Comparison of the determination and evaluation of quartz exposure and exposure levels at workplaces across Europe

Part 1: Quartz measurements and their strategies

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Abstract There is a need for a general comparison of studies of quartz exposure in Europe. The study questions whether the exposure data sourced from a number of countries for use in epidemiological studies are in fact directly comparable. The publication addresses this question with reference to a comparison of exposure data obtained in Austria, Switzerland, Germany and Finland. Part 1 of the publication first describes the measurement convention, sampling and analytics employed during quantification of quartz exposure. The correlation was found to be close in this case. Significant differences are however observed between measurement strategies. These are described and discussed in Part 2 of the publication with reference to the exposure data from certain working areas.

Vergleich der Messung und Bewertung von Quarzexpositionen und Expositionsniveaus an Arbeitsplätzen in Europa – Teil 1: Quarzmessungen und deren Messstrategien

Zusammenfassung Es besteht Bedarf an einem grundsätzlichen Vergleich von Untersuchungen zur Quarzstaubexposition in Europa. Ob die in epidemiologischen Studien verwendeten Expositionsdaten aus verschiedenen Staaten direkt vergleichbar sind, wird hinterfragt. Der Beitrag geht dieser Frage beispielhaft anhand eines Vergleichs von Expositionsdaten aus Österreich, der Schweiz, Deutschland und Finnland nach. Im ersten Teil der Veröffentlichung werden zunächst Messkonvention, Probenahme und Analytik im Rahmen der Ermittlung von Quarzexpositionen beschrieben. Hier zeigt sich eine gute Übereinstimmung. Es sind jedoch deutliche Unterschiede bei der Messstrategie festzustellen. Diese werden im Teil 2 der Veröffentlichung beispielhaft anhand von Expositionsdaten aus bestimmten Arbeitsbereichen beschrieben und diskutiert.

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1 Introduction

Quartz is employed as an agent or is released in the form of quartz dust in a range of working processes. Exposure to respirable quartz dust at workplaces remains significant, despite technical progress and the concerted efforts undertaken to reduce dust exposure.

All over Europe the prevention of respirable quartz exposure is a key issue, both in the regulatory sphere, where limit values and the classification of, for instance, mineral powders are under discussion, and in epidemiological and occupational health science.

The number of cases of silicosis caused by exposure to quartz dust and formally recognised as occupational diseases has fallen steadily in recent decades owing to the success of prevention measures.

Against this background, there is a need for a general comparison of studies of quartz exposure in Europe, in the first instance to serve as a basis for the management of preventive measures and the monitoring of exposure. Such a comparison is also necessary for the quantification of past exposure to quartz in the context of cases of suspected occupational disease.

The institutions

- Schweizerische Unfallversicherungsanstalt (SUVA), Switzerland,
- Österreichische Staubbekämpfungsstelle (ÖSBS), Austria,
- Finnish Institute of Occupational Health (FIOH), Finland,
- Institut für Gefahrstoff-Forschung (IGF) der Berufsgenossenschaft Rohstoffe und chemische Industrie (BG RCI) and
- Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA)

which have cooperated closely for many decades, have therefore set themselves the tasks firstly in this part 1 of the publication of describing the determination of quartz exposure of occupational origin, and secondly in a following part 2 of comparing examples of the values obtained. The intention here is to investigate whether the exposure data are comparable, as exposure data are increasingly being collated in national and international epidemiological studies. The comparison conducted constitutes a first phase, taking the example of occupationally related quartz exposure in Switzerland, Austria, Finland and Germany.

2 Participating institutions and legal remit

SUVA, the Swiss accident insurance institution, is an independent public-law body. All employees in the industrial and construction sectors in Switzerland are compulsorily insured against accidents by SUVA. At the same time, SUVA has

Table 1. Reasons and framework for shift-related quartz exposure measurements.

	SUVA	ÖSBS	FIOH	IGF	IFA
Prevention/inspection	Yes				
Occupational diseases	Yes	Rarely	Yes	Yes	Yes
Measurement campaign	Yes				
Personal sampling	Yes				
Static sampling	Yes, in some cases person related				
Typical sampling durations in h	1.5 to 3.5	2 to 3	4 to 7	2*	2*
Exposure duration	Shift measurements				

* Minimum sampling time, preferably longer

the tasks of a public authority in the prevention of accidents and occupational diseases; these also include the issuing and monitoring of workplace limit values. In this connection, SUVA can monitor companies and conduct measurements in accordance with Article 84 of the Accident Insurance Act. The measurements are usually performed in relation to the prevention of occupational diseases, and in some cases for clarification of whether diseases are occupational in origin.

The Technical Department of the ÖSBS, the Austrian institution devoted to combating dust and silicosis, is situated in Leoben and is concerned with the effects of dust on health and with the protection of insured employees in industrial sectors presenting an elevated risk. The ÖSBS's member institutions are the AUVA (general accident insurance institution), the ZAI (central labour inspectorate) and the VAEB (insurance institution for railways and mining). The ÖSBS is also a test body for dust protection equipment, dust protection measures and substances hazardous to health. It is accredited to EN ISO/EC 17025 [1] by the Ministry of Economics and Labour. Exposure measurements are conducted under the Employee Protection Act (AschG [2]) and the Ordinance of the Federal Minister of Labour, Social Affairs and Consumer Protection on Limit Values for Working Materials and on Carcinogenic and Reprotoxic Working Materials (Limit Value Ordinance 2011 – GKV 2011 [3]). For the purpose of data collection, all quartz exposure data are obtained in the course of dust measurements performed on behalf of ÖSBS member institutions.

The Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) and the Institute for Hazardous Substances Research (IGF) of the Berufsgenossenschaft Rohstoffe und chemische Industrie (BG RCI) operate within the scope of the German Social Accident Insurance. Exposure measurements are conducted by the measuring services of the social accident insurance institutions under the prevention brief of the German Social Code (SGB) VII, within the measurement system for exposure assessment of the accident insurance institutions (MGU) [4]. The goal is to achieve, where possible, a comprehensive assessment of exposure at the workplace which in turn is to serve as a basis for recommendations on protective measures and on current industrial good practice.

The FIOH is a multidisciplinary research and specialist organisation in the field of occupational health and safety. The institute operates under the aegis of the Finnish Ministry of Social Affairs and Health. The FIOH is a national governmental institute covering relevant research aspects of working conditions and the world of work, including the surveillance of well-being at work, physical, chemical, biological and physiological forms of exposure, occupational medicine, psychology and stress, epidemiology, safety, and the organisation of work. The institute maintains regional offices in six different towns around the country.

In 2003, the EU Scientific Committee on Occupational Exposure Limits (SCOEL) recommended an occupational exposure limit for respirable crystalline silica (OEL_{8h}) of less than 0.05 mg/m³; as yet however, no binding EU OEL_{8h} exists for respirable crystalline silica. Some countries, including Finland, have brought their respirable silica OEL_{8h} into line with the 0.05 mg/m³ limit. Until 2006, the Finnish OEL was 0.2 mg/m³.

All the institutions referred to above collect and compile exposure data in the course of prevention activity which can also be referred to for the comparison of limit values. These data do not originate from the traditional "compliance measurements" requested by third-party measuring bodies on behalf of employers.

3 Measurement strategy

Reasons and the framework for shift-related quartz exposure measurements are quite comparable (see **Table 1**). The measurement strategies employed for the recording of quartz exposure by the institutions concerned differ, in some cases significantly. This has repercussions for the measured exposure levels.

At SUVA, the companies at which measurements are to be performed are selected by industrial safety inspectors. A shortlist is prepared with the aid of directly indicating measurements performed with light-scattering photometers. Personal exposure measurements are performed only when violations of limit values are suspected. In the case of gravel quarries, the parties responsible also refer to the results of a nationwide measurement campaign conducted during the nineteen-eighties and nineties. In recent years, measurements have been carried out almost exclusively in companies that exceeded the limit values significantly in the past. The measurements conducted are not therefore representative; they do not reflect the state of technology in Swiss companies.

The ÖSBS is requested by its members to conduct dust measurements at workplaces at a company or in certain areas of a company. The Technical Department does not act of its own accord, but is always tasked with the performance of measurements. An aim of dust measurements is to improve dust hygiene conditions in order to protect employees from occupational diseases, and also to assess workplaces for the potential need for occupational health inspections. In very rare cases, measurements are performed in connection with investigations into cases of occupational disease. Workplace measurements in Austria are always carried out under normal working conditions and are based upon EN 689 [5] and Standard Operation Procedure Ex 009, "Exposure dust sampling" [6]. Dust sampling performed for evaluation of the workplace is generally worker-specific. In some cases, the measurement task may also involve dust measurements in parts of plants – for example in the vicinity of crushers – where no employees are located (assessment of extraction plant and dust-reducing measures). In rare cases, reasonable worst-case measurements or measurements during unusual working conditions are performed. Consequently, quartz dust exposure measurements are also performed at workplaces where high quartz dust concentrations are not expected, such as in the air-conditioned drivers' cabs of wheel loaders. This permits a workplace evaluation for the purposes of dust measurement referred to above. The ÖSBS conducted quartz dust investigations in the quarrying industry in 2006 and 2007 in connection with the EU-wide NePSi project[1].

Workplace measurements conducted by the German social accident insurance institutions are launched by the Technical Supervisory Service. Workplaces are not selected at random for measurement. In some cases, measurements are conducted in response to suspected cases of high exposure. The social accident insurance institutions also identify sources of exposure on machinery and plant, and conduct measurement campaigns at comparable workplaces in different companies in order to issue VSKs ("process- and substance-specific criteria") or EGUs ("exposure assessment recommendations of the social accident insurance institutions") in accordance with the Technical Rule for Hazardous Substances (TRGS) 402 "Identification and assessment of the risks from activities involving hazardous substances: inhalation exposure" [7]. The bodies of data are thus representative and reflect normal workplace situations on the one hand, and document unfavourable exposure scenarios on the other.

In Finland, workplace measurements of respirable crystalline silica have been conducted for the most part by the FIOH during customer service assignments – occupational hygiene surveys or follow-up measurements – carried out by occupational hygienists in the institute's six regional offices located across the country. In some cases, samples have also been taken in reasonable worst-case situations. Samples have been collected according to the European standard EN 689 [5] either in the breathing zone of workers or at stationary sampling sites at a height of 1.5 m above the floor for the purpose of estimating the average exposure of workers to respirable crystalline silica over an 8-hour working shift. Prior to 2006, all samples were collected at stationary sