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EVALUATION OF COAL MINE DUST PERSONAL SAMPLER PERFORMANCE

Final Report

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The performance and accuracy of the coal mine dust personal sampler was evaluated. Mechanical properties of the sampler, such as battery life and pump flow meter accuracy, were kept constant. Penetration curves were obtained using monodisperse aerosols of several diameters for three sampling flow rates and three pulsation rates at each flow rate. The effects of particle charge, sampler orientation, air velocity, and mass loading were evaluated using polydisperse coal dust. Results were compared to the respirable mass dust criterion of the Los Alamos (LASL) Atomic Energy Commission, the British Medical council respirable (BMRC) coal dust criterion, and the American Conference of Governmental Industrial Hygienists (ACGIH) criterion. The respirable mass best represented the BMRC criteria when the cyclone was operated at 1.4 liters per minute (lpm) and 0.3 pulsation resulting in a 10 percent error over the range of interest. Respirable mass best represented the LASL and ACGIH criteria when the cyclone was operated at 1.7lpm and 0 pulsation with, a 10 percent error over the range of interest. The authors recommend that every effort be made to reconcile the LASL and BMRC criteria to achieve uniformity.

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INTRODUCTION

The objective of this research contract was to evaluate the performance and accuracy of the coal mine dust personal sampler and to determine the quantitative effect of pump pulsating flow, particle charge, mass loading, and sampler orientation. Determination of these effects provides information as to the accuracy of samples currently being obtained and for the improvement of the samples for better health protection of the coal miners.

For the purposes of this study, the investigation singularly involved the characteristics of the 10 mm cyclone portion of the sampler. It was assumed, for example, that the filter captured essentially 100 percent of the particles penetrating the cyclone under all conditions of operation. Mechanical parameters such as battery life, accuracy of pump flow meters as delivered, etc. were not included in the study but instead were kept constant or compensated by laboratory procedures.

The evaluation of the cyclone included obtaining penetration curves using monodisperse aerosols of several diameters for three sampling flow rates and three levels of pulsation at each rate. Polydisperse coal dust was used to evaluate the effects of particle charge, sampler orientation, air velocity, and mass loading. Results were compared to the respirable coal dust criterion of British Medical Research Council (BMRC) (1, 2, 3); to the respirable mass dust criterion of the Los Alamos Atomic Energy Commission (LASL); and to the American Conference of Governmental Industrial Hygienists (ACGIH) similar criterion.

The project was divided into two parts, the first part dealing with the monodisperse studies and the second with the coal dust studies.

PART I - MONODISPERSE STUDIES

INTRODUCTION. Cyclone penetration curves were obtained using monodisperse ferric oxide spheres produced by a spinning disc aerosol generator.

The aerodynamic diameter of the particles was obtained by measurement of the falling speed in a modified Millikan falling particle apparatus. Although this method is inadequate for polydisperse aerosols due to the small numbers of particles measured, it is satisfactory for monodisperse aerosols. Size distribution was determined by optical microscope. Sphericity of particles was checked by electron micrography.

The cyclone penetration was determined by using ^{113}In tracer in the colloidal solution from which the aerosol was produced. The amounts retained in the cyclone and the amounts penetrating the cyclone (collected on the filter) were quantified. Use of the tracer technique permitted short sampling times and multiple replication.

The experimental equipment and procedures were calibrated and the experimental error evaluated in all areas which would have a significant effect on the results obtained.

EXPERIMENTAL

Dynamic Test Chamber

The test chamber used is shown schematically in Figure 1. Aerosol was introduced into the filtered air stream from a spinning disc generator (later, from a coal dust feeder). A Stairmand disc insured thorough mixing of the aerosol, and a perforated plate upstream of the test section provided a uniform flow profile. The chamber air velocity was controlled by adjustment of the blower speed and/or air-bleed slide valve. The uniformity of air flow velocity and aerosol concentration in the test area was evaluated. Air velocities were measured with an Alnor 8500 thermo-Anemometer. A sixteen-point traverse of the test section area was made with the anemometer probe held in a test stand. Individual readings were within $\pm$ 10 percent of the mean velocity of 50 ft. per min. A 14" x 12" area in the center of the test section was measured to represent where sampling equipment was to be located. A fifteen-point traverse of this area indicated that individual velocity readings within $\pm$ 2 percent of mean velocities of 300 ft. per min.

Uniformity of aerosol concentration was evaluated by generating an iron oxide aerosol tagged with ^{113}In with the spinning disc generator. Samples were taken with four membrane filters placed horizontally across the sampling area. After sampling for 30 minutes at 2 liters per minute, the activity on the filters was counted with a gamma spectrometer as representing the aerosol collected. The concentration measured on all filters was within $\pm$ 5 percent of the mean. The particle size was approximately 4 μm. Velocity in the chamber was 50 ft. per min.

Figure 2 shows the arrangement of sampling equipment at the test section during a typical run. From left to right, the purpose of the sampled stream was as follows:

(1) B & L. Bausch and Lomb Model 40-1A light scattering photometer with digital readout, used as a control device to insure uniformity of conditions during the run. For coal dust tests, uniformity of particle size distribution was also monitored.

(2) ESP. A point-to-plane electrostatic precipitator for collecting particles on electron micrograph grids. Micrographs were inspected for visual sphericity of particles.

(3) Millikan. The modified Millikan falling drop apparatus, used to measure the terminal velocity of particles during the monodisperse portion of the project.

(4) Elutriator. An elutriator furnished by the National Institute of Occupational Safety and Health, a duplicate of the British Mines Research Establishment (BMRE) elutriator head, used for collection of aerosol according to BMRC criteria.

(5) Filter. An open-face plastic, 37 mm diameter filter holder, using 5 μm pore size Gelman Vinyl Metricel TM filters.

(6) Cyclone assembly. Three 10 mm nylon cyclone and filter assemblies, operated at different degrees of pulsation at the sample flow rate.

The array of sampling equipment varied with different phases of the investigation. The above description applies to the bulk of the monodisperse work.

Personal Samplers

Mine Safety Appliance Company personal pumps, Model G, were used with MSA 10 mm nylone cyclones and filter holder assemblies. The apparatus is shown in Figure 3.

An attempt was made to include Unico Micronaire pumps, but difficulty was experienced with delivery and operation of the equipment. For this reason, use of the Unico equipment was dropped in order to avoid delay of the project. The Unico sampler is functionally identical to the MSA, the only important difference in regard to this study being the frequency and magnitude of the pulsations of flow.

MSA pump pulsation, when operating on a sampler, had a frequency of 38 Hz and a magnitude of 2.5. Pulsation is defined as

$$\text{Pulsation} = \frac{(\text{max flow}) - (\text{min flow})}{\text{average flow}}$$

An oscilloscope trace of the MSA pulsation is shown in Figure 4. The trace was obtained from the output of a fast response (1000 Hz) temperature compensated anemometer (Thermo Systems Model 1051-1, 1054B-36A, 1352B) in the air line downstream of the sampler.

Filters

The filters used were Gelman No. 60714, 37 mm diameter, 5 micron pore size Vinyl-Metricel™ VM-1 membrane filters. For the monodisperse work, particulate material on the filter was measured by gamma-ray spectrometer. In the coal dust experiments, coal dust on the filter was determined by tare and gross weighings on a Cahn Model RG electrobalance operated in a "laminar flow" clean room controlled at constant temperature and humidity. The filters were allowed to come to equilibrium for a minimum of one hour with the room atmosphere before weighing.

Aerosol Production -- Monodisperse

Ferric oxide microspheres were produced using an Environmental Research Corporation Model 8330 spinning disc aerosol generator. An alcoholic solution of colloidal dialized β ferric oxide was continuously fed onto a one-inch diameter disc, spinning at 60,000 rpm, with a continuous drive syringe pump. The liquid spins off the disc and breaks up into liquid droplets which subsequently evaporate, leaving nearly spherical aggregates of iron oxide. The size of the final particle depended upon the initial concentration of ferric oxide used.

The colloidal iron solution was made by diluting from 0.5 to 2.0 ml of β-Fe_2O_3 Aquasol (obtained from Diamond Shamrock Corporation) to 25 ml with 90 percent ethyl alcohol. The diluted solution was made up fresh for each experiment because it proved to be unstable after standing several hours. The ^{113}In tracer was obtained from a sealed, self-contained ^{113}In generator (New England Nuclear Model NRP-016) as the decay product of ^{113}Sn. The indium was eluted by drawing 0.05N HCl over the metal surface and into a small vacuum vial. The elution volume was approximately 5 ml, containing enough activity for two experiments lasting approximately four hours. Two ml of the ^{113}In solution was mixed with 25 ml of the dilute sol prior to use in the aerosol generator.

Optical Sizing

The aerodynamic diameter was determined by the modified Millikan apparatus as described, but the number of particles so measured was too small to provide a measure of the dispersion of particle size. Optical sizing was used for dispersion estimates. Samples were taken for the duration of each run at 2 lpm on 5 µm pore size membrane filter mounted in an open-face plastic holder. The filter was mounted dry for sizing by microscope at 430x magnification using a Porton reticle. At least 100 particles were measured on each slide. Sizes were classified in groups of sizes estimated to the nearest 1/2 Porton circle size. The data was plotted on log probability paper and σ_g determined as the ratio of the (cumulative) 84.1% size to the 50% size. Resulting values of σ_g ranged from 1.04 to 1.13 and averaged 1.08.

For the penetration curves (Figs. 5, 6, 7) the observed aerodynamic diameter was plotted as the abscissa, σ_g assumed equal to 1.00. It is possible to convert the count distribution to mass distribution by the Hatch-Choate equation (4) and then to apply the computations made by Lynch (12) to estimate the error in penetration curve data caused by the assumption of $\sigma_g = 1.00$. On this basis, the error that would be caused by use of aerosol with $\sigma_g = 1.1$ was estimated as follows:

Count Median Diameter	% Error in Penetration Relative to $\sigma_g = 1.00$
2	-5.7
3	0.0
4	-0.24
5	-0.8
6	-9.0

Thus the error in penetration curve data from this cause is negligible for all but the 6 μm size, and at that size is less than the variability of the raw data. This estimate also concurs with that of Moss and Ettinger (15) who selected an aerodynamic diameter of 3.8 μm as a size at which the cyclone was insensitive to σ_g.

Aerodynamic Sizing

Aerodynamic particle diameter was measured using a photographic version of a Millikan falling particle apparatus. In this apparatus, a particle is admitted by gravity into a small hole in the top of a quiet zone. A chopped laser beam is directed horizontally across the quiet zone, with a low power microscope eyepiece and film holder mounted so as to collect forward-scattered light from a particle falling through the laser beam. The apparatus has been described in detail (5). The light source used here was a 3.5 milliwatt He-Ne multimode continuous wave laser, chopped at 10 Hz or 4 Hz; the light duration was about 10-percent-on/90-percent-off for each cycle. Equally-spaced dots on the film resulted from a particle falling at constant speed. The image on the film was projected onto a screen and the distance between the dots measured by dividers and rule. The falling speed was calculated from the time-distance relationship of the film image dots. The apparatus was calibrated by placing a microscope stage micrometer in the quiet zone of the apparatus, letting the laser light shine continuously on the micrometer and exposing the film. The micrometer image projected onto the screen served as a calibration scale. Magnifications for these measurements was 145x. Typically zero to six tracks were observed for each experiment. Experiments where no tracks were observed were not included in the data. The small number of tracks renders this method applicable only for monodisperse aerosols.

Aerodynamic diameters were calculated using the Stokes relationship

$$d_a^2 g/18\mu \qquad (1)$$

where V is the particle settling velocity
g is the acceleration of the particle due to gravity
μ is the viscosity of air
d_a is the aerodynamic particle diameter, equal to $\sqrt{\rho}\,d$ where ρ is the particle density and d is the diameter of the sphere.

Electron Micrographs

During several experiments, particles were collected on electron microscope grids for sizing. The particles were collected on the grid using a point-to-plane electrostatic precipitator identical to the design of Morrow and Mercer (6). The grids were shadowed with chromium after collection. The electron micrograph magnification was calibrated using a 54864 lines-per-inch carbon replica ruling. The particle diameters were measured on the micrograph and examined for sphericity. Particle density can be calculated from Equation 1 when both the aerodynamic and projected particle diameters are known; the density so obtained was 2.4 gm per cm^3. Lippman (7) reported 2.56 and Seltzer (5) reported 1.20. The density data does not enter further into the results of this work but was conducted to determine relative uniformity of methods of producing monodisperse aerosol.

MEASUREMENT OF CYCLONE PENETRATION

Preceding the actual run, the dynamic test chamber was adjusted for the desired velocity; sampling apparatus set up (typically as in Figure 2) and flow rates adjusted; and syringe loaded with colloidal iron oxide sol. The feed to the spinning disc generator was started and adjusted to remove sattelites, then the samplers started promptly and as simultaneously as possible. The runs lasted typically from 20 to 40 minutes.

At the conclusion of the run, the cyclones were promptly removed from the chamber. Cyclones were individually placed in separate tubes containing 25 ml 0.05N HCl and placed in an ultrasonic bath for fifteen minutes. While the cyclones were being cleaned, the filters were placed in a 5.0 cm diameter plastic Petri dishes. The dishes were counted on the crystal of a gamma ray spectrometer tuned to count solely the 393 Kev energy peak resulting from the photons emitted during the ^{113}In decay. Background counts were determined by counting a blank filter in a Petri dish for 100 seconds. After subtracting the background, the counts were calculated back to a time zero reference (usually the time of the indium elution) using an exponential decay law for the ^{113}In having a half-life ($t_{1/2}$) of 103.8 minutes, e.g.

$$S/S_o = (1/2)^n$$

where S is the number of sample counts corrected for background at time t
S_o is the equivalent count at t = 0
t is the elapsed time from zero time
$t_{1/2}$ is the indium-113 half-life
n is $t/t_{1/2}$ = number of half-lives.

After the cyclones were cleaned, a 1 ml aliquot of the cyclone wash solution was placed on a 37 mm filter paper in a 5 cm diameter Petri dish. Thus, both the penetration sample (dry filter) and cyclone retention sample aliquot were counted at the same geometry.

Penetration was computed as

$$\text{Penetration} = \frac{\text{dry filter count}}{\text{dry filter count} + (25 \times \text{aliquot count})}$$

all counts being corrected for background and computed to time zero.

Adequacy of cleaning the cyclone bodies was checked by counting them. Counts on the same order as background (10 to 15 counts per 100 seconds) were obtained. At large cyclone penetration values (90%) the signal to background (S/B) ratio for the cyclone wash was about 2, and the corresponding S/B ratio for the filter was 1000. For penetrations less than 10 percent, S/B was approximately 200 for both.

Development of Cyclone Penetration Curves

Curves of cyclone penetration versus aerodynamic particle diameter were generated from the data obtained by the methods previously described. Each pair of points for the cyclones operating under the different flow conditions was used in a general linear least-squares curve-fitting Subroutine, ORTHON2, available from the University of Minnesota, Computer Center Library. The polynomial which produced the best fit in the least-squares sense (by examination of the standard error of estimate and standard error in the coefficients) was used to represent the data shown in Figures 5, 6, and 7. Table 1 gives the equations representing the curves. For each curve, 45 to 50 pair of data points were available, in excess of the minimum number recommended for the size of the polynomial obtained. The techniques used to generate the aerosol could not reliably produce aerosols smaller than 2 µm or larger than 6 µm. This was not a serious problem because at 2 µm the penetration is nearly 100 percent and at 6 µm is close to zero and would be zero at 7 µm in all cases except one (1.4 lpm and 0.0 pulsation) where zero is reached at 10 µm.

The curves obtained from the initial least squares fit were manually extrapolated to 100 percent penetration at 1 µm and 0.0 percent at 10 µm so that the entire range of interest could be used to determine the cyclone penetration curve E'(D) for each specific condition. The completed curves were broken into three sections $0<D<3$, $2<D<5$, and $4<D<10$ µm and least squares fits performed on points read from the smoothed curves. In the range of 2 to 6 µm, the smoothed curve data analysis duplicated the original data curve with less than 1 percent deviation. The error bars represent 95 percent confidence bounds calculated from the standard error in the coefficients of the initial least squares best fit of the data. Table 2 presents the equations for the smoothed penetration curves and the ranges of the equations as applied.

Computation of Respirable Mass Sampled

The cyclone penetration becomes the measured respirable mass when the sampler is used to sample a dust cloud. The ratio of measured respirable mass to respirable mass criteria of both BMRC and LASL-AEC has been calculated for each of the nine penetration curves for assumed log-normal dust dispersions covering the range of 1 to 10 µm mass median and geometric standard deviations from 1.1 to 4.1.

The respirable mass can formally be defined for spherical particles as:

$$RM = \int_0^{\infty} E(D)\ P(D)\ \left(\frac{\rho \pi D^3}{6}\right)\ d \ln D \qquad (2)$$

where P(D) is the number density function per cubic meter of air for a log-normally distributed aerosol having a geometric mean diameter Dg and geometric standard deviation σ_g defined by

$$P(D) = \frac{1}{\sqrt{2\pi}\ln \sigma_g} \exp \left[\frac{-(\ln D - \ln D_g)^2}{2 \ln^2 \sigma_g}\right]$$

and $\left(\frac{\rho \pi D^3}{6}\right)$ is the mass of a particle of diameter D and density ρ.

E(D) can take several forms, depending upon the definition of the pulmonary deposition curve. According to the respirable mass criterion established for coal mines by BMRC (2) the respirable mass fraction is

$$E(D) = BMRC(D) = 1 - (7.08/D)^2 \qquad 1 - \left(\frac{D}{7.08}\right)^2$$

for $0<D\leq 7.08$ and $BMRC(D) = 0$ for all $D\geq 7.08$. In the case of the Los Alamos definition of respirable mass fraction (12)

$$E(D) = AEC(D)$$

$$AEC(D) = 1 \text{ for } 0.0<D\leq 2.0$$

$$\begin{aligned} AEC(D) = {} & 6.103034 - 5.987785D + \\ & 2.770594D^2 - 0.6884753D^3 + \\ & 0.09342388D^4 - 0.00651553D^5 + \\ & 0.0001825093D^6 \\ & \qquad \text{for } 2.0<D\leq 8.0 \end{aligned}$$

$$\begin{aligned} AEC(D) = {} & 0.1136477 + 0.03693936D - \\ & 0.01123596D^2 + 0.0007089895D^3 - \\ & 0.00000684794 3D^4 \\ & \qquad \text{for } 8.0<D\leq 10.0 \end{aligned}$$

$$AEC(D) = 0.0 \qquad \text{for all } D>10.0$$

In order to obtain a sample corresponding to one of the two respirable mass criteria, the cyclone should have a penetration characteristic curve identical to one of the two E(D) functions described. The equations representing the smoothed penetration curves were used to compute the ratio of the mass that would be measured as "respirable", called "respirable mass sampled" to the respirable mass as defined by either the BMRC or LASL-AEC criteria. The equation is

$$K = \frac{\int_0^\infty P(D)\ E'(D)\ D^3\ d \ln D}{\int_0^\infty P(D)\ BMRC(D)\ D^3\ d \ln D} \qquad (3)$$

where E'(D) is the equation describing the cyclone penetration under the conditions of test.

The integrations were carried out to 10 μm, not to infinity, because the integrand falls to zero before 10 μm. Equation 3 was evaluated numerically using the trapezoidal rule. Simpson's Rule was also used and gave results equal to the trapezoidal method. The number of intervals for the numerical quadrature varied between 20 and 1000 per micrometer. Convergence was established after a five-fold increase in the number of intervals gave the same result to four significant figures.

RESULTS AND DISCUSSION

Tables B1 through B40 (See Appendix B) show Equation 3 calculated for the BMRC and the LASL criteria using count median diameters (CMD) and mass median diameters (MMD). MMD is related to CMD through the equation

$$\ln \text{MMD} = \ln \text{CMD} + 3 \ln^2 \sigma g$$

The extensive tabulation results from the fact that the ratio K in Equation 3 is a function of the geometric mean diameter and geometric standard deviation (Dg, σ_g) of the dust cloud being sampled. Obviously K would be unity if E'(D) equals E(D).

Figures C1 to C18 (Appendix C) are contour bands of 0.1 intervals of K for respective cyclone conditions compared to the two respirable mass criteria.

Comparison to BMRC Criteria

Figures C1 to C9 portray the ratio K, as defined above, that would be obtained on different dust dispersions. Figure 8, (also C2) representing cyclone operation at 1.4 lpm and 0.3 pulsation, yields $0.9<K<1.1$ (+ 10 percent error) over approximately 90 percent of the range of interest. In the opinion of the authors, the region of greater error is, in practical terms, of even less significance than portrayed because dust clouds of that characteristic would be unusual and seldom encountered.

Figure 9 (also C3), 1.4 lpm and zero pulsation, shows a similar pattern, with $1.0<K<1.2$, or $\pm {}^{20}_{0}$ percent error compared to the BMRC criterion. If for practical reasons the specification of zero pulsation is important, a correction factor K' of 1.1 could be assumed in computing equivalency of results, yielding a $\pm$ 10 percent error in computed equivalent BMRC.

$$K' = \frac{\text{cyclone penetration}}{\text{BMRC criterion}} = 1.1$$

or the equivalent correction factor:

cyclone penetration x 0.91 = BMRC criterion.

Thus a practical resolution would be to sample with the 10 mm cyclone at 1.4 lpm and zero pulsation; correct the respirable mass as measured by a multiplier of 0.91; with results varying from BMRC criteria by $\pm$ 10 percent over the entire region of practical interest.

All other operating conditions (Figures C1, C4 through C9) show markedly greater deviations from a K value of 1, spread over much greater portions of the regions of interest. Other workers (5, 8) have recommended 1.4 lpm for the cyclone when compared to the BMRC. Seltzer, et al., in reference 5 does not explicitly call for 1.4 lpm, but his data indicate a smaller error when using 1.4 lpm.

Comparison to LASL-AEC Criteria

Figures C10 - C18 show the K values for the LASL criterion that would be obtained on different dust dispersions. Figures C14 (1.7 lpm, 0.3 pulsation) and C15 (1.7 lpm, 0.0 pulsation) are approximately comparable in providing a K value between 0.9 and 1.1 over the broadest range. Sampling at 1.7 lpm and zero pulsation (Figure 10, also C15) has the advantage that the degree and frequency of pulsation need not be specified. For almost all situations to be encountered in practice, the 10 mm cyclone will yield respirable mass data within ± 10 percent of LASL criterion when operated at 1.7 lpm and zero pulsation.

Other laboratories (5, 9, 10) have recommended 1.7 lpm for comparison to the LASL criterion. The AIHA (3) recommends 1.7 lpm for comparison to the ACGIH criterion, which is almost identical to the LASL.

Options to Achieve K = 1.0

Obviously, for a respirable mass sampler to yield direct results comparable to a respirable mass criterion, the performance of the sampler must match the criterion. If the penetration of the first stage does not match the criterion, computational correction of the measured respirable mass theoretically requires a knowledge of the mass median diameter and geometric standard deviation of the dust cloud being sampled. This requirement largely negates the logistic value of the respirable mass sampler as compared to older methods. If a "practical" solution is sought by depending upon the ranges of diameter and dispersion usually found in occupational exposures and applying a correction factor, the cyclone can be in error by a factor as high as 2. (See envelopes previously described.) This potential error is uncomfortably high. Furthermore, there will be many situations where the "usual" ranges do not prevail and the error can be very high. The same considerations pertain to conversion of data from BMRC to LASL criteria and vice versa. The conversion cannot be made, theoretically, without knowledge of the size and dispersion of the dust cloud.

Two options present themselves:

a. Continued research may develop a sampler whose penetration matches the defined penetration. The 10 mm cyclone, for example at 1.4 lpm and 0.3 pulsation, is fairly close to the BMRC criterion. Continued experimentation would no doubt find a combination of flow rate and pulsation that duplicated the criterion closely. In any such investigation, the frequency of the pulsation would need to be considered as a parameter (it was constant at 38 Hz in this study).

   It is possible that a redesign of the cyclone would also result in matching of the criterion at some reasonable flow rate and zero pulsation. In this regard, the penetration curve represented by the LASL criterion is typical and representative of cyclone performance; the BMRC criterion has a curvature the reverse of that considered typical for cyclones.

b. The physiological data leading to the criteria exhibit a tremendous scatter, as would be expected, which was smoothed by computer modeling of the airway passages of the human being (11). It is further probable that the physiological data was influenced or biased by the sampling devices then available, viz., the 10 mm cyclone or the BMRE elutriator. While review of the physiological data and resulting committee decisions is not within the scope of the present investigation, it does seem appropriate to at least pose the question: "Can the criterion be modified to match the (now better understood) characteristics of the sampler?". If so, the sampling portion of the environmental investigations would then be on a firm, uniform footing, and a lot of possibly meaningless computational corrections could be eliminated.

No sampling technique will ever be perfect. If the technique reasonably represents the physiological facts, however, the environmental data so gathered will be adequate for enforcement, evaluation, and epidemiological data.

Every effort should be made to reconcile the BMRC criteria and the LASL criteria. The historical reasons for adoption of the BMRC criterion for coal mine dust are understandable. However, the LASL criterion is being (has been, to a degree) adopted for all other pneumoconiosis-producing dusts.

The LASL criterion has all the practical advantages on its side, as compared to the BMRC, because the 10 mm cyclone (LASL) has so many logistic advantages over the BMRC. As a matter of fact, the BMRE instrument which conforms to the BMRC criterion cannot be used, due to its size, weight, and orientation requirements, as a personal sampler. The errors inherent in evaluation of dust exposure by general area sampling instead of personal sampling are far more significant, in the opinion of the authors, than the difference between BMRC and LASL-AEC criteria. Among other things, the shape of the BMRC curve is basically incompatible with the characteristics of ideal cyclone separators.

On the other hand, it seems reasonable to suppose that the physiology of coal miner's lungs is not significantly different than that of other workers in dusty trades. Theoretically, if one criterion is "right", the other must necessarily be "wrong". If, on the other hand, both are "reasonably right", then there would seem to be no <u>technical</u> reason why one or the other should not be abandoned.

On the assumption that the LASL criterion is "reasonably right", and in spite of the administrative difficulties involved, a once-and-for-all correction should be applied for conversion of BMRC-based epidemiology to the LASL basis. This could be done, for example, by adjustment of the coal dust TLV and no doubt by several other mechanisms. In spite of the administrative difficulties, such a change would be beneficial in the long run if technically sound.

CONCLUSIONS AND RECOMMENDATIONS

1. For application to coal mine dust (BMRC criterion of respirable mass), the best operating mode of the 10 mm cyclone would be 1.4 lpm at 0.3 pulsation, yielding a ± 10 percent error from the BMRC criterion over practically the entire range of interest, without correction factor.

   If for practical reasons zero pulsation is preferred, comparable results yielding ± 10 percent error from BMRC can be achieved by sampling at 1.4 lpm, zero pulsation, and multiplying the measured respirable mass by a factor of 0.91.

   All other operating modes tested failed to yield results that would permit the application of a single correction factor over the ranges of size and dispersion of interest.

2. For application to other pneumoconiosis-producing dust (LASL-AEC and ACGIH criteria) the best operating mode of the 10 mm cyclone is 1.7 lpm, zero pulsation. This will yield measured respirable mass within ± 10 percent of the criteria, without correction factor, for almost all situations to be encountered in practice.

3. It is inescapable that for a sampler to measure the respirable mass as defined, its first-stage penetration must match the defined characteristic. If it does not, computational correction of results requires an independent knowledge of the particle size and dispersion of the cloud being sampled. This requirement largely negates the logistic value of the personal sampler.

4. Conversion of data from BMRC to LASL-AEC criteria, and vice versa, is subject to the same consideration as item 3 above.

5. Two options present themselves:

   a. Further experimentation with flow rate and pulsation could lead to a closer match to the criteria. Cycione redesign could lead to a better match of the LASL criteria. The shape of the BMRC curve is incompatible with cyclone penetration curves in general (see discussion).

   b. The physiological data should be reviewed to determine whether it would be technically acceptable to modify the criteria to match the (now better understood) characteristics of the sampler (see discussion).

6. The BMRC and LASL criteria should be reconciled, and one abandoned, so as to achieve a uniform criteria. There would seem to be no physiological basis for two criteria. The epidemiological basis could probably be modified and reconciled. The LASL criterion would appear to have more practical advantages than BMRC (see discussion).

PART II - POLYDISPERSE STUDIES USING COAL DUST

INTRODUCTION

The second part of the investigation involved the evaluation of the personal sampler using polydisperse coal dust to determine the effects of ambient air velocity, dust concentration, mass loading, electrostatic charge on the particle, and sampler orientation.

EXPERIMENTAL

General:

The dynamic test chamber was used in a manner similar to that described in Part I. The spinning disc aerosol generator was replaced with a coal dust feeder, all cyclones operated at 2 lpm using pulsation smoothers in the air line between the pump and the sampling head. For all coal dust experiments, a temperature of 80 F and a relative humidity of 60 percent was maintained. Coal dust collected on the filters was weighed on an electrobalance having microgram sensitivity.

The 2 lpm sampling flow was selected because this was the current operating requirement defined in the Federal Register (13). Suction was obtained from Mines Safety Appliance personal pumps, Bendix Unico personal pumps, and a Gast 1 cfm carbon vane pump. For the personal pumps, Cassella pulsation smoothers were used to virtually eliminate airflow pulsation. The airflow setting was calibrated using a wet test meter with the pulsation smoother and sampling head in position during calibration procedure.

Coal Dust

Illinois No. 6 coal, pulverized and sized by the Donaldson Company, Minneapolis, Minnesota, was used in all experiments. The Coulter Counter Model B median diameter measurement for the coal dust was 4.0 ± 0.4 µm; the geometric standard deviation was 2.6 ± 0.2. This size distribution specification was selected from a literature survey (14) as being the most representative of the reported values. A large variation was apparent in the literature data, including a wide variety of coal mining situations as well as a variety of particle sizing techniques. The specification was somewhat arbitrary, in the midrange of reported values. It is obvious that the nature of the coal and rock, the mining methods and machinery, and ventilation airflows will influence the size distribution of the coal dust in any given mine even if sizing techniques used were uniform. The specification was promulgated with the intent to provide a basis for this and future work which provided a test dust (a) reasonably representative of dust in coal mines, (b) practical to produce on a 100-pound sample basis, (c) reproducible, (d) with size distribution specification related to quality control of ground product, avoiding the intricacies of dispersion in air and research level aerodynamic sizing techniques. The Coulter Counter data, representing the displaced volume of individual particles, is convertible to equivalent spherical diameter. For particles the shape of coal dust, the mass distribution so obtained was anticipated to be a fair representation of data obtained by aerodynamic sizing, and proved to be so.

This value is also in close agreement with the value calculated, for a different reason, by Moss and Ettinger (15). They reported that the penetration of a sampler operating on the ACGIH criteria curve is independent of the geometric standard deviation if the aerodynamic mass median diameter is 4.8 um.

Coal Dust Feeder

The coal dust was dispersed into the dynamic test chamber using the Minnesota No. 3 Dust Feeder (16).

> Coal dust is placed in a vertical cylinder attached to a long screw inside a pressure chamber. The screw projects through a pressure seal and is driven by a variable speed motor. Immediately above the surface of the coal dust and at the base of a stationary tube is a blade and slit arrangement. As the dust cylinder turns and moves upward, dust is scraped into the tube through the slit. The air pressure in the chamber propels the dust up the tube and through an orifice into an impactor where sonic velocities serve to break up agglomerates. The dust-laden air then flows through another orifice into a short piece of pipe centered behind the Stairmand Disc of the dynamic test chamber.

Uniformity of the Coal Dust Delivery

A Bausch and Lomb Model 40-1A optical particle counter provided both particle count and size analysis for each experiment. The variation in total count during a run was typically $\pm$ 15 percent, approaching $\pm$ 25 percent at low dust concentrations or low chamber velocities.

For all 200 experiments, the median diameter (uncalibrated B & L discriminator settings) varied $\pm$ 16 percent. The geometric standard deviation was 1.81 $\pm$ 0.13 ($\pm$ 7 percent).

Filters and Filter Weighing

It was determined early in the work that obtaining accurate and reproducible weighings on the order of 200 micrograms of coal dust on a filter would require carefully controlled conditions and standardization of technique. The detailed procedure developed is described in Appendix A. A weighing error of $\pm$ 0.1% was achieved.

Gelman Instrument Company, Metricel VM-1 membrane filters having 5 um pore size were used in all experiments. MSA polyvinyl chloride membrane filters supplied with the MSA sampling kits were not used because they had an initial high electrical charge, at times great enough to physically lift the balance pans. The Gelman filter did not appear to have an initial charge. At the completion of some runs, the loaded filters behaved as though they were charged. Exposure to 500 microcurie ^{210}Po source removed this charge. The same ionization source was capable of removing static charge from the MSA filters. For uniformity, and because filter behavior was not a subject of investigation, the Gelman filters were used throughout.

The weighing was done in a horizontal airflow clean room under controlled temperature and humidity conditions. The filters were stored in the weighing room for a minimum one-hour period prior to weighing to allow equilibration with the temperature and humidity of the surroundings. Before weighing, the filter was passed in front of the polonium source, and the ionization source was passed over both pans prior to closing the balance case door.

