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TECHNICAL REPORT
No. 98

COLLECTION EFFICIENCY OF THE ROTOROD FP SAMPLER

F. X. WEBSTER

31 January 1963

U. S. Army Chemical Corps
Research and Development Contract
DA-42-007-CML-543

AEROSOL LABORATORY

METRONICS ASSOCIATES, INC.
STANFORD INDUSTRIAL PARK
PALO ALTO, CALIFORNIA

P134-17

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ABSTRACT

Reported are the results of 28 small-scale field trials run to investigate the collection efficiency of the Rotorod FP sampler, a low-cost impaction sampling device now widely used for the collection of 1-5μ FP atmospheric tracer aerosols. Since the high impaction speed of the Rotorod is essentially constant over a wide range of wind speeds, its collection efficiency is primarily a function of the particle sizes comprising the tracer aerosol to be sampled. From 4-8 trials were run with each of 6 different lots of FP tracer material in order to investigate the dependency of collection efficiency on particle size; the mass-mean diameters (MMD) of these 6 lots ranged from 1.8 - 3.8 microns.

The Rotorod collection efficiency increased from 28 to 69% as the tracer aerosol MMD was increased from 1.8 to 3.8 microns. Within a given trial or series of trials using tracer aerosols having the same or closely similar MMD, the collection efficiency coefficient of variation ranged from a minimum of 0.058 to a maximum of 0.156.

Collection efficiencies obtained with tracer aerosols having particle sizes more nearly representative of those lots which are currently being used in atmospheric diffusion studies ranged from 53% for 2.4 microns MMD to 61% for 3.4 microns MMD.

Graphs are included to show the dependence of Rotorod collection efficiency on either MMD or PPG; for trials using tracer aerosols for which the values of either of these particle size parameters are known, the collection efficiencies to be expected may be estimated from these graphs.

CONTENTS

I. INTRODUCTION AND SUMMARY

A. Objective and Conclusion

One of the specific tasks to be performed under Contract CML-543 was to reinvestigate and define with greater confidence the collection efficiency of the FP collector rod for the Rotorod sampler with the coating technique as employed at Dugway Proving Ground. Prior to the work reported herein the only definitive measurements of the collection efficiency of the FP collector rod as presently used were those made in connection with the original development work.* Since this earlier work involved collection efficiency measurements for several different combinations of collector configuration and surface coating, the number of replicate results obtained with any one combination was necessarily limited. In addition most of these earlier measurements were intentionally made using FP material from a single lot for which the particle size characteristics were fairly well known. This latter experimental limitation was obviously necessary in order that the larger effect of lot-to-lot variations in particle size characteristics would not completely obscure the effects on collection efficiency of the various collector rod configurations and impaction surface coatings then being investigated.

As will be shown presently, lot-to-lot variations in FP particle size accounted for the major portion of the variations in collection efficiency found in the present investigation. Within a given trial in which a suitable lot of FP material and an efficient mode of aerosolization are used, the uncertainty in sampling results due directly to variable Rotorod collection efficiency appears to be no greater than the overall uncertainty inherent in any other mode of aerosol sampling.

This latter statement is in essence the practical conclusion to be drawn from the CML-543 series of Rotorod FP collection efficiency measurements. The detailed experimental data supporting this conclusion, as well as the other subsidiary findings, are presented below in Section III.

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* CML-448 Memorandum Report No. 9, 11 May 1960.

B. Scope and Experimental Procedures

The CML-543 series of collection efficiency measurements consisted of 7 field experiments of 4 trials each (Metronics FE's 134-140). All 28 trials were conducted under essentially fair weather daytime conditions. As the assessment of the collector rods and reference filters from each field experiment was completed the detailed results obtained were then presented in preliminary form in a CML-543 Monthly Progress Report. These data have been rechecked and, together with some minor corrections and a few additional data, are presented in their entirety in this report.

The test procedures used in each trial were essentially as follows: 1) a line source release of FP was made from a hi-speed blower-type aerosol generator mounted on the tail gate of a station wagon which was driven slowly along a route approximately 300 to 750 feet upwind of the nearest sampler, 2) the resulting airborne FP were collected at two separate stations, each of which consisted of a closely-spaced array of Rotorod samplers (RR's) surrounded by reference membrane filter samplers (MF's), and 3) before, during, and following each series of trials the wind speed, direction, temperature, and humidity were continuously recorded at a fixed station at Metronics building--the field test site being located usually not more than a few hundred feet from the building. A typical arrangement of closely-spaced RR's and reference MF comprising each sampling array is shown schematically in Figure 3.

The FP collector rods used were silicone grease-coated for particle retention and were of the current standard design being used at Dugway, namely the H-shaped 60 x 30 x 0.38 mm chromel ribbon collector as shown in Dwg. #A70-3-1061, revision dated 19 May 1961. When rotated at the standard speed of 2400 RPM this collector rod samples air at 41.3 ℓ/m. The MF's consisted of 1-inch diameter aerosol sampling membranes held in magnetic type holders and aspirated at 5 to 8 ℓ/m.

A more detailed description of the FP collector rod, rod coating procedures, and the FP materials used are given in Section II and in Appendices B and C. Also presented in Section II are photographs of the Rotorod sampler, and the FP dissemination and sampling equipment as set up during a typical collection efficiency field experiment.

C. Results Summary

Presented in Table 1 is a concise summary of the FP collection efficiencies obtained from the CML-543 series of measurements. In this table the average percent efficiency obtained in all trials using the same lot of material is presented in the order of increasing FP mass mean diameter (MMD). With one exception the collection efficiency increases in step with the increase in MMD, or expressed in terms of the independent variable explicitly measured, the collection efficiency increases as the FP particles-per-gram (PPG) decreases.

Table 1

Rotorod FP Collection Efficiency Summary

FP Material Used			Collection Efficiency Results			
MMD	Color & Type	PPG	No. Values	Avg % Eff.	Std. Dev.	Coeff. Var.
1.8	Yellow-2266	7.9×10^{10}	14	28.1%	4.4	0.156
2.4	Yellow-2266	3.3×10^{10}	12	52.9	3.1	0.058
2.4	Green-3206	3.3×10^{10}	24	54.1	4.8	0.089
3.1	Yellow-2267	1.6×10^{10}	24	74.7	6.3	0.085
3.4	Yellow-2267	1.2×10^{10}	24	60.7	7.1	0.116
3.8	Yellow-2267	0.9×10^{10}	16	69.2	8.1	0.117

The exception to the trend is, of course, the 74.7% collection efficiency obtained with the 3.1μ FP material. Although the data per se on which this result is based appear to be as adequate as those for any of the other results shown, there are some other factors which should be mentioned concerning the particular test conditions and material used. Shortly after the start of the first trial of the series from which these data were obtained 140), a shift in wind direction necessitated a change in the route that had to be taken by the FP line source disseminator vehicle. As a consequence a compromise from the original test plan had to be made to the extent that the line source vehicle had to approach within 150 feet of the nearest sampling station instead of the 300 to 750 feet closest upwind approach used in all other tests. This shorter travel distance from line source to samplers may have contributed to the somewhat greater than usual variation among the reference filter samplers.

The FP material with which the 74.7% efficiency was obtained has lower-than-average percentages of particles in both the fine-particle and large-particle ends of the spectrum--thus tending to be collected efficiently while at the same time exhibiting a smaller than typical MMD.

The collection efficiency result of most practical interest is the 60.7% efficiency obtained with the 3.4μ FP. This FP is from Dugway Lot 12-21 and is typical of the 12-series lots as will be evident by examining the tabulations of PPG and MMD values presented in Table 6 of CML-543 Final Report.

The most encouraging results obtained in this investigation are those for the 2.4μ yellow and 2.4μ green FP's. The close agreement obtained in collection efficiency justifies the implicit assumption made at the beginning of the investigation that the primary variables to be considered do not include such chance differences as those of particle color and intensity, time and process of manufacture, and minor differences in chemical composition. The 2.4μ yellow is type 2266 FP from SAL Lot 8B which was manufactured several years ago by New Jersey Zinc Co. The 2.4μ green is type 3206 FP recently developed and manufactured by U.S. Radium Corp. and furnished to Dugway as Lot H324-2 and since used in Dugway Trial 502 B-7.

Although a few trials were conducted under wind speeds as low as 3 mph and a few others under winds as high as 18 mph, the winds experienced during most trials were in the range 8 to 14 mph. Even though too few data were obtained under a range of meteorological conditions sufficient to warrant a conclusion in this regard, it should also be mentioned that there was observed no readily evident variation in collection efficiency that could be attributed to differences in meteorological conditions.

