Beryllium Concentrations at European Workplaces: Comparison of 'Total' and Inhalable Particulate Measurements

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ABSTRACT

A field study was carried out in order to derive a factor for the conversion of historic worker exposure data on airborne beryllium (Be) obtained by sampling according to the 37-mm closed faced filter cassette (CFC) 'total' particulate method into exposure concentration values to be expected when sampling using the 'Gesamtstaubprobenahmesystem' (GSP) inhalable sampling convention. Workplaces selected to represent the different copper Be work processing operations that typically occur in Germany and the EU were monitored revealing a broad spectrum of prevailing Be size distributions. In total, 39 personal samples were taken using a 37-mm CFC and a GSP worn side by side for simultaneous collection of the 'total' dust and the inhalable particulates, respectively. In addition, 20 static general area measurements were carried out using GSP, CFC, and Respicon samplers in parallel, the latter one providing information on the extra-thoracic fraction of the workplace aerosol. The study showed that there is a linear relationship between the concentrations measured with the CFC and those measured with the GSP sampler. The geometric mean value of the ratios of time-weighted average concentrations determined from GSP and CFC samples of all personal samples was 2.88. The individual values covered a range between 1 and 17 related to differences in size distributions of the Be-containing particulates. This was supported by the area measurements showing that the conversion factor increases with increasing values of the extra-thoracic fraction covering a range between 0 and 79%.

KEYWORDS: aerosols; dust sampling conventions; exposure assessment methodology

INTRODUCTION

Beryllium (Be) is a lightweight metal element used in the metal industry in high-tech applications. The vast majority of Be used today is in solid, massive forms of metals containing Be, such as pure Be metal, copper–beryllium alloys (CuBe), aluminium–beryllium alloys, and nickel–beryllium alloys. Most Be is used in CuBe alloys containing <2% Be by weight. Overall, usage in the alloy form comprises over 85% of the Be in commerce. Be metal is generally imported into the EU in article form as finished parts. Similarly, alloys containing Be are also imported as finished parts, but is also imported in a semi-finished form. The operations performed downstream from the metal production facilities in the USA mirror the operations performed in the EU. The inhalation of Be particulate

can cause chronic Be disease, a serious lung condition, in some individuals. The degree of risk varies depending on the genetic disposition of the individual, degree of exposure, form of the product, and the nature of the processing operations.

Personal occupational exposure limits (OELs) have been developed over time for exposure to airborne Be. The OELs that are used in most countries range from 2000 to 1000 ng m^{-3}, 8-h time-weighted average (TWA) value. For the past several years, the Be industry has been publicly advocating a 10-fold lowering of the 8-h TWA OEL to 200 ng m^{-3} [closed face filter cassette (CFC)] based primarily on the scientific evidence generated as part of a 15-year joint research program with the National Institutes for Occupational Safety and Health (NIOSH) in the USA (Deubner and Kent, 2007). Ireland, Poland, and Spain in the EU and the State of California in the USA have adopted the 200 ng m^{-3} OEL. In the USA, exposure assessment is generally carried out following the Occupational Health and Safety Administration (OSHA) and NIOSH guideline prescribing the closed face 37-mm filter cassette (CFC) 'total dust' sampling method. In Europe, the 'inhalable' fraction sampling method following the CEN 481 convention (CEN, 1993) is prescribed in many countries such as for example the UK and Germany. The sampling characteristic of the CFC method is different from the one of the Gesamtstaubprobenahmesystem (GSP) 'inhalable' sampler. In the past, OELs for Be were summarily adopted without regard to sampling methodology. As all the human epidemiology studies used to establish the current OELs are based on the CFC method, there is a need to properly account for the difference in results between the CFC and the inhalable fraction sampling methods when sampling in the same atmosphere. This difference should also be considered when setting an OEL that requires the GSP inhalable method to assess compliance.

Historically, most of the data available for Be concentrations and the corresponding health risk studies at workplaces have been based on samples taken with the CFC method. One study has also evaluated Be health risks based on respirable particulate sampling. Schuler *et al.* (2012) compared 'total' CFC particulate sampling exposure data to respirable sampling data. The health risks were found to correlate with both, the respirable and the 'total' sampling methods; however, the underlying data for the respirable sampling

were 198 samples versus 4022 samples for the CFC method. No studies have been conducted to correlate inhalable particulate method exposure data with chronic Be disease, which is the critical health effect associated with exposure to Be.

