RESPIRATORY FUNCTION IN MEN CASTING CADMIUM ALLOYS

PART I: ASSESSMENT OF VENTILATORY FUNCTION

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The ventilatory function of the lungs was assessed in all but four of those workers from the two factories who took part in the investigation described by Bonnell (1955). The maximum ventilatory capacity test and tracings of the expiratory fast vital capacity were used as tests of ventilatory function. The performance of the group of subjects exposed to cadmium fume was compared with that of a control group of subjects who had not been so exposed. Individual performances in these tests, differing widely from the mean performance of the appropriate control group, were then compared with the clinical and radiological findings.

Methods

The tests were performed immediately before or immediately after the clinical examination. Subjects from the control and exposed groups reported in mixed order and, to avoid any possible bias in the conduct of the test, the operator was not informed of the group to which a particular individual belonged.

The following measurements were made on each subject with adequate rest periods between each part of the test.

- (1) Vital capacity, five estimations.
- (2) Maximum ventilatory capacity (M.V.C.) at 30 and 70 respirations per minute (R.P.M.). These measures are referred to as M.V.C.₃₀ and M.V.C.₇₀, the suffix in each case indicating the respiratory rate.
- (3) Four expiratory fast vital capacity curves were recorded.

The tests were performed on the spirometer described by Bernstein, D'Silva, and Mendel (1952) which was known to be free from appreciable recording error for the airflows involved.

The vital capacity was taken as the mean of the last four of the five estimates. For the M.V.C. test the subject was asked to breathe in and out of the spirometer as deeply as he was able in time to a metronome. He was asked to breathe through his mouth having been shown how to hold the mask on his face without producing a leak. The operator continually exhorted the

subject to breathe more deeply, and helped him by conducting the timing. The recording lasted about 15 seconds. The performance was repeated only if a leak occurred at the face-piece, or if the tidal excursions were grossly uneven, indicating that the subject was not performing to the best of his ability with each breath. It was never necessary to repeat the test at any respiratory rate more than once. All determinations were performed with the subjects standing.

From the mean tidal excursion for each tracing, the M.V.C. and the swept fraction were calculated for each respiratory rate (D'Silva, Freeland, and Kazantzis, 1953; D'Silva and Kazantzis, 1954).

For the expiratory fast vital capacity test the subject was asked to place the mask on his face, inspire as deeply as he was able, and, on receiving a signal, to expire into the spirometer as deeply and as fast as he could. This procedure was repeated four times by each subject. The mean time constant (D'Silva and Kazantzis, 1954) of the four fast vital capacity curves was determined.

Gas volumes were reduced to 37° C. saturated with water vapour at 760 mm. Hg.

Results

Factory A.—Of the 58 men who had worked at some time in the cadmium shop and who were examined clinically, 56 men performed the present series of tests. Sixteen men of this total exposed group had at some time been engaged on casting copper-cadmium alloys (Group 1A, cadmium casting workers). The remaining 40, while working in the same comparatively small shop and being exposed to cadmium fume to a varying degree, had not actually been employed in casting cadmium (Group 1A, vicinity workers). The control group (CA) was made up of 60 men who had never worked in the cadmium shop. They were chosen on an age basis (Bonnell, 1955, Table 1) by the administrative staff of the factory from a considerably larger number of volunteers from other parts of the

TABLE 1

MEAN VALUES AND STANDARD DEVIATIONS FOR AGE, HEIGHT, AND WEIGHT IN THE CONTROL AND EXPOSED GROUPS OF BOTH FACTORIES

Group	Number of Subjects	Age		Height (in.)		Weight (lb.)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
<i>Factory A</i>							
Control (CA)...	60	49.4	9.30	67.2	2.32	157.6	21.94
Cadmium workers (1A)	16	48.9	8.44	68.0	3.01	154.3	19.74
Vicinity workers (1A)	40	49.0	10.60	67.4	2.33	160.5	27.47
<i>Factory B</i>							
Control (CB)...	44	39.8	12.00	66.4	2.15	139.9	13.97
Cadmium workers (1B)	40	41.4	10.62	66.9	2.99	148.9	25.66

works. All the men in this group performed the present tests. The mean ages, with standard deviations, for the groups described are shown in Table 1. Corresponding figures for the heights and weights are also shown. It can be seen that the groups are similar regarding these three characteristics, and analysis by Student's *t* test shows no significant differences between the means. Throughout this paper the 5% level of significance is referred to unless otherwise stated but the probability levels are shown in the Tables.

