GPO PRICE $ ____

CFSTI PRICE(S) $ ____

Hard copy (HC) $2.00

Microfiche (MF) .50

ff 653 July 65

IITRI

NASA CR 71167

FACILITY FORM 602

N66-20691 (ACCESSION NUMBER)	(THRU)
47 (PAGES)	1 (CODE)
CR 71167 (NASA CR OR TMX OR AD NUMBER)	23. (CATEGORY)

Report No. IITRI-U6003-17
(Quarterly Report)

INVESTIGATION OF LIGHT SCATTERING IN HIGHLY REFLECTING PIGMENTED COATINGS

National Aeronautics
and Space Administration

IIT RESEARCH INSTITUTE

Report No. IITRI-U6003-17
(Quarterly Report)

INVESTIGATION OF LIGHT SCATTERING IN HIGHLY REFLECTING PIGMENTED COATINGS

November 1, 1965 through February 1, 1966

Contract No. NASr-65(07)
IITRI Project U6003

Prepared by

G. A. Zerlaut, B. H. Kaye
and M. R. Jackson

of

IIT RESEARCH INSTITUTE
Technology Center
Chicago, Illinois 60616

for

National Aeronautics and Space Administration
Office of Advanced Research and Technology
Washington 25, D. C.

Copy No. 21

February 28, 1966

FOREWORD

This is Report No. IITRI-U6003-17 (Quarterly Report) of IITRI Project U6003, Contract No. NASr-65(07), entitled "Investigation of Light Scattering in Highly Reflecting Pigmented Coatings". This report covers the period from November 1, 1965 to February 1, 1966. Previous Quarterly Reports were issued in October 1963, February 1964, May 1964, September 1964, January 1965, March 1965, May 1965, August 1965, and November , 1965. The project is under the technical direction of the Research Projects Laboratory of the George C. Marshall Space Flight Center, and Mr. Daniel W. Gates is project manager.

Major contributors to the program include G. A. Zerlaut, project leader; Dr. S. Katz and Dr. B. H. Kaye, theoretical analysis; and M. R. Jackson, experimental investigator. Experimental data are recorded in logbook C16369.

Respectfully submitted,

IIT RESEARCH INSTITUTE

G.A. Zerlaut

G. A. Zerlaut
Group Leader
Polymer Research

Approved by:

T. H. Meltzer
Manager
Polymer Research

GAZ/am/jb

ABSTRACT

This report continues the Monte Carlo investigations which have been performed during the past year. The report begins with a discussion of the inadequacy of currently used terminology relating to reflective pigmented coatings. The two basic methods of drawing random intercepts on a circle are discussed. One method involves drawing lines between two random numbers on the circle's perimeter; the other involves drawing lines perpendicular to the radius for randomly selected angles to a fixed direction. The second method has a 33% longer track length than the first method. Since the absorption of light depends upon the time spent inside a particle (i.e., the average track length), the absorption factors for the two possible track systems should be quite different.

A Monte Carlo grid-plotting experiment showed that the maximum number of independent scattering centers occurs at a volume fraction of 17%; this is surprisingly close to the value of 20% obtained experimentally.

The implications of the Monte Carlo studies for metal-filled conducting paints and filtration problems are discussed in detail.

TABLE OF CONTENTS

List of Tables

List of Figures

TABLE OF CONTENTS (CONTINUED)

Page

List of Figures

LIST OF FIGURES (CONTINUED)

INVESTIGATION OF LIGHT SCATTERING IN HIGHLY REFLECTING PIGMENTED COATINGS

I. INTRODUCTION

The objective of this program is the application of light-scattering theories to polydisperse, highly reflecting, highly pigmented coatings. The program is aimed at a definition of the light scattering parameters associated with the maximum reflection of solar radiation. The definition of these factors should facilitate the eventual development of more efficient solar reflectors and, perhaps more important, may extend the applications of light-scattering theory to the solution of other problems.

Previous work has involved (1) a review of classical light-scattering theory with emphasis on that portion having the most promise for application to multiple scattering events, (2) the generation of data on the optical properties of carefully prepared arrays of silver bromide particles dispersed in gelatin, and (3) the conception of theoretical approaches and random-walk techniques with which to treat the problem of multiple scattering.

The adaptation of classical Mie theory to multiple scattering and the experimental studies on silver bromide dispersions have been discussed in several of the previous Quarterly Reports. The complete review of classical light-scattering theory will be given in the summary Final Report which is currently planned for distribution in June of this year. This report will also contain a complete review of the studies pertaining to the silver bromide dispersions.

This report continues the Monte Carlo investigations which were discussed in the last three quarterly reports (Reports No. IITRI-C6018-14, IITRI-C6018-15 and IITRI-U6003-16). This report continues the discussion of the random intercepts of a circle begun in Quarterly Report No. C6018-15 and an extension of the grid-plotting experiment discussed in the last Quarterly Report No. U6003-16. Implications of the Monte Carlo treatment generated thus far are presented both for metal-filled, electrically-conducting paints and for filtration theory.

II. CONCEPT OF A HIGHLY REFLECTING PAINT FILM

In an essay on the meaning of time, Millikan states that the beginnings of science are nearly always found in the first steps taken toward refining and making more precise, natural but inaccurately defined concepts (ref. 1). When considering problems associated with the development of highly reflective paint, we find that as we extend our desire to control and predict the properties of a paint film many of the words used in paint technology are not defined precisely enough and the first stage in developing the new technology is the elaboration of a new terminology.

As recently as 1961, S. H. Bell (ref. 2) speaking on the use of powders in the paint industry specifies the functions of a paint as either decorative or protective. In his essay on paints there is no hint of the concept that a paint can also be considered as a quantitative radiant-energy valve. In the most general terms, a paint film should be described as a multiphase coating containing dispersed solid particles of one or more substances cemented together by another substance.

---

1. Millikan, R. A.,essay in "Time and Its Mysteries", p. 28 Collier Books, New York, New York, 1962.
2. Bell, S. H., "Pigments and Fillers for Use in Paints" Society for Chemical Ind., Monogram 14, p. 169, 1961.

Important properties of the paint film are:

(a) The volume ratio of the different substances present in the coating.

(b) The size and shape distribution of the dispersed particles.

(c) The physical properties of the dispersed particles and the cementing medium.

(d) The spatial distribution of the substances present in the film.

(e) The texture of the surface boundaries of the film.

The prediction of all the above quantities from measured properties of the raw materials is impossible at the present stage of development even for the simplest paint system. Newman (ref. 3) discussed the problems of predicting the performance of paint films from a knowledge of the size distribution of the pigment and his conclusion was "When one determines a particle size distribution of a pigment from, for example, sedimentation data on the highly dispersed pigment and then attempts to draw a close correlation with paint properties, the problems involved are almost of the same order as would arise if a bomb was dropped onto the Houses of Parliament, and a builder was confronted with a heap of rubble, never

---

3. Newman, A. C. C., particle size in relation to the use of pigments in paint "Symposium on Particle Size Analysis" 1947, published by Institute of Chem. Eng.

having seen the building before, and having no detailed plan, and was then asked to reconstruct the building in its original condition complete in every detail".

In the studies carried out so far in this contract we have continually been plagued by difficulties caused by the inability to assign exact meaning to concepts and the lack of knowledge on how the properties of the raw material effect the properties of the final film. In the period covered by this report, we have tried to find an exact definition of "diffuse light" and have been enable to find a precise definition in standard optical textbooks. Again in trying to extend the concept of a random-energy walk through a paint film we have found little information on how a paint pigment is distributed in the final paint film. Finally, when attempting to construct various models of paint films, it was realized that throughout the previous reports the concept "highly reflecting paint films" had not been defined. One cannot define a highly reflecting paint film without reference to the boundary conditions of the system being studied. For example, does one attempt to maximize radiative properties with respect to unit weight or unit volume of the film? When defining reflectance of the paint, it is necessary to specify the radiation concerned. In the studies of this contract we are concerned with an environment in which the energy is direct radiation from the sun (in a vacuum), but this fact should be explicit in any definition of high reflectivity. Because of the changes brought about by absorbed radiation, it may also be necessary to take into account a time integral of the radiation reflected by the paint film for the required time interval. Since in these studies we are concerned with paint for spacecraft we have decided that a highly reflective paint film should be optimized with respect to unit weight of film.

In the earlier studies carried out under this contract effort was concentrated on understanding the complex scattering behavior of single particles. As the studies proceeded it became apparent that modification of Mie theory to account for radiation interaction in a paint film were going to be exceedingly complex. Finally, the simulation studies initially undertaken to study the forward penetration of a parallel beam of light indicated that the packing of the particles in the paint film may be a very important factor in establishing the scattering power of the paint film (ref. 4). Therefore, before proceeding with actual optimization studies, it was decided to further study the packing properties of pigment particles in a paint film.

---

4. G. A. Zerlaut, B. H. Kaye and M. Jackson, "Investigation of Light Scattering in Highly Reflecting Pigmented Coatings", Report No. IITRI-U6003-16, November, 1965

III. SIMULATED SYSTEMS USING RANDOM-NUMBER TECHNIQUES

A. Random Intercepts of a Circle (Part 2)

In Report No. IITRI-C6018-15, three methods of drawing random intercepts of a circle were described. A fourth method of constructing intercepts would be to choose one point on the perimeter using a random number table and then to choose a direction in the same manner. However, this method is mathematically equivalent to Method 1 (IITRI-C6018-15) in which equal probability of entry and exit was used to construct the intercepts. Therefore, Methods 1 and 4 and Methods 2 and 3 are equivalent. In subsequent discussions Methods 1 and 4 will be called Method A and Methods 2 and 3 will be called Method B.

In Figures 1 through 3 are shown three simulated sets of 20 random lines drawn using Method A, and in Figure 4 a set of 20 lines drawn using Method B. If we consider the physical significance of the two sets of diagrams, it would seem that systems constructed using Method A correspond to the problem of determining the average track length of a photon through a pigment particle. As mentioned in the Section II of this report, it is difficult to give a precise definition of diffuse light. For the purposes of this discussion we shall define diffuse light as light in which the density of photons per unit volume is the same at any location in space and that all directions for the photon tracks are equally probable.

