

# A Comparison of the CATHIA-T Sampler, the GK2.69 Cyclone and the Standard Cowled Sampler for Thoracic Fiber Concentrations at a Taconite (Iron Ore)-Processing Mill

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Several recommendations have been made to the effect that the most appropriate health-based size-selective criterion for fibers is the thoracic convention of the International Organization for Standardization (ISO). The performance of two thoracic samplers, the CATHIA-T (37-mm filter) and the GK2.69 cyclone (37-mm filter), was investigated against the standard 25-mm cowled sampler (current NIOSH 7400 standard method) to determine the effect of thoracic sampling on field results. A total of 270 samples: 80 field and 10 field blank samples for each sampler type, were taken from seven stations in the processing mill of an iron ore mine whose ore contains amphibole minerals. Slides were prepared using the dimethyl formamide/Euparal technique and relocatable cover slips. Two counters examined the slides according to NIOSH 7400 counting A rules with phase contrast microscopes. Prior to counting the sample slides, four reference slides were randomly selected and counted three times on different days to compare the coefficient of variation (CV) between and within counters. Also, seven reference slides were chosen to explore variability between the two microscopes. The average CV between counters (0.148) showed slightly higher than the average CVs within counters (0.072 for Counter 1 and 0.119 for Counter 2). The average CV between the two microscopes was 0.147. Compared to the standard cowled sampler, the overall fiber concentration was lower for the CATHIA-T sampler (CATHIA-T/Cowled = 0.63) and higher for the GK2.69 cyclone (GK2.69/Cowled = 1.66). **The result for the CATHIA-T sampler is as expected from laboratory trials, but the result for the GK2.69 cyclone is not as expected. In conclusion, the CATHIA-T sampler has a potential advantage as a high-flow static sampler for screening coarse particles.** However, these findings resulted from one field sampling site that contains amphibole minerals, not all of which are asbestiform. Thus, additional field samples from other environments might be helpful to confirm the performance of these samplers.

*Keywords:* aerosol samples; CATHIA; fibers; GK2.69; NIOSH 7400 method; thoracic sampling

## INTRODUCTION

Fiber dimension is considered to be one of the primary factors that accounts for health risks. Different fiber dimensions may also be associated with differ-

ent diseases such as asbestosis (fibers longer than  $\sim 2 \mu\text{m}$  and thicker than  $\sim 0.15 \mu\text{m}$ ), mesothelioma (fibers longer than  $\sim 5 \mu\text{m}$  and thinner than  $\sim 0.1 \mu\text{m}$ ) and lung cancer (fibers longer than  $\sim 10 \mu\text{m}$  and thicker than  $\sim 0.15 \mu\text{m}$ ) (Lippmann, 1990). Baron (1996) suggested that it would be reasonable to expand the definition of fibers that determine health effects from 'respirable fibers [50% cut point:  $5 \mu\text{m}$

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aerodynamic diameter ( $d_{ae}$ )]' to 'thoracic fibers (50% cut point:  $10\ \mu\text{m}\ d_{ae}$ )' because fibers between these definitions can penetrate to the upper lung airways and may cause diseases. Thus, it would be prudent to characterize personal exposures to this range.

A standard method to measure fiber concentrations is to use 25-mm cellulose membrane filter collection and enumeration of fibers through phase contrast microscopy. This method is described in Method 7400 (NIOSH, 1994), OSHA ID-160 (OSHA, 1998), MDHS 39/4 (HSE, 1995), World Health Organization (WHO) (WHO, 1997) and ISO 8672 (ISO, 1993a). However, the current sampling method for fibers has two drawbacks: (i) the sample is normally taken 'open-face' allowing the collection of large particles or agglomerates ( $>10\ \mu\text{m}\ d_{ae}$ ) which can obscure the view of fibers and (ii) the current method also collects fibers greater than a mean of  $3\ \mu\text{m}$  physical diameter which are less likely to penetrate to the lungs. The latter problem can be solved by following either National Institute for Occupational Safety and Health (NIOSH) counting B rules (except that these rules use a different aspect ratio) or current European fiber counting rules based on WHO counting rules which ignore fibers wider than  $3\ \mu\text{m}$  from the count. However, this does not prevent agglomeration of large particles over the filter that obscures the view. Obscuration of large areas of the filter may lead to rejection of the sample. Therefore, in order to avoid large particles or agglomerates on a filter, adoption of already existing size-selective samplers or development of a new sampler has been suggested (Dement, 1990; Lippmann, 1994a,b; WHO, 1997; Baron, 2001). Jones *et al.* (2000, 2005) investigated four thoracic samplers as to whether they are capable of collecting fibers with characteristics close to the thoracic convention and comparable with the standard cowled sampler. The thoracic samplers were two cyclone samplers (the GK2.69 and a modified SIMPEDS), one inertial sampler (the CATHIA-T) and a porous foam sampler [the Institute of Occupational Medicine (IOM) thoracic sampler]; all samplers used 37-mm filters except for the modified SIMPEDS (25-mm filters). Man-made mineral fibers (MMMF) containing a high proportion of fibers with aerodynamic diameter  $>10\ \mu\text{m}$  were used in their study to demonstrate the effect of thoracic size selection. They found that the performance of the GK2.69, the modified SIMPEDS, and the CATHIA-T matched well to the thoracic convention (ACGIH, 1993; CEN, 1993; ISO, 1993b), whereas the cowled sampler did not. The IOM thoracic sampler with a foam insert underestimated fiber concentrations with respect to the thoracic convention. Maynard (1999) observed similar trends when testing aerosol penetration through thoracic samplers (the GK2.69, the modified SIMPEDS, the CATHIA-T and the IOM thoracic sampler) with a polydisperse aerosol of glass micro-

spheres under calm air conditions. The sampling efficiency of the GK2.69, the modified SIMPEDS and the CATHIA-T resulted in no length dependency for fibers  $<60\ \mu\text{m}$  long, while the IOM sampler showed a significantly lower sampling efficiency for fibers  $>30\ \mu\text{m}$  long (Maynard, 2002; Jones *et al.*, 2005). These results were based on laboratory studies. The uniformity of fiber deposition over a filter surface was also tested by Kauffer *et al.* (1996) and Jones *et al.* (2005). Kauffer *et al.* (1996) observed a uniform fiber deposition over the filters of the CATHIA-T sampler from a factory manufacturing asbestos paper and aerosol-contaminated buildings. Jones *et al.* (2005) also reported that the distribution of fibers for the GK2.69, the CATHIA-T and the IOM thoracic sampler was similar to the fiber distribution of the cowled sampler, while the modified SIMPEDS generated highspots on the filters.

A European collaborative project (Jones *et al.*, 2001), published by the UK Health and Safety, performed field studies at eight sites: five sites producing MMMF, two sites for asbestos (one site for chrysotile fibers and the other site for asbestos cement sawing) and one site for carbon fibers, to assess the performance of the thoracic samplers. Unlike the other sampling sites, the sampling site-processing chrysotile fibers generated markedly higher concentrations sampled with the GK2.69 cyclone than those of the cowled sampler; overall, the relative concentration of the GK2.69 to the cowled sampler at the chrysotile sampling site was 1.80, while the other seven sampling sites ranged from 0.85 to 1.18 for the airborne fibers not touching particles. The results from the chrysotile asbestos sampling site disagreed with the previous laboratory tests from the comparison of fiber concentrations of the GK2.69 and the standard cowled sampler (Jones *et al.*, 2005). Therefore, in order to support the use of thoracic samplers instead of the standard cowled sampler, more field sampling was considered important.

In the current study, field samples from a site with detectable fiber concentrations were collected to investigate the performance of the two most promising thoracic samplers against the cowled sampler. The GK2.69 cyclone and the CATHIA-T sampler were selected (see Fig. 1), but the other thoracic samplers were not considered for the present study due to inhomogeneous filter deposit on the modified SIMPEDS and poor collection efficiency of the IOM thoracic sampler.