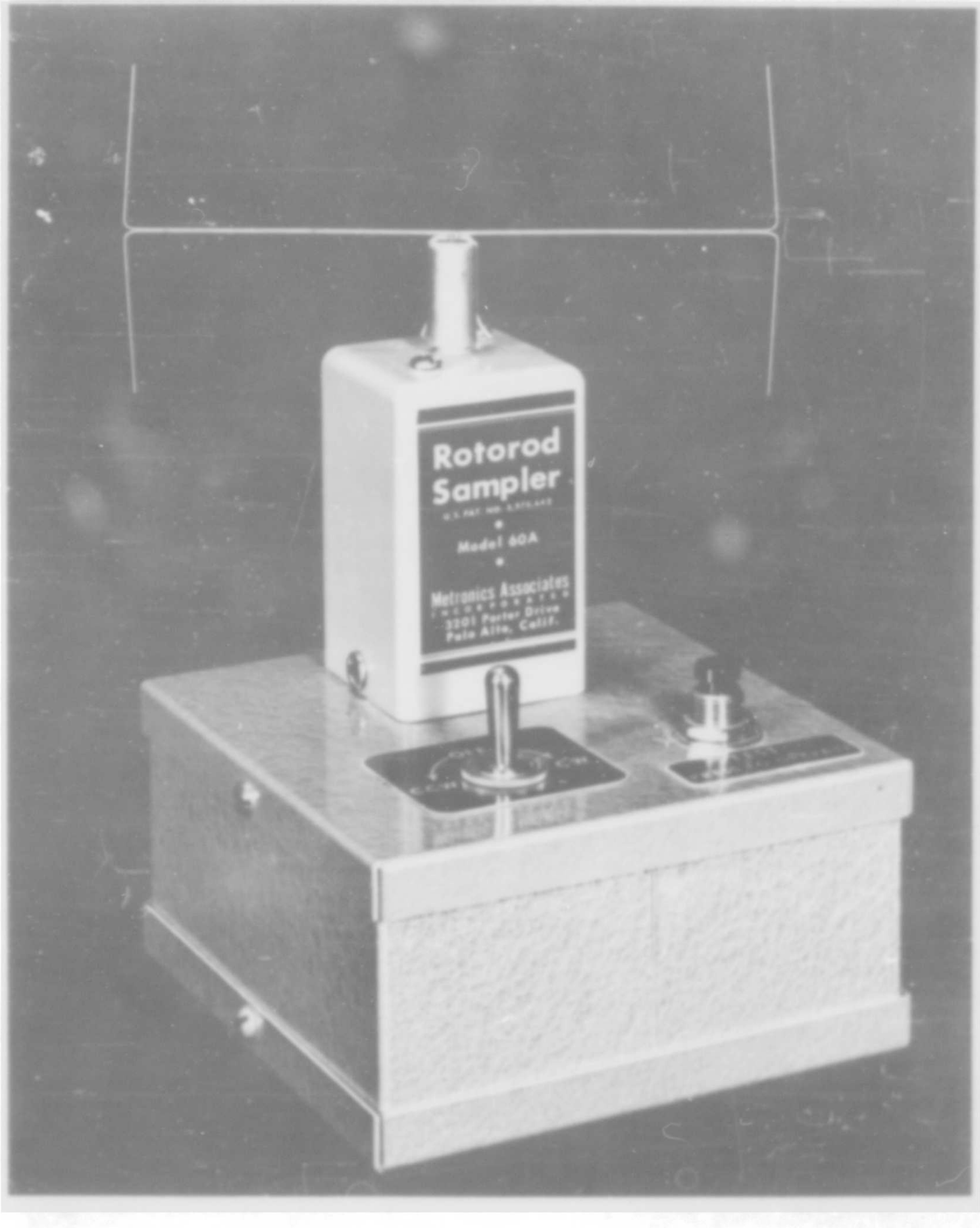

Fig. 1--FP Collector Rod mounted on Rotorod sampler. The FPCR is firmly secured by means of a welded-on spring-wire clip (Fig. 2) which engages in slots milled in hub of Rotorod sampler. The small chassis box shown, in addition to serving as a mounting base for Rotorod sampler and a 3-way switch ("OFF"--"Clockwise"--"Counter-clockwise" for obtaining 2 collections per Rod), also houses miniature size dry-cell batteries sufficient for rotating FPCR 3-4 hours at 2400 RPM. Complete sampler with batteries and collector rod weighs 20 ounces. Also provided at rear of chassis (not shown) is receptacle for connecting sampler to external batteries.

II. TEST PROCEDURES

A. FP Collector Rod

The configuration and principal dimensions of the collector rod investigated in this study are given in Figure 2. The H-shaped configuration shown was developed in December 1959 to provide a device which could be used with the Rotorod sampler for the collection of 1-5μ **FP**-2267 airborne particles. Since it was developed primarily for this purpose this device is generally known as the **FP** Collector Rod and is frequently designated by the abreviation, **FPCR**. To differentiate from the U-shaped 1/16-inch collector width square brass rod developed earlier for collection of 15-25μ particles, the **FPCR** has also been identified in technical reports and memoranda as the H-shaped, 0.38 mm collector width chromel ribbon rod.

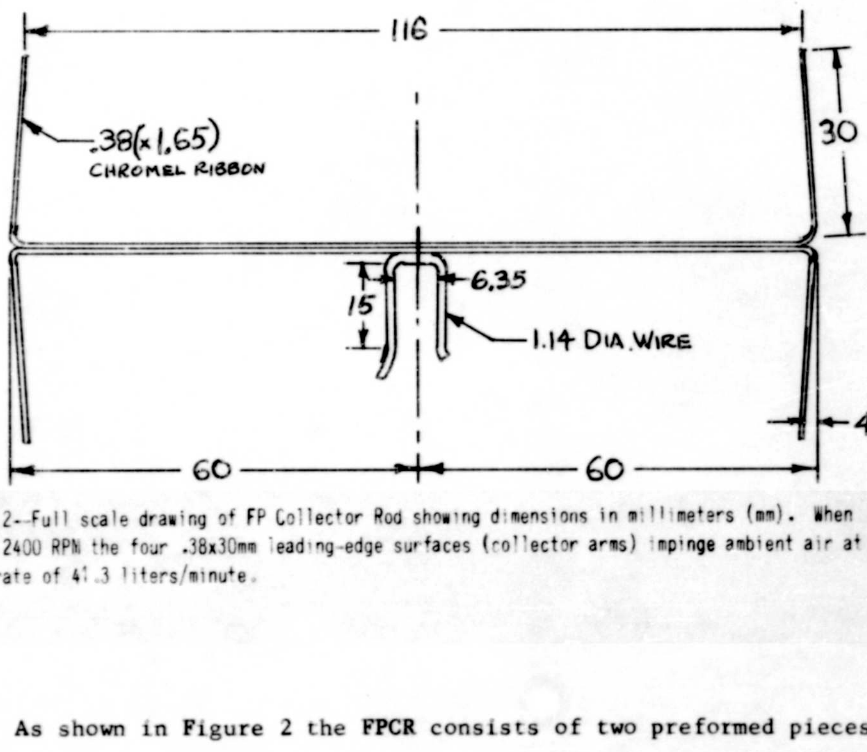

Fig. 2--Full scale drawing of FP Collector Rod showing dimensions in millimeters (mm). When rotated 2400 RPM the four .38x30mm leading-edge surfaces (collector arms) impinge ambient air at volume rate of 41.3 liters/minute.

As shown in Figure 2 the **FPCR** consists of two preformed pieces of .38 x 1.65 mm cross-section chromel ribbon wire spot welded together back-to-back. The resulting H-shaped assembly is then welded to a centrally positioned spring-wire clip which has been designed to engage in the slotted hub of the Rotorod sampler. An **FPCR** thus assembled and attached to Rotorod sampler is shown in Figure 1.

Included in the Appendix is a detailed drawing of the FPCR showing its principal dimensions in inches and also the dimensional tolerances for properly manufactured collector rods. It is estimated that about 20,000 such collectors have been manufactured and used in FP tracer field experiments.

As is clearly evident in Figure 1 and also dimensionally shown in Figure 2, the forearms or collector arm portions of the rod are not straight up and down but are inclined toward center about 4°. When the FPCR is rotated at the standard speed of 2400 RPM the resulting centrifugal force acting on these collector arms cause them to straighten out and become parallel to the axis of rotation. When thus rotated the FPCR presents to any surrounding particle-laden air two pairs of slightly rounded impaction surfaces 0.38 mm wide x 60 mm long and moving at a speed of 905 meters per minute (33.7 mph). The volume of air thus swept out per minute is 41.3 liters. If half of the particles in this volume of air were to collide and be retained on these surfaces the FPCR would then be collecting particles at the same rate as a membrane filter when aspirated at a sampling rate of 20.6 liters per minute. For the FPCR this rate of particle collection is obtained at a power consumption of less than 2 watts.

B. Collector Rod Coating Procedure

If a shiny clean collector rod is rotated in particle-laden air the number of particles colliding on its leading-edge surfaces may be very great, i.e., its collection efficiency as derivable from impaction theory may be quite substantial. However, very few such colliding particles would be retained, and hence "collected", if the intended collection surfaces were not first coated with an appropriate tacky material. In earlier impaction sampling experiments it was found that an 8 to 10-fold increase in particle retention could be obtained by a proper choice of impaction surface coatings.* From such considerations it is obvious that the nature of the coating material and application procedure greatly affects the overall collection efficiency.

Although some exploratory work toward improved coatings was undertaken during the course of the present investigation, all of the definitive measurements of collection efficiency were made using the currently standard silicone grease procedure. In addition to providing high retention efficiency this procedure has the special merits of simplicity of application and long shelf-life, i.e. collector rods can be coated weeks in advance of a test and then used without any apparent deterioration in collection efficiency.

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* For example see Table 5, SAL, QR 111-15.

A brief description of the coating procedure follows. The material used is Dow-Corning High Vacuum Grease which is a silicone grease preparation commonly used in chemical laboratories as a sealant and lubricant for ground glass stoppers and joints. A small dab of the grease is taken up on the pad of the forefinger and then spread evenly and thinly between forefinger and thumb. A collector rod is grasped firmly just below the bend with the other hand--in such a manner that a pull on a collector arm will not permanently change the bend angle. The impaction edges near the bend of one collector arm are then grasped between the greased fingers and the fingers moved along the edges to the end of the arm. By grasping with gentle pressure and moving collector arm in a uniform manner a thin smooth coating of the grease is transferred to the narrow impaction surfaces.

Note that by this procedure both edges of a collector arm are coated at the same time, hence the collector rod thus prepared can be rotated, first in one direction and then in the other, to collect two samples. Since silicone grease does not flow or melt and thus distribute itself over the metal surfaces there is a tendency to use excessive amounts of grease and for some of this excess to overhang the narrow edges of the collector arms. Any such overhang increases the effective width of the collector and thus decreases collection efficiency. In addition an excessively thick grease coating unnecessarily complicates the particle counting task. A more detailed description of the procedures used for coating collector rods for Rotorod sampling is given in Appendix C.

C. Field Test Procedures and Equipment

1. FP Materials

Although the implications of impaction theory on Rotorod collection efficiency will be considered in more detail later in connection with the discussion of results, it is quite appropriate that such implications be taken into account in discussing the selection of the FP materials used. In addition to impaction theory there are a number of practical considerations which should be taken into account in the selection of test materials; some of these will be mentioned below in connection with specific lots of FP material.

From a consideration of impaction theory it is evident that the collection efficiency varies as the particle-size-density parameter ρd^2 and varies as the resultant impaction velocity (i.e. resultant of wind and collector speed). Thus for a given collector geometry, coating material, rotational speed, and particle density, as was used in this investigation, the collection efficiency of the Rotorod sampler is primarily a function of particle diameter squared, and to a much lesser extent, is a function of wind speed.

FP tracer material, like any other finely ground powder, is comprised of a broad-band spectrum of particle sizes. Most FP materials which have been used as atmospheric tracers have particle size diameters ranging from below 1/2μ to about 5μ. Some lots of FP tracer have an occasional few particles larger than 10μ diameter.

For expressing and comparing the size properties of powdered materials several different kinds of averaged or mean-valued diameters are customarily measured. The kind of mean-valued diameter that is most useful and technically correct depends on the intended application or purpose of the powdered material.

Fairly early in the development of the FP tracer technique it was found that the most appropriate criterion for characterizing and assessing the usefulness of various lots of tracer material is the number of particles-per-gram (PPG) that can be made airborne when a weighed specimen from a given lot is aerosolized in a reproducible manner.

The PPG number for a given FP lot may also be expressed in terms of a reciprocally related number; when the solid state density of the material is known (for FP-2267, ρ = 4.0 gm/cm^3) and it is assumed that the FP are essentially spherical, then this number is the mass-mean-diameter (MMD) of that FP lot. Such a mass-mean-diameter is related to particles-per-gram by the expression

$$\text{MMD} = \left[\frac{47.75 \times 10^{10}}{\text{PPG}}\right]^{1/3}.$$

The theoretical model and experimental technique used in making standard aerosolization tests for determining the PPG values of FP tracer materials has been described in detail in the FP Manual.* Additional theoretical and experimental considerations together with a review of the reliability and application of data from several such tests has also been presented in Quarterly Report 111-10.**

Except for some recent improvements in equipment and procedures the aerosolization tests and related physical analyses of FP materials performed in connection with this investigation were made essentially as described in the

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* "The Stanford Fluorescent-Particle Tracer Technique: An Operational Manual", June 1955, Contract DA-18-064-CML-2564.

** Stanford Aerosol Laboratory Quarterly Report 111-10, July-August-September 1956, Contract DA-42-007-403-CML-111.

foregoing referenced reports.

To investigate the dependence of Rotorod collection efficiency on tracer particle size a survey of existing data from both earlier and currently run aerosolization tests was made to select FP lots which would be representative of a broad spectrum of those materials which would be likely to be used in tracer work. The lot numbers and particle size properties of the materials selected for this purpose are given in Table 2. The data columns are arranged in the order of increasing MMD from left to right across the table.

All of the materials listed in Table 2 have been used as tracers in atmospheric diffusion studies. The material which has been used in the largest variety of tracer experiments is SAL 8B; the material was manufactured by New Jersey Zinc Co. in 1952 and has been used quite extensively in the past by this Laboratory, and has been adopted as a "standard" or reference FP material. For example, the PPG value of 3.3 x 10^{10} given for SAL 8B is based on 42 observations accumulated over a period of several years. Because of the comparatively large amount of field and laboratory test data available on this FP lot, it was selected for use in the original development series of Rotorod trials. Hence it was logical to use this particular material as a control material for investigating the Rotorod collection efficiency in greater detail.

The other materials listed in Table 2 are representative of "small size", "middle size", and "large size" FP tracers. In order to obtain collection efficiency measurements that might be more directly related to such measurements obtained elsewhere, two of the "middle size" materials were selected from among lots that have been used extensively at Dugway, namely, green fluorescing H324-2 and yellow fluorescing DPG 12-21.

The green fluorescing H324-2 material was also selected primarily to determine the effect on collection efficiency of using an FP material which, while having a PPG and MMD closely matching (see Table 2) that of standard lot SAL-8B, is otherwise of different manufacture, type, lot, and fluorescent color.

From impaction theory it is evident that FP materials of different manufacture and color but having closely similar PPG and MMD values should likewise give closely similar Rotorod collection efficiencies. From a practical point of view, however, since the identification and counting phase of an FP tracer system is dependent on the intrinsic brilliance, color, and shape of the individual particles comprising such materials, it is conceivable that there could be apparent differences in their experimentally measured collection efficiencies. Thus, since the experimental procedure used in this investigation tacitly excluded color, brilliance, etc. as collection efficiency variables, then

Table 2

FP MATERIALS USED IN ROTOROD COLLECTION EFFICIENCY TRIALS

(CML-543 Trial-Series 1962)

	Material: Type -- Fluorescent Color -- Lot Number					
	2266 Yellow MA 104	2266 Yellow SAL 8B	3206 Green H324-2	2267 Yellow 1339-2	2267 Yellow DPG 12-21	2267 Yellow H310 A-E
Used in Collection Eff. Trial-Series	FE 137	FE 134&135	FE 138	FE 140	FE 139	FE 136
Aerosolization Test No.	AGPT 29A	AGPT 13	AGPT 65	AGPT 78	AGPT 63	AGPT 57
Mass Mean Diameter (MMD)	1.8μ	2.4μ	2.4μ	3.1μ	3.4μ	3.8μ
Particles-Per-Gram (PPG)	7.9×10^{10}	3.3×10^{10}	3.3×10^{10}	1.6×10^{10}	1.2×10^{10}	0.9×10^{10}
Particle Size Analysis:						
Specimen No.	H58-P3	H62-P1		H65-P1		H80-P1
Number of Particles Sized	1820	1592		527		1752
Size Range:						
< 1/2 μ	51.9%	21.2%		10.4%		8.7%
1/2 - 5 μ	47.6%	78.1%		86.8%		83.2%
> 5 μ	0.49%	0.69%		2.8%		8.05%
Manufacturer	NJZ	NJZ	USRC	USRC	USRC	USRC
Year Manufactured	1954	1952	1961	1962	1960	1960

in essence the close agreement obtained (see Table 1) between this green FP and the standard yellow FP is a test of the adequacy of the experimental procedure per se.

2. Test Conditions and Procedures

Given in Table 3 is a list of the field experiments run, together with the range of meteorological conditions, the amounts of FP disseminated and the number of samples collected during each of the 28 trials run.

Shown schematically in Figure 3 is a typical close-spaced arrangement of Rotorod samplers (RR) and surrounding reference membrane filter samplers (MF) used at each of the two sampling stations operated during each trial. In the first two experiments of the series (FE 134 and FE 135) the array at each station consisted of a single Rotorod surrounded by a trio of MF's; this was increased to a dual array of two RR's and five MF's per station in FE 136 and FE 137; the array was then enlarged to that shown in Figure 5 for FE 138 and the remaining experiments run during this series.

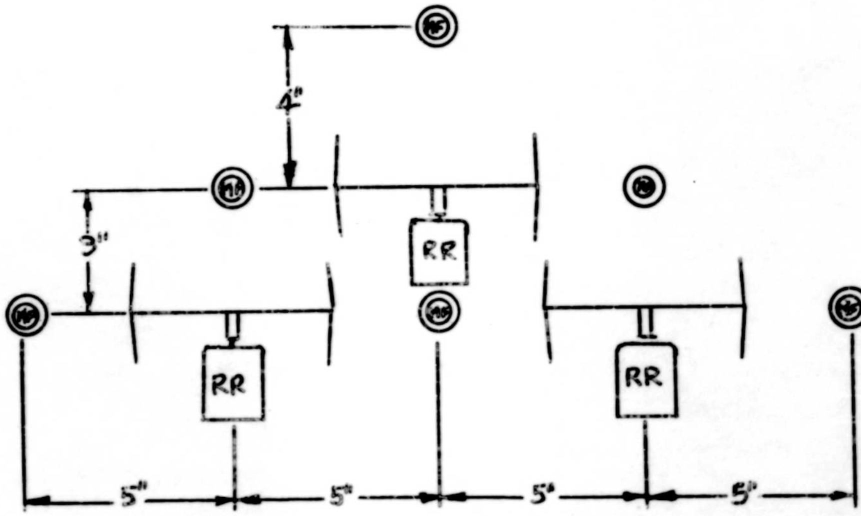


Fig. 3--Typical arrangement of RR's and MF's used in 12 trials of the CML-543 series of FP collection efficiency field experiments. Except for fewer samplers per array the same close spacing was used in all other trials of this series.

In addition to the sampler arrays for making collection efficiency measurements, a number of auxiliary RR's and MF's were used in each trial to monitor the FP aerosol cloud. The procedure of using these monitor samplers was essentially as follows. After sufficient time had elapsed for the FP cloud to have traveled from the moving line source to beyond the sampling array, one of

Table 3

SUMMARY OF DISSEMINATION, SAMPLING, AND METEOROLOGICAL CONDITIONS FOR THE CML-543 SERIES ROTOROD FP COLLECTION EFFICIENCY TRIALS

Trial Series FE No.	Date 1962	Time Period	Trials Run	Meteorological Conditions-Range/Average Wind Speed	Dir.Var.	Temp	RH
134	26 Jan	1515-1632 PST	4	3 - 5 mph	45°	56°F	69%
135	27 Mar	1518-1556 PST	4	9--11 mph	15°	71°F	50%
136	9 May	1447-1537 PDT	4	11--16 mph	30°	68°F	45%
137	14 May	1521-1715 PDT	4	13--18 mph	48°	64°F	49%
138	17 Jul	1659-1754 PDT	4	9--12 mph	30°	79°F	50%
139	21 Aug	1515-1606 PDT	4	13--15 mph	22°	83°F	45%
140	16 Nov	1544-1643 PST	4	9--13 mph	24°	58°F	28%

Trial Series FE No.	FP Dissemination: Min. Travel Dist. to Nearest Sampler	Avg. Feed Rate	Line Source Strength-Avg.	Samples Collected: Collector Rods	Membrane Filters
134	300 ft	5.0 gm/min	0.013 gm/ft	9	24
135	300 ft	8.1 gm/min	0.015 gm/ft	20	40
136	300 ft	8.0 gm/min	0.025 gm/ft	20	40
137	750 ft	5.1 gm/min	0.030 gm/ft	20	56
138	300 ft	6.3 gm/min	0.024 gm/ft	30	48
139	500 ft	8.6 gm/min	0.024 gm/ft	28	48
140	150 ft	7.0 gm/min	0.017 gm/ft	28	48

the auxiliary samplers was stopped and its collection surface immediately examined under UV illumination. If too few FP's had been collected the disseminator crew was then signalled to make another pass with the aerosol generator. When the deposition density was deemed to be sufficient for obtaining statistically adequate total count estimates, the samplers were turned off simultaneously on count-down, thus completing that trial. Two passes were usually sufficient, although in a few cases, under highly variable wind conditions, as many as four passes have been required. The manner of using the FP aerosol generator for each trial is shown in Figure 4.

