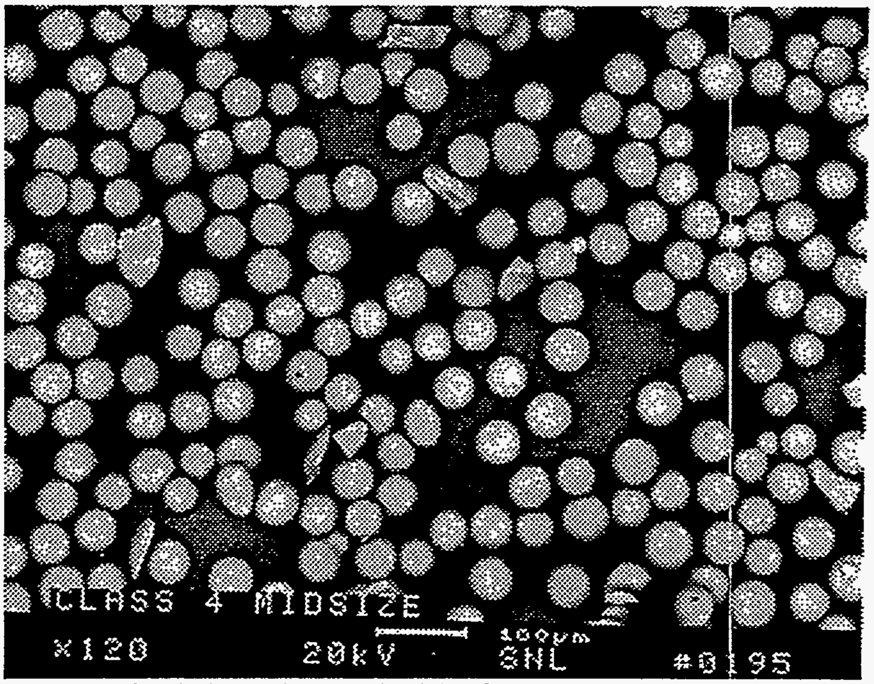

Figure 4 SEM photomicrograph of the Class IV - Medium beads. A 100 μm reference sizing bar is included at the bottom of the photograph.

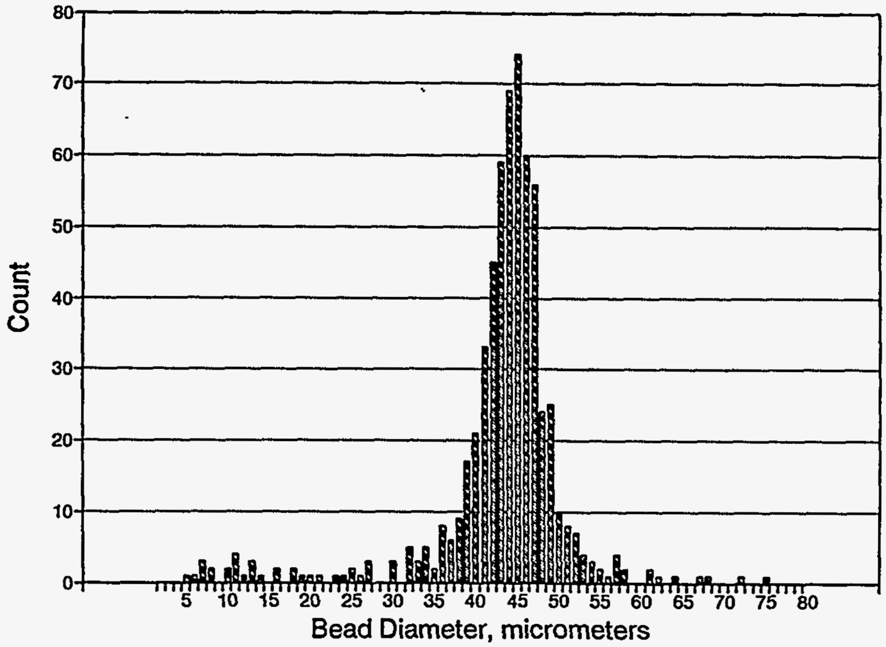

Figure 5 Frequency distribution plot of the raw SEM data for the Class V - Small beads

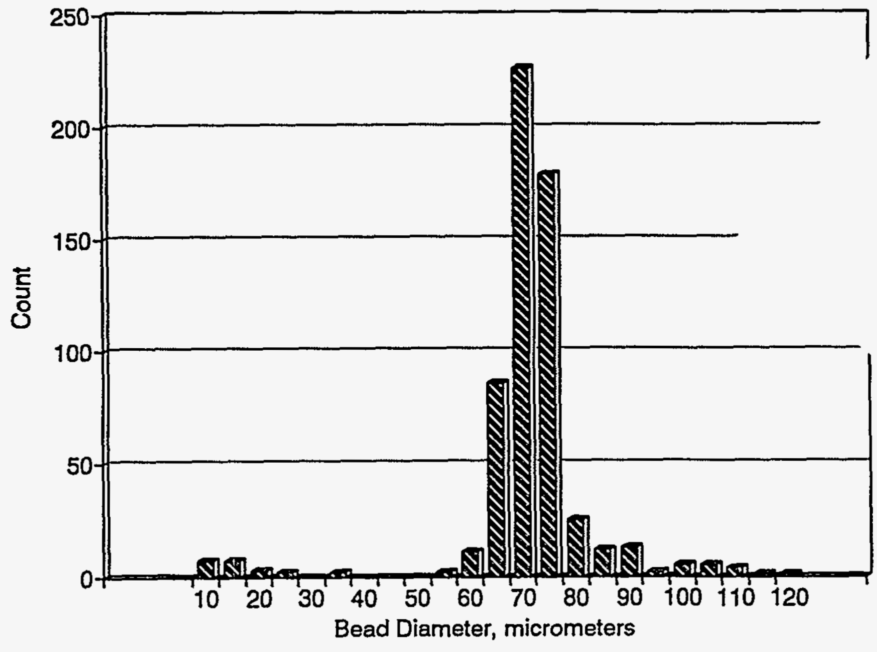

Figure 6 Frequency distribution plot of the raw SEM data for the Class V - Medium beads

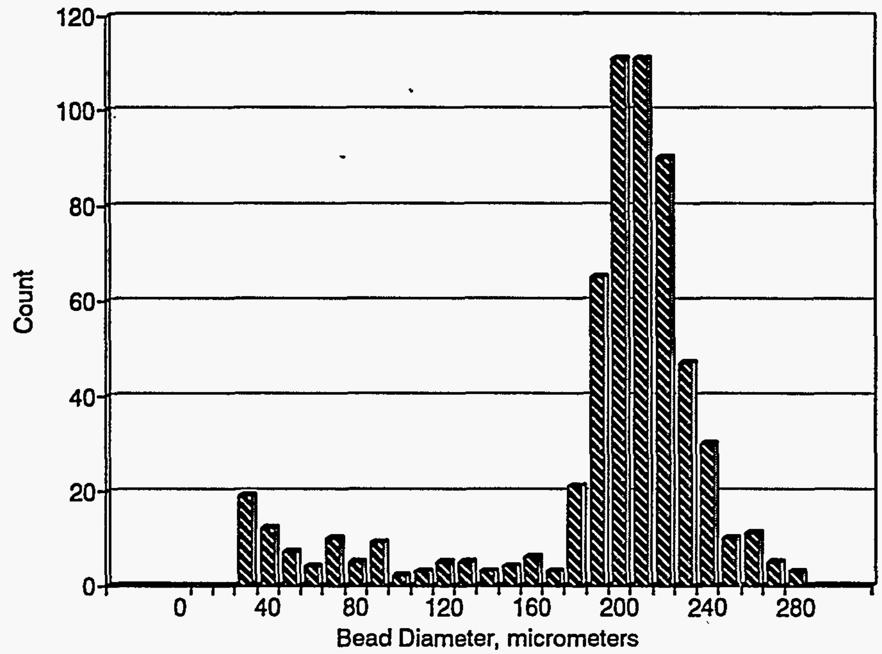

Figure 7 Frequency distribution plot of the raw SEM data for the Class V - Large beads

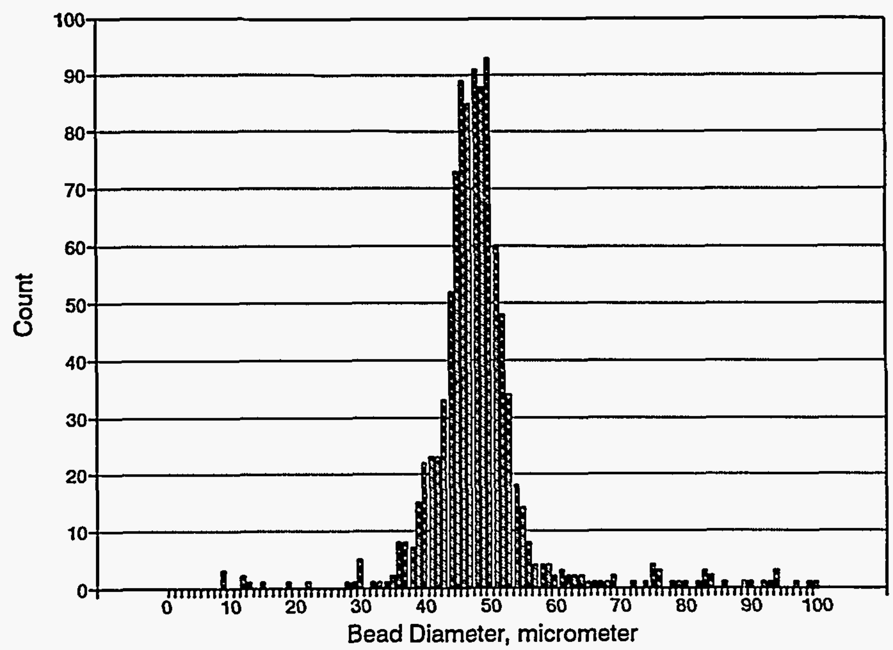

Figure 8 Frequency distribution plot of the raw SEM data for the Class IV - Medium beads

5.4 Bead Non-circularity

An analysis was carried out to determine the effect of bead non-circularity on terminal velocity settling rates by using the maximum and minimum diameters for each bead image from the SEM/Image analysis data. For this analysis we assumed that the non-circular beads were in a prolate ellipsoid shape--a shape for which dynamic shape factors can be calculated from parameters that have been determined experimentally [Lerman, 1979]. The dynamic shape factor is defined as the ratio of the actual resistance force of an irregularly shaped particle to the resistance force of a sphere having the same volume and fall velocity [Hinds, 1982]. In this analysis, the density of the beads is correctly understood to be the same for the spherical and non-spherical beads. Thus, only shape effects are considered since varying bead density would also have an effect on settling velocity. The dynamic shape factor for a prolate ellipsoid is given as follows

$$K = \frac{5X^{\frac{1}{3}}}{(4+X)}$$

where K is the dynamic shape factor and χ is the ratio of the ellipsoid longer axis (maximum diameter) to the shorter axis (minimum diameter).