Many laboratory and field studies carried out in various industrial environments have shown that measurements of inhalable concentrations are generally higher than those made when using the 'total' particulate (CFC) method. In the papers of Werner *et al.* (1996), Davies *et al.* (1999), and Skaugset *et al.* (2013), where the IOM sampler was used for inhalable sampling, mean conversion factors from 1.2 up to 4.2 were reported depending on the coarseness of the workplace aerosol monitored. There are also field studies dedicated specifically to Be comparing different sampling methods. Dufresne *et al.* (2009) compared Be concentrations as measured with the IOM, the 37-mm CFC, a respirable cyclone and two cascade impactors: a low flow (Sierra impactor) and a high flow (Moudi impactor). The assumed upper cut-off for their inlets is 50 and 100 μm, respectively. The measurements were carried out in a magnesium foundry and in an aluminium smelter. The results are in qualitative agreement with those of the inter-comparison studies cited previously revealing that the IOM sampling results, when compared with the CFC sampling results, yield about a 3-fold higher ratio.

In another study on Be, Virji *et al.* (2011) used a Marple personal cascade impactor and a CFC for characterization of the exposure to airborne Be in a production facility. They found, that at many workplaces, the non-respirable fraction of the dust can be substantial. The median of the mass median diameter values measured at sites of specific Be processing ranged from 5 to 14 μm showing that different processes do generate quite different size distributions. Due to lack of size resolution of the Marple impactor in the size range >10 μm, the upper value of 14 μm of the mass median aerodynamic diameter (MMAD) is probably underestimated. Measurements of Be concentrations in the aluminium industry were reported by Skaugset *et al.* (2012). From the analysis of Respicon samples, it was found that on average, ~50% of the Be was associated with particles in the extra-thoracic size regime.

An overview on Be exposure concentrations averaged over all industries in 26 European countries is given by Cherrie *et al.* (2011). The geometric mean

concentrations ranged from 70 to 170 ng m^{-3}, the 90th percentile not >2000 ng m^{-3}. Cherrie assumed that these exposures 'were measured as inhalable dust'.

The purpose of this study was to conduct personal sampling for Be using the German GSP as an inhalable sampler and the 37-mm CFC as a sampler for 'total' particulate to compare employee exposure values for Be obtained by the two methods. Data on this specific comparison are not available in the literature. Sampling sites covered widely used metallurgical processing of alloys containing Be. The aim was to determine a conversion factor from 'total' particulate sampling (CFC) to inhalable sampling (GSP) specific to Be for use in the development of an OEL in Europe based specifically on Be research studies that utilized the CFC sampling method. The second objective was to conduct personal exposure monitoring of the inhalable Be concentration on workers for a full work shift to get an impression on employee's exposure in those operations where specifically Be-containing alloys are used. The study was not intended to provide a complete exposure survey for Be at all workplaces in Europe, but does comprise a good representative example of exposures at work operations most commonly conducted in Europe. Be exposures have also been measured in manufacturing sectors not associated with usage of Be metal or Be-containing alloys, e.g. construction, cement, glass, steel production, furniture making, and shipbuilding (Vincent *et al.*, 2009). As the Be industry does not serve these sectors, these exposures are generally associated with naturally occurring Be that is present in many earthen products.

MATERIALS AND METHODS

Sampling sites

In total, six sites were visited in the time period between December 2013 and July 2014. All companies were processing CuBe alloys. At most of the workplaces, the alloys were processed mechanically such as drilling, milling, stamping, turning, and sawing. The others involved high temperatures such as welding and annealing. No melting or casting processes were among the metallurgical processes monitored. The sites, operations, and the personnel and the areas monitored were selected by an industrial hygienist certified by the American Board of Industrial Hygiene and experienced in CuBe processing operations. Each person having a potential for exposure to airborne Be was monitored and static samples were collected in areas where there was a likelihood of measuring process generated particles. According to the industrial hygienist, the processes monitored and the controls utilized were representative of operations processing CuBe alloys in the EU and in the USA. In brief, the sites are described as follows:

Plant A

The company processes CuBe alloy raw materials (0.5% and 2.0% Be) and cuts bars and plates into smaller units as requested by their customers. Band and circular saws are used in one single hall. The machines have individual local exhaust ventilation (LEV). Filtered air is redirected into the hall. The hall has no forced room ventilation system. In addition, there is some physical testing of work pieces involving grinding, which was equipped with LEV. This takes place in a separate room adjacent to the production hall.

