Study of Space Cabin Atmospheres

NASA Research Grant NGR-22-007-053

Status Report For the Period

January 1, 1966 to June 30, 1966

Submitted by
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and
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September 30, 1966

I. Summary of Activities

A. Field Aeoosol Generator

In our last status report we described the need for a portable aerosol generator which would provide known concentrations of a homogeneous aerosol for use in the calibration of the Aerosol Particle Analyzer and for later use in evaluating other particle sensing systems. During the present report period a prototype of such a generator was designed and two units were fabricated.

The performance characteristics of this aerosol generator were studied polystyrene latex spheres of 0.557 and 0.796 micron diameters and polyvinyl toluene latex spheres of 1.9 and 2.68 micron diameters. These sizes are suitable for calibration of the Aerosol Particle Analyzer. It was expected that predictable aerosol concentrations of a given particle size could be established with the generator by fixing the liquid suspension concentration of the latex spheres, generator operating pressure, and dilution air flow rate.

Generator performance was evaluated by collection of the latex aerosol on a membrane filter with subsequent counting by light microscopy to determine aerosol concentration. This work has shown that we can generate a homogeneous aerosol with negligible multiple particles; however, to date we cannot predict the aerosol concentration with the accuracy required for calibration of sampling instruments.

In using the aerosol generator for the calibration of the Aerosol Particle Analyzer we noted significant readings in the fifth channel which indicated that in addition to the primary latex particles we were generating high concentrations of secondary small particles. Our light microscopy counting procedure with a resolution of approximately 0.3 microns did not reveal such particles. Other investigators have noted a similar difficulty which they attributed to small particles formed from the water soluble emulsifiers used in the latices. If each primary water droplet from the generator contains a latex sphere, any water soluble material in the droplet will focus on the latex sphere during drying and a single particle remains. If a droplet is generated which does not contain a sphere, the water soluble material forms a secondary particle whose size is only a fraction of that of the latex sphere. These secondary particles are not resolved by light microscopy, but we have confirmed their presence by electron microscopy.

To resolve this secondary particle problem we have attempted to remove a major portion of the water soluble emulsifiers by serially washing the basic hydrosol. Our initial evaluation of this procedure indicated a significant reduction in small particle count. We intend to actively pursue this problem in the next report period. It is intended that a standard procedure for conditioning and generation of the latices will be established and published as a separate report.

B. Calibration of Aerosol Particle Analyzer

During this report period we have cooperated with the Electronics Research Center and Block Engineering Inc. in the calibration and qualification tests of prototype Aerosol Particle Analyzers. Included in our test series was a qualification test conducted at 5 psia in the altitude chamber at the Harvard School of Public Health.

C. Fortran Program

A Fortran program has been prepared which calculates arithmetic and geometric values of particle number and mass mean diameter, standard deviation, particle count, and particle mass concentration. This program is designed for future use in the interpretation of data from the analysis of heterogeneous aerosols. Although the program was designed for an IBM 1620 computer, it can be used on other systems capable of reading or translating Fortran with minor modification. This program has been of considerable value in the handling of the data on the latex washing experiments. It is anticipated that this program will also be valuable for handling the data from the

T 003 experiment to be conducted on Apollo Flight Mission AS 204A. The program is being modified to include particle area measurements and it is planned that it will then be submitted as a special report under this contract.

D. Collection Bias of the Electrostatic precipitator

The point-plane electrostatic precipitator has been routinely used in this laboratory for the direct collection of aerosols on an electron microscope grid. This technique was used in identifying the secondary particles generated from water soluble stabilizers as described above. There has been some suspicion that this device introduces a size distribution sampling error. A study of this possible sampling error has been conducted by Dr. Reist under partial support from this contract. A copy of a paper describing his study which was presented at the Ninth AEC Air Cleaning Conference is attached to this report. This study shows the size distribution of the sample collected using this technique closely approximates the actual particle size distribution of the test aerosol and can be used for our contract requirements.

E. Apollo Earth Orbital Experiment T-3

W. A. Burgess accompanied Dr. W. Leavitt, Electronic Research Center to the Manned-Spacecraft Center at Houston, Texas in April in connection with Experiment T 003, Apollo

Flight Mission AS 204A. W. A. Burgess is assigned as an Associate Investigator on the experiment and is cooperating in the experimental design.