III. RESULTS: Collection Efficiency of the Standard Rotorod FP Sampler

A. Experimental Data and Results Summary

A concise tabular summary of the collection efficiencies obtained with the currently standard Rotorod FP sampler is presented in Table 1 in the Introduction and Summary section of this report. These summarized results are also presented graphically in Figures 6 and 7 immediately following this section.

The tracer dosages measured with each individual FPCR and with its adjacent three reference MF's, together with the calculated collection efficiency corresponding to each such set of dosages, are given in Appendix A in Tables A-1 through A-10. Except for FE 135 there is one numbered table of individual sampling and collection efficiency results corresponding to each numbered field experiment listed in Table 3. The data for FE 135 appear in four numbered tables (A-2 to A-5) corresponding to separate tabulations of results obtained with two different lots of the standard FPCR and two groups of modified collector rods. At the end of the longer tables in Appendix A is a summary of the collection efficiency results pertaining to that field experiment. Since FE 134 and FE 135 were run with the same lot of FP material the individual results from these two trial-series were combined together for the results summary (Table 1).

The results summary presented in Table 1 provides two categories of general information which should be considered in making the selection of tracer materials and equipment and in the appraisal of experimental data from FP tracer studies. First, Table 1 shows the range of Rotorod collection efficiencies that can be expected with different lots of FP material having marked differences in MMD. It is evident that the collection efficiency increases from 28 to 69% as the MMD increases from 1.8 to 3.8 microns. Second, Table 1 shows the variation in collection efficiency that may be expected, and hence the range of uncertainty in Rotorod dosages that may be obtained within a given trial or series of trials for which the FP materials have the same or closely similar MMD values. Thus, the maximum coefficient of variation observed is 0.156 and the smallest is 0.058. Accordingly, if the variation or uncertainty in field trial results greatly exceeds these limits, factors other than the collection efficiency uncertainty are involved.

Quite intentionally for the purposes of this investigation, tracer materials were selected so as to be representative of FP lots which are "too fine" and FP lots which are "too coarse" for completely satisfactory FP tracer work. Quite apart from causing a substantial reduction in Rotorod collection efficiency, the use of an FP material having high percentages of fine particles (e.g. more than 25% less than $1/2\mu$) unduly complicates the overall assessment phase of a tracer experiment. Particle counts made by different operators and even repeat counts made by the same operator became highly variable. This is just as true for membrane filters as for Rotorod collectors and any other conventional particle collector. From an economic point of view the time and effort spent in the careful analysis and selection of candidate FP tracer materials will be repaid many times over in the reduction of counting time and in the enhancement of the reliability of results.

The use of "too coarse" an FP material, i.e. from a lot having small PPG or large MMD, obviously results in enhancement of the Rotorod collection efficiency, as well as that of other impaction sampling devices such as the drum sampler. Although the use of large-particle FP does suggest the likelihood of significant fallout loss, it should be pointed out that FP material from lots having MMD's as large as any used in this investigation have previously been used in long distance travel experiments without any readily measurable loss ascribable to fallout. However, it is undesirable to use a tracer material containing a high percentage of large particles because the sensitivity of the tracer technique is reduced. If large particles are present the number of particles per gram is sharply reduced and for a given weight of tracer released, sample size and sample reliability will be reduced. Accordingly a tracer material having maximum collection efficiency with the Rotorod sampler is not necessarily the optimum material for field test use.

B. Collection Efficiency as a Function of FP Tracer Particle Size

The collection efficiency of the Rotorod FP sampler depends on the impaction efficiency of the collector. This impaction efficiency is in turn a function of the impaction parameter, K, where

$$K = \frac{1}{18} \frac{\rho d^2 v}{\eta D}$$

ρ = particle density

d = particle diameter

v = speed of collector relative to aerosol

η = viscosity of air

D = width of collector

Since any actual FP tracer material covers a wide range of particle sizes, the mean collection efficiency is not a simple function of particle size but depends also on the variation of efficiency with the impaction parameter, K. If the efficiency is proportional to K within the range of interest, then the mean collection efficiency will be proportional to the mean square diameter of the particles (MSD). Theoretical impaction efficiency vs log K for cylinders is approximately linear over a wide range of particle size. In this case the mean collection efficiency should depend on the geometrical mean diameter (GMD) of the particles.

Since the experimental procedures involved measurement of the number of particles per gram of material, only the mass mean diameter (MMD) was determined directly. However, for some of the materials tested the fraction of particles less than 0.5μ and greater than 5μ were determined. Assuming that the particles have log-normal distributions the GMD can be estimated by plotting the cumulative percentages of particles on log-probability paper. The GMD is then determined from the intersection of the curve with the 50% level. The mean square diameter may then be computed from the GMD and the MMD by the relation

$$MSD = \left[(MMD)^2 \cdot (GMD) \right]^{2/3}$$

Impaction parameters were computed from the measured MMD and from the estimated GMD and MSD. These values were plotted against collection efficiency and compared with theoretical curves for impaction on a cylinder and on a ribbon. The points determined from the GMD appear to be closer to the theoretical curve for the ribbon while those determined from the MSD lie closer to the curve for the cylinder. Since the Rotorod collector is more nearly a ribbon than a cylinder, the former values may be more appropriate to use as the basis for efficiency estimates.

In view of the uncertainties involved in the estimates of the GMD and MSD of the particles and since the MMD can be determined readily from FP aerosolization tests without obtaining the size distributions, plots of efficiency against PPG (Figure 6) and against MMD (Figure 7) were made, and smooth curves drawn, ignoring points for the 3.1μ FP material since its efficiency appeared to be out of line with respect to the other materials. The curves shown in Figures 6 and 7 should be adequate for interpolation within the range of the measured efficiencies, and may be adjusted when additional measurements are obtained.

Although the impaction efficiency parameter K increases with the square of the particle diameter, the number of particles per gram varies inversely as the cube of the particle diameter. Hence the number of recoverable particles per gram of FP tracer disseminated will increase as particle diameter increases <u>only</u>

within the range of diameters which give the most rapid increase in collection efficiency with diameter. The maximum recoverable particles per gram of **FP** disseminated will be obtained when the particle diameter d and the collection efficiency E_d are related by

$$\frac{d \ln E_d}{d \ln d} = 3$$

Using experimental data obtained from earlier collection efficiency studies an attempt has been made to obtain a function relating the Rotorod collection efficiency to particle size. After trying a number of different functions, it was found that a linear function could be used to obtain results consistent with the limited amount of data available on **FP** lots for which both particle size distributions and gross efficiency values are known. The constants derived from this limited amount of data indicate the efficiency to be zero for particles smaller than 0.9μ and to be 100% for particles greater than 3.4μ with a linear increase from 0 to 100% between 0.9μ and 3.4μ. To the degree that this particular function is correct the optimum particle size giving the maximum number of particles recovered per unit weight is 1.35μ.

