

173/1
(see AIC. 173/1)
(5 Jan 87)
for previous paper

COMPARISON OF AIA AND NIOSH METHODS ON ASBESTOS FIBRE MEASUREMENTS IN THE WORKPLACE

E. GONZALEZ-FERNANDEZ,* PAULINO D. DE LA OSA* and FÉLIX R. MARTÍN†

*Instituto Nacional de Seguridad e Higiene en el Trabajo, Centro Nacional de Nuevas Tecnologías, Torrelaguna, 73, 28027 Madrid, Spain and †Faculty of Biology, Statistic Department, C.U.I. Arcos de Jalón University of Madrid, Spain

Abstract—Industrial hygiene evaluation of airborne asbestos dust by the membrane-filter/phase-contrast optical-microscope method has been adopted by most countries, but detailed procedures differ. In the present work sampling results obtained in an asbestos cement factory by the NIOSH Analytical Method P & CAM 239 and the AIA Recommended Technical Method No. 1 (adopted as the European standard) have been compared. The concentrations measured by the AIA method were on average less than those determined by the NIOSH method, the mean ratio AIA/NIOSH being 0.29. Analysis of variance showed the difference to be statistically significant. Investigations into the source of the difference showed that it arose from the different methods of mounting and evaluating the samples rather than from the methods of sample collection. The fitting of a cowl to the sampling head in the AIA method had no effect. These findings regarding the source of variation are consistent with previous results by the same team using laboratory-prepared samples. However, it appears that the relationship between the methods may not be the same for all workplaces where asbestos is found. The findings of this study have implications not only for comparing fibre concentrations measured by the AIA and NIOSH methods but also for harmonizing environmental standards.

INTRODUCTION

AIRBORNE ASBESTOS fibre concentrations of all types (principally chrysotile) in working environments are generally sampled on membrane-filters and counted by phase-contrast optical-microscopy. This, despite its many limitations, is accepted by most countries as a routine method. Experience has shown that the method does not always produce comparable results when used by different laboratories and by different counters (BECKETT and ATTFIELD, 1974; GIBBS *et al.*, 1977). It is well known that differences can arise owing to variations in sampling, slide preparation and optical counting (BECKETT, 1980; BUSCH *et al.*, 1979; PICKFORD, 1980). Much of the investigation of the inter- and intra-laboratory reliability (WALTON, 1982) of the method has focused on the analytical equipment and methodology. However, to characterize the inherent variability of the entire sampling/analytical procedure, factors such as inter-counter variability and sampling error must be added to the intra-filter variation.

Most countries today are attempting to develop a well standardized method for counting asbestos fibres at workplaces and new regulations for occupational exposures to asbestos are now under consideration by the Commission of the European Communities (CEC) and Occupational Safety and Health Administration (OSHA) as well as International Organization for Standardization (ISO) and American Society for Testing and Materials (ASTM).

Previous studies have investigated the effects of counting rules and aspect ratio on the levels and reproducibility of fibre counts (COWIE and CRAWFORD, 1982; CRAWFORD *et al.*, 1982).

A comparison (GONZALEZ-FERNANDEZ and MARTÍN, 1986) between the counting

criteria established in the Analytical Method P & CAM 239, published by the National Institute for Occupational Safety and Health (NIOSH, 1977) and the counting rules from the Recommended Technical Method No. 1, published by Asbestos International Association (AIA, 1979), has been made on a set of artificially prepared samples of chrysotile, crocidolite and amosite, using different mounting media and eyepiece graticules. On average the AIA method gave rather higher counts than the NIOSH method for chrysotile (ratio 1.2) but lower counts for crocidolite (ratio 0.5); the data for amosite were more scattered and the difference was not statistically significant. The differences between mountants and graticules were shown to be contributory factors. However, the possible effects of differences in sampling between the AIA and NIOSH methods were not studied and it was recognized that the findings might not necessarily apply to industrial samples.

The aim of this paper is to compare the entire sampling/analytical NIOSH P & CAM 239 method with the more recently recommended RTM 1 method by AIA, which has been considered as the European Reference Method. Matched pairs of samples were taken at several workplaces in a chrysotile and crocidolite asbestos-cement factory by using both NIOSH and AIA sampling procedures. Furthermore, a second comparison was made between AIA and NIOSH counting rules with a batch of samples chosen randomly from those taken according to the NIOSH sampling guidelines. In this case, each filter wedge was mounted and counted according to the NIOSH and AIA methods. The airborne asbestos fibre concentrations found by each method were used for a health hazard evaluation against the OSHA standard of 2.00 fibre ml⁻¹ (f ml⁻¹) at 95% confidence level.