II. Future Activities

The following extensions of the present work effort will be carried out during the next report period.

1. The operating characteristics of the aerosol generator will be studied and changes introduced to permit generation of predictable concentrations of particles. Eliminations of the secondary aerosol generated from water soluble emulsifiers used in the latices will be attempted using a washing technique.

2. This laboratory will continue to assist in the calibration and qualification tests of the Aerosol Particle Analyzer.

3. The Fortran program for the calculation of particle size distribution and particle concentration will be enlarged and submitted as a separate report.

As cited in our last status report we intend to carry out a review of aerosol sensing methods other than optical sensors to evaluate their applicability for spacecraft. We have chosen three particle sensing methods described in the literature for feasibility study during the next report period. A hot wire sensing element will be the first technique to be evaluated. The second method to be studied involves directing the aerosol to a piezo-electric crystal sensor designed to sense the force of particles impacting on the crystal. A third sensor which will be evaluated is an acoustical system based on pressure changes seen as particles pass through an orifice.

III. Personnel

Dr. Parker Reist (see attached curriculum vitae) has accepted the position of Project Engineer on this grant. Dr. Reist will give major attention to aerosol generation and calibration of particle sensors.

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SIZE DISTRIBUTION SAMPLING ERRORS INTRODUCED BY THE POINT-PLANE ELECTROSTATIC PRECIPITATOR SAMPLING DEVICE

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This work was done in connection with contracts of Harvard University with the U. S. Atomic Energy Commission and the National Aeronautics and Space Administration.

SERIES DISTRIBUTION SAMPLING ERRORS INTRODUCED BY THE POINT-PLANE ELECTROSTATIC PRECIPITATOR SAMPLING DEVICE

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ABSTRACT

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In using the point plane electrostatic precipitator it is generally assumed that the size distribution of the sample collected represents reasonably well the actual particle size distribution of the test aerosol. This paper reports an investigation made to determine the accuracy of this assumption and concludes that for count size distributions the error introduced by this sampling device is insignificant.

AUTHOR

I. INTRODUCTION

The point-plane electrostatic precipitator provides a simple and rapid method for the collection of aerosol samples for subsequent analysis using the electron microscope. Designs for this type of precipitator have been given by Baum[1], Arnold, Morrow and Stöber[2], Morrow and Mercer[3], and Billings and Silverman[4].

The last three designs consist essentially of an insulated tube in which are placed a point electrode (a phonograph needle, for example) and a plane electrode. The point electrode is placed at right angles to the direction of flow with the plane electrode opposite it.

An electrical potential is placed across the electrodes and either direct current or alternating current can be used. Voltages may range from 4 to 15 KV. If the unit is operated at a voltage sufficient to cause a corona discharge around the point electrode, particles passing between the point and plane will become charged and will be collected on the plane electrode. An electron microscope grid can be placed on the plane electrode and a sample will be collected directly on the grid, thus eliminating time consuming and error producing transfer procedures.

II. PREVIOUS WORK

Baum[1] did not make precise estimates of the sampling efficiency of his precipitator design for various particle sizes but recommended that this be studied since he found that the over-all efficiency of his unit was less than 100%. On the other hand, Morrow and Mercer[3] and Morrow, Raabe and Yurkstas[5] compared size distributions obtained with a point-to-plane precipitator to those obtained with a thermal precipitator and concluded that the results were essentially indistinguishable. For their studies, aerosols consisting of particles of UO_2, Fe_2O_3 and CrO were used. Mean sizes ranged from 0.07 μ ($\sigma g = 1.40$)[3] to 0.39 μ ($\sigma g = 2.25$).

Studies by Arnold, Morrow and Stöber[2] of two rock dusts led to the conclusion that there was essentially no difference between samples collected using the thermal precipitator (which according to Green and Lane[6] gives essentially complete collection of particles less than 5μ diameter) and the point-plane electrostatic precipitator. They pointed out, however, that there was some evidence that particles having diameters greater than one micron were sampled in larger quantities by the electrostatic precipitator than by the thermal precipitator.