DATA AND RESULTS

EFFECT OF AIR VELOCITY, DUST CONCENTRATION, AND TOTAL MASS

Four personal samplers, three with standard 10 mm nylon cyclones and one with an aluminum cyclone, were mounted at the sampling station. The aluminum cyclone was a dimensional duplicate made by forming a wax casting (core) of the nylon cyclone and measuring by conventional techniques the pertinent dimensions. A reamer was made to these dimensions for machining the aluminum stock. In addition, the elutriator and the intake tube to the B & L counter were mounted at the same location, with inlets facing into the air flow.

Tests were conducted at respirable dust concentrations of approximately 0.5 to 6 mg/m^3 and at test chamber air velocities of 50, 100 and 300 ft. per min. The ratio of cyclone mass penetration to elutriator mass penetration was compared. The resulting data is presented in Figures 11 to 13 as cyclone penetration versus elutriator penetration for each velocity. The slope, intercept, and correlation coefficient of the least squares best fit straight line is shown in Table 3.

Dust Concentration

The small variance of the slope coefficient and the high correlation coefficient indicate that the relationship is quite linear, and therefore there is no difference in the effect of air velocity, dust concentration, or total mass load between the cyclone and the BMRE. This is not, unfortunately, conclusive proof that there is no effect in an absolute sense. However, it is unlikely that the effect of these variables would be so identical on the two different devices if an absolute effect did, in fact, exist.

The slight deviation from zero-zero intercept, plus the fact that the error in the intercept coefficient is larger than the value, leads to the interpretation that the presence of the intercept value is merely a result of the least squares curve fit procedure. The theoretical intercept is obviously zero-zero, and no tests were run at very low concentrations approaching zero.

Air Velocity

The slopes of these lines at different air velocities are nearly equal. The standard deviation in the slope coefficients makes it impossible to statistically evaluate the effect of ambient air velocity on cyclone performance. In any event, the range of the slopes is small enough to make such an effect insignificant. The average of the ratios for the three velocities is 0.72 ± 0.02 ($\pm$ 3 percent). This compares well with the 0.70 value interpolated from the monodisperse results shown in Tables B5 and B6, using the aerodynamic mass median diameter (5.1) and geometric standard deviation (2.09) of the coal dust obtained from the Lundgren Impactor results (see Table 4).

Total Mass Loading

The samplers were not run for eight hours at heavy loads of 3 to 6 mg/m^3 respirable dust to determine effects of mass loading because errors at levels so far over applicable standards would have little practical significance. The cyclones were operated in the range of 2 mg/m^3 for four to six hours to obtain the data for Figures 11 to 13. If significant errors due to mass loading had occurred, the scatter in the data would be expected to be greater, the correlation coefficient poorer, and standard deviation in the slope larger. The data indicates no significant error due to total mass loading in the range of applicable standards.

Nylon Versus Aluminum Cyclone

The aluminum cyclone was available for this phase of the work as it had been prepared for investigation of electrostatic charge. The slope of the aluminum cyclone penetration versus BMRE is essentially the same as for the nylon cyclone at 50 and 100 ft. per min. ambient air velocity, and significantly different at 300 fpm. (Table 3). The available data offers no explanation for this observation. The samplers and test chamber were grounded.

SAMPLER ORIENTATION AND POSITION

For orientation investigations, the test chamber was operated at 50 and 300 ft. per min. Respirable dust concentrations were maintained between 0.1 - 2 mg/m^3. Six samplers were used, all mounted vertically, with two each facing into the air flow, two away from the air flow, and two at right angles to the air flow, operating at 2 lpm pulsation free sampling rate. Space limitation inside the test chamber prevented the use of the horizontal elutriator. The data was analyzed relative to the cyclone facing into the air stream. Table 5 represents the results of 18 experiments. Orientation in regard to ambient air flow had no significant effect on measurement of respirable mass. In view of the fact that cyclone inlet velocity (at 2 lpm flow) is 1770 ft. per min., far above any reasonable ambient air velocity, this result is not surprising.

Samplers operating in a horizontal position were compared at chamber air velocities of 100 fpm. Only one ambient air velocity was selected because at this point in the investigation it was well established that cyclone penetration was independent of air velocity. The sampler inlets faced at three orientations to the direction of air flow; upstream, downstream, and perpendicular. As before, there did not appear to be any difference in orientation. Unfortunately, a direct comparison of horizontal to vertical position at the same velocity and orientation was not made. The forces exerted on the particle by the centrifugal action of the cyclone are several orders of magnitude larger than the force of gravity, leading to the premise that there should be little or no difference in penetration for a cyclone operating horizontally or vertically.

THE EFFECTS OF AEROSOL CHARGE ON CYCLONE PENETRATION

Particle charge may influence cyclone penetration because the nylon dielectric can accumulate large amounts of charge and thereby alter the normal orbits of the particles within the cyclones. Such an effect was studied by Lippmann & Kydonius (17), who report that transmission through the cyclone is reduced for highly-charged particles.

Two methods were used to study these effects; changing the particle charge for a series of penetration tests, and comparing the difference in penetrations between cyclones fabricated from dielectrics and conductors.

The dust generator, because of the method of dust dispersion, produces particles with high initial electrical charge. The charge can be removed from the particles by passing them through a region of ionized air in which particle charge is neutralized by either electron or molecular ion attachment. Air was ionized using any one or all of the following radioactive sources: 5 microcurie ^{85}Kr, 20 mc and 40 mc ^{210}Po. Clean air was passed through the polonium devices and mixed with the coal dust while the dusty air was passed through the chamber containing the krypton capsule. When all three units were in use, a 70 percent reduction in total charge was obtained.

Average particle charge was calculated from particle mobility using a particle mobility unit designed by the Particle Technology Research Group at the University of Minnesota. The mobility tube analyzer (Figure 14) consisted of two electrically isolated coaxial cylinders to which an electric potential was applied. The inside cylinder had an outside diameter of 2.54 cm, the outside cylinder had an inside diameter of 3.6 cm, and an active length of 17.7 cm. The electric field strength between the cylinders during these experiments was 940 volts/cm. The dusty air was pulled through the region between the cylinders at a rate of 43 lpm, and collected on a membrane filter at the end of the cylinders. The air flow was laminar. Under these conditions, the particle charge can be calculated from the equation

$$q = \frac{3.12 \times 10^{3} \, \bar{v} \, Dp}{E} (1-P)$$

where Dp = particle diameter in μm

E = electric field strength in volts per centimeter

$\bar{v}$ = average velocity of the particles (air) between the cylinders in centimeters per second

q = number of electron units of charge on the particle

P = penetration

The mobility tube penetration was calculated from the mass of coal dust collected on the cylinders and the filter. The cylinders were weighed on an Ainsworth Type 10N laboratory balance, the filter was weighed on the Cahn electrobalance. The mean error in weighing was estimated as 12 percent and rarely exceeded 17 percent.

The data is presented as the ratio of cyclone penetration to elutriator penetration versus average number of unit charges (q) per particle. The particle diameter used to calculate the mean charge was 5.0 um. Figure 15 shows a plot of the penetration ratios versus charge for both the nylon and metal cyclone, and Table 6 the results of a least squares analysis of the data. The near zero slope for both cyclones indicates that charge possibly has a similar effect on both cyclones, further if an effect of charge is present, it also effects the metal elutriator in the same way it effects the cyclones. Because the separating forces exerted on the particle are so different for the two samplers, it would seem unlikely that charge effects would cancel in the penetration ratio. The correlation coefficient for both sets of data is close to zero, which either indicates the straight line is not an appropriate model or that charge and penetration have no correlation. Judging from the scatter in the points in Figure 15 and the fact that there does not appear to be any best curve that would represent the points, the latter interpretation seems most reasonable. Therefore, because the intercept is close to the K value of 0.72 found for uncharged particles (Table 3), and the slope and correlation coefficient are near zero, it is concluded that particle charge of the magnitude tested has no effect on the cyclone penetration.

This result contradicts the results of Kydonius cited (17), who found a significant difference in penetration between highly charged and nearly neutral particles with cyclones sampling at rates of 4 lpm or less in a multicyclone sampler. A progress report by Lippmann (18) also indicates charge can have an effect, but it appears that between 1.75 and 2.5 lpm the effect is not significant except for diameters less than 2 μm. Lippmann's curves in his Figure 14 in the progress report were accidentally mislabeled (19).

COAL DUST SIZE DISTRIBUTION

The aerodynamic size distribution of the coal dust was determined for comparison with the Coulter Counter procurement specification and more importantly to permit comparison of the K value (ratio of cyclone penetration to BMRE or LASL criteria, Part I) for the coal dust as compared to monodisperse spheres.

The B & L optical counter was not calibrated for coal dust and was used only as a quality control monitor to insure consistency of size distribution and concentration during experimental runs. Aerodynamic size distribution of the coal dust at the sampling station was determined directly by use of a Lundgren Impactor (20). This impactor offers two significant advantages over many others. The rotating drum targets greatly reduce the build-up and blow-off problems experienced with stationary impactor targets. Secondly, substrates of varying materials and low tare weights may be mounted on the drums, improving the accuracy of weight determinations.

The impactor was operated at a sampling rate of 3.0 cfm. From the manufacturer's calibration curve, a 3 cfm sampling rate would give stage cut points corresponding to particles having aerodynamic diameters of 18, 5.2, 1.8 and 0.52 μm. Preweighed mylar films coated with petroleum jelly were used as the collection surface. The films were weighed on the electrobalance using a similar procedure as for the sampler filters. The mylar films were too large to place on the balance pans, making it necessary to fold them. Once the films were folded (jelly surface to jelly surface) and weighed, they were unfolded and mounted on the drums. The process of unfolding the film created lumps on the surface of the jelly which could either be blown off or scraped off against the stage entrance slit. To eliminate the lumps, the drums were placed under an infrared lamp and the petroleum jelly allowed to melt and flow over the film. Careful handling prevented the loss of any material. The final filter, because of its size and the fact it could not be folded, was weighed on the Ainsworth balance. The experiments lasted 45 minutes each, corresponding to one rotation of the drum and six sets of six point scans on the optical particle counter discriminator. The results are shown in Figure 16.

To confirm these results, coal dust samples from six locations on the dynamic test chamber exhaust filter were submitted to Donaldson Company for Coulter Counter analysis. The results of the Coulter Counter analysis on the final exhaust filter along with the Coulter Counter analysis of the starting coal dust and the Lundgren Impactor results are shown in Table 4.

SOURCES OF EXPERIMENTAL ERROR AND ERROR ANALYSIS

Error Analysis

The error in the respirable mass is the sum of the error contributing to the measurement. Assuming the errors are independent and normally distributed, then the maximum variation in RM can be calculated.

The mass of coal dust collected is the difference in filter mass before and after each experiment, approximately 400 μg. The readability of the balance is 2 μg. The volume of air sampled is the product of air flow and sampling time. The sampling flowmeters had been previously calibrated to better than $\pm$ 2 percent at 2 lpm and an adjustment error of 2 percent was assumed.

Let M_i = initial filter mass - mg
M_f = final filter mass - mg
F = airflow - lpm
t = sampling time - min
R = respirable mass - mg/m^3

$$\Delta M = M_f - M_i$$

$$R = (M_f - M_i)/Ft$$

$$dR = \frac{\partial R}{\partial M_f} dM_f + \frac{\partial R}{\partial M_i} dM_i + \frac{\partial R}{\partial F} dF + \frac{\partial R}{\partial t} dt$$

let $dR = \Delta R$ then

$$\Delta R = [\Delta M_f + \Delta M_i + \Delta M \left(\frac{/\Delta F/}{F} + \frac{\Delta t}{t}\right)] \frac{1}{Ft}$$

Some typical values in these experiments are

M_f = 5.400 mg
M_i = 5.000 mg

$\Delta M_f = \Delta M_i = 0.006$ mg (Appendix A)
$F = 2.0$ lpm = 0.002 meters^3 per minute
$\Delta F = 0.08$ lpm
$t = 120$ min.
$\Delta t = 0.05$ min.

then

$R = 1.67$ mg/m^3 and
$\Delta R = 0.117$ or $\pm$ 0.06 mg/m^3 ($\pm$ 3.4%) (one standard deviation)

This is contrasted by the less strict official requirements for coal mine dust sampling (21). Assume an eight-hour sampling time, at a constant respirable mass concentration of 2.0 mg/m^3 (collected on the cyclone filter). ΔM can be as large as 2 mg, ΔM_f as large as $\pm$ 0.05 mg and ΔF as large as 0.1 lpm. The time term $\Delta t/t$ should be negligible. Then

$\Delta R = 0.208$ or $\pm$ 0.104 ($\pm$ 5.4%) (official requirement)

The percentage error would obviously increase at lower values of R or shorter sampling times. Based on the official requirements, a 120-min. sample would have an error of $\pm$ 15%. The error in these experiments is thus smaller than currently permitted in actual field sampling situations. Obviously the rougher field situation would be expected to increase the total error.

<u>Cyclone Assembly</u>

The vortex finder of the cyclone fits into the top of the cyclone body and rests on an internal shoulder, held in place by compression exerted by the bracket, or mounting jig, which holds the cyclone-filter cassette assembly together. There is, of course, some clearance between the outside diameter of the vortex finder and the inside diameter of the cyclone body. If the compression forces are not in reasonably good axial alignment, the vortex finder is tipped out of axial alignment and does not rest squarely on the shoulder inside the body. This can open up the cyclone inlet, or open up a radial crack between the vortex finder and shoulder, depending upon the orientation of the misalignment.

In these experiments, this defect was noted early in the coal dust work when high variability between replicate tests was observed. Visual inspection revealed an abnormal deposition pattern of coal dust inside the body. The suspect experimental results were discarded and the work repeated, with a return to the technique used for monodisperse work, wherein the cyclone joint was covered with putty. It was also observed that sufficiently careful assembly would prevent the axial misalignment.

The amount of error introduced by this mechanical fault was not investigated but was obviously large. Such misalignment could easily occur in field assembly, or even after assembly while the sampler was in use. A mechanical (not aerodynamic) redesign of the vortex finder-body connection is the obvious correction required for standardized, mass-produced cyclones.

SUMMARY OF COAL DUST RESULTS

1. There is no significant difference in penetration characteristics of the 10 mm cyclone and the BMRE elutriator due to

   (a) ambient air velocity ranging from 50 to 300 ft. per min.
   (b) dust loading ranging from 0.5 to 6 mg/m^3 (respirable)
   (c) mass loading resulting from runs at 2 mg/m^3 (respirable) dust concentrations for six hours.

2. The aluminum cyclone showed unexplained differences as compared to the nylon cyclone for ambient air velocity of 300 ft. per min., but not for 50 to 100 ft. per min.

3. There is no significant difference in penetration characteristics due to orientation (inlet facing toward, away from, or perpendicular to air flow) or positions vertical and horizontal. Upside down position was not investigated.

4. The effect of aerosol charge on cyclone penetration was to increase the variability of the results, but no significant trend was found.

5. The coal dust size distribution used reasonably represents typical coal mine dust, can be economically and reproducibly procured in 100-lb. lots, and reasonable consistency of size distribution was established in the experiments.

6. Error analysis of coal dust filter weighings shows a weighing error under laboratory conditions of $\pm$ 0.1 percent.

7. The ratio (K) of respirable mass determined by cyclone to that required to match the BMRC criteria was determined from coal dust experiments and verifies the results predicted by monodisperse experiments.

8. An error analysis of the experimental data results in a total expected error of approximately $\pm$ 5 percent.

9. Poor design of the vortex finder-cyclone body connection was noted, wherein axial misalignment could occur resulting in change of dimension of the cyclone inlet and/or opening of a radial crack in the cyclone body as assembled. Either situation results in large sampling errors. Mechanical (not aerodynamic) redesign of the connection is recommended.

GENERAL S[illegible]ARY AND CONCLUSIONS

1. Respirable mass, as determined by the 10 mm cyclone sampler, best represents the BMRC criterion if the sampler is operated at 1.4 lpm and 0.3 pulsation, resulting in ± 10 percent error from the criterion over the range of interest.

   If pulsation-free sampling is more practical of achievement, the cyclone best matches the BMRC criterion at 1.4 lpm and zero pulsation, resulting in $^{+20}_{-0}$ percent error. By application of a correction factor

   Respirable mass (cyclone) x 0.91 = respirable mass (BMRC)

   and the error would then be ± 10%.

2. Respirable mass, as determined by the 10 mm cyclone sampler, best represents the LASL criterion when operated at 1.7 lpm and zero pulsation, with an error of ± 10 percent over the range of interest.

3. For coal mine dust sampling, using the 10 mm cyclone at 2 lpm pulsation free, the appropriate conversion factor for respirable mass so determined to the BMRC criterion is 1.4, rather than the 1.6 specified by current regulations. The conversion should be

   Respirable mass (cyclone 2 lpm) x 1.4 = Respirable mass (BMRC)

4. There is no apparent reason other than historical for the current use of both BMRC and LASL criteria. (See RESULTS AND DISCUSSION, PART I.) Every effort should be made to reconcile and merge the two criteria. The LASL criteria has the advantage of basically representing the same mathematical function as the sampler (cyclone), and that the cyclone itself is a logistically useful personal sampler. If this were accomplished, respirable mass could be measured directly, without conversion factor, with ± 10 percent error over any reasonably expected range of size distribution to be encountered in field sampling.

5. Under normal sampling conditions of airborne dust, the cyclone sampler can adequately determine respirable mass regardless of particle charge, sampler orientation and position (except possibly upside down, which was not investigated), dust concentration, and ambient air velocity. The ratio of dust collected on the cyclone after-filter to the dust collected on the elutriator filter is consistent with the results calculated from penetration curves obtained from monodisperse aerosol investigations.

6. Results of this study are compared to those of other investigators in Table 7.

7. A design defect in the mechanical connection between vortex finder and cyclone body which could cause large sampling errors was noted. Mechanical (not aerodynamic) redesign of this connection is recommended.

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Tabld 1

Equations for Experimental Cyclone Penetration E'(D)

Flow lpm	Pulsation	Range of D (um)	
2.0	0	2.2 - 5.2	$E'(D) = -2.59 + 3.59D - 1.12D^2 + 0.102D^3$
	0.3	2.2 - 5.2	$E'(D) = -2.44 + 3.48D - 1.10D^2 + 0.100D^3$
	0.8	2.2 - 5.2	$E'(D) = -3.21 + 5.76D - 2.76D^2 + 0.516D^3 - 0.0337D^4$
1.7	0	2.0 - 5.5	$E'(D) = -0.671 + 1.72D - 0.533D^2 + 0.0445D^3$
	0.3	2.0 - 5.5	$E'(D) = -0.633 + 1.72D - 0.545D^2 + 0.0463D^3$
	1.3	2.0 - 5.5	$E'(D) = -1.06 + 3.03D - 1.48D^2 + 0.265D^3 - 0.0162D^4$
1.4	0	2.0 - 6.0	$E'(D) = 4.64 - 5.57D + 3.21D^2 - 0.867D^3 + 0.108D^4 - 0.005D^5$
	0.3	2.0 - 6.0	$E'(D) = -0.0878 + 1.03D - 0.295D^2 + 0.0217D^3$
	1.3	2.0 - 6.0	$E'(D) = 2.76 - 2.53D + 1.70D^2 - 0.668D^3 + 0.138D^4 - 0.0142D^5 + 0.000577D^6$

Table 2

EQUATIONS FOR SMOOTHED PENETRATION CURVES

Flow	Pulsation	Range	Equation
1.4 lpm	0.0	0 - 2.5	$PEN = 1.001 + 0.01338D - 0.005109D^2 - 0.01388D^3 + 0.004936D^4$
		2.5 - 4.5	$PEN = 4.644 - 5.572D + 3.213D^2 - 0.8671D^3 + 0.1082D^4 - 0.005082D^5$
		4.5 - 9.5	$PEN = 5.002 - 2.107D + 0.3721D^2 - 0.03168D^3 + 0.001054D^4$
		≥ 9.5	$PEN = 0$
1.4 lpm	0.3	0 - 2.5	$PEN = 1.001 + 0.01338D - 0.005109D^2 - 0.01388D^3 + 0.004936D^4$
		2.5 - 4.5	$PEN = -0.08780 + 1.029D - 0.2948D^2 + 0.02165D^3$
		4.5 - 9	$PEN = 4.561 - 1.560D + 0.1831D^2 - 0.007975D^3 + 0.00006979D^4$
		≥ 9	$PEN = 0$
1.4 lpm	1.3	0 - 2.5	$PEN = 0.9968 - 0.01055D + 0.01850D^2 + 0.01355D^3 - 0.01347D^4$
		2.5 - 4.5	$PEN = 2.758 - 2.531D + 1.699D^2 - 0.6676D^3 + 0.1384D^4 - 0.01424D^5 + 0.0005775D^6$
		4.5 - 7.5	$PEN = 2.997 - 1.332D + 0.2211D^2 - 0.01624D^3 + 0.0004453D^4$
		≥ 7.5	$PEN = 0$
1.7 lpm	0.0	0 - 2.5	$PEN = 0.9999 - 0.0004971D + 0.0008159D^2 + 0.0006232D^3 - 0.0005970D^4$

Table 2 (cont.)

Flow	Pulsation	Range	Equation
1.7 lpm	0.0	2.5 - 4.5	$PEN = -0.6713 + 1.7190D - 0.5332D^2 + 0.04458D^3$
		4.5 - 6.3	$PEN = 9.758 - 4.866D + 0.9019D^2 - 0.07364D^3 + 0.002236D^4$
		≥ 6.3	$PEN = 0$
1.7 lpm	0.3	0 - 2.5	$PEN = 0.9998 + 0.0002072D + 0.001175D^2 + 0.00001061D^3 - 0.0007530D^4$
		2.5 - 4.5	$PEN = - 1.086 + 2.248D - 0.7660D^2 + 0.08530D^3 - 0.002462D^4$
		4.5 - 6.3	$PEN = 10.30 - 5.296D + 1.010D^2 - 0.08461D^3 + 0.002631D^4$
		≥ 6.3	$PEN = 0$
1.7 lpm	1.3	0 - 2.5	$PEN = 0.9976 - 0.004462D + 0.01514D^2 + 0.006588D^3 - 0.01115D^4$
		2.5 - 4.5	$PEN = -1.060 + 3.025D - 1.483D^2 + 0.2655D^3 - 0.01623D^4$
		4.5 - 6.3	$PEN = 1.743 - 0.8659D + 0.1597D^2 - 0.01296D^3 + 0.0003908D^4$
		≥ 6.3	$PEN = 0$
2.0 lpm	0.0	0 - 2.5	$PEN = 0.9993 - 0.003961D + 0.003328D^2 + 0.004437D^3 - 0.002662D^4$
		2.5 - 4.5	$PEN = -2.587 + 3.593D - 1.$[illegible]$D^2 + 0.1021D^3$

Table 2 (cont.)

Flow	Pulsation	Range	Equation
2.0 lpm	0.0	4.5 - 6.8	$PEN = 4.341 - 2.154D + 0.3979D^2 - 0.03244D^3 + 0.0009845D^4$
		≥ 6.8	$PEN = 0$
2.0 lpm	0.3	0 - 2.5	$PEN = 0.9992 - 0.003633D + 0.004155D^2 + 0.004267D^3 - 0.003171D^4$
		2.5 - 4.5	$PEN = -2.437 + 3.477D - 1.099D^2 + 0.1005D^3$
		4.5 - 6.3	$PEN = 4.3873 - 2.281D + 0.4402D^2 - 0.03736D^3 + 0.001176D^4$
		≥ 6.3	$PEN = 0$
2.0 lpm	1.3	0 - 2.5	$PEN = 1.003 + 0.001513D - 0.01071D^2 - 0.01060D^3 - 0.001956D^4$
		2.5 - 4.5	$PEN = -3.211 + 5.761D - 2.758D^2 + 0.5155D^3 - 0.03368D^4$
		4.5 - 5.8	$PEN = 1.253 - 0.6554D + 0.1269D^2 - 0.01078D^3 + 0.0003393D^4$
		≥ 5.8	$PEN = 0$

Table 3

EFFECT OF AMBIENT AIR VELOCITY
ON CYCLONE VS. BMRE PENETRATION

COEFFICIENTS IN EQUATION: CYC = A + B (BMRE)

Approach Velocity FPM	Slope B	Intercept A	Correlation Coefficient	Cyclone Cons't
50	0.70 ± .02	0.06 ± .07	0.98	Nylon
	0.76 ± .04	0.03 ± 0.1	0.95	Metal
100	0.73 ± .03	0.05 ± .08	0.98	Nylon
	0.72 ± .02	0.04 ± .05	0.99	Metal
300	0.74 ± .04	-0.18 ± 0.2	0.92	Nylon
	0.60 ± .04	0.02 ± 0.1	0.94	Metal

Table 4

TEST COAL DUST PROPERTIES

Material	Aerodynamic Mass Median Diameter Microns (Lundgren Impactor)	Equivalent Spherical Diameter, Microns (Coulter Counter)		Geom. Std. Deviation
		Uncorrected	Corrected for Density	
Test Dust Specification	---	4.0 ± 0.4	4.38 ± 0.44	2.6 ± 0.2
Test Dust (Bulk)	---	3.8	4.16	2.38
Aerosol Tested	5.1	---	---	2.09
Deposit on After Filter	---	5.2	5.7	2.52

Table 5

EFFECT OF CYCLONE ORIENTATION

Penetration Ratio, Stated Position to Same Position Facing Upstream

Sample Rate 2 LPM

Approach Velocity FPM	Position	Facing	
		Perpendicular	Downstream
50	Vertical	1.03 ± .07	1.04 ± .07
300	Vertical	0.99 ± .12	1.09 ± .10
100	Horizontal	0.99 ± .12	0.98 ± .15

Table 6

Least Squares Analysis of Charge Effects

	Cyclone	
	Nylon	Metal
Number of Points	60	55
Intercept	0.67	0.71
Slope	0.035	0.023
Correlation Coefficient	0.16	0.10

Table 7

SUMMARY OF RECOMMENDED FLOW RATES

Investigator	Aerosol	Rec. Flow to Match	Criteria
Ettinger, Partridge and Royer (9)	Uranine-Methylene Blue Mono-Disperse	1.4 lpm	LASL
Knight and Lichti (8)	Various, Polydisperse	1.4 lpm 2.08 lpm	BMRC STD BMRC FINE
Knuth (10)	Latex Spheres, Methylene Blue, Iron Oxide, Monodisperse	1.4 lpm	LASL
Lippmann and Kydonieus (17)	Ferric Oxide, Monodisperse	1.8 lpm	LASL
Seltzer, Bernaski and Lynch (5)	Ferric Oxide, Monodisperse	1.7 lpm	LASL
This Study	Ferric Oxide, Monodisperse Coal Dust, Polydisperse	1.7 lpm 1.4 With Pulse 1.4 Zero Pulse (20% Error)	LASL BMRC BMRC

