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Laboratory Evaluation of the CIP 10 Personal Dust Sampler*

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The "capteur individuel de poussiere" CIP 10 personal dust sampler—developed by the Centre d'Etudes et Recherches de Charbonnages de France (CERCHAR) research organization—is a small, quiet, lightweight unit which samples at a flow rate of 10 L/min. It is a three-stage sampler, using two stages to remove nonrespirable dust particles and one stage to collect the respirable fraction. Airflow through the sampler is induced by the third stage, which is a rotating collector cup that contains a fine grade sponge. Laboratory tests were conducted in a dust chamber using aerosols of Arizona road dust, coal dust and silica dust. Aerosol concentrations measured with the CIP 10 were compared to those measured with the coal mine dust personal sampler unit used in the United States. The results of this study showed that aerosol concentrations measured with the CIP 10 were linearly related to those obtained with the coal mine dust personal sampler. The relationship, however, was dependent on preselector configuration and aerosol characteristics. The collection medium allows some small particles (less than 3 μm) to pass through the sampler without being collected. As much as 13% (by weight) of the aerosol that penetrated through the preseparating stages was exhausted from the sampler.

Introduction

Monitoring of the industrial environment to ensure that workers are not exposed to unhealthy concentrations of noxious fumes and dusts often is accomplished with personal samplers (particulate sampling devices which are secured to the worker's clothing). The personal sampler commonly consists of a sampling head, which is located in the worker's breathing zone (near the worker's head), and an air pump, attached to the worker's belt. For respirable mass sampling, the sampling head normally consists of a filter for particulate collection and a Dorr-Oliver 10-mm nylon cyclone preseparator. The sampling head is connected to the pump through a length of flexible tubing. The 10-mm nylon cyclone preseparator was included in a listing of available size-selective devices for use with "respirable" mass dust limits written by the Aerosol Technology Committee, American Industrial Hygiene Association.[1] A preseparator identical to the Dorr-Oliver cyclone is required as part of all approved coal mine dust personal sampler units used for sampling respirable coal mine dust in coal mines in the United States.[2]

Since its development the personal respirable dust sampler has undergone several evolutionary changes; however, it is recognized that there is still room for improvement. The connecting tubing is an inconvenience to the wearer and has the potential of getting caught when the wearer works near machinery. The tubing also can get kinked or pinched, making the validity of the sample questionable. Since the personal sampler is operated at an airflow rate of 1.7 or 2.0 L/min, the amount of sample available for analysis often is limited. Finally, it has been shown[3,4] that the orientation of the cyclone inlet with respect to the direction of airflow may affect the cyclone's particle collection characteristics, particularly at higher wind speeds.

*Reference to specific brands, equipment, or trade names in this report does not imply endorsement by the Mine Safety and Health Administration.

A personal sampler whose design attempts to avoid many of these problems has recently been developed by the Centre d'Etudes et Recherches de Charbonnages de France (CERCHAR) research organization. The sampler, called the CIP 10, has a height of 16.5 cm (6.5 in), a width of 7 cm (2.75 in) and a maximum thickness of 4.5 cm (1.75 in). Its weight is 280 grams (10 oz). The CIP 10 is shown with the coal mine dust personal sampler unit in Figure 1. Figure 2 shows a schematic diagram of the CIP 10. The sample inlet is symmetrical with respect to the vertical axis of the sampler—an effort to minimize orientation effects. The sampling head, air mover and power pack are all combined into an integral package with no interconnecting tubing. Sampled air is induced into the sampler by a sponge ring contained in a rotating plastic cup. Unusual preseparation and sample collection methods are used. The preseparator consists of a small impactor, which removes the larger particles entering the sampler, and a polyurethane foam sponge, which additionally removes a fraction of the nonrespirable dust. Particles penetrating the foam sponge are collected by the denser, rotating foam-sponge ring in the plastic cup. The penetration characteristics of the preseparator are determined by the porosity and thickness of the sponge used. The unit has a sampling flow rate of 10 L/min which is controlled by the rotation rate of the sponge ring.