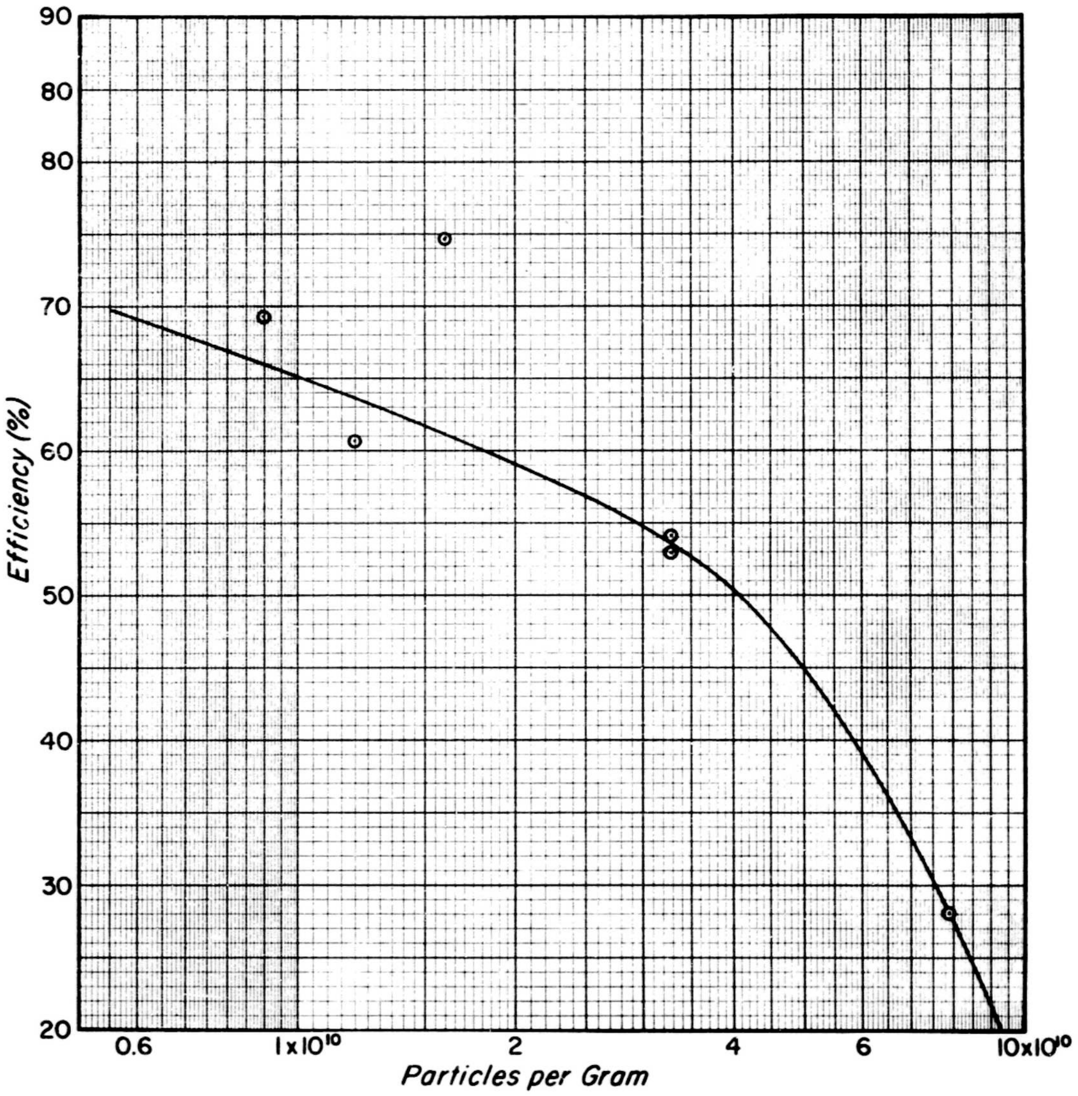


Fig. 6--Rotorod FP Collection Efficiency vs Particles-per-Gram (PPG). Data points from results summary for CML-543 series of collection efficiency field experiments (Table 1).

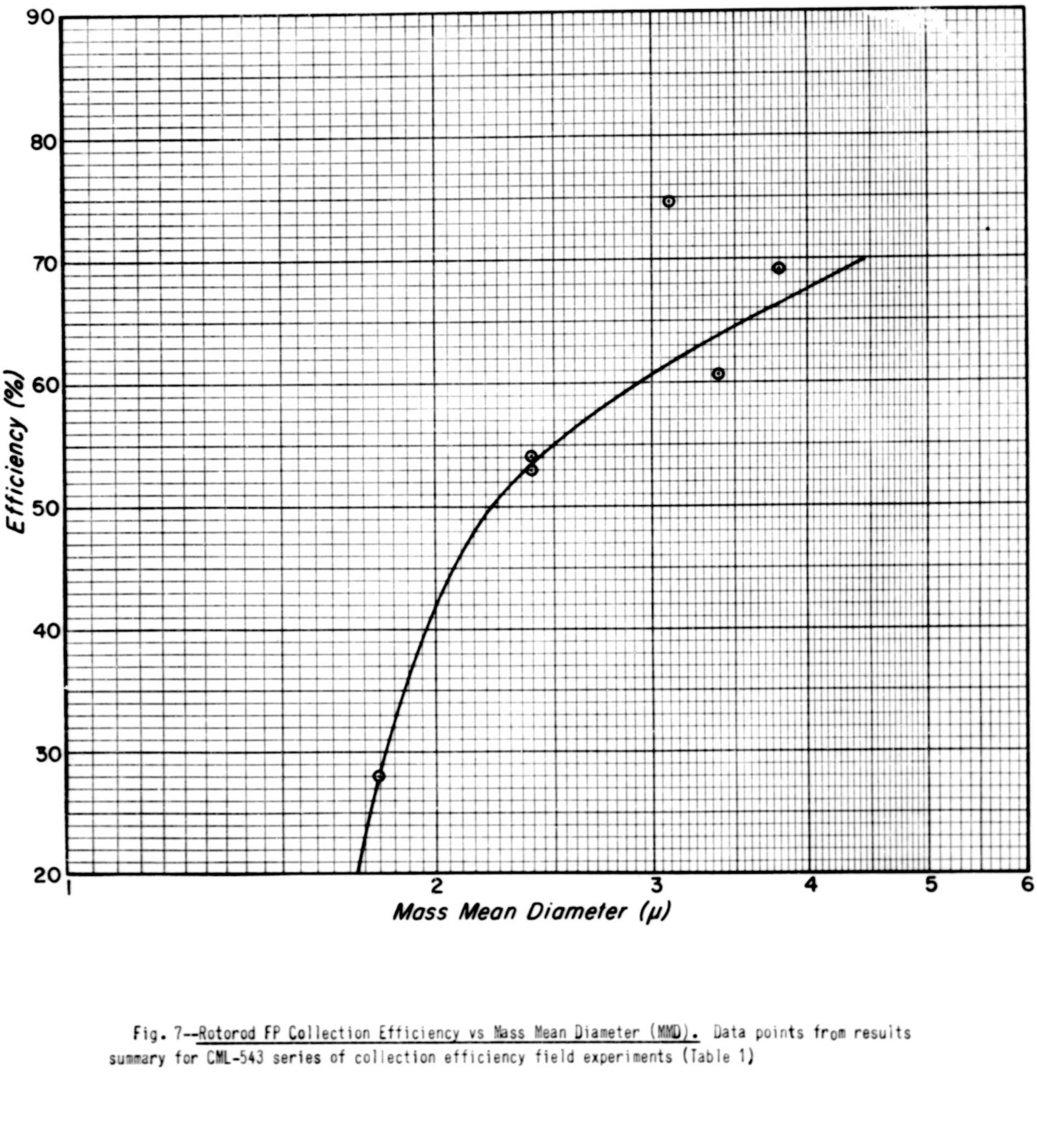


Fig. 7--Rotorod FP Collection Efficiency vs Mass Mean Diameter (MMD). Data points from results summary for CML-543 series of collection efficiency field experiments (Table 1)

APPENDICES

Table A-1

Rotorod Collection Efficiency Test Results*

FE 134 - Trials A, B, C & D   26 Jan 1962

FP Material: SAL 8B - 3.3 x 10^{10}PPG - 2.4μ MMD

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency= Rotorod Dosage / Avg. MF Dosage
134A*	1	MF-Left	581	
		MF-Above	586	
		MF-Right	587	
		RR-Center	430	73.5%
		RR-Special**	429	73.3%
134A*	2	MF-Left	617	
		MF-Above	580	
		MF-Right	650	
		RR-Center	453	73.6%
134B	1	MF-Left	1972	
		MF-Above	2384	
		MF-Right	2013	
		RR-Center	1147	54.0%
134B	2	MF-Left	3089	
		MF-Above	3070	
		MF-Right	3016	
		RR-Center	1587	51.9%
134C*	1	MF-Left	553	
		MF-Above	564	
		MF-Right	519	
		RR-Center	416	76.3%
134C*	2	MF-Left	429	
		MF-Above	431	
		MF-Right	396	
		RR-Center	341	81.4%
134D	1	MF-Left	1213	
		MF-Above	1054	
		MF-Right	1066	
		RR-Center	544	49.0%
134D	2	MF-Left	1187	
		MF-Above	1134	
		MF-Right	1020	
		RR-Center	546	49.0%

* Electric power failure during Trials A and C caused MF samplers to stop running several seconds before Rotorod samplers could be turned off. The abnormally high collection efficiencies thus obtained in these two trials were therefore not used in calculation of average efficiency.

** The "special" Rotorod sampler used in Trial A at this position was insulated from ground and electrically charged to an above-ground potential of 1000 volts. Other Rotorod sampler was grounded.

Table A-2

Rotorod Collection Efficiency Test Results

FE 135 a* - Trials A, B, C & D 27 Mar 1962

FP Material: SAL 8B - 3.3 x 10^{10} PPG - 2.4μ MMD

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
135A	1a	MF-Left	6600	
		MF-Above	6180	
		MF-Right	6040	
		RR-Center	3190	50.7%
135A	2a	MF-Left	7260	
		MF-Above	6530	
		MF-Right	6590	
		RR-Center	3870	57.0%
135B	1a	MF-Left	1840	
		MF-Above	1720	
		MF-Right	2060	
		RR-Center	1040	55.6%
135B	2a	MF-Left	2170	
		MF-Above	1730	
		MF-Right	2050	
		RR-Center	1150	58.1%
135C	1a	MF-Left	1240	
		MF-Above	1240	
		MF-Right	1130	
		RR-Center	660	55.0%
135C	2a	MF-Left	1680	
		MF-Above	1430	
		MF-Right	1480	
		RR-Center	760	49.7%
135D	1a	MF-Left	2210	
		MF-Above	2230	
		MF-Right	2200	
		RR-Center	1110	50.2%
135D	2a	MF-Left	1640	
		MF-Above	2260	
		MF-Right	2130	
		RR-Center	1100	54.7%

* Two arrays of MF's and RR's used at each sampling station, one standard (FE 135 a) and one special (FE 135 b); only the results from the standard array are presented in this Table. Results from FE 135 b are given in tables on the next three following pages.

Table A-3

Rotorod Collection Efficiency Test Results*

FE 135 b - Trial A 27 Mar 1962

FP Material: SAL 8B - 3.3 x 10^{10} PPG - 2.4μ MMD

* Supplementary results obtained using standard 60-mm radius and special 30-mm radius collector arms mounted on common Rotorod hub.

Station No.	Sampler Type - Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage 60-mm Rad.	30-mm Rad.
1b	MF - Left	6040		
	MF - Above	6310		
	MF - Right	5520		
	RR - Center			
	60-mm Rad.	2995	50.2%	
	30-mm Rad.	1865		31.2%
2b	MF - Left	6590		
	MF - Above	7230		
	MF - Right	7830		
	RR - Center			
	60-mm Rad.	3645	50.5%	
	30-mm Rad.	2270		31.4%
		Average	50.4%	31.3%

Table A-4

Rotorod Collection Efficiency Test Results*

FE 135 b - Trials B & C 27 Mar 1962

FP Material: SAL 8B - 3.3 x 10^{10}PPG - 2.4μ MMD

* Supplementary results obtained using standard FPCR's fabricated and coated with silicone grease at Dugway.