In an evaluation of particle sizing and aerosol sampling techniques, Ettinger and Posner[7] found good agreement between count median diameters of samples collected on two different electrostatic precipitators and three different thermal precipitators. The mean size of the UO_2 aerosol used was about 0.25 μ with a geometric standard deviation of about 2.25. When electrostatic precipitator samples were compared with membrane filter samples of a UO_2 aerosol with count mean diameter of about 0.5 - 0.75 μ and a geometric standard deviation of about 2.00 the membrane filter samples were consistently higher than the electrostatic precipitator samples. Ettinger and Posner surmised that among other things the discrepancy might be due to variation in collection characteristics of the two techniques.

The study reported herein pertains to possible errors in point-plane electrostatic precipitator collection for larger particle sizes. The resulting data extends our knowledge of the operating characteristics of this type of sample collector to essentially the entire range of particle sizes of interest.

III. EXPERIMENTAL PROCEDURE

A homogeneous aerosol cloud of polystyrene latex particles (Dow Chemical Company) was generated in the apparatus schematically illustrated in Figure 1. This apparatus consists of a Pen-i-sol nebulizer, a source of dilution and drying air and a horizontal drying column. At the end of this column a tee was placed so that the aerosol cloud that was generated could be split into two fractions. One fraction was passed through an HA millipore filter and the volumetric flow rate was measured with a rotameter. The other portion of the cloud was passed through the point-plane electrostatic precipitator and then through another rotameter for flow measurement.

Four different sizes of polystyrene latex were used. Table 1 gives the particle diameter and approximate aerosol concentrations produced by the particle generator. These concentrations were determined by sampling with the membrane filter and counting the particles collected, using phase contrast microscopy. Because of the tendency of the Pen-i-sol nebulizer to produce some doublets and multiple particles, particle counts were made separately for single, double and total particles. Sufficient particles of each class were counted so that the number of particles times the number of fields counted exceeded 500[8].

The electrostatic precipitator used in this investigation was an alternating current unit of a design similar to the one described by Billings and Silverman[4]. A sketch of the unit is shown in Figure 2. The electrode spacing was 7.5 mm and all samples were collected using a rms potential of 7000 volts. Samples were collected on a standard carbon-coated 200 mesh copper screen. The effective sampling area of the screen was