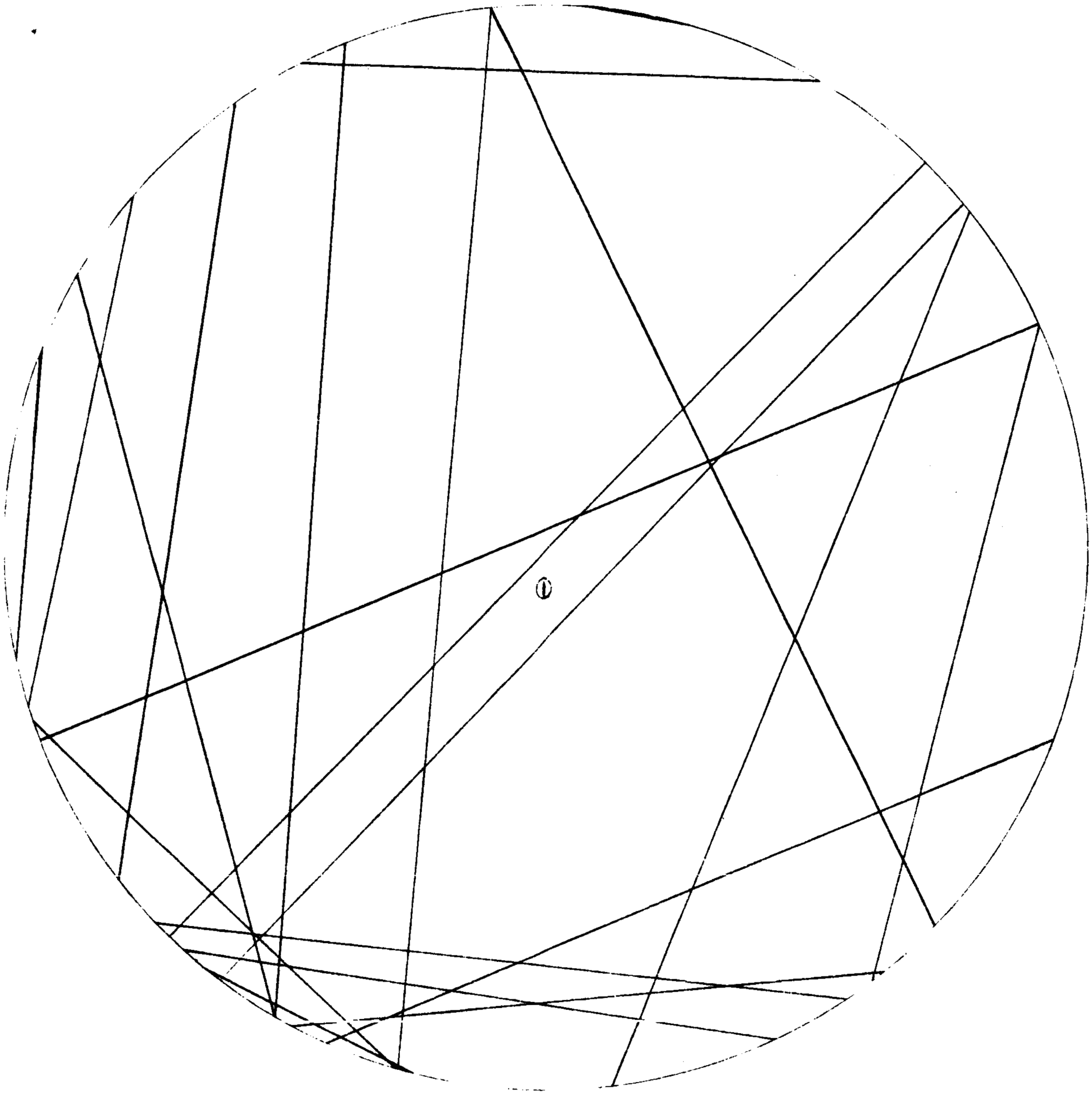


Figure 1

LINES DRAWN BETWEEN TWO RANDOM NUMBERS
SELECTED ON THE PERIMETER
OF A CIRCLE

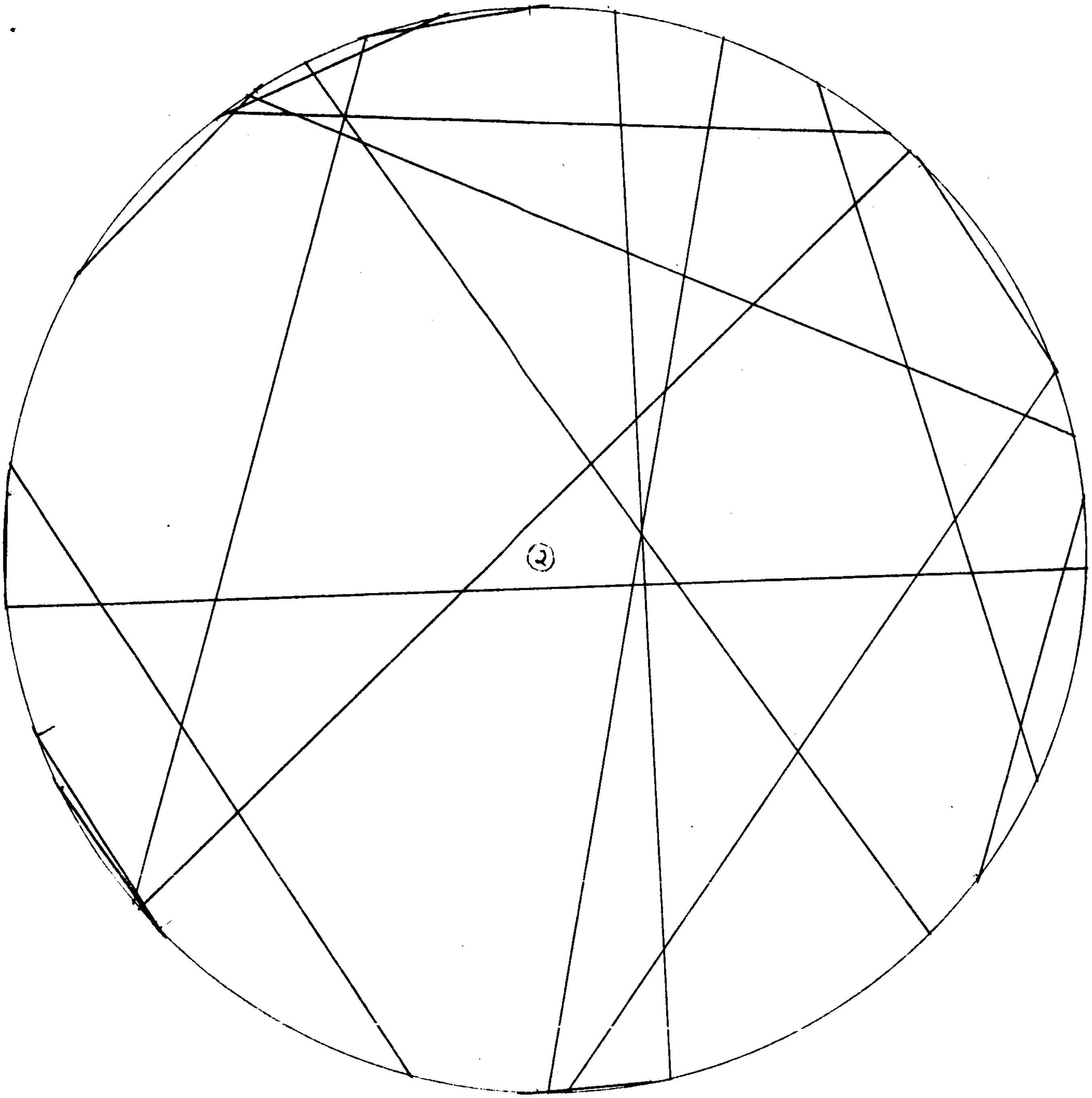


Figure 2

LINES DRAWN BETWEEN TWO RANDOM NUMBERS
SELECTED ON THE PERIMETER
OF A CIRCLE

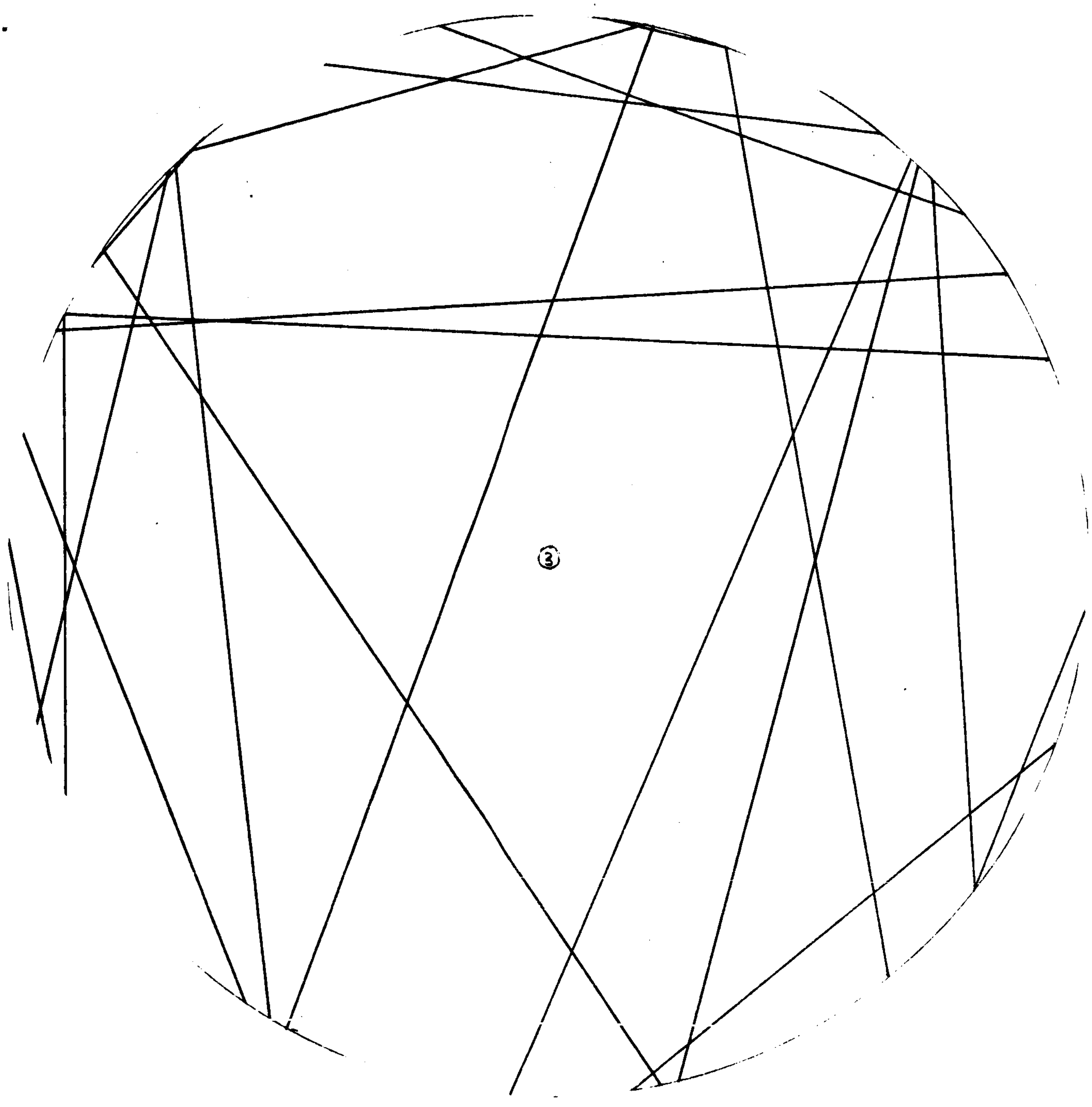


Figure 3

LINES DRAWN BETWEEN TWO RANDOM NUMBERS
SELECTED ON THE PERIMETER
OF A CIRCLE

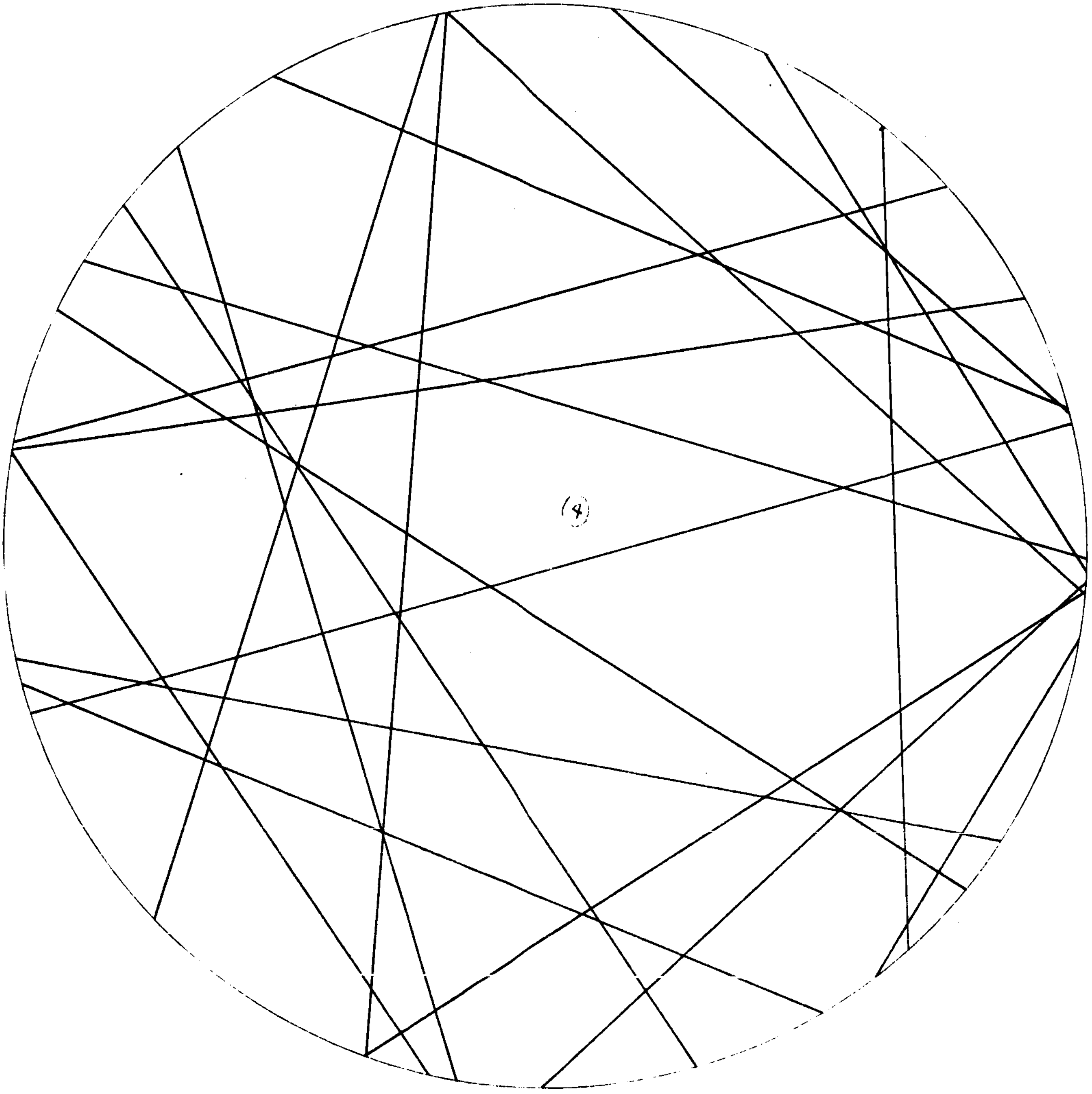


Figure 4

LINES DRAWN PERPENDICULAR TO RADIUS
FOR RANDOMLY SELECTED
ANGLES TO A FIXED DIRECTION

Using this definition the density of photon entries at any point of the pigment perimeter is equal at all points of the perimeter. This is equivalent to saying that all points of entry for any specified photon are equally probably. The probability of directions permissible for the photon after it crosses the pigment boundary is difficult to assess since we cannot talk about refraction phenomena unless we have an extended wave front. If we can assume equal probabilities for all possible directions then the possible tracks correspond to the intercepts constructed using Method A. If we are considering gas molecules instead of photons, we would have to consider the effect of collisions. The effect of collisions would be to bring the density of particles per unit volume to the same value for all regions of the system for which track lengths are being considered and this would tend to make track lengths equivalent to those constructed using Method B, since in this technique the density of intersection of tracks is more uniform over the area considered.

The average track length for systems constructed by Methods A and B are quite different. The average track length for Figures 1, 2, and 3, are 1.3, 1.1, 1.2 radius units and for the system of Figure 4, 1.6 radius units. Although the data is fragmentary, the implications are important. If we take the average of the values for Figures 1, 2, and 3 as 1.2 units, then the average track length for the system for

Figure 4 is 33% longer than for the other systems. Since the absorption of the light will depend on the time spent inside the particle, i.e., the average track length, the absorption factors for the two possible track systems should be quite different.

B. Extension of the Monte Carlo Grid Plotting Experiment

A simulation experiment for studying cluster formation in a paint film was described in the last Quarterly Report. In the period covered by this report, this experiment was extended from a volume concentration of 20% to 30%. Results are summarized in Tables 1 and 2. In Figure 5 the absolute number of scattering centers per unit volume for the extended range of volume concentrations are given. It can be seen that the occurrence of a maximum at 17% by volume of pigment is fully confirmed by this extended data. In Figure 6 the growth of the various sized clusters is shown for clusters containing less than six units. The particle size distribution of the clusters formed at the highest volume fraction is given in Figure 7. It can be seen that the distribution can be described by the log-normal function and this confirms the earlier work at the lower volume concentrations. In Figure 8 the curve for the rate of overlapping is given and it can be seen that again the work at the lower concentrations is confirmed (see Figure 5, IITRI Report U6003-16).