## METHODS

### *Sample collection*

Area samples were obtained from seven stations at a taconite (iron ore)-processing mill whose ore contains amphibole minerals. Sample locations and



Fig. 1. Thoracic size-selective samplers (left: CATHIA-T sampler and right: GK2.69 cyclone).

number of sample sets (one of each sampler types) at each sampling site are listed in Table 1. At each sampling site, side-by-side samples of two thoracic samplers were taken along with the standard cowled sampler. Thoracic samplers were the CATHIA-T utilized with 37-mm filter and the GK2.69 cyclone utilized with 37-mm filter (Fig. 1). The CATHIA-T static sampler was developed at the Institut National de Recherche et de Sécurité in France (Fabries *et al.*, 1998). The GK2.69 cyclone, developed by Kenny and Gussman (1997), was designed as a dual sampler, a respirable sampler ( $4.2 \text{ l min}^{-1}$ ) and a thoracic sampler ( $1.6 \text{ l min}^{-1}$ ). The standard 25-mm cowled sampling method, current NIOSH 7400 method, was used as a reference. A total of 270 samples, 80 field and 10 field blank samples for each sampler type, were obtained over 8 days. Six CATHIA-T samplers and six GK2.69 cyclones were used to collect the samples. Samplers were not individually identifiable. They were cleaned and returned to the field where they could have been used at the same or different sites. The sampling time period ranged from 50 to 318 min. All sampling pumps (XR series, SKC, Inc., Eighty Four, PA, USA; or Gil-Air or Air-Con series, Sensidyne, Clearwater, FL, USA) were

Table 1. Sample locations and number of sample sets at each station

Station	Location	Number of sample sets <sup>a</sup>
1	Rail car loadout	5
2	West concentrator	9
3	Fine crusher line (a)	10
4	Fine crusher line (b)	19
5	Conveyor	11
6	Dry cobber main deck	12
7	North concentrator	14
Total number of sample sets		80
Total number of samples including field blank samples <sup>b</sup>		270

<sup>a</sup>A set is one GK 2.69 sampler, one CATHIA-T sampler and standard cowled cassette located side-by-side.

<sup>b</sup>Ten field blank samples for each sampler type were obtained.

calibrated before and after sampling using a Drycal DC-Lite calibrator (BIOS International Corporation, Pompton Plains, NJ, USA) to ensure that the variations of flow rates are acceptable. Flow rates and sample loading rates for each sampler type are given in Table 2. In the laboratory study of Jones *et al.* (2005), the same amount of sample loading was collected on all samplers by using intermittent sampling method. However, this may not lead to the same result in the transitory conditions normal to the field. Therefore, all samplers were exposed for the same time periods at constant flow rates and thus the samplers running at different flow rates per unit area of filter produced substantially different amount of loading. Field sampling therefore introduces sample loading into the overall performance assessment.

#### Slide preparation and examination

Sample slides were prepared using the dimethyl formamide/Euparal solution technique and relocatable field cover slips (Pang, 2000). Two counters examined fibers at a magnification of  $\times 400$  using two phase contrast microscopes, Leica DMRB (Leica Microsystems Inc., Bannockburn, IL, USA) and ML2000 (Meiji Techno Co., Ltd, Saitama, Japan). Each counter was randomly assigned to a number of 80 field sampling sets and for each sampling set, the designated counter examined all three sample slides (slides for the CATHIA-T, the GK2.69 and the cowled sampler), but on different days. Fibers were counted according to NIOSH 7400 counting A rules, i.e. all fibers longer than  $5 \mu\text{m}$  and an aspect ratio  $\geq 3:1$  were counted regardless of fiber diameter. Prior to counting fibers, quality control was maintained by checking the resolution of the microscopes with a HSE/NPL test slide and the diameter of the Walton-Beckett graticule with a stage micrometer, and by performing a blind recount from one of the 10 slides previously counted. All field blank slides were

Table 2. Filter area, sampling flow rate and sample loading rate on a filter surface