FIG. 1

SCHEMATIC ILLUSTRATION OF AEROSOL GENERATOR

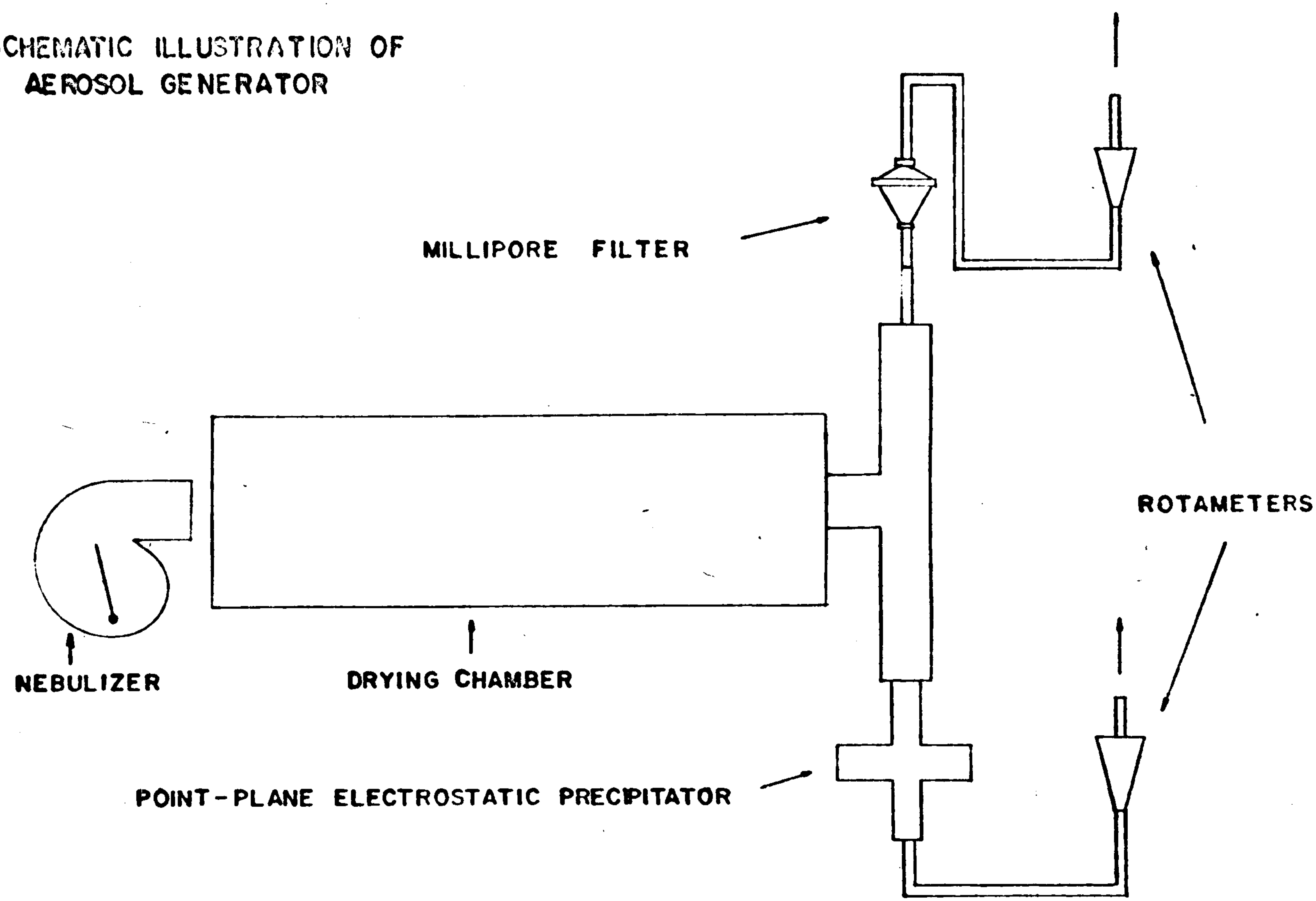


TABLE 1

APPROXIMATE PARTICLE CONCENTRATIONS PRODUCED BY

AEROSOL GENERATOR

Particle Diameter (Microns)	Particle Concentration, Particles Per Liter		
	Singlets	Doublets	Total
0.557	2.0×10^6	8.2×10^5	5.1×10^6
0.796	2.7×10^6	8.5×10^5	5.1×10^6
1.305	8.5×10^5	2.5×10^5	1.3×10^6
2.68	1.1×10^5	2.5×10^4	2.1×10^5