Plant B

Electric contacts containing CuBe alloys (0.15–0.5% Be) are stamped and welded in automatic systems. All units are enclosed and have LEV. Workers perform surveillance and cleaning tasks. The machine hall has a displacement ventilation system. Clean cool air is supplied in ~1 m height through many inlets evenly distributed over the production hall. This ventilation scheme ensures sufficient make-up air near the workers.

Plant C

CuBe (1.6–2.0% Be) is treated by various mechanical processes: lathe turning, drilling, grinding, sanding, and polishing. In addition, there are welding and electrical discharge machining operations. Some of the processes had LEV, e.g. welding or used coolants for finishing operations, e.g. milling and grinding.

Plant D

Milling, turning, and lathe turning are the main operations carried out on CuBe alloys (0.4–0.7% Be; 1.8–2.0% Be; 0.2–0.6% Be). Most of the processes are not enclosed. There is no LEV system. Coolants are used in computerized Numerical Control (CNC) milling and sawing operations, which act as dust suppressants.

Plant E

Processing of rods of CuBe alloys (1.9–2.0% Be) into small pieces, which are subsequently surface treated by deburring, plating, and pickling. All processes monitored have local ventilation and are enclosed.

Plant F

Large pieces of CuBe alloys (1.8–2.0% Be) are heated, forged, and pierced. In addition, rings are formed in a ring roller. No ventilation system exists in the pre-forming hall. Pre-formed and ring rolled parts are further processed in a turning machine, equipped with LEV.

At all sites, the different metal processing machines were inside large machinery halls with building areas larger than 1000 m². Emissions from different work areas could mix. Depending on their tasks, workers were partly moving around inside the halls.

Personal and static general area samples were taken. Workers were told to carry out their tasks in the normal way. The area measurements were always within 2 m proximity to the emission source. The number of samples and their allocation to categories of working processes are shown in Supplementary Table S1, available at *Annals of Occupational Hygiene* online.

Samples were generally taken over a complete shift. In a few cases, shorter sampling periods were chosen when the workflow of Be-containing material did not cover a full shift. At all sites, background samples were taken using the GSP and CFC placed in a remote room not in direct contact to the production hall. The sampling volume was accumulated on the filters during several shifts.

Sampling instruments

Personal and static sampling of 'total' dust and inhalable dust was carried out using the 37-mm closed faced filter two-piece cassette (CFC) with 4-mm inlet diameter (Analyt-MTC GmbH, Mullheim, Germany) and the GSP (GSA, Neuss, Germany). Static dust monitoring was complemented with a Respicon TM (Helmut Hund GmbH, Wetzlar, Germany). This instrument was used to get some rough information on the size distribution and the temporal pattern of the aerosol concentration (Koch *et al.*, 1999).

All filters used in this study were special metal sampling filters with low background contamination [mixed cellulose ester (MCE) filters, 5-µm pore

size; Analyt-MTC GmbH]. They were either already integrated in the sampling devices (CFC) or were transported in special capsules that were inserted in the sampling instruments before the measurements started. Loaded filters were put back into the transport capsules. Filter samples were always transported with the loaded side facing up.

All personal samplers were operated using sampling pumps of the same type: SKC-PCXR8 purchased from Analyt-MTC GmbH. They provide a constant air flow rate that can be adjusted between 1000 and 5000 ml min⁻¹. The pump allowed for 8-h continuous operation. For the static samples, the airflow through the samplers was established via critical orifices operated by an oil-free vacuum pump.

Prior to each sampling action, the flows through the sampling devices were checked using a flow calibration device. For this purpose, a primary calibration standard based on volume displacement was used (Defender 520; Mesa Labs, Inc., Butler, NJ). The accuracy is 1% of reading. The intended flow rates were 2 l min⁻¹ for the CFC, 3.5 l min⁻¹ for the GSP, and 3.1 l min⁻¹ for the Respicon.