A possible source of variability is the use of a cowl, as required by the AIA sampling procedure (PECK *et al.*, 1985). Few investigations have been undertaken into the differences between the collection characteristics of cowed and uncowed filter holders. There is also some disparity between the results obtained for asbestos air samples taken with and without a cowl.

A brief experiment (SPEIGHT and MARSH, 1984) showed a difference by a factor of about four between results obtained with cowed and uncowed filters when sampling airborne amosite insulation fibres. However, an experimental procedure (KNIGHT *et al.*, 1985) in which cowed and uncowed sampling heads were used side by side for personal asbestos chrysotile sampling showed no significant difference between fibre densities measured by cowed and non-cowed filter holders.

To elucidate the influence of the cowl in the AIA sampling of asbestos fibres, matched pairs of samples were taken with and without cowl. Two different types of cowls were tested, one metallic and the other of non-conducting polypropylene.

MATERIALS AND METHODS

Apparatus

A Carl Zeiss III phase contrast photomicroscope was used to count all the samples at 500× magnification with 4 mm objective. The graticules used were: Porton reticle (Edmund Scientific Co. Barrington, New Jersey, Stock No. 30084) with a field area of 0.0016 mm², and a Walton-Beckett graticule No. G 22 (Graticules Ltd, Tonbridge, Kent, U.K.) with a field area of 0.0085 mm². A drawing of these graticules is shown in Fig. 1. A Carl Zeiss stage micrometer 5+100/100 mm was used to calibrate the

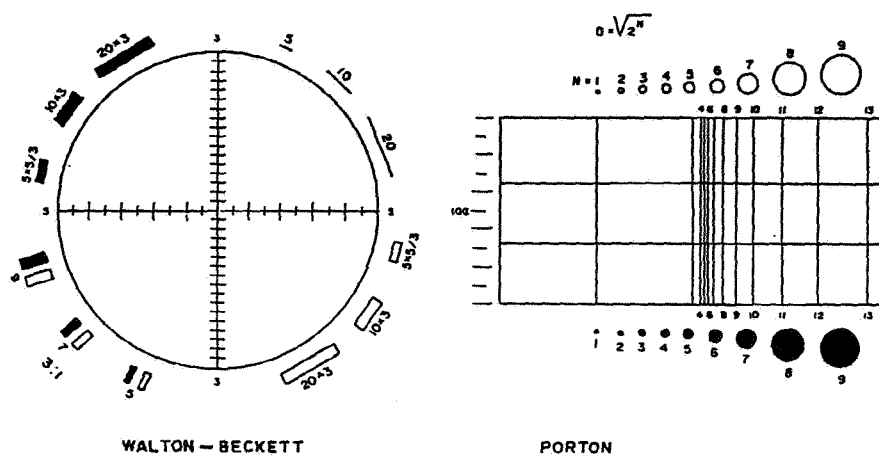


FIG. 1. Illustration of graticules used. Not to scale.

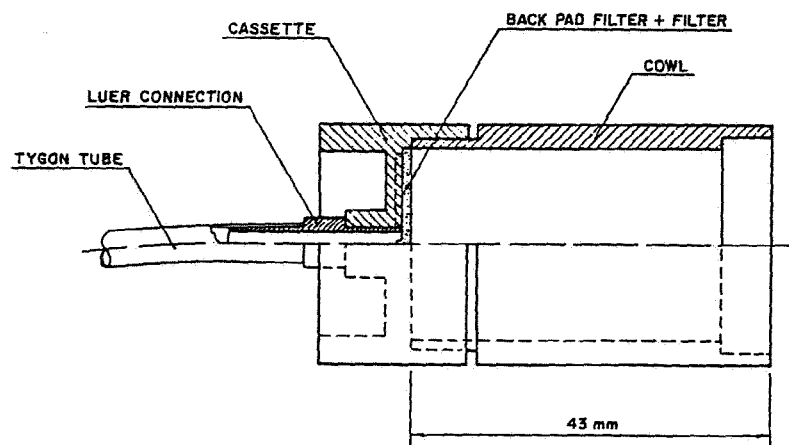


FIG. 2. 25 mm dia. cassette fitted with a protective metallic cowl.

eyepiece graticules at the magnification used. The HSE/NPL phase contrast standard test slide Mark II (designed and developed by the U.K. Health and Safety Executive and the National Physical Laboratory, U.K.) was used for the determination of the detection limit. This slide has seven blocks of fine ridged lines producing successively smaller phase changes. Block No. 6 was detectable along the entire length of the lines with our microscope. Detection of block No. 5 is considered to be an acceptable performance, which should allow chrysotile fibres $0.15 \mu\text{m}$ dia. to be seen (LE GUEN *et al.*, 1984).