Shape factors were calculated for all bead images from the raw SEM data for all the Class V sizes and distribution summaries are given in Table 6[2]. Average shape factors range from 1.018 to 1.022 for the three sizes examined. A frequency distribution plot for the Class V - Medium size category is given in Figure 9. A reasonably narrow distribution is observed with nearly all of the calculated shape factors falling between values of 1.01 and 1.02. Distribution plots for the other Class V sizes are not given here however they are very similar to the data shown in Figure 9.

Table 6
Dynamic Shape Factors Calculated for
Class V Small, Medium and Large Beads

Size Category	Dynamic Shape Factor		
	Minimum	Maximum	Average
Class V - Small	1.006	1.050	1.018
Class V - Medium	1.001	1.050	1.020
Class V - Large	1.005	1.050	1.022

[2] Dynamic shape factors were not determined for the Class IV - Medium category since these beads were primarily used in test readiness exercises where precise definition of the bead sizing and shape was not required.

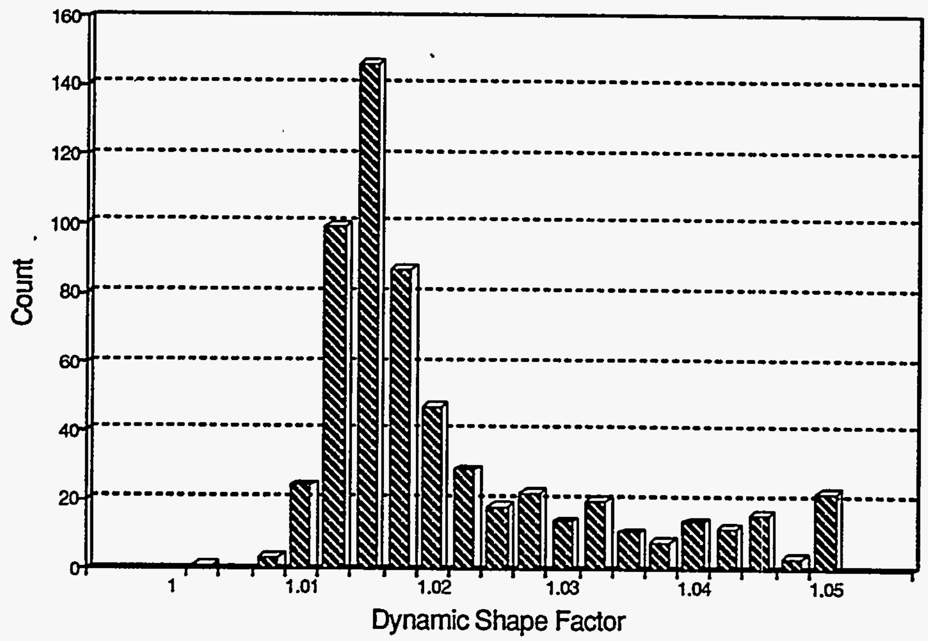

Figure 9 Frequency distribution plot of the dynamic shape factors calculated from the SEM data for the Class V - Medium beads

The expression relating terminal settling velocity to dynamic shape factor is given by the following

$$V_{TS}=\frac{\rho_p d_e^2 g}{18\eta\chi}$$

where V_{TS} is the settling velocity, ρ_p is the particle density, d^2_e is the volume equivalent particle diameter, g is the gravitational constant, η is the fluid viscosity and χ is the dynamic shape factor. From this expression it can be seen that the terminal settling velocity is inversely proportional to the dynamic shape factor. Note also that the dynamic shape factor for a true sphere is unity. Average dynamic shape factors for the three Class V sizes examined are around 1.02. Thus, changes in vertical settling velocity resulting from non-spherical beads would result in an approximate 2% error if the beads are assumed to be perfect spheres. In other words, the non-spherical beads would fall at a rate approximately 2% slower than true spheres of the same density and volume.

5.5 Bead Size Distribution Parameters

The results from bead distribution analysis and log-normal function fitting routines for all four size categories by both number and mass are given in Table 7. Distribution parameters such as number median diameter (NMD) in the "discrete data" column are calculated directly from the raw data whereas the parameters in the "Log-normal Fit" column are taken from the log-normal function that best fits the raw data. The goodness of fit of the log-normal function to the raw data was determined by calculation of the chi-square (χ^2) statistic. The computed chi square values for all four distributions were in the range of 0.1 or less indicating that the computed log-normal function and the raw data bead distributions were statistically equivalent, thus indicating a good fit of the function to the raw data. A comparison of measured and log-normal fit data is given in Figure 10 for the Class IV - Medium size category. Graphical comparisons of measured data and fitted functions are given in Appendix B for all size categories.

Table 7
Log-Normal Distribution Parameters for Bead Number and Mass

Size Category	Discrete Data		Log-Normal Fit		
	NMD	σ_g	NMD	σ_g	χ^2
Class V - Small	45.0	1.12	44.9	1.08	0.112
Class V - Medium	70.1	1.08	69.5	1.06	0.115
Class V - Large	203	1.09	204	1.08	0.007
Class IV - Medium	48.2	1.11	48.1	1.08	0.008
	MMD	σ_g	MMD	σ_g	χ^2
Class V - Small	45.9	1.13	45.6	1.08	0.120
Class V - Medium	71.0	1.08	70.2	1.05	0.148
Class V - Large	207	1.08	207	1.08	0.066
Class IV - Medium	49.3	1.11	49.1	1.08	0.078

Notes: NMD = number median diameter
MMD = mass median diameter
σ_g = geometric standard deviation
χ^2 = chi square statistic

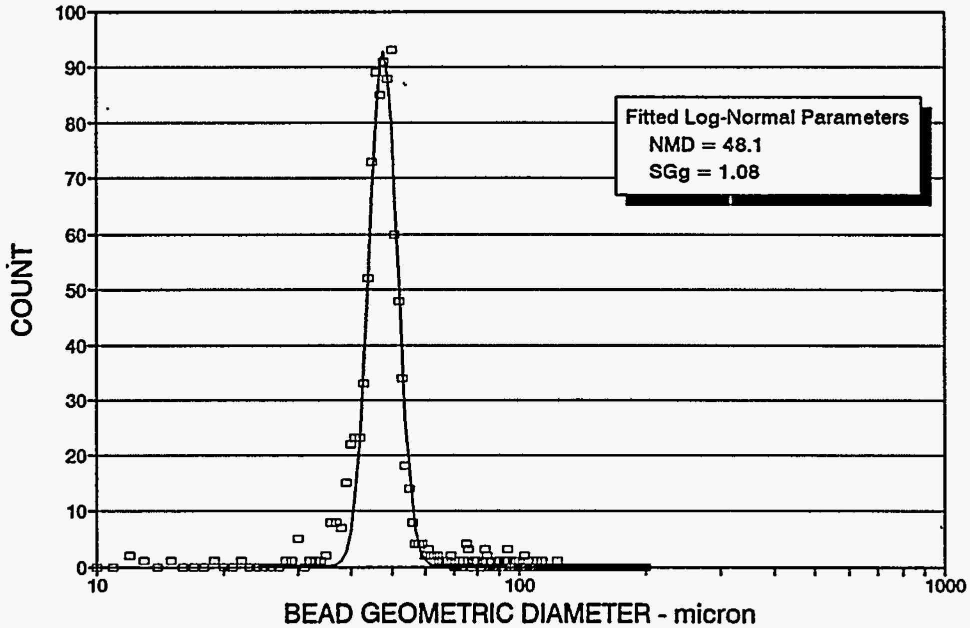

Figure 10 Graphical comparison of measured data (boxes) and a fitted log-normal function (solid line) for the Class IV - Medium bead category

6.0 Summary and Conclusions

Commercially available soda-lime glass beads were examined for size and morphology characteristics by a scanning electron microscope equipped with automated image processing hardware and software. Four size classifications of beads were examined in order to provide precise size and shape characterization for use in the Crystal Mist field trials conducted in December 1993 and July 1994. Measured sizes of the bead samples were found to fall within the suppliers specifications. Log-normal functions fit to the measured distributions revealed good fits, and confirming expectations that a log-normal distribution adequately defines the bead samples. The distributions were found to be quite narrow with geometric standard deviations on the order of 1.08 to 1.12 for the four size classifications examined. The image processing software also enabled an analysis of the degree to which the beads were true spheres. Results from these analysis reveal that the beads are slightly non-spherical however, their deviation from true spheres results in terminal velocity errors on the order of -2 percent when compared to true spheres. In light of the larger uncertainties in bead distribution parameters, these errors are understood to be negligible.

7.0 References

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Appendix A

Cataphote Inc. Technical Specification Sheets

Microbeads®
Engineered Particles

Cataphote Microbeads are high quality, specially engineered spherical glass products. They are manufactured from specially selected raw materials and designed to meet critical specifications of range and percent true spheres for a wide variety of industrial and scientific applications. Microbeads are available in severial series, each tailored for exacting technical and scientific applications.

Class IV Series Engineering Grade
These are designed and manufactured to meet a wide range of technical and engineered applications where roundness and tight range control are important.

Class V Series Precision Grade
Manufactured to precise specifications these spheres provide the controls necessary to achieve high performance. They are available with 90 or 95% range specified and 90 or 95% true spheres.

Class VI Series Spacer Grade
Special exacting standards are utilized to ensure size range accuracies of a maximum of 1% between screen increments. Maximum roundness requirements ensure 90% true spheres for Spacer Grade Microbeads.

Cataphote's commitment to quality
Microbeads are backed by over 40 years of Cataphote, Inc., technology - famous throughout the world for consistent quality. From our single largest bead plant in the world, we ship our product to exacting customers around the globe.

Cataphote's stringent quality control methods assure you the finest product available. Because of our state-of-the-art manufacturing methods, we guarantee the consistency of size and high percentage of rounds required for engineering applications.

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For more information, please call us.

CATAPHOTE INC.™
Part of the Worldwide Glaverbel Group

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Phone:1-800-221-2574
601-939-4612
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TECHNICAL DATA

Microbeads®

CHEMICAL PROPERTIES

All glasses are affected to some degree by chemical and weathering agents. In most cases, the effect of weathering is minute. The degree of resistance to various agents is proportional to the hardness and/or refractive index of the specific glass. The higher the refractive index, the more susceptible is the glass to chemical attack.

ACID RESISTANCE:

Microbeads have excellent resistance to most common acids. Two exceptions are hydrofluoric acid which attacks them vigorously, and phosphoric acid which will etch them in time.

ALKALI RESISTANCE:

This glass has fair resistance to mild alkalies, but strong alkali solutions, especially when hot, will etch the surface.

WATER RESISTANCE:

Water will remove some surface alkali. In the extremely fine sizes, where a tremendous surface area is exposed the beads show a fairly high alkalinity.

TYPICAL COMPOSITION OF STANDARD GLASS BEADS

Chemical	% by Weight
SiO_2	71 - 74%
Na_2O	12.0 - 15.0
CaO	8.0 - 10.0
MgO	1.5 - 3.8
Al_2O_3	0.2 - 1.5
K_2O	0 - 0.2
Fe_2O_3	0 - Trace

Note: Soda-lime plate glass is used in the manufacture of microbeads. The composition of this material is an amorphous fusion of these oxides and are not crystalline types of free oxides (silica). Therefore no danger of silicosis exist. The composition of the glass beads varies within the above limits depending upon individual sources of glass used as raw materials. The CAS Registry number for this glass is 65997-17-3.