The approximate number of years spent in the casting shop by each individual in the exposed group is shown on a scatter diagram (Fig. 1). It was not possible to assess accurately the number of years spent on the copper-cadmium process by the 16 cadmium casting workers as all of them had also performed other duties in the same shop, but the 16 cadmium workers and 32 of the 40 vicinity workers had been employed in the casting shop for more than 10 years.

The results of the tests for the three groups and for the total exposed group are shown in Table 2. For each, the vital capacity, the M.V.C.₇₀, the swept fraction at two respiratory rates, and the time constant of the expiratory fast vital capacity curve are shown. The mean value and standard deviation for each group are given. The differences between the mean values for the control and exposed groups were analysed using the *t* test. For vital capacity, for M.V.C.₇₀, and for swept fractions, the *P* values refer to the probability of obtaining a mean value less than the control mean, and for time constant they refer to the probability of obtaining a mean value greater than the control mean. The mean value for the vital capacity and maximum ventilatory capacity is not significantly lower in the total exposed group or its component subgroups compared with the control group. The mean values for the two swept fractions are signifi-

cantly lower in the total exposed group, and the mean expiratory time constant is significantly higher in the exposed than in the control group. Table 2 shows that when the total exposed group is split into cadmium casting and vicinity workers the values for the swept fractions and time constant differ furthest from the control values in the group of workers casting cadmium. The differences of these means are highly significant. For the vicinity workers the mean value of the swept fraction at 70 R.P.M. is significantly lower, and the mean

FIG. 1.—Approximate number of years spent in the casting shop in the exposed group.

TABLE 2
MEAN VALUES AND STANDARD DEVIATIONS (IN BRACKETS) FOR VITAL CAPACITY, MAXIMUM VENTILATORY CAPACITY AT 70 R.P.M., SWEEP FRACTIONS AT 30 AND 70 R.P.M., AND FOR TIME CONSTANT OF EXPIRATORY FAST VITAL CAPACITY CURVE AT FACTORY A

Test		Control Group (CA)	Total Exposed Group (1A)	Cadmium Casting Workers	"Vicinity" Workers
Vital capacity		3.99 (0.72)	4.12 (1.06) 0.8 > P > 0.75	4.46 (1.18) 0.98 > P > 0.95	3.98 (1.00) 0.5 > P > 0.4
M.V.C. ₇₀		138 (32)	130 (47) 0.2 > P > 0.15	132 (51) 0.3 > P > 0.25	130 (46) 0.2 > P > 0.1
Swept fraction	at 30 r.p.m. ..	71.7 (8.83)	67.9 (11.24) 0.025 > P > 0.01	65.1 (10.30) P < 0.01	69.0 (11.54) 0.1 > P > 0.05
	at 70 r.p.m. ..	49.3 (7.75)	44.3 (10.75) P < 0.01	41.1 (8.87) P < 0.001	45.5 (11.15) 0.025 > P > 0.01
Time constant (sec.) ..		0.59 (0.16)	0.76 (0.44) P < 0.01	0.84 (0.39) P < 0.001	0.73 (0.46) 0.025 > P > 0.01

The P values refer to comparisons between each group and the control group.

value for the time constant significantly higher than in the control group.

To summarize the findings in factory A: there is no evidence that exposure to cadmium affects the vital capacity adversely, and the groups cannot be distinguished by means of their maximum ventilatory capacities. The swept fractions at the two respiratory rates are significantly lower in the exposed group, and the time constant of the expiratory fast vital capacity curve significantly greater. These measures thus provide a method for differentiating between the means of the control and exposed groups.