ASBESTOS INTERNATIONAL ASSOCIATION

The asbestos industries' world wide organisation for
environmental and occupational health protection

68 GLOUCESTER PLACE,
LONDON W1H 3HL
TEL: 01-486 3528/9
TELEX: 298618 INTA G

RECEIVED
NOV 20 1987

To: Dust Advisory Panel (DAP)

Herewith copy of "Comparison of AIA and NIOSH Methods on Asbestos Fibre
Measurements in the Workplace", E. Gonzalez-Fernandez et al. - Ann.Occup.Hyg.,
Vol 31 No. 3, pp 363-373, 1987.

AIA/20/2/7/HAS
19 November 1987

With Compliments

file: (Asbestos)
Analytical



Filter holders

These were three-piece styrene plastic cassettes of 37 mm dia. (Millipore, Ref. M000037A0) and 25 mm dia. (Millipore, Ref. M000025A0). The 25 mm cassette was fitted with a protective metallic cowl (Fig. 2) not commercially available or with a polypropylene 50-mm non-conducting extension cowl (Millipore, Ref. M000025R0).

Chemicals

Dimethyl phthalate, diethyl oxalate, triacetin and acetone, analytical reagent grades from Merck, were used. Membrane AAWP04700 filters (Millipore Iberica, S.A. Spain) were added to the ester mixtures.

Sampling and analytical procedures

A brief description of both AIA and NIOSH methods is reported here. The details of the AIA method have been reported by the Asbestos International Association (AIA, 1979) and the NIOSH method by U.S. Department of Health, Education and Welfare (NIOSH, 1977).

The main differences between the two methods can be summarized as follows:

	NIOSH Method	AIA Method
Filter type (diameter, pore size)	37 mm, 0.8 μm	25 mm, 1.2 μm
Foil-wrapped cassette	No	Yes
Flow rate (l. min^{-1})	1-2.5	1.0
Filter mountant	esters mixture	acetone-triacetin
Reticle type	Porton or Patterson	Walton-Beckett
Field area at the specimen plane (mm^2)	0.003-0.006	0.00785
Phase-shift detection limit (μm)	Not specified	0.44

Experimental samples were obtained for different durations of time according to the sampling flow rates mentioned using calibrated Model Fix-Flow MSA portable pumps (Mine Safety Appliances Co. Pittsburgh). The entire filter was used to determine fibre concentrations for samples taken by the AIA method. The filter was cleared by acetone vapour plus one drop of triacetin. A wedge-section of the filter was used to count fibres for samples taken by the NIOSH method. In this case, a mixture of dimethyl phthalate and diethyl oxalate (1:1) with 0.05 g membrane filter type AA added per ml of solution was used as an embedding medium. According to the AIA criteria for counting asbestos fibres a fibre is any particle having the following geometric dimensions—length greater than 5 μm , diameter less than 3 μm and length to diameter ratio (aspect) greater than 3:1; specific situations are considered in the case of complex configurations of fibres or aggregates (single fibres, split fibres, grouped fibres and fibres with other particles); a Walton-Beckett eyepiece graticule is recommended. By the NIOSH counting criteria, any particle which has a physical dimension longer than 5 μm and with an aspect ratio of 3:1 or greater is deemed to be an asbestos fibre. There is no specification for the maximum diameter of the fibre, and bundles of fibres are counted as one fibre unless both ends of the fibre can be clearly resolved. For fibre counting, a recommendation is made to use a Porton reticle, although others such as the Patterson Globe and Circle can be substituted.

Sampling survey and experimental design

A field study was conducted over 4 months, viz. in January, March and April 1982 and in January 1983 in an asbestos-cement factory in four different workplaces. In total 176 samples were taken, 88 on 37 mm dia. membrane filters and 88 on 25 mm dia. membrane filters, using sampling flow rates of 1.5 and 1.0 l. min⁻¹ for NIOSH and AIA methods, respectively. The cassettes were randomly placed membrane-face down on the left and right lapels of the workers, one on each lapel. A measured quantity of air between 100 and 300 l. was drawn through each membrane filter, depending on local work and environmental conditions, so that the fibre densities on the filter would lie between the recommended limits of NIOSH and AIA methods. Each pair of samples was run for the same length of time.

A second comparison was made between the NIOSH and AIA mounting and counting procedures in 54 samples chosen from those taken with the NIOSH procedure. From the samples that had previously been mounted and counted with the NIOSH package counting rules, another wedge-shaped piece, about 30°, of each membrane filter was cleared by acetone vapour plus triacetin and counted with the AIA counting rules. The combination procedures of these two methods is abbreviated to NIOSH-AIA method.

Counts were made by two different counters over two different wedges of each sample mounted according to the NIOSH and AIA analytical methods. Emphatic instructions were given not to interchange counting rules between methods.