The respirable mass concentration is determined by preweighing and post-weighing of the plastic cup and sponge ring. The impactor and both polyurethane sponges, however, can be removed from the sampler and washed to recover the particulate material for further analysis. Because of the higher flow rate of the CIP 10, it collects more material than does a personal sampler with the 10-mm nylon cyclone.

Polyurethane foam sponges are available with three pore sizes and in two thicknesses. A coarse sponge contains 45 pores per inch, a medium sponge contains 60 pores per inch

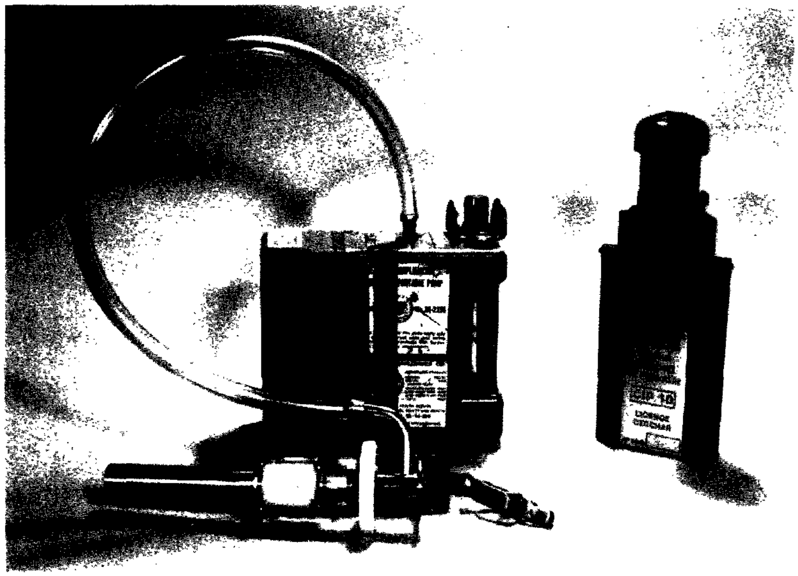

Figure 1—Coal mine dust personal sampler unit and CIP 10.

and a fine sponge contains 100 pores per inch. Coarse and medium sponges are available in both 10-mm and 20-mm thicknesses; the fine grade sponge is supplied only in the smaller thickness.

The sponge in the collection cup is a fine-grade foam material. Particulate collection is not absolute; therefore, a fraction of small particles passes through the sampler without being collected. The fraction retained in the cup is supposed to represent the "respirable fraction" of the aerosol sampled.

This paper describes an investigation conducted to evaluate the particulate collection characteristics of the CIP 10 personal dust sampler and to compare aerosol concentration measurements obtained with it to measurements obtained with the coal mine dust personal sampler (CMDPS) used to sample United States coal mine environments.

Procedures

Two CIP 10 samplers, a CMDPS and a total dust sampler were placed in close proximity in a dust chamber and exposed to a coal dust, silica dust, or Arizona road dust (ARD) aerosol for a period of four to six hours. Comparative measurements with the ARD aerosol were obtained in a 0.3-m^3 chamber. The ARD aerosol was introduced into the chamber using a TSI Model 3400 fluidized bed aerosol generator (TSI, Inc., St. Paul, Minn.).[5] Comparative measurements in the coal and silica aerosols were obtained in a 3.2-m^3 dust chamber[6] using a lift tube dust feeder.[7] The parameters (mass median aerodynamic diameter and geometric standard deviation) defining the particle-size distributions of the test aerosols are shown in Table I. The CMDPS was operated at a flow rate of 2.0 L/min, and the total dust sampler at 1.7 L/min. The 37-mm diameter, 5-μm pore size polyvinyl chloride membrane filters used in the CMDPS and total dust sampler were preweighed and postweighed to 0.001 mg on a Mettler ME-30 microanalytical balance, and the CIP 10 collector cups were preweighed and postweighed to 0.01 mg on a Mettler H-64 semimicroanalytical balance (Mettler Instrument Corp., Hightstown, N.J.). The collector cups were weighed on a different balance because of their large mass, approximately 3400 mg.