Factory B.—The exposed group (1B) was made up of 40 of the 42 men who took part in the clinical examination. Thirty-six of these men were also examined by Buxton (Part II). The control group (CB), composed of subjects performing the same kind of work casting metals but who had never been exposed to cadmium fume, was made up

from workers volunteering for examination from the brass and iron foundries. As in Factory A, they were picked by the administrative staff on an age basis (Bonnell, 1955, Table 1). All 44 men who were clinically examined performed the lung function tests, and, of these, 37 men were examined by Buxton. The means and standard deviations for age, height, and weight, are given in Table 1. The groups are homogeneous in these respects, and no significant differences can be detected with the t test.

The number of years spent by each individual in the casting shop is shown in the scatter diagram (Fig. 1). The pattern of exposure is different from that in Factory A. In Factory B 28 men out of 40 worked in the cadmium casting shop for less than 10 years, 12 men had been exposed for from 10 to 28 years. Also, the type of exposure in the two factories was not comparable, as the casting process in Factory B was different, and the workshop was much larger than that in Factory A.

TABLE 3
MEAN VALUES AND STANDARD DEVIATIONS (IN BRACKETS) FOR VITAL CAPACITY, M.V.C.₇₀, SWEEP FRACTIONS AT 30 AND 70 R.P.M., AND FOR TIME CONSTANT OF EXPIRATORY FAST VITAL CAPACITY CURVE AT FACTORY B

Test		Control Group (CB)	Total Exposed Group (1B)	> 10 Years' Exposure	< 10 Years' Exposure
Vital capacity		4.46 (0.69)	4.32 (0.82) 0.25 > P > 0.2	3.95 (1.03) 0.02 > P > 0.01	4.47 (0.68) P > 0.05
M.V.C. ₇₀		148 (29)	142 (50) 0.3 > P > 0.25	118 (50) P < 0.01	153 (47) P > 0.05
Swept fraction	at 30 r.p.m. ..	70.0 (9.19)	67.3 (14.03) 0.25 > P > 0.2	61.6 (14.96) P < 0.01	69.7 (13.14) P > 0.05
	at 70 r.p.m. ..	47.5 (8.35)	46.2 (12.29) 0.3 > P > 0.25	41.8 (12.58) 0.05 > P > 0.02	48.1 (11.87) P > 0.05
Time constant (sec.) ..		0.58 (0.26)	0.79 (0.63) 0.02 > P > 0.01	0.98 (0.82) P < 0.01	0.71 (0.52) P > 0.05
Age		39.8 (12.00)	41.4 (10.62) P > 0.05	49.8 (9.11) P < 0.01	37.8 (9.20) P > 0.05

The P values refer to comparisons between each group and the control group.

The results for the two groups are shown in Table 3. For each group, the mean and standard deviation are given for vital capacity, for M.V.C.₇₀, for the swept fraction at the two respiratory rates, and for the time constant of the expiratory fast vital capacity curve. For each measurement, the significance of the difference between the means in the exposed and control groups was tested by the *t* test. No significant differences between the means were found for vital capacity, maximum ventilatory capacity, or swept fraction, but the mean time constant of the expiratory fast vital capacity curve was significantly longer in the exposed group. The trend of the means in the other observations is, however, in the expected direction and the scatter around the mean is greater in the exposed group.

When the exposed group is divided into those subjects with 10 years' and over and less than 10 years' exposure, significant differences are found between the control group and those exposed over 10 years (Table 3). However, the subjects with the longer exposure were the older members of the group so that the mean age of the 12 subjects comprising the maximally exposed group was about 10 years greater than that of the control group or of the group exposed for less than 10 years. The effect of age on performance in the tests had therefore to be ascertained before differences could be attributed to exposure to cadmium fume.