The experiment to examine the influence of using cowled and uncowed 25 mm sampling heads was made as follows. Personal air samples were taken concurrently in the same workplaces as mentioned before. The samples were collected for the same periods and flow rates to give fibre densities of around 50–300 fibres mm⁻². The filters were cleared, mounted and counted according to the AIA RTM 1 method and some counts were repeated to reduce errors.

RESULTS AND DISCUSSION

Table A1 in the Appendix shows the raw count data obtained in the survey of an asbestos-cement factory over the 4 months.

Table 1 shows the fibre densities on the filters and fibre concentrations for the samples evaluated with the full AIA and NIOSH sampling/analytical methods, subdivided by workplace. An overall AIA/NIOSH mean ratio of 0.29 ± 0.04 was obtained; thus, fibre concentrations found by the AIA RTM 1 method were 71% (range 67–75%) less than the concentrations found by the NIOSH P & CAM 239 method. The fibre densities on the filters were well within the recommended limits of 0.5–5.0 fibres per Porton reticle (NIOSH method) or 0.4–10.0 fibres per Walton-Beckett graticule (AIA method). It is known that when the fibre densities on the filter are lower than 10 f mm⁻², counts are highly prone to error (TEICHERT, 1980).

Pooled coefficients of variation of 14.4% for all AIA countings and 17.8% for all NIOSH countings were obtained with no significant differences found at $\alpha < 0.05$.

Table 2 shows the results obtained when the AIA and NIOSH mounting and counting procedures were applied to 54 samples, all taken according to the NIOSH sampling scheme. The overall AIA/NIOSH mean ratio was 0.35 ± 0.05 ; thus the AIA method counts 65% (range 60–70%) fewer fibres than the NIOSH method.

TABLE 1. COMPARISON OF FIBRE MEASUREMENTS BY COMPLETE NIOSH AND AIA METHODS. GEOMETRIC MEAN VALUES FOR DIFFERENT WORKPLACES CALCULATED FROM DETAILED DATA IN TABLE 1A

Workplace	No. of pairs of samples	Fibre density		Fibre concentration		Ratio of concentrations AIA/NIOSH
		AIA (f mm ⁻²)	NIOSH (f mm ⁻²)	AIA (f ml ⁻¹)	NIOSH (f ml ⁻¹)	
Mill, loading and mixing	42	66	169	0.27	1.15	0.23
Big pipe turning	22	81	147	0.42	1.41	0.30
Small pipe turning	10	85	179	0.31	1.03	0.30
Pipe cutting	14	109	236	0.60	1.94	0.31
Overall mean $\pm$ S.D. 0.29 $\pm$ 0.04						

TABLE 2. COMPARISON OF FIBRE COUNTS USING BOTH NIOSH AND AIA METHODS ON SAMPLES TAKEN BY THE NIOSH P & CAM 239 PROCEDURE ONLY

Workplace	No. of samples	Concentration		Ratio AIA/NIOSH
		AIA (f ml ⁻¹)	NIOSH (f ml ⁻¹)	
Mill, loading and mixing	21	0.43	1.15	0.37
Big pipe turning	14	0.45	1.41	0.32
Small pipe turning	10	0.42	1.03	0.41
Pipe cutting	9	0.58	1.94	0.30
Overall mean $\pm$ S.D. 0.35 $\pm$ 0.05				

TABLE 3. ANALYSIS OF VARIANCE FOR METHODS (NIOSH, AIA, NIOSH-AIA) AND WORKPLACES

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between methods	2	153.09	76.54	102.611*
Between workplaces	3	31.80	10.60	14.209*
Interaction	6	1.89	0.32	0.423 N.S.
Residual	427	318.52	0.75	

Terms marked * are significant at better than the 0.1% level.
N.S. = Not significant.

Establishing whether the changes in counting are of statistical significance is readily done by analysis of variance (ANOVA). For this the statistical computing package BMDP (DIXON, 1983) was employed. A natural logarithmic transformation was used to normalize the distribution (Box and Cox, 1964) and all statistical analyses were made with transformed data. If any factor or interaction of statistical significance was found, we used the Student-Newman-Keuls test (SNK-test) to determine whether mean values of each level factor showed any significant difference (SOKAL and ROHLF, 1969).