Sampler type	Filter diameter (mm)	Filter area (mm <sup>2</sup> )	Flow rate (l min <sup>-1</sup> )	Sample loading rate [ml (mm <sup>2</sup> min) <sup>-1</sup> ]
CATHIA-T	37	803.4	7.0	8.7
GK2.69	37	855	1.6	1.9
Standard cowled	25	385	2.0	5.2

Table 3. CV between counters, within counters and between the two microscopes

	Within counters		Between counters	Between microscopes
	Counter 1	Counter 2		
Number of samples	4	4	4	7
Range of fiber concentration (fibers cc <sup>-1</sup> )	0.097–0.240	0.090–0.308	0.104–0.235	0.055–0.646
CV range	0.010–0.111	0.011–0.230	0.044–0.342	0.018–0.305
Average CV	0.072	0.119	0.148	0.147

counted by both counters and the average number of fibers was subtracted from the real sample counts to estimate fiber density and fiber concentration.

In order to check the differences between and within counters, four reference slides were chosen at random and counted three times on different days. Additionally, seven reference slides were randomly selected and counted by the two counters to determine the difference between the two microscopes.

### Analysis

For quality assurance, the coefficient of variation (CV) was estimated as a measure of the variability of fiber concentrations between and within counters and between the two microscopes. Reproducibility of individual sampler types over eight sampling days and at seven sampling stations was tested by estimating normalized CV by the corresponding cowled sampler's CV.

Individual ratios of the fiber concentrations of the CATHIA-T/Cowled and the GK2.69/Cowled were calculated. Although fiber concentrations for a few samples were >1.0 fibers cc<sup>-1</sup> thus yielding high ratios, those concentrations were not treated as outliers because visual observation of those slides confirmed no error by sample preparation. Thus, the geometric mean of fiber concentrations and the geometric means of fiber concentration ratios are reported instead of arithmetic means to minimize the effect of those high concentrations in data analysis. The differences between fiber concentrations of the thoracic samplers against the cowled sampler were estimated using the following extension of the standard bias equation (Kennedy *et al.*, 1995):

$$\text{Difference}_{i,\text{CATHIA(or GK2.69)}} = \frac{\text{FC}_{i,\text{CATHIA(or GK2.69)}}}{\text{FC}_{i,\text{Cowled}}} - 1,$$

where FC<sub>*i*</sub> = fiber concentration of sample ID *i* (*i* = 1 – 80).

## RESULTS AND DISCUSSION

### Quality assurance

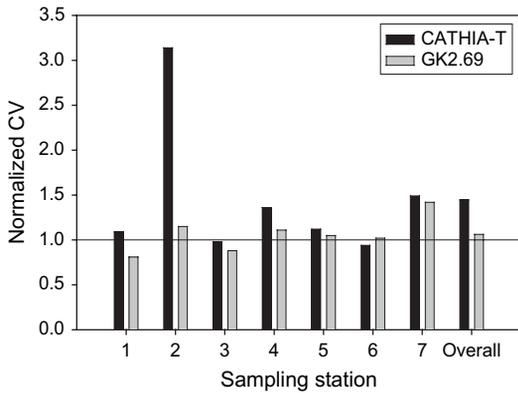
As shown in Table 3, the overall CVs of fiber concentrations within counters were 0.072 for Counter 1 and 0.119 for Counter 2. The overall variation between counters was 0.148, higher than those within counters, as expected. These CVs were lower than the overall CV (0.46) recommended by NIOSH 7400 method and within acceptable ranges of 0.22–0.37 by Pang (2000, 2007) and 0.14–0.22 by Harper and Bartolucci (2003). Also, the variation of fiber concentrations between the two microscopes ranged from 0.018 to 0.305 (average CV = 0.147) which fell into an acceptable range. Thus, variations due to different counters and microscopes were small enough to be negligible for the further analysis.

### Reproducibility of individual sampler types

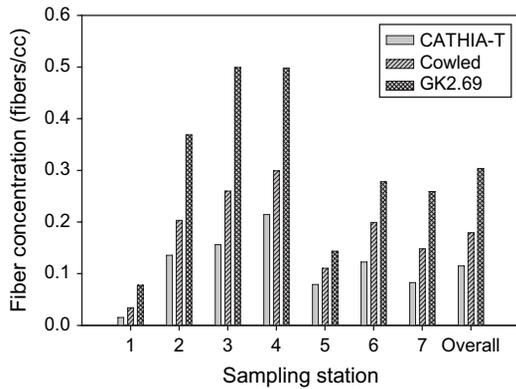
In order to test the reproducibility of individual thoracic sampler types against the cowled sampler, the CV of the CATHIA-T sampler and the GK2.69 cyclone was normalized by the corresponding standard cowled sampler's CV (Fig. 2). The normalized CV (0.63/0.20 = 3.14) of the CATHIA-T at sampling station 2 was less consistent than that of the other sampling stations because of the relatively small CV (0.20) of the cowled sampler at this location compared to the other sampling stations (0.45–0.84), while the CV (0.63) of the CATHIA-T sampler was within the range of CVs (0.49–0.92) at the other stations. Overall, both thoracic samplers can be considered to have performed consistently over the eight sampling days; the normalized CV was 1.45 for the CATHIA-T sampler and 1.06 for the GK2.69 cyclone.

### Performance of individual sampler

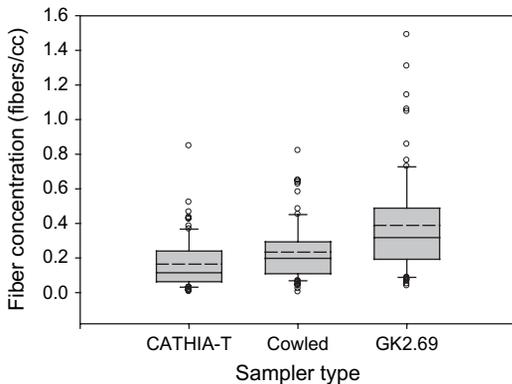
As shown in Figs 3 and 4, overall, the GK2.69 cyclone yielded higher fiber concentrations compared



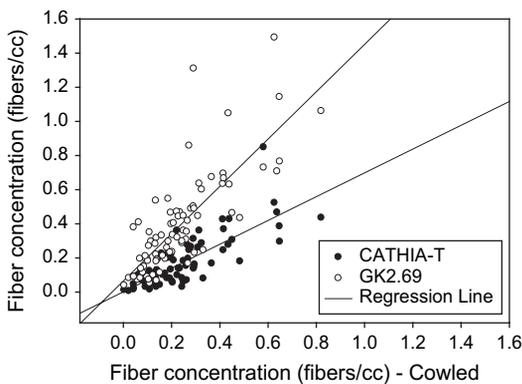
**Fig. 2.** Normalized CV of the CATHIA-T sampler and the GK2.69 cyclone. Normalized by the corresponding cowled sampler's CV.



**Fig. 5.** Geometric mean of fiber concentrations at each sampling station and overall.



**Fig. 3.** Fiber concentrations (fibers  $cc^{-1}$ ) for each sampler. Box plot shows the 10th, 25th, median (solid line), mean (dashed line), 75th and 90th percentiles.



**Fig. 4.** Fiber concentrations of the CATHIA-T and GK2.69 samplers in each sample set versus the cowled sampler fiber concentration from the same set.

to the other two samplers, whereas the CATHIA-T and the cowled sampler showed similar results. Fiber concentrations ranged from 0.006 to 0.848 fibers  $cc^{-1}$  (geometric mean: 0.113 fibers  $cc^{-1}$ ), 0.004 to

0.821 fibers  $cc^{-1}$  (geometric mean: 0.178 fibers  $cc^{-1}$ ) and 0.039 to 1.491 fibers  $cc^{-1}$  (geometric mean: 0.295 fibers  $cc^{-1}$ ) for the CATHIA-T, the cowled and the GK2.69 sampler, respectively. Each sampler type generated a lognormal distribution of concentration values. Especially, very high concentrations ( $>1.0$  fibers  $cc^{-1}$ ) were observed from five samples of the GK2.69 cyclone producing a long tail to the distribution; two occurred at sampling station 3 [fine crusher line (a)] and three at sampling station 4 [fine crusher line (b)].