Table 1

CLUSTER FORMATION DATA FOR MONTE CARLO EXPERIMENT

No. Units in Cluster	Number of Clusters Having Stated Number of Units at Fractional Concentration											Cumulative % No. @ 0.30 Concentration
	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.30	
1	243	239	228	213	191	174	155	151	146	135	121	36.7
2	93	89	83	84	82	83	76	73	65	66	56	53.6
3	58	56	55	56	57	52	49	52	52	47	38	65.2
4	23	21	22	21	22	22	21	20	23	25	23	72.1
5	21	20	21	16	15	17	19	17	16	15	14	76.4
6	18	15	14	16	18	19	14	11	12	9	9	79.1
7	16	16	13	12	10	10	10	12	9	7	6	80.9
8	4	10	12	15	14	13	14	15	13	10	13	81.8
9	10	8	10	9	10	11	8	4	6	8	8	84.2
10	5	7	10	10	9	11	16	11	9	6	6	86.1
11	4	6	8	8	7	5	1	3	3	5	4	87.3
12	2	3	2	3	6	4	5	5	3	4	3	88.2
13	0	1	2	4	3	6	3	2	3	3	3	89.1
14	2	3	2	2	1	1	5	3	3	1	1	89.4
15	2	2	1	2	1	3	3	4	3	3	5	90.9
16	3	2	2	1	3	1	3	2	5	4	4	92.1
17	1	1	2	4	1	1	2	2	3	5	3	93.0
18	0	0	1	2	2	2	1	1	1	0	2	
19	0	0	0	0	1	1	3	2	2	1	0	
20	0	0	1	1	2	1	0	4	0	1	0	
21	1	0	0	0	0	0	0	1	2	2	0	93.6
22		1	0	0	0	0	0	1	3	4	4	94.9
23		0	1	1	1	0	0	0	0	1	4	96.1
24		1	1	1	0	2	0	0	0	0	0	
25					0	0	0	1	0	2	1	96.4
26					1	0	0	0	0	0	1	96.7
27					0	1	0	0	0	0	0	
28					0	0	0	0	1	0	0	
29					2	0	1	0	1	1	1	97.0
30						0	0	1	1	2	1	97.3
31						0	0	1	1	0	0	
32						0	0	0	0	0	0	
33						0	1	0	0	0	1	97.6
34						0	0	0	0	0	0	
35						1	0	1	0	1	1	97.9
36						0	0	0	0	0	0	
37						0	0	0	0	0	0	
38						1	0	0	0	0	0	
39						1	0	0	0	0	0	
40							0	0	0	1	1	98.2
41							0	1	0	0	0	
42							0	0	0	0	0	
43							0	0	1	0	0	
44							1	0	0	0	0	
45							1	0	0	0	0	
46								1	1	2	0	
47								0	0	0	1	98.5
48								0	0	0	0	
49								0	0	0	0	
50								0	0	0	0	
51								0	0	0	1	98.8
52								0	0	0	0	
53								0	0	0	1	99.1
54								0	0	0	0	
55								1	0	0	0	
56									0	0	0	
57									0	1	1	99.4
58									0	0	0	
59									0	0	0	
60									0	0	0	
61									1	0	0	
62									0	0	0	
63									0	0	0	
64									0	1	1	99.7
65									0	0	0	
66									0	0	0	
67									1	0	0	
68										0	0	
69										0	0	
70										0	0	
71										0	0	
72										1	1	100
73												

Table 2

INDEPENDENT SCATTERING CENTER DATA (MONTE CARLO EXPERIMENT)

No. Pairs of Coordinates	Number Overlapping Particles	Fraction Plotted	No. Independent Scattering Centers
1580	180	0.20	506
1669	199	0.21	501
1758	218	0.22	491
1841	231	0.23	481
1924	244	0.24	459
2012	262	0.25	443
2110	290	0.26	412
2210	320	0.27	403
2317	357	0.28	390
2417	387	0.29	374
2552	422	0.30	340

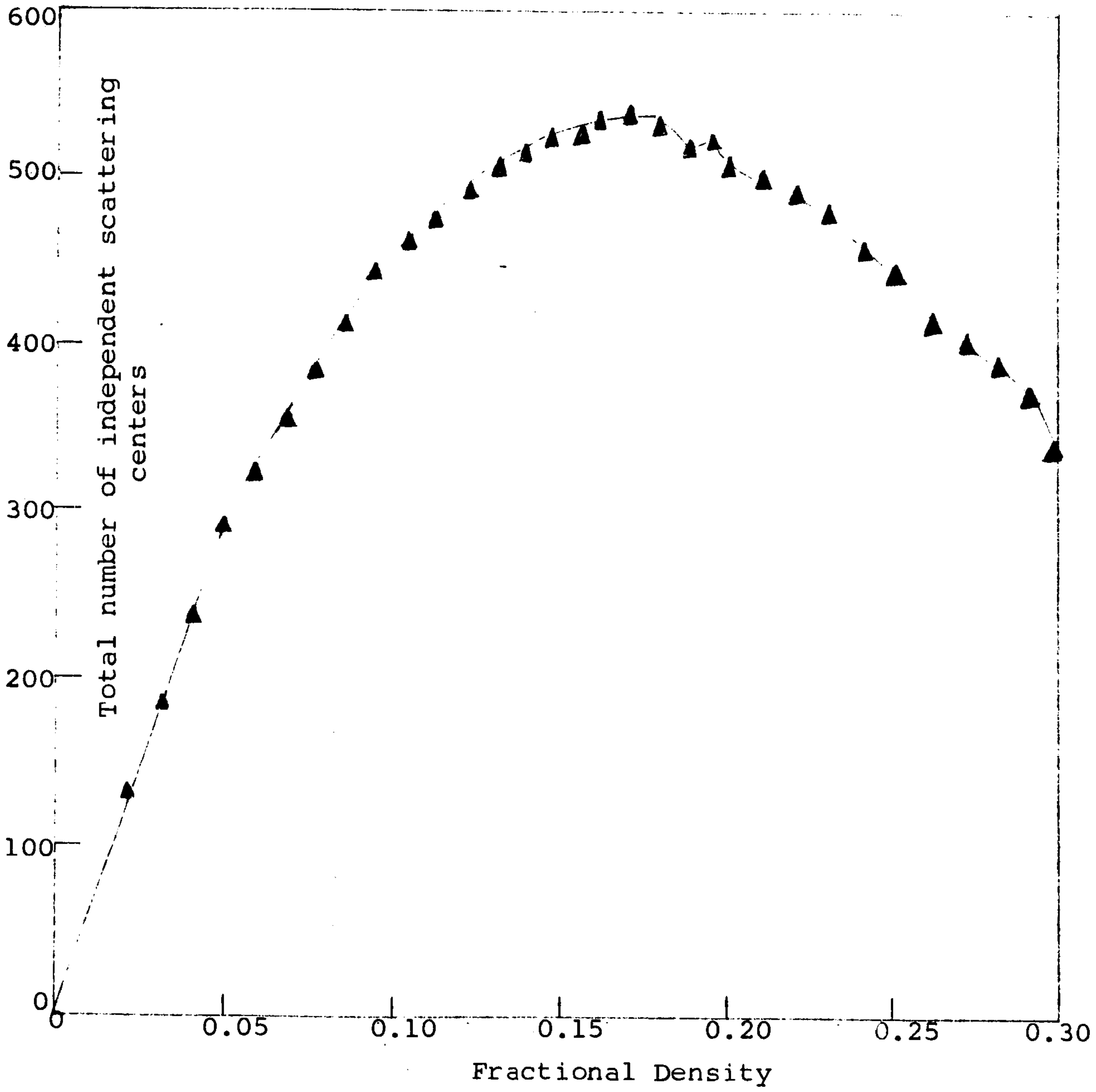


Figure 5

ABSOLUTE NUMBER OF SCATTERING CENTERS PER UNIT VOLUME

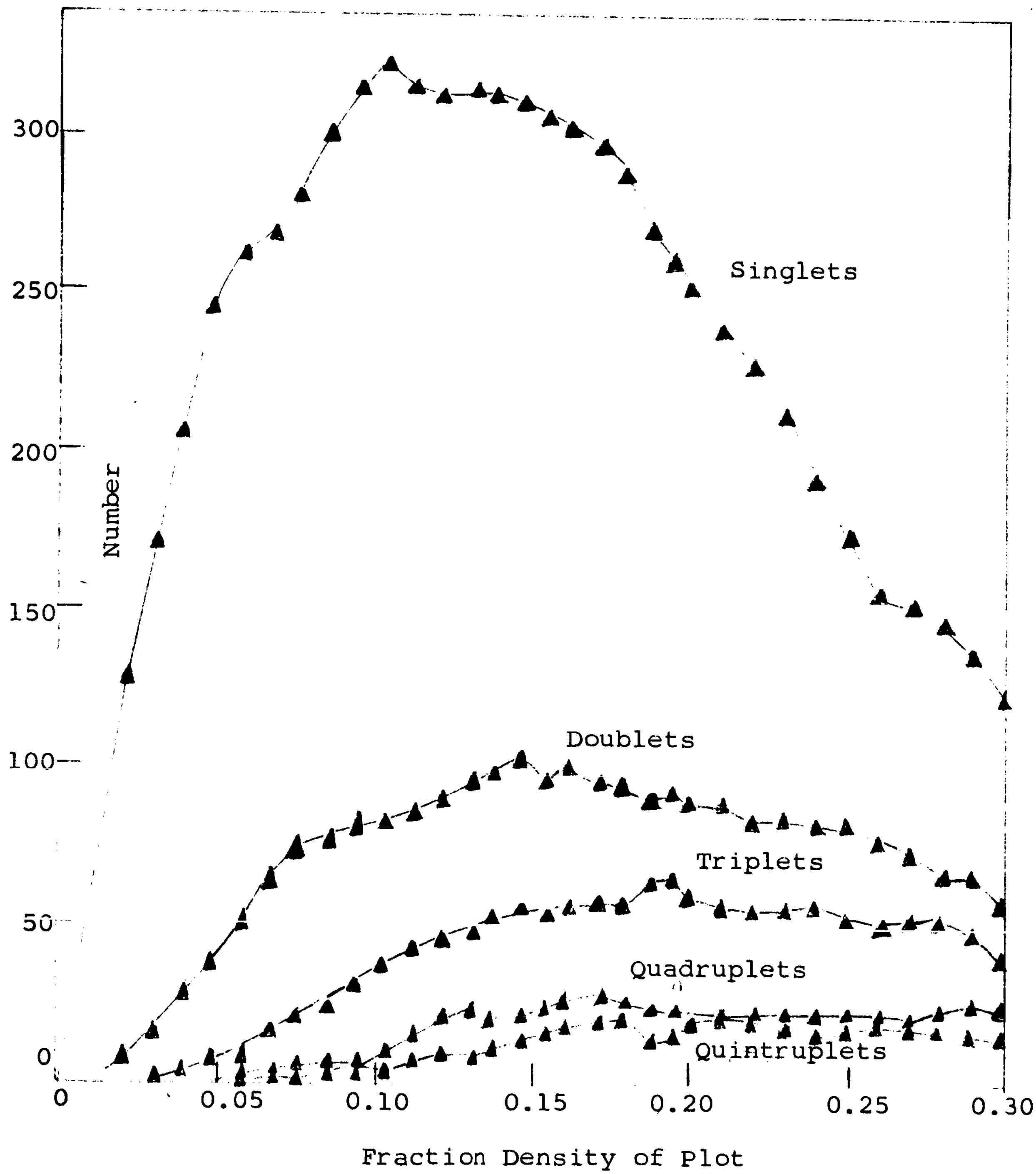


Figure 6

NUMBER OF DIFFERENT SIZED CLUSTERS AT VARIOUS VOLUME CONCENTRATION IN MONOSIZED BLOCK MONTE CARLO EXPERIMENT

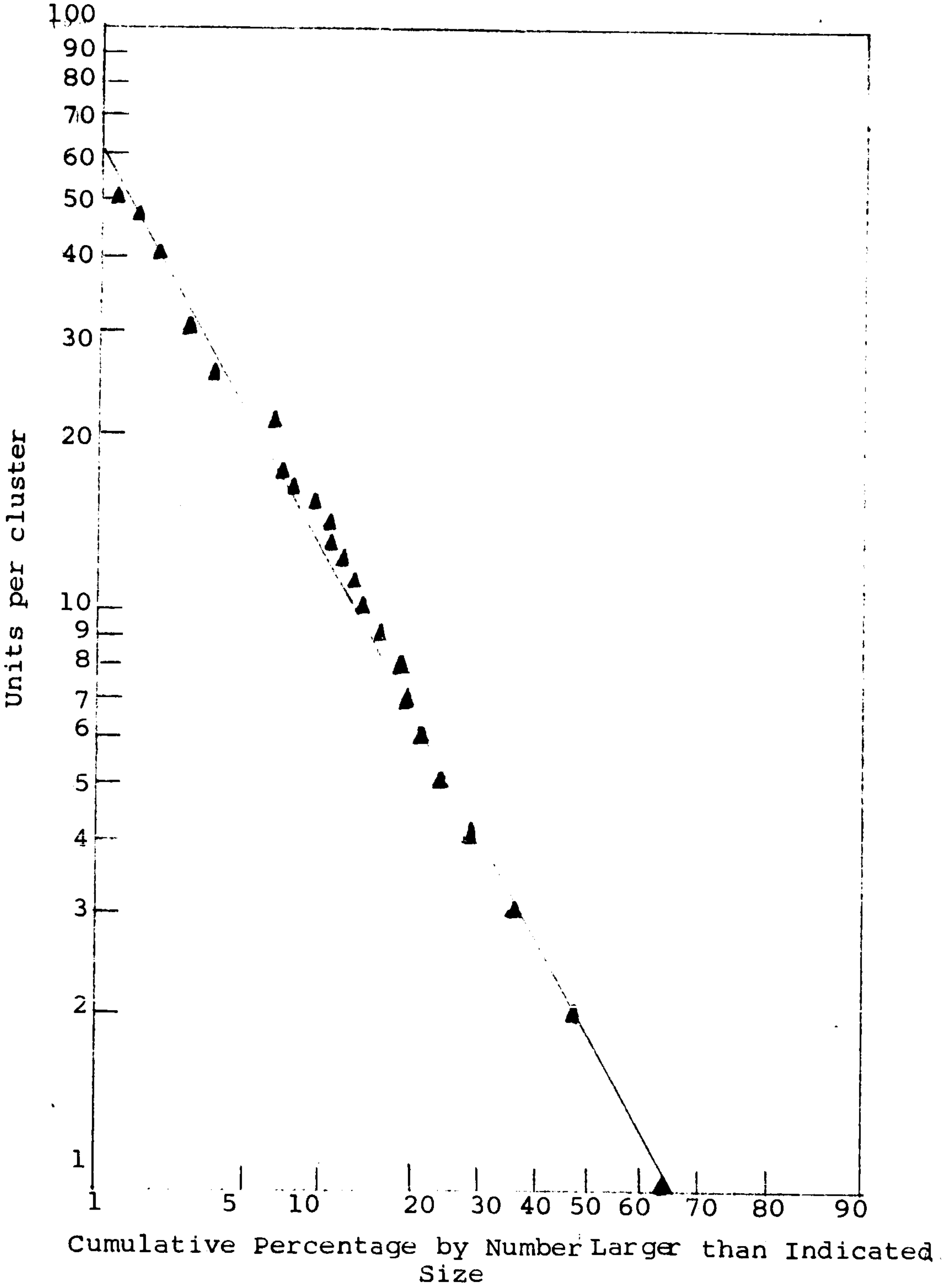
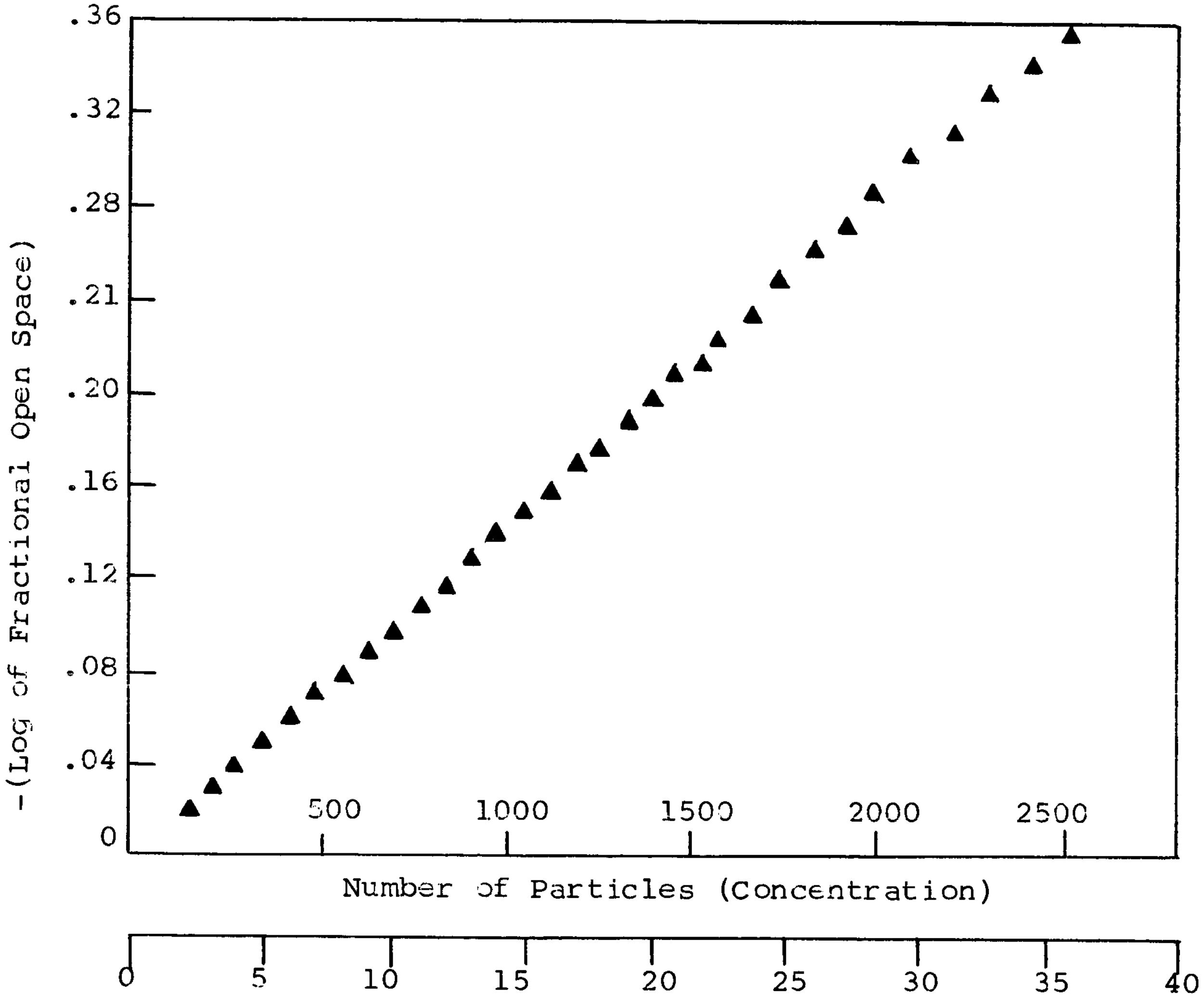


Figure 7

SIZE DISTRIBUTION OF CLUSTERS FORMED IN BLOCK PLOTTING EXPERIMENT AT 30% DENSITY



Percentage Coverage Achieved if no Overlapping Occurred

Figure 8

PLOT OF - (LOGARITHM OF FRACTIONAL OPEN SPACE)
AGAINST TOTAL NUMBER OF PARTICLES

IV. ADDITIONAL IMPLICATIONS OF MONTE CARLO STUDIES

A. Metal-Filled Conducting Paint Films

In the development of micro-circuitry, paints have been developed which are filled with metal particles so that at suitable volume concentrations the paint film can conduct electricity. The Monte Carlo plotting experiment can be used to gain an understanding of the development of conducting paths within the paint film. At the higher concentrations used in the Monte Carlo experiment it is difficult to locate the developing clusters within the general density of particles on the graph paper. In Figures 9 through 12 the larger clusters which had developed at 27 to 30% by volume concentration are outlined. The extent and configuration of the cluster is shown by the line traced through the individual particles. The smaller clusters have been omitted for clarity and no attempt has been made to show all clusters on each of the four diagrams. A detailed description of the clusters growth is given in Table 3. The property of this system which is of special interest in predicting electrical properties is the attainment of a continuous path through the unit volume and how many paths exist at any higher concentration. The maximum volume concentration considered so far is not sufficient for continuous paths to be formed but from Figure 12 the distribution of equivalent linear paths which exist at this volume concentration can be calculated by measuring the projected length of the cluster in a given direction. In Tables 4 and 5,