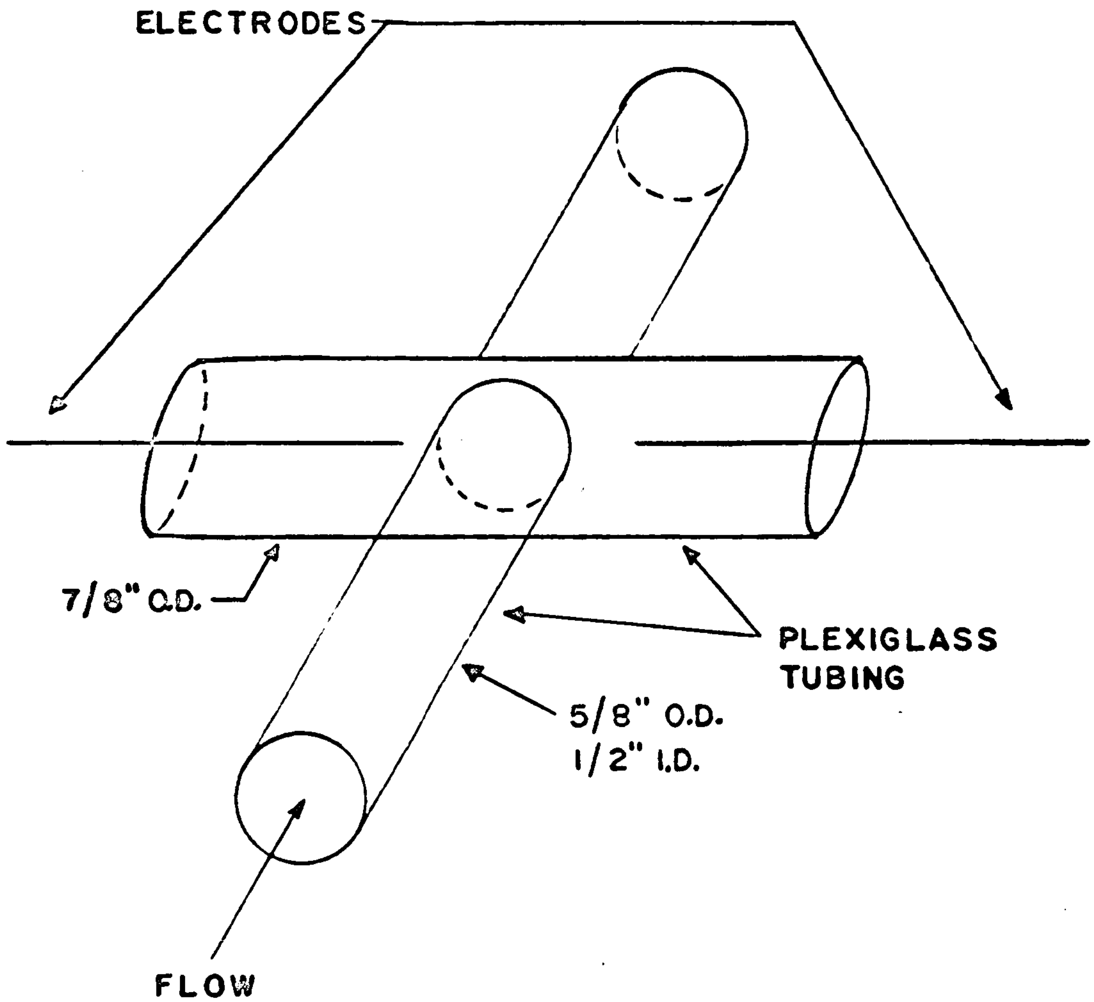


FIGURE 2. SCHEMATIC REPRESENTATION OF POINT PLANE ELECTROSTATIC PRECIPITATOR.

TABLE 2

MEASURED COLLECTION EFFICIENCIES FOR VARIOUS GAS VELOCITIES THROUGH THE POINT-PLANE ELECTROSTATIC PRECIPITATOR

Singlets

Velocity (cm/sec)	Particle Diameter, Microns 0.557	0.796	1.305	2.68
5	1.67	1.38		5.14
15	1.16	2.03		1.79
30	4.36	0.91	1.65	4.73
70	0.75	1.20		1.85

Doublets

Velocity (cm/sec)	Particle Diameter, Microns 0.557	0.796	1.305	2.68
5	2.62	1.84		8.05
15	1.53	2.59		6.18
30	2.92	1.23	1.96	4.61
70	0.66	1.67		6.56

4.45×10^{-2} cm^2. Representative grid areas were photographed using a Phillips Model 75 electron microscope and the resulting negatives were printed on 8 x 10 photographic paper for counting. Photographs of a 28,800 line calibration grid were taken and printed in a similar way before and after each change of a magnification or film. Three grid areas were photographed per sample; one from the middle of the sample and the other two near the sample edge, at right angles to each other.

Similar to the counting procedure for the membrane filter samples, separate counts were made on the number of singlets and doublets collected by the electrostatic precipitator. Because of the relatively low concentration of aerosol used in these experiments, coagulation of the suspended particles was not considered to be significant and thus collection efficiencies for singlets and doublets could be considered to be independent of each other.

Collection efficiency was defined as 100 times the ratio of the total number of particles of a certain type collected by the electrostatic precipitator in a given period of time to the total number of particles of the same type which in the same time passed through the precipitator.

Runs were made to determine the collection efficiencies of the four homogeneous aerosols at flow through velocities of 5, 15, 30, and 70 centimeters per second. Flow at the highest velocity tested gave a Reynolds number of about 350, so that in all cases flow through the electrostatic precipitator was laminar.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The efficiencies measured, using the technique described above, are shown in Table 2. Because of difficulties during the experiment in getting proper loading of the aerosol, data for the 1.305 μ particles were collected for only one velocity.