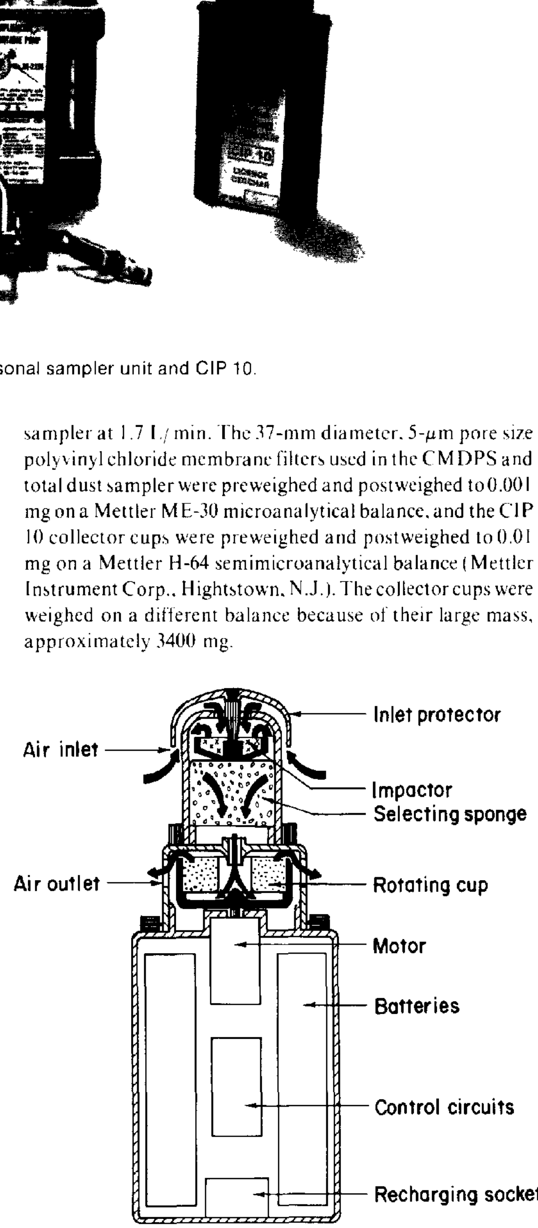

Figure 2—Schematic of the CIP 10.

TABLE I
Aerosol Particle Size Parameters

	Mass Median Aerodynamic Diameter (μm)	Geometric Standard Deviation
Coal	8.48	2.68
ARD[A]	5.58	2.14
Silica	8.16	2.34

[A]ARD = Arizona road dust.

The weight of the CIP 10 collector cup is sensitive to changes in temperature and humidity. To correct for weight changes because of these environmental factors, a "reference" collector cup was weighed along with those used for sample collection. Sample weights were adjusted by the weight change of the reference cup. The consistency of weight changes among collector cups was tested by weighing 4 cups at 5 different times and comparing the weight changes of the cups. The results, shown in Table II, indicate that although some observed weight changes were greater than 2 mg the differences in weight changes among collector cups were small compared to sample sizes likely to be collected during full-shift sampling in most industrial environments. The largest difference among the weight changes of the 4 collector cups (0.16 mg) would result in an error of 0.03 mg/m^3 in the calculation of a full-shift aerosol concentration.