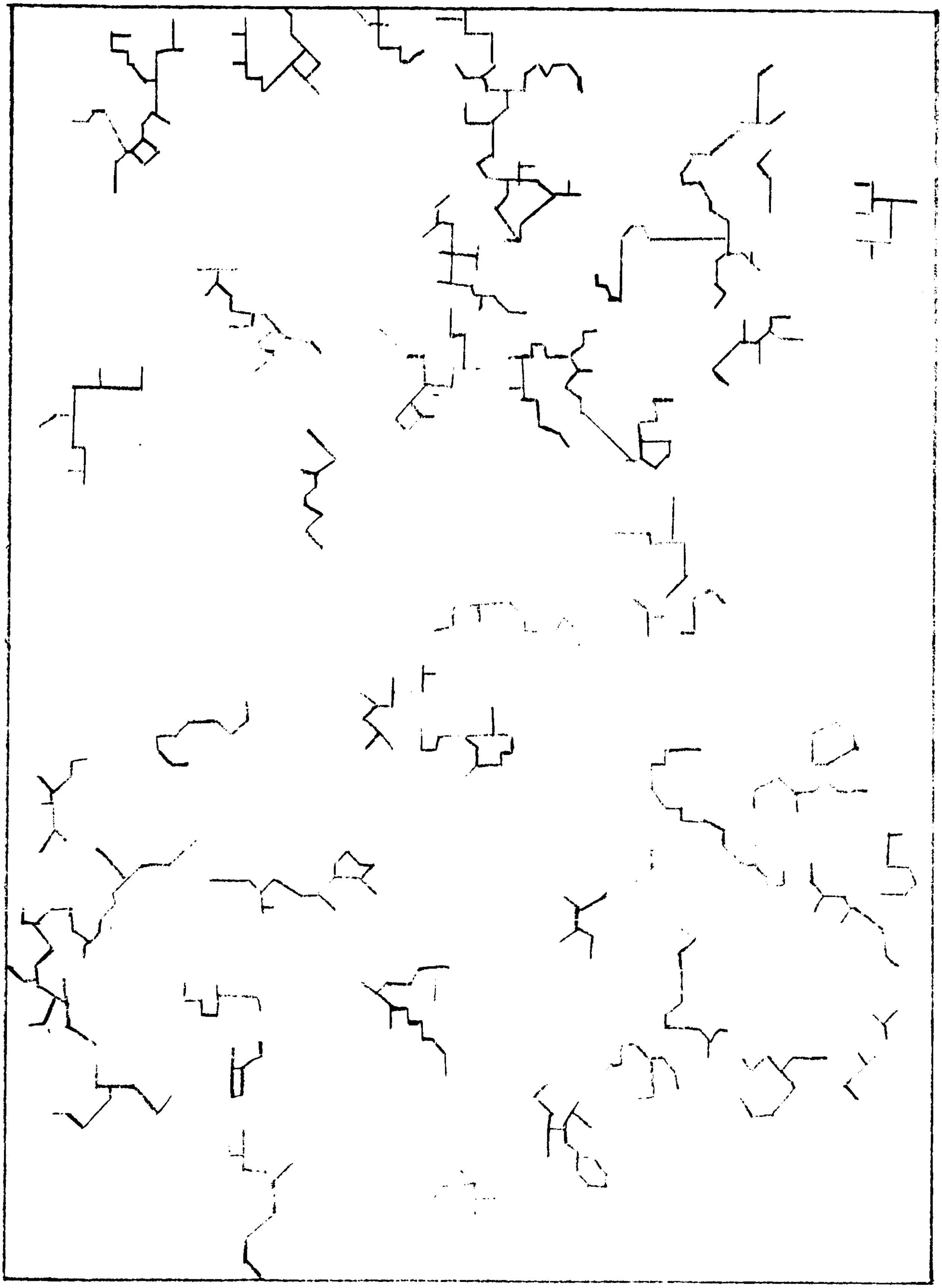


Figure 9

CLUSTERS DEVELOPED AT 27% VOLUME CONCENTRATION

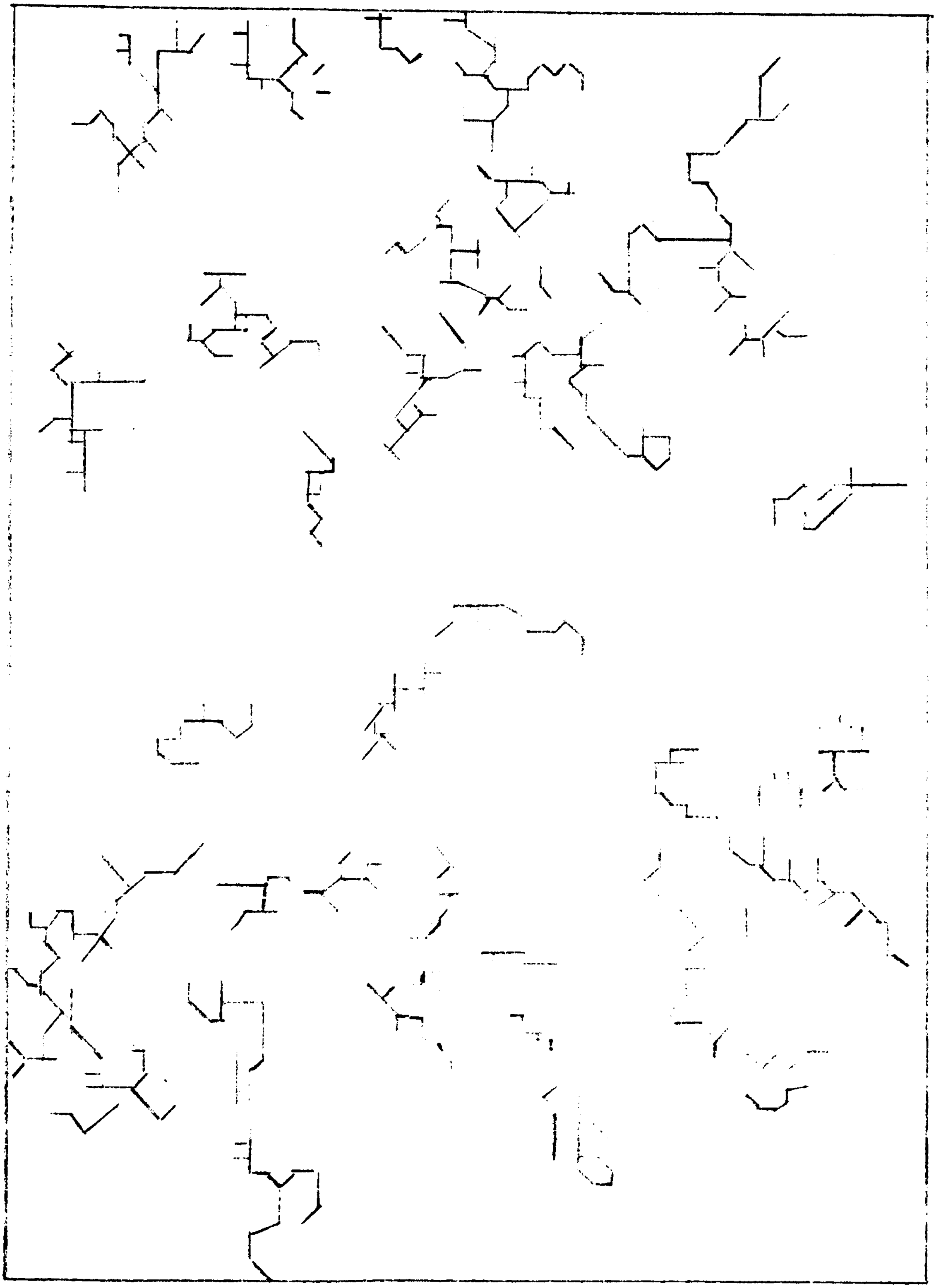


Figure 10

CLUSTERS DEVELOPED AT 28% VOLUME CONCENTRATION

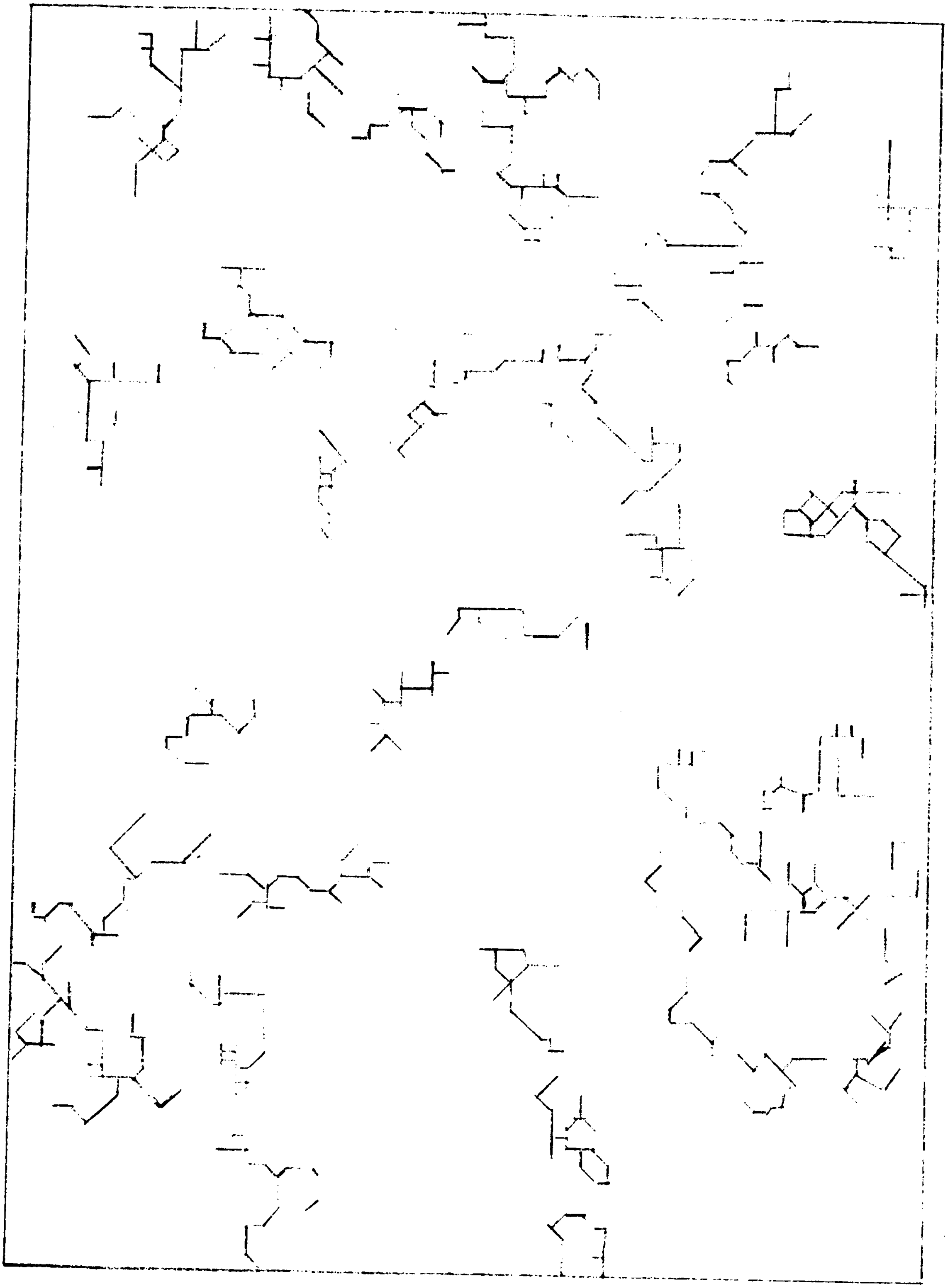


Figure 11

CLUSTERS DEVELOPED AT 29% VOLUME CONCENTRATION

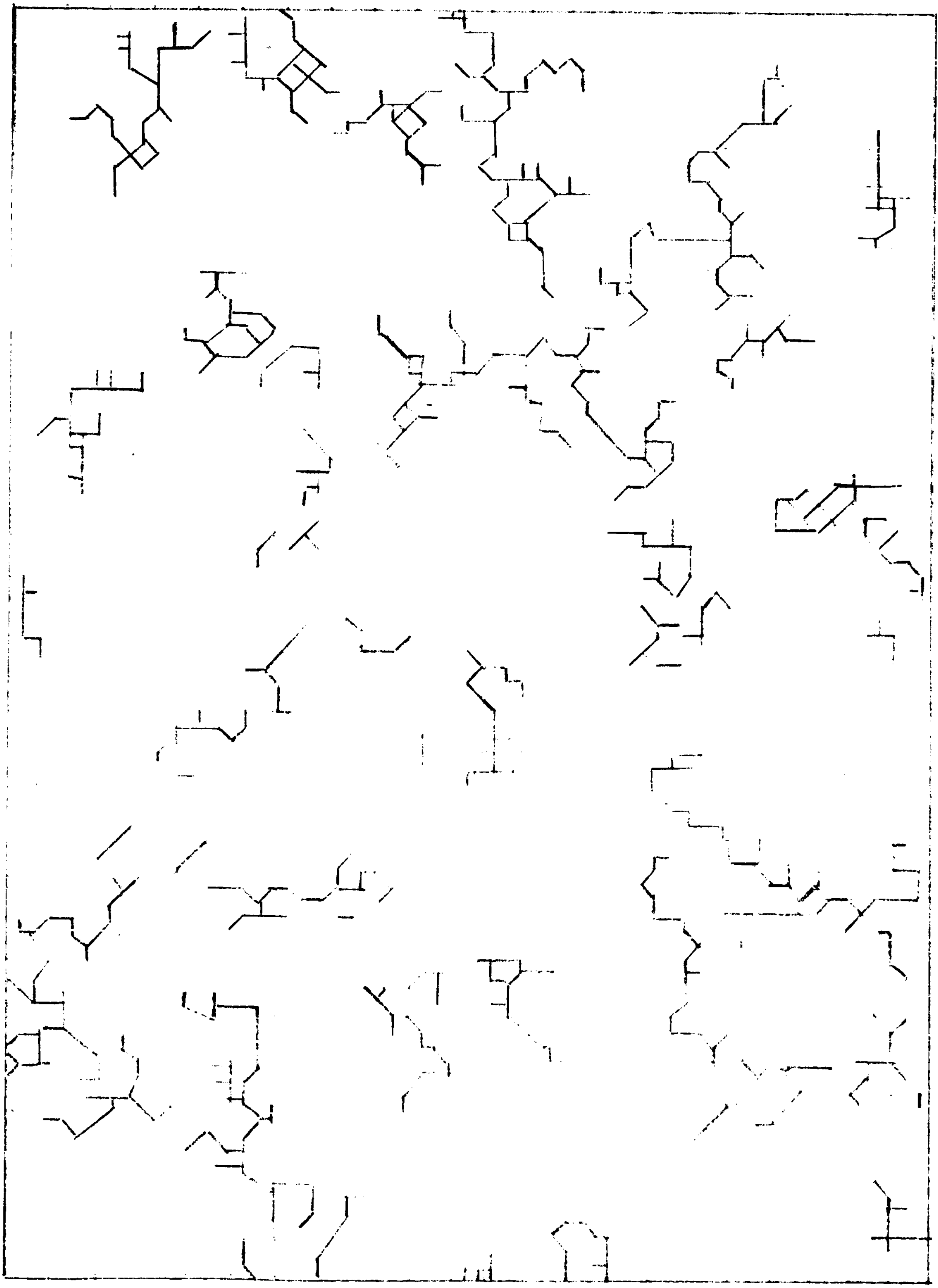


Figure 12

CLUSTERS DEVELOPED AT 30% VOLUME CONCENTRATION

Table 3

COMBINED VERTICAL AND HORIZONTAL SPAN LENGTH DATA FOR CLUSTERS

Span	Cumulative percent number at 0.30 Concentration
1	18.0
2	42.6
3	58.6
4	68.6
5	76.4
6	82.6
7	85.2
8	88.6
9	91.2
10	93.0
11	95.0
12	95.6
13	96.0
14	96.4
15	96.6
16	97.2
17	97.8
18	97.8
19	98.2
20	98.2
21	98.8
22	99.8
23	99.8
24	100.0

Table 4

HORIZONTAL SPAN LENGTH DATA FOR CLUSTERS FORMED IN MONTE CARLO EXPERIMENT

Span	Number of Clusters Having Stated Span at Fractional Concentrations											Cumulative % No. @ 0.30 Concentration
	.20	.21	.22	.23	.24	.25	.26	.27	.28	.29	.30	18.0
1	274	270	258	143	117	104	82	78	70	61	45	46.0
2	113	106	101	102	108	101	94	93	86	84	70	63.2
3	53	53	53	52	51	55	57	56	55	49	43	71.6
4	24	25	29	28	28	25	21	20	23	20	21	78.8
5	15	17	18	21	22	23	26	18	16	17	18	84.4
6	13	12	13	12	9	10	11	14	12	13	14	86.4
7	7	8	8	10	12	12	11	11	11	10	5	91.6
8	3	4	6	7	6	6	8	7	9	9	13	93.2
9	1	2	2	2	1	1	2	4	3	4	4	96.8
10	1	2	2	2	3	3	3	5	6	5	9	98.0
11				1	1	2	2	3	3	3	3	98.4
12					1	0	0	1	2	2	1	98.8
13					1	1	1	0	0	0	1	99.0
14						1	1	1	1	1	1	99.2
15								1	0	0	0	99.2
16									1	1	1	99.6
17									0	0	0	99.6
18									0	0	0	99.6
19									0	1	1	99.8
20									0	0	0	99.8
21									1	1	1	100.0

Table 5

VERTICAL SPAN LENGTH DATA FOR CLUSTERS FORMED IN MONTE CARLO EXPERIMENT

Span	Number of Clusters Having Stated Span at Fractional Concentrations											Cumulative % No. @ 0.30 Concentration
	.20	.21	.22	.23	.24	.25	.26	.27	.28	.29	.30	18.0
1	277	272	258	141	124	103	82	80	71	62	45	39.2
2	103	102	96	96	88	95	77	72	64	62	53	56.0
3	59	56	59	59	63	57	56	57	57	53	42	65.6
4	24	22	25	24	21	25	24	21	25	23	24	74.0
5	16	19	17	24	25	26	27	24	23	19	21	80.8
6	11	13	15	16	17	15	13	12	12	15	17	84.0
7	6	8	10	8	10	10	15	11	10	9	8	85.6
8	0	0	1	3	3	2	2	5	5	4	4	89.2
9	3	3	4	5	5	7	7	7	7	11	9	90.8
10	2	1	0	0	0	0	0	1	2	1	4	52.0
11		0	1	1	1	2	2	3	3	3	3	92.8
12		0	0	0	0	0	0	0	0	0	2	93.2
13		0	0	0	1	0	1	1	1	1	1	93.6
14		0	0	0	0	0	0	1	2	2	1	94.0
15		1	1	1	0	1	0	1	1	1	1	94.6
16					1	0	1	2	2	2	2	95.2
17					1	2	2	3	3	4	3	96.6
18								1	1	1	0	96.6
19								0	0	0	1	96.8
20								0	0	0	0	96.8
21								1	1	1	2	98.0
22											0	98.0
23											0	98.0
24											1	100.0

the projected cluster length on the horizontal and vertical axis are given. The distribution of these cluster lengths are given in Figure 13. It can be seen that, as can be anticipated from statistical properties of randomly distributed systems, the distribution of lengths is the same in each direction. In Figure 14, the two sets of data from Figure 13 have been combined to form the best estimate of the equivalent linear path lengths distribution, and this distribution will describe projections in any direction provided that a sufficiently large number of clusters are considered. This graph can be used to study the properties of paint film in the following manner. If we have two paint films of thickness n_1 and n_2 pigment diameters, then from Figure 14 the ratio of the probabilities of straight through paths for the two films should be the ratio of the conductances of the two films. From the expected fluctuation in any given probability of occurrence it should be possible to predict fluctuations in conductances of films of the same thickness and area and for films of different area. This concept will be developed more fully in the next report when data for higher concentrations are available. In Figures 15 and 16 are given the number of clusters which span up to six diameters at various values of the volume concentration.