From these efficiencies, there appears to be no indication that varying the collection velocity from 5 cm/sec to 70 cm/sec affects the collection efficiency of the point-plane electrostatic precipitator for any of the sizes studied. It was thus possible to average these values to compare collection efficiencies for the four sizes of particles. The averaged values are plotted as Figure 3.

Using various aerosols, Arnold, Morrow and Stöber[2], Morrow and Mercer[3], Ettinger and Posner[7], and Yoder[9], all found no sampling bias from the point-plane electrostatic precipitator with particles of mean diameters less than 0.5 μ. Thus is can be concluded that the curve shown in Figure 3 is essentially a straight line below 0.5 μ diameter.

A large increase in collection efficiency is observed for the 2.68 micron particles both singlets and doublets and it is reasonable to expect it to continue to increase for still larger particles. The greater efficiency found for the 2.68 μ particles agrees with observations of Arnold et al.[2], mentioned earlier, that particles greater than one micron in diameter were sampled in greater quantities by the electrostatic precipitator than by the thermal precipitator.

From Figure 3 particles of approximately 0.8 micron diameter appear to be collected with minimum efficiency. Comparison of the averaged results for the singlets and doublets (Table 3) also tends to indicate a minimum collection efficiency about this same size range. The efficiency goes down for doublets for the 0.577 μ particles, while in all other cases an increased collection efficiency for doublets is observed. J. Dyment, working at the U.K. Atomic Weapons Research Establishment, found that point-plane electrostatic precipitator samples of a heterogeneous aerosol were deficient in particles in the range 0.5 to 1.0 μ when compared to the results obtained using an oscillating thermal precipitator[10]. This is similar to the results found by Ettinger and Posner[7], mentioned earlier. This decrease could be explained by the dip in efficiency shown in Figure 3.