Aerosol concentrations measured by each sampler were calculated from the weight change of the collector and the volume of air sampled. In some cases, after the sample weight was determined, the particulate material retained in the cup and on the total dust filter was removed by washing with isopropanol. The removed dust was sized using a Model TA II Coulter Counter (Coulter Electronics, Inc., Hialeah, Fla.).[8] Data from the size analyses were used to measure the size dependence of aerosol capture by the collector cup. Equivalent volume diameters measured with the Coulter Counter were equated to the Stokes diameters (the diameter of a unit density sphere with the same falling speed as the irregularly shaped particle) by multiplying the equivalent volume diameter by the square root of the particle's density.[9] In order to determine the quantity and size distribution of the aerosol which passes completely through the CIP 10, an apparatus was constructed which had one CIP 10 exhaust into a sealed container. Air was removed from the container through a 37-mm diameter, open-face filter holder at a flow rate of 10.0 L/min. A critical orifice was used to control this flow. The filter was preweighed and postweighed to 0.001 mg. The sample was then sized in the same manner as were the other samples.

Results and Discussion

Table III shows comparative measurements obtained in the 3 aerosols with the CMDPS and with the CIP 10 using 3 sponge configurations: 20-mm coarse, 20-mm medium, and 10-mm coarse followed by 10-mm fine. The mean and standard deviation of the ratios of the concentration measured by the CIP 10 and the concentration measured by the CMDPS for each configuration in each aerosol are shown in Table IV. The differences of the ratios derived for the different aerosols (for each configuration) show that the relationships between measurements obtained with the two instruments are dependent on the characteristics (size distribution and density) of the aerosol sampled. Measurements obtained with the CIP 10 in the coal aerosol were within 10% of those obtained with the CMDPS when the 20-mm coarse sponge was used as a preseparator. The measurements were nearly equivalent in the silica aerosol with the 20-mm medium sponge preseparator and within 6% in the ARD aerosol with the combined coarse and fine 10-mm sponges.

The data shown in Table III are compared graphically in Figure 3. Also shown in Figure 3 are the least squares regression equations (which define the overall relationships established between comparative measurements obtained with the two sampling devices) and the standard error of estimate (which defines the variability to be expected in a CIP 10 measurement for a given CMDPS measurement). The relationship derived from comparative measurements obtained with the CIP 10 with the 20-mm medium sponge indicates that measurements obtained with this configuration are approximately the same as those obtained with the CMDPS. The relatively high standard error of estimate (0.32 mg/m^3) obtained with this configuration is attributed to the difference in particle collection characteristics of the two instruments.

TABLE II
Weight Changes of CIP 10 Collector Cups Observed during Repeated Weighings (mg)

Cup	C_{1-2}[A]	C_{2-3}	C_{3-4}	C_{4-5}	C_{1-3}	C_{1-4}	C_{1-5}	C_{2-4}	C_{2-5}	C_{3-5}
A	-0.27	-0.37	-0.07	+2.07	-0.64	-0.71	+1.36	-0.44	+1.63	+2.00
B	-0.23	-0.38	-0.11	+2.06	-0.61	-0.72	+1.34	-0.49	+1.57	+1.95
C	-0.27	-0.35	-0.09	+2.15	-0.62	-0.71	+1.44	-0.44	+1.71	+2.06
D	-0.32	-0.31	-0.05	+2.09	-0.63	-0.68	+1.41	-0.36	+1.73	+2.04
Range of Differences	0.09	0.07	0.06	0.09	0.03	0.04	0.10	0.13	0.16	0.11

[A]C_{a-b} indicates the change between the a^{th} weighing and the b^{th} weighing.

TABLE III
Comparison of Aerosol Concentrations Measured with the CMDPS and the CIP 10

	Coal			ARD[A]			Silica (SiO_2)		
Preselector Sponge	CMDPS	CIP 10	CIP 10/ CMDPS	CMDPS	CIP 10	CIP 10/ CMDPS	CMDPS	CIP 10	CIP 10/ CMDPS
20-mm Coarse	0.26	0.32	1.23	0.34	0.53	1.56	0.43	0.54	1.26
	0.26	0.28	1.08	0.34	0.57	1.68	0.43	0.51	1.19
	1.38	1.59	1.15	0.91	1.71	1.88	2.81	3.19	1.14
	1.38	1.49	1.08	0.91	1.50	1.65	2.81	3.18	1.13
	2.23	2.01	0.90	1.02	1.76	1.73	6.65	7.71	1.16
	2.27	2.44	1.07	1.02	1.57	1.54	6.65	8.17	1.23
	2.27	2.70	1.19	1.48	2.94	1.99	8.53	10.34	1.21
				1.48	2.70	1.82	8.53	9.96	1.17
				1.58	2.58	1.63			
20-mm Medium	0.38	0.25	0.66	0.25	0.27	1.08	0.57	0.58	1.02
	0.38	0.23	0.61	0.25	0.29	1.16	0.57	0.63	1.11
	0.48	0.29	0.60	1.58	1.80	1.14	1.35	1.26	0.93
	0.48	0.35	0.73	2.21	2.33	1.05	1.35	1.32	0.98
	1.75	1.15	0.66	2.21	2.50	1.13	1.56	1.57	1.01
	1.75	1.13	0.65	3.89	4.05	1.04	1.56	1.40	0.90
	2.23	1.38	0.62	3.89	4.40	1.13			
10-mm Coarse and 10-mm Fine	0.81	0.59	0.73	0.69	0.73	1.06	0.75	0.61	0.81
	0.81	0.63	0.78	0.69	0.78	1.13	0.75	0.64	0.85
	1.54	1.06	0.69	1.94	2.02	1.04	1.87	1.40	0.75
	1.54	1.12	0.73	2.20	2.22	1.01	1.87	1.40	0.75
	2.11	1.34	0.64				2.46	1.99	0.81
	2.11	1.33	0.63				2.46	1.96	0.80
							4.81	3.48	0.72
							4.81	3.97	0.83
							6.32	4.33	0.69
							6.32	4.85	0.77

[A]ARD = Arizona road dust.

Figure 4 shows typical plots of the percentage of each aerosol collected in the CIP 10's collector cup with the three preseparator sponge configurations, as a function of particle size. Also shown are the size distributions of the aerosol fractions which were found to pass completely through the instruments. As the data show, except for the coarse sponge configuration, the penetration characteristics (percentage of dust collected in cup) for all 3 aerosols were similar for particles larger than 3 μm. The fraction of particles less than 3 μm in size penetrating the mixed configuration was significantly less, however. This is probably the reason for the amount of aerosol found penetrating the collection cup (Graph B) being significantly different with the mixed configuration than it was with the other two configurations.

Figure 5 shows a comparison of the sample collection characteristics in ARD of the CIP 10 with the three preselector sponge configurations to the British Medical Research Council (BMRC)[10] and American Conference of Governmental Industrial Hygienists (ACGIH)[11] respirable dust criteria. As shown, for particles with aerodynamic equivalent diameters larger than approximately 3 μm, the shape of the collection curve is similar to the ACGIH criterion, but the fraction of aerosol collected is larger than specified. For particles smaller than 3 μm, the fraction of particulates collected decreases with decreasing particle size, in contrast to both respirable dust criteria.

The data in Table IV also show that there was a larger fraction of the ARD than the other aerosols found in the collection cup. This is attributed to the fact that the ARD aerosol had the smallest mass median diameter and geometric standard deviation; therefore, a larger fraction of the aerosol penetrated the first stage preseparators.

The percentage of aerosol found to completely pass through the CIP 10 for the respective preseparator configurations is shown in Table V. Except for the ARD aerosol, the respirable fraction found penetrating the sampler was fairly constant (11% to 13%). From these experimental results, no explanation could be given as to why the fraction of ARD aerosol penetrating the CIP 10 was significantly less (58%) than that obtained for the other aerosols.

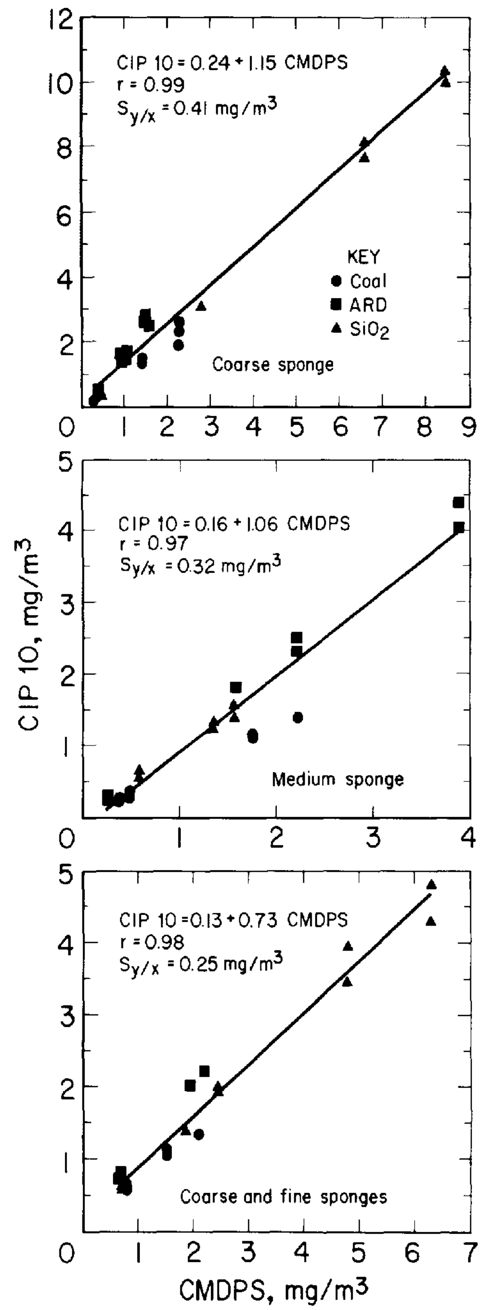

Figure 3—Comparison of aerosol concentrations measured with the CMDPS and the CIP 10.

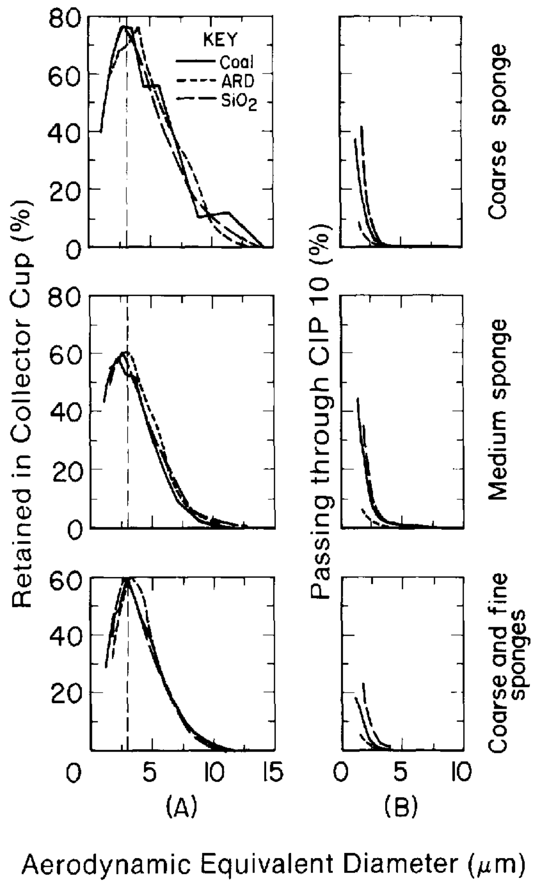

Figure 4—Percentages of aerosol captured by and passing through CIP 10.