The two personal instruments were attached to the person on one side of the lapel using their corresponding holders. The opening of the GSP was situated in a horizontal direction; the inlet of the CFC essentially faced downward along the lapel. The identical orientation of the instruments was also maintained for the static samples. The Respicon is not orientation dependent as it has a circular slit inlet. The instruments were mounted next to each other at a lab stand with their inlets at the same height.

Chemical analysis

For all sampling instruments, only the MCE filters were used for analysis. The MCE filters were digested using the following procedure: (i) Microwave digestion with 1-ml sulfuric acid (98%, suprapure; Merck) and 1-ml nitric acid (65%, suprapure; Merck). The digestion is carried out according to the work flow as given in Supplementary Table S2, available at *Annals of Occupational Hygiene* online. (ii) Addition of water (Milli-Q system, conductivity < 0.05 µS). A final sample volume of 50 ml was selected to be used for the analysis of Be.

The Be content in the solution was measured by inductively coupled plasma mass spectrometry

(X-series II; Thermo Fisher Scientific GmbH, Dreieich, Germany) using the prepared samples after recommended dilution with water. For all solvent ratios and final sample volumes, blank solutions including acids and filter material are prepared too. Every sample was analyzed at least twice using two different dilutions to avoid or detect possible matrix interference. The Be concentration in the solution was determined by standard addition. Quality control was facilitated using certified reference materials (SRM, TMRAIN-04, Lot # 0913, Environment Canada) of 0.378 ng ml^{-1}, arithmetic standard deviation (2-sigma limit for an individual measurement) of 0.0688 ng ml^{-1}.

The limit of quantification was evaluated by spiking a filter with 0.5 ng of Be and following the digestion and analysis procedure as described previously. The intended concentration of the 50-ml sample was therefore 10 pg ml^{-1}. The evaluation, according to DIN 32645 (DIN, 2008), included the filter blank solution and three standard additions of 25 pg. The limit of quantification (3.3 × limit of detection) was found to be 5 pg ml^{-1} corresponding to 0.25 ng/filter and 0.25 ng m^{-3} for an air sample volume of 1 m^3, the typical shift value sampled by the CFC during a working shift.

Two tests were carried out in order to determine the recovery of Be on spiked filters. First, seven 37-mm MCE filters were spiked with known amounts of Be between 5 and 50 ng from a reference solution, digested, and analyzed according to the above procedure. The results revealed an average recovery of 99.5%. In a second test, spiked filters with Be content that was unknown to the analytical laboratory were provided by Materion Corporation. Analysis according to the procedure described above revealed Be masses between 0 and 2000 ng, matching the spiked masses with an average recovery 100.06%.

Statistical analysis

In order to quantify correlations between pairs of concentration data for sampler #1 and sampler #2, the data were log transformed. Linear regression was applied to the transformed data:

$$\log(c_1) = a + b \cdot \log(c_2). \qquad (1)$$

Estimates as well as upper and lower 95% confidence intervals of the regression parameters, *a* and *b*,

as well as the regression coefficient, R^2, were calculated using the regression function in Excel. Furthermore, geometric mean values of the concentration ratios were calculated. An extreme studentized deviate outlier test was used to identify outliers of the concentration ratios.

RESULTS

In total, 39 personal samples and 21 static samples were taken. During a shift, two workers were monitored in parallel. The available instrumentation allowed only 1 set of instruments for a static shift sampling. In most cases, the sample volume was ~1 m^3 for the CFC, 1.75 m^3 for the GSP, and 1.55 m^3 for the Respicon. The corresponding concentration data, arranged by process categories, are shown in Supplementary Table S3, available at *Annals of Occupational Hygiene* online, for the personal samples and Supplementary Table S4, available at *Annals of Occupational Hygiene* online, for the static samples. Concentration values of less than the limit of quantification (0.25 ng m^{-3}) are replaced by this value for further statistical analysis of the data sets. The outlier test was applied to the logarithms of the conversion factors. The largest value ($\ln(85.6)$) is identified as outlier ($P = 0.05$). The corresponding data pairs were omitted in the regression analysis. The data are arranged according to the work process monitored. However, in many cases, it was not possible to isolate one single process as the workers were moving around and were exposed to atmospheres from different sources. Table 1 represents a summary of the data of the personal and static samples.