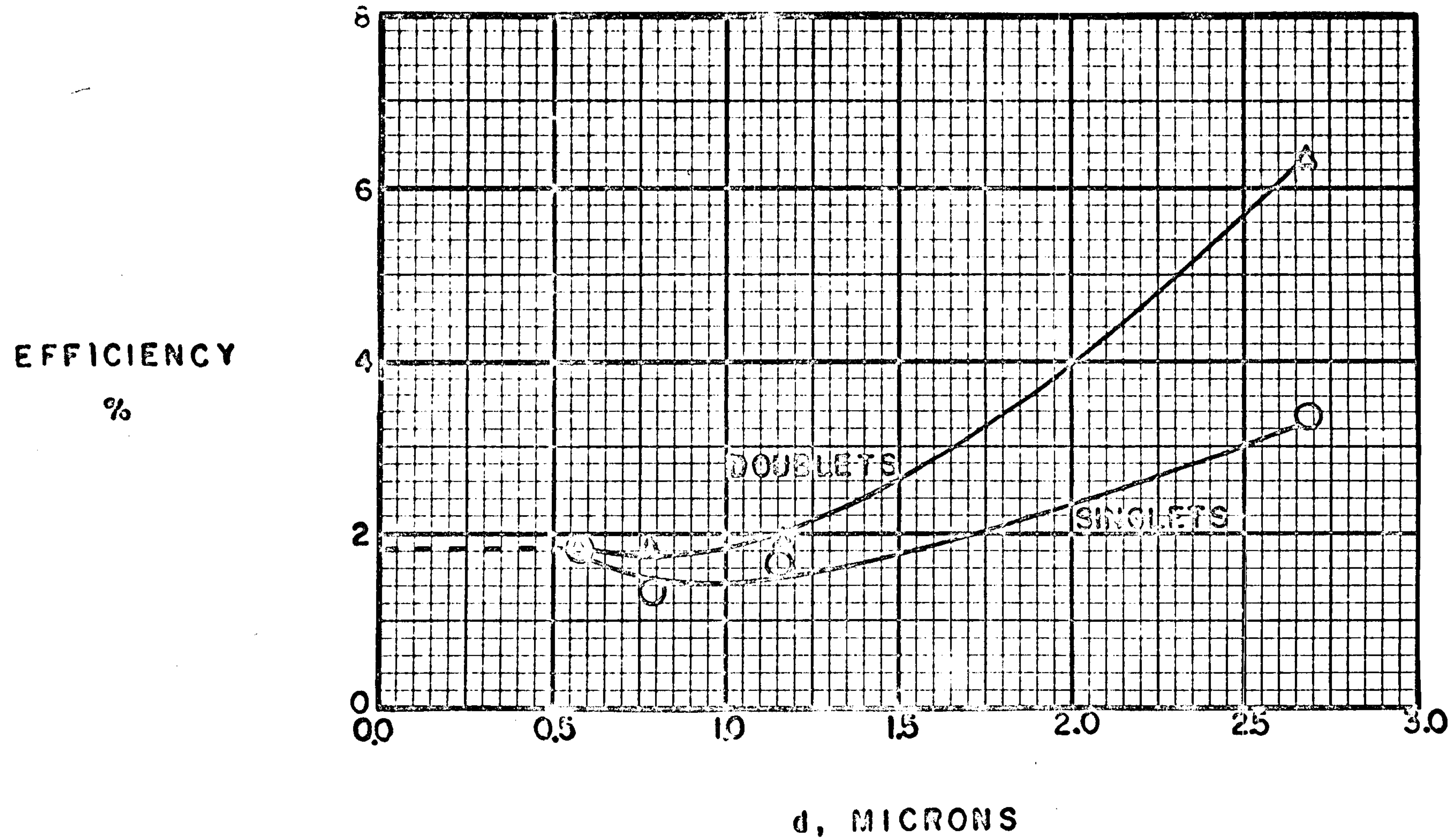
TABLE 3

AVERAGED COLLECTION EFFICIENCIES, PERCENT

Particle Diameter (Microns)	Singlets	Doublets
0.557	1.98	1.93
0.796	1.38	1.83
1.305	1.65	1.96
2.68	3.38	6.35

FIG. 3

ESP COLLECTION EFFICIENCY vs. PARTICLE SIZE



V. CONCLUSIONS

1. The collection efficiency of the point-plane electrostatic precipitator is independent of the sample velocity through the unit when sampling in the laminar flow range.

2. From the information presented in previous sections of this report, it is concluded that there is no bias introduced by the electrostatic precipitator for particle sizes less than about 0.5 μ.

3. The point-plane electrostatic precipitator will tend to over-sample particles of sizes above about 1.5 microns, this effect increasing with increasing particle size.

4. There is a decrease in collection efficiency for particles whose sizes lie in the range 0.5 to 1.0 μ. For the determination of count size distributions this decrease should be negligible; for determining mass size distributions, however, the error introduced by this variation could be significant.

VI. ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of P. A. Schwartz who assisted him in the collection of the data for this report.

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THESIS

Master's Thesis, M.I.T. September, 1957.
Effect of Synthetic Detergents on Reaeration in Heaving Bodies.
Doctoral Thesis, HSPH, 1965.
Disposal of Radioactive Krypton in Porous Media

PUBLICATIONS

1. Parker C. Reist, Melvin W. First, and Leslie Silverman, Development of the "Diffusion Board" Concept in Reactor Containment, USAEC Report, NYO-841-6, Harvard Air Cleaning Laboratory, September 1, 1966.

2. D. G. Smith, P. C. Reist and L. Silverman, "Increased Detection Sensitivity for Krypton 85", Presented at the 9th AEC Air Cleaning Conference, Boston, September 1966.

3. P. C. Reist, "Size Distribution Sampling Errors Introduced by the Point-Plane Electrostatic Precipitator Sampling Device", Presented at the 9th AEC Air Cleaning Conference, Boston, September 1966.

4. D. C. Smith, P. C. Reist and Leslie Silverman, A Review of Detection Sensitivity for Monitoring of Krypton 85, USAEC Report NYO-841-5, Harvard Air Cleaning Laboratory, October 1966.

5. Parker C. Reist and Leslie Silverman, "The Disposal of Waste Radioactive Gases in Porous Underground Media". Paper submitted for publication

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