PHYSICAL PROPERTIES

OPTICAL PROPERTIES:

Color: Glass beads are high quality, colorless optical crown lenses.

Refractive Index*: The refractive index of Microbeads is 1.51 using a tungsten light source.

WEIGHT PROPERTIES:

*Density of the solid glass is 2.42 - 2.50 g/cm3 (grams per cubic centimeter).

Bulk density can be as low as 1.36 g/cm3 and as high as 1.55. Average values are usually 1.45 - 1.50. For specific requirements contact technical services.

THERMAL PROPERTIES:

*Coefficient of thermal expansion, for the range 0 - 300° C, is 8.5 - 8.7 x 10-6 per ° C.

*Thermal conductivity (approximate values):

at -100° C	1.9 x 10-3 (cal. cm/cm2.0 C)
at 0° C	2.4 x 10-3
at 100° C	2.7 x 10-3

CATAPHOTE INC™

Microbeads (continued)

*Mean specific heat (cm) for the range:

0 - 200° C	0.216 cal/g.° C
0 - 400° C	0.241
0 - 800° C	0.272

ELECTRICAL PROPERTIES:
*Dielectric constant at 1 MHz and 20° C is 7.0
*Loss tangent (%) at 1 MHz and 20° C is 0.40
*Log of volume resistivity is 6.5 at 250° C and 5.2 at 350° C.

STRENGTH PROPERTIES:
*Modulus of elasticity (Young's modulus) at 20° C is 10.5 x 106 pounds per square inch.

*The hardness of Microbeads is approximately 5.5 on the Mohs scale.

Crushing strength: The spherical shape results in tremendous resistance to crushing and for this reason, the beads can successfully be used on highways and in "shot" blasting of metal and other surfaces. The resistance strength is approximately 40,000 psi.

VISCOSITY DATA:

Softening point	722 - 730°C
Annealing point	540 - 548° C
Strain point	505 - 510° C

*These are approximate values only, and apply to the solid glass rather than to beads in bulk.

Because glass is not a crystalline solid (it has a molecular structure similar to that of a liquid at very low temperatures), it does not have a sharply defined melting point, but rather a gradual decrease in viscosity (increase in fluidity) as the temperature increases.

Surface softening	400° C	(750° F)
Softening throughout	800° C	(1475° F)
Molten stream	1200° C	(2,192° F)

Cataphote's commitment to quality

Microbeads are backed by over 40 years of Cataphote, Inc., technology - famous throughout the world for consistent quality. From our single largest bead plant in the world, we ship our product to exacting customers around the globe.

Cataphote's stringent quality control methods assure you the finest product available. Because of our state-of-the-art manufacturing methods, we guarantee the consistency of size and high percentage of rounds required for engineering applications.

8/26/92

For more information, please call us.

CATAPHOTE INC.™

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601-939-4612

Microbeads®

Class IV
Engineering Grade

Microbead engineering grade spheres are manufactured from high quality optial crown glass. The compositions are of a type designed to resist wear and fracture. These spheres are annealed in their spherical shape to equalize internal stresses, containing not more than fifteen percent (15%) irregularly shaped particles. Engineering grade is reasonably free of sharp angular particles, particles showing milkiness or surface scoring and foreign matter. These spheres are offered in a range of sizes that are guaranteed to be eighty percent within the range specified.

A variety of surface treatments are available including silicone,silane or specialty coatings. If not specified all material will have non-treated surfaces. Engineering grade spheres show no tendency toward decomposition, including surface etching, when exposed to atmospheric conditions, moisture, dilute acids or alkalines.

Refractive Index: 1.51 (Tested by liquid immersion method at 25° C).
Range: 80%
True Spheres: 85%
Specific Gravity: 2.42 - 2.50
Color: Crystal and free from all surface films.

REGULAR

Reg. Sieve Size	Nominal Range (In Inches)	Micron Range
-20+30	.0328 - .0232	840 - 590
-30+40	.0232 - .0164	590 - 420
-35+45	.0195 - .0138	500 - 350
-40+50	.0164 - .0116	420 - 297
- 45+60	.0138 - .0097	350 - 250
-50+70	.0116 - .0082	297 - 210
-60+80	.0097 - .0069	250 - 177
-70+100	.0082 - .0058	210 - 149
-80+120	.0069 - .0049	177 - 125
-100+140	.0058 - .0041	149 - 105
-120+170	.0049 - .0035	125 - 88
-140+200	.0041 - .0029	105 - 74
-170+230	.0035 - .0024	88 - 62
-200+270	.0029 - .0021	74 - 53
* -230+325	.0024 - .0017	62 - 44 ✓
ULTRA FINE		
-270+400	.0021 - .0011	53 - 37
-325	.0017 - .0005	44 - 13
-400	.0015 - .0004	37 - 1

Cataphote's commitment to quality

Microbeads are backed by over 40 years of Cataphote, Inc., technology - famous throughout the world for consistent quality. From our single largest bead plant in the world, we ship our product to exacting customers around the globe.

Cataphote's stringent quality control methods assure you the finest product available. Because of our state-of-the-art manufacturing methods, we guarantee the consistency of size and high percentage of rounds required for engineering applications.

9/92

CATAPHOTE INC.™

Part of the Worldwide Glaverbel Group

Post Office Box 2369
Jackson, Mississippi 39225-2369 USA
Phone:1-800-221-2574
601-939-4612
FAX: 601-932-5339

Microbeads®

Class V
Precision Grade

Microbead Precision grade spheres are manufactured from high quality optcial crown glass. The compositions are of a type designed to resist wear and fracture. These spheres are annealed in their spherical shape to equalize internal stresses. They contain no more than two percent (2%) irregular shaped particles and are reasonably free of sharp angular particles or particles showing milkiness or surface scoring and foreign matter. These spheres are offered in a range of sizes that are guaranteed to be 90 or 95% within the range specified.

All material is 90% in range with a minimum of 90% true spheres. 95% true spheres can be specified at an additional charge.

Range: 90%
True Spheres: 90%, or 95%.

Refractive Index: 1.51 (Tested by liquid immersion method at 25° C).

Specific Gravity: 2.42 - 2.50

Color: Crystal and free from all surface films.

	U.S. Sieve Size	Nominal Range (In Inches)	Micron Range	
	-20 + 25	.0331 - .0278	841 - 707	
	-25 + 30	.0278 - .0234	707 - 595	
	-30 + 35	.0234 - .0197	595 - 500	
	-35 + 40	.0197 - .0165	500 - 420	
	-40 + 45	.0165 - .0139	420 - 354	
	-45 + 50	.0139 - .0116	354 - 297	
	-50 + 60	.0116 - .0098	297 - 250	
	-60 + 70	.0098 - .0083	250 - 210	
*	-70 + 80	.0083 - .0070	210 - 177	* $22/kg
	-80 +100	.0070 - .0059	177 - 149	
	-100+120	.0059 - .0049	149 - 125	
	-120+140	.0049 - .0041	125 - 105	
	-140+170	.0041 - .0035	105 - 88	
	-170+200	.0035 - .0029	88 - 74	* $27.50/kg
*	-200+230	.0029 - .0025	74 - 63	
	-230+270	.0025 - .0021	63 - 53	
	-270+325	.0021 - .0017	53 - 44	
*	-325+400	.0017 - .0015	44 - 37	* $55/kg

8/26/92

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Cataphote's stringent quality control methods assure you the finest product available. Because of our state-of-the-art manufacturing methods, we guarantee the consistency of size and high percentage of rounds required for engineering applications.

For more information, please call us.

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MATERIAL SAFETY DATA SHEET
FOR SODA LIME GLASS

TO THE PURCHASER: This MSDS contains important environmental, health and toxicology information for your employees who have ordered this product. Please be sure this information is given to them. If you resell this product, a copy of the MSDS should be given to the buyer.

MANUFACTURER:	CATAPHOTE, INC. P.O. Box 2369 Jackson, MS 39225-2369	ISSUE DATE: 2-19-93
TELEPHONE:	EMERGENCY INFORMATION	(601)939-4612 1-800-221-2574

SECTION I

Product Name: GLAS-SHOT, MICROBEADS, MACROBEADS, FILLER BEADS, GLASS BEADS, PAVEMENT BEADS AND MIL SPEC BEADS, CRUSHED GLASS (CULLET)

Chemical Abstract Service Number: 65997-17-3
HMIS: Health 0 Flammability: 0 Reactivity: 0

SECTION II - HAZARDOUS INGREDIENTS

Hazardous Components	OSHA PEL	ACGIH TLV
Nuisance dust	15 mg/m3	10 mg/m3
Nuisance dust-respirable	5 mg/m3	5 mg/m3

Note: Soda-lime plate glass is used in the manufacture of glass beads. The composition of this material is an amorphous fusion of these oxides and are not crystalline types of free oxides (silica). Therefore, no danger of silicosis exist.

SARA TITLE III - INFORMATION
This product is not an extremely hazardous material according to Federal Register, Vol. 51, No. 221, PP 41582-41594. It is not on the toxic chemicals listed in Committee Print Number 99-169 and is not a hazardous substance identified on the list of CERCLA chemicals.

SECTION III - PHYSICAL/CHEMICAL CHARACTERISTICS

Boiling Point - not measurable
Vapor pressure - n/a
Vapor Density - n/a
Solubility in Water - n/a
Appearance and Odor -white, tasteless, odorless

Specific Gravity - 2.4 - 2.6
Melting Point - above 1100°F
Evaporation Rate - n/a

SECTION I V - FIRE AND EXPLOSION HAZARD DATA

Flash Point - n/a
Flammable Limits - does not ignite
Extinguishing Media - not a fire hazard
LEL - n/a UEL - n/a
Special Fire Fighting Procedures - not required
Unusual Fire and Explosion Hazards - none

SECTION V - REACTIVITY DATA

Stability - stable
Conditions to avoid - n/a
Incapability (Materials to avoid) - Concentrated Hydrofluoric acid
Hazardous Decomposition or by products - n/a
Hazardous Polymerization - will not occur
Conditions to Avoid - none

SECTION VI - HEALTH HAZARD DATA

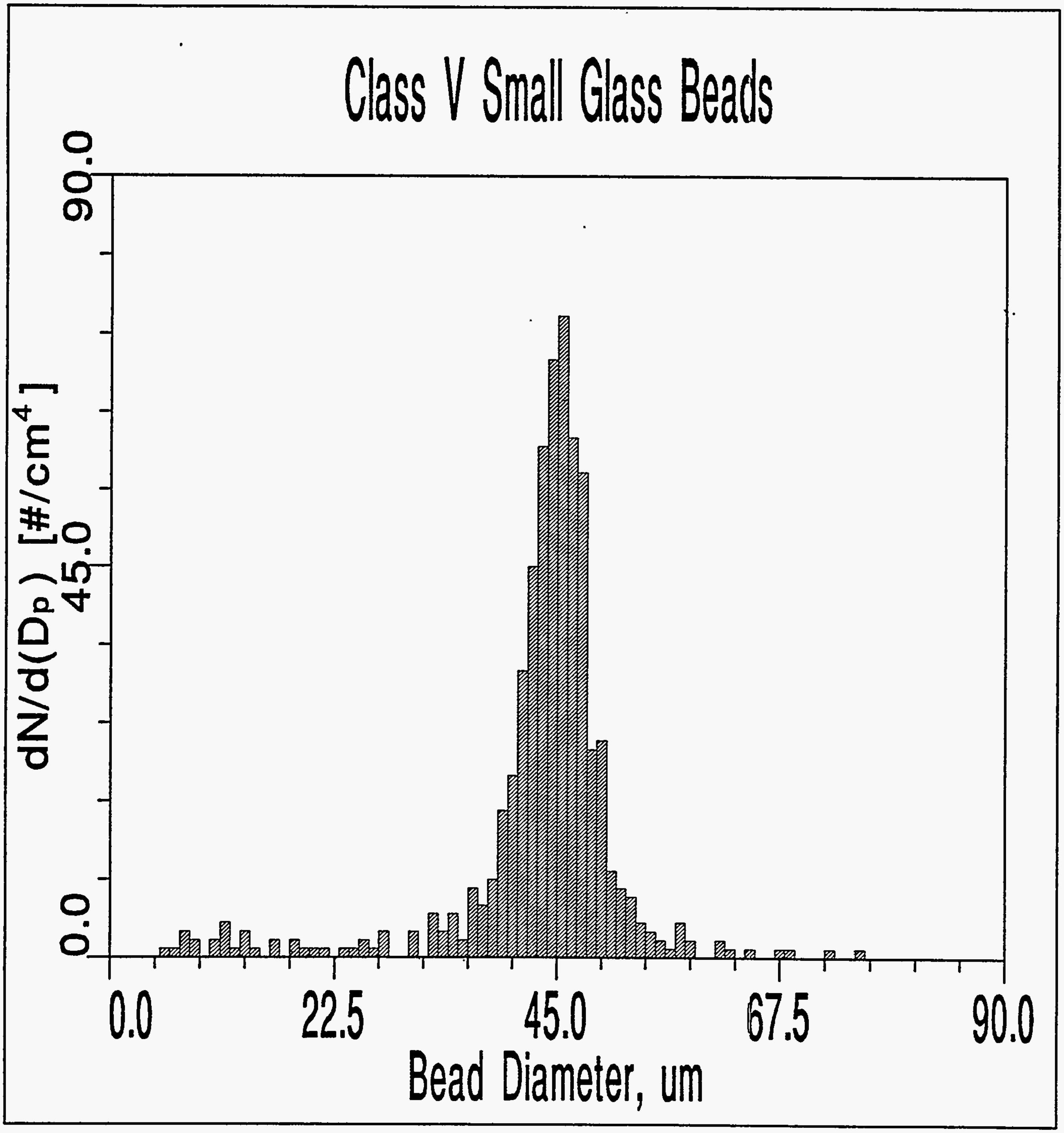
ROUTES OF ENTRY - inhalation, ingestion
HEALTH HAZARDS - none
CARCINOGENICITY - this product is not listed as a potential carcinogen in either the NTP, IARC, or OSHA.
Signs and Symptoms of Exposure - Overexposure may cause temporary respiratory and eye irritation.
Medical Conditions Generally Aggravated by Exposure - Overexposure can aggravate existing respiratory conditions and eye irritation.
Emergency and First Aid Procedures - If beads or dust cause eye irritation, flush the affected eye(s) with water or commercial eye wash. If unable to remove bead/dust by this method, seek medical care. If existing respiratory conditions are aggravated in your use of this product, get to a well ventilated area. Seek medical attention if condition is not alleviated.
Steps to be Taken in Case Material is Released or Spilled - Vacuum or sweep up excess material to avoid a possible slipping hazard.
WASTE DISPOSAL METHOD - Glass beads are considered to be non-hazardous by the EPA under 29CFR 1910.1200, and if disposed as waste, the RCRA status of UNUSED material is non-hazardous according to the list of CERCLA chemicals. If permitted by applicable Federal, State and Local regulation, glass beads can be disposed of in a solid waste landfill.
Precautions to be Taken in Handling and Storing - none
Other Precautions - none

SECTION VII - CONTROL MEASURES

Respiratory Protection - Use NIOSH approved dust respirator
Ventilation - Local Exhaust - As required for nuisance dust
Mechanical - As required for nuisance dust
Protective Gloves - As required per job
Eye Protection - Safety glasses/goggles for dust
Other Protection Clothing or Equipment - none

Appendix B

Bead Sizing Raw Data


Class V Small Glass Beads
dN/d(Dp) [#/cm4]
90.0
45.0
0.0
0.0
22.5
45.0
67.5
90.0
Bead Diameter, um

DISTFIT REPORT FOR THE INPUT DATA

Class V Small Glass Beads
DATE: 1/26/95 TIME: 16:33
User name: Wayne Einfeld
Data File: CLASSVS
Moment Type (X-axis) : Dp [um]
Included intervals : 16.0 - 65.0 [um] (16 - 64)
Weighting Type (Y-axis): N [#/cm3]
Input Data Type : Interval

GEOMETRIC MEASURES OF CENTRAL TENDENCY

	Total	Mean	Median	Mode	Std Dev
Discrete data :	584.0	43.9	44.9	45.3	1.16
Analytical data:	518.0	44.9	44.9	---	1.08
Function :	515.0	44.9	44.9	---	1.08

ANALYTICAL FITTING FUNCTIONS

Type	Par 1	Par 2	Par 3	ChiSq
1: LNDF	N = 518.0	NMD = 44.9	SDg = 1.08	0.112

FRACTIONAL CLASSIFICATIONS

Respirable N Fraction	Discrete Data	Analytical Data	Function
ACGIH Based on LNDF:	1.69E-9	1.147E-13	3.635E-14
ACGIH Based on Polynomial:	0.0	0.0	2.346E-3:

Size Classification	Discrete Data	Analytical Data	Function
Fraction < 1 [um]:	0.0	0.0	0.0
Fraction > 1 [um]:	1.0	1.0	1.0

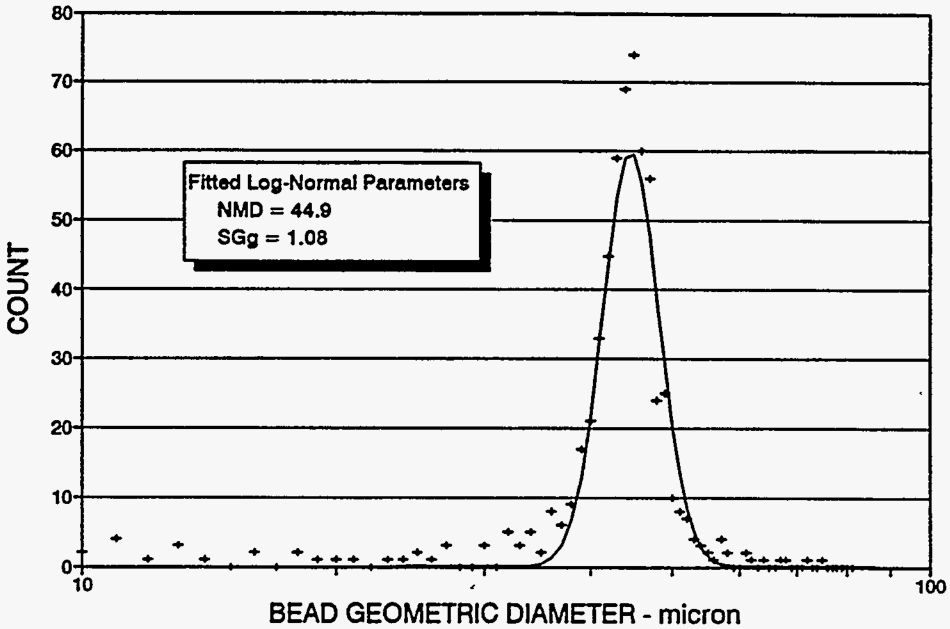
DISCRETE DATA

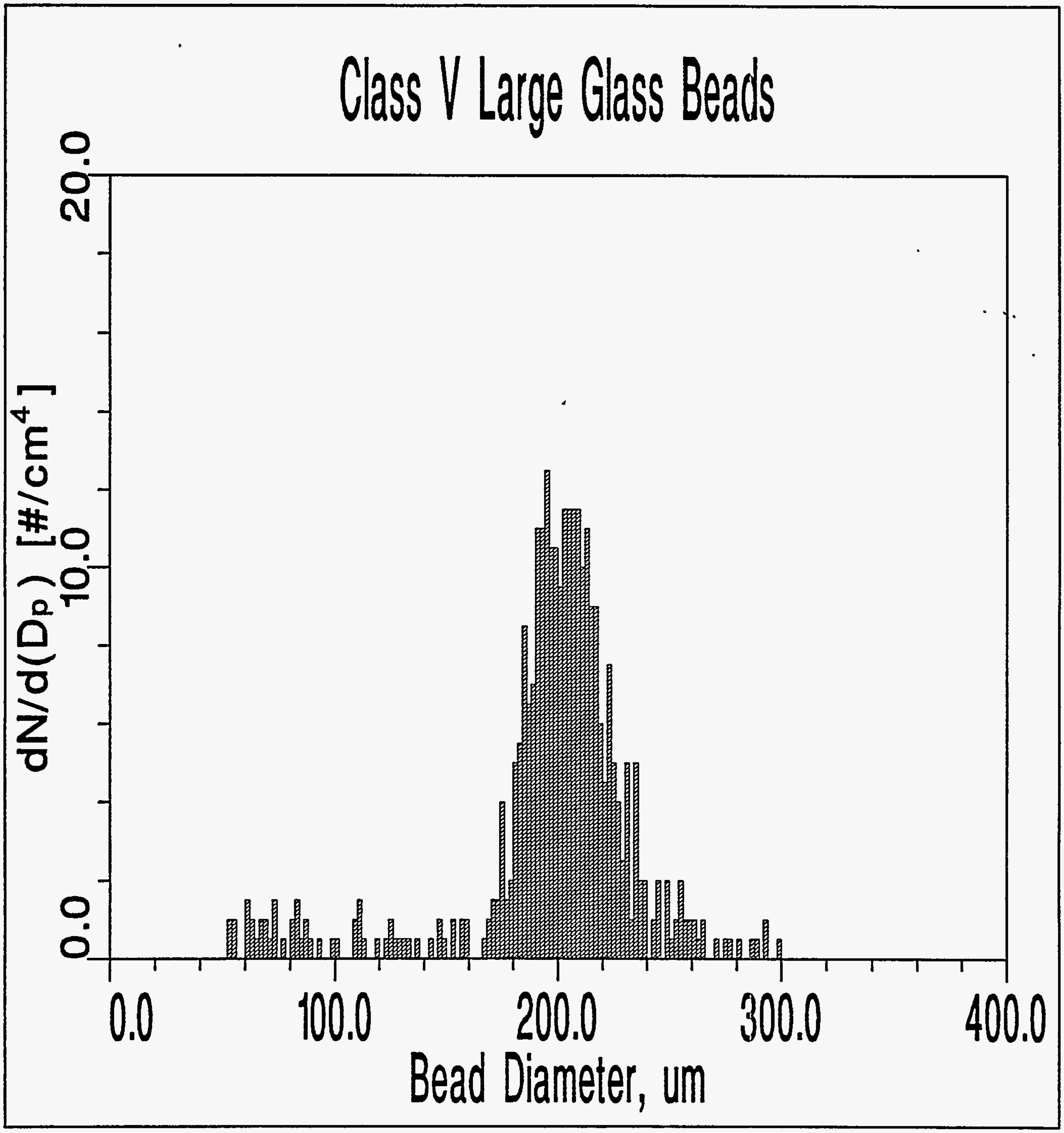
Dp	Input Data	Analytical Data	% Diff.	Correction
1.0	1.0E-30	0.0	100.0	1.0
2.0	1.0E-30	0.0	100.0	1.0
3.0	1.0E-30	0.0	100.0	1.0
4.0	1.0E-30	0.0	100.0	1.0
5.0	1.0	0.0	100.0	1.0
6.0	1.0	0.0	100.0	1.0
7.0	3.0	0.0	100.0	1.0
8.0	2.0	0.0	100.0	1.0
9.0	1.0E-30	0.0	100.0	1.0
10.0	2.0	0.0	100.0	1.0
11.0	4.0	0.0	100.0	1.0
12.0	1.0	0.0	100.0	1.0
13.0	3.0	0.0	100.0	1.0
14.0	1.0	0.0	100.0	1.0