Summary and Conclusions

This study was conducted to compare measurements obtained with a respirable dust sampler (CIP 10) developed in France by the CERCHAR research organization and the coal mine dust personal sampler unit. Comparative measurements of aerosols of ARD, coal and silica were obtained in the laboratory using the two samplers. Several variations in the first stage preseparator of the CIP 10 were evaluated to establish which preseparator configuration gave respirable mass concentration determinations most similar to those obtained with an approved coal mine dust personal sampler. The collection characteristics of the respirable dust retained were determined and compared to two criteria (ACGIH and BMRC) adopted for defining respirable dust.

The results of this study showed that measurements obtained with the CIP 10 could be related linearly to those obtained with a coal mine dust personal sampler unit. The relationship derived from comparative measurements was dependent on the size distribution and density of the aerosol sampled, however. The relationship between measurements also varied depending on the preseparation configuration used in the CIP 10.

Sample collection by the CIP 10 was found to differ from both the ACGIH and BMRC respirable aerosol criteria, regardless of the choice of preselector configuration. With any preseparator configuration, the fraction of small particles (less than approximately 3 μm) captured in the sample decreases with decreasing equivalent aerodynamic diameter. As much as 40% (by weight) of particles smaller than 1.5 μm may pass through the instrument without being captured in either the preselector or sample collection stages. The penetration was found to be as much as 13% of the respirable fraction passing through the preselector and to be dependent on the type of aerosol sampled. For particle sizes greater than 3 μm in size, the shape of the particle collection curve approximates that of the ACGIH criterion, although the fraction of particulates collected is greater than that specified by the criterion. Because the collection characteristics of the CIP 10 differ from the ACGIH and BMRC aerosol criteria, the relationship between concentrations measured with it and with an instrument which more closely approximates one of the criteria is strongly dependent on the size distribution of the aerosol being sampled.

Although the CIP 10 provides the user with several advantages by collecting a larger sample mass, eliminating connecting tubing which could become caught or kinked, and reducing orientation effects on particulate collection, it fails to sample according to any of the adopted respirable dust criteria. If measurements made with the CIP 10 are to be compared with standards based on the accepted respirable dust criteria, the relationship between measurements made with this instrument and measurements which meet the criteria must be determined.

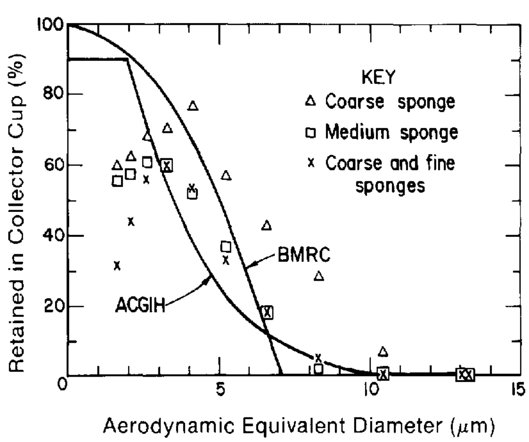

Figure 5—Comparison of percentages of ARD aerosol captured by the CIP 10 to respirable dust criteria.

TABLE IV
Mean and Standard Deviation of the Ratios of Comparative Measurements Obtained with the CIP 10 and the CMDPS

	Preseparator Configuration					
	20-mm Coarse		20-mm Medium		10-mm Coarse and 10-mm Fine	
Aerosol	Mean	S.D.	Mean	S.D.	Mean	S.D.
Coal	1.10	0.107	0.65	0.044	0.70	0.058
ARD[A]	1.72	0.150	1.10	0.047	1.06	0.051
Silica	1.19	0.045	0.99	0.074	0.78	0.051

[A]ARD = Arizona road dust.

TABLE V
Percentage of Respirable Aerosol Fraction Passing through the CIP 10

	Preseparator Configuration		
Aerosol	20-mm Coarse	20-mm Medium	10-mm Coarse and 10-mm Fine
Coal	11.0	13.0	13.6
ARD[A]	4.7	7.3	7.4
Silica	8.7	11.2	13.3

[A]ARD = Arizona road dust.

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