Partial regression coefficients on age and on years of exposure to cadmium were calculated from the pooled data of the two groups, treating the control group as having zero exposure (Table 4). From the partial regression coefficients it was concluded that between the control and maximally exposed groups, differences in the means for vital capacity, M.V.C.₇₀, and swept fraction at 30 and 70 R.P.M. could be explained by the effect of age. For the time constant of the expiratory fast vital capacity curve, a significant regression on exposure

was demonstrated, the regression on age not reaching the 10% level of significance. For the time constant, the difference between the groups is therefore likely to be due, at least in part, to exposure to cadmium as distinct from age.

Individual Performances in the Two Factories Compared with Clinical and Radiological Findings

Individual performances have been compared with the mean performance of the control group in the factory. Values for the swept fraction lower than twice the standard deviation from the mean, or for the time constant greater than twice the standard deviation from the mean for the control group, have been selected for comparison with clinical and radiological findings. The limits set are different in the two factories owing to the different values obtained for the control groups in each, but the differences are small. Values outside these limits in the two factories are shown in Tables 5 and 6, a blank space denoting a value within twice the standard deviation from the mean. The diagnosis given in the Table was made at the end of the clinical examination, and is not necessarily identical with the final diagnosis given by Bonnell, which was arrived at after consideration of clinical, respiratory function, and radiological findings (Bonnell, 1955).

Factory A.—Table 5 shows subjects who have swept fractions less than 54% at 30 R.P.M., or 34% at 70 R.P.M., or who have an expiratory fast vital capacity curve with a time constant greater than 0.91 second. The first six of these subjects (A5, A8, A10, A12, A13, A16) had values outside the limits described on all three counts. All gave histories of increasing dyspnoea on exertion for a number of years. Radiological appearances in four out of the six were suggestive of emphysema (A10 was not radiographed). Two subjects (A14, A15) had one swept fraction and a time constant outside

TABLE 4
SIGNIFICANCE OF PARTIAL REGRESSION COEFFICIENTS ON AGE (b_1) AND EXPOSURE TO CADMIUM FUME (b_2) IN FACTORY B

		Regression Coefficient	$\pm$	Standard Error	<i>t</i>	P (One-sided Test)
Vital capacity	b_1	-0.039	$\pm$	0.0063	6.23	$P < 0.001$
	b_2	-0.0068	$\pm$	0.011	0.60	$0.3 > P > 0.25$
M.V.C. ₇₀	b_1	-1.77	$\pm$	0.35	5.06	$P < 0.001$
	b_2	-0.80	$\pm$	0.63	1.27	$0.15 > P > 0.1$
Swept fraction	at 30 r.p.m.	b_1	$\pm$	0.11	3.21	$P < 0.01$
		b_2	$\pm$	0.20	1.30	$0.1 > P > 0.05$
	at 70 r.p.m.	b_1	$\pm$	0.11	1.59	$0.1 > P > 0.05$
		b_2	$\pm$	0.19	1.31	$0.1 > P > 0.05$
Time constant	b_1	+0.0056	$\pm$	0.0048	1.17	$0.15 > P > 0.1$
	b_2	+0.019	$\pm$	0.0085	2.20	$0.025 > P > 0.01$

TABLE 5

SWEPT FRACTIONS AND TIME CONSTANTS FALLING OUTSIDE TWICE THE STANDARD DEVIATION FROM THE MEAN FOR CONTROL GROUP WITH RADIOLOGICAL AND CLINICAL FINDINGS AT FACTORY A