15.0	1.0E-30	0.0	100.0	1.0
16.0	2.0	1.0E-30	100.0	1.0
17.0	1.0E-30	1.0E-30	0.0	1.0
18.0	2.0	1.7922E-29	100.0	1.0
19.0	1.0	5.6418E-26	100.0	1.0
20.0	1.0	7.6206E-23	100.0	1.0
21.0	1.0	4.8792E-20	100.0	1.0
22.0	1.0E-30	1.6112E-17	-1.6112E15	1.0
23.0	1.0	2.9494E-15	100.0	1.0
24.0	1.0	3.1836E-13	100.0	1.0
25.0	2.0	2.1377E-11	100.0	1.0
26.0	1.0	9.3537E-10	100.0	1.0
27.0	3.0	2.7773E-8	100.0	1.0
28.0	1.0E-30	5.7986E-7	-5.7986E25	1.0
29.0	1.0E-30	8.7837E-6	-8.7837E26	1.0
30.0	3.0	9.9255E-5	100.0	1.0
31.0	1.0E-30	8.5753E-4	-8.5753E28	1.0
32.0	5.0	5.7908E-3	99.88	1.0
33.0	3.0	3.1174E-2	98.96	1.0
34.0	5.0	0.1362	97.28	1.0
35.0	2.0	0.4904	75.48	1.0
36.0	8.0	1.478	81.53	1.0
37.0	6.0	3.773	37.12	1.0
38.0	9.0	8.263	8.185	1.0
39.0	17.0	15.69	7.69	1.0
40.0	21.0	26.1	-24.28	1.0
41.0	33.0	38.36	-16.24	1.0
42.0	45.0	50.24	-11.66	1.0
43.0	59.0	59.1	-.1699	1.0
44.0	69.0	62.87	8.889	1.0
45.0	74.0	60.87	17.74	1.0
46.0	60.0	53.98	10.04	1.0
47.0	56.0	44.07	21.31	1.0
48.0	24.0	33.3	-38.76	1.0
49.0	25.0	23.4	6.39	1.0
50.0	10.0	15.36	-53.61	1.0
51.0	8.0	9.457	-18.21	1.0
52.0	7.0	5.481	21.7	1.0
53.0	4.0	3.001	24.96	1.0
54.0	3.0	1.558	48.06	1.0
55.0	2.0	0.7691	61.55	1.0
56.0	1.0	0.362	63.8	1.0
57.0	4.0	0.1629	95.93	1.0
58.0	2.0	7.0301E-2	96.48	1.0
59.0	1.0E-30	2.9147E-2	-2.9147E30	1.0
60.0	1.0E-30	1.1637E-2	-1.1637E30	1.0
61.0	2.0	4.484E-3	99.78	1.0
62.0	1.0	1.6706E-3	99.83	1.0
63.0	1.0E-30	6.0291E-4	-6.0291E28	1.0
64.0	1.0	2.1115E-4	99.98	1.0
65.0	1.0E-30	7.187E-5	-7.187E27	1.0
66.0	1.0E-30	2.3814E-5	-2.3814E27	1.0
67.0	1.0	7.6919E-6	100.0	1.0
68.0	1.0	2.4253E-6	100.0	1.0
69.0	1.0E-30	7.4743E-7	-7.4743E25	1.0

70.0	1.0E-30	2.2542E-7	-2.2542E25	1.0
71.0	1.0E-30	6.6604E-8	-6.6604E24	1.0
72.0	1.0	1.9301E-8	100.0	1.0
73.0	1.0E-30	5.4916E-9	-5.4916E23	1.0
74.0	1.0E-30	1.5355E-9	-1.5355E23	1.0
75.0	1.0	4.223E-10	100.0	1.0
76.0	1.0E-30	1.1435E-10	-1.1435E22	1.0
77.0	1.0E-30	3.0507E-11	-3.0507E21	1.0
78.0	1.0E-30	8.0256E-12	-8.0256E20	1.0
79.0	1.0E-30	2.0835E-12	-2.0835E20	1.0
80.0				

CLASS V SMALL GLASS BEAD DISTRIBUTION
MEASURED AND LOG-NORMAL FIT





Class V Large Glass Beads
dN/d(Dp) [#/cm4]
20.0
10.0
0.0
0.0
100.0
200.0
300.0
400.0
Bead Diameter, um

DISTFIT REPORT FOR THE INPUT DATA

Class V Large Glass Beads
DATE: 1/26/95 TIME: 17:08
User name: Wayne Einfeld
Data File: CLASS5L
Moment Type (X-axis) : Dp [um]
Included intervals : 146.0 - 242.0 [um] (49 - 96)
Weighting Type (Y-axis): N [#/cm3]
Input Data Type : Interval

GEOMETRIC MEASURES OF CENTRAL TENDENCY

	Total	Mean	Median	Mode	Std Dev
Discrete data :	487.0	202.0	203.0	195.0	1.09
Analytical data:	457.0	203.0	203.0	---	1.08
Function :	448.0	204.0	204.0	---	1.09

ANALYTICAL FITTING FUNCTIONS

Type	Par 1	Par 2	Par 3	ChiSq
1: LNDF	N = 463.0	NMD = 204.0	SDg = 1.08	6.915E-2

FRACTIONAL CLASSIFICATIONS

Respirable N Fraction	Discrete Data	Analytical Data	Function
ACGIH Based on LNDF:	0.0	0.0	1.37E-36
ACGIH Based on Polynomial:	0.0	0.0	0.0

Size Classification	Discrete Data	Analytical Data	Function
Fraction < 1 [um]:	0.0	0.0	0.0
Fraction > 1 [um]:	1.0	1.0	1.0