For the personal samples taken by the inhalable sampler (GSP), the TWA values of the Be concentrations vary by four orders of magnitude from <1 to >10 000 ng m^{-3}. The majority of the TWA values of the inhalable particulates (36 out of 39 personal samples) are <2000 ng m^{-3}. The concentrations determined from the CFC samples cover the range between 0.5 and 1000 ng m^{-3}. For the static samples, the variation of the concentration values is about three orders of magnitude. Background concentrations ranging from 0.2 to 1.5 ng m^{-3} for the GSP and 0.25 to 4.35 ng m^{-3} are reported in Supplementary Table S5, available at *Annals of Occupational Hygiene* online. They are different at the various sites but are always lower than the workplace values measured at that site. Even at Plant D, the relatively high background concentration is half of the lowest TWA-value for the personal sample.

Table 1. Summary of the concentration data for the personal and the static samples as measured with the CFC, the GSP, and the Respicon (static samples only).

		Geometric mean	Max	Min
Personal samples	CFC (ng m^{-3})	5.88	1032.00	0.25
	GSP (ng m^{-3})	18.55	12214.00	0.25
	GSP/CFC	2.88	17.39	1.00
Static samples	CFC (ng m^{-3})	7.41	190.00	0.25
	GSP (ng m^{-3})	17.63	1069.00	0.52
	GSP/CFC	1.99	9.54	1.06
	Respicon			
	Respirable (ng m^{-3})	2.81	124.00	0.25
	Thoracic (ng m^{-3})	5.44	151.00	0.41
	Inhalable (ng m^{-3})	8.03	461.00	0.48
	EF (%)	28.37*	79.00	0.00

EF denotes the extra-thoracic fraction defined in equation (2) as measured with the Respicon. Outliers are not included.
*Arithmetic mean.

The ratios of the GSP and CFC values range from 1 to 17 for the personal samples and from 1 to 10 for the static samples. The geometric mean value of all conversion factors GSP/CFC is 2.88 for the personal and 1.99 for the static samples. In the practice of occupational exposure evaluations, area measurements are only used for qualitative purposes and generally are not representative of actual employee exposures. The Respicon employed in the static samples does, however, provide some information on particle size distribution. Since it was operated in parallel with the CFC and the GSP, the data obtained from the static samples were used primarily to investigate the influence of aerosol size distribution on the conversion factors.

Estimates as well as upper and lower 95% confidence intervals of the regression parameters, a and b, as well as the regression coefficient, R^2, were calculated using the regression function in Excel. The analysis of all personal concentration data of the CFC (sampler #2) and the GSP (sampler #1) based on the regression of pairwise data according to equation (1) are shown Fig. 1 for the personal samples and Fig. 2 for the static samples. For the personal samples, the regression coefficients are $a = 2.65$ and $b = 1.05$. The corresponding values of the static samples are $a = 1.99$ and $b = 1.00$. As the values of the regression coefficient
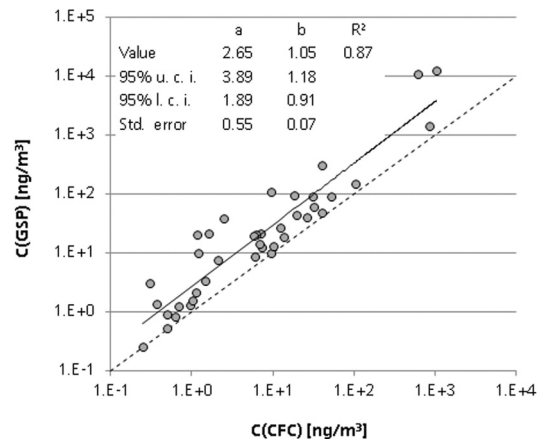

Figure 1   Log-log-plot of all personal concentration data for 'total' and inhalable particulates and the results of the corresponding regression analysis, u.c.i. (l.c.i.) upper (lower) limit of 95% confidence interval.