Figure 5 shows the geometric mean of fiber concentrations at each sampling station. The GK2.69 cyclone gave consistently higher concentration results than the other samplers for all sampling stations. For all three sampler types, fiber concentrations at sampling stations 3 and 4 were higher than the other stations because samples were collected from near fine crusher lines. On the other hand, fiber concentrations at sampling station 1 were lower than the other stations because samples were collected near the rail car loadout where a large local ventilation system was installed underneath the platform. Samplers were placed in locations selected to ensure a range of loadings and concentrations. The range of concentrations should not be taken as indicative of personal exposures.

The geometric means of difference estimates for thoracic samplers are given in Table 4, showing a negative result for the CATHIA-T sampler and a positive result for the GK2.69 cyclone. These results indicate generally, lower concentrations for the CATHIA-T sampler and higher concentrations for the GK2.69 cyclone compared to the cowled sampler. For both thoracic samplers, the 95% confidence interval did not contain zero, indicating statistically significant differences between each thoracic sampler and the cowled sampler.

As shown in Figs 3–6 and Table 4, fiber concentrations of the CATHIA-T sampler are closer to the concentrations of the standard cowled sampler than are

Table 4. Geometric mean and 95% confidence interval of difference estimates

Variable	Number of samples	Geometric mean	Confidence interval (95%)	
			Lower	Upper
CATHIA-T	80	-0.368	-0.445	-0.279
GK2.69	80	0.659	0.470	0.871

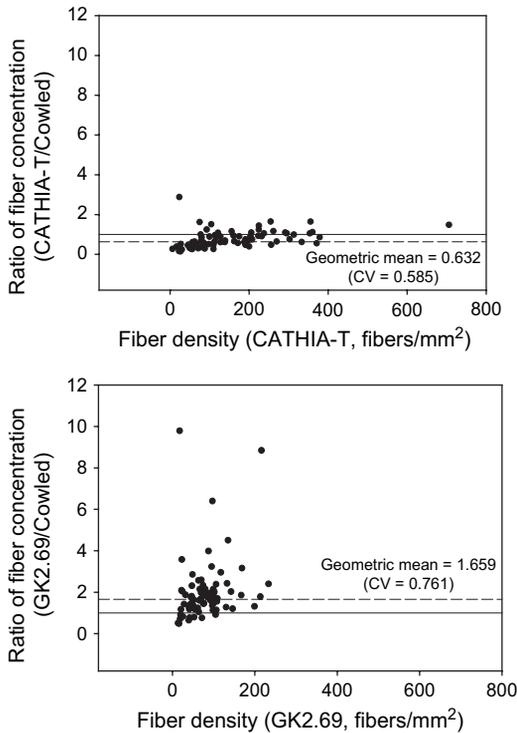


Fig. 6. Ratio of fiber concentrations: CATHIA-T (fibers mm<sup>-2</sup>) versus CATHIA-T/Cowled (left) and GK2.69 (fibers mm<sup>-2</sup>) versus GK2.69/Cowled (right).

those from the GK2.69 cyclone. The geometric mean ratio of the CATHIA-T/Cowled sampler is 0.63, which is in agreement with the previous study (average ratio = 0.81) that evaluated the performance of different thoracic samplers in laboratory trials (Jones *et al.*, 2005). Note that 0.81 is an average ratio obtained from the graph published by Jones *et al.* (2005), which included a matrix of five aerodynamic diameter classes ( $d_{ae} = 2, 4, 6, 8$  and  $10 \mu\text{m}$ ) and four length classes ( $L < 15 \mu\text{m}$ ,  $13 < L < 30 \mu\text{m}$ ,  $L > 30 \mu\text{m}$  and  $L > 50 \mu\text{m}$ ). Overall agreement is not necessarily the same as agreement over each size interval. Since fiber concentrations of the CATHIA-T sampler were lower than those of the cowled sampler, it can be assumed that fibers whose size exceeds the thoracic convention were screened before entering the sampler.