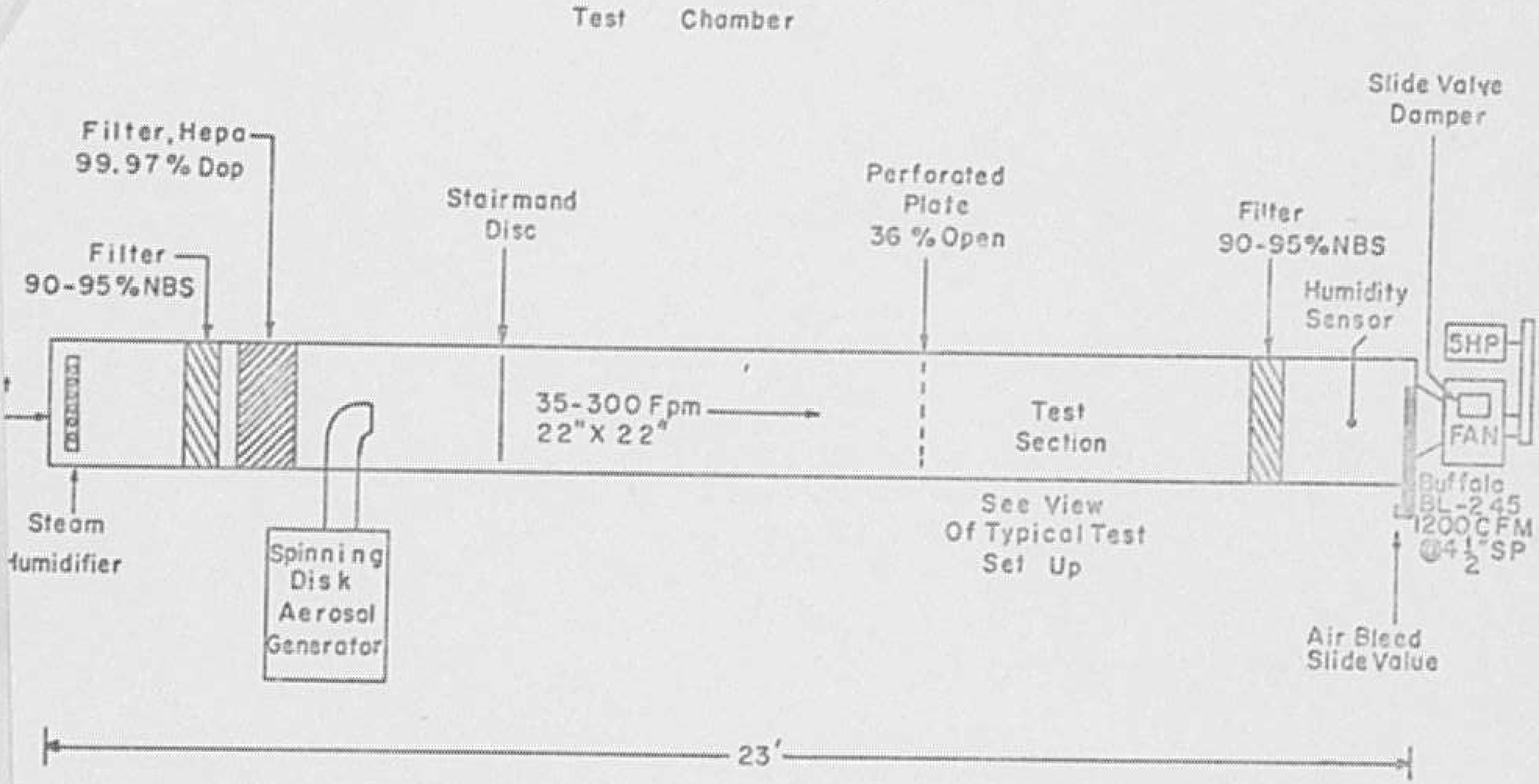

Figure 1. Schematic View of Dynamic Test Chamber

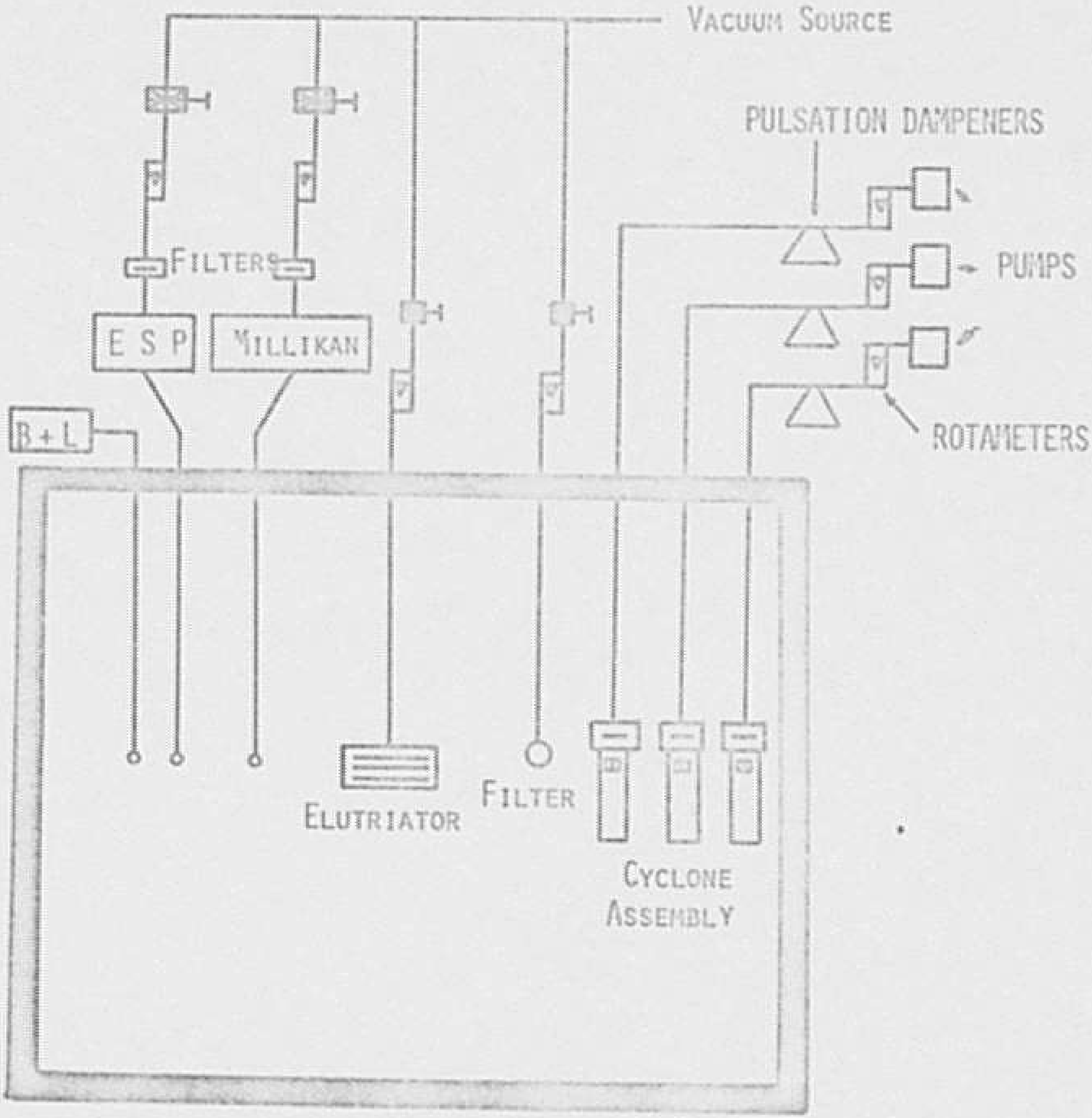

Figure 2. Arrangement at Test Section

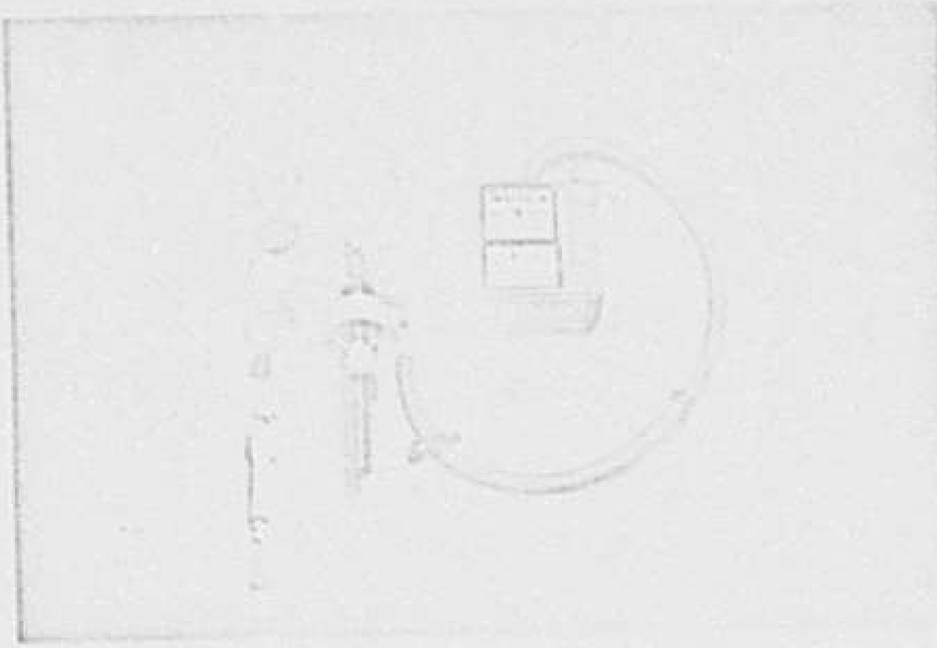

Figure 3. Respirable Mass Sampler

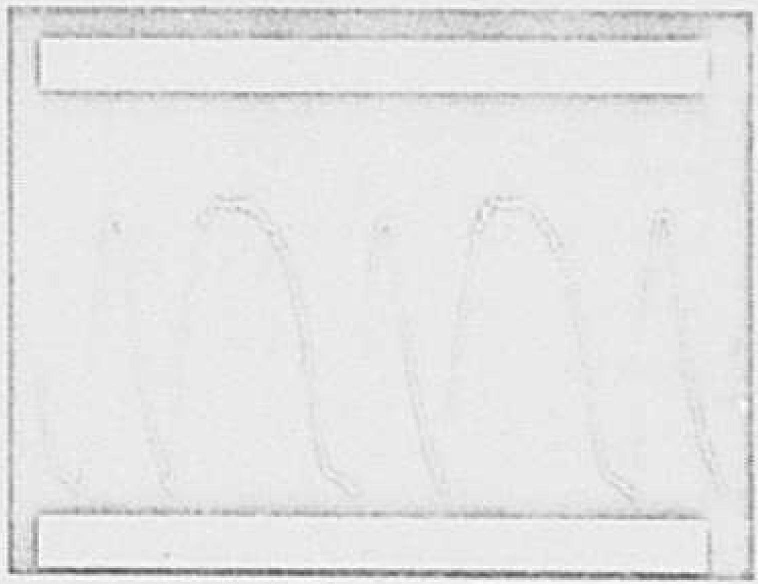

Figure 4. Pump Pulsation. Average air flow 2.0 lpm; scale 1.1 lpm per division, 5 milliseconds per division.

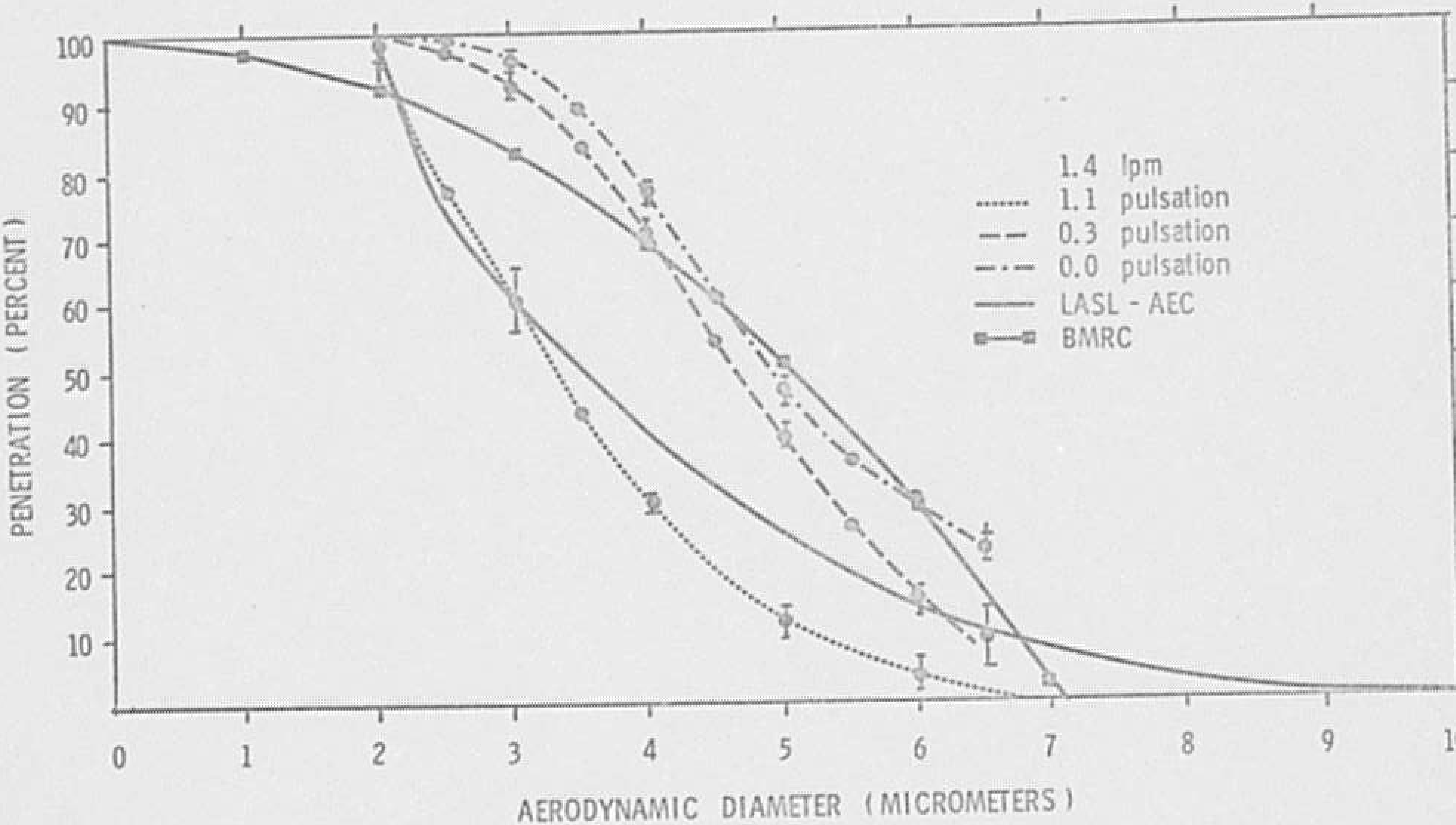

Figure 5. Plot of polynomial curve fit of experimental data at 1.4 lpm. Error bars are the 95 percent confidence limits.

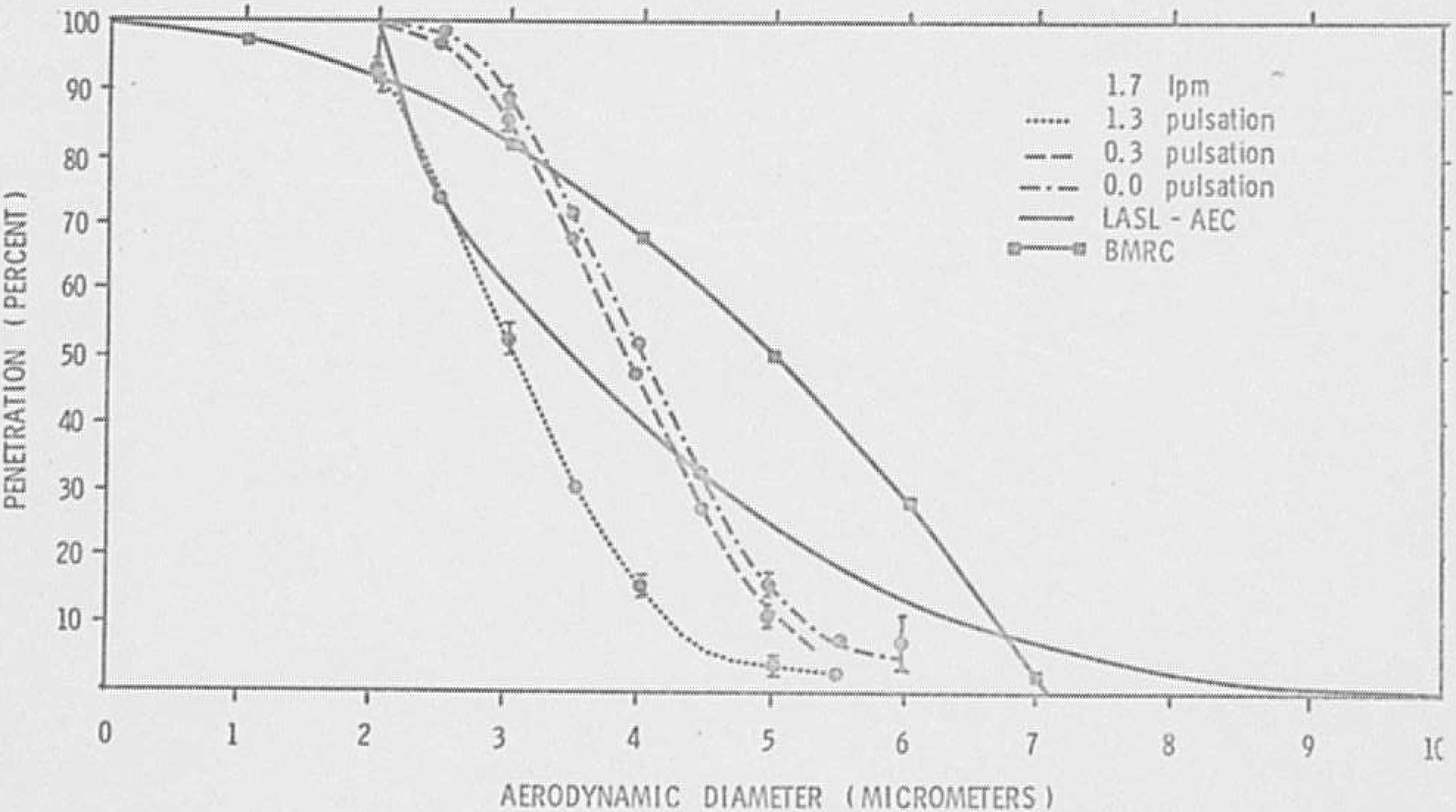

Figure 6. Plot of polynomial curve fit of experimental data at 1.7 lpm. Error bars are the 95 percent confidence limits.

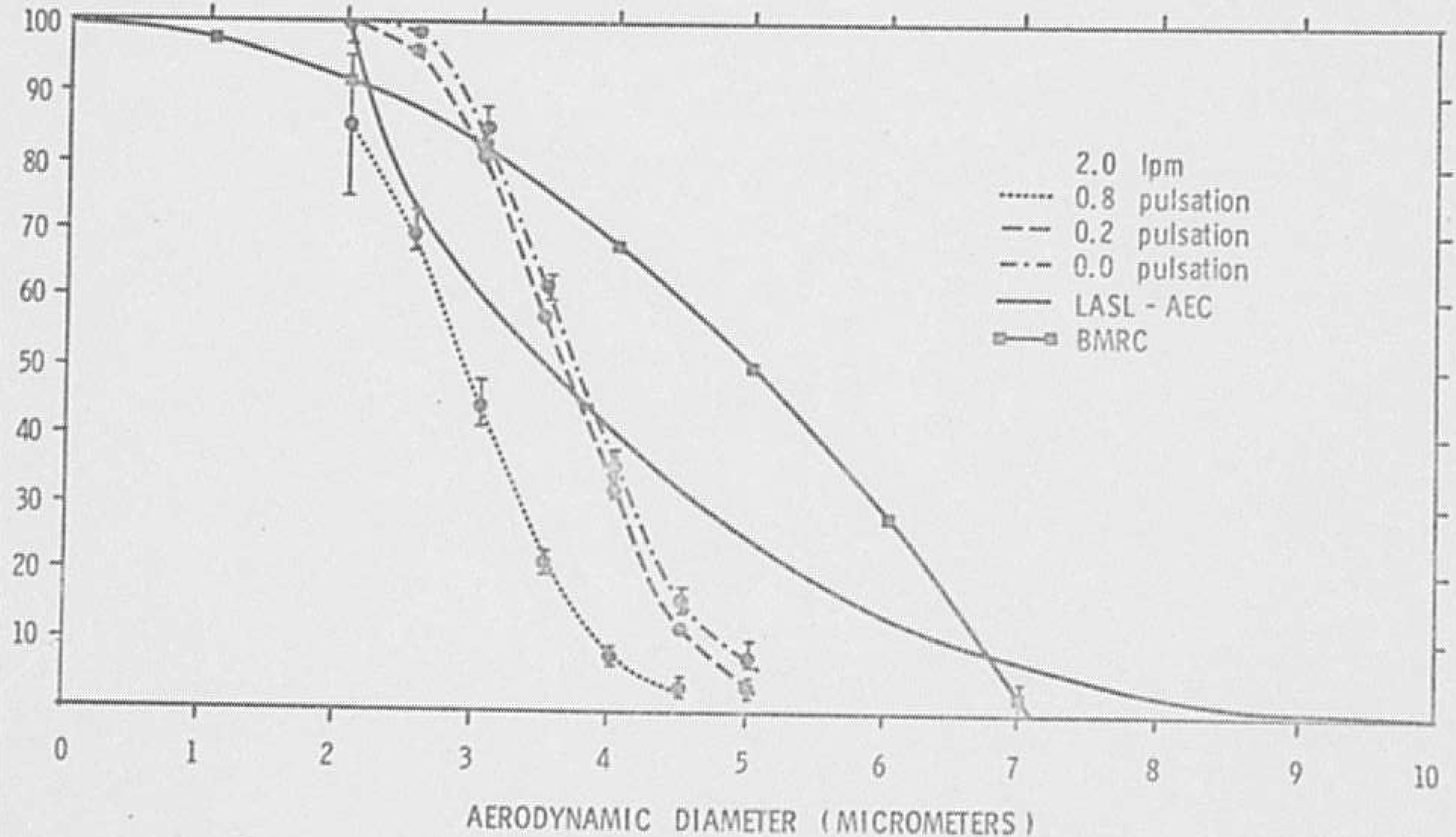

Figure 7. Plot of polynomial curve fit of experimental data at 2.0 lpm. Error bars are the 95 percent confidence limits.

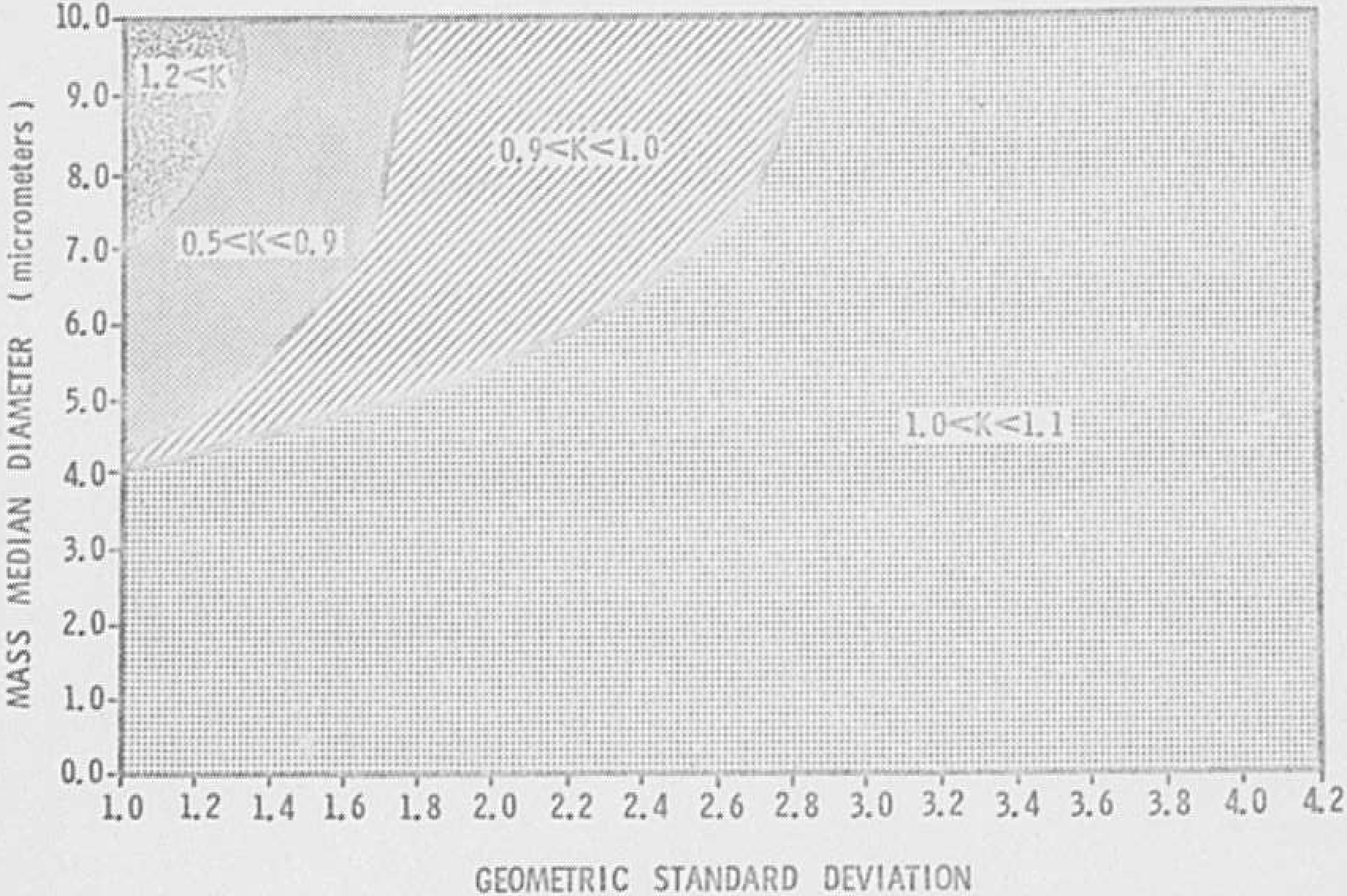

Figure 8. Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 1.4 lpm, Pulsation 0.3.

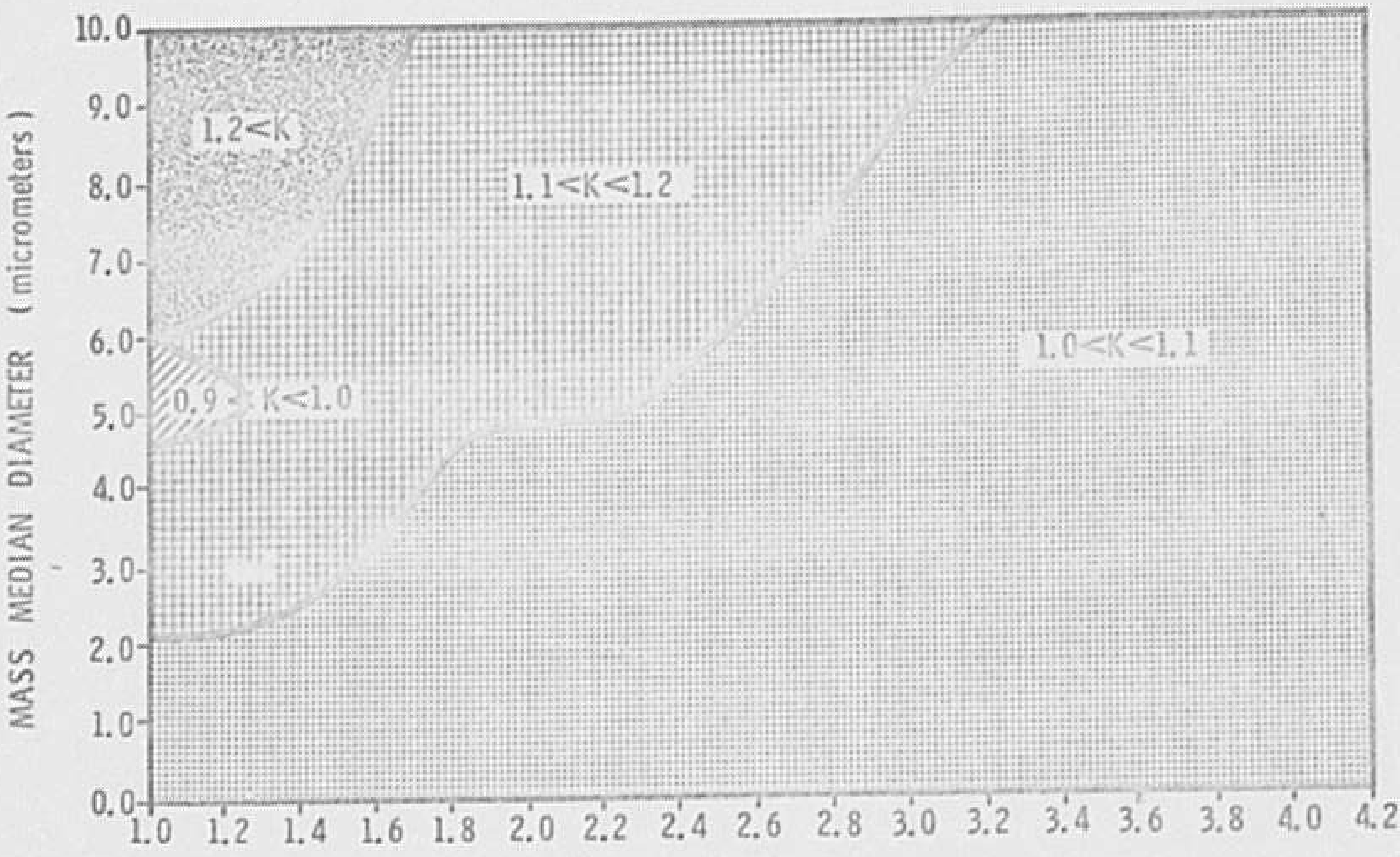

Figure 9. Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 1.4 lpm, Pulsation 0.0.

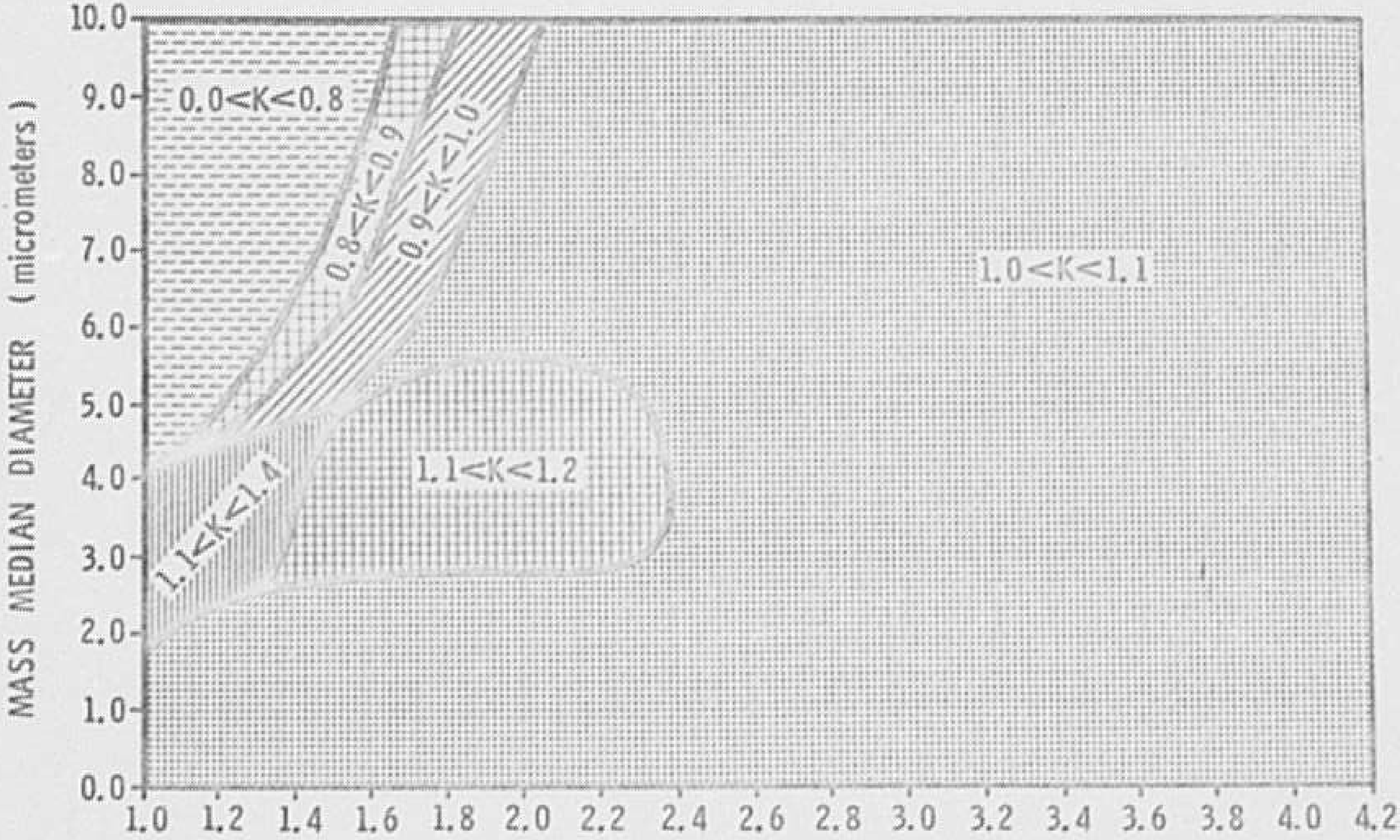

Figure 10. Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 1.7 lpm, Pulsation 0.0.

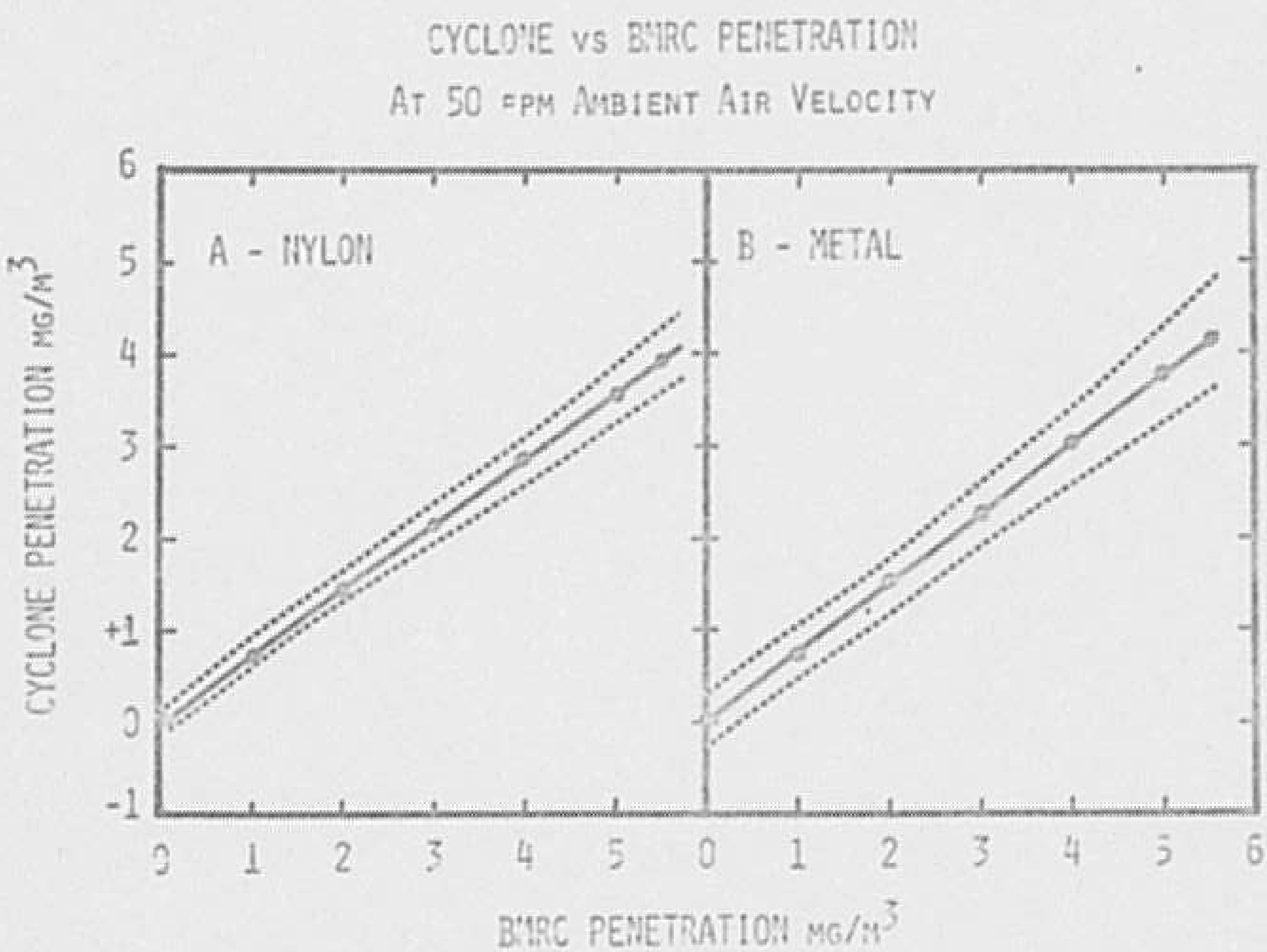

Figure 11. Least squares analysis of cyclone penetration vs. BMRC penetration at 50 fpm ambient air velocity. Solid line is the regression line. Dotted lines are the 95 percent confidence limits.