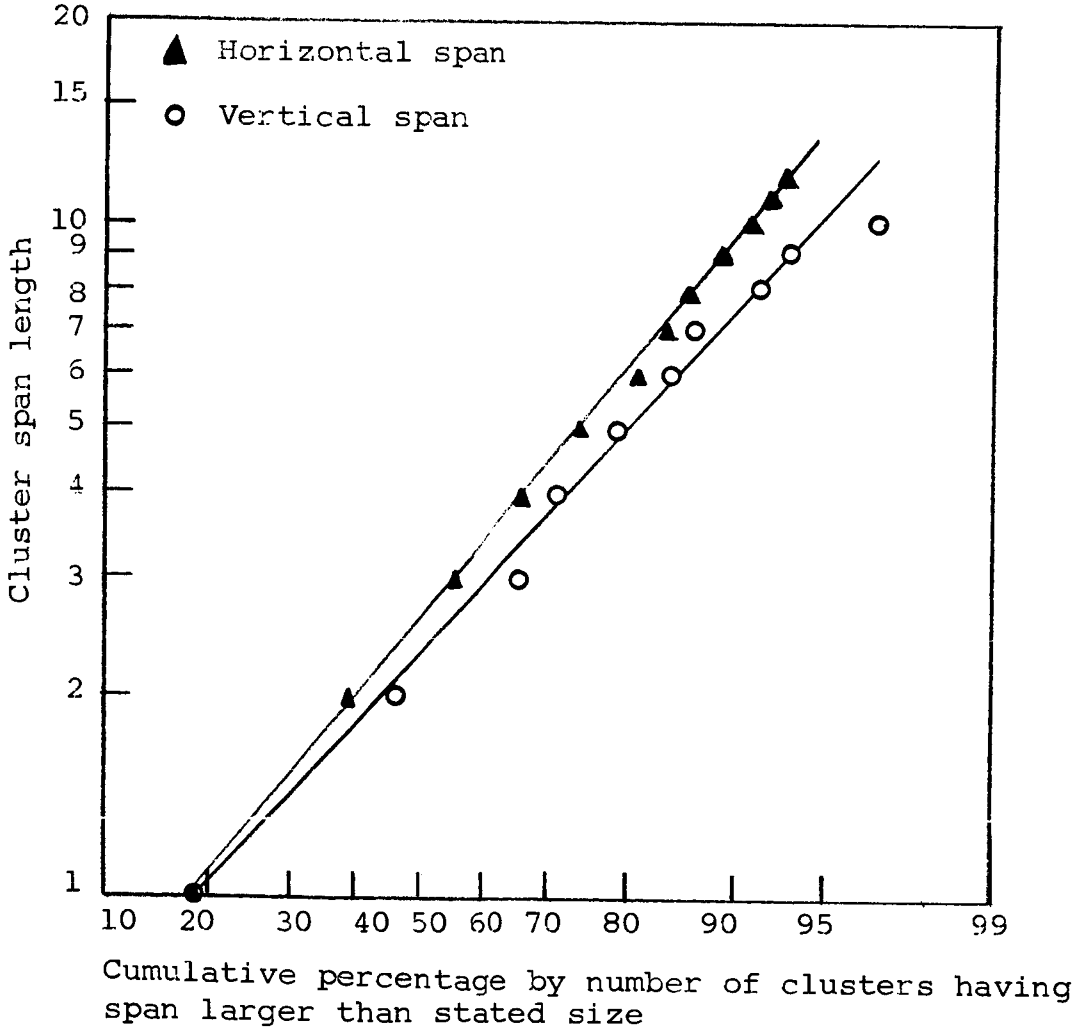


Figure 13

NUMBER DISTRIBUTION OF HORIZONTAL AND VERTICAL CLUSTER SPAN LENGTHS

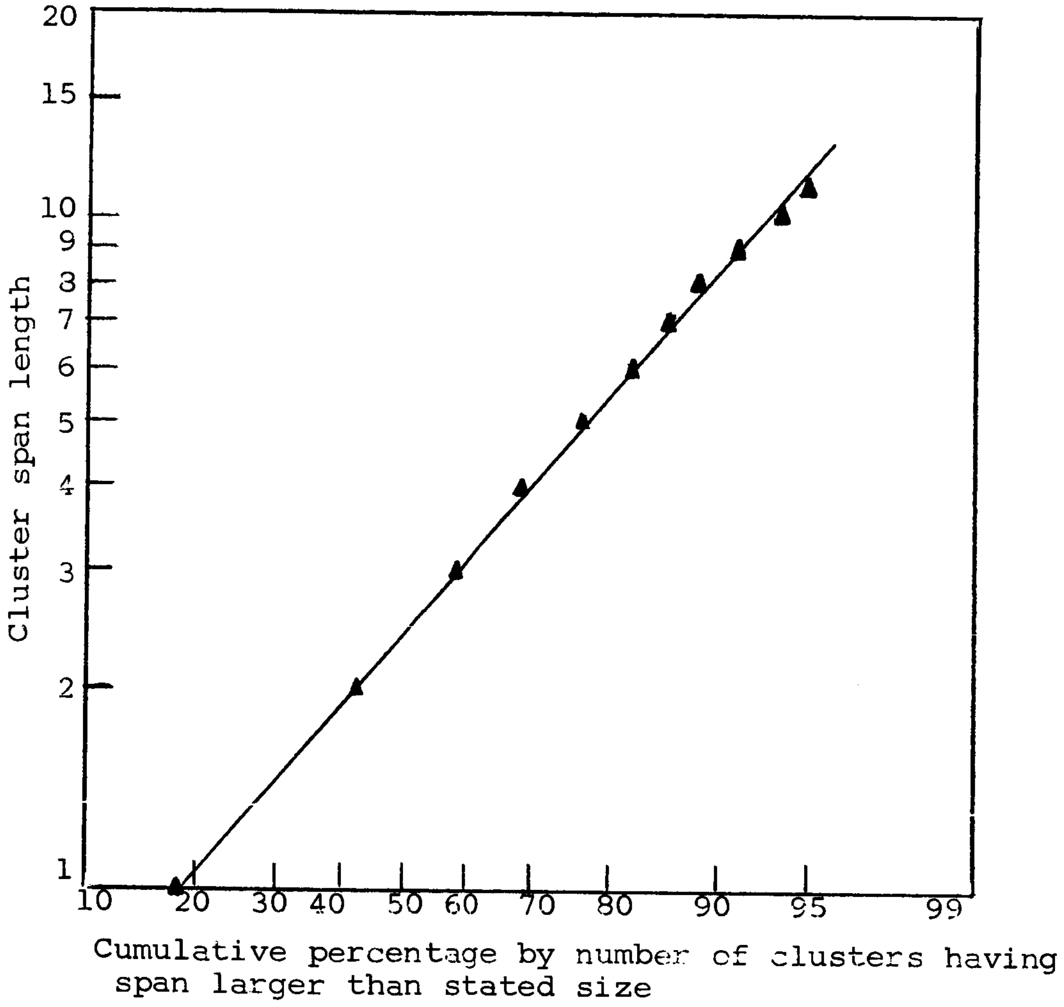


Figure 14

NUMBER DISTRIBUTION OF HORIZONTAL AND VERTICAL CLUSTER SPAN LENGTHS

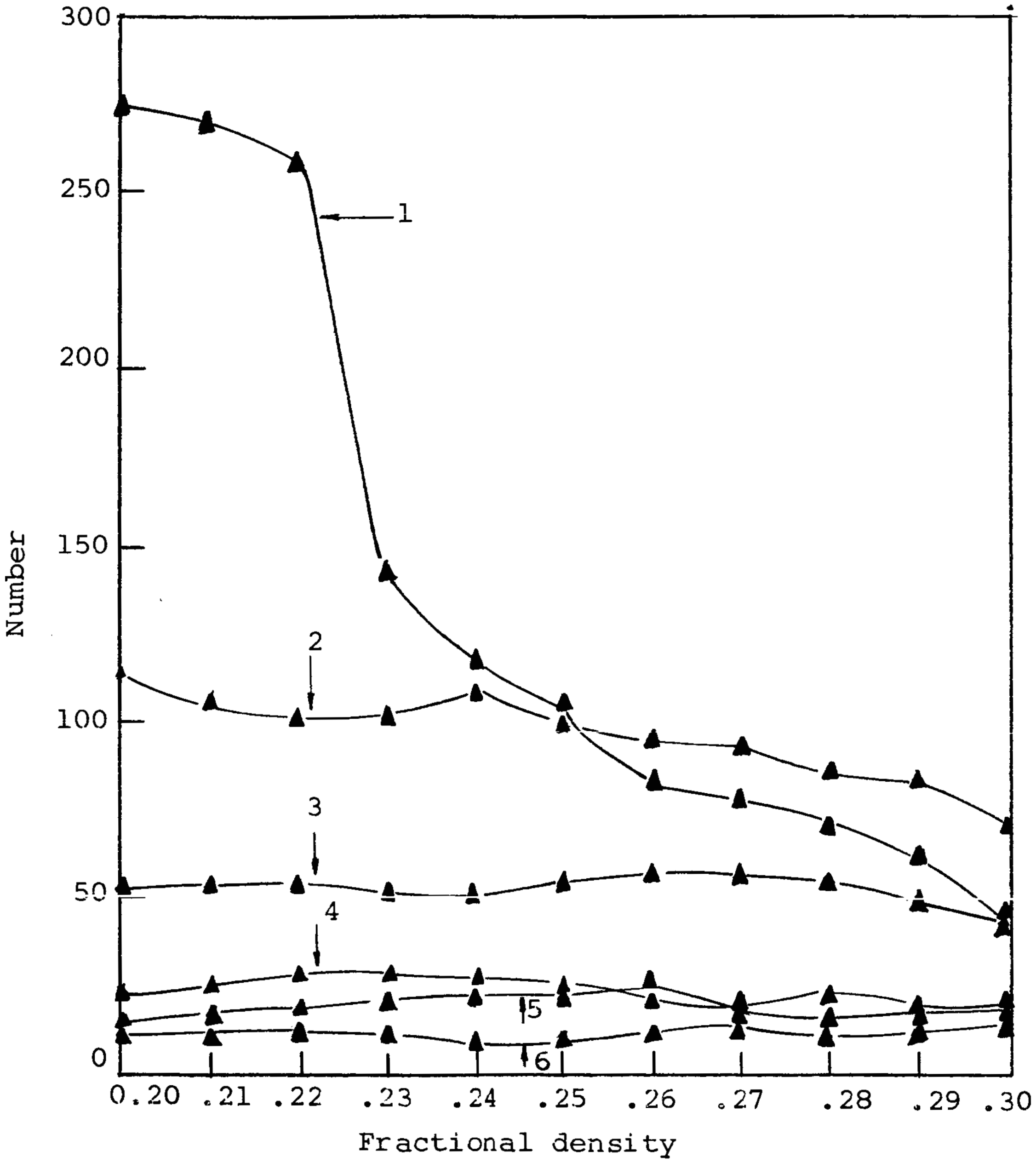


Figure 15

DISTRIBUTION OF HORIZONTAL SPAN OF CLUSTERS
EXPRESSED IN PARTICLE DIAMETERS

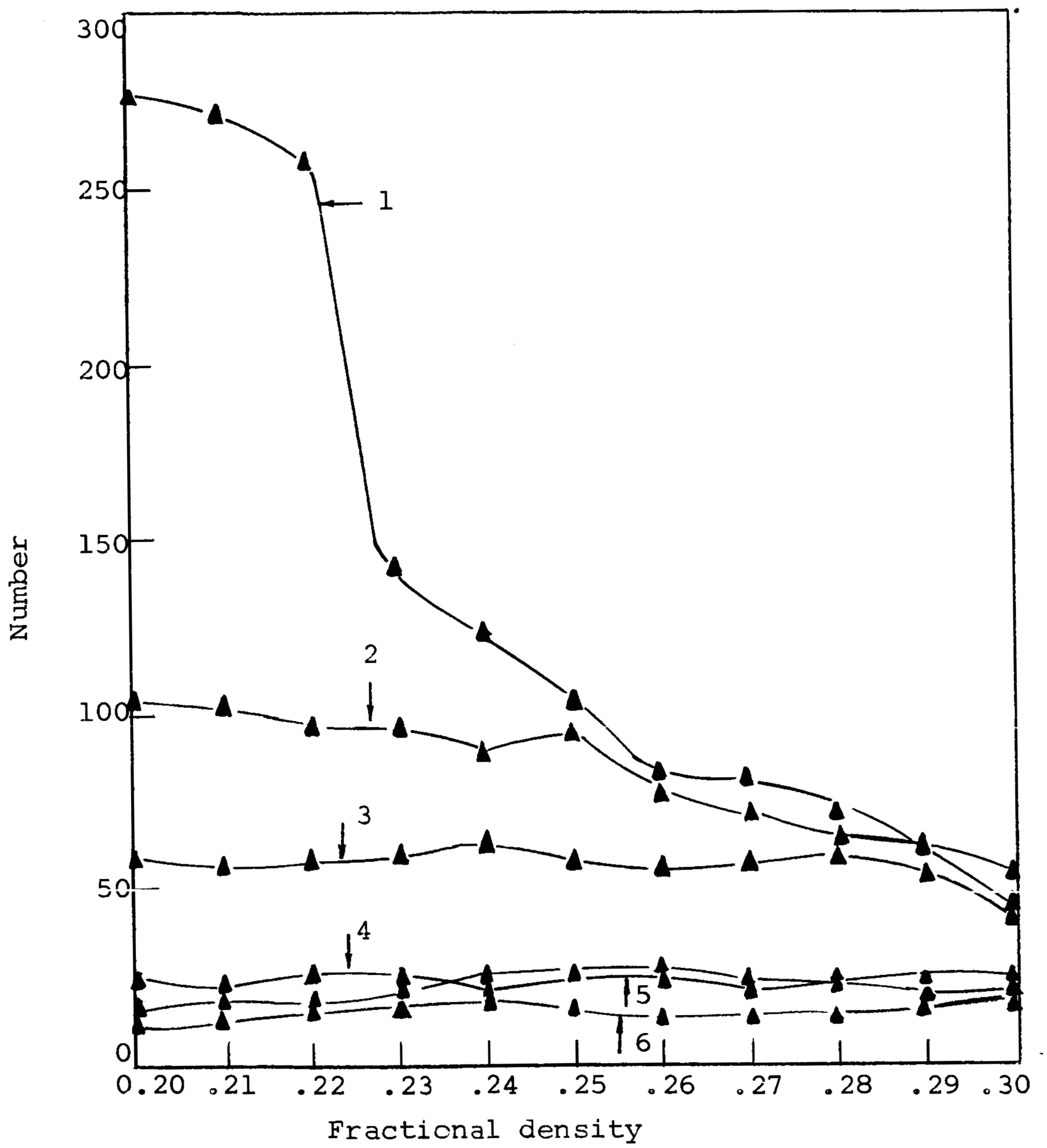


Figure 16

DISTRIBUTION OF HORIZONTAL SPAN OF CLUSTERS
EXPRESSED IN PARTICLE DIAMETERS

B. Filtration Theory

1. Fibrous Filters

Some filter systems are made by assembling in a random manner an array of fibers. The random intercepts drawn in Figures 1 through 4 can be considered as unit elements in a filter composed of randomly assembled fibers. The fact that the systems drawn by Method A and Method B can both satisfy the definition random and yet have different physical properties shows the inadequacy of much current terminology in filtration theory.

Two major mechanisms are used to capture particles passed through a filter. These are:

1. Direct obstruction to the passage of a particle by the pore system of the filter
2. Capture of the particle by single fibers when the particles impact onto the fiber.

For both these mechanisms, random fibers assembled to form systems analogous to those constructed by Method B will be more efficient since for this system the pore distribution has smaller probability for the larger apertures and has more fiber per unit area when captured by the second mechanism.