Trial No.	Station No.	Sampler Type - Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
B	1b	MF - Left	2060	
		MF - Above	2050	
		MF - Right	1590	
		RR - Center	1000	52.1%
B	2b	MF - Left	2050	
		MF - Above	1700	
		MF - Right	1530	
		RR - Center	1190	67.4%
C	1b	MF - Left	1130	
		MF - Above	1290	
		MF - Right	1270	
		RR - Center	700	56.9%
C	2b	MF - Left	1480	
		MF - Above	1350	
		MF - Right	1300	
		RR - Center	780	56.5%
			Average	57.9%

Table A-5

Rotorod Collection Efficiency Test Results*

FE 135 b - Trial D 27 Mar 1962

FP Material: SAL 8B - 3.3 x 10^{10}PPG - 2.4μ MMD

* Supplementary results obtained using standard FPCR's electrically connected to hi-voltage dc power supply so as to be maintained at an above ground potential of 1200 volts (positive) during sampling operation.

Station No.	Sampler Type - Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
1b	MF - Left	2200	
	MF - Above	1980	
	MF - Right	2210	
	RR - Center	1060	49.9%
2b	MF - Left	2130	
	MF - Above	2490	
	MF - Right	2110	
	RR - Center	1230	54.9%
		Average	52.4%

Table A-6

Rotorod Collection Efficiency Test Results

FE 136 - Trials A, B, C & D   9 May 1962

FP Material: H310 A-E - 0.9 x 10^{10}PPG - 3.8μMMD

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency= Rotorod Dosage / Avg. MF Dosage
136A	1a	MF-Left	348	
		MF-Above	347	
		MF-Right	270	
		RR-Center	202	62.8%
	1b	MF-Left	270	
		MF-Above	296	
		MF-Right	294	
		RR-Center	235	81.9%
	2a	MF-Left	310	
		MF-Above	273	
		MF-Right	292	
		RR-Center	224	76.8%
	2b	MF-Left	292	
		MF-Above	307	
		MF-Right	367	
		RR-Center	261	81.0%
136B	1a	MF-Left	310	
		MF-Above	343	
		MF-Right	314	
		RR-Center	230	71.4%
	1b	MF-Left	314	
		MF-Above	291	
		MF-Right	314	
		RR-Center	232	75.7%
	2a	MF-Left	243	
		MF-Above	277	
		MF-Right	270	
		RR-Center	201	76.4%
	2b	MF-Left	270	
		MF-Above	260	
		MF-Right	252	
		RR-Center	198	75.9%

(Table A-6 continued on next page)

Table A-6 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency= Rotorod Dosage / Avg. MF Dosage
136C	1a	MF-Left	196	
		MF-Above	185	
		MF-Right	182	
		RR-Center	118	62.8%
	1b*	MF-Left	182	
		MF-Above	208	
		MF-Right	210	
		RR-Center	119	59.5%
	2a	MF-Left	252	
		MF-Above	240	
		MF-Right	234	
		RR-Center	152	62.8%
	2b*	MF-Left	234	
		MF-Above	251	
		MF-Right	203	
		RR-Center	139.	60.7%
136D	1a	MF-Left	281	
		MF-Above	235	
		MF-Right	252	
		RR-Center	189	73.8%
	1b*	MF-Left	252	
		MF-Above	249	
		MF-Right	278	
		RR-Center	179	68.8%
	2a	MF-Left	296	
		MF-Above	294	
		MF-Right	299	
		RR-Center	169	57.1%
	2b*	MF-Left	299	
		MF-Above	309	
		MF-Right	272	
		RR-Center	176	60.1%
			Average	69.2%

* The FP Collector Rods used at these stations were fabricated and coated with silicone grease at Dugway.

Table A-7

Rotorcd Collection Efficiency Test Results

FE 137 - Trials A, B, C & D 14 May 1962

FP Material: MA 104 - 7.9 x 10^{10} PPG - 1.8μ MMD

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency= Rotorod Dosage / Avg. MF Dosage
137A	1a	MF-Left	1254	
		MF-Above	1462	
		MF-Right	1365	
		RR-Center	375	27.6%
	1b	MF-Left	1365	
		MF-Above	1371	
		MF-Right	1076	
		RR-Center	378	29.8%
	2a	MF-Left	1230	
		MF-Above	1101	
		MF-Right	1326	
		RR-Center	321	26.3%
	2b	MF-Left	1326	
		MF-Above	1037	
		MF-Right	1105	
		RR-Center	360	31.1%
137B	1a	MF-Left	1639	
		MF-Above	1521	
		MF-Right	1612	
		RR-Center	518	32.6%
	1b	MF-Left	1612	
		MF-Above	1730	
		MF-Right	1756	
		RR-Center	503	29.6%
	2a	MF-Left	1746	
		MF-Above	1686	
		MF-Right	1754	
		RR-Center	441	25.5%
	2b	MF-Left	1754	
		MF-Above	1585	
		MF-Right	1863	
		RR-Center	518	29.9%

(Table A-7 continued on next page)

Table A-7 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency=Rotorod Dosage / Avg. MF Dosage
137C	1a	MF-Left	803	
		MF-Above	1074	
		MF-Right	1131	
		RR-Center	327	32.6%
	1b*	MF-Left	1131	
		MF-Above	927	
		MF-Right	1050	
		RR-Center	253	24.4%
	2a	MF-Left	1088	
		MF-Above	1155	
		MF-Right	1005	
		RR-Center	186	17.2%**
	2b*	MF-Left	1005	
		MF-Above	962	
		MF-Right	1007	
		RR-Center	344	34.7%
137D	1a	MF-Left	1167	
		MF-Above	1156	
		MF-Right	1175	
		RR-Center	264	22.6%
	1b*	MF-Left	1175	
		MF-Above	1117	
		MF-Right	1010	
		RR-Center	193	17.5%
	2a	MF-Left	977	
		MF-Above	971	
		MF-Right	1112	
		RR-Center	117	11.5%**
	2b*	MF-Left	1112	
		MF-Above	876	
		MF-Right	1234	
		RR-Center	313	29.1%
			Average	28.1%

* The FP Collector Rods used at these stations were fabricated and coated with silicone grease at Dugway.

** During Trials C and D the RPM of Rotorod at Station 2a considerably below normal due to excessive battery drainage. Hence these two efficiency values are not representative and therefore are not included in the average.

Table A-8

Rotorod Collection Efficiency Test Results

FE 138 - Trials A, B, C & D 23 July 1962

FP Material: H324-2 (Green) - 3.3 x 10^{10} PPG - 2.4μ MMD

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
138A	1a*	MF-Left	2476	
		MF-Above	3006	
		MF-Right	2850	
		RR-Center	1488	53.6%
	1b	MF-Left	2353	
		MF-Above	2476	
		MF-Right	1169	
		RR-Center	1368	68.4%
	1c	MF-Left	1169	
		MF-Above	2850	
		MF-Right	3647	
		RR-Center	1508	59.0%
	2a*	MF-Left	1241	
		MF-Above	1147	
		MF-Right	1071	
		RR-Center	616	53.4%
	2b	MF-Left	944	
		MF-Above	1241	
		MF-Right	1127	
		RR-Center	618	56.0%
	2c	MF-Left	1127	
		MF-Above	1071	
		MF-Right	1116	
		RR-Center	568	51.4%

(Table A-8 continued on next page)

Table A-8 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency=Rotorod Dosage / Avg. MF Dosage
138B	1a*	MF-Left	1571	
		MF-Above	1770	
		MF-Right	1653	
		RR-Center	851	51.1%
	1b	MF-Left	1339	
		MF-Above	1571	
		MF-Right	1658	
		RR-Center	856	56.2%
	1c	MF-Left	1658	
		MF-Above	1653	
		MF-Right	1847	
		RR-Center	995	57.9%
	2a*	MF-Left	1684	
		MF-Above	1316	
		MF-Right	1453	
		RR-Center	740	49.9%
	2b	MF-Left	1447	
		MF-Above	1684	
		MF-Right	1303	
		RR-Center	690	46.7%
	2c	MF-Left	1303	
		MF-Above	1453	
		MF-Right	1376	
		RR-Center	787	57.2%

(Table A-8 continued on next page)

Table A-8 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency= Rotorod Dosage / Avg. MF Dosage
138C	1a	MF-Left	944	
		MF-Above	907	
		MF-Right	921	
		RR-Center	566	61.3%
	1b	MF-Left	1147	
		MF-Above	944	
		MF-Right	989	
		RR-Center	558	54.3%
	1c**	MF-Left	989	
		MF-Above	921	
		MF-Right	1232	
		RR-Center	543	51.9%
	2a	MF-Left	1563	
		MF-Above	1381	
		MF-Right	1402	
		RR-Center	776	53.6%
	2b	MF-Left	1257	
		MF-Above	1563	
		MF-Right	1579	
		RR-Center	804	54.8%
	2c**	MF-Left	1579	
		MF-Above	1402	
		MF-Right	1500	
		RR-Center	882	59.0%

(Table A-8 continued on next page)

Table A-8 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
138D	1a	MF-Left	2047	
		MF-Above	2542	
		MF-Right	2600	
		RR-Center	1178	49.2%
	1b	MF-Left	2106	
		MF-Above	2047	
		MF-Right	2627	
		RR-Center	1082	47.9%
	1c**	MF-Left	2627	
		MF-Above	2600	
		MF-Right	1959	
		RR-Center	1226	51.2%
	2a	MF-Left	2192	
		MF-Above	2105	
		MF-Right	2416	
		RR-Center	1052	47.0%
	2b	MF-Left	2305	
		MF-Above	2192	
		MF-Right	1511	
		RR-Center	1107	55.3%
	2c**	MF-Left	1511	
		MF-Above	2416	
		MF-Right	2457	
		RR-Center	1120	52.6%

* The FPCR's used at these stations have particle collection surfaces which had been ground flat on polishing wheel.