b are statistically indistinguishable from 1.00, the hypothesis that the magnitude of the CFC concentration influences the GSP/CFC ratio is not supported. In other words, there is a linear relationship between the concentrations measured with the CFC and those measured with the GSP sampler. This suggests that the geometric mean values of 2.88 for the personal
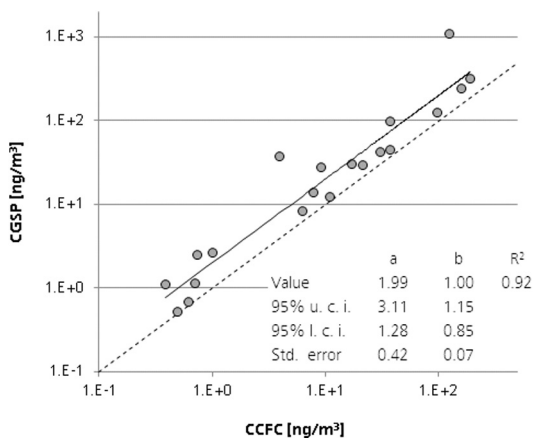
Figure 2   Log-log-plot of all static concentration data for 'total' and inhalable particulates and the results of the corresponding regression analysis, u.c.i. (l.c.i.) upper (lower) limit of 95% confidence interval.

samples and 1.99 for the static samples are appropriate conversion factors for the set of Be alloy processing operations selected in this study.

DISCUSSION

This field study was designed to compare the concentrations of airborne Be measured at multiple workplaces using two different types of samplers: the CFC and the GSP. The GSP's sampling characteristic has been shown to comply with the definition of inhalable particulate sampling (Kenny *et al.*, 1999). The CFC's sampling performance regarding the inhalable sampling convention has been subject to many published studies in the literature and conversion factors as large as 5 between the CFC sampling and inhalable sampling have been reported.

For Be, side by side data involving the CFC and the GSP sampler are not available. Therefore, a sampling program was initiated to monitor exposure concentrations for metallurgical processes covering Be aerosols of different size distributions because it was expected that the differing size distributions captured by the two methods influences the conversion factor. Personal as well as area samples were taken. Besides the CFC and the GSP sampler, a Respicon was used for the area samples. This sampler allows for size segregated sampling of the respirable, the thoracic, and the inhalable fraction.

For all sampling instruments, only the MCE filters were used for analysis. The internal wall losses of the Respicon were determined by Li *et al.* (2000) to be <20% confined to a narrow size range around the cut-off sizes

of the virtual impaction stages. For the GSP sampler, no information is available regarding losses on the inner surfaces. In Germany, the measurement of the inhalable particulate concentration is based on the evaluation of the GSP filter only. Inner losses on the sampling cone are not incorporated. The issue of wall losses in the CFC has been extensively discussed in the past decade. Ashley and Harper (2013) give some guidance on how to include them. For Be, median values for CFC wall losses of 12% was reported for four samples. The vast majority of the available historic CFC concentration data for Be that are used in context with epidemiology were obtained without taking the wall losses into account. As the main objective of this study was to establish a conversion factor between GSP inhalable sampling and CFC 'total' particulate sampling that allows for the use of the historic CFC data in the light of the inhalable convention, wall losses were not included in the determination of the exposure concentration. This study suggests the application of a geometric mean conversion factor of 2.88 for the conversion between 'total' particulate sampling to inhalable sampling is appropriate due to the linear relationship between the concentrations measured with the CFC and those measured with the GSP sampler.

These values are compared with published data obtained for other metal processing work environments. Tsai *et al.* (1996) and Tsai and Vincent (2001) report on nickel concentrations for nickel alloy processing and for processes in the primary nickel industry, respectively. They obtained a geometric mean conversion factor of 2.0 (range between 1.57 and 2.40) for Ni processing and 2.15 (1.16–4.01) for Ni mining and production. Earlier studies of Vinzents *et al.* (1995) reveal factors of 1.4 for aluminium in welding fume and 3.4 for aluminium averaged over a cross section of all workplaces in Norway. For electroplating of arsenic, Nield *et al.* (2014) report on a conversion factor of 1.4. For manganese, the geometric mean values of conversion ratios are found to range from 1.4 to 2.6 (IEH, 2004). Overall, the ranges of the individual values on metal-associated conversion factors found in published studies were similar to what was found in this study. A classification of conversion factors according to tasks carried out by the workers was not possible in our study due to the small number of individual measurements carried out for each task. In 8 out of the 39 personal measurements, the conversion factors were larger than 8. Six of them were measured