TABLE 4. HEALTH HAZARD EVALUATION OF THE WORKPLACES FROM THE NIOSH RESULTS VS OSHA STANDARD OF 2.0 f ml^{-1}

Workplace studied	January	Sampled in 1982 March	April	Sampled in 1983 February
Mill loading and mixing	No decision		Compliance No risk	
Big pipe turning	Non-compliance Risk	Compliance No risk		Non-compliance Risk
Small pipe turning	Non-compliance Risk	Compliance No risk		No decision
Pipe cutting	Non-compliance Risk	No decision		Non-compliance Risk

TABLE 5. FIBRE CONCENTRATIONS FROM PERSONAL AIR SAMPLING USING COWLED AND UNCOWLED FILTER HOLDERS

Workplace sampled	Metallic cowl (f ml^{-1})	Plastic cowl (f ml^{-1})	Without cowl (f ml^{-1})
Mill loading and mixing	0.0/0.0	0.0/0.1	0.1/0.1
	0.4/0.4	0.3	0.6/1.0
	0.4	0.3	0.5
	0.8	0.6	0.8
	0.2/0.2	0.2	0.1/0.2
	0.2/0.2	0.1	0.1/0.2
	0.1	0.1	0.1
	0.1	0.0	0.1
	0.4	0.4	0.3
	0.4	0.3	0.3
	0.3	0.2	0.1
Big pipe turning	0.1	0.1	0.1
	0.1	0.1	0.1
Small pipe turning	1.5	1.1	1.2
	1.8	1.3	1.5
	0.1	0.1/0.1	0.1
	0.2	0.1/0.2	0.2
Pipe cutting	0.2	0.4	0.2

TABLE 6. ANALYSIS OF VARIANCE FOR AIA SAMPLING METHODS, TESTED WITH AND WITHOUT COWLS, AND WORKPLACES SAMPLED

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Between sampling methods	2	0.34	0.17	0.227 N.S.
Between workplaces	3	6.92	2.31	3.049 N.S.
Interaction	6	2.10	0.35	0.462 N.S.
Residual	49	37.10	0.76	

N.S. = Not significant.

Table 3 shows the ANOVA results for all counts of all the samples taken (Table A1); geometric mean values of these counts were given in Tables 1 and 2. It can be observed that there is statistically significant difference, at better than the 0.1% level, between the methods used. As expected, difference between workplaces is a significant source of variation, owing to the intrinsic variation in fibre loadings depending on the workplace studied. The differences between the three methods have been evaluated by the SNK-test. This showed that mean fibre concentrations obtained by the entire NIOSH method were significantly higher than those obtained by the entire AIA method and also significantly higher than those obtained when samples taken by the NIOSH method were mounted and counted by AIA procedures (NIOSH-AIA method); moreover, there was no significant difference between the entire AIA and NIOSH-AIA methods. Thus it is apparent that the statistically significant difference between the results obtained by the NIOSH P & CAM and the AIA RTM-1 methods arises from differences in mounting methods and package counting rules rather than from differences in sampling methods. This is consistent with the findings from our previous work in which the effect of mounting and counting procedures on fibre counts was pointed out (GONZALEZ-FERNANDEZ and MARTÍN, 1986). However, the results from these studies taken together suggest that the relationship between the AIA and NIOSH methods is not constant but varies with asbestos type and source of sample.

Table 4 shows the health hazard evaluation according to the asbestos fibre concentrations obtained by the NIOSH method in each workplace, using a statistical approach on a long-term sampling scheme. The time-weighted average concentrations were calculated and used to determine 'compliance', 'non-compliance' or 'no decision' at 95% confidence in comparison with the OSHA standard of 2 f ml^{-1} . There were five situations of risk, three with no risk and in two cases there was no decision. If these same statistical criteria for health hazard evaluation were applied to the asbestos fibre concentrations obtained by the AIA sampling/analytical method, all the workplaces would be judged to be in compliance ('no risk'). This different result is due to the count differences pointed out in Table 1.

Table 5 summarizes the results obtained when personal air samples were taken at several workplaces by the AIA RTM 1 method using cowl and uncowl 25 mm filter heads. An ANOVA was carried out, as shown in Table 6, and an *F*-test performed. The *F*-test indicates that neither the difference between sampling methods nor the difference between workplaces is a significant source of variation.

CONCLUSIONS

In this study we found that there was a significant difference between the entire AIA and NIOSH sampling/analytical procedures for measuring airborne asbestos fibres. The AIA RTM 1 method gives, on average, 71% less fibre concentration than the NIOSH P & CAM 239 method and therefore very different conclusions can be drawn in a risk evaluation of the workplaces sampled. This discrepancy appears to be due to differences in mounting and counting criteria between the two methods rather than to sampling differences. The attachment of a cowl to the filter holder, as required in the AIA method, had no significant effect on the sampling result.

The relationship between the methods may not be the same for all workplaces where asbestos is found.

The findings of this study have implications not only for the comparison of fibre concentrations measured by the AIA and NIOSH methods but also for the harmonization of environmental standards.