The effective pore size distribution for the fiber simulation systems for Figures 1 through 4 were measured using the graticule shown in Figure 17. The largest circle which could be placed in any aperture defined by the random fibers was defined as the effective pore size for the passage of spherical particles

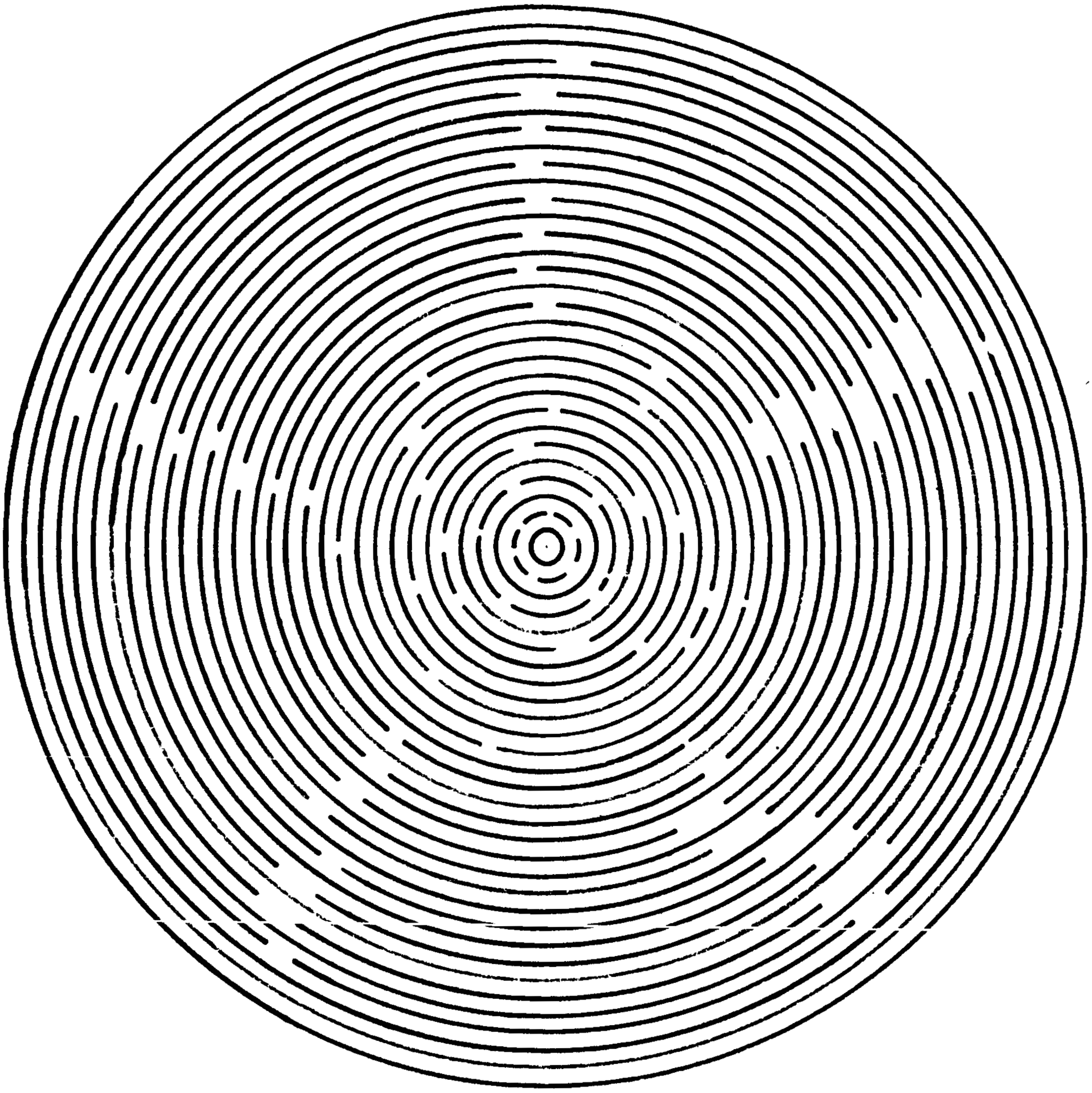


Figure 17

GRATICULE FOR DETERMINING PORE SIZE

through the filter. The size distributions measured for the systems in Figures 1 through 4 are given in Figures 18 through 21, respectively. It will be noted that the number of apertures for systems drawn by Method A are 70, 80, 70 and for the system drawn by Method B is 109. It will also be noted that the pore structure is quite different for the system constructed by Method B. If it were desired to simulate fiber systems in this way the effect of the fiber diameter can be taken into account by decreasing the radius of the circle considered able to pass through the simulated aperture by the magnitude of the fiber diameter. If a filter mat is constructed by allowing relatively short fibers to fall into position the randomness of the fiber system will be analogous to system B since this corresponds to the equal probability of all points in the plane of imposition having a line through them. If, however, long fibers are assembled so that the density of fibers at the perimeter is uniform the fibrous system is analogous to system A for a circular perimeter.

The fact that the two systems, each of which can be defined as random in a technical sense, have different properties, suggests that it may be possible to make major advances in filtration theory by considering the exact meaning of randomness in a fiber system and devising techniques for achieving a random system with optimum properties.

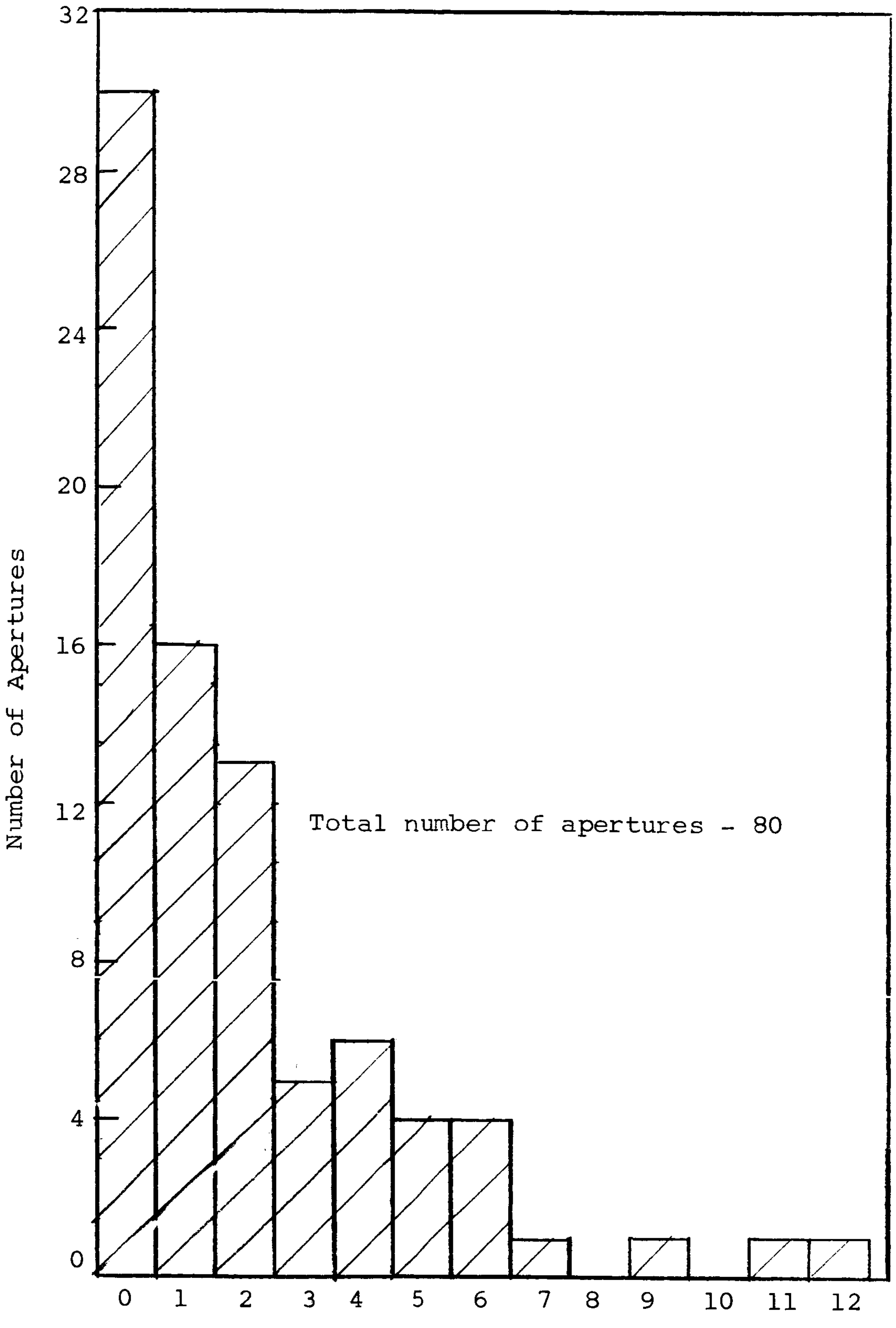


Figure 18
PORE SIZE DISTRIBUTION OF SIMULATED FILTERS (Figure 1)

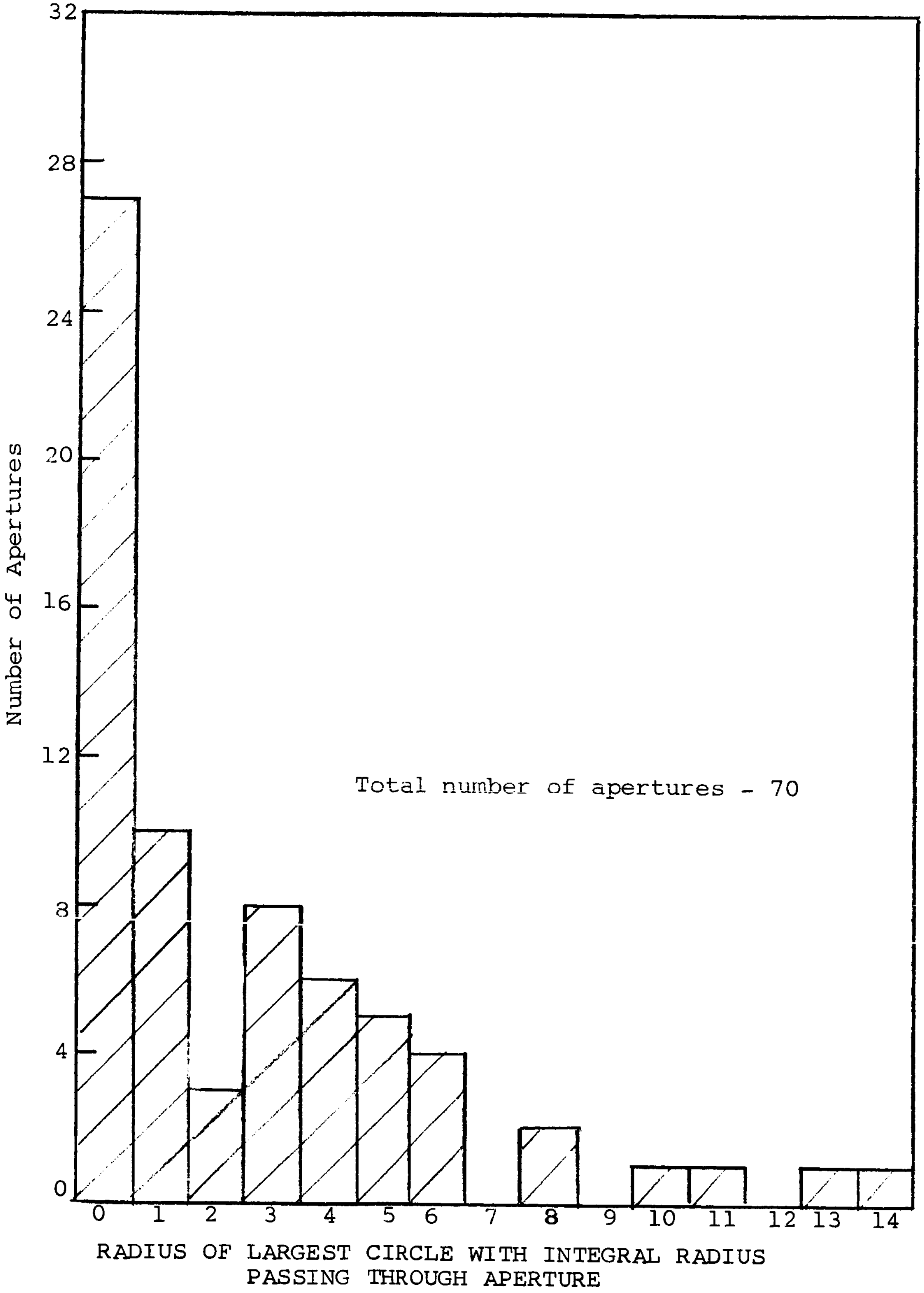


Figure 19
PORE SIZE DISTRIBUTION OF SIMULATED FILTERS (Figure 2)