Case No.	Age	Years' Exposure	Swept Fraction		Time Constant (sec.)	Radiological Findings	Clinical Notes on Respiratory System	Clinical Diagnosis
			At 30 R.P.M.	At 70 R.P.M.				
A5	58	18	46.2	25.6	2.08	Some signs of emphysema	2 yr. dyspnoea, chronic winter cough	Emphysema
A8	55	20	47.9	31.0	1.21	Emphysema	4 yr. dyspnoea	Emphysema
A10	42	17	51.2	30.8	1.11	Not radio-graphed		Emphysema
A12	54	10	37.6	27.3	3.13	Emphysema	3 yr. dyspnoea, cough 10 yr. dyspnoea, 3 yr. winter cough	Emphysema
A13	61	8	49.8	25.2	1.47	Emphysema	5 yr. dyspnoea, 8-10 yr. chronic winter cough	Emphysema
A14	64	13	—	28.6	0.93	Nil	2 yr. dyspnoea, many yr. cough	Chronic bronchitis
A15	45	18	—	29.0	1.28	Nil	Many yr. chronic bronchitis and asthma	Nil
A16	50	33	50.8	27.8	1.13	Nil	9 yr. dyspnoea, ? functional element	Nil
A17	60	13	—	—	0.94	Nil	Nil	Nil
A18	64	13	—	33.8	—	Nil	Nil	Nil
A20	40	20	—	30.8	—	Nil	2 yr. chronic winter cough	Nil
A21	64	Control	—	—	1.12	Pneumoconiosis	Chronic winter bronchitis	Nil
A22	54	Control	48.1	34.0	—	Some signs of emphysema	Nil	Nil
A23	69	Control	48.8	—	—	Localized emphysema R. upper zone only	Nil	Nil
A1	56	30	—	—	—	Emphysema	Unwell 6 mth., progressive dyspnoea	Emphysema
A2	52	13	42.3	24.4	2.39	Emphysema	7 yr. progressive dyspnoea, cough 4 yr.	Emphysema
A3	58	11	29.5	16.7	2.45	Emphysema	10 yr. dyspnoea	Emphysema
A4	49	12	29.8	16.8	4.00	Emphysema	6 yr. dyspnoea, cough, and sputum	Emphysema

the limits set. In six subjects (A17, A18, A20, A21, A22, A23) either the time constant or one or more swept fractions fell outside the adopted limits, but not both time constant and swept fractions. Three of these six subjects belonged to the control group. No member of the control group appeared outside the limits on all counts.

Radiological abnormalities were diagnosed in nine subjects (not shown in Table 5) whose performance in the tests fell within the limits described above. Seven of these subjects, three from the control and four from the exposed group, were considered by the radiologist to show some signs of emphysema. The remaining two showed evidence of pneumoconiosis. In none of the seven cases was an unqualified diagnosis of emphysema made, the radiographs being commented on as showing "some signs of emphysema", "slight emphysema", or "localized emphysema". On clinical examination one of these nine subjects was diagnosed as having emphysema, the other eight were passed as normal. Two subjects from the exposed group diagnosed clinically as having emphysema and four from the control group diagnosed with chronic bronchitis showed no abnormality on radiological examination and performed within the described limits in the ventilatory function tests.

Four men who had worked on the copper-cad-

mium process for a number of years but who were on sick leave during the survey were not included in the exposed group. They were investigated at the London Hospital during the succeeding six months, the findings being reported in full by Bonnell (1955). Clinical and radiological diagnoses of emphysema were made in all four cases. The results in the ventilatory function tests were outside the limits described for three out of the four subjects on all counts. The findings in these four men (A1, A2, A3, A4) are included in Table 5.

Factory B.—Subjects with a swept fraction of less than 52% at 30 R.P.M. or 31% at 70 R.P.M., and those with an expiratory fast vital capacity curve with a time constant greater than 1.10 seconds are shown in Table 6 together with clinical and radiological findings. Four subjects from the exposed group (B1, B3, B4, B6) gave values outside these limits for both swept fractions and for the time constant. Subsequent comparison with the clinical findings showed that all four gave histories of progressive dyspnoea on exertion and in two of these the radiological findings were suggestive of emphysema. The one control subject (B12), all of whose values fell outside the above limits, was passed as normal on clinical and radiological examination. One subject from the exposed group (B2) had a time constant and one swept fraction

TABLE 6

SUBJECTS WITH SWEEP FRACTION OR TIME CONSTANT OUTSIDE THE DESCRIBED LIMITS COMPARED WITH CLINICAL AND RADIOLOGICAL FINDINGS AT FACTORY B

Case No.	Age	Years' Exposure	Swept Fraction		Time Constant (sec.)	Radiological Findings	Clinical Notes on Respiratory System	Clinical Diagnosis
			At 30 R.P.M.	At 70 R.P.M.				
B1	52	10	30.6	17.1	3.27	Nil	15 yr. dyspnoea, chronic cough	Emphysema
B2	49	27	50.8	—	1.33	Emphysema	Nil	Nil
B3	43	9	36.0	17.1	3.02	Nil	5 yr. dyspnoea, chronic cough	Emphysema
B4	58	22	44.0	27.2	1.38	Localized emphysema	3 yr. dyspnoea, chronic cough	Emphysema
B5	59	17	—	—	1.50	Emphysema probable	6 mth. dyspnoea (increasing)	Emphysema
B6	50	7	30.6	16.3	1.50	Emphysema	1 yr. dyspnoea, cough, sputum	Emphysema
B11	39	14	—	28.5	—	Nil	Nil	Nil
B12	39	Control	47.9	30.1	1.88	Nil	20 yr. ago pleurisy now N.A.D.	Nil
B13	54	Control	50.6	—	—	Nil	Many years cough and sputum	Nil
B14	53	Control	—	—	1.12	Emphysema	Nil	Nil
B15	58	Control	—	25.1	—	Nil	Felt giddy during tests	Nil

outside the limits, and five subjects (B5, B11, from the exposed; B13, B14, B15, from the control group) had either time constant or one swept fraction outside these limits but not both.

Abnormalities were diagnosed on radiological grounds in two subjects whose performance in the ventilatory function tests fell within the limits described. One subject was passed as normal on clinical examination, the other gave a history of asthma.

In summary, in Factory A nine subjects who had been exposed to cadmium gave values outside the limits set on the three counts considered. A clinical diagnosis of emphysema was made in eight of the nine cases, and a radiological diagnosis of emphysema in seven of the nine cases.

In Factory B four subjects from the exposed and one from the control group gave values outside the limits set on the three counts considered. A clinical diagnosis of emphysema was made in the four from the exposed group and a radiological diagnosis of emphysema in two of those four subjects.

Comment

The subjects comprising the control groups in this investigation were not selected on the basis of freedom from disease, so that a similar incidence of respiratory disorder may be expected to occur in the control groups as in the populations from which these groups were drawn. The significant differences between the results of the tests of ventilatory function obtained from the control and exposed groups suggest that these groups differ with respect to some factor affecting the incidence of disease. The only factor that we know to be different in the two groups is the environmental one, namely, exposure to cadmium fume.

In certain forms of ventilatory impairment, as in asthma and emphysema, the M.V.C. is reduced disproportionately to any reduction in vital capacity (Gaensler, 1951), so it is in distinguishing this form of ventilatory impairment that the swept fraction would be of most use. A decrease both in the vital capacity and in the M.V.C. produced by a restriction of rib movements in normal subjects has been shown not to reduce the swept fraction (D'Silva and others, 1953).

The tidal excursion in the M.V.C. test at rates between 20 and 100 R.P.M. has been shown (Bernstein and Kazantzis, 1954) to be made up of portions of the inspiratory and expiratory fast vital capacity curves. It is reasonable to assume that a slowing of either inspiration or expiration, or of both processes, would lead to a reduction in swept fraction. From Tables 5 and 6 it can be seen that the majority of subjects with low swept fractions also had long time constants for their expiratory fast vital capacity curves. It may be that in some instances a low swept fraction may be due to the association of a normal expiratory curve and a slow inspiratory curve, while in other instances a slow expiratory curve may be compensated by a fast inspiratory curve, thus giving a normal swept fraction. Expiratory fast vital capacity curves were obtained from all subjects, but the importance of the inspiratory curve was not recognized at the time of this investigation.