However, in this study, a result inconsistent with the findings by Jones *et al.* (2005) was observed. In

Jones *et al.*, the GK2.69 cyclone generated lower fiber concentrations against the cowled sampler for fibers equal to or less than an aerodynamic diameter of  $10 \mu\text{m}$  (GK2.69/Cowled = 0.71). The geometric mean ratio of the GK2.69/Cowled in the current study is 1.66 which is much greater than that expected. Cherrie *et al.* (1986) investigated the influence of fiber density on the fiber concentration and found that lighter loading could bias counts high against average. Due to the potential for bias in counting results at low densities, Cherrie *et al.* (1986) suggested to avoid counting fibers at low densities ( $< 100$  fibers mm<sup>-2</sup>). Lee (1990) also reported that fiber counting errors are known to increase at lower fiber densities. In the current study, the geometric mean of sample loading was 112 fibers mm<sup>-2</sup> for the cowled sampler and 68 fibers mm<sup>-2</sup> for the GK2.69 cyclone; 71% (57 out of 80 samples) for the GK2.69 cyclone showed  $< 100$  fibers mm<sup>-2</sup>. Thus, in order to test the influence of fiber density, fiber densities of the GK2.69 cyclone and corresponding cowled samples were divided into four categories and ratios of fiber concentrations were estimated. As shown in Table 5, unexpectedly high results of the GK2.69 cyclone do not appear to be related to fiber density; the geometric mean ratios are always positive for both high and low fiber densities. Also, among 80 pairs of the GK2.69 and the cowled sampler, only 10 pairs had a ratio of fiber concentrations  $< 1$ . Further studies would be necessary to confirm our findings.

In the European collaborative study (Jones *et al.*, 2001), fiber concentrations of the cowled sampler operated at  $1 \text{ l min}^{-1}$  [sample loading:  $2.4 \text{ ml (mm}^2 \text{ min)}^{-1}$ ] were compared with those of the GK2.69 cyclone operated at  $1.6 \text{ l min}^{-1}$  [sample loading:  $1.9 \text{ ml (mm}^2 \text{ min)}^{-1}$ ]. Interestingly, among eight field sites, the chrysotile asbestos site generated markedly higher (1.8 times) concentration of the GK2.69 cyclone than the cowled sampler, whereas the other sites produced similar concentrations for the airborne fibers not touching particles. The asbestos sampling site involved sampling near the tipping of chrysotile asbestos from sacks in the production of asbestos cement. At this sampling site, the results for the GK2.69 were similar to those for a second cyclone sampler (modified SIMPEDS). An eighth field trial had been planned as part of the European collaborative study but was replaced by a controlled simulation involving sawing of asbestos cement sheet. Those results were reported along with the field trial. That asbestos cement sawing gave concentrations (for airborne fibers not touching particles) from the GK2.69 that were very close to those from the cowled sampler. Thus, a relative high concentration has been seen for sampling chrysotile asbestos (tipping chrysotile from bags), amphibole asbestos (field sampling in the current), but concentrations similar to those from

Table 5. Ratio of fiber concentrations of the GK2.69 cyclone and the cowled sampler

	Pair comparison			
	High fiber density		Low fiber density	
	GK2.69 > 100 <sup>a</sup> and corresponding Cowled sampler	GK2.69 >100 <sup>a</sup> and Cowled > 100 <sup>a</sup>	GK2.69 < 100 <sup>a</sup> and corresponding Cowled sampler	GK2.69 <100 <sup>a</sup> and Cowled < 100 <sup>a</sup>
Number of pairs	23	21	57	30
Range	0.9–8.8	0.9–3.1	0.5–9.8	0.5–9.8
Mean	2.3	1.8	1.8	2.3
Geometric mean	2.0	1.8	1.5	1.9
Standard deviation	1.6	0.6	1.4	1.8
CV	0.7	0.3	0.8	0.8

<sup>a</sup>Fiber density (fibers mm<sup>-2</sup>).

the cowled sampler for sawing asbestos cement and (from the field sites of the European study) for carbon fiber grinding, MMMF production, rock wool sawing, glass wool sawing, glass fiber production and ceramic fiber production.