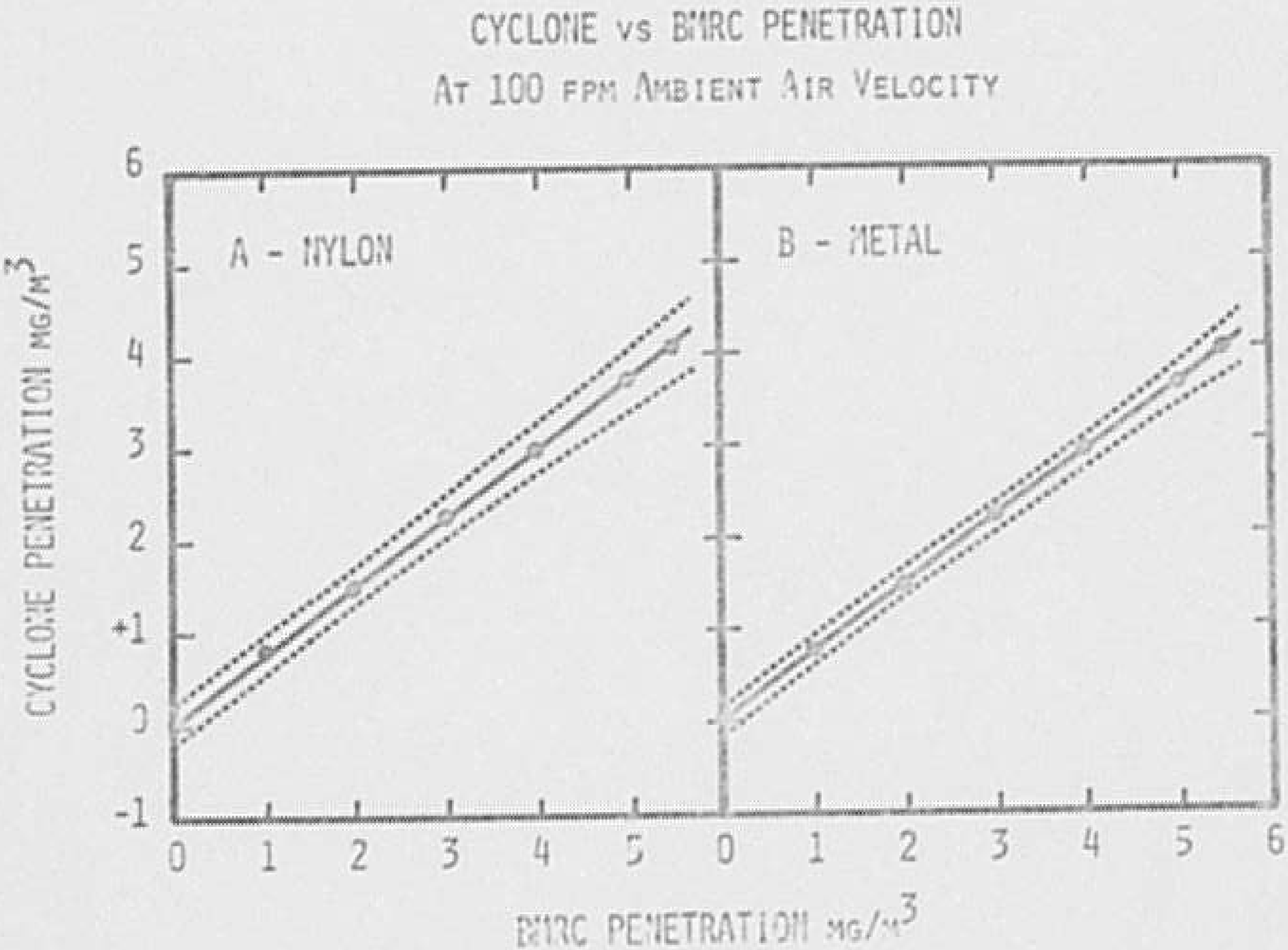

Figure 12. Least squares analysis of cyclone penetration vs. BMRC penetration at 100 fpm ambient air velocity. Solid line is the regression line. Dotted lines are the 95 percent confidence limits.

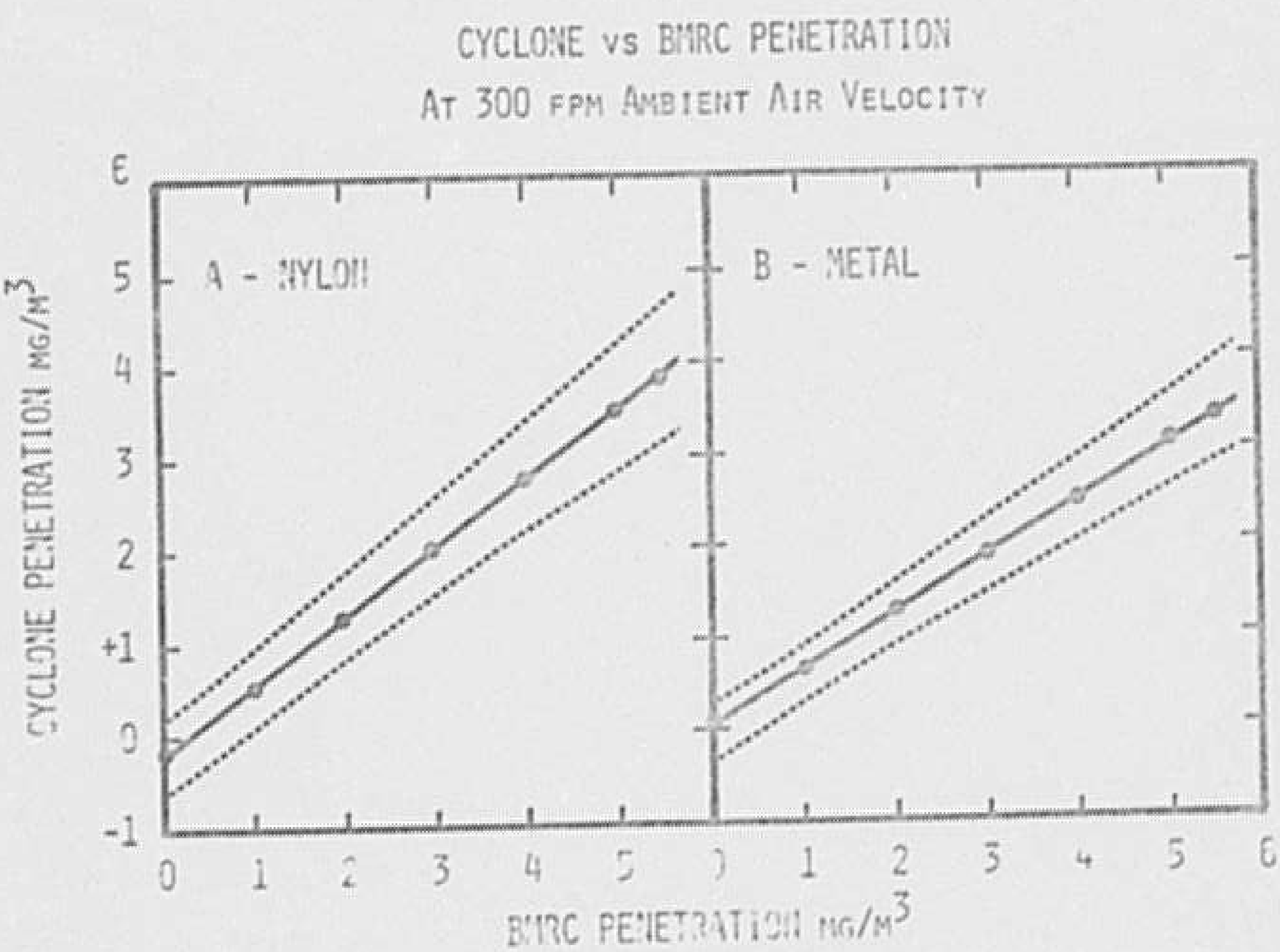

Figure 13. Least squares analysis of cyclone penetration vs. BMRC penetration at 300 fpm ambient air velocity. Solid line is the regression line. Dotted lines are the 95 percent confidence limits.

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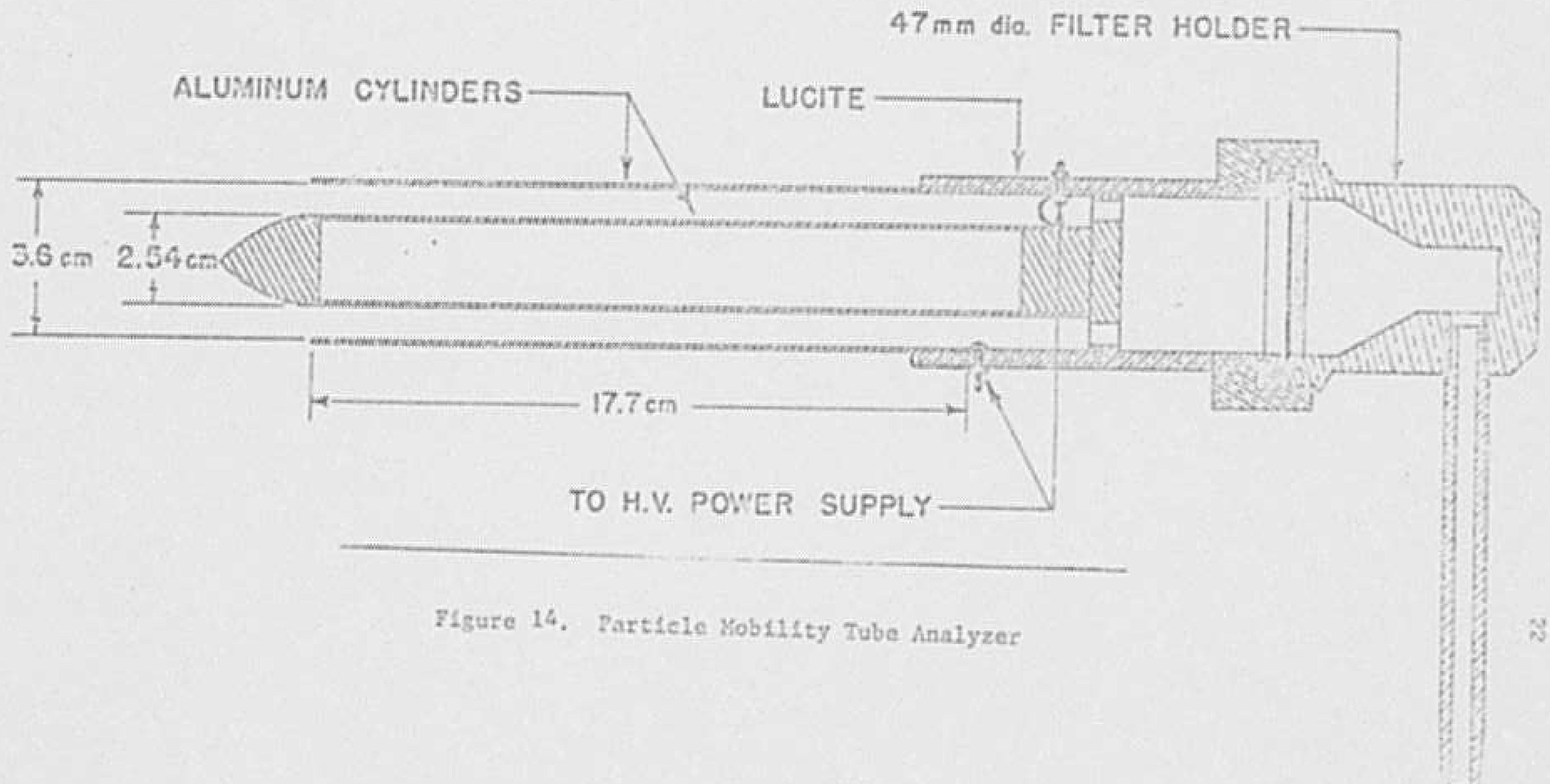

Figure 14. Particle Mobility Tube Analyzer

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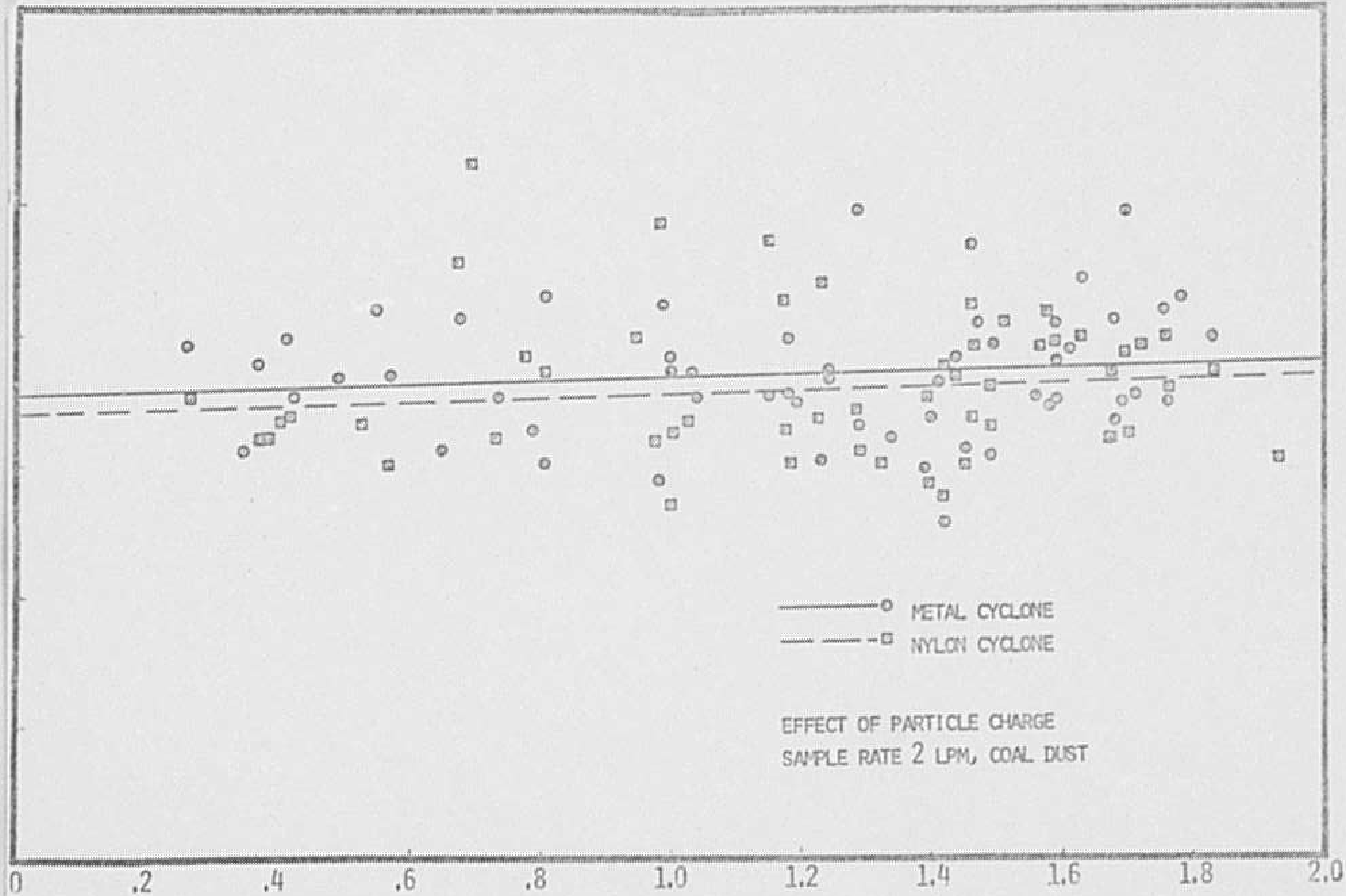

Figure 15. Effect of Particle Charge. Ratio of cyclone to BMRC respirable mass versus particle charge.

PARTICLE CHARGE, $q_L \times 10^3$

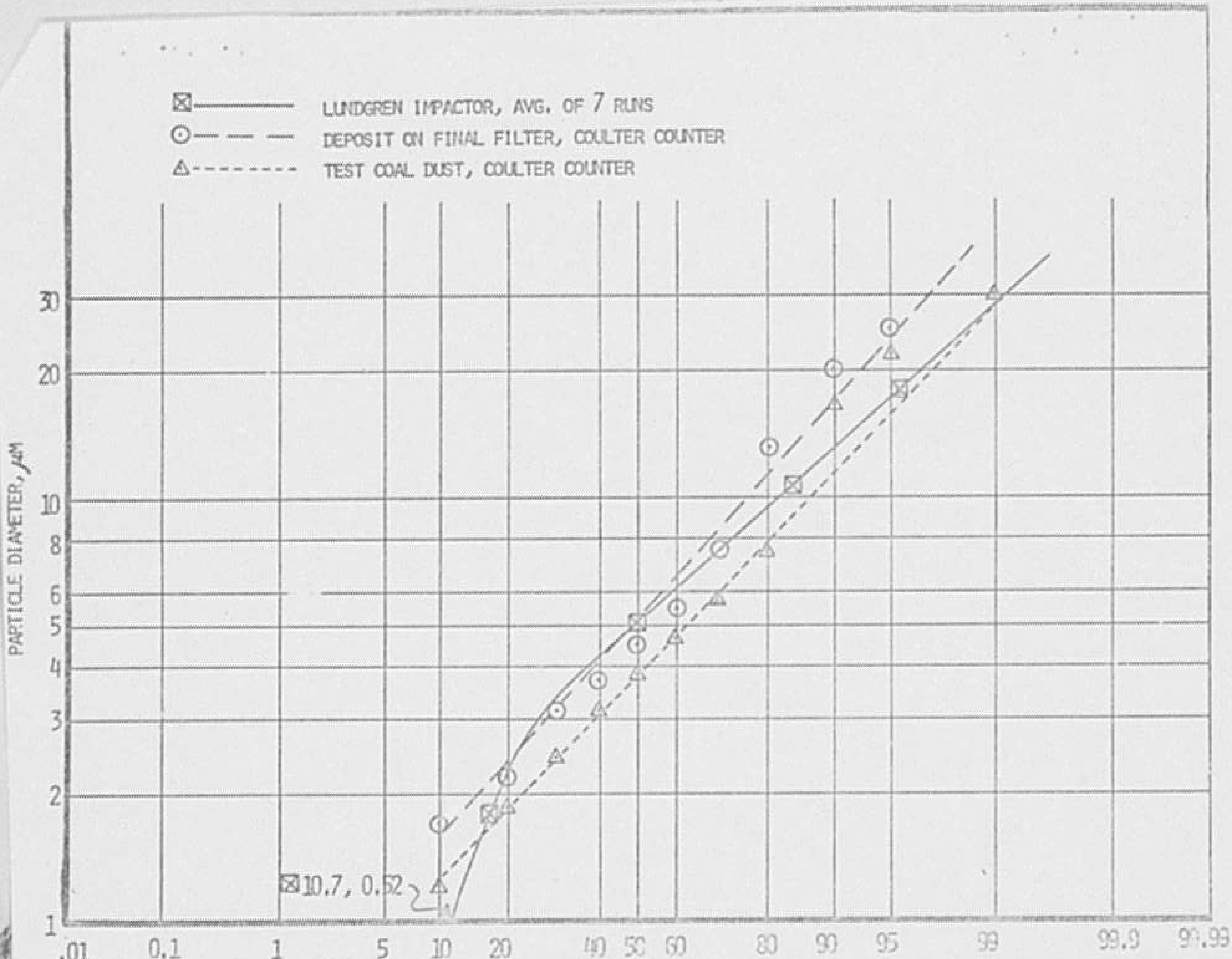

Figure 16. Coal Dust Size Data.

APPENDIX A

Filter Weighing Procedure

A Cahn Model RG electrobalance with a Sargent Model SR strip chart recorder was used for all filter weighings. Class M weights were used to calibrate the balance scale. The balance and amplifier were on a 700-pound marble table to reduce the effects of vibrations. The only other equipment on the marble table were small items such as weighing forceps, weights, and static eliminator. The recorder was on a separate table. A work bench for making up the filter cassets was also provided.

A weighing procedure that would minimize variations in either room or local environment was desired. It was subjectively observed that the presence or movement of visitors in the weighing room seemed to affect the smoothness of the weighing in spite of the uniform horizontal flow of conditioned air (analyst and visitors alike were always downwind of the electrobalance). Whether this was due to mechanical vibration transmitted through the clean room floor, minor perturbations of air pressure, or other factors was not determined. As a matter of practical solution, all other personnel were excluded from the room during weighing; and movements of the analyst were routinized both as to gross body position and movement as well as to manipulation of the balance.

The weighing procedure was as follows:

1. Turn balance and recorder on. (The balance and recorder was left on for the duration of the coal dust work.)

2. Place the stirrups for 37 mm diameter filters on balance loops A and C. The stirrup on loop A is for samples and loop C for weights (the conventional arrangement).

3. Set balance recorder range to zero and zero the recorder. The recorder zero was set at center scale to monitor both positive and negative deflections, using the recorder as null device.

4. Place a 13 mg (approximately the weight of a filter) wire on Pan A and a membrane filter on Pan C. The exact mass of the wire is not important as long as all initial and final weighings are made with the same wire.

5. Set the Mass Dial Range to 10 mg full scale, the Mass Readout to 5.000 mg, Recorder Range to 0.1, and Filter to 1.

6. Bring the recorder pen to the center line zero by adjusting the set 0/10 knob. If zero is not achieved with the Set 0/10 knob, add or remove pieces of membrane filter on Pan C until zero can be achieved.

7. Calibrate the Mass Readout by setting the dial to 10.000 mg and add a 5 mg Class M weight to Pan A. (Note: This is 5.000 mg

added to the initial setting of 5.000 mg.) Bring the recorder pen to zero by adjusting the Set 10 knob on the balance. If zero cannot be obtained, pieces of membrane filter may have to be added or removed to bring both Set knobs into range.

8. Repeat steps 6 and 7 until no further adjustment of the Set knobs is required.

9. Remove the wire from Pan A.

10. Place filter to be weighed on Pan A.

11. Turn the Mass Dial to the point that brings the recorder pen back to the zero point. The mass in excess of the wire is read from the Mass Dial in milligrams.

12. After every two filter weighings, replace the 13 mg tare wire, set the Mass Dial knob to 5.000, and check the balance zero. (Usage has shown insignificant zero drift, and the 5 mg calibration rarely changed during a weighing session.)

The same procedure is used in the final filter weighings, the difference in the final and initial weighings being the mass of coal dust collected. The weighing procedure was evaluated by repeated weighing of a membrane filter. The membrane filter was weighed as described and the filter removed from the pan. The same filter was again placed on Pan A and weighed. The filter was passed in front of the ionization source to remove static charge each time. After every two weighings, the 13 mg wire was placed on Pan A and the zero checked. At the same time, the 5.000 mg calibration was also checked. This process was repeated seven times for a total of fourteen weighings. The mean of all weighings was 5.996 mg $\pm$ 0.010 mg (one standard deviation). A long-time stability check was also performed. The same membrane filter was retained; and during the course of weighing other membrane filters, the test filter was weighed. A total of eighteen separate weighings over a fourteen-day period resulted in a mean tare of 6.001 $\pm$ 0.006 mg ($\pm$ 0.1%). This precision is ten times better than allowed the manufacturer of the preweighed cassettes and five times better than allowed at the Respirable Mine Dust Sample Processing Laboratory (21).

APPENDIX B

Compilation of K Values
Tables B-1 to B-40

Table B-1

CYCLONE TO BMRC PENETRATION RATIO
MASS MEDIAN DIAMETER = 1.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0211	1.0211	1.0255	1.0209	1.0212	1.0242	1.0212	1.0216	1.0007
1.30	1.0223	1.0223	1.0257	1.0235	1.0235	1.0224	1.0239	1.0240	.9972
1.50	1.0254	1.0252	1.0206	1.0271	1.0265	1.0156	1.0268	1.0261	.9879
1.70	1.0292	1.0279	1.0096	1.0280	1.0264	1.0028	1.0234	1.0235	.9726
1.90	1.0319	1.0289	.9978	1.0254	1.0228	.9873	1.0199	1.0169	.9563
2.10	1.0337	1.0288	.9859	1.0213	1.0178	.9735	1.0131	1.0092	.9424
2.30	1.0347	1.0280	.9769	1.0171	1.0128	.9626	1.0067	1.0021	.9316
2.50	1.0353	1.0271	.9693	1.0132	1.0084	.9542	1.0012	.9951	.9235
2.70	1.0357	1.0261	.9646	1.0099	1.0046	.9478	.9966	.9912	.9176
2.90	1.0358	1.0251	.9605	1.0071	1.0016	.9429	.9930	.9873	.9133
3.10	1.0358	1.0243	.9574	1.0048	.9990	.9393	.9900	.9841	.9101
3.30	1.0357	1.0235	.9549	1.0029	.9969	.9365	.9875	.9816	.9078
3.50	1.0355	1.0228	.9530	1.0012	.9952	.9343	.9856	.9795	.9062
3.70	1.0354	1.0222	.9515	.9999	.9937	.9326	.9839	.9778	.9050
3.90	1.0352	1.0216	.9503	.9987	.9925	.9313	.9826	.9764	.9041
4.10	1.0350	1.0211	.9494	.9977	.9915	.9303	.9814	.9752	.9035

Table B-2

CYCLONE TO BMRC PENETRATION RATIO
MASS MEDIAN DIAMETER = 2.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0629	1.0629	1.0148	1.0852	1.0799	.9542	1.0841	1.0773	.9146
1.30	1.0731	1.0686	.9707	1.0760	1.0684	.9433	1.0660	1.0561	.8704
1.50	1.0732	1.0616	.9336	1.0493	1.0386	.8973	1.0269	1.0148	.8284
1.70	1.0695	1.0522	.9120	1.0258	1.0135	.8719	.9969	.9830	.8077
1.90	1.0663	1.0449	.9016	1.0103	.9975	.8605	.9780	.9657	.8006
2.10	1.0636	1.0397	.8972	1.0007	.9878	.8584	.9684	.9554	.8001
2.30	1.0614	1.0365	[illegible]	.9946	.9818	.8558	.9623	.9477	.8076
2.50	1.0595	1.0332	.8960	.9907	.9781	.8570	.9588	.9464	.8054
2.70	1.0578	1.0311	.8970	.9880	.9757	.8590	.9566	.9446	.8106
2.90	1.0562	1.0294	.8984	.9862	.9742	.8614	.9554	.9437	.8149
3.10	1.0548	1.0280	.8999	.9849	.9732	.8639	.9547	.9434	.8191
3.30	1.0536	1.0269	.9015	.9840	.9725	.8664	.9545	.9433	.8231
3.50	1.0524	1.0259	.9031	.9834	.9722	.8688	.9544	.9435	.8269
3.70	1.0513	1.0250	.9047	.9829	.9719	.8711	.9545	.9439	.8305
3.90	1.0503	1.0243	.9062	.9826	.9718	.8734	.9547	.9443	.8338
4.10	1.0494	1.0236	.9076	.9824	.9718	.8754	.9549	.9447	.8369

Table B-3

CYCLONE TO BMRC PENETRATION RATIO
MASS MEDIAN DIAMETER = 3.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.1635	1.1276	.7251	1.0719	1.0450	.6344	1.0096	.9767	.5383
1.30	1.1253	1.0860	.7326	1.0080	.9784	.6411	.9294	.8980	.5521
1.50	1.1032	1.0581	.7500	.9712	.9438	.6669	.8979	.8706	.5854
1.70	1.0931	1.0452	.7725	.9593	.9343	.6965	.8933	.8690	.6210
1.90	1.0867	1.0387	.7910	.9584	.9335	.7224	.8965	.8746	.6518
2.10	1.0818	1.0348	.8078	.9566	.9354	.7436	.9015	.8812	.6772
2.30	1.0778	1.0322	.8208	.9578	.9380	.7610	.9065	.8876	.6982
2.50	1.0744	1.0303	.8316	.9593	.9407	.7753	.9111	.8934	.7157
2.70	1.0715	1.0288	.8406	.9608	.9432	.7873	.9152	.8984	.7304
2.90	1.0689	1.0277	.8482	.9622	.9455	.7975	.9188	.9028	.7429
3.10	1.0666	1.0267	.8547	.9635	.9475	.8062	.9220	.9067	.7537
3.30	1.0646	1.0258	.8604	.9647	.9493	.8138	.9248	.9101	.7631
3.50	1.0628	1.0251	.8653	.9658	.9510	.8204	.9273	.9131	.7714
3.70	1.0612	1.0245	.8697	.9668	.9525	.8263	.9295	.9159	.7788
3.90	1.0597	1.0239	.8735	.9677	.9538	.8315	.9315	.9183	.7854
4.10	1.0584	1.0234	.8771	.9686	.9550	.8362	.9333	.9205	.7914

Table B-4

CYCLONE TO BMRC PENETRATION RATIO
MASS MEDIAN DIAMETER = 4.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.1115	1.0201	.4352	.7707	.7064	.2430	.5470	.4943	.1454
1.30	1.1048	1.0097	.5000	.7966	.7459	.3605	.6450	.6074	.2755
1.50	1.1075	1.0159	.5915	.8409	.7999	.4716	.7255	.6881	.3913
1.70	1.1043	1.0205	.6553	.8731	.8382	.5529	.7781	.7459	.4759
1.90	1.0990	1.0225	.7012	.8947	.8641	.6110	.8129	.7845	.5373
2.10	1.0938	1.0239	.7348	.9097	.8823	.6535	.8371	.8115	.5832
2.30	1.0890	1.0243	.7602	.9205	.8955	.6857	.8547	.8313	.6185
2.50	1.0848	1.0244	.7798	.9286	.9055	.7108	.8680	.8453	.6466
2.70	1.0811	1.0243	.7955	.9349	.9133	.7310	.8784	.8582	.6694
2.90	1.0770	1.0241	.8083	.9399	.9196	.7474	.8869	.8677	.6882
3.10	1.0750	1.0238	.8189	.9440	.9247	.7612	.8937	.8756	.7041
3.30	1.0725	1.0235	.8279	.9474	.9290	.7728	.8995	.8822	.7178
3.50	1.0703	1.0232	.8356	.9502	.9326	.7828	.9044	.8878	.7295
3.70	1.0683	1.0229	.8423	.9526	.9357	.7915	.9086	.8926	.7399
3.90	1.0665	1.0226	.8481	.9547	.9384	.7992	.9122	.8968	.7490
4.10	1.0648	1.0223	.8533	.9566	.9408	.8059	.9155	.9005	.7571

Table B-5

CYCLONE TO BMRC PENETRATION RATIO
MASS MEDIAN DIAMETER = 5.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	.9683	.7997	.2424	.3009	.3109	.0727	.1948	.1398	.0325
1.30	1.0773	.9052	.3591	.5772	.5174	.1961	.4079	.3590	.1304
1.50	1.1093	.9646	.4774	.7136	.6642	.3378	.5759	.5333	.2643
1.70	1.1122	.9914	.5666	.7908	.7490	.4458	.6767	.6396	.3720
1.90	1.1082	1.0045	.6304	.8367	.8005	.5254	.7391	.7004	.4517
2.10	1.1027	1.0115	.6768	.8661	.8340	.5828	.7804	.7510	.5112
2.30	1.0975	1.0154	.7114	.8863	.8572	.6259	.8092	.7825	.5567
2.50	1.0927	1.0177	.7379	.9007	.8740	.6592	.8304	.8058	.5925
2.70	1.0885	1.0191	.7589	.9115	.8868	.6856	.8465	.8236	.6213
2.90	1.0848	1.0200	.7758	.9199	.8967	.7071	.8591	.8376	.6450
3.10	1.0815	1.0205	.7898	.9265	.9047	.7248	.8693	.8490	.6649
3.30	1.0786	1.0208	.8015	.9319	.9112	.7397	.8777	.8584	.6817
3.50	1.0761	1.0210	.8114	.9364	.9166	.7524	.8847	.8662	.6962
3.70	1.0737	1.0210	.8199	.9401	.9212	.7634	.8907	.8730	.7088
3.90	1.0717	1.0210	.8274	.9433	.9251	.7730	.8958	.8788	.7199
4.10	1.0698	1.0210	.8339	.9451	.9285	.7814	.9003	.8839	.7298

Table B-6

CYCLONE TO BMRC PENETRATION RATIO
MASS MEDIAN DIAMETER = 6.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PU[illegible]ION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0486	.6456	.1443	.1357	.0854	.0232	.0739	.0366	.0067
1.30	1.1058	.8247	.2702	.4124	.3526	.1129	.2619	.2144	.0655
1.50	1.1211	.9187	.3985	.6071	.5534	.2500	.4618	.4169	.1848
1.70	1.1214	.9638	.5000	.7189	.6726	.3692	.5933	.5532	.2980
1.90	1.1164	.9866	.5750	.7851	.7448	.4594	.6765	.6408	.3870
2.10	1.1103	.9991	.6301	.8272	.7914	.5266	.7316	.6994	.4550
2.30	1.1044	1.0064	.6715	.8555	.8233	.5775	.7698	.7405	.5075
2.50	1.0991	1.0110	.7034	.8757	.8462	.6170	.7976	.7707	.5490
2.70	1.0945	1.0139	.7285	.8905	.8633	.6483	.8186	.7936	.5823
2.90	1.0904	1.0158	.7487	.9019	.8765	.6736	.8350	.8115	.6098
3.10	1.0868	1.0171	.7654	.9109	.8869	.6946	.8481	.8260	.6327
3.30	1.0836	1.0180	.7793	.9181	.8955	.7121	.8588	.8378	.6521
3.50	1.0807	1.0186	.7910	.9241	.9025	.7270	.8676	.8476	.6687
3.70	1.0782	1.0190	.8011	.9290	.9084	.7399	.8751	.8560	.6832
3.90	1.0759	1.0193	.8099	.9332	.9134	.7511	.8815	.8631	.6959
4.10	1.0738	1.0195	.8176	.9360	.9178	.7609	.8871	.8693	.7072