The selection of abnormal individual performances presents difficulties when there is much individual variation within the limits of normal, and when, as happens with most tests, normal and abnormal populations overlap to a greater or lesser extent. The difficulties are greater when the test

requires the cooperation of the subject, as in this instance.

In this investigation subjects with one or more low swept fractions, or a long time constant compared with the performance of the control group, have been selected for comparison with the clinical and radiological findings. The division between an "abnormal" and a "normal" performance was set at twice the standard deviation from the mean performance for the control group, so that about one observation in 40 in a sample from the control group population would be expected, without allowing for individual age differences, to fall below the lower limit for the swept fraction, or above the upper limit for the time constant.

A single low swept fraction or a long time constant could also be due to an extraneous influence during the test, such as a diversion of the subject's attention, inhalation of saliva, or a desire to cough. Two low swept fractions and in addition a long time constant in the same subject are unlikely to be due to such a cause. Of the time constants recorded for 21 subjects in Tables 5 and 6, 17 were greater than the mean plus three times the standard deviation. Only about one subject in 200 from the control group would be expected to fall outside these limits.

Tables 5 and 6 show that the subjects who performed "abnormally" on all the tests showed clinical evidence of emphysema. Not all the subjects with low results in one or two tests showed clinical evidence of respiratory disease, and there were three subjects diagnosed clinically as having emphysema who performed within the limits described on all the tests.

Difficulties involved in the purely clinical diagnosis of emphysema have been discussed by Fletcher (1952) and in the radiological diagnosis of emphysema by Knott and Christie (1951). The assessment of the ventilatory function of the lung taken in conjunction with other findings may

be of considerable value in arriving at a diagnosis. It is believed that the methods described in this paper provide a more sensitive index of ventilatory impairment than those hitherto used.

Summary

Vital capacity, maximum ventilatory capacity at 30 and 70 R.P.M., and expiratory fast vital capacity records have been obtained from groups of workers exposed to cadmium fume in two factories and from control groups with similar age distributions. From this data, swept fractions (at the respiratory rates investigated) and time constants of the expiratory fast vital capacity curves have been obtained.

Measurements of the swept fractions and of the time constants of the expiratory fast vital capacity curves have proved useful in differentiating between the control and the exposed groups.

Standards of normality based on the performance of the control group have been laid down, and individual performances outside the 5% confidence limits have been compared with the clinical and radiological findings.

The significance of the swept fraction and the time constant, and the measure of agreement with the clinical and radiological findings have been discussed.

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REFERENCES

- Bernstein, L., D'Silva, J. L., and Mendel, D. (1952). *Thorax*, 7, 255.
 —, and Kazantzis, G. (1954). *Ibid.*, 9, 326.
 Bonnell, J. A. (1955). *British Journal of Industrial Medicine*, 12, 181.
 D'Silva, J. L., Freeland, D. E., and Kazantzis, G. (1953). *Thorax*, 8, 303.
 —, and Kazantzis, G. (1954). *Ibid.*, 9, 128.
 Fletcher, C. M. (1952). *Proc. roy. Soc. Med.*, 45, 577.
 Gaensler, E. A. (1951). *Amer. Rev. Tuberc.*, 64, 256.
 Knott, J. M. S., and Christie, R. V. (1951). *Lancet*, 1, 881.

PART II: THE ESTIMATION OF THE TOTAL LUNG VOLUME, ITS SUBDIVISIONS, AND THE MIXING COEFFICIENT

BY

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Method

The apparatus used, which in principle employed a closed circuit helium technique with a katharometer, was a modification of that described by Bates and Christie (1950). The side circuit carbon dioxide absorber

was omitted, and crushed ice was placed in the spirometer jacket 20 minutes before the start of the experiment. This reduced the rise in temperature in the spirometer. The subject, who was seated in an upright chair, was instructed to breathe normally. He inhaled pure oxygen from a Douglas bag for seven minutes and expired into