REFERENCES

- ASBESTOS INTERNATIONAL ASSOCIATION (1979) Recommended Technical Method No. 1 (RTM 1). Health and Safety Publication, AIA, 68 Gloucester Place, London, U.K.
- BECKETT, S. T. and ATTFIELD, M. D. (1974) *Ann. occup. Hyg.* 17, 85-96.
- BECKETT, S. T. (1980) *Ann. occup. Hyg.* 23, 259-272.
- BOX, G. E. P. and COX, D. R. (1964) *Jl R. statist. Soc. B26*, 211-252.
- BUSCH, K. A., HORNUNG, R. W., SMITH, R. J. and LEIDEL, N. A. (1979) *Dusts and Disease, Occupational and Environmental Exposures to Selected Fibrous and Particulate Dusts*, pp. 185-197. Parthotex Publishing, New York.
- COWIE, A. J. and CRAWFORD, N. P. (1982) Technical Report No. TM/82/83. Institute of Occupational Medicine, Edinburgh, Scotland, U.K.
- CRAWFORD, N. P., THORPE, H. L. and ALEXANDER, W. (1982) Technical Report No. TM/82/84. Institute of Occupational Medicine, Edinburgh, Scotland, U.K.
- DIXON, W. J. (Ed.) (1983) *BMDP. Statistical Software*. Printing with Additions. University of California Press, Berkeley, U.S.A.
- GIBBS, G. W., BARON, P., BECKETT, S. T., DILLEN, R., DU TOIT, R. S. J., KOPONEN, M. and ROBOCK, K. (1977) *Ann. occup. Hyg.* 20, 321-332.
- GONZALEZ-FERNANDEZ, E. and MARTIN, F. R. (1986) *Ann. occup. Hyg.* 30, 397-410.
- KNIGHT, K. L., BLOOR, D. M. and MILLER, F. (1985) *Ann. occup. Hyg.* 29, 289-291.
- LE GUEN, J. M. M., OGDEN, T. L., SHENTON-TAYLOR, T. and VERRILL, J. F. (1984) *Ann. occup. Hyg.* 28, 237-247.
- NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (1977) *Manual of Analytical Methods* (2nd Edn), Vol. 1, pp. 239-1-239-2. U.S. Dept of Health, Education, and Welfare, Public Health Service, Center for Disease Control, Cincinnati, Ohio, U.S.A.
- PECK, A., SEROCKI, J. J. and DICKER, L. C. (1985) *Am. ind. Hyg. Ass. J.* 46, B-14-B-16.
- PICKFORD, G. (1980) *Proceedings of the Third International Colloquium on Dust Measuring Technique and Strategy*, pp. 71-76. Association Française de L'Amiante, London, U.K.
- SOKAL, R. R. and ROHLF, F. J. (1969) In: *Biometry*, pp. 265-273. W. H. Freeman and Co., San Francisco, California, U.S.A.
- SPEIGHT, R. G. and MARSH, A. H. (1984) *Ann. occup. Hyg.* 28, 353-359.
- TEICHERT, U. (1980) *Proceedings of the Third International Colloquium on Dust Measuring Technique and Strategy*, pp. 29-37. Association Française de L'Amiante, London, U.K.
- WALTON, W. H. (1982) *Ann. occup. Hyg.* 25, 205-208.

APPENDIX

TABLE A1. NUMBER OF FIELDS OBSERVED AND NUMBER OF FIBRES CALCULATED FOR THE SAMPLES TAKEN IN THE SURVEY OF WORKPLACES SAMPLED IN AN ASBESTOS-CEMENT FACTORY OVER 4 MONTHS

NIOSH method			AIA method			NIOSH-AIA method		
No. of fields	f mm ⁻²	f ml ⁻¹	No. of fields	f mm ⁻²	f ml ⁻¹	No. of fields	f mm ⁻²	f ml ⁻¹
<i>Workplace sampled: mill loading and mixing</i>								
25/50	1706/1269	16.2/12.0	100/100	44/14	0.3/0.1	—	—	—
100/100	291/269	2.8/2.6	100/100	82/68	0.5/0.4	—	—	—
100/100	394/400	3.7/3.8	50/50	473/244	2.8/1.5	—	—	—
100/100	166/178	1.6/1.7	100/100	36/38	0.2/0.3	—	—	—
100/100	119/147	1.4/1.7	100/100	9/8	0.1/0.1	—	—	—
100/100	69/119	0.9/1.5	100/100	28/26	0.3/0.2	—	—	—
100/100	263/300	3.0/3.5	100/100	26/8	0.2/0.1	—	—	—
100/100	175/225	2.0/2.6	100/100	17/12	0.1/0.1	—	—	—
100/100	100/84	0.4/0.4	100/100	51/40	0.2/0.1	—	—	—
100/100	663/406	3.1/2.0	75/75	164/144	0.3/0.3	—	—	—

(continued)