at site C, two at site E. They were all obtained at workplaces where surfaces were treated by sandblasting, grinding, and polishing, and the worker was close to these sources of the Be-containing particulates. These tasks are common to metal finishing operations and it is to be expected that the aspirated dust has a high fraction of coarse particles. This reflects the physics of aerosol sampling suggesting the aerosol size distribution to be a key factor determining the aspiration efficiency of the two samplers and, hence, the conversion factors between the measured concentrations. This becomes evident from the data from the static samples. The aerosol size information provided by the Respicon helps to further elaborate on this. An extra-thoracic fraction that is the size fraction >10 μm can be obtained from the thoracic concentration, C_{RT}, measured by the Respicon and the inhalable concentration, C_{INH}, measured by the Respicon or by the GSP:

$$F_{ET} = \left(C_{INH} - C_{RT}\right)/C_{INH}. \tag{2}$$

The fraction of the inhalable concentration allocated to the extra-thoracic size range based on the Respicon samples range from 0 to 79% (see Table 1). When the inhalable concentration at the static sampling sites is taken from the GSP samples in conjunction with the Respicon samples, the extra-thoracic (ET)-fraction spans a range up to 85%. (It is known that the Respicon underestimates the extra-thoracic size fraction and a conversion factor of 1.5 has been proposed to account for this. See also Supplementary Figure S1, available at *Annals of Occupational Hygiene* online.)

Large percentages in the extra-thoracic size range were measured in Plant C, where the largest GSP/CFC-conversion factors were obtained for the static as well as the personal samples. As can be seen from Fig. 3, there is a trend of increasing ratio of GSP and CFC concentration as the extra-thoracic fraction increases, i.e. the larger the particles, the lower the aspiration efficiency of the CFC sampler. This may be partly due to the orientation of the CFC sampler in which its inlet hole faces downward. This finding is in agreement with results of Görner *et al.* (2010) and Buchan *et al.* (1986) who measured the aspiration efficiency of the CFC sampler at various angles of inclination in a laboratory study as well as with results from Skaugset *et al.* (2013) obtained in a field study carried out in the aluminium industry.
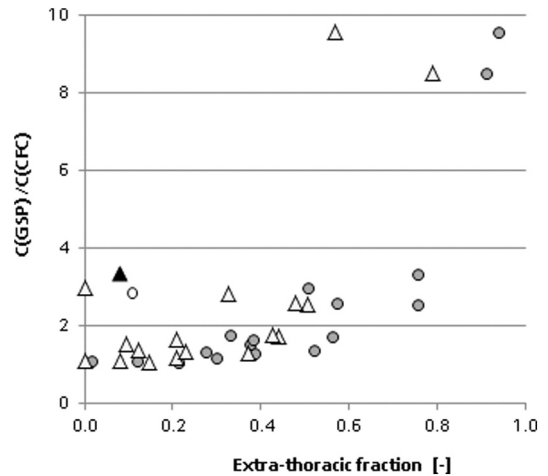

Figure 3   GSP/CFC-conversion factor as a function of the extra-thoracic fraction. Triangles: ET-fraction based on Respicon samples, circles: ET-faction based on Respicon samples (thoracic) and GSP samples (inhalable).

This implies that the application of the mean conversion factor between 'total' and inhalable Be particulates determined in this study can be used for the conversion of historic concentration values if it is assumed that the workplaces selected are representative in view of the Be size distributions. The value of 2.88 is in accord with what was found in other metal producing work environments.

CONCLUSIONS

A field study was carried out in order to derive a factor for the conversion of historic data on Be concentrations obtained by sampling according to the CFC 'total' particulate method into concentration values to be expected when sampling following the inhalable convention. Workplaces, selected to represent the different CuBe work processing operations that typically occur in Germany and the EU, as well as the USA, were monitored revealing a broad spectrum of prevailing Be size distributions. The data set and the statistical evaluation from this study reveal a geometric mean value of 2.88 for the factor used to convert Be concentrations from CFC sample to concentrations obtained from inhalable samplers. This fact has to be taken into account for the derivation of an OEL from Be epidemiology studies that have been based on the CFC 'total' particulate method, where the inhalable fraction sampling method is to be the basis for assessing compliance. The findings of this study mirror results found in previous studies with in other metal processing plants.

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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