** The FPCR's used at these stations were fabricated and coated with silicone grease at Dugway.

FE 138 SUMMARY

Efficiency measurements made	24
Average Collection Efficiency	54.1%
Standard Deviation	4.82%
Coefficient of Variation	.089

Table A-9

Rotorod Collection Efficiency Test Results

FE 139 - Trials A, B, C & D 21 Aug 1962

FP Material: DPG 12-21 - 1.2×10^{10} PPG - 3.4μ MMD

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
139A	1a	MF-Left	813	
		MF-Above	878	
		MF-Right	896	
		RR-Center	611	70.9%
	1b	MF-Left	813	
		MF-Above	813	
		MF-Right	853	
		RR-Center	561	67.9%
	1c	MF-Left	853	
		MF-Above	896	
		MF-Right	1032	
		RR-Center	641	69.1%
	2a	MF-Left	793	
		MF-Above	813	
		MF-Right	760	
		RR-Center	509	64.5%
	2b	MF-Left	860	
		MF-Above	793	
		MF-Right	654	
		RR-Center	512	66.5%
	2c	MF-Left	654	
		MF-Above	760	
		MF-Right	713	
		RR-Center	505	71.2%

(Table A-9 continued on next page)

Table A-9 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
139B	1a	MF-Left	437	
		MF-Above	362	
		MF-Right	378	
		RR-Center	261	66.6%
	1b	MF-Left	388	
		MF-Above	437	
		MF-Right	394	
		RR-Center	268	66.0%
	1c	MF-Left	394	
		MF-Above	378	
		MF-Right	424	
		RR-Center	278	69.6%
	2a	MF-Left	504	
		MF-Above	471	
		MF-Right	470	
		RR-Center	258	53.5%
	2b	MF-Left	525	
		MF-Above	504	
		MF-Right	419	
		RR-Center	256	53.0%
	2c	MF-Left	419	
		MF-Above	470	
		MF-Right	459	
		RR-Center	256	57.0%

(Table A-9 continued on next page)

Table A-9 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency=Rotorod Dosage / Avg. MF Dosage
139C	1a	MF-Left	690	
		MF-Above	670	
		MF-Right	718	
		RR-Center	410	59.2%
	1b	MF-Left	760	
		MF-Above	690	
		MF-Right	685	
		RR-Center	390	54.8%
	1c	MF-Left	685	
		MF-Above	718	
		MF-Right	762	
		RR-Center	407	56.4%
	2a	MF-Left	658	
		MF-Above	747	
		MF-Right	720	
		RR-Center	360	50.8%
	2b	MF-Left	739	
		MF-Above	672	
		MF-Right	728	
		RR-Center	381	53.4%
	2c	MF-Left	728	
		MF-Above	720	
		MF-Right	699	
		RR-Center	355	49.6%

(Table A-9 continued on next page)

Table A-9 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency= Rotorod Dosage / Avg. MF Dosage
139D	1a*	MF-Left	710	
		MF-Above	751	
		MF-Right	692	
		RR-Center	506	70.4%
	1b**	MF-Left	796	
		MF-Above	710	
		MF-Right	840	
		RR-Center	462	59.1%
	1c	MF-Left	839	
		MF-Above	692	
		MF-Right	894	
		RR-Center	492	60.9%
	2a*	MF-Left	711	
		MF-Above	708	
		MF-Right	748	
		RR-Center	416	57.6%
	2b**	MF-Left	580	
		MF-Above	711	
		MF-Right	867	
		RR-Center	381	53.0%
	2c	MF-Left	867	
		MF-Above	748	
		MF-Right	725	
		RR-Center	421	54.0%

* The FPCR's used at these stations are Metronics fabricated Rods which had been coated with silicone grease 77 days prior to use.

** The FPCR's used at these stations are Dugway fabricated Rods which had been coated with silicone grease 8 months prior to use.

FE 139 SUMMARY

Efficiency measurements made	24
Average Collection Efficiency	60.7%
Standard Deviation	7.05%
Coefficient of Variation	.116

Table A-10

Rotorod Collection Efficiency Test Results

FE 140 - Trials A, B, C & D   16 Nov 1962

FP Material: 1339-2 - 1.6 x 10^{10} PPG - 3.1μ MMD

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
140A	1a	MF-Left	1229	
		MF-Above	1377	
		MF-Right	1242	
		RR-Center	906	70.6%
	1b	MF-Left	1327	
		MF-Above	1229	
		MF-Right	1216	
		RR-Center	920	73.2%
	1c	MF-Left	1216	
		MF-Above	1242	
		MF-Right	1441	
		RR-Center	910	70.0%
	2a	MF-Left	1102	
		MF-Above	1193	
		MF-Right	1247	
		RR-Center	856	72.5%
	2b	MF-Left	1222	
		MF-Above	1102	
		MF-Right	1209	
		RR-Center	760	64.5%
	2c	MF-Left	1209	
		MF-Above	1247	
		MF-Right	1315	
		RR-Center	814	64.8%

(Table A-10 continued on next page)

Table A-10 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
140B	1a	MF-Left	690	
		MF-Above	817	
		MF-Right	672	
		RR-Center	552	76.0%
	1b	MF-Left	822	
		MF-Above	690	
		MF-Right	824	
		RR-Center	602	77.3%
	1c	MF-Left	824	
		MF-Above	672	
		MF-Right	715	
		RR-Center	581	78.8%
	2a	MF-Left	726	
		MF-Above	852	
		MF-Right	674	
		RR-Center	686	89.9%
	2b	MF-Left	1056	
		MF-Above	762	
		MF-Right	863	
		RR-Center	762	85.2%
	2c	MF-Left	863	
		MF-Above	657	
		MF-Right	1052	
		RR-Center	694	80.9%

(Table A-10 continued on next page)

Table A-10 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency=Rotorod Dosage / Avg. MF Dosage
140C	1a	MF-Left	1495	
		MF-Above	1313	
		MF-Right	1037	
		RR-Center	804	62.7%
	1b	MF-Left	1200	
		MF-Above	1495	
		MF-Right	1308	
		RR-Center	943	70.7%
	1c	MF-Left	1308	
		MF-Above	1037	
		MF-Right	1091	
		RR-Center	891	77.8%
	2a	MF-Left	864	
		MF-Above	1183	
		MF-Right	997	
		RR-Center	800	78.8%
	2b	MF-Left	1213	
		MF-Above	864	
		MF-Right	1129	
		RR-Center	826	77.3%
	2c	MF-Left	1129	
		MF-Above	997	
		MF-Right	1120	
		RR-Center	886	81.9%

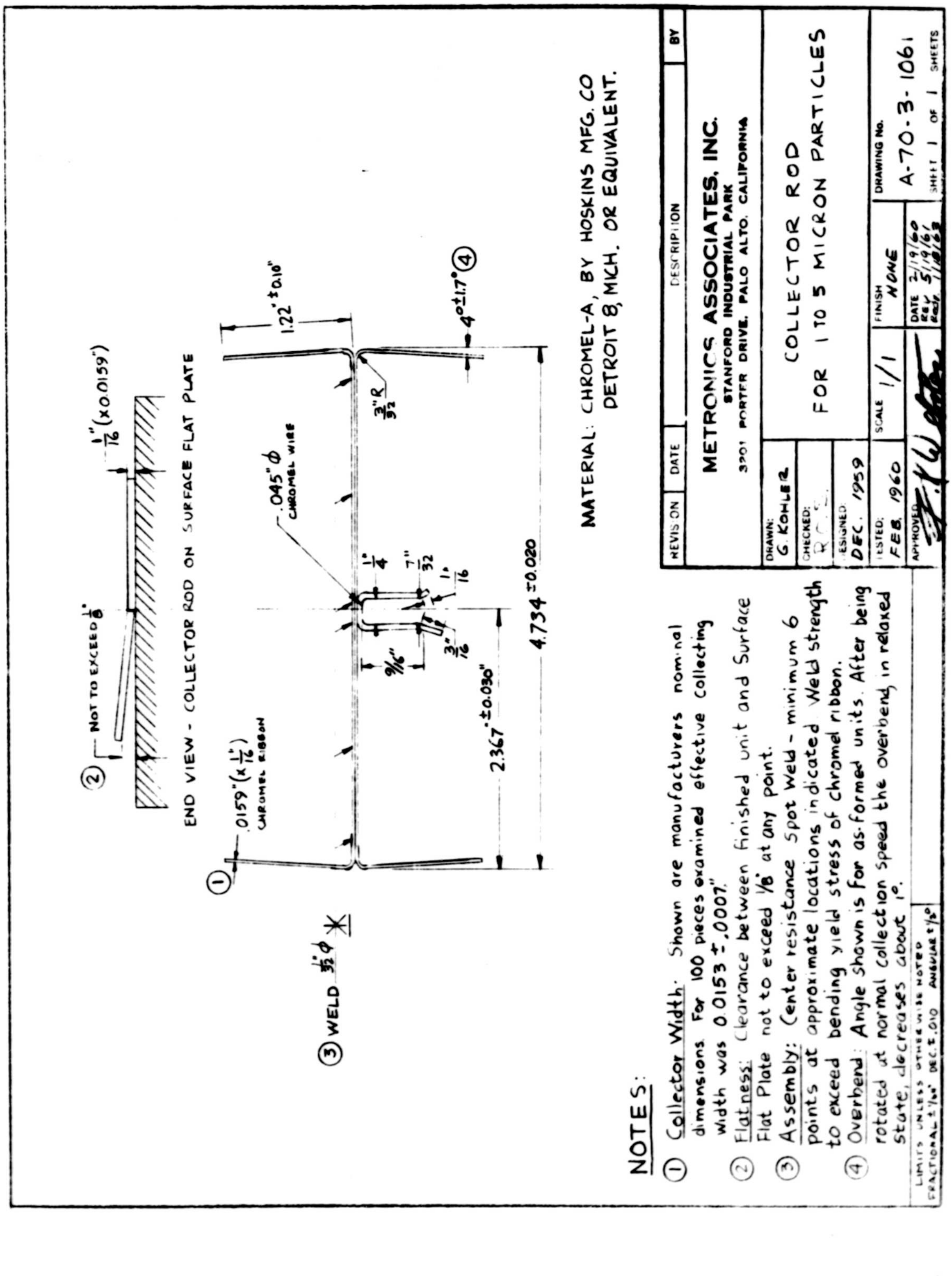
(Table A-10 continued on next page)