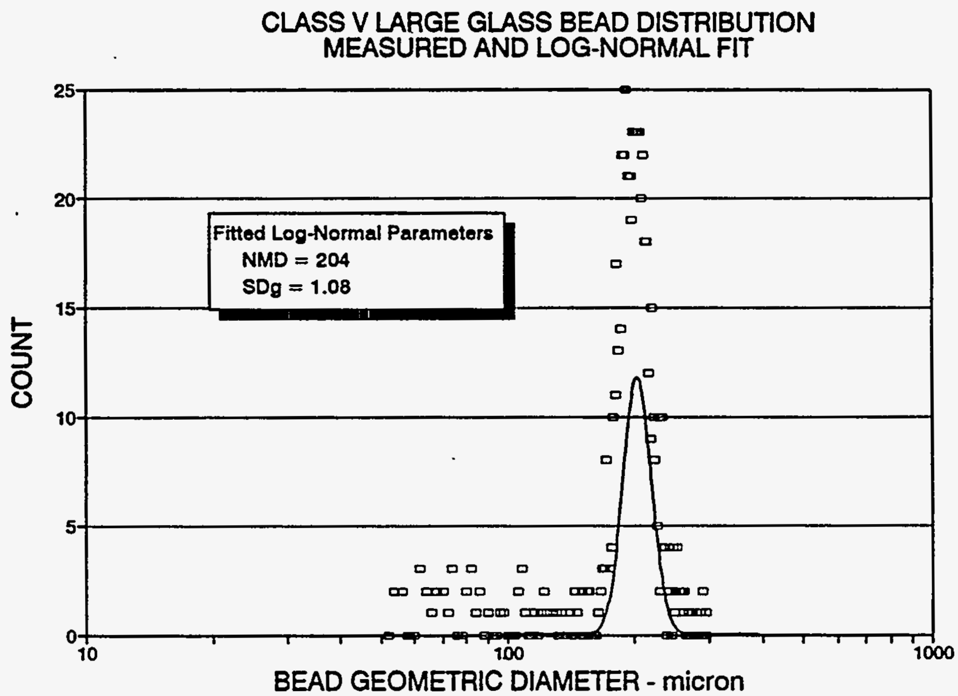
DISCRETE DATA

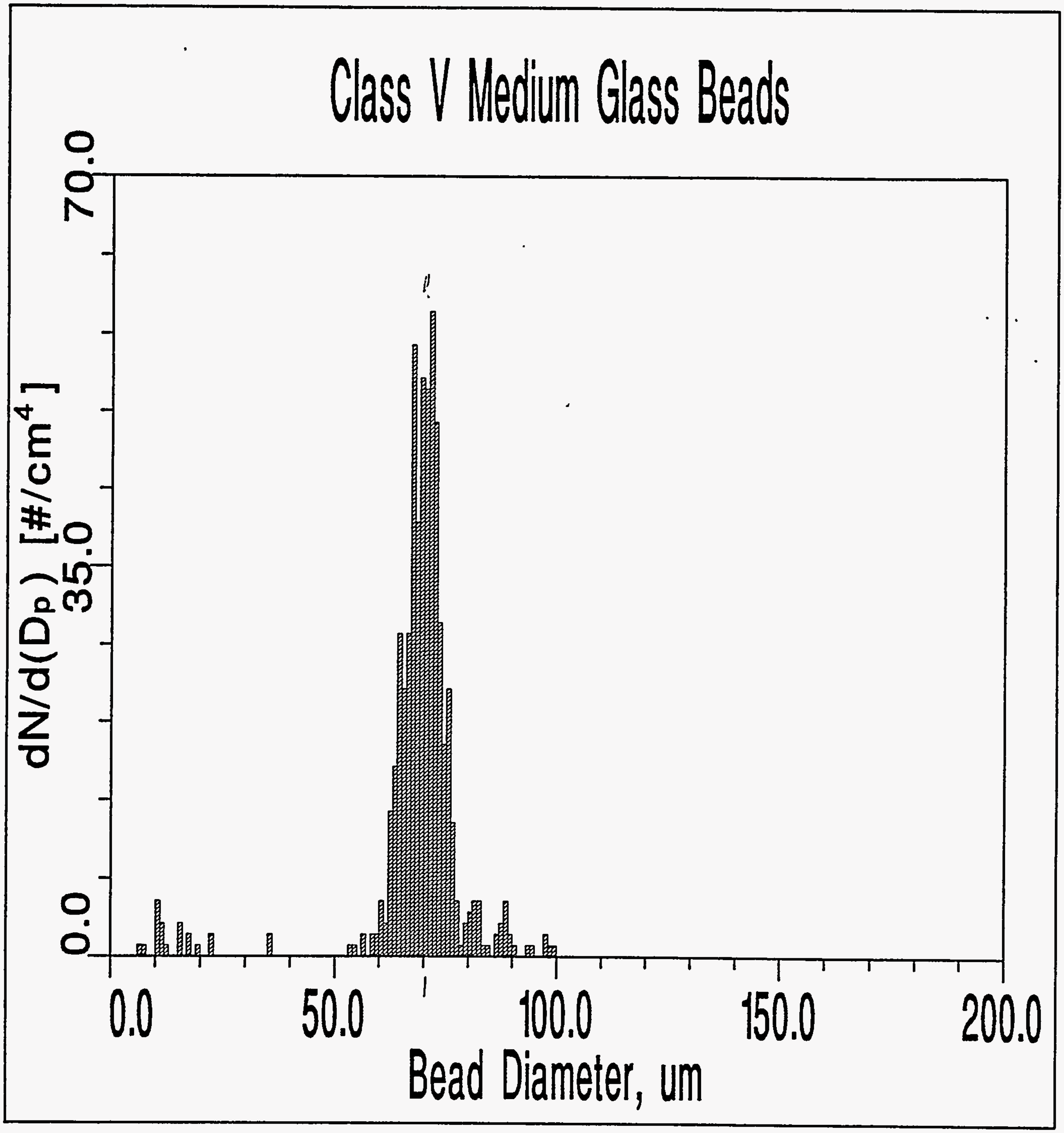
Dp	Input Data	Analytical Data	% Diff.	Correction
50.0	1.0E-30	0.0	100.0	1.0
52.0	2.0	0.0	100.0	1.0
54.0	2.0	0.0	100.0	1.0
56.0	1.0E-30	0.0	100.0	1.0
58.0	1.0E-30	0.0	100.0	1.0
60.0	3.0	0.0	100.0	1.0
62.0	2.0	0.0	100.0	1.0
64.0	1.0	0.0	100.0	1.0
66.0	2.0	0.0	100.0	1.0
68.0	2.0	0.0	100.0	1.0
70.0	1.0	0.0	100.0	1.0
72.0	3.0	2.566E-36	100.0	1.0
74.0	1.0E-30	2.1184E-34	99.98	1.0
76.0	1.0	1.4059E-32	100.0	1.0

78.0	1.0E-30	7.5373E-31	24.63	1.0
80.0	2.0	3.3074E-29	100.0	1.0
82.0	3.0	1.2022E-27	100.0	1.0
84.0	1.0	3.6605E-26	100.0	1.0
86.0	2.0	9.4313E-25	100.0	1.0
88.0	1.0	2.0758E-23	100.0	1.0
90.0	1.0E-30	3.9369E-22	-3.9369E10	1.0
92.0	1.0	6.4864E-21	100.0	1.0
94.0	1.0E-30	9.3539E-20	-9.3539E12	1.0
96.0	1.0E-30	1.1889E-18	-1.1889E14	1.0
98.0	1.0	1.3406E-17	100.0	1.0
100.0	1.0	1.3491E-16	100.0	1.0
102.0	1.0E-30	1.2187E-15	-1.2187E17	1.0
104.0	1.0E-30	9.9337E-15	-9.9337E17	1.0
106.0	1.0E-30	7.3426E-14	-7.3426E18	1.0
108.0	2.0	4.9444E-13	100.0	1.0
110.0	3.0	3.0465E-12	100.0	1.0
112.0	1.0	1.7246E-11	100.0	1.0
114.0	1.0E-30	9.0044E-11	-9.0044E21	1.0
116.0	1.0E-30	4.3516E-10	-4.3516E22	1.0
118.0	1.0	1.9532E-9	100.0	1.0
120.0	1.0E-30	8.1691E-9	-8.1691E23	1.0
122.0	1.0	3.1931E-8	100.0	1.0
124.0	2.0	1.1698E-7	100.0	1.0
126.0	1.0	4.0278E-7	100.0	1.0
128.0	1.0	1.3067E-6	100.0	1.0
130.0	1.0	4.0038E-6	100.0	1.0
132.0	1.0	1.1614E-5	100.0	1.0
134.0	1.0E-30	3.1963E-5	-3.1963E27	1.0
136.0	1.0	8.3627E-5	99.99	1.0
138.0	1.0E-30	2.0843E-4	-2.0843E28	1.0
140.0	1.0E-30	4.9575E-4	-4.9575E28	1.0
142.0	1.0	1.1273E-3	99.89	1.0
144.0	1.0E-30	2.455E-3	-2.455E29	1.0
146.0	2.0	5.1282E-3	99.74	1.0
148.0	1.0	1.0291E-2	98.97	1.0
150.0	1.0E-30	1.9867E-2	-1.9867E30	1.0
152.0	2.0	3.6952E-2	98.15	1.0
154.0	1.0E-30	6.6302E-2	-6.6302E30	1.0
156.0	2.0	0.1149	94.25	1.0
158.0	2.0	0.1926	90.37	1.0
160.0	1.0E-30	0.3125	-3.1254E31	1.0
162.0	1.0E-30	0.4916	-4.9159E31	1.0
164.0	1.0E-30	0.7503	-7.5027E31	1.0
166.0	1.0	1.112	-11.22	1.0
168.0	2.0	1.603	19.85	1.0
170.0	3.0	2.248	25.06	1.0
172.0	3.0	3.071	-2.37	1.0
174.0	8.0	4.09	48.88	1.0
176.0	3.0	5.314	-77.12	1.0
178.0	4.0	6.741	-68.53	1.0
180.0	10.0	8.357	16.43	1.0
182.0	11.0	10.13	7.907	1.0
184.0	17.0	12.02	29.31	1.0
186.0	13.0	13.96	-7.372	1.0

188.0	14.0	15.89	-13.48	1.0
190.0	22.0	17.73	19.41	1.0
192.0	22.0	19.41	11.78	1.0
194.0	25.0	20.86	16.57	1.0
196.0	21.0	22.02	-4.838	1.0
198.0	21.0	22.84	-8.739	1.0
200.0	19.0	23.29	-22.56	1.0
202.0	23.0	23.36	-1.562	1.0
204.0	23.0	23.06	-.2716	1.0
206.0	23.0	22.42	2.53	1.0
208.0	23.0	21.47	6.669	1.0
210.0	20.0	20.26	-1.28	1.0
212.0	22.0	18.84	14.34	1.0
214.0	18.0	17.29	3.942	1.0
216.0	18.0	15.65	13.04	1.0
218.0	12.0	13.99	-16.56	1.0
220.0	9.0	12.34	-37.13	1.0
222.0	15.0	10.76	28.3	1.0
224.0	10.0	9.262	7.384	1.0
226.0	8.0	7.883	1.465	1.0
228.0	5.0	6.634	-32.67	1.0
230.0	10.0	5.521	44.79	1.0
232.0	2.0	4.546	-127.3	1.0
234.0	10.0	3.704	62.96	1.0
236.0	4.0	2.988	25.31	1.0
238.0	4.0	2.386	40.35	1.0
240.0	1.0E-30	1.887	-1.8871E32	1.0
242.0	2.0	1.479	26.07	1.0
244.0	4.0	1.148	71.3	1.0
246.0	1.0E-30	0.8835	-8.8349E31	1.0
248.0	4.0	0.674	83.15	1.0
250.0	1.0	0.5099	49.01	1.0
252.0	2.0	0.3825	80.87	1.0
254.0	4.0	0.2847	92.88	1.0
256.0	2.0	0.2103	89.49	1.0
258.0	2.0	0.1541	92.29	1.0
260.0	2.0	0.1121	94.39	1.0
262.0	1.0	8.0965E-2	91.9	1.0
264.0	2.0	5.8065E-2	97.1	1.0
266.0	1.0E-30	4.1356E-2	-4.1356E30	1.0
268.0	1.0E-30	2.9259E-2	-2.9259E30	1.0
270.0	1.0	2.0566E-2	97.94	1.0
272.0	1.0E-30	1.4364E-2	-1.4364E30	1.0
274.0	1.0	9.9697E-3	99.0	1.0
276.0	1.0	6.8781E-3	99.31	1.0
278.0	1.0E-30	4.7174E-3	-4.7174E29	1.0
280.0	1.0	3.2168E-3	99.68	1.0
282.0	1.0E-30	2.1812E-3	-2.1812E29	1.0
284.0	1.0E-30	1.471E-3	-1.471E29	1.0
286.0	1.0	9.8669E-4	99.9	1.0
288.0	1.0	6.5841E-4	99.93	1.0
290.0	1.0E-30	4.3711E-4	-4.3711E28	1.0
292.0	2.0	2.8876E-4	99.99	1.0
294.0	1.0E-30	1.8984E-4	-1.8984E28	1.0
296.0	1.0E-30	1.2421E-4	-1.2421E28	1.0

298.0	1.0	8.09E-5	99.99	1.0
300.0				


CLASS V LARGE GLASS BEAD DISTRIBUTION
MEASURED AND LOG-NORMAL FIT
Fitted Log-Normal Parameters
NMD = 204
SDg = 1.08
COUNT
25
20
15
10
5
0
10
100
1000
BEAD GEOMETRIC DIAMETER - micron


Class V Medium Glass Beads
70.0
35.0
0.0
dN/d(Dp) [#/cm4]
0.0
50.0
100.0
150.0
200.0
Bead Diameter, um

DISTFIT REPORT FOR THE INPUT DATA

~~TITLE~~ Class 5 medium
DATE: 1/26/95 TIME: 16:01
User name: Wayne Einfeld
Data File: CLASS5M
Moment Type (X-axis) : Dp [um]
Included intervals : 40.0 - 90.0 [um] (36 - 85)
Weighting Type (Y-axis): N [#/cm3]
Input Data Type : Interval

GEOMETRIC MEASURES OF CENTRAL TENDENCY

	Total	Mean	Median	Mode	Std Dev
Discrete data :	553.0	70.1	70.0	71.4	1.08
Analytical data:	489.0	69.5	69.5	---	1.06
Function :	109.0	67.1	69.5	---	1.13

ANALYTICAL FITTING FUNCTIONS

Type	Par 1	Par 2	Par 3	ChiSq
1: LNDF	N = 489.0	NMD = 69.5	SDg = 1.06	0.115

FRACTIONAL CLASSIFICATIONS

Respirable N Fraction	Discrete Data	Analytical Data	Function
ACGIH Based on LNDF:	0.0	0.0	1.153E-32
ACGIH Based on Polynomial:	0.0	0.0	1.113E-32

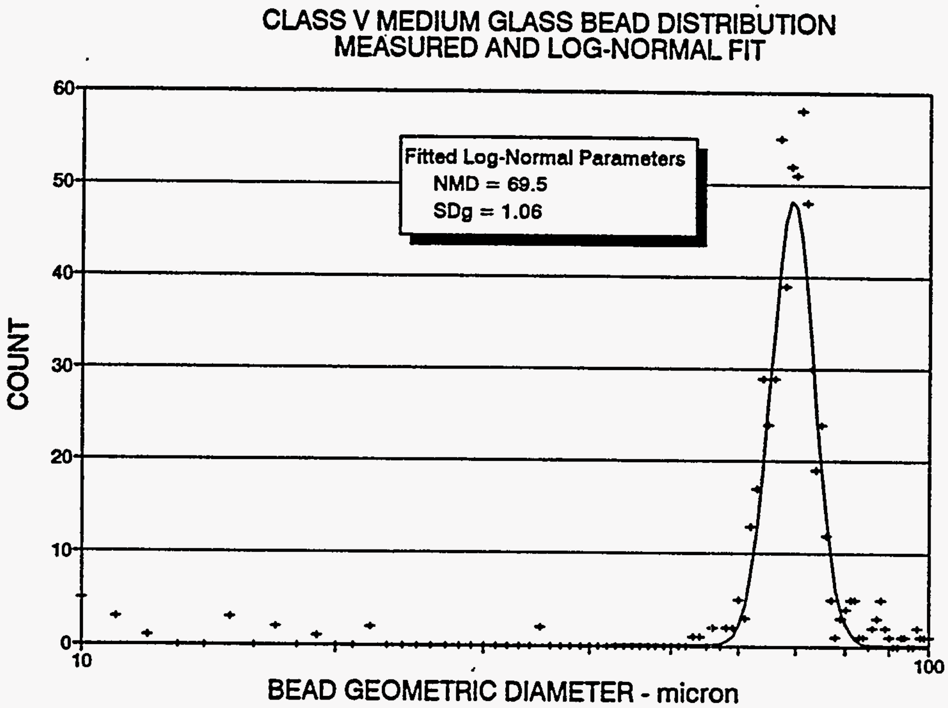
Size Classification	Discrete Data	Analytical Data	Function
Fraction < 1 [um]:	0.0	0.0	0.0
Fraction > 1 [um]:	1.0	1.0	1.0

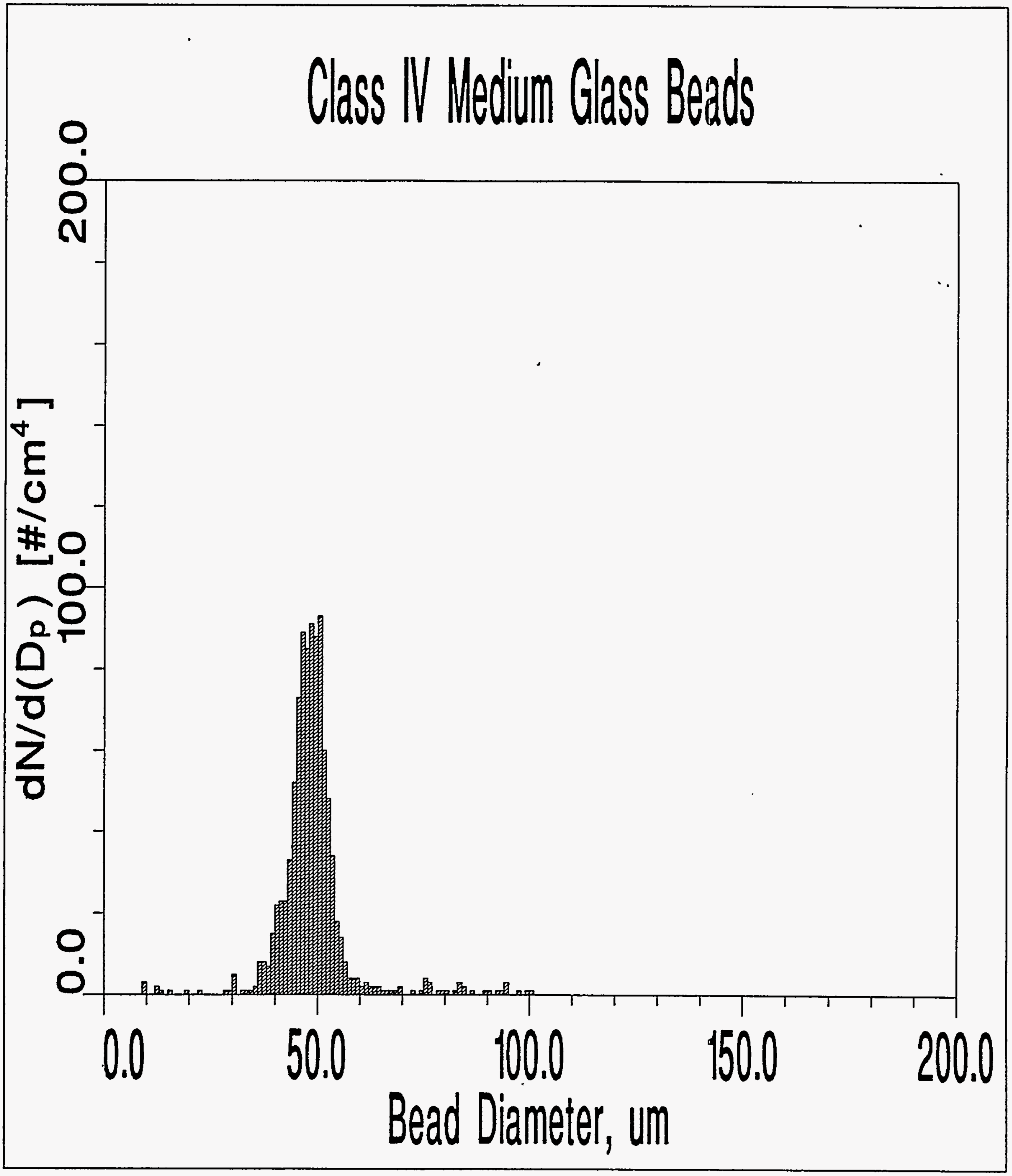
DISCRETE DATA

Dp	Input Data	Analytical Data	% Diff.	Correction
5.0	1.0E-30	0.0	100.0	1.0
6.0	1.0	0.0	100.0	1.0
7.0	1.0	0.0	100.0	1.0
8.0	1.0E-30	0.0	100.0	1.0
9.0	1.0E-30	0.0	100.0	1.0
10.0	5.0	0.0	100.0	1.0
11.0	3.0	0.0	100.0	1.0
12.0	1.0	0.0	100.0	1.0
13.0	1.0E-30	0.0	100.0	1.0
14.0	1.0E-30	0.0	100.0	1.0
15.0	3.0	0.0	100.0	1.0
16.0	1.0E-30	0.0	100.0	1.0
17.0	2.0	0.0	100.0	1.0
18.0	1.0E-30	0.0	100.0	1.0

19.0	1.0	0.0	100.0	1.0
20.0	1.0E-30	0.0	100.0	1.0
21.0	1.0E-30	0.0	100.0	1.0
22.0	2.0	0.0	100.0	1.0
23.0	1.0E-30	0.0	100.0	1.0
24.0	1.0E-30	0.0	100.0	1.0
25.0	1.0E-30	0.0	100.0	1.0
26.0	1.0E-30	0.0	100.0	1.0
27.0	1.0E-30	0.0	100.0	1.0
28.0	1.0E-30	0.0	100.0	1.0
29.0	1.0E-30	0.0	100.0	1.0
30.0	1.0E-30	0.0	100.0	1.0
31.0	1.0E-30	0.0	100.0	1.0
32.0	1.0E-30	0.0	100.0	1.0
33.0	1.0E-30	0.0	100.0	1.0
34.0	1.0E-30	1.5732E-34	99.98	1.0
35.0	2.0	1.0613E-31	100.0	1.0
36.0	1.0E-30	4.6277E-29	-4528.0	1.0
37.0	1.0E-30	1.343E-26	-1.3429E6	1.0
38.0	1.0E-30	2.6664E-24	-2.6664E8	1.0
39.0	1.0E-30	3.7133E-22	-3.7133E10	1.0
40.0	1.0E-30	3.7113E-20	-3.7113E12	1.0
41.0	1.0E-30	2.7185E-18	-2.7185E14	1.0
42.0	1.0E-30	1.4877E-16	-1.4877E16	1.0
43.0	1.0E-30	6.1915E-15	-6.1915E17	1.0
44.0	1.0E-30	1.9917E-13	-1.9917E19	1.0
45.0	1.0E-30	5.0272E-12	-5.0272E20	1.0
46.0	1.0E-30	1.0096E-10	-1.0096E22	1.0
47.0	1.0E-30	1.6341E-9	-1.6341E23	1.0
48.0	1.0E-30	2.1571E-8	-2.1571E24	1.0
49.0	1.0E-30	2.3483E-7	-2.3483E25	1.0
50.0	1.0E-30	2.1302E-6	-2.1302E26	1.0
51.0	1.0E-30	1.6257E-5	-1.6257E27	1.0
52.0	1.0E-30	1.0531E-4	-1.0531E28	1.0
53.0	1.0	5.8392E-4	99.94	1.0
54.0	1.0	2.7931E-3	99.72	1.0
55.0	1.0E-30	1.1611E-2	-1.1611E30	1.0
56.0	2.0	4.2233E-2	97.89	1.0
57.0	1.0E-30	0.1353	-1.3529E31	1.0
58.0	2.0	0.384	80.8	1.0
59.0	2.0	0.971	51.45	1.0
60.0	5.0	2.2	56.0	1.0
61.0	3.0	4.487	-49.58	1.0
62.0	13.0	8.281	36.3	1.0
63.0	17.0	13.89	18.31	1.0
64.0	29.0	21.26	26.71	1.0
65.0	24.0	29.81	-24.21	1.0
66.0	29.0	38.45	-32.6	1.0
67.0	55.0	45.79	16.74	1.0
68.0	39.0	50.52	-29.53	1.0
69.0	52.0	51.79	0.4106	1.0
70.0	51.0	49.49	2.961	1.0
71.0	58.0	44.22	23.77	1.0
72.0	48.0	37.04	22.84	1.0
73.0	30.0	29.16	2.801	1.0

74.0	19.0	21.64	-13.87	1.0
75.0	24.0	15.16	36.82	1.0
76.0	12.0	10.06	16.15	1.0
77.0	5.0	6.334	-26.69	1.0
78.0	1.0	3.792	-279.2	1.0
79.0	3.0	2.162	27.93	1.0
80.0	4.0	1.177	70.58	1.0
81.0	5.0	0.6125	87.75	1.0
82.0	5.0	0.3053	93.89	1.0
83.0	1.0	0.146	85.4	1.0
84.0	1.0	6.7095E-2	93.29	1.0
85.0	1.0E-30	2.9672E-2	-2.9672E30	1.0
86.0	2.0	1.2646E-2	99.37	1.0
87.0	3.0	5.2015E-3	99.83	1.0
88.0	5.0	2.0674E-3	99.96	1.0
89.0	2.0	7.9507E-4	99.96	1.0
90.0	1.0	2.962E-4	99.97	1.0
91.0	1.0E-30	1.0702E-4	-1.0702E28	1.0
92.0	1.0E-30	3.7543E-5	-3.7543E27	1.0
93.0	1.0	1.2801E-5	100.0	1.0
94.0	1.0	4.2466E-6	100.0	1.0
95.0	1.0E-30	1.372E-6	-1.372E26	1.0
96.0	1.0E-30	4.3213E-7	-4.3213E25	1.0
97.0	2.0	1.3279E-7	100.0	1.0
98.0	1.0	3.9852E-8	100.0	1.0
99.0	1.0	1.1689E-8	100.0	1.0
100.0				