TABLE A1.—(continued)

NIOSH method			AIA method			NIOSH-AIA method		
No. of fields	f mm ⁻²	f ml ⁻¹	No. of fields	f mm ⁻²	f ml ⁻¹	No. of fields	f mm ⁻²	f ml ⁻¹
100/100	69/69	0.4/0.4	100/100	94/83	0.3/0.3	—	—	—
100/100	213/297	1.3/1.9	100/100	106/106	0.3/0.3	—	—	—
100/100	78/94	0.5/0.6	100/100	89/88	0.2/0.2	—	—	—
100/100	631/331	4.0/2.1	25/40	440/333	1.2/0.9	—	—	—
100/100	19/38	0.1/0.2	100/100	20/22	0.1/0.1	100	31	0.2
100/100	175/191	1.1/1.2	50/50	321/335	1.3/1.3	100	138	0.9
100/100	63/50	0.4/0.3	100/100	41/119	0.1/0.5	100	57	0.4
100/100	97/106	0.7/0.7	100/100	80/108	0.3/0.4	100	55	0.4
100/100	81/44	0.4/0.2	100	36	0.1	100	51	0.2
100/100	200/172	1.0/0.8	100	162	0.5	100	127	0.6
100/100	69/47	0.4/0.3	100	29	0.1	100	63	0.4
100/100	125/147	0.8/0.9	100	120	0.5	100	97	0.6
100/100	244/413	1.2/2.0	100/100	85/87	0.3/0.3	100/100	86/62	0.4/0.3
100/100	137/131	0.7/0.6	100/100	50/51	0.2/0.2	—	—	—
100/100	138/78	0.7/0.4	100/100	64/44	0.2/0.2	—	—	—
100/100	125/166	0.7/0.8	100/100	94/83	0.3/0.3	100/100	56/53	0.2/0.3
100/100	175/109	0.8/0.5	100/100	138/171	0.4/0.5	—	—	—
100/100	166/169	0.8/0.8	100/100	119/129	0.4/0.4	100/100	82/84	0.4/0.4
100/100	200/353	1.1/1.9	100/100	119/111	0.4/0.4	100/100	132/102	0.7/0.5
100/100	97/153	0.5/0.8	100/100	35/49	0.1/0.1	—	—	—
100/100	144/131	0.7/0.6	100/100	21/18	0.1/0.1	—	—	—
100/100	81/131	0.4/0.6	100/100	13/17	0.0/0.1	—	—	—
100/100	259/197	1.2/0.9	100/100	32/25	0.1/0.1	100/100	144/55	0.7/0.3
100/100	50/47	0.2/0.2	100/100	36/63	0.1/0.2	100/100	7/12	0.0/0.0
100/100	153/184	0.7/0.9	100/100	109/111	0.3/0.3	—	—	—
100/100	219/303	1.1/1.5	100/100	148/184	0.4/0.6	100/100	129/137	0.6/0.6
100/100	247/413	1.2/2.0	75/50	272/326	0.8/0.9	100/100	160/178	0.8/0.8
100/100	338/278	1.9/1.6	100/100	11/12	0.0/0.0	100/100	114/125	0.6/0.8
100/100	319/288	0.9/0.8	50/50	155/402	0.2/0.5	100/100	175/114	0.5/0.3
100/100	284/244	0.8/0.7	100/100	145/138	0.2/0.2	100/100	87/108	0.3/0.3
100/100	216/313	0.6/0.9	100/100	135/140	0.2/0.2	100/100	37/44	0.1/0.1
100/100	219/406	0.6/1.1	100/100	102/74	0.1/0.1	100/100	61/75	0.2/0.2
<i>Workplace sampled: big pipe turning</i>								
100/100	306/291	5.9/5.5	100/100	117/81	1.9/1.3	—	—	—
100/100	194/188	4.8/4.6	100/100	189/118	2.5/1.5	—	—	—
100/100	138/141	2.8/2.9	100/100	61/68	0.9/1.0	—	—	—
100/100	163/181	3.8/4.1	75/100	220/169	2.7/2.0	—	—	—
100/100	266/463	4.7/8.8	—	—	—	—	—	—
100/100	75/113	0.5/0.7	100/100	79/87	0.4/0.4	—	—	—
100/100	219/266	1.6/1.9	100/100	68/81	0.3/0.4	—	—	—
100/100	141/184	1.2/1.7	75/75	187/191	1.1/1.1	—	—	—
100/100	125/175	1.5/2.0	100/100	50/39	0.3/0.3	—	—	—
100/100	81/100	0.6/0.7	75	159	0.8	100	67	0.5
100/100	56/50	0.4/0.4	100/100	54/144	0.3/0.7	100	38	0.2
75/75	1129/825	8.7/6.3	50/50	295/386	1.4/1.8	50	381	2.4
100/100	703/631	4.8/4.4	50/50	337/324	1.4/1.5	50	375	2.6
100/100	106/75	0.7/0.5	—	—	—	100	32	0.3
100/100	156/184	1.1/1.2	—	—	—	100	82	0.6
100/100	463/369	3.1/2.5	—	—	—	50	264	1.8
100/100	397/419	1.9/2.0	100/75	187/248	0.6/0.8	100/75	199/233	0.9/1.1
100/100	172/125	0.8/0.6	100/100	96/93	0.3/0.3	—	—	—
100/100	178/141	0.8/0.7	100/100	79/128	0.3/0.4	100/100	65/62	0.3/0.3
100/100	175/359	0.9/1.9	100/100	45/34	0.1/0.1	100/100	84/95	0.4/0.5
100/100	175/197	0.8/0.9	100/100	22/28	0.1/0.1	—	—	—
100/100	188/159	0.9/0.8	100/100	32/26	0.1/0.1	100/100	39/48	0.2/0.2