Table A-10 (continued)

FE-Trial No.	Station No.	Sampler Type-Psn	Total Dosage	Efficiency = Rotorod Dosage / Avg. MF Dosage
140D	1a	MF-Left	749	
		MF-Above	818	
		MF-Right	714	
		RR-Center	590	77.6%
	1b	MF-Left	881	
		MF-Above	749	
		MF-Right	832	
		RR-Center	591	72.0%
	1c	MF-Left	832	
		MF-Above	714	
		MF-Right	807	
		RR-Center	601	76.6%
	2a	MF-Left	546	
		MF-Above	554	
		MF-Right	554	
		RR-Center	390	70.8%
	2b	MF-Left	567	
		MF-Above	546	
		MF-Right	471	
		RR-Center	369	69.9%
	2c	MF-Left	471	
		MF-Above	554	
		MF-Right	612	
		RR-Center	394	72.2%

FE 140 SUMMARY

Efficiency measurements made	24
Average Collection Efficiency	74.7%
Standard Deviation	6.34%
Coefficient of Variation	0.085


NOT TO EXCEED 1/8"
1/16"(x0.0159")
END VIEW - COLLECTOR ROD ON SURFACE FLAT PLATE
.0159"(x 1/16") CHROMEL RIBBON
.045" Φ CHROMEL WIRE
3/32" R
1.22" ±0.10"
4° ±1.7°
1/4"
7/32"
1/16"
3/16"
9/16"
2.367" ±0.030"
4.734 ±0.020
WELD 1/32" Φ
MATERIAL: CHROMEL-A, BY HOSKINS MFG. CO
DETROIT 8, MICH. OR EQUIVALENT.
NOTES:
1 Collector Width: Shown are manufacturers nominal dimensions. For 100 pieces examined effective collecting width was 0.0153 ±.0007"
2 Flatness: Clearance between finished unit and Surface Flat Plate not to exceed 1/8" at any point.
3 Assembly: Center resistance Spot Weld - minimum 6 points at approximate locations indicated. Weld strength to exceed bending yield stress of chromel ribbon.
4 Overbend: Angle shown is for as-formed units. After being rotated at normal collection speed the overbend, in relaxed state, decreases about 1°.
LIMITS UNLESS OTHERWISE NOTED
FRACTIONAL ±1/64" DEC. ±.010 ANGULAR ±1/2°
REVISION
DATE
DESCRIPTION
BY
METRONICS ASSOCIATES, INC.
STANFORD INDUSTRIAL PARK
3201 PORTER DRIVE, PALO ALTO, CALIFORNIA
DRAWN: G. KOHLER
CHECKED:
DESIGNED: DEC. 1959
TESTED: FEB. 1960
APPROVED:
COLLECTOR ROD
FOR 1 TO 5 MICRON PARTICLES
SCALE 1/1
FINISH NONE
DATE 2/19/60
REV 5/19/61
REV 1/18/63
DRAWING No. A-70-3-1061
SHEET 1 OF 1 SHEETS

APPENDIX C

Procedure for Coating Collector Rods for Rotorod Sampling

I. Coating Materials

To ensure the complete retention of all aerosol particles which are impacted on the whirling collector arms of a Rotorod Sampler, it is essential that the intended collection surfaces be coated with a tacky or adhesive material. Only those surfaces parallel to the axis of rotation need be coated, i.e. coat only those surfaces which sweep-out a cylindrical annulus when the collector rod is rotated. Note - when not being rotated the free ends of the normally upward (or downward) projecting arms of the collector rod are bent inward toward each other a few degrees; when the rod is rotated approximately 2400 RPM these free ends move outward until collector arms become parallel to axis of rotation, i.e., become vertically oriented when sampler is operated on top of a post or tripod.

The two materials found to be most generally satisfactory for coating collector rods are rubber cement and silicone grease. Other materials used are glycerine-gelatine, corn syrup, and double-coated scotch tape. In addition to the particle retention qualities, ease of application, and ready availability of various coating materials, consideration must also be given to the effect that a given coating material may have on the preservation and analysis of the specific type of particles to be collected and examined. Also for many applications of the Rotorod Sampler, if the collector rods are to be examined under a visible light microscope the bright metal surfaces of the rod should be painted with a flat black paint of the type used inside optical instruments.

II. Rubber Cement

A satisfactory coating of rubber cement is applied by dipping each arm of the collector rod into a container of properly thinned rubber cement. A minimum of two dips is required to build-up a suitably smooth and tacky collection surface - and when properly done two dips are sufficient for obtaining high collection and retention efficiency.

The rubber cement as supplied by the manufacturer is too viscous and hence must be thinned with a suitable solvent. Proper consistency is obtained when two to five drops of the thinned cement fall from the end of a collector rod after it is quickly withdrawn from the liquid. The recommended materials for this procedure are "Best-Test White Rubber Paper Cement" and "Bestine Solvent and Thinner", both manufactured by Union Rubber & Asbestos Company, Trenton, New Jersey. These materials are usually available at a well stocked stationery and art supply store. A formulation consisting of about equal proportions of cement and thinner usually give the desired consistency.

The thinned cement is usually stored in two wide-mouth glass jars with tight fitting screw-top caps - two jars are prepared so that two arms of a collector rod can be immersed at the same time. The recommended step-wise procedure for coating rods* is as follows:

1. The rod arms are dipped into the cement slowly to facilitate uniform wetting of the metal surfaces and to prevent air bubbles from being carried into the liquid where they may later become attached to the rod and hence disturb an otherwise smooth surface coating.
2. After both arms of the collector rod have been immersed to the desired depth the rod is withdrawn slowly to allow the excess cement to drain off smoothly so that a uniform layer of cement will be retained on the rod.
3. On removal from the liquid the rod is kept suspended tip-end down to allow any excess fluid cement to flow to the tip-end. Any globule of liquid collecting at the tip-end should be removed promptly by touching the tip of the rod with a piece of blotting paper.
4. After allowing at least one minute for the first dip to dry the second coating can then be applied by repeating the above steps.
5. After the second coat has been allowed to dry for a few minutes the coated rods should then be stored until needed in an essentially dust-free container. Although extreme aging reduces the collection and retention efficiency of the rubber cement coating, collector rods which have been coated up to 90 hours prior to use have given about as good collection efficiencies as have freshly coated rods.

III. Silicone Grease

Under certain environmental conditions such as very high or low temperatures or when the Rotorod Sampler is operated in rain or fog the rubber cement

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* This step-wise procedure applies literally only to the 2 arm U-shaped brass collector rod designed for 20-micron particles (1.59 mm impactor width); modification of this procedure for coating the 4 arms of the H-shaped chromel collector rod for 1-5 micron particles (0.38 mm impactor width) should be fairly obvious.

coating tends to lose some of its tackiness. Under such conditions a thin coating of silicone grease provides a satisfactory surface for retention of impacted particles. Also for sampling very large particles (e.g., 50 micron glass beads) the silicone grease is superior to rubber cement. For this purpose Dow Corning High Vacuum Grease is a satisfactory material and is used in the consistency as supplied by the manufacturer.

A coating of this grease may be applied to either of the two standard collector rods in the following manner:

1. Lightly touch the surface of the grease in its container with the forefinger to pick up a small amount.
2. Spread this evenly and thinly on the fingers by smearing between the forefinger and the thumb.
3. Hold the collector rod firmly at the center and grasp one end of narrow impaction surfaces between the two greased fingers. Using gentle pressure, slide fingers along entire length of impaction surfaces, thus transferring to these metal surfaces a thin coating of grease.

At best a grease coating will not be as smooth as a rubber cement coating but if applied carefully will be satisfactory and especially so for retention of particles 10 microns and larger. Since both impaction surfaces of each collection arm are coated with the silicone grease, the collector rod thus prepared can then be rotated, first in one direction and then in the other, to collect two separate samples.

Since silicone grease, unlike the thinned rubber cement, does not flow and thus distribute itself uniformly over the metal surfaces there is a tendency to use excessive amounts of grease and for some of this excess to overhang the narrow edges of the rod. Any such overhang increases the effective impaction width and thus decreases the collection efficiency. Such overhang can be avoided by using smaller amounts of grease on the fingers when applying it to rod. Excess grease overhanging the edges can be removed without greatly disturbing the prepared impaction surfaces by running a sharp edged tool along both sides of each collector arm.

One advantage of silicone grease as a collector rod coating is that such coatings do not appear to lose with age any of their particle collection and retention effectiveness as do rubber cement and other coating materials. Thus silicone grease coated rods may be safely prepared several weeks in advance of the time they are to be exposed. Prepared rods, coated with grease or any other tacky material, should of course be stored in a dust-free container, both before and after exposure.

IV. Removal of Rod Coatings

The rubber cement coating can be easily peeled off by starting at the fixed end of the collector arm and merely rolling it toward and off the tip end. All particulate material will be enclosed within the tiny rubber ball and the rod can then be redipped in the thinned rubber cement without further cleaning treatment.

The silicone grease coating can be largely removed by wiping with an absorbent lint-free cloth. If necessary, further cleansing can be accomplished with ethylene dichloride heated to boiling in a narrow mouth flask. Insertion of a collector arm into the neck of the flask allows condensation on the rod and a resultant washing as the condensate flows down the rod and drips back into the flask. This step can be avoided by careful wiping followed by visual inspection to ensure that all particulate material of the kind to be sampled has been removed along with the grease.

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