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Table B-7

CYCLONE TO BMRC PENETRATION RATIO
MASS MEDIAN DIAMETER = 7.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.9998	.7813	.1145	.0394	.0151	.0061	.0297	.0082	.0008
1.30	1.2075	.7797	.2177	.3011	.2450	.0708	.1783	.1345	.0363
1.50	1.1457	.8021	.3431	.5222	.4666	.1918	.3777	.3322	.1342
1.70	1.1330	.9395	.4494	.6577	.6084	.3116	.5258	.4839	.2443
1.90	1.1248	.9702	.5308	.7401	.6967	.4076	.6238	.5859	.3371
2.10	1.1172	.9875	.5928	.7926	.7540	.4812	.6895	.6553	.4101
2.30	1.1165	.9979	.6334	.8281	.7933	.5377	.7355	.7042	.4675
2.50	1.1047	1.0045	.6743	.8532	.8214	.5810	.7690	.7402	.5130
2.70	1.0996	1.0080	.7028	.8717	.8423	.6169	.7942	.7674	.5499
2.90	1.0951	1.0117	.7257	.8853	.8584	.6454	.8137	.7887	.5802
3.10	1.0912	1.0138	.7445	.8959	.8712	.6689	.8293	.8057	.6056
3.30	1.0877	1.0152	.7602	.9057	.8814	.6886	.8420	.8197	.6271
3.50	1.0847	1.0163	.7736	.9130	.8899	.7054	.8525	.8312	.6455
3.70	1.0819	1.0171	.7850	.9190	.8970	.7198	.8614	.8410	.6615
3.90	1.0795	1.0176	.7949	.9241	.9030	.7323	.8689	.8494	.6755
4.10	1.0773	1.0180	.8035	.9285	.9082	.7433	.8754	.8566	.6879

Table B-8

CYCLONE TO BMRC PENETRATION RATIO
MASS MEDIAN DIAMETER = 8.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	8.0514	1.7569	.1360	.0109	.0019	.0015	.0130	.0018	.0001
1.30	1.3819	.7656	.1858	.2270	.1757	.0481	.1296	.0896	.0221
1.50	1.1822	.8544	.3032	.4550	.3991	.1520	.3154	.2702	.1010
1.70	1.1473	.9186	.4099	.6061	.5548	.2678	.4710	.4260	.2044
1.90	1.1332	.9554	.4950	.7007	.6550	.3682	.5790	.5396	.2977
2.10	1.1237	.9768	.5602	.7620	.7211	.4437	.6531	.6172	.3736
2.30	1.1160	.9899	.6104	.8035	.7666	.5042	.7054	.6720	.4342
2.50	1.1076	.9983	.6495	.8330	.7993	.5519	.7435	.7133	.4828
2.70	1.1050	1.0039	.6806	.8547	.8236	.5900	.7724	.7443	.5224
2.90	1.0992	1.0078	.7057	.8712	.8422	.6213	.7940	.7684	.5550
3.10	1.0950	1.0106	.7264	.8842	.8570	.6467	.8126	.7878	.5823
3.30	1.0914	1.0126	.7437	.8945	.8688	.6682	.8271	.8035	.6053
3.50	1.0881	1.0140	.7583	[illegible]	.8784	.6865	.8390	.8166	.6254
3.70	1.0852	1.0151	.7708	.9100	.8867	.7022	.8491	.8277	.6427
3.90	1.0826	1.0160	.7817	.9159	.8936	.7159	.8576	.8371	.6579
4.10	1.0802	1.0166	.7912	.9209	.8995	.7279	.8650	.8452	.6712

Table B-9

CYCLONE TO BMRC PENETRATION RATIO

MASS MEDIAN DIAMETER = 9.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	52.7647	6.3962	.2107	.0032	.0001	.0004	.0074	.0006	.0000
1.30	1.6272	.7755	.1659	.1767	.1302	.0349	.0997	.0632	.0145
1.50	1.2286	.8343	.2736	.4015	.3460	.1239	.2487	.2263	.0705
1.70	1.1640	.9010	.3786	.5822	.5096	.2339	.4261	.3825	.1740
1.90	1.1423	.9422	.4654	.6663	.6189	.3324	.5408	.5004	.2680
2.10	1.1301	.9570	.5334	.7347	.6926	.4124	.6214	.5642	.3433
2.30	1.1212	.9825	.5854	.7814	.7428	.4757	.6788	.6447	.4061
2.50	1.1140	.9926	.6280	.8147	.7793	.5261	.7210	.6895	.4570
2.70	1.1080	.9994	.6613	.8393	.8065	.5666	.7530	.7236	.4980
2.90	1.1029	1.0041	.6882	.8583	.8276	.5997	.7770	.7503	.5331
3.10	1.0984	1.0075	.7105	.8726	.8441	.6272	.7975	.7716	.5621
3.30	1.0945	1.0100	.7290	.8843	.8574	.6502	.8136	.7890	.5867
3.50	1.0911	1.0119	.7448	.8938	.8683	.6699	.8268	.8035	.6073
3.70	1.0880	1.0133	.7583	.9017	.8774	.6867	.8380	.8157	.6262
3.90	1.0853	1.0143	.7700	.9084	.8851	.7014	.8474	.8260	.6423
4.10	1.0828	1.0152	.7802	.9140	.8917	.7143	.8556	.8350	.6565

Table B-10

CYCLONE TO BMRC PENETRATION RATIO

MASS MEDIAN DIAMETER = 10.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	*1.1515	30.6011	.3576	.0010	.0001	.0001	.0044	.0001	.0000
1.30	1.9428	.8040	.1530	.1416	.0994	.0265	.0882	.0468	.0101
1.50	1.2031	.8202	.2510	.3564	.3037	.1035	.2330	.1895	.0627
1.70	1.1826	.8861	.3533	.5246	.4713	.2070	.3889	.3450	.1504
1.90	1.1517	.9305	.4406	.6359	.5871	.3045	.5050	.4687	.2400
2.10	1.1363	.9581	.5104	.7102	.6661	.3857	.5934	.5552	.3178
2.30	1.1260	.9756	.5655	.7615	.7213	.4511	.6551	.6199	.3820
2.50	1.1181	.9872	.6092	.7981	.7613	.5036	.7007	.6881	.4346
2.70	1.1116	.9950	.6442	.8252	.7912	.5460	.7354	.7290	.4779
2.90	1.1062	1.0006	.6727	.8450	.8142	.5809	.7624	.7339	.5129
3.10	1.1015	1.0046	.6962	.8620	.8323	.6098	.7839	.7570	.5442
3.30	1.0974	1.0075	.7160	.8749	.8469	.6342	.8013	.7759	.5700
3.50	1.0938	1.0098	.7327	.8854	.8589	.6550	.8157	.7916	.5922
3.70	1.0906	1.0115	.7470	.8941	.8689	.6729	.8278	.8047	.6115
3.90	1.0877	1.0128	.7595	.9015	.8773	.6884	.8381	.8159	.6284
4.10	1.0851	1.0138	.7703	.9077	.8845	.7021	.8470	.8257	.6434

Table B-11

COUNT MEDIAN DIAMETER = 1.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0218	1.0218	1.0270	1.0221	1.0223	1.0253	1.0226	1.0229	1.0001
1.30	1.0294	1.0294	1.0324	1.0356	1.0349	1.0264	1.0365	1.0358	.9857
1.50	1.0549	1.0502	.9852	1.0513	1.0456	.9639	1.0420	1.0352	.9056
1.70	1.0793	1.0530	.8659	1.0088	.9922	.8132	.9675	.9505	.7436
1.90	1.0928	1.0323	.7492	.9241	.9026	.6696	.8587	.8335	.5971
2.10	1.1045	1.0088	.6659	.8574	.8244	.5697	.7693	.7393	.4980
2.30	1.1161	.9898	.6100	.8032	.7663	.5038	.7050	.6721	.4338
2.50	1.1271	.9756	.5717	.7634	.7239	.4592	.6593	.6247	.3909
2.70	1.1369	.9649	.5445	.7338	.6927	.4279	.6260	.5902	.3610
2.90	1.1455	.9568	.5245	.7112	.6690	.4050	.6010	.5645	.3393
3.10	1.1530	.9505	.5092	.6937	.6505	.3877	.5818	.5447	.3229
3.30	1.1595	.9455	.4973	.6797	.6359	.3742	.5666	.5292	.3103
3.50	1.1651	.9414	.4877	.6683	.6240	.3634	.5544	.5166	.3002
3.70	1.1700	.9381	.4799	.6589	.6142	.3547	.5443	.5053	.2920
3.90	1.1743	.9353	.4734	.6510	.6060	.3474	.5360	.4978	.2853
4.10	1.1781	.9330	.4680	.6443	.5991	.3413	.5289	.4905	.2796

CYCLONE TO BMRC PENETRATION RATIO

COUNT MEDIAN DIAMETER = 2.0 MICROMETERS

Table B-12

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0676	1.0676	1.0054	1.0898	1.0838	.9837	1.0877	1.0799	.9039
1.30	1.1048	1.0886	.8709	1.0689	1.0529	.8183	1.0345	1.0152	.7363
1.50	1.1059	1.0489	.7025	.9375	.9058	.6070	.8506	.8200	.5248
1.70	1.1095	1.0015	.5944	.8181	.7785	.4797	.7097	.6740	.4034
1.90	1.1237	.9720	.5355	.7450	.7020	.4131	.6295	.5918	.3423
2.10	1.1390	.9545	.5015	.7005	.6558	.3755	.5824	.5439	.3080
2.30	1.1523	.9435	.4803	.6718	.6262	.3522	.5527	.5137	.2870
2.50	1.1632	.9361	.4660	.6521	.6059	.3368	.5327	.4934	.2731
2.70	1.1720	.9309	.4559	.6379	.5914	.3259	.5184	.4790	.2634
2.90	1.1791	.9271	.4484	.6274	.5806	.3178	.5078	.4693	.2562
3.10	1.1850	.9242	.4427	.6192	.5723	.3117	.4997	.4601	.2507
3.30	1.1899	.9220	.4382	.6128	.5657	.3069	.4933	.4536	.2464
3.50	1.1940	.9201	.4345	.6075	.5604	.3030	.4881	.4484	.2430
3.70	1.1975	.9186	.4315	.6032	.5560	.2998	.4838	.4441	.2402
3.90	1.2005	.9174	.4290	.5996	.5523	.2972	.4803	.4405	.2378
4.10	1.2032	.9164	.4269	.5965	.5492	.2949	.4773	.4375	.2358

le B-13

COUNT MEDIAN DIAMETER = 3.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.1675	1.1250	.6992	1.0561	1.0258	.5975	.9821	.9472	.4970
1.30	1.1163	1.0403	.5702	.8691	.8240	.4357	.7351	.6938	.3468
1.50	1.1088	.9690	.4858	.7240	.6751	.3474	.5875	.5452	.2732
1.70	1.1328	.9399	.4502	.6588	.6095	.3125	.5269	.4850	.2452
1.90	1.1549	.9269	.4333	.6268	.5776	.2964	.4982	.4567	.2326
2.10	1.1712	.9202	.4242	.6089	.5599	.2879	.4825	.4413	.2260
2.30	1.1831	.9162	.4186	.5977	.5489	.2827	.4728	.4318	.2221
2.50	1.1918	.9137	.4149	.5903	.5415	.2794	.4664	.4255	.2196
2.70	1.1984	.9119	.4124	.5850	.5363	.2771	.4619	.4212	.2179
2.90	1.2036	.9106	.4105	.5811	.5325	.2754	.4586	.4179	.2167
3.10	1.2076	.9097	.4091	.5781	.5295	.2741	.4560	.4155	.2158
3.30	1.2110	.9089	.4080	.5757	.5272	.2732	.4541	.4135	.2151
3.50	1.2137	.9083	.4071	.5738	.5253	.2724	.4525	.4120	.2145
3.70	1.2160	.9079	.4064	.5722	.5238	.2718	.4512	.4107	.2141
3.90	1.2179	.9075	.4058	.5709	.5225	.2712	.4501	.4097	.2137
4.10	1.2196	.9071	.4053	.5698	.5215	.2708	.4492	.4088	.2134

Table B-14

CYCLONE TO BMRC PENETRATION RATIO

COUNT MEDIAN DIAMETER = 4.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0945	.9995	.4082	.7270	.6602	.2125	.4926	.4384	.1217
1.30	1.0779	.9133	.3687	.5935	.5340	.2060	.4238	.3750	.1385
1.50	1.1331	.8974	.3657	.5579	.5030	.2152	.4124	.3670	.1542
1.70	1.1696	.8961	.3702	.5499	.4971	.2249	.4139	.3702	.1661
1.90	1.1903	.8968	.3747	.5481	.4965	.2323	.4169	.3741	.1744
2.10	1.2028	.8975	.3783	.5480	.4971	.2376	.4196	.3774	.1803
2.30	1.2109	.8982	.3811	.5484	.4980	.2416	.4218	.3800	.1846
2.50	1.2164	.8988	.3832	.5488	.4988	.2446	.4236	.3820	.1878
2.70	1.2204	.8992	.3849	.5493	.4995	.2469	.4250	.3837	.1903
2.90	1.2234	.8996	.3863	.5497	.5001	.2488	.4262	.3850	.1923
3.10	1.2257	.8999	.3874	.5501	.5007	.2503	.4272	.3861	.1939
3.30	1.2276	.9002	.3884	.5505	.5012	.2516	.4280	.3870	.1953
3.50	1.2291	.9004	.3891	.5508	.5016	.2526	.4286	.3877	.1964
3.70	1.2303	.9005	.3898	.5510	.5019	.2535	.4292	.3884	.1973
3.90	1.2313	.9007	.3904	.5513	.5022	.2543	.4297	.3890	.1981
4.10	1.2322	.9008	.3909	.5515	.5025	.2549	.4301	.3894	.1989

ble B-15

COUNT MEDIAN DIAMETER = 5.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	.9595	.7692	.2240	.3358	.2675	.0623	.1696	.1166	.0268
1.30	1.1161	.8159	.2607	.3931	.3337	.1049	.2455	.1995	.0597
1.50	1.1902	.8501	.2970	.4440	.3881	.1460	.3056	.2606	.0961
1.70	1.2165	.8668	.3209	.4738	.4199	.1737	.3404	.2965	.1217
1.90	1.2277	.8760	.3367	.4921	.4394	.1921	.3618	.3187	.1390
2.10	1.2333	.8817	.3475	.5040	.4522	.2047	.3759	.3333	.1510
2.30	1.2364	.8854	.3553	.5123	.4610	.2139	.3857	.3435	.1597
2.50	1.2383	.8881	.3611	.5183	.4675	.2207	.3929	.3510	.1663
2.70	1.2395	.8900	.3655	.5229	.4724	.2259	.3983	.3566	.1713
2.90	1.2404	.8915	.3690	.5264	.4762	.2300	.4026	.3610	.1753
3.10	1.2410	.8927	.3718	.5292	.4792	.2333	.4059	.3646	.1785
3.30	1.2415	.8937	.3741	.5315	.4817	.2360	.4087	.3674	.1811
3.50	1.2418	.8944	.3760	.5334	.4838	.2383	.4110	.3698	.1834
3.70	1.2421	.8951	.3777	.5350	.4855	.2403	.4129	.3718	.1852
3.90	1.2423	.8957	.3791	.5364	.4870	.2419	.4145	.3735	.1868
4.10	1.2424	.8961	.3803	.5376	.4882	.2433	.4159	.3750	.1882

Table B-16

CYCLONE TO BMRC PENETRATION RATIO
COUNT MEDIAN DIAMETER = 6.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.1112	.6413	.1351	.1117	.0659	.0188	.0632	.0289	.0048
1.30	1.2647	.7712	.2039	.2697	.2154	.0607	.1570	.1146	.0298
1.50	1.2731	.8223	.2545	.3653	.3104	.1066	.2386	.1949	.0651
1.70	1.2696	.8473	.2878	.4182	.3643	.1408	.2898	.2463	.0942
1.90	1.2657	.8613	.3099	.4498	.3968	.1646	.3220	.2790	.1154
2.10	1.2625	.8700	.3252	.4703	.4180	.1814	.3435	.3008	.1307
2.30	1.2601	.8758	.3362	.4843	.4326	.1937	.3585	.3161	.1420
2.50	1.2581	.8799	.3444	.4945	.4432	.2029	.3694	.3273	.1505
2.70	1.2566	.8830	.3507	.5021	.4512	.2101	.3777	.3358	.1572
2.90	1.2554	.8853	.3557	.5080	.4574	.2158	.3842	.3425	.1625
3.10	1.2543	.8871	.3598	.5127	.4623	.2204	.3894	.3478	.1668
3.30	1.2535	.8886	.3631	.5165	.4663	.2241	.3936	.3521	.1704
3.50	1.2528	.8898	.3659	.5196	.4696	.2273	.3971	.3557	.1734
3.70	1.2522	.8908	.3682	.5223	.4724	.2300	.4000	.3588	.1759
3.90	1.2516	.8917	.3702	.5245	.4748	.2323	.4025	.3614	.1781
4.10	1.2512	.8924	.3719	.5265	.4768	.2343	.4047	.3636	.1800

le B-17

COUNT MEDIAN DIAMETER = 7.0 MICROMETERS

IR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.[illegible]
SIGMA									
1.10	2.4761	.8711	.1151	.0307	.0104	.0047	.0253	.0061	.0005
1.30	1.5220	.7691	.1727	.1944	.1460	.0393	.1099	.0721	.0170
1.50	1.3745	.8079	.2265	.3090	.2559	.0824	.1942	.1522	.0471
1.70	1.3263	.8344	.2641	.3759	.3224	.1182	.2531	.2103	.0760
1.90	1.3036	.8507	.2899	.4167	.3637	.1447	.2919	.2491	.0986
2.10	1.2906	.8612	.3081	.4434	.3909	.1639	.3183	.2756	.1156
2.30	1.2822	.8684	.3213	.4618	.4098	.1783	.3369	.2945	.1285
2.50	1.2763	.8735	.3313	.4751	.4235	.1892	.3507	.3085	.1384
2.70	1.2720	.8773	.3390	.4851	.4339	.1977	.3611	.3192	.1462
2.90	1.2688	.8802	.3451	.4929	.4420	.2045	.3693	.3275	.1524
3.10	1.2662	.8826	.3501	.4991	.4484	.2100	.3759	.3342	.1575
3.30	1.2642	.8845	.3542	.5041	.4536	.2146	.3812	.3397	.1618
3.50	1.2625	.8860	.3576	.5082	.4580	.2184	.3857	.3442	.1654
3.70	1.2610	.8873	.3605	.5117	.4616	.2217	.3894	.3481	.1684
3.90	1.2598	.8884	.3630	.5147	.4647	.2245	.3926	.3514	.1710
4.10	1.2588	.8893	.3651	.5173	.4674	.2269	.3954	.3542	.1733

able B-18

CYCLONE TO BMRC PENETRATION RATIO
COUNT MEDIAN DIAMETER = 8.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	11.8756	2.2614	.1482	.0082	.0011	.0011	.0119	.0013	.0001
1.30	1.8866	.7982	.1547	.1466	.1037	.0278	.0829	.0490	.0107
1.50	1.4896	.8029	.2070	.2673	.2162	.0664	.1635	.1231	.0357
1.70	1.3851	.8261	.2464	.3427	.2899	.1020	.2254	.1834	.0632
1.90	1.3410	.8429	.2744	.3900	.3372	.1295	.2682	.2257	.0862
2.10	1.3174	.8544	.2945	.4212	.3688	.1503	.2980	.2555	.1040
2.30	1.3029	.8624	.3093	.4430	.3909	.1660	.3193	.2770	.1179
2.50	1.2932	.8683	.3206	.4589	.4072	.1780	.3352	.2930	.1287
2.70	1.2862	.8727	.3293	.4708	.4194	.1876	.3474	.3053	.1373
2.90	1.2810	.8761	.3363	.4801	.4290	.1952	.3569	.3150	.1442
3.10	1.2770	.8788	.3420	.4875	.4367	.2014	.3646	.3228	.1499
3.30	1.2738	.8810	.3467	.4936	.4429	.2066	.3709	.3292	.1547
3.50	1.2712	.8828	.3507	.4985	.4481	.2110	.3761	.3346	.1587
3.70	1.2690	.8843	.3540	.5027	.4524	.2147	.3805	.3391	.1622
3.90	1.2672	.8856	.3569	.5063	.4561	.2179	.3843	.3429	.1651
4.10	1.2656	.8867	.3594	.5094	.4593	.2207	.3875	.3463	.1677

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	86.1694	9.2602	.2392	.0024	-.0000	.0003	.0065	.0003	.0000
1.30	2.3611	.8507	.1441	.1149	.0760	.0208	.0661	.0355	.0072
1.50	1.6149	.8043	.1928	.2354	.1862	.0553	.1412	.1024	.0282
1.70	1.4450	.8210	.2327	.3159	.2639	.0897	.2039	.1626	.0538
1.90	1.3777	.8372	.2619	.3678	.3153	.1177	.2491	.2070	.0765
2.10	1.3432	.8490	.2833	.4026	.3502	.1393	.2813	.2390	.0948
2.30	1.3225	.8576	.2994	.4271	.3750	.1559	.3047	.2624	.1043
2.50	1.3089	.8639	.3116	.4450	.3932	.1688	.3222	.2800	.1207
2.70	1.2994	.8688	.3212	.4586	.4071	.1791	.3357	.2936	.1299
2.90	1.2923	.8726	.3289	.4691	.4179	.1874	.3463	.3044	.1374
3.10	1.2869	.8756	.3352	.4776	.4266	.1942	.3549	.3131	.1436
3.30	1.2826	.8780	.3404	.4844	.4336	.1999	.3620	.3203	.1487
3.50	1.2791	.8801	.3447	.4901	.4395	.2047	.3678	.3262	.1531
3.70	1.2762	.8818	.3485	.4949	.4445	.2088	.3728	.3313	.1569
3.90	1.2738	.8832	.3517	.4990	.4487	.2123	.3770	.3356	.1601
4.10	1.2716	.8845	.3544	.5025	.4523	.2154	.3807	.3394	.1629

Table B-20

CYCLONE TO BMRC PENETRATION RATIO
COUNT MEDIAN DIAMETER = 10.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	*4.3350	48.8642	.4161	.0007	-.0001	.0001	.0039	.0001	.0000
1.30	2.9508	.4223	.1378	.0928	.0585	.0163	.0548	.0269	.0052
1.50	1.7487	.8103	.1821	.2104	.1630	.0473	.1245	.0871	.0230
1.70	1.5054	.8184	.2217	.2937	.2426	.0802	.1867	.1461	.0467
1.90	1.4137	.8329	.2517	.3440	.2969	.1081	.2333	.1916	.0689
2.10	1.3674	.8447	.2741	.3867	.3344	.1302	.2672	.2251	.0873
2.30	1.3411	.8536	.2909	.4133	.3612	.1475	.2921	.2500	.1021
2.50	1.3237	.8603	.3040	.4330	.3811	.1610	.3110	.2659	.1140
2.70	1.3116	.8655	.3142	.4479	.3963	.1719	.3256	.2835	.1236
2.90	1.3028	.8696	.3225	.4595	.4082	.1807	.3371	.2952	.1315
3.10	1.2960	.8728	.3293	.4688	.4177	.1880	.3465	.3047	.1381
3.30	1.2907	.8755	.3349	.4764	.4255	.1941	.3542	.3125	.1436
3.50	1.2864	.8777	.3396	.4827	.4320	.1992	.3606	.3190	.1483
3.70	1.2829	.8796	.3436	.4880	.4375	.2036	.3660	.3245	.1523
3.90	1.2799	.8812	.3471	.4926	.4421	.2075	.3707	.3292	.1558
4.10	1.2774	.8825	.3501	.4965	.4462	.2108	.3747	.3333	.1588

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0004	1.0004	1.0046	1.0002	1.0004	1.0034	1.0005	1.0008	.9804
1.30	.9993	.9993	1.0026	1.0005	1.0005	1.0004	1.0009	1.0009	.9747
1.50	1.0048	1.0046	1.0001	1.0065	1.0059	.9962	1.0062	1.0055	.9680
1.70	1.0174	1.0161	.9980	1.0162	1.0147	.9914	1.0137	1.0118	.9615
1.90	1.0303	1.0273	.9954	1.0238	1.0211	.9857	1.0182	1.0153	.9547
2.10	1.0408	1.0359	.9927	1.0284	1.0248	.9803	1.0201	1.0162	.9489
2.30	1.0489	1.0420	.9902	1.0309	1.0266	.9757	1.0204	1.0157	.9443
2.50	1.0548	1.0463	.9881	1.0322	1.0273	.9720	1.0199	1.0148	.9408
2.70	1.0591	1.0493	.9864	1.0327	1.0273	.9692	1.0192	1.0136	.9383
2.90	1.0622	1.0513	.9850	1.0328	1.0271	.9670	1.0183	1.0125	.9366
3.10	1.0645	1.0527	.9839	1.0326	1.0267	.9653	1.0174	1.0114	.9353
3.30	1.0661	1.0536	.9830	1.0324	1.0262	.9640	1.0166	1.0104	.9345
3.50	1.0673	1.0542	.9823	1.0320	1.0257	.9630	1.0158	1.0096	.9340
3.70	1.0682	1.0546	.9817	1.0316	1.0252	.9622	1.0151	1.0088	.9336
3.90	1.0688	1.0548	.9812	1.0312	1.0248	.9616	1.0145	1.0081	.9335
4.10	1.0693	1.0549	.9808	1.0308	1.0243	.9611	1.0139	1.0075	.9334

Table B-22

CYCLONE TO LASL - AEC PENETRATION RATIO
MASS MEDIAN DIAMETER = 2.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0239	1.0239	.9775	1.0453	1.0402	.9577	1.0443	1.0377	.8809
1.30	1.0953	1.0907	.9908	1.0983	1.0906	.9629	1.0881	1.0760	.8884
1.50	1.1301	1.1180	.9831	1.1050	1.0938	.9449	1.0814	1.0687	.8724
1.70	1.1434	1.1248	.9750	1.0966	1.0835	.9321	1.0657	1.0518	.8635
1.90	1.1469	1.1239	.9698	1.0867	1.0729	.9255	1.0528	1.0386	.8611
2.10	1.1461	1.1203	.9668	1.0783	1.0644	.9228	1.0435	1.0295	.8622
2.30	1.1435	1.1162	.9652	1.0716	1.0578	.9221	1.0368	1.0231	.8647
2.50	1.1403	1.1121	.9644	1.0662	1.0527	.9224	1.0319	1.0186	.8679
2.70	1.1369	1.1082	.9641	1.0619	1.0487	.9233	1.0282	1.0153	.8713
2.90	1.1335	1.1047	.9641	1.0583	1.0454	.9244	1.0253	1.0127	.8746
3.10	1.1302	1.1015	.9642	1.0553	1.0428	.9256	1.0230	1.0108	.8777
3.30	1.1272	1.0986	.9645	1.0528	1.0405	.9269	1.0212	1.0093	.8807
3.50	1.1243	1.0960	.9648	1.0506	1.0386	.9282	1.0196	1.0080	.8835
3.70	1.1217	1.0936	.9652	1.0487	1.0370	.9294	1.0183	1.0070	.8861
3.90	1.1192	1.0914	.9656	1.0470	1.0355	.9306	1.0173	1.0062	.8885
4.10	1.1169	1.0894	.9659	1.0456	1.0343	.9317	1.0163	1.0055	.8907

FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
ULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.5670	1.5188	.9766	1.4437	1.4075	.8545	1.3597	1.3154	.7250
1.30	1.4441	1.3937	.9402	1.2935	1.2561	.8227	1.1927	1.1535	.7085
1.50	1.3614	1.3057	.9266	1.1986	1.1648	.8231	1.1081	1.0745	.7224
1.70	1.3101	1.2527	.9259	1.1497	1.1198	.8348	1.0707	1.0415	.7442
1.90	1.2747	1.2184	.9288	1.1219	1.0950	.8473	1.0516	1.0257	.7645
2.10	1.2488	1.1945	.9325	1.1042	1.0798	.8584	1.0407	1.0172	.7818
2.30	1.2290	1.1770	.9360	1.0921	1.0696	.8678	1.0337	1.0122	.7962
2.50	1.2134	1.1635	.9391	1.0833	1.0623	.8756	1.0289	1.0089	.8082
2.70	1.2006	1.1529	.9419	1.0766	1.0569	.8822	1.0255	1.0067	.8184
2.90	1.1901	1.1441	.9443	1.0713	1.0526	.8879	1.0229	1.0052	.8271
3.10	1.1811	1.1369	.9465	1.0669	1.0492	.8927	1.0209	1.0040	.8346
3.30	1.1735	1.1307	.9483	1.0634	1.0464	.8970	1.0193	1.0032	.8412
3.50	1.1668	1.1254	.9500	1.0603	1.0440	.9007	1.0180	1.0025	.8469
3.70	1.1610	1.1208	.9515	1.0577	1.0420	.9040	1.0169	1.0019	.8521
3.90	1.1558	1.1167	.9528	1.0555	1.0403	.9069	1.0160	1.0015	.8566
4.10	1.1512	1.1131	.9540	1.0535	1.0388	.9095	1.0152	1.0012	.8608

Table B-24

CYCLONE TO LASL - AEC PENETRATION RATIO
MASS MEDIAN DIAMETER = 4.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.8316	1.6810	.7171	1.2701	1.1641	.4004	.9014	.8145	.2395
1.30	1.7073	1.5603	.7850	1.2309	1.1527	.5571	.9968	.9278	.4257
1.50	1.5588	1.4299	.8325	1.1836	1.1258	.6638	1.0212	.9685	.5507
1.70	1.4535	1.3432	.8626	1.1492	1.1033	.7278	1.0241	.9818	.6263
1.90	1.3834	1.2875	.8827	1.1262	1.0877	.7690	1.0232	.9875	.6763
2.10	1.3349	1.2497	.8968	1.1103	1.0760	.7976	1.0216	.9904	.7117
2.30	1.2998	1.2226	.9073	1.0987	1.0688	.8184	1.0201	.9922	.7382
2.50	1.2732	1.2023	.9152	1.0899	1.0627	.8343	1.0187	.9933	.7589
2.70	1.2523	1.1866	.9215	1.0830	1.0580	.8467	1.0176	.9941	.7754
2.90	1.2356	1.1740	.9266	1.0774	1.0541	.8568	1.0166	.9947	.7889
3.10	1.2218	1.1636	.9307	1.0728	1.0509	.8651	1.0157	.9951	.8003
3.30	1.2103	1.1550	.9342	1.0690	1.0483	.8721	1.0150	.9955	.8099
3.50	1.2004	1.1477	.9372	1.0657	1.0460	.8780	1.0143	.9957	.8182
3.70	1.1919	1.1413	.9398	1.0629	1.0440	.8832	1.0137	.9960	.8255
3.90	1.1845	1.1358	.9420	1.0604	1.0423	.8876	1.0132	.9961	.8319
4.10	1.1780	1.1310	.9440	1.0583	1.0408	.8916	1.0128	.9963	.8376

3-25

MASS MEDIAN DIAMETER = 5.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.8888	1.5599	.4728	.7429	.6065	.1417	.3799	.2727	.0634
1.30	1.8358	1.5426	.6119	.9836	.8817	.3343	.6952	.6118	.2222
1.50	1.6928	1.4721	.7286	1.0890	1.0136	.5155	.8789	.8138	.4034
1.70	1.5635	1.3937	.7964	1.1116	1.0529	.6281	.9513	.8991	.5229
1.90	1.4707	1.3331	.8367	1.1104	1.0624	.6973	.9809	.9375	.5995
[illegible]	[illegible]	1.2890	.8625	1.1039	1.0629	.7428	.9945	.9571	.6515
2.30	[illegible]	1.2565	.8803	1.0967	1.0607	.7745	1.0014	.9683	.6889
2.50	1.3226	1.2319	.8932	1.0902	1.0579	.7979	1.0051	.9753	.7172
2.70	1.2951	1.2126	.9030	1.0846	1.0551	.8158	1.0072	.9799	.7393
2.90	1.2732	1.1972	.9106	1.0797	1.0525	.8299	1.0084	.9831	.7571
3.10	1.2554	1.1846	.9168	1.0755	1.0501	.8413	1.0091	.9855	.7718
3.30	1.2406	1.1741	.9218	1.0719	1.0480	.8508	1.0095	.9873	.7841
3.50	1.2281	1.1653	.9260	1.0687	1.0461	.8587	1.0097	.9887	.7946
3.70	1.2174	1.1576	.9296	1.0659	1.0444	.8655	1.0098	.9897	.8037
3.90	1.2081	1.1510	.9327	1.0634	1.0429	.8714	1.0099	.9906	.8116
[illegible]	1.2000	1.1452	.9354	1.0612	1.0415	.8765	1.0098	.9914	.8186

CYCLONE TO LASL - AEC PENETRATION RATIO

MASS MEDIAN DIAMETER = 6.0 MICROMETERS

Table 3-26

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	2.0173	1.2420	.2776	.2611	.1644	.0446	.1423	.0705	.0128
1.30	1.9029	1.4191	.4650	.7097	.6068	.1943	.4506	.3690	.1128
1.50	1.7783	1.4573	.6321	.9630	.8778	.3966	.7326	.6614	.2931
1.70	1.6452	1.4141	.7336	1.0547	.9868	.5417	.8705	.8116	.4373
1.90	1.5401	1.3611	.7932	1.0831	1.0275	.6338	.9333	.8840	.5339
2.10	1.4632	1.3167	.8304	1.0901	1.0430	.6940	.9641	.9217	.5996
2.30	1.4067	1.2819	.8553	1.0897	1.0486	.7356	.9805	.9432	.6464
2.50	1.3642	1.2547	.8730	1.0868	1.0502	.7658	.9900	.9565	.6813
2.70	1.3313	1.2332	.8861	1.0832	1.0500	.7885	.9958	.9653	.7083
2.90	1.3051	1.2159	.8962	1.0796	1.0491	.8063	.9995	.9714	.7299
3.10	1.2839	1.2016	.9042	1.0761	1.0478	.8206	1.0019	.9758	.7474
3.30	1.2664	1.1897	.9107	1.0730	1.0465	.8322	1.0036	.9791	.7621
3.50	1.2516	1.1797	.9161	1.0701	1.0452	.8420	1.0048	.9816	.7745
3.70	1.2390	1.1710	.9206	1.0676	1.0439	.8502	1.0056	.9836	.7851
3.90	1.2281	1.1635	.9245	1.0652	1.0426	.8573	1.0062	.9852	.7944
4.10	1.2186	1.1569	.9278	1.0631	1.0415	.8635	1.0067	.9865	.8025

ble B-27

MASS MEDIAN DIAMETER = 7.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	2.0240	.7907	.1159	.0399	.0153	.0062	.0301	.0083	.0008
1.30	1.9372	1.2509	.3493	.4831	.3931	.1136	.2861	.2157	.0582
1.50	1.8323	1.4107	.5487	.8350	.7462	.3067	.6040	.5312	.2146
1.70	1.7057	1.4143	.6765	.9902	.9160	.4690	.7916	.7284	.3678
1.90	1.5955	1.3763	.7530	1.0499	.9884	.5783	.8849	.8312	.4782
2.10	1.5111	1.3357	.8007	1.0721	1.0199	.6509	.9326	.8863	.5547
2.30	1.4478	1.3010	.8323	1.0796	1.0342	.7010	.9589	.9181	.6094
2.50	1.3997	1.2727	.8544	1.0810	1.0407	.7371	.9743	.9378	.6500
2.70	1.3623	1.2498	.8707	1.0800	1.0436	.7643	.9839	.9508	.6813
2.90	1.3326	1.2312	.8831	1.0779	1.0446	.7853	.9902	.9597	.7061
3.10	1.3085	1.2157	.8928	1.0755	1.0447	.8021	.9945	.9662	.7262
3.30	1.2886	1.2027	.9007	1.0730	1.0442	.8158	.9975	.9710	.7429
3.50	1.2719	1.1917	.9071	1.0706	1.0435	.8271	.9997	.9747	.7569
3.70	1.2577	1.1823	.9125	1.0683	1.0427	.8367	1.0013	.9776	.7690
3.90	1.2455	1.1741	.9171	1.0662	1.0418	.8449	1.0025	.9799	.7794
4.10	1.2348	1.1669	.9210	1.0642	1.0410	.8520	1.0034	.9818	.7885

CYCLONE TO LASL - AEC PENETRATION RATIO

MASS MEDIAN DIAMETER = 8.0 MICROMETERS

Table B-28

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.9099	.4168	.0324	.0026	.0005	.0004	.0033	.0004	.0000
1.30	1.9441	1.0771	.2615	.3194	.2472	.0677	.1824	.1261	.0310
1.50	1.8659	1.3486	.4785	.7181	.6298	.2399	.4978	.4265	.1505
1.70	1.7507	1.4017	.6255	.9248	.8465	.4087	.7167	.6531	.3119
1.90	1.6401	1.3826	.7163	1.0141	.9480	.5300	.8380	.7810	.4308
2.10	1.5511	1.3484	.7733	1.0518	.9954	.6125	.9016	.8520	.5157
2.30	1.4828	1.3153	.8110	1.0676	1.0186	.6700	.9373	.8936	.5769
2.50	1.4304	1.2870	.8373	1.0738	1.0303	.7114	.9586	.9195	.6224
2.70	1.3893	1.2634	.8565	1.0756	1.0364	.7424	.9720	.9356	.6574
2.90	1.3567	1.2439	.8710	1.0753	1.0395	.7664	.9810	.9484	.6850
3.10	1.3302	1.2276	.8824	1.0740	1.0410	.7855	.9871	.9569	.7074
3.30	1.3083	1.2138	.8915	1.0723	1.0415	.8010	.9914	.9632	.7259
3.50	1.2899	1.2021	.8989	1.0704	1.0415	.8138	.9946	.9681	.7414
3.70	1.2742	1.1920	.9051	1.0685	1.0412	.8246	.9970	.9719	.7547
3.90	1.2608	1.1832	.9104	1.0667	1.0407	.8338	.9988	.9749	.7661
4.10	1.2490	1.1755	.9149	1.0649	1.0401	.8417	1.0002	.9773	.7761

Table B-29

MASS MEDIAN DIAMETER = 9.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.5037	.1823	.0060	.0001	.0000	.0000	.0002	.0000	.0000
1.30	1.9268	.9182	.1964	.2093	.1542	.0413	.1180	.0749	.0172
1.50	1.8860	1.2807	.4199	.6163	.5311	.1902	.4125	.3443	.1205
1.70	1.7844	1.3812	.5804	.8618	.7812	.3585	.6532	.5864	.2668
1.90	1.6763	1.3826	.6829	.9777	.9081	.4878	.7937	.7343	.3903
2.10	1.5850	1.3563	.7481	1.0305	.9706	.5784	.8715	.8194	.4815
2.30	1.5132	1.3260	.7914	1.0547	1.0025	.6420	.9161	.8701	.5481
2.50	1.4572	1.2983	.8215	1.0657	1.0194	.6881	.9431	.9019	.5978
2.70	1.4132	1.2746	.8434	1.0704	1.0288	.7227	.9603	.9229	.6360
2.90	1.3780	1.2546	.8599	1.0720	1.0340	.7493	.9718	.9374	.6661
3.10	1.3494	1.2377	.8728	1.0719	1.0369	.7704	.9797	.9479	.6905
3.30	1.3257	1.2233	.8830	1.0711	1.0385	.7875	.9854	.9557	.7106
3.50	1.3059	1.2110	.8914	1.0698	1.0392	.8017	.9896	.9616	.7275
3.70	1.2890	1.2004	.8983	1.0683	1.0394	.8136	.9927	.9663	.7419
3.90	1.2744	1.1911	.9042	1.0667	1.0394	.8237	.9951	.9700	.7542
4.10	1.2618	1.1830	.9092	1.0651	1.0391	.8324	.9970	.9730	.7651

CYCLONE TO LASL - AEC PENETRATION RATIO

MASS MEDIAN DIAMETER =10.0 MICROMETERS

Table B-30

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	.7566	.0661	.0008	.0000	-.0000	.0000	.0000	.0000	.0000
1.30	1.8898	.7816	.1687	.1377	.0966	.0259	.0779	.0455	.0098
1.50	1.8967	1.2124	.3710	.5297	.6489	.1530	[illegible]	[illegible]	[illegible]
1.70	1.8097	1.3560	.5406	.8028	.7212	.3168	.5951	.5280	.2302
1.90	1.7060	1.3782	.6526	.9419	.8695	.4510	.7524	.6912	.3555
2.10	1.6139	1.3607	.7249	1.0087	.9460	.5478	.8428	.7886	.4513
2.30	1.5396	1.3339	.7732	1.0411	.9862	.6168	.8957	.8476	.5223
2.50	1.4809	1.3075	.8068	1.0570	1.0083	.6669	.9281	.8849	.5756
2.70	1.4344	1.2839	.8312	1.0648	1.0209	.7046	.9489	.9097	.6166
2.90	1.3971	1.2637	.8496	1.0682	1.0283	.7336	.9629	.9269	.6490
3.10	1.3666	1.2464	.8638	1.0695	1.0327	.7566	.9726	.9393	.6752
3.30	1.3414	1.2316	.8752	1.0694	1.0352	.7752	.9795	.9484	.6968
3.50	1.3203	1.2189	.8844	1.0688	1.0367	.7906	.9847	.9555	.7149
3.70	1.3023	1.2078	.8921	1.0677	1.0375	.8035	.9886	.9610	.7302
3.90	1.2868	1.1982	.8985	1.0665	1.0379	.8144	.9915	.9653	.7435
4.10	1.2734	1.1897	.9040	1.0651	1.0379	.8238	.9939	.9689	.7550

Table B-31

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER - 1.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	.9999	.9999	1.0049	1.0002	1.0004	1.0033	1.0006	1.0010	.9706
1.30	.9975	.9975	1.0004	1.0035	1.0029	.9946	1.0045	1.0038	.9552
1.50	1.0625	1.0578	.9923	1.0589	1.0532	.9709	1.0496	1.0427	.9122
1.70	1.1983	1.1691	.9613	1.1280	1.1016	.9029	1.0742	1.0552	.8255
1.90	1.3255	1.2521	.9087	1.1269	1.0947	.8122	1.0415	1.0110	.7242
2.10	1.4187	1.2958	.8554	1.1014	1.0590	.7318	.9882	.9496	.6397
2.30	1.4833	1.3155	.8107	1.0675	1.0184	.6695	.9370	.8933	.5765
2.50	1.5283	1.3228	.7753	1.0351	.9816	.6227	.8939	.8470	.5303
2.70	1.5605	1.3244	.7474	1.0071	.9507	.5873	.8592	.8101	.4955
2.90	1.5842	1.3232	.7253	.9838	.9251	.5601	.8312	.7807	.4692
3.10	1.6022	1.3208	.7076	.9639	.9040	.5387	.8085	.7570	.4488
3.30	1.6167	1.3179	.6932	.9474	.8864	.5216	.7898	.7376	.4325
3.50	1.6274	1.3150	.6813	.9334	.8716	.5076	.7744	.7216	.4193
3.75	1.6365	1.3121	.6713	.9216	.8591	.4960	.7614	.7082	.4084
3.90	1.6440	1.3094	.6628	.9114	.8484	.4863	.7503	.6968	.3992
4.10	1.6502	1.3066	.6555	.9025	.8392	.4781	.7408	.6871	.3916

Table B-32

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER - 2.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.0427	1.0427	.9820	1.0645	1.0586	.9609	1.0624	1.0547	.8029
1.30	1.2457	1.7274	.9820	1.2052	1.1071	.9226	1.1663	1.1446	.8302
1.50	1.4219	1.3407	.9033	1.2054	1.1646	.7065	1.0937	1.0544	.6748
1.70	1.5290	1.3802	.8191	1.1275	1.0729	.6611	.9761	.9289	.5567
1.90	1.5895	1.3751	.7575	1.0540	.9930	.5844	.8905	.8372	.4842
2.10	1.6250	1.3618	.7156	.9994	.9350	.5357	.8310	.7760	.4394
2.30	1.6471	1.3486	.6865	.9602	.8950	.5035	.7901	.7343	.4102
2.50	1.6617	1.3374	.6658	.9316	.8657	.4811	.7610	.7049	.3902
2.70	1.6720	1.3281	.6504	.9101	.8438	.4649	.7396	.6834	.3757
2.90	1.6794	1.3205	.6387	.8938	.8270	.4527	.7233	.6670	.3649
3.10	1.6851	1.3143	.6295	.8805	.8138	.4432	.7106	.6543	.3565
3.30	1.6895	1.3090	.6222	.8700	.8032	.4357	.7004	.6441	.3499
3.50	1.6930	1.3046	.6161	.8614	.7945	.4296	.6921	.6358	.3445
3.70	1.6959	1.3009	.6111	.8542	.7873	.4246	.6852	.6289	.3401
3.90	1.6982	1.2977	.6069	.8481	.7812	.4203	.6794	.6232	.3364
4.10	1.7002	1.2949	.6033	.8430	.7760	.4167	.6744	.6183	.3333

Table B-33

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER - 0.3 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.5048	1.5464	.9610	1.4517	1.4180	.8213	1.3499	1.3019	.6831
1.30	1.6433	1.5313	.8394	1.2794	1.2129	.6413	1.0821	1.0212	.5105
1.50	1.6833	1.4711	.7375	1.0991	1.0249	.5274	.8920	.8277	.4160
1.70	1.7048	1.4144	.6775	.9914	.9173	.4702	.7935	.7299	.3690
1.90	1.7145	1.3761	.6433	.9305	.8575	.4401	.7396	.6780	.3453
2.10	1.7192	1.3507	.6220	.8937	.8218	.4225	.7082	.6477	.3317
2.30	1.7216	1.3333	.6091	.8698	.7987	.4114	.6880	.6284	.3232
2.50	1.7230	1.3209	.5999	.8533	.7829	.4039	.6743	.6152	.3175
2.70	1.7238	1.3117	.5932	.8414	.7714	.3985	.6644	.6058	.3135
2.90	1.7244	1.3047	.5881	.8325	.7629	.3946	.6570	.5988	.3105
3.10	1.7247	1.2991	.5842	.8256	.7562	.3915	.6513	.5934	.3082
3.30	1.7249	1.2947	.5811	.8200	.7510	.3891	.6468	.5891	.3064
3.50	1.7251	1.2910	.5786	.8150	.7467	.3871	.6431	.5856	.3049
3.70	1.7252	1.2880	.5765	.8118	.7432	.3855	.6401	.5827	.3038
3.90	1.7253	1.2854	.5748	.8087	.7402	.3842	.6375	.5803	.3028
4.10	1.7253	1.2832	.5733	.8061	.7377	.3831	.6354	.5783	.3019

Table B-34

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER - 4.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.8.	1.4801	.6863	1.2722	1.1098	.3572	.8281	.7370	.2046
1.30	1.8282	1.5491	.6254	1.0666	.9057	.3493	.7189	.6390	.2349
1.50	1.8111	1.4344	.5845	.8917	.8039	.3439	.6591	.5866	.2465
1.70	1.7930	1.3738	.5676	.8431	.7621	.3448	.6345	.5675	.2547
1.90	1.7797	1.3408	.5603	.8196	.7423	.3473	.6233	.5593	.2608
2.10	1.7702	1.3210	.5569	.8066	.7316	.3497	.6176	.5554	.2653
2.30	1.7634	1.3081	.5550	.7985	.7252	.3518	.6143	.5534	.2688
2.50	1.7583	1.2992	.5539	.7933	.7210	.3535	.6123	.5522	.2715
2.70	1.7544	1.2927	.5533	.7896	.7181	.3549	.6110	.5515	.2736
2.90	1.7513	1.2878	.5530	.7869	.7159	.3561	.6101	.5511	.2753
3.10	1.7488	1.2839	.5527	.7845	.7144	.3571	.6094	.5508	.2767
3.30	1.7467	1.2809	.5526	.7833	.7131	.3580	.6090	.5507	.2778
3.50	1.7450	1.2784	.5525	.7820	.7121	.3587	.6085	.5505	.2788
3.70	1.7436	1.2743	.5525	.7809	.7114	.3593	.6083	.5505	.2797
3.90	1.7424	1.2745	.5524	.7801	.7107	.3598	.6081	.5504	.2804
4.10	1.7413	1.2731	.5524	.7793	.7102	.3603	.6079	.5504	.2810

Table B-35

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER - 5.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.9037	1.5262	.4445	.6662	.5308	.1225	.3366	.2313	.0532
1.30	1.9090	1.3961	.4461	.6727	.5710	.1795	.4218	.3413	.1024
1.50	1.8765	1.3361	.4667	.6978	.6097	.2274	.4803	.4095	.1511
1.70	1.8387	1.3102	.4850	.7102	.6347	.2625	.5145	.4481	.1837
1.90	1.8165	1.2961	.4981	.7281	.6501	.2842	.5354	.4715	.2057
2.10	1.8098	1.2874	.5074	.7360	.6603	.2990	.5489	.4867	.2205
2.30	1.7895	1.2815	.5142	.7415	.6673	.3095	.5583	.4972	.2312
2.50	1.7811	1.2773	.5193	.7455	.6724	.3174	.5651	.5048	.2391
2.70	1.7745	1.2742	.5232	.7485	.6763	.3234	.5703	.5106	.2452
2.90	1.7694	1.2717	.5263	.7509	.6793	.3281	.5742	.5150	.2500
3.10	1.7652	1.2698	.5289	.7528	.6817	.3319	.5774	.5186	.2539
3.30	1.7618	1.2683	.5309	.7543	.6835	.3350	.5800	.5215	.2571
3.50	1.7590	1.2670	.5327	.7556	.6852	.3376	.5821	.5238	.2597
3.70	1.7565	1.2659	.5341	.7567	.6866	.3398	.5839	.5258	.2620
3.90	1.7545	1.2649	.5354	.7576	.6877	.3416	.5854	.5276	.2639
4.10	1.7527	1.2641	.5365	.7584	.6887	.3433	.5868	.5290	.2655

Table B-36

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER - MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	2.0316	1.1726	.2471	.2043	.1205	.0344	.1155	.0528	.0088
1.30	1.9629	1.1847	.3132	.4143	.3399	.0932	.2412	.1761	.0458
1.50	1.8954	1.2242	.3790	.5438	.4822	.1580	.3552	.2902	.0969
1.70	1.8623	1.2428	.4221	.6134	.5343	.2065	.4251	.3613	.1382
1.90	1.8391	1.2508	.4500	.6533	.5763	.2390	.4677	.4051	.1676
2.10	1.8203	1.2543	.4688	.6780	.6027	.2616	.4952	.4337	.1884
2.30	1.8070	1.2559	.4821	.6945	.6204	.2778	.5141	.4533	.2035
2.50	1.7968	1.2567	.4919	.7062	.6330	.2898	.5276	.4675	.2150
2.70	1.7888	1.2569	.4993	.7147	.6423	.2991	.5377	.4781	.2238
2.90	1.7824	1.2570	.5051	.7213	.6494	.3064	.5455	.4863	.2307
3.10	1.7772	1.2569	.5097	.7264	.6550	.3122	.5517	.4928	.2364
3.30	1.7729	1.2568	.5135	.7305	.6596	.3170	.5567	.4981	.2410
3.50	1.7693	1.2567	.5167	.7339	.6633	.3210	.5608	.5024	.2449
3.70	1.7663	1.2565	.5194	.7367	.6664	.3244	.5642	.5061	.2481
3.90	1.7636	1.2564	.5216	.7391	.6690	.3273	.5672	.5092	.2509
4.10	1.7613	1.2563	.5236	.7411	.6712	.3298	.5697	.5119	.2534

Table B-37

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER = 7.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	2.0092	.7069	.0934	.0249	.0084	.0036	.0265	.0049	.0004
1.30	1.9362	.9784	.2197	.2473	.1057	.0501	.1395	.0917	.0216
1.50	1.9008	1.1173	.3133	.4273	.3539	.1139	.2686	.2105	.0651
1.70	1.8734	1.1786	.3730	.5310	.4554	.1670	.3575	.2970	.1074
1.90	1.8508	1.2070	.4119	.5717	.5164	.2054	.4144	.3536	.1400
2.10	1.8330	1.2232	.4375	.6297	.5552	.2328	.4520	.3915	.1642
2.30	1.8191	1.2320	.4559	.6551	.5814	.2529	.4700	.4179	.1823
2.50	1.8081	1.2375	.4693	.6730	.6009	.2650	.4968	.4370	.1960
2.70	1.7994	1.2410	.4795	.6862	.6138	.2796	.5108	.4515	.2068
2.90	1.7923	1.2434	.4875	.6962	.6243	.2888	.5217	.4626	.2153
3.10	1.7864	1.2452	.4939	.7041	.6325	.2953	.5303	.4715	.2223
3.30	1.7815	1.2464	.4991	.7104	.6393	.3024	.5373	.4787	.2280
3.50	1.7774	1.2474	.5034	.7155	.6448	.3075	.5430	.4847	.2328
3.70	1.7739	1.2481	.5071	.7199	.6493	.3118	.5478	.4896	.2367
3.90	1.7708	1.2487	.5102	.7235	.6532	.3155	.5519	.4939	.2404
4.10	1.7682	1.2492	.5129	.7266	.6565	.3187	.5554	.4975	.2434

Table B-38

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER = 8.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.6531	.3538	.0232	.0013	.0002	.0002	.0019	.0002	.0000
1.30	1.8971	.8026	.1556	.1474	.1043	.0279	.0833	.0493	.0107
1.50	1.8944	1.0211	.2633	.3399	.2749	.0845	.2079	.1566	.0455
1.70	1.8771	1.1195	.3339	.4644	.3929	.1362	.3055	.2405	.0856
1.90	1.8502	1.1679	.3802	.5404	.4672	.1795	.3717	.3128	.1194
2.10	1.8415	1.1943	.4118	.5880	.5155	.2101	.4165	.3571	.1454
2.30	1.8278	1.2098	.4339	.6215	.5464	.2328	.4403	.3886	.1654
2.50	1.8166	1.2197	.4503	.6446	.5720	.2501	.4709	.4118	.1808
2.70	1.8075	1.2263	.4625	.6615	.5894	.2626	.4881	.4291	.1929
2.90	1.8000	1.2310	.4726	.6746	.6028	.2743	.5015	.4427	.2027
3.10	1.7937	1.2344	.4804	.6846	.6134	.2839	.5121	.4535	.2100
3.30	1.7884	1.2369	.4866	.6930	.6218	.2901	.5207	.4623	.2172
3.50	1.7839	1.2389	.4921	.6996	.6288	.2961	.5278	.4695	.2228
3.70	1.7801	1.2405	.4966	.7052	.6346	.3012	.5337	.4756	.2275
3.90	1.7767	1.2417	.5004	.7099	.6395	.3055	.5388	.4808	.2315
4.10	1.7738	1.2428	.5037	.7139	.6437	.3093	.5431	.4853	.2351

Table B-39

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER = 9.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	1.2345	.1434	.0037	.0000	*.0000	.0000	.0001	.0000	.0000
1.30	1.8345	.6610	.1119	.0892	.0595	.0162	.0513	.0276	.0056
1.50	1.8605	.9366	.2245	.2742	.2169	.0644	.1644	.1193	.0329
1.70	1.8760	1.0659	.3020	.4101	.3426	.1155	.2647	.2111	.0699
1.90	1.8619	1.1313	.3540	.4970	.4251	.1590	.3366	.2797	.1034
2.10	1.8472	1.1676	.3897	.5537	.4816	.1915	.3868	.3256	.1306
2.30	1.8341	1.1893	.4152	.5923	.5200	.2182	.4225	.3639	.1515
2.50	1.8233	1.2033	.4345	.6196	.5476	.2351	.4407	.3900	.1681
2.70	1.8138	1.2128	.4484	.6401	.5682	.2500	.4686	.4099	.1813
2.90	1.8061	1.2195	.4597	.6556	.5840	.2619	.4840	.4254	.1920
3.10	1.7996	1.2244	.4687	.6676	.5965	.2716	.4963	.4379	.2007
3.30	1.7940	1.2282	.4761	.6776	.6065	.2796	.5063	.4480	.2080
3.50	1.7893	1.2311	.4822	.6859	.6148	.2863	.5145	.4564	.2142
3.70	1.7852	1.2335	.4874	.6923	.6217	.2921	.5215	.4634	.2195
3.90	1.7816	1.2353	.4918	.6979	.6275	.2970	.5276	.4694	.2239
4.10	1.7785	1.2359	.4957	.7028	.6325	.3012	.5326	.4746	.2279

Table B-40

CYCLONE TO LASL - AEC PENETRATION RATIO
COUNT MEDIAN DIAMETER = 10.0 MICROMETERS

AIR FLOW	1.4 LPM			1.7 LPM			2.0 LPM		
PULSATION	0.0	0.3	1.1	0.0	0.3	1.3	0.0	0.2	0.8
SIGMA									
1.10	.5510	.8495	.0004	.0000	.0000	.0000	.0000	.0000	.0000
1.30	1.7565	.5490	.0020	.0552	.0340	.0097	.0326	.0160	.0031
1.50	1.8618	.8629	.1940	.2241	.1736	.0504	.1326	.0926	.0245
1.70	1.8719	1.0176	.2757	.3652	.3016	.0977	.2322	.1817	.0581
1.90	1.8632	1.0978	.3317	.4600	.3913	.1425	.3075	.2525	.0909
2.10	1.8508	1.1429	.3708	.5232	.4525	.1762	.3615	.3045	.1161
2.30	1.8397	1.1703	.3989	.5657	.4953	.2022	.4005	.3427	.1408
2.50	1.8280	1.1881	.4198	.5979	.5263	.2224	.4294	.3713	.1575
2.70	1.8169	1.2002	.4358	.6211	.5495	.2384	.4515	.3932	.1715
2.90	1.8111	1.2088	.4483	.6388	.5674	.2513	.4687	.4104	.1829
3.10	1.8044	1.2152	.4584	.6527	.5816	.2618	.4824	.4242	.1922
3.30	1.7987	1.2201	.4667	.6642	.5930	.2705	.4936	.4355	.2001
3.50	1.7939	1.2239	.4735	.6732	.6024	.2778	.5028	.4448	.2067
3.70	1.7896	1.2270	.4793	.6808	.6102	.2841	.5106	.4527	.2124
3.90	1.7858	1.2294	.4843	.6873	.6169	.2894	.5172	.4594	.2173
4.10	1.7825	1.2315	.4885	.6928	.6226	.2941	.5229	.4651	.2216

APPENDIX C

Compilation of K Value Contours
Figures C-1 to C-18

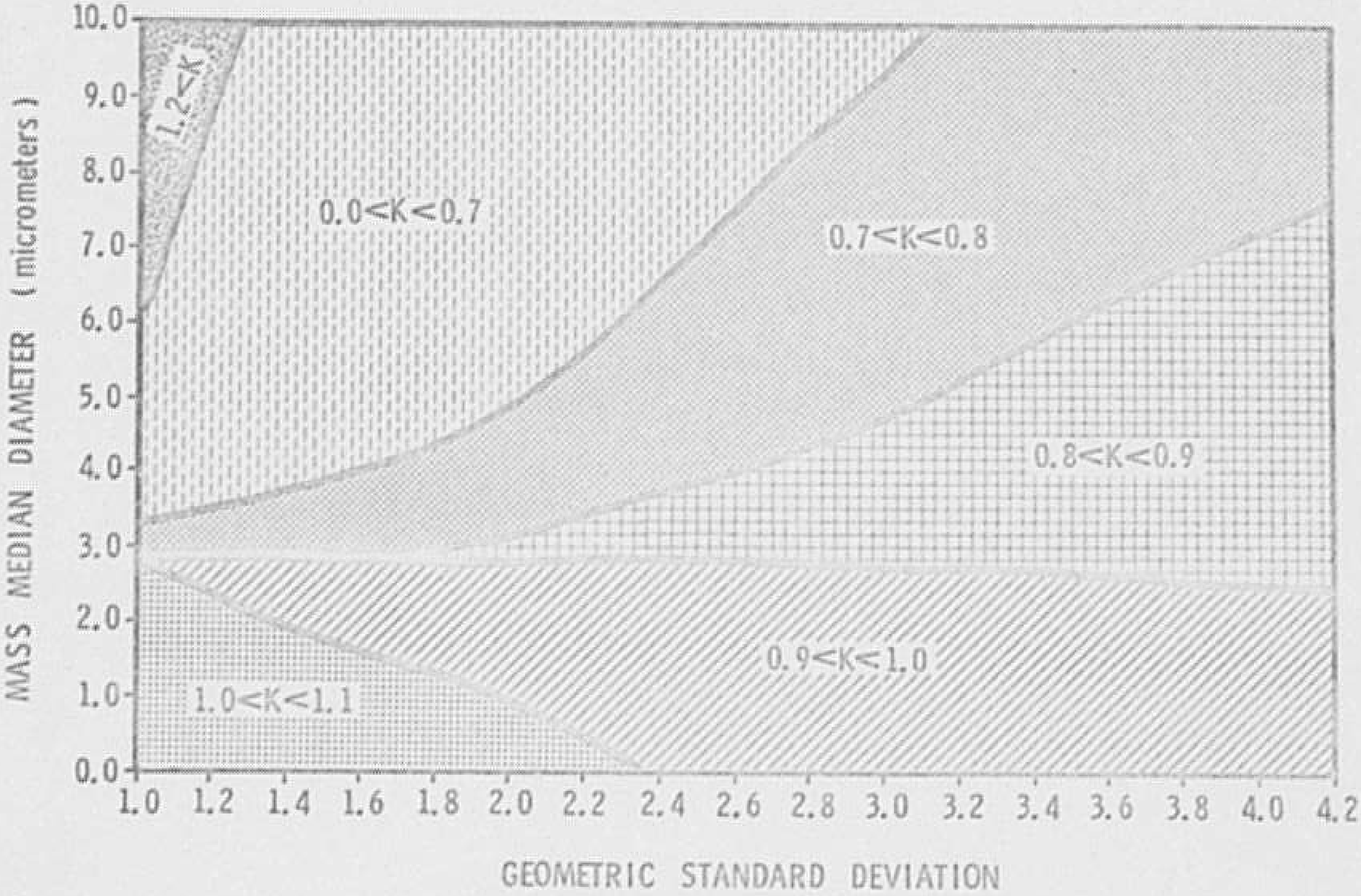

Figure C-1 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 1.4 lpm, Pulsation 1.1.

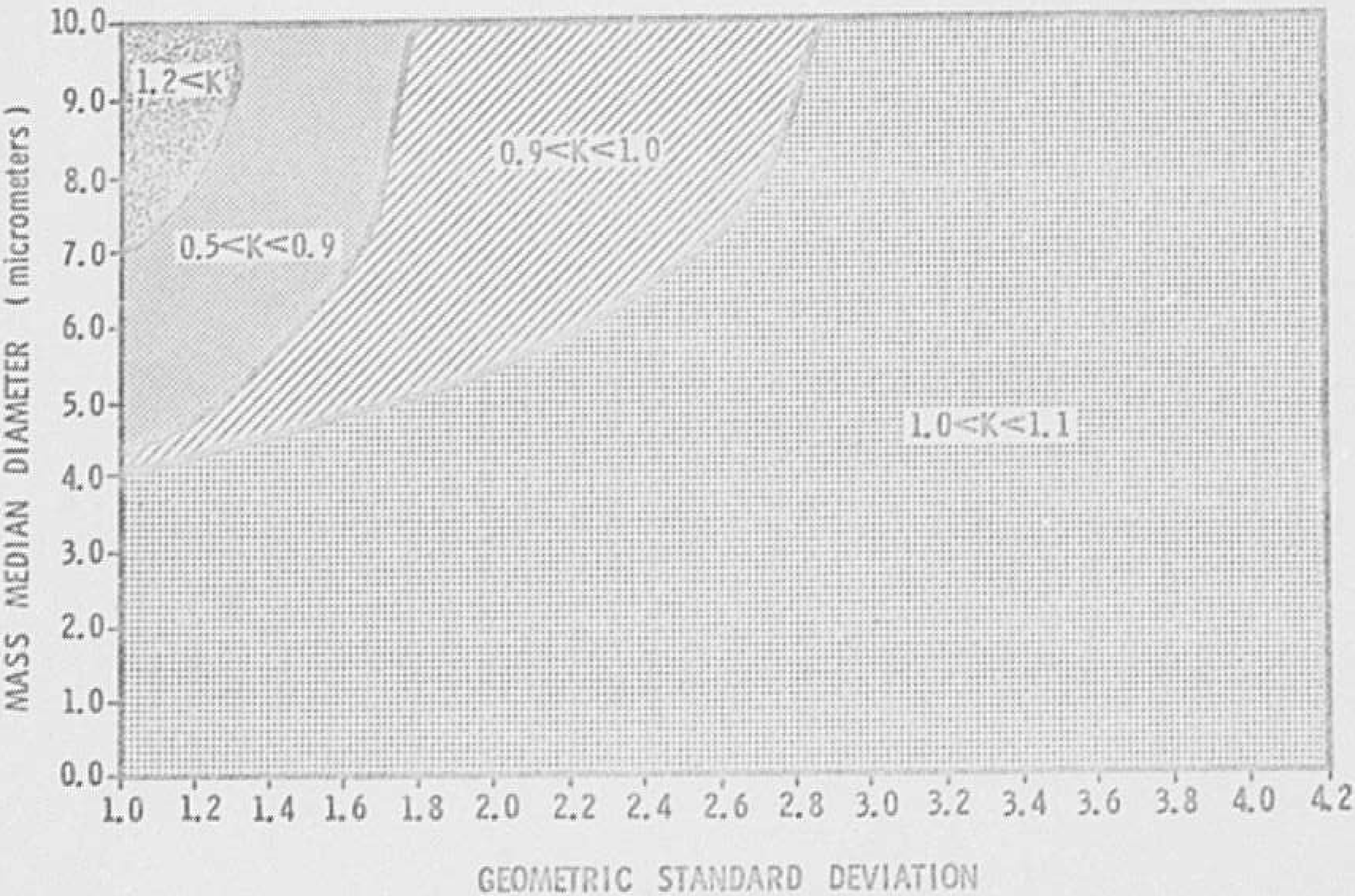

Figure C-2 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 1.4 lpm, Pulsation 0.3.

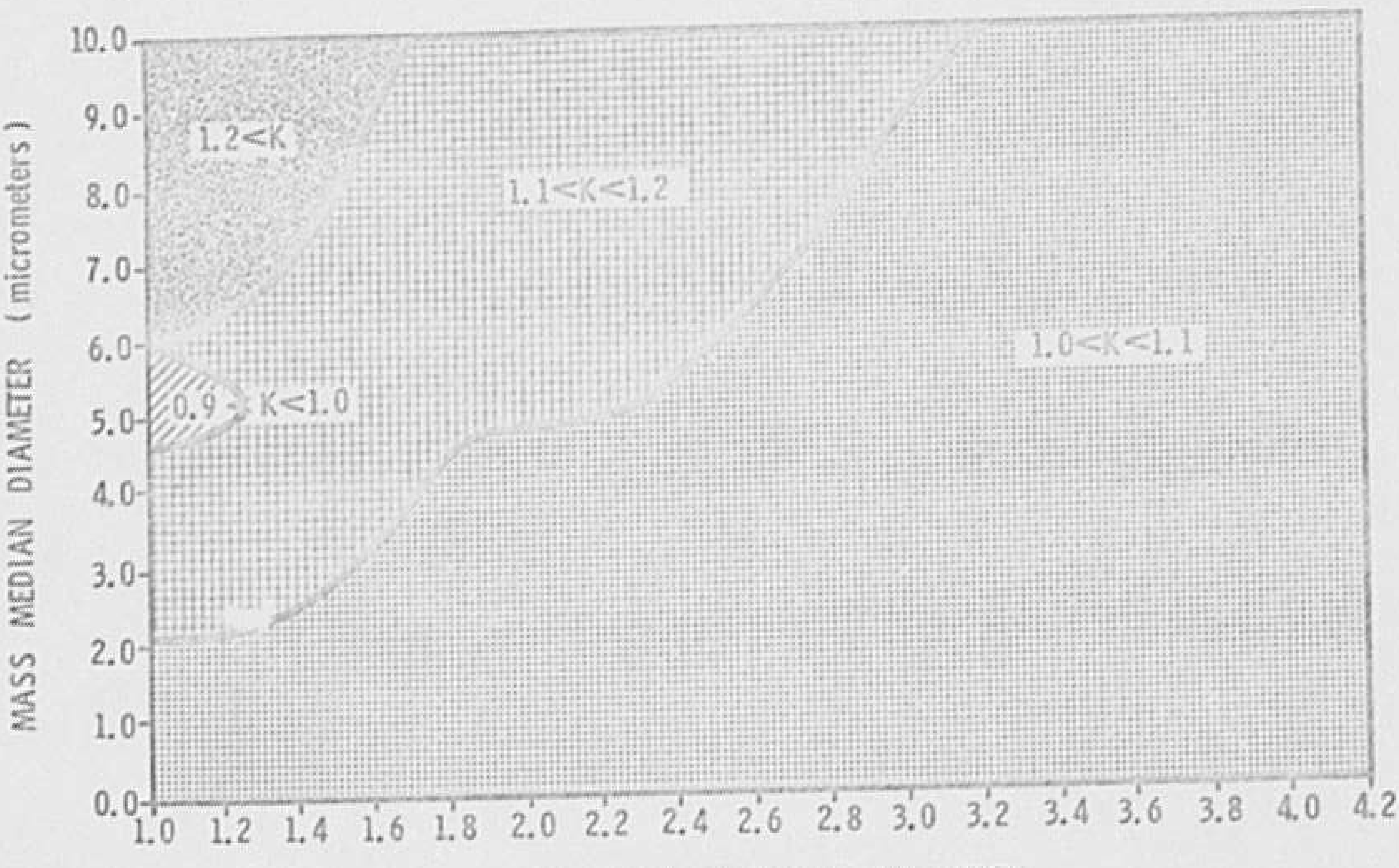

Figure C-3 . Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 1.4 lpm, Pulsation 0.0.

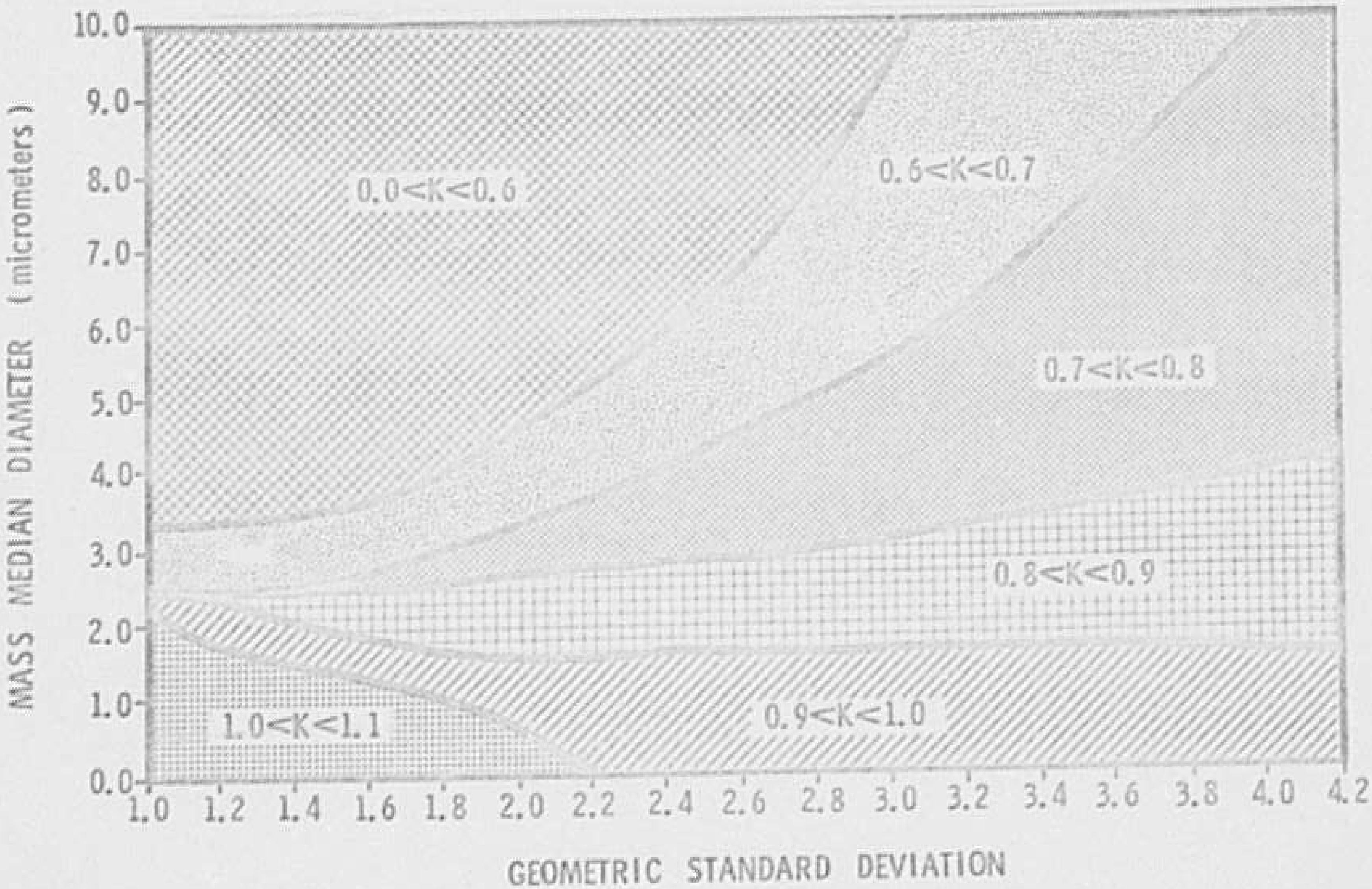

Figure C-4 Values of K. Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 1.7 lpm, Pulsation 1.3.

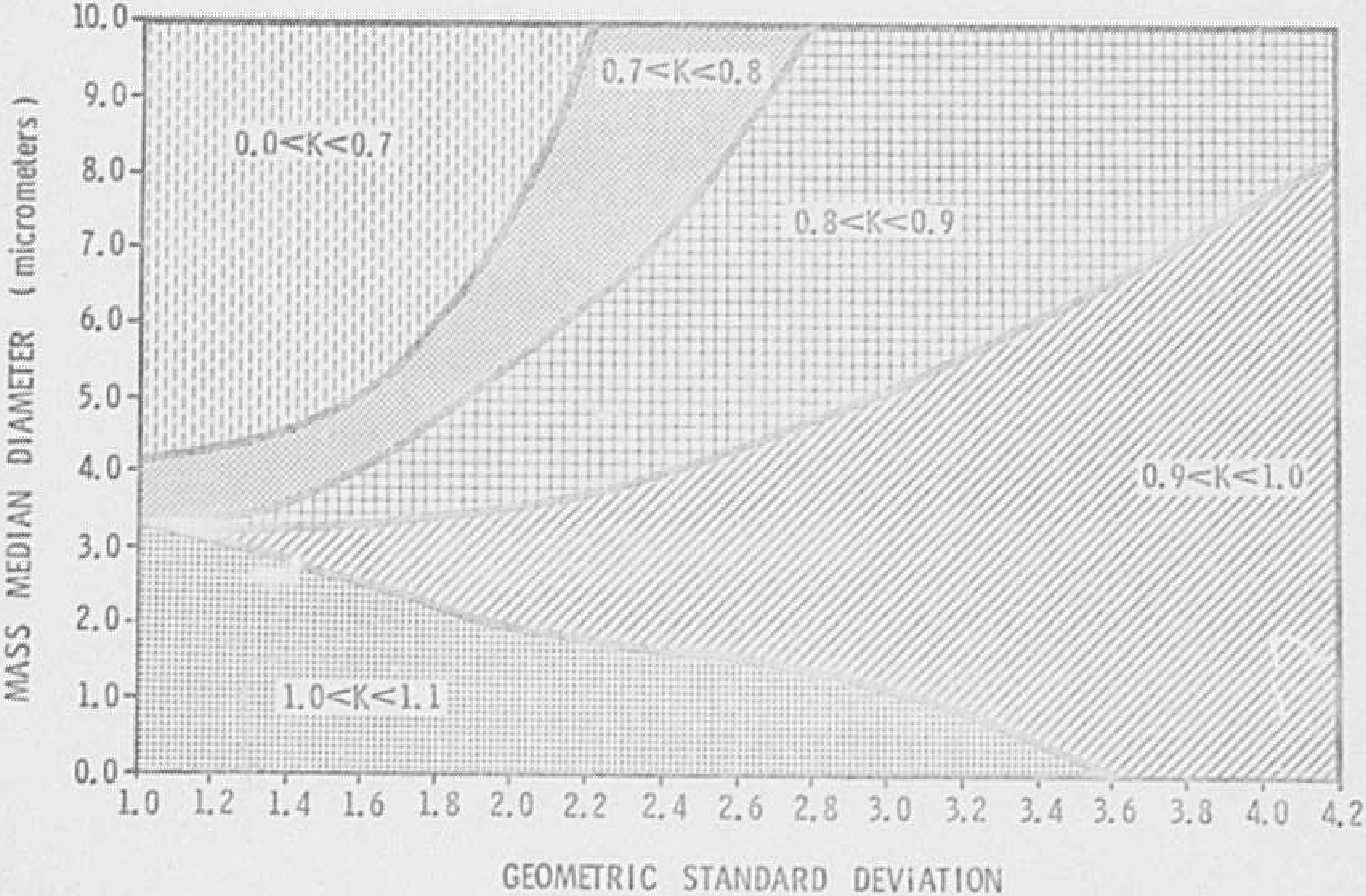

Figure C-5 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 1.7 lpm. Pulsation [illegible].

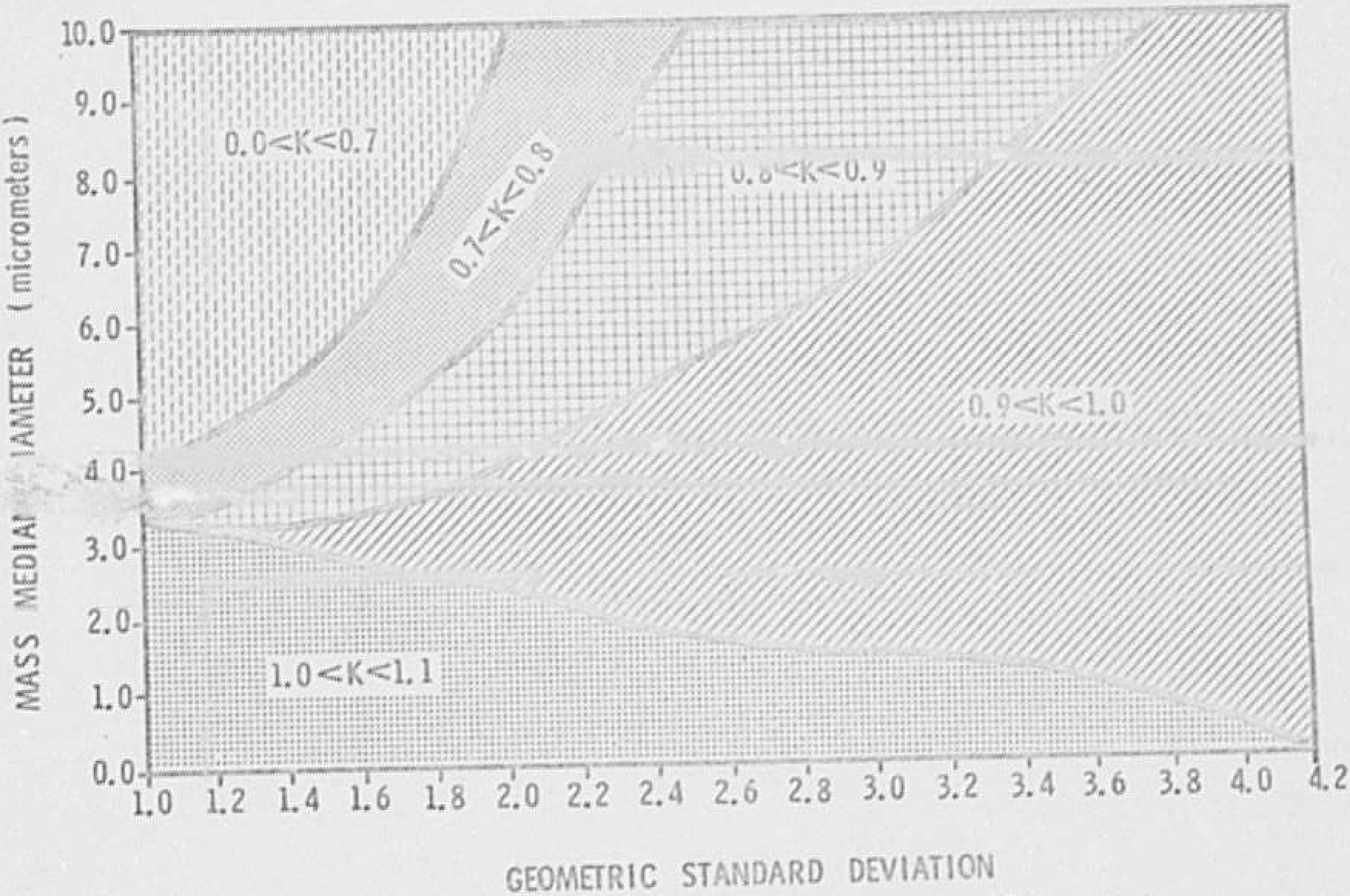

Figure C-6 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 1.7 lpm, Pulsation 0.0.

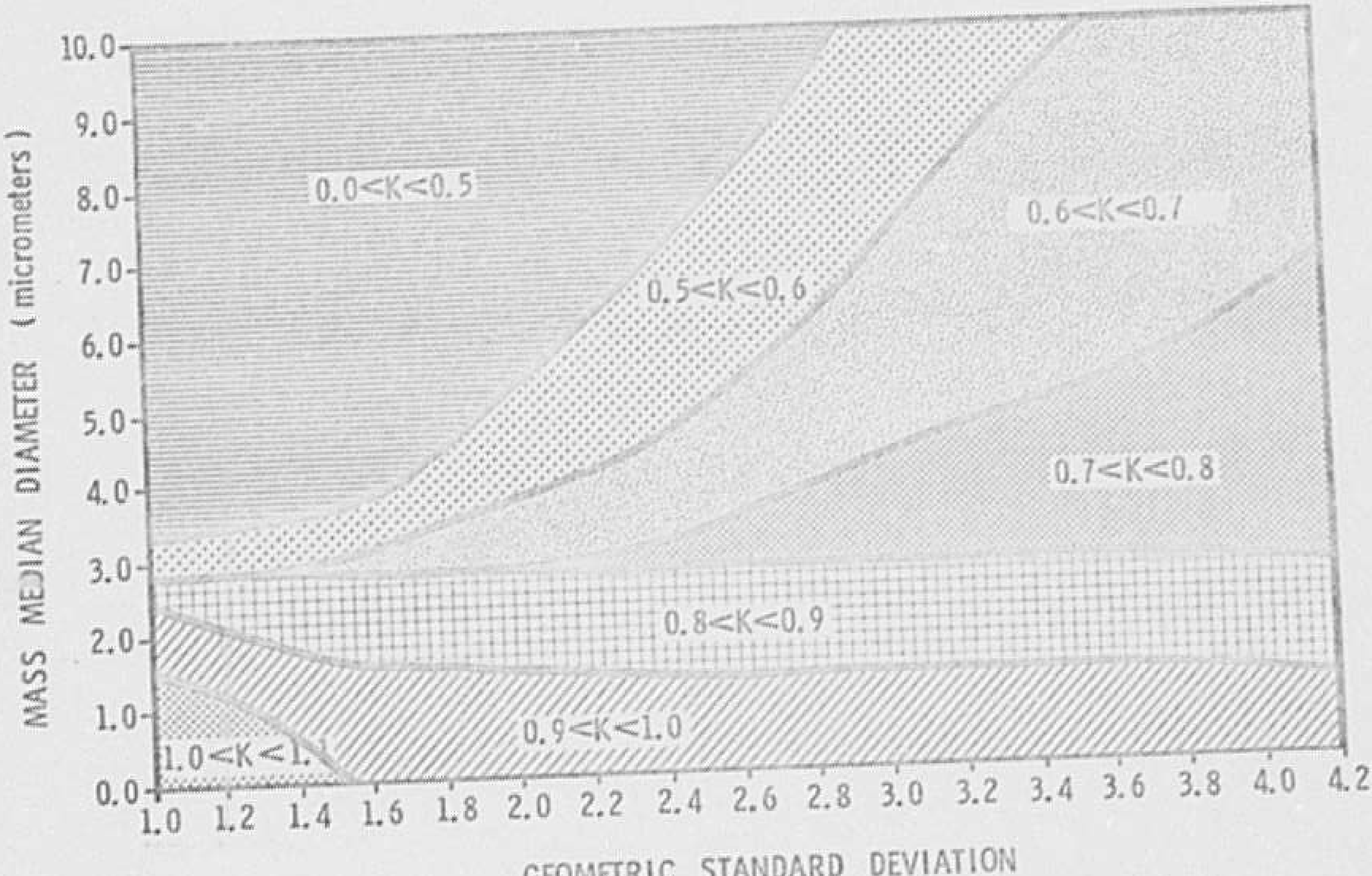

Figure C-7 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 2.0 lpm, Pulsation 0.8.

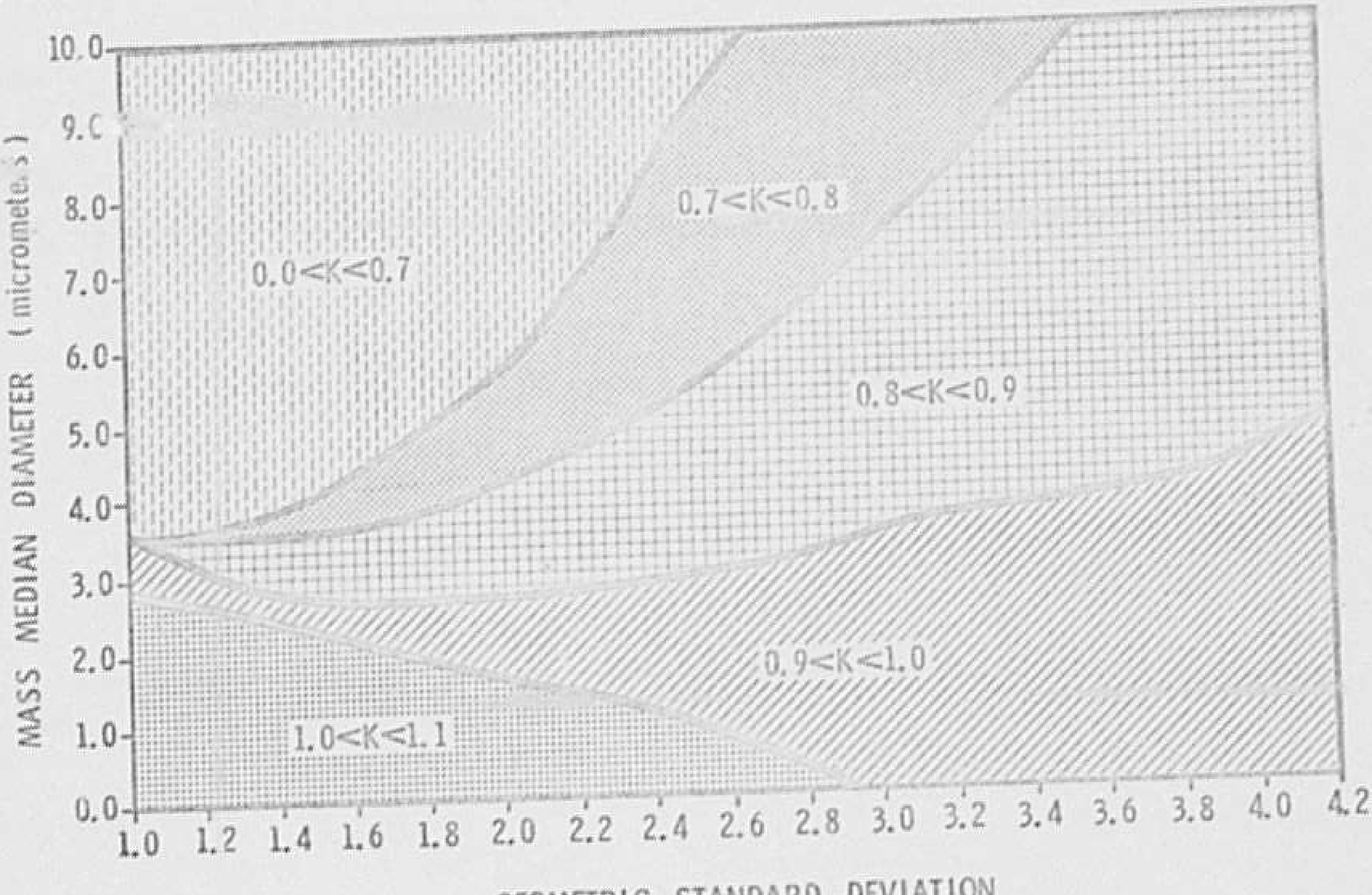

Figure C-8 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 2.0 lpm, Pulsation 0.2.

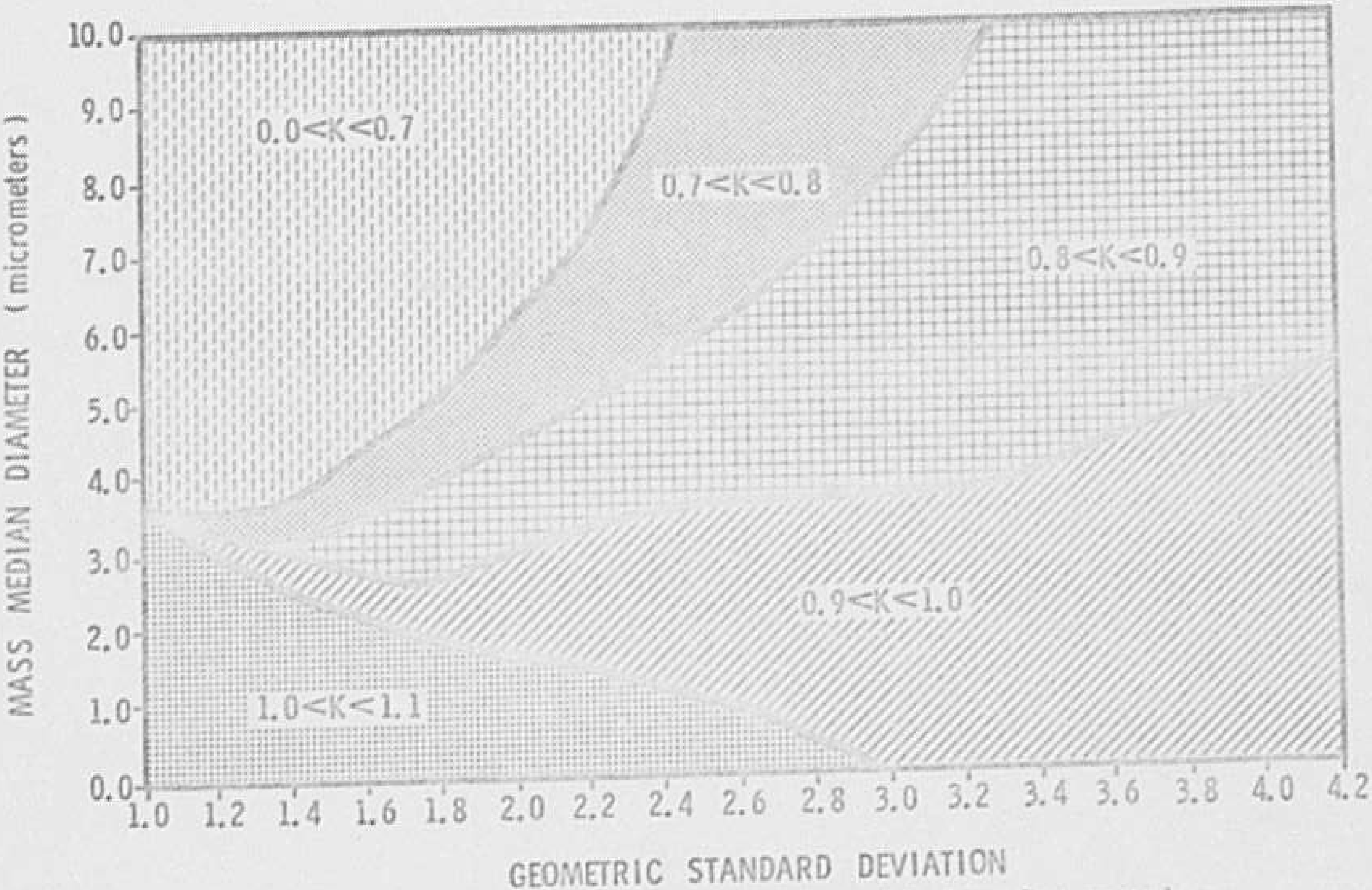

Figure C-9 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by BMRC Criteria, Computed for Various Dust Clouds. Flow 2.0 lpm, Pulsation 0.0.

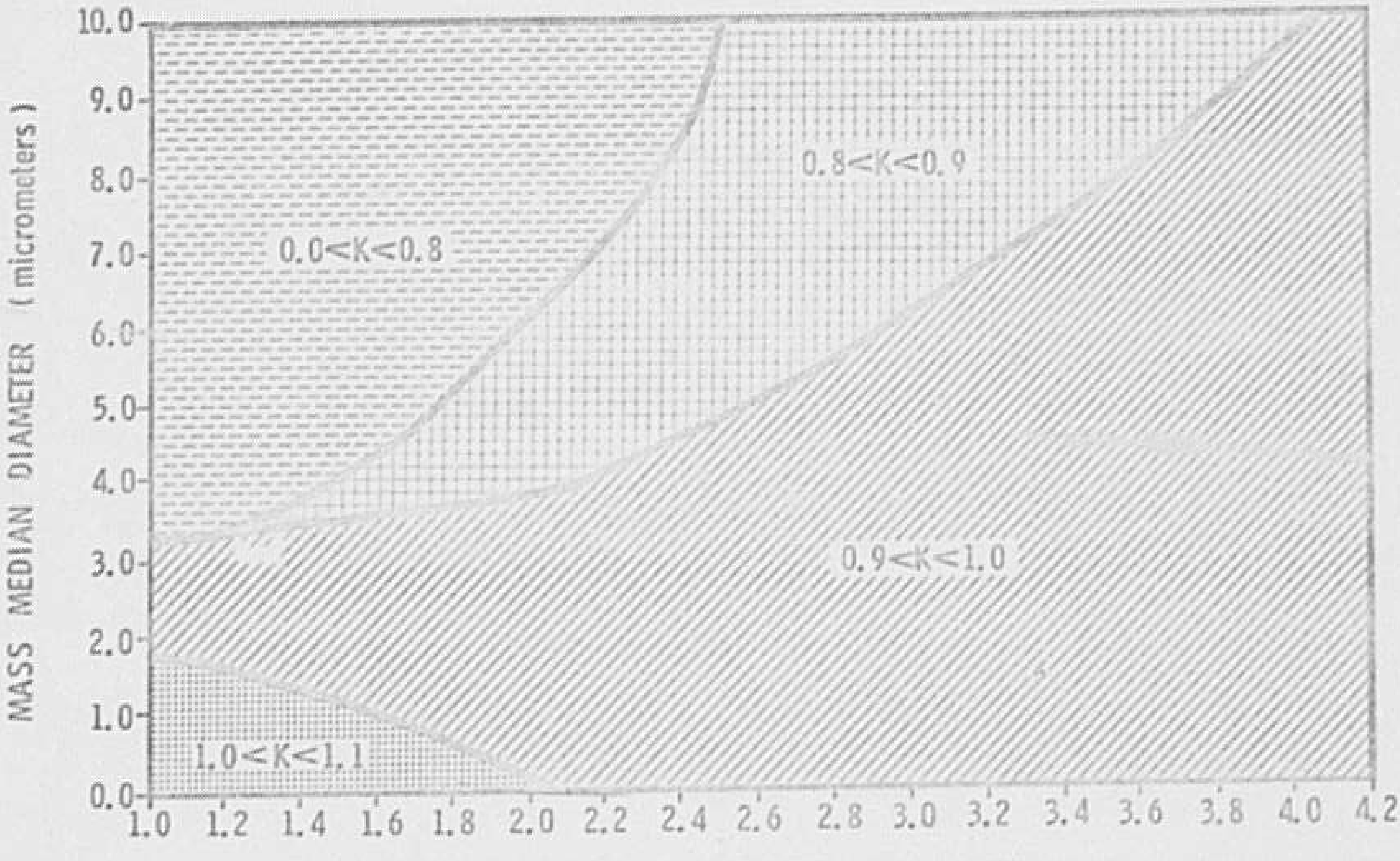

Figure C-10 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria. Computed for Various Dust Clouds. Flow 1.4 lpm. Pulsation 1.1.

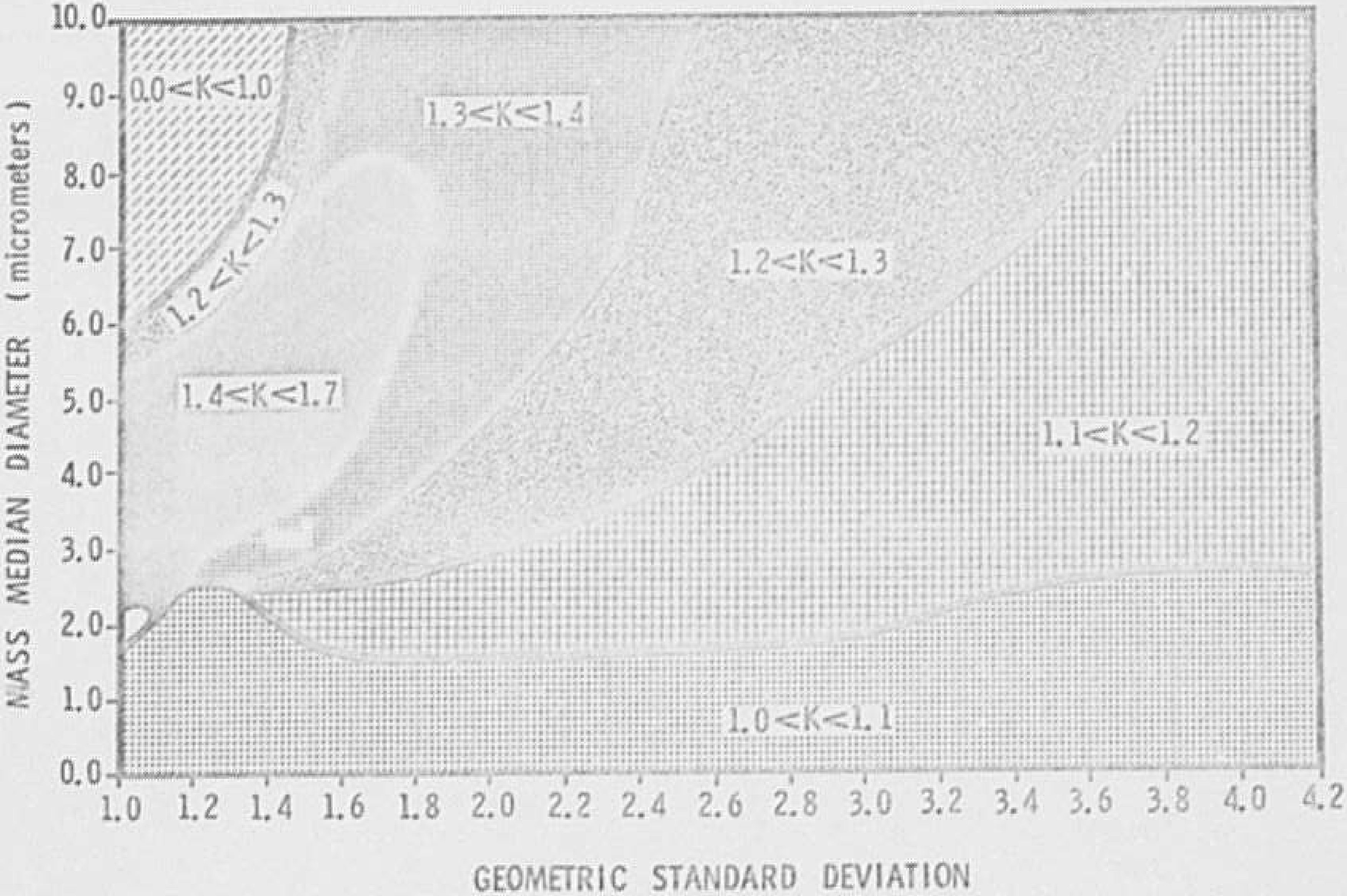

Figure C-11 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 1.4 lpm. Pulsation 0.3.

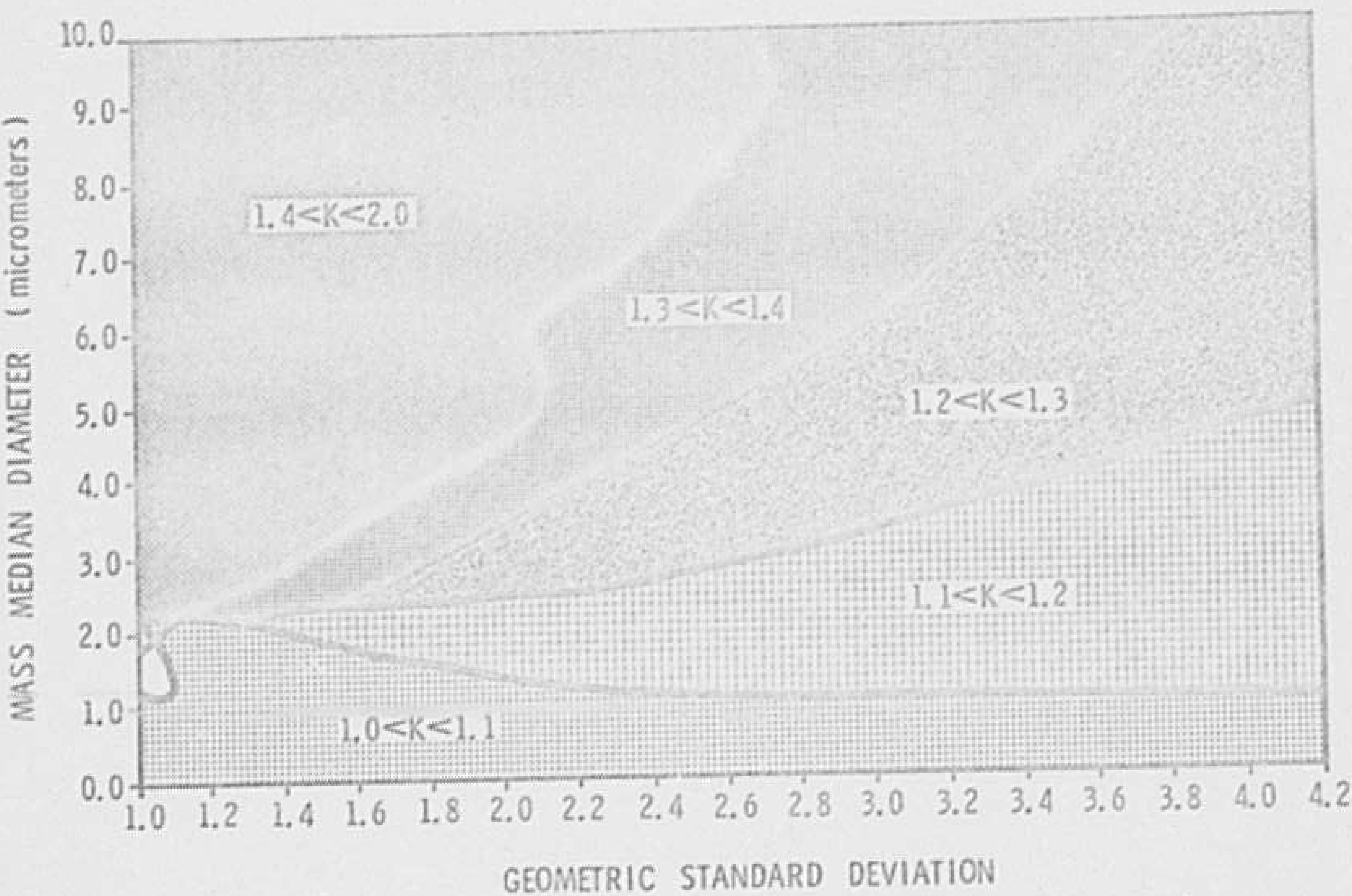

Figure C-12 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 1.4 lpm, Pulsation 0.0.

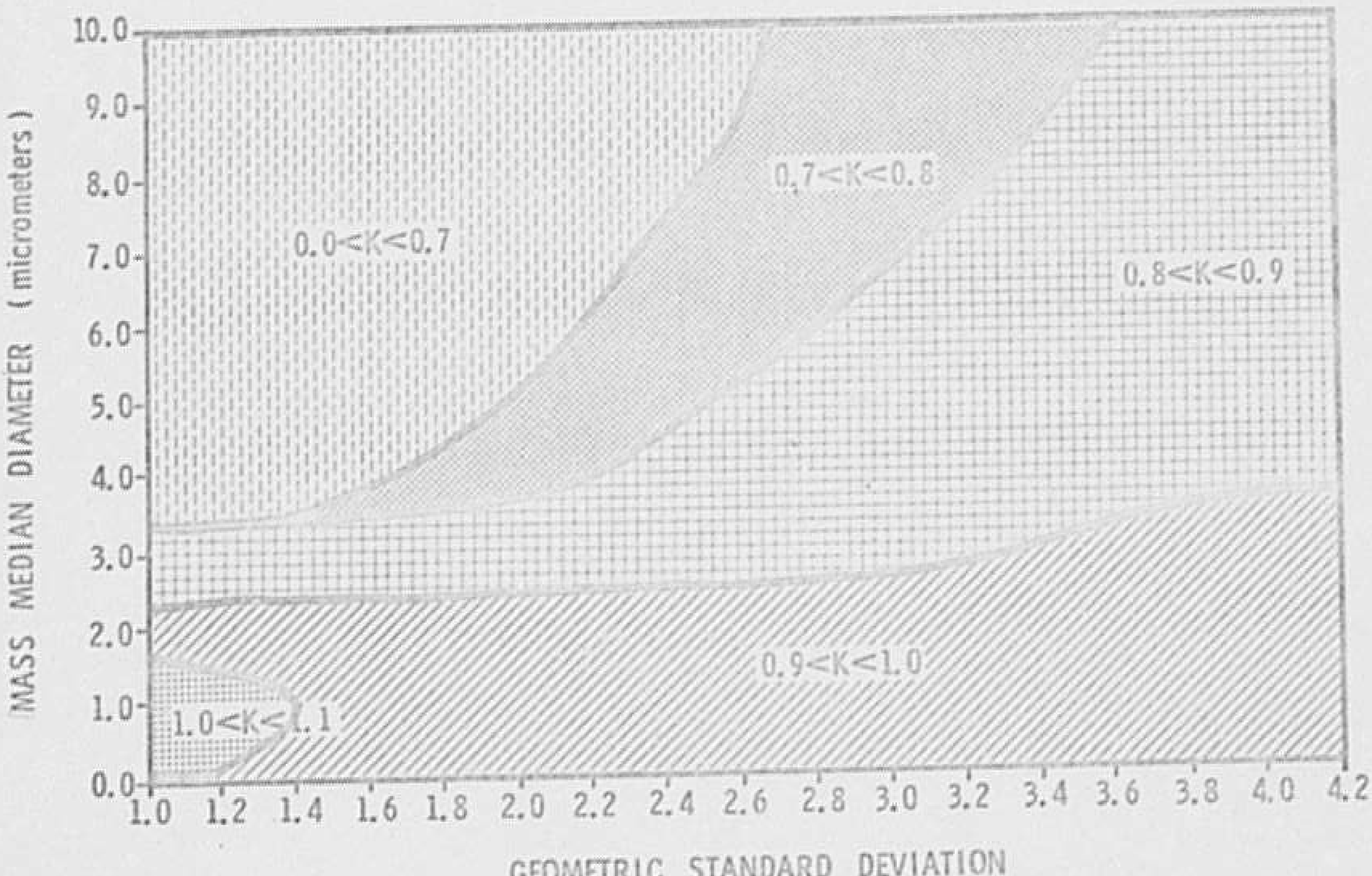

Figure C-13 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 1.7 lpm. Pulsation 1.1.

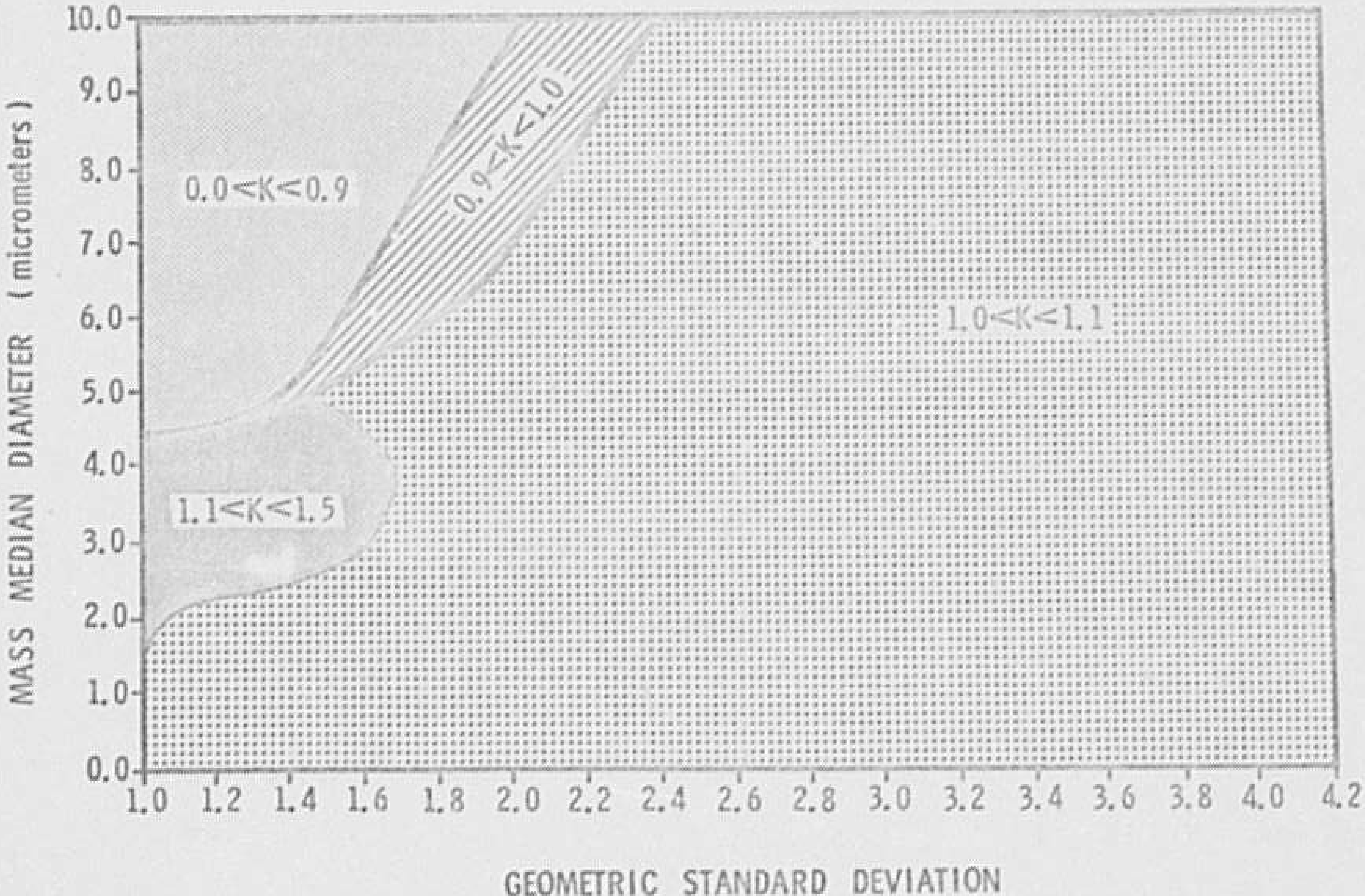

Figure C-14 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 1.7 lpm, Pulsation 0.3.

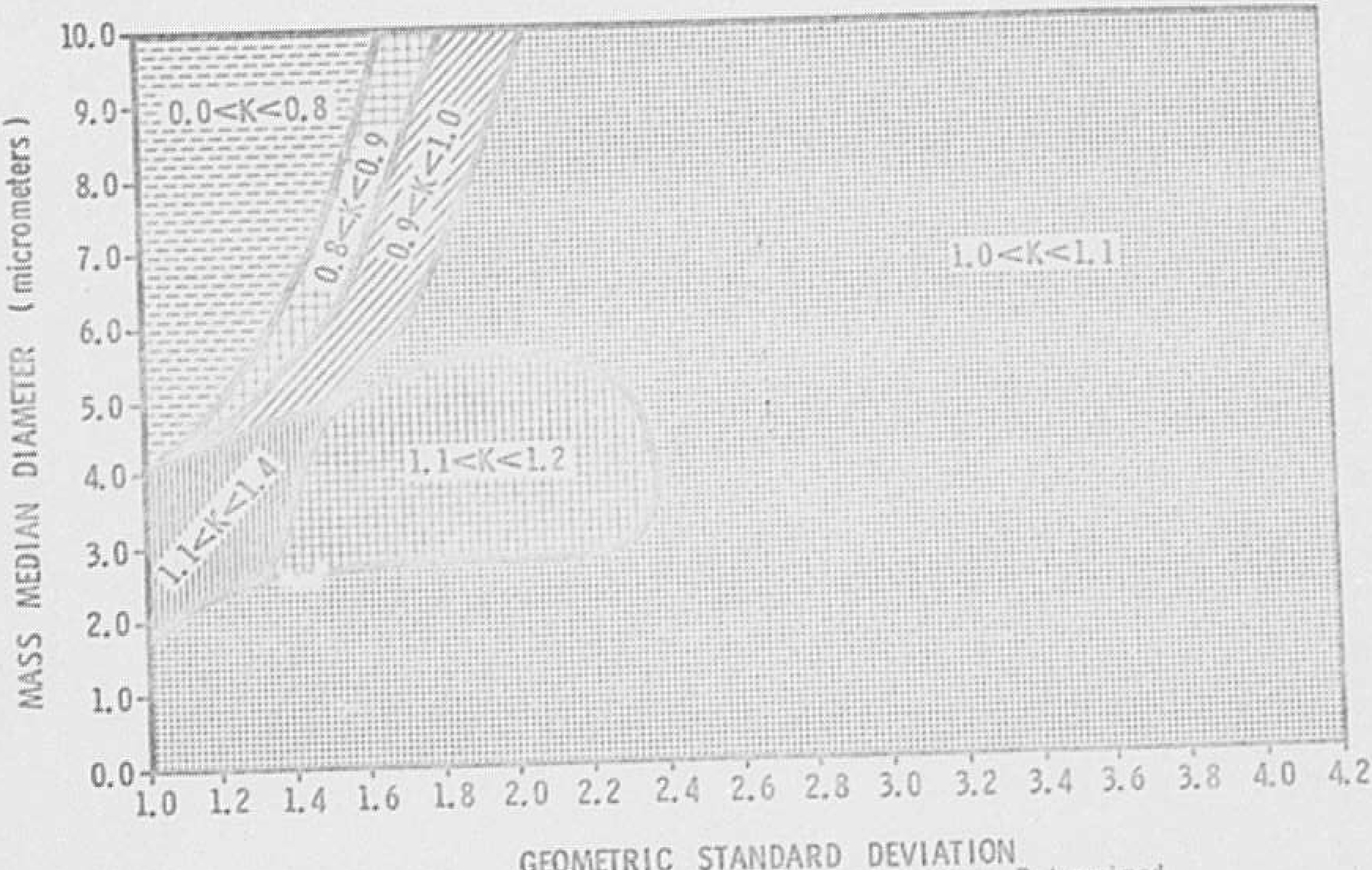

Figure C-15 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 1.7 lpm, Pulsation 0.0.

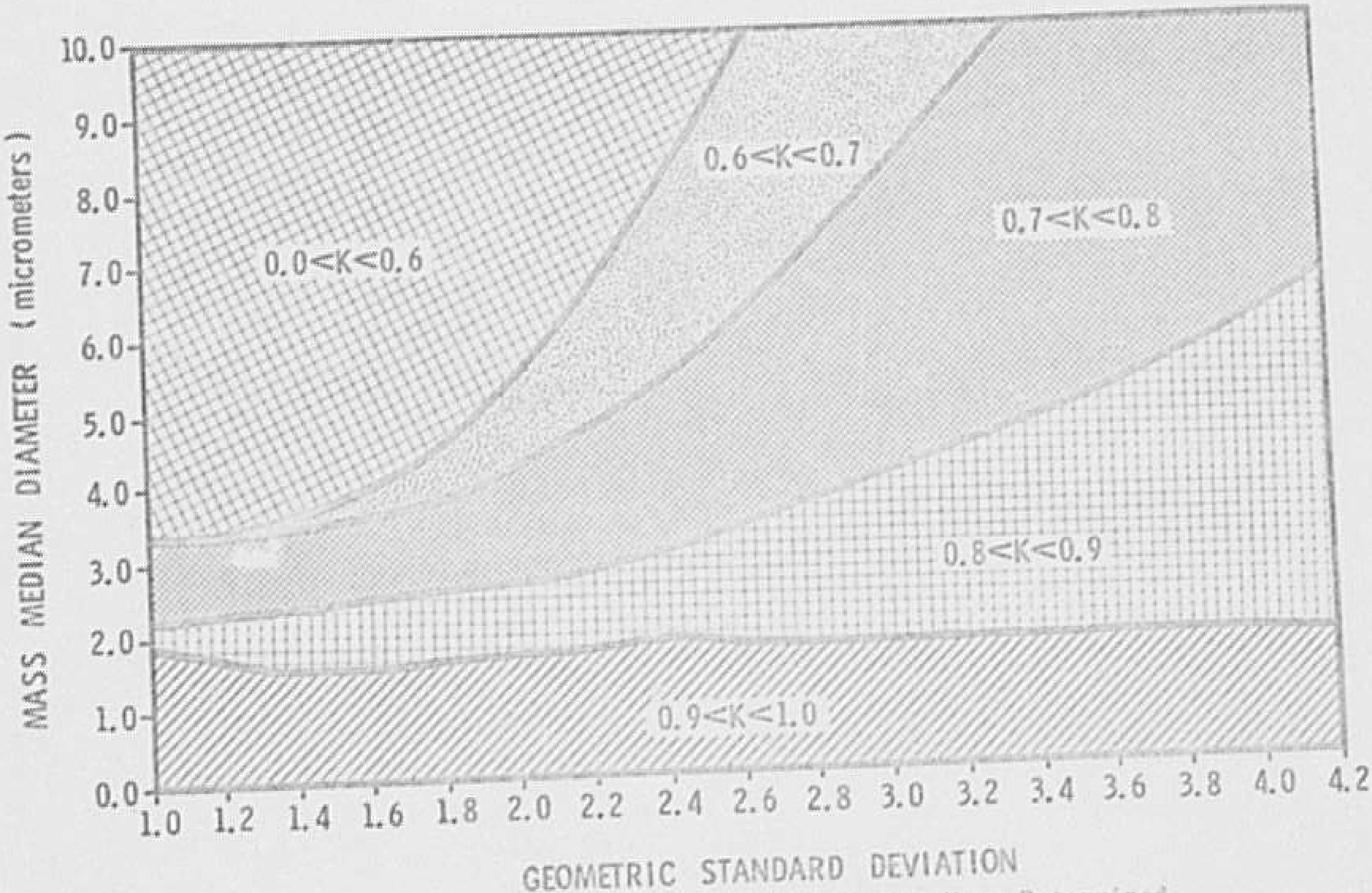

Figure C-16 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria. Computed for Various Dust Clouds. Flow 2.0 lpm. Pulsation 0.8.

90

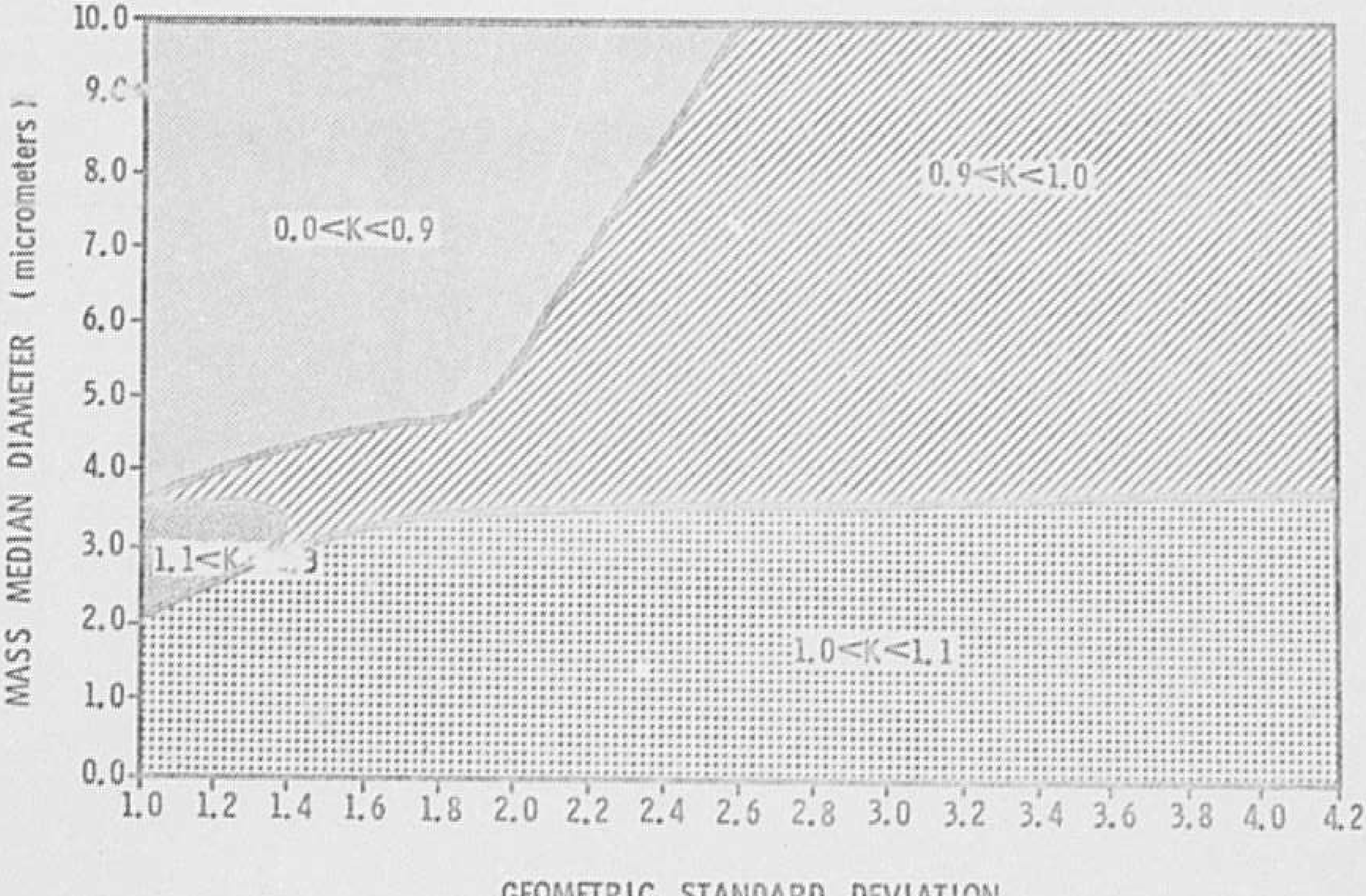

Figure C-17 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 2.0 lpm, Pulsation 0.2.

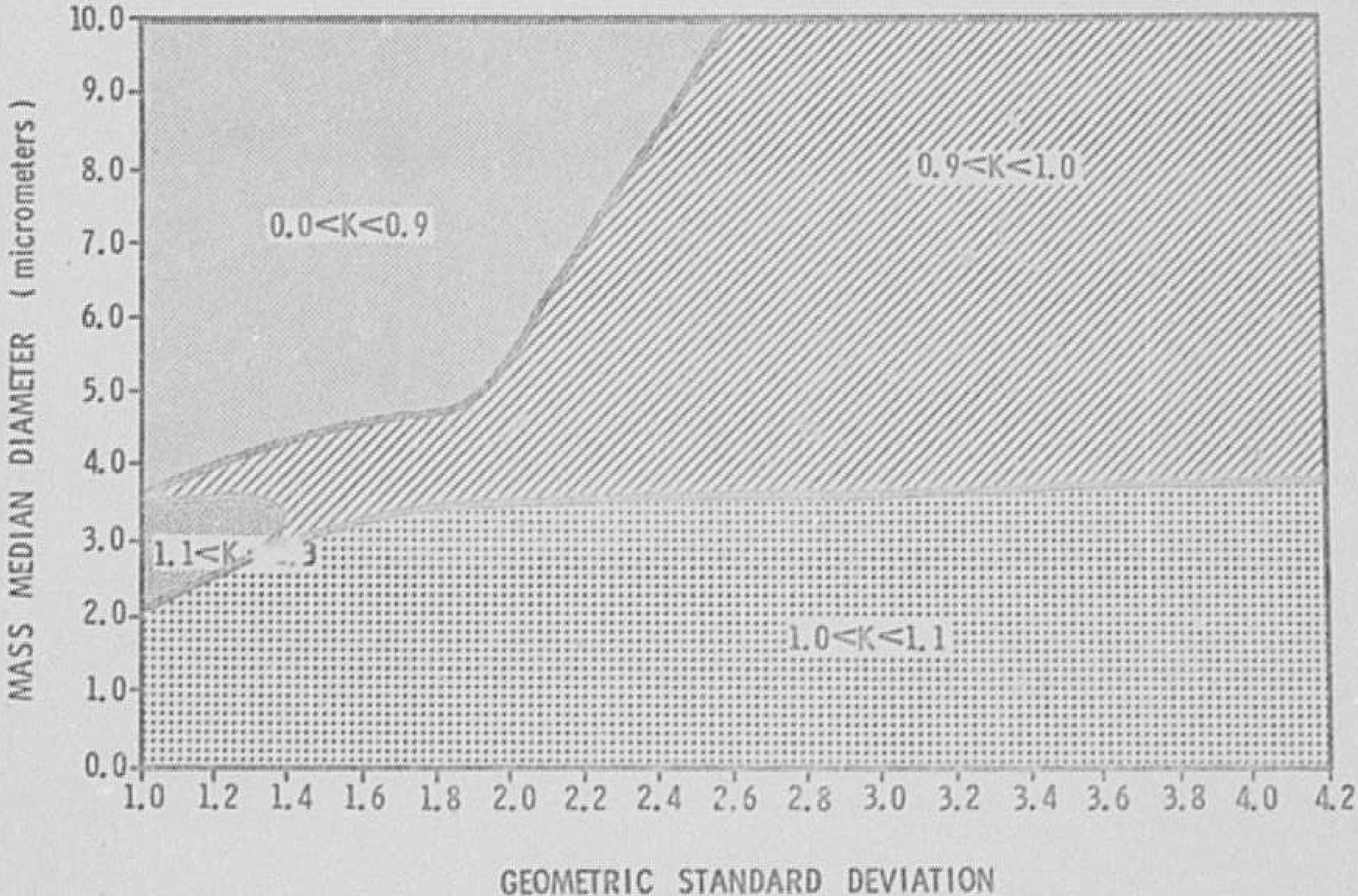

Figure C-17 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 2.0 lpm, Pulsation 0.2.

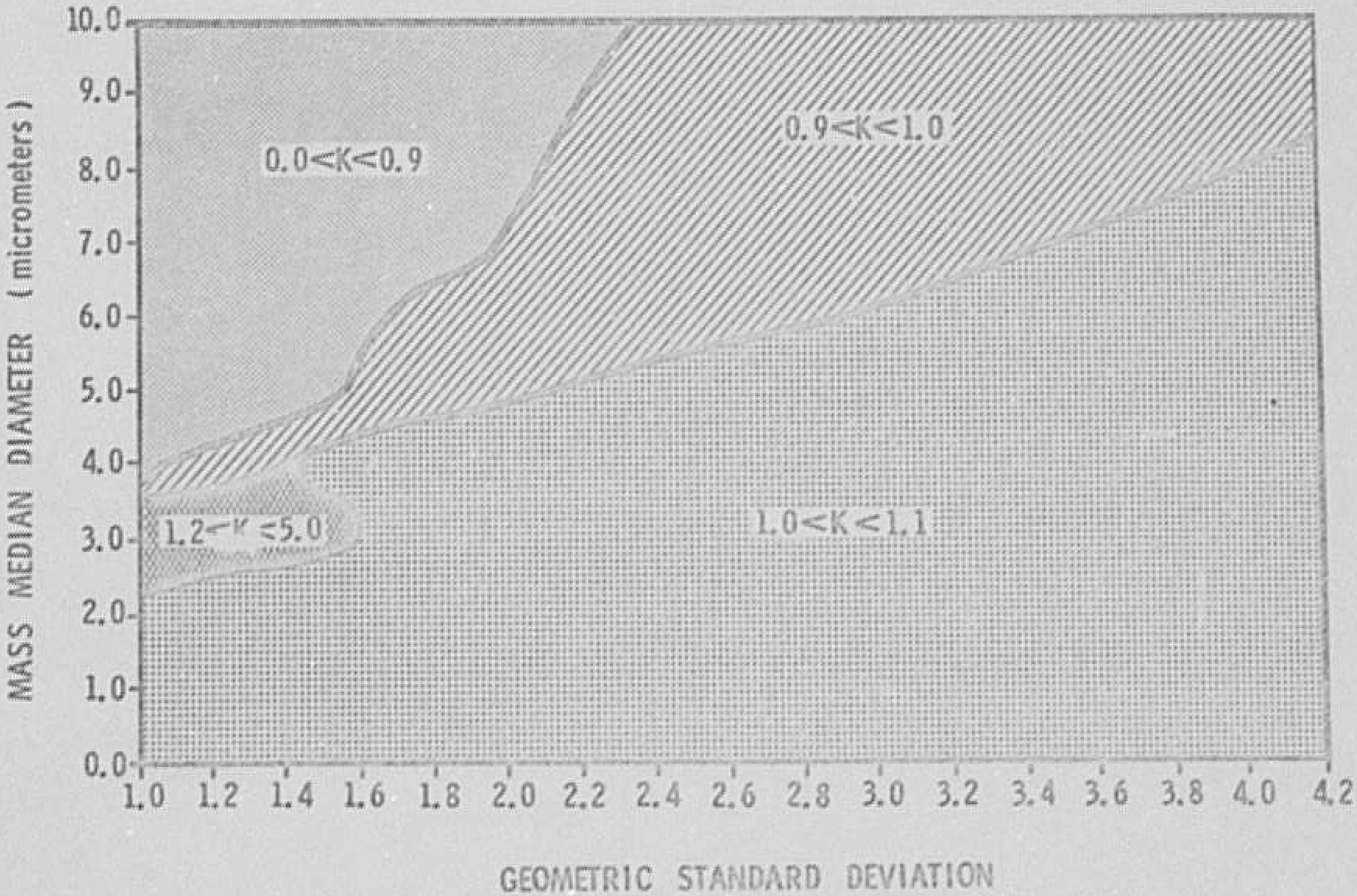

Figure C-18 Values of K, Ratio of Respirable Mass Determined by Cyclone to that Prescribed by LASL-AEC Criteria, Computed for Various Dust Clouds. Flow 2.0 lpm, Pulsation 0.0