CLASS V MEDIUM GLASS BEAD DISTRIBUTION
MEASURED AND LOG-NORMAL FIT
Fitted Log-Normal Parameters
NMD = 69.5
SDg = 1.06
COUNT
60
50
40
30
20
10
0
10
100
BEAD GEOMETRIC DIAMETER - micron



Class IV Medium Glass Beads
200.0
100.0
0.0
dN/d(Dp) [#/cm4]
0.0
50.0
100.0
150.0
200.0
Bead Diameter, um

DISTFIT REPORT FOR THE INPUT DATA

Class IV Glass Beads
DATE: 1/26/95 TIME: 14:45
User name: Wayne Einfeld
Data File: CLASS4
Moment Type (X-axis) : Dp [um]
Included intervals : 29.0 - 73.0 [um] (29 - 72)
Weighting Type (Y-axis): N [#/cm3]
Input Data Type : Interval

GEOMETRIC MEASURES OF CENTRAL TENDENCY

	Total	Mean	Median	Mode	Std Dev
Discrete data :	933.0	47.8	48.2	50.2	1.11
Analytical data:	860.0	48.1	48.1	---	1.08
Function :	1.111E3	47.3	48.1	---	1.03

ANALYTICAL FITTING FUNCTIONS

Type	Par 1	Par 2	Par 3	ChiSq
1: LNDF	N = 860.0	NMD = 48.1	SDg = 1.08	7.861E-2

FRACTIONAL CLASSIFICATIONS

Respirable N Fraction	Discrete Data	Analytical Data	Function
ACGIH Based on LNDF:	0.0	7.883E-15	1.219E-1'
ACGIH Based on Polynomial:	0.0	0.0	1.088E-3:

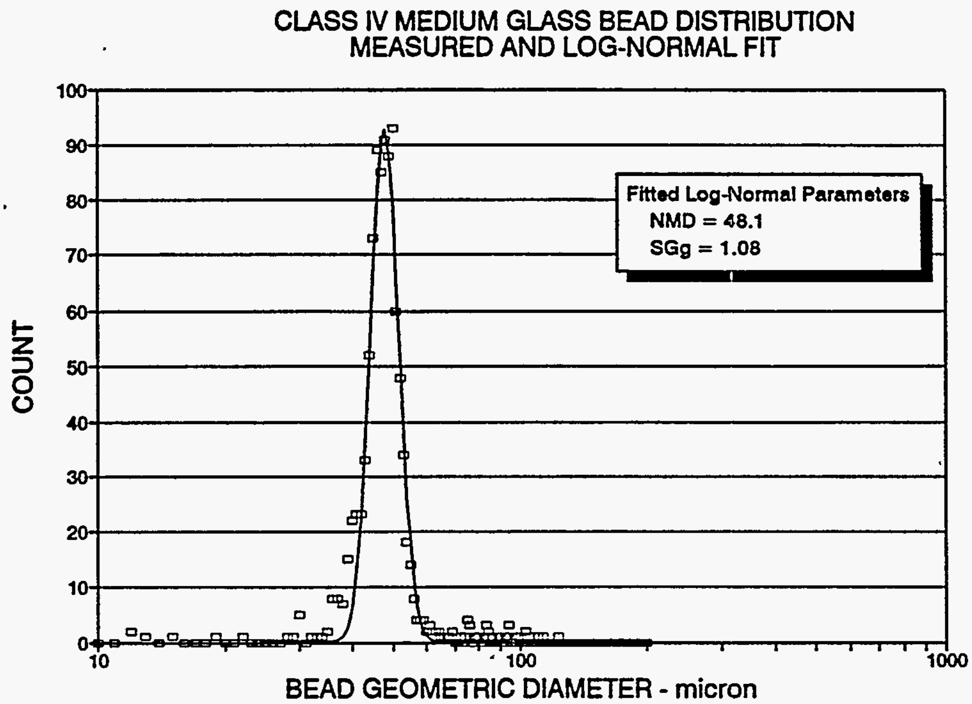
Size Classification	Discrete Data	Analytical Data	Function
Fraction < 1 [um]:	0.0	0.0	0.0
Fraction > 1 [um]:	1.0	1.0	1.0

DISCRETE DATA

Dp	Input Data	Analytical Data	% Diff.	Correction
1.0	1.0E-30	0.0	100.0	1.0
2.0	1.0E-30	0.0	100.0	1.0
3.0	1.0E-30	0.0	100.0	1.0
4.0	1.0E-30	0.0	100.0	1.0
5.0	1.0E-30	0.0	100.0	1.0
6.0	1.0E-30	0.0	100.0	1.0
7.0	1.0E-30	0.0	100.0	1.0
8.0	1.0E-30	0.0	100.0	1.0
9.0	3.0	0.0	100.0	1.0
10.0	1.0E-30	0.0	100.0	1.0
11.0	1.0E-30	0.0	100.0	1.0
12.0	2.0	0.0	100.0	1.0
13.0	1.0	0.0	100.0	1.0
14.0	1.0E-30	0.0	100.0	1.0

15.0	1.0	0.0	100.0	1.0
16.0	1.0E-30	3.2907E-35	100.0	1.0
17.0	1.0E-30	2.3853E-31	76.15	1.0
18.0	1.0E-30	6.7735E-28	-6.7635E4	1.0
19.0	1.0	8.4894E-25	100.0	1.0
20.0	1.0E-30	5.1873E-22	-5.1873E10	1.0
21.0	1.0E-30	1.6803E-19	-1.6803E13	1.0
22.0	1.0	3.0979E-17	100.0	1.0
23.0	1.0E-30	3.454E-15	-3.454E17	1.0
24.0	1.0E-30	2.4537E-13	-2.4537E19	1.0
25.0	1.0E-30	1.1618E-11	-1.1618E21	1.0
26.0	1.0E-30	3.8133E-10	-3.8133E22	1.0
27.0	1.0E-30	8.9786E-9	-8.9786E23	1.0
28.0	1.0	1.563E-7	100.0	1.0
29.0	1.0	2.0657E-6	100.0	1.0
30.0	5.0	2.1222E-5	100.0	1.0
31.0	1.0E-30	1.7308E-4	-1.7308E28	1.0
32.0	1.0	1.1417E-3	99.89	1.0
33.0	1.0	6.1951E-3	99.38	1.0
34.0	1.0	2.8072E-2	97.19	1.0
35.0	2.0	0.1077	94.62	1.0
36.0	8.0	0.354	95.57	1.0
37.0	8.0	1.009	87.39	1.0
38.0	7.0	2.517	64.04	1.0
39.0	15.0	5.55	63.0	1.0
40.0	22.0	10.91	50.42	1.0
41.0	23.0	19.25	16.28	1.0
42.0	23.0	30.75	-33.69	1.0
43.0	33.0	44.72	-35.5	1.0
44.0	52.0	59.57	-14.56	1.0
45.0	73.0	73.11	-.1518	1.0
46.0	89.0	83.08	6.649	1.0
47.0	85.0	87.84	-3.34	1.0
48.0	91.0	86.78	4.64	1.0
49.0	88.0	80.44	8.59	1.0
50.0	93.0	70.23	24.49	1.0
51.0	60.0	57.94	3.428	1.0
52.0	48.0	45.33	5.555	1.0
53.0	34.0	33.73	0.7815	1.0
54.0	18.0	23.94	-33.02	1.0
55.0	14.0	16.25	-16.09	1.0
56.0	8.0	10.58	-32.2	1.0
57.0	4.0	6.614	-65.35	1.0
58.0	4.0	3.983	0.4246	1.0
59.0	4.0	2.315	42.13	1.0
60.0	2.0	1.301	34.97	1.0
61.0	3.0	0.7078	76.41	1.0
62.0	2.0	0.3737	81.31	1.0
63.0	2.0	0.1918	90.41	1.0
64.0	2.0	9.5764E-2	95.21	1.0
65.0	1.0	4.6606E-2	95.34	1.0
66.0	1.0	2.2135E-2	97.79	1.0
67.0	1.0	1.0272E-2	98.97	1.0
68.0	1.0	4.6631E-3	99.53	1.0
69.0	2.0	2.0732E-3	99.9	1.0

70.0	1.0E-30	9.0362E-4	-9.0362E28	1.0
71.0	1.0E-30	3.8651E-4	-3.8651E28	1.0
72.0	1.0	1.624E-4	99.98	1.0
73.0	1.0E-30	6.7084E-5	-6.7084E27	1.0
74.0	1.0	2.7268E-5	100.0	1.0
75.0	4.0	1.0915E-5	100.0	1.0
76.0	3.0	4.3057E-6	100.0	1.0
77.0	1.0E-30	1.6752E-6	-1.6752E26	1.0
78.0	1.0	6.4322E-7	100.0	1.0
79.0	1.0	2.439E-7	100.0	1.0
80.0	1.0	9.1392E-8	100.0	1.0
81.0	1.0E-30	3.3859E-8	-3.3859E24	1.0
82.0	1.0	1.241E-8	100.0	1.0
83.0	3.0	4.5024E-9	100.0	1.0
84.0	2.0	1.6177E-9	100.0	1.0
85.0	1.0E-30	5.7586E-10	-5.7586E22	1.0
86.0	1.0	2.0321E-10	100.0	1.0
87.0	1.0E-30	7.1112E-11	-7.1112E21	1.0
88.0	1.0E-30	2.4689E-11	-2.4689E21	1.0
89.0	1.0	8.5076E-12	100.0	1.0
90.0	1.0	2.9108E-12	100.0	1.0
91.0	1.0E-30	9.8915E-13	-9.8915E19	1.0
92.0	1.0	3.3399E-13	100.0	1.0
93.0	1.0	1.1209E-13	100.0	1.0
94.0	3.0	3.74E-14	100.0	1.0
95.0	1.0E-30	1.2411E-14	-1.2411E18	1.0
96.0	1.0E-30	4.0973E-15	-4.0973E17	1.0
97.0	1.0	1.346E-15	100.0	1.0
98.0	1.0E-30	4.4015E-16	-4.4015E16	1.0
99.0	1.0	1.433E-16	100.0	1.0
100.0	1.0	4.6459E-17	100.0	1.0
101.0				


CLASS IV MEDIUM GLASS BEAD DISTRIBUTION
MEASURED AND LOG-NORMAL FIT
COUNT
0
10
20
30
40
50
60
70
80
90
100
10
100
1000
BEAD GEOMETRIC DIAMETER - micron
Fitted Log-Normal Parameters
NMD = 48.1
SGg = 1.08

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