The European collaborative study examined whether the apparent increase in fibers not touching particles for the chrysotile asbestos could be explained by particles becoming detached from fibers in the cyclone. The counts of fibers touching particles indicated that this was not the explanation.

Another possible explanation might be that flocs or tufts of fibers are subject to disturbance in the cyclone vortex and that might suffice to release some fibers from such flocs. The inner diameter of the vortex tube for the GK2.69 cyclone is 6.1 mm (cyclone inner diameter: 26.9 mm). Visible flocs, of several millimeter diameter, are common in operations such as tipping chrysotile from bags and would be subject to opposing velocities and forces in the vortex finder. However, at the present study site the mineral present is not chrysotile, and the number of particles consisting of fibrillar bundles is likely to be much lower as a proportion of total fibers. In fact, only a few percent of fibers from this location meet the morphological characteristics (especially narrow width) typical of asbestos. An evaluation of 344 particles meeting the NIOSH A rules definition of a fiber found only 3.8% met the criterion of being both >10 µm long and <1 µm wide.

Note that in the current study, only ~5% of counted fibers were >3 µm physical diameter in the CATHIA-T and the GK2.69 cyclone samples. If the proportion of fibers that are wider than 3 µm is large, the geometric mean ratio of individual thoracic samplers to the cowled sampler would be lower than the current ratios.

The GK2.69 cyclone has unexpectedly provided higher concentrations than the cowled sampler in two situations, for the amphiboles in a taconite-processing mill and for the chrysotile asbestos in a previous study (Jones *et al.*, 2001). That may be ac-

ceptable, e.g. for demonstrating compliance, but it will be important to understand how it occurs and when or where it is likely to arise. Further laboratory analyses are needed to clarify the causes, and field studies to confirm the sampler performance in the field.

## CONCLUSIONS

This study has compared the performance of two thoracic samplers, the CATHIA-T (37-mm filter) and the GK2.69 cyclone (37-mm filter), in comparison to the standard 25-mm cowled sampler (current NIOSH 7400 standard method) to determine the effect of thoracic sampling on field results. The comparison of samplers relies on fiber counts, and two counters and two microscopes were used in the current study. Variations of fiber concentrations between and within counters and between the two microscopes were <0.15 (CV) which fell into an acceptable range per NIOSH recommendation. Variation in counts may also be affected by the quality of samples from a particular type of sampler. The overall reproducibility of individual thoracic samplers was consistent with the cowled sampler over the sampling days.

Overall, fiber concentrations were lower for the CATHIA-T sampler (0.63 times) and higher for the GK2.69 cyclone (1.66 times) compared to the cowled sampler. Since the sampling efficiency of the CATHIA-T sampler appeared to be similar to the thoracic convention (Jones *et al.*, 2005), it can be assumed that large fibers whose size exceeds the thoracic convention were screened before entering the sampler leading to the relatively low fiber concentrations observed in the current study.

One limitation of the CATHIA-T sampler is that the sampler is not appropriate for a personal sampler due to its large size and weight and the high sampling flow rate (7 l min<sup>-1</sup>) which requires a mains-operated pump (personal pumps operating at this flow rate have recently come onto the market, but it is not

known if they are able to overcome the pressure drop across a membrane filter of submicron pore size for appreciable periods of time).

Comparison with the results from a previous study showed that the GK2.69 cyclone produced concentrations which are relatively high at some but not all field sites. The reasons need further investigation.

Customized GK series cyclones with the vortex inner diameter of 8.0 mm to perform a thoracic cut at  $3.2 \text{ l min}^{-1}$  have been constructed to collect additional field samples from other environments as a follow-up study to the current investigation.

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*Disclaimer*—The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the NIOSH.

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