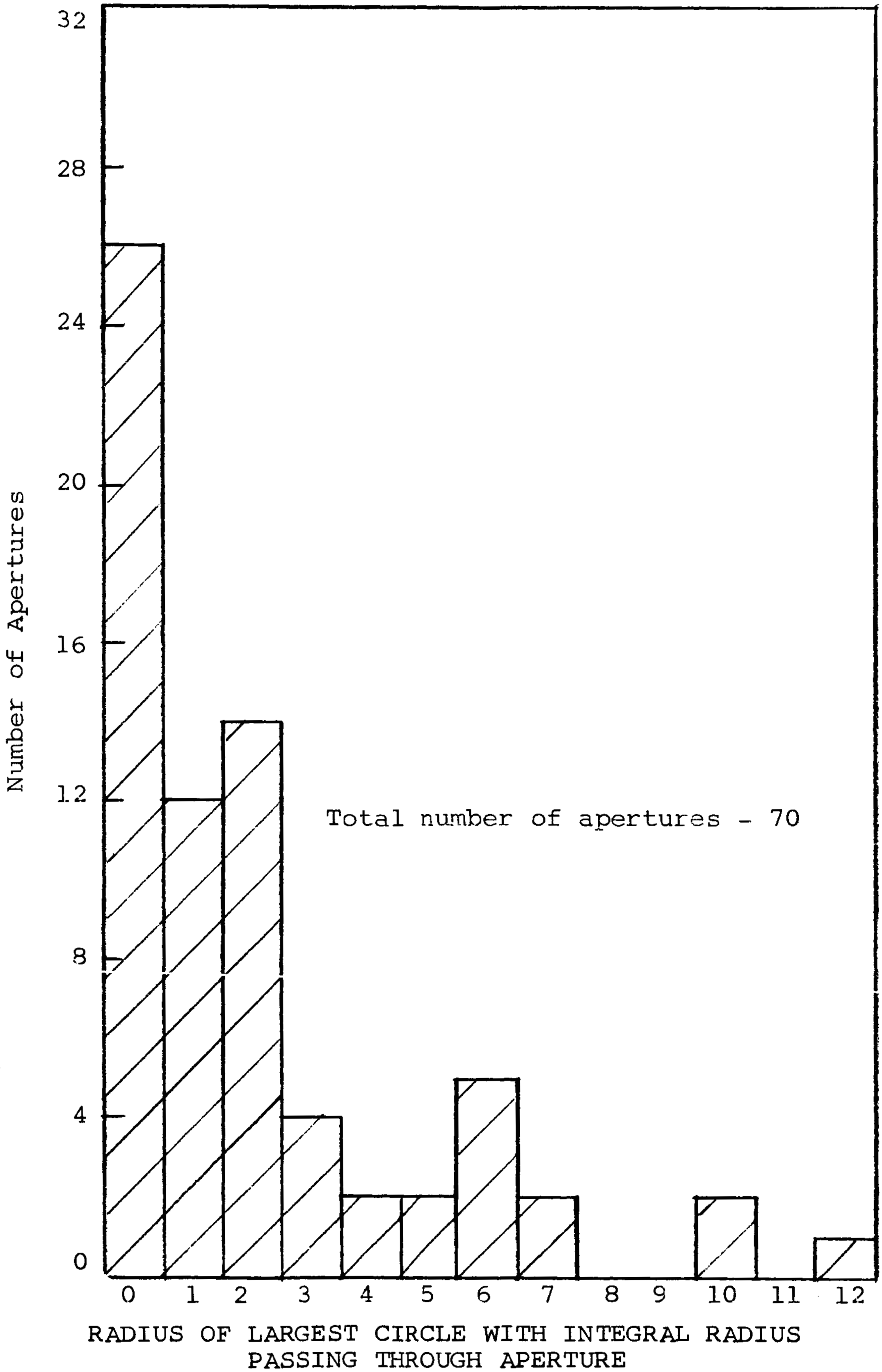
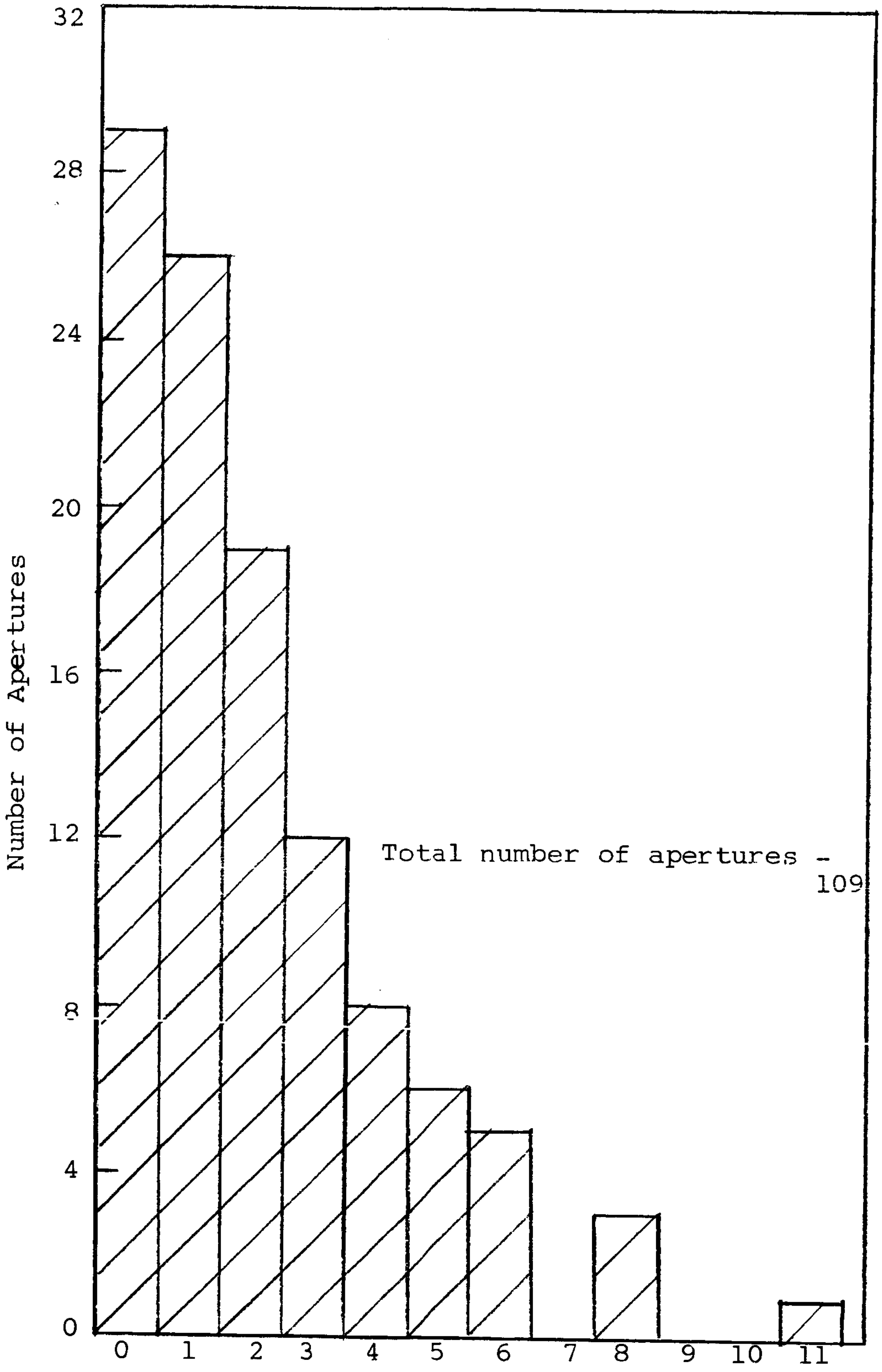


Figure 20

PORE SIZE DISTRIBUTION OF SIMULATED FILTERS (Figure 3)



RADIUS OF LARGEST CIRCLE WITH INTEGRAL RADIUS PASSING THROUGH APERTURE

Figure 21
PORE SIZE DISTRIBUTION OF SIMULATED FILTERS (Figure 4)

2. Use of Random Intercept Diagrams to Devise Monte Carlo Methods for Studying Aerosol Filtration Problems

The prediction of the performance of any filtering device is complicated because of the many variables which have to be taken into account when constructing an appropriate theoretical system. Many workers have chosen to study the various factors which are known to influence filter performance in isolation. Thus effects due to the fow conditions or to the electrostatic forces are studied separately. It is difficult to asses the usefullness of these studies to actual filtration systems because of the subtile way in which these variables interact. One way of studying the behavior of complex interacting systems is to construct an abstract model in which the major variables have been simulated and which can be used to predict the orders of importance of the various mechanisms by using the model as a basis for a Monte Carlo experiment. In a Monte Carlo routine a succession of events are simulated using the abstract system and the behavior of the model as it undergoes these successive events is studied.

Consider the system of Figure 1 to be a set of simulated films for a given filter system. To simulate particle capture we now use another transparent sheet of paper on which a random set of particle profiles is fixed by the postulated characteristics of the distribution of particles in an air stream. This simulated set of particles can be placed on top of the fibers in many positions and the probability of capture simulated. In this way the effect of the interaction of a random stream of particles encountering random fibers can be predicted. The effect of the fiber diameter can be simulated by drawing a dotted line at a distance of half a fiber width around the particle profile. This has been illustrated for several particles in Figure 22. It is often useful to think of particles pursuing a random walk through the fiberous system. Thus, imagine a composite filter to consist of many sections like those of Figure 1 in series with each other. Imagine we wanted to predict how many filter sections would be required to capture all the particles of Figure 22. We could have a series of drawings like that of Figure 1 each of which could be placed on top of Figure 22 in many random orientations and the experiment could be repeated until all particles were captured. Each super-position of the simulated fiber system would be a step in the random walk of the particles through the filter.

The concepts of the above discussion can obviously be extended to any system of fibers either the regular pattern of a woven cloth or the orientation of the bristles on a brush filter. It is even possible to simulate the effect of rotary motion. For instance in the case of the system shown in Figures 1 through 4, the fiber system could be rotated a definite distance simulating the movement occuring for a given movement of air steam through the system and the increased capture rate studied.

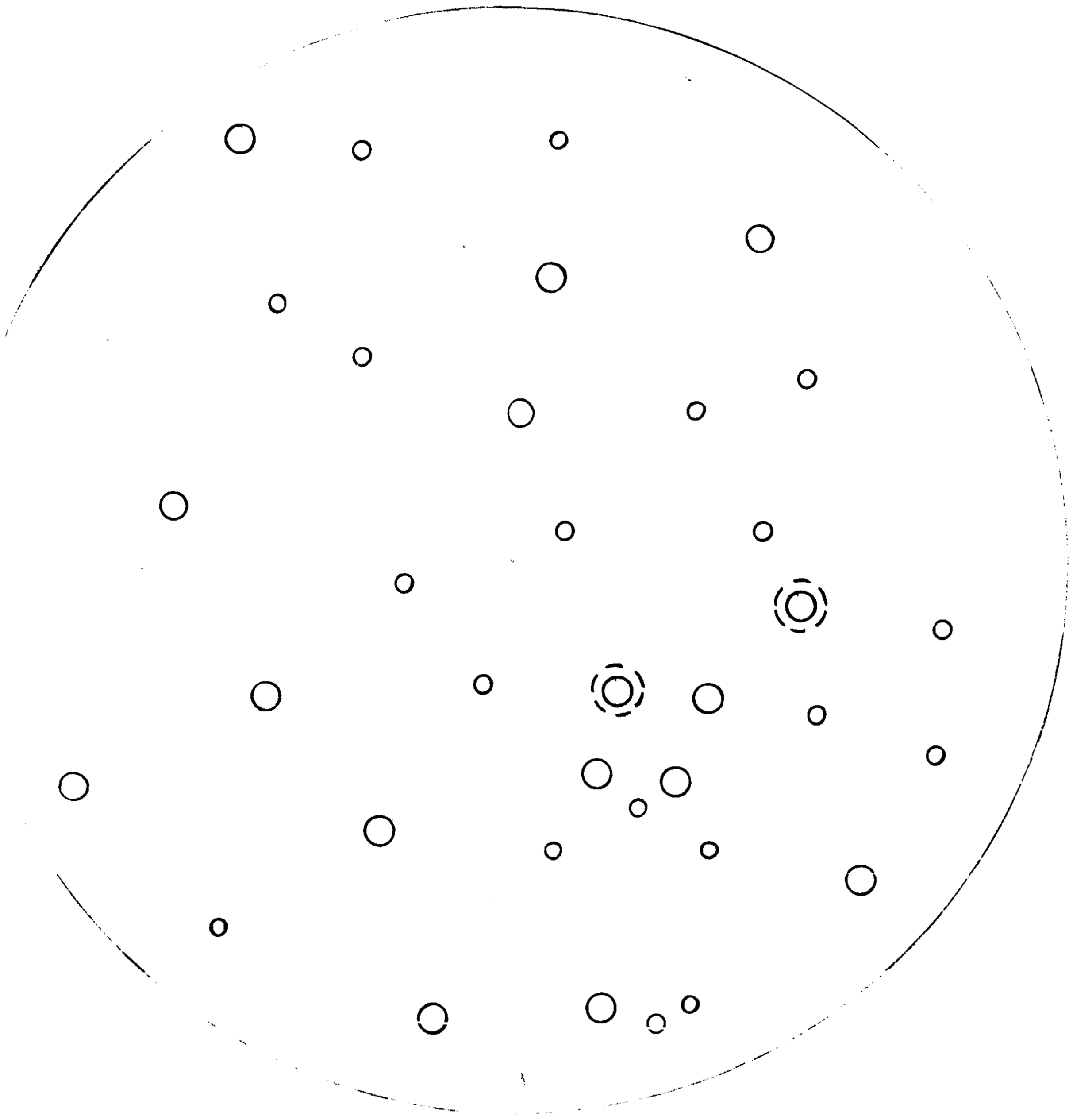


Figure 22

SIMULATED RANDOM ARRAY OF PARTICLES
IN AN AIR STEAM

---- denotes encounter diameter

It is anticipated that the use of Monte Carlo techniques for simulating the random walk of particles through a filter system could be very useful for investigation capture efficiency of various fiber element orientations and the effects of rotation of the filtering mechanisms.

This report is being distributed as follows:

Distribution List:

Copy No.	Recipient
1-25 + reproducible	National Aeronautics & Space Administration Office of Grants and Research Contracts Washington, D. C.
26	Mr. J. J. Gangler National Aeronautics & Space Administration Office of Advanced Research and Technology Washington 25, D. C.
27-30 + reproducible	Mr. D. W. Gates (M-RP-T) National Aeronautics & Space Administration George C. Marshall Space Flight Center Huntsville, Alabama
31	Mr. Conrad Mook Code RV National Aeronautics & Space Administration Washington, D.C.
32	Mr. William F. Carroll Jet Propulsion Laboratory California Institute of Technology 4800 Oak Grove Drive Pasadena, California
33	Mr. Sam Katzoff National Aeronautics & Space Administration Langley Research Center Langley Field, Virginia
34	Mr. Joseph C. Richmond National Bureau of Standards Washington, D.C.
35	Mr. James Diedrich, Mail Stop 7-1 National Aeronautics & Space Administration Lewis Research Center Cleveland, Ohio
36	IIT Research Institute Division U Files
37	IIT Research Institute Editors, J. J. Brophy, Main Files

DISTRIBUTION LIST (CONTINUED)

Copy No.	Recipient
38	IIT Research Institute J. I. Bregman
39	IIT Research Institute B. A. Murray
40	IIT Research Institute Y. Harada, Division G
41	IIT Research Institute J. E. Gilligan, Division U
42	IIT Research Institute S. Katz, Division C
43	IIT Research Institute B. Kaye, Division C
44	IIT Research Institute V. Raziunas, Division C
45	IIT Research Institute M. Jackson, Division C
46	IIT Research Institute G. A. Zerlaut, Division C