(continued)

TABLE A1.—(continued)

NIOSH method			AIA method			NIOSH-AIA method		
No. of fields	f mm ⁻²	f ml ⁻¹	No. of fields	f mm ⁻²	f ml ⁻¹	No. of fields	f mm ⁻²	f ml ⁻¹
100/100	75/56	0.8/0.6	100/100	27/25	0.2/0.2	100/100	19/31	0.2/0.4
100/100	44/91	0.2/0.4	100/100	39/40	0.1/0.1	—	—	—
100/100	153/144	0.8/0.7	100/100	24/38	0.1/0.1	100/100	59/46	0.2/0.2
100/100	175/109	0.9/0.6	100/100	94/35	0.3/0.1	100/100	70/58	0.4/0.3
<i>Workplace sampled: small pipe turning</i>								
100/100	225/197	1.7/1.5	75/100	155/141	0.7/0.7	75	206	1.5
100/100	331/353	2.1/2.3	75/50	175/268	0.7/1.1	75	184	1.2
100/100	88/169	0.6/1.0	—	—	—	100	11	0.1
100/100	94/81	0.6/0.5	—	—	—	100	87	0.5
100/100	297/209	1.4/1.0	100/100	68/63	0.2/0.2	—	—	—
100/100	347/297	1.6/1.4	100/100	106/106	0.3/0.3	100/100	88/68	0.4/0.3
100/100	703/759	3.3/3.6	75/100	254/215	0.8/0.7	50/50	268/371	1.3/1.8
100/100	212/344	1.1/1.8	100/100	113/160	0.4/0.5	100/100	122/109	0.7/0.5
100/100	66/109	0.3/0.6	100/100	47/23	0.1/0.1	100/100	25/39	0.2/0.2
100/100	31/47	0.3/0.5	100/100	22/24	0.2/0.2	—	—	—
100/100	137/119	0.7/0.5	100/100	52/54	0.1/0.2	100/100	28/23	0.1/0.2
100/100	222/219	1.1/1.1	100/100	94/55	0.3/0.2	100/100	75/87	0.4/0.4
<i>Workplace sampled: pipe cutting</i>								
100/100	175/159	2.4/2.2	100/100	29/44	0.3/0.4	—	—	—
100/100	213/181	4.0/3.4	100/100	60/42	0.7/0.5	—	—	—
100/100	197/181	3.7/3.5	100/100	84/86	1.0/1.0	—	—	—
100/100	119/125	2.5/2.7	100/100	35/37	0.5/0.5	—	—	—
100/100	444/328	2.8/1.4	50/50	241/357	1.0/1.4	—	—	—
100/100	306/281	2.2/2.0	75/100	159/121	0.7/0.6	—	—	—
100/100	463/450	5.7/5.6	75/50	228/373	1.8/3.0	50	256	3.2
100/100	503/513	4.8/4.9	50/25	538/562	3.3/3.4	50	318	3.0
100/100	350/313	3.1/2.8	50/50	331/321	1.9/1.9	75	157	1.5
100/100	138/125	0.7/0.6	—	—	—	100	29	0.1
100/100	431/525	2.3/2.8	75/100	146/116	0.6/0.5	100	193	1.1
100/100	366/303	1.7/1.4	100/100	49/49	0.1/0.1	100/100	73/86	0.4/0.4
100/100	325/303	1.5/1.5	100/100	106/126	0.3/0.3	100/100	91/87	0.4/0.4
100/100	81/50	0.3/0.2	100/100	80/83	0.3/0.3	100	34	0.2
100/100	113/191	0.6/1.1	100/100	41/61	0.1/0.2	100/100	100/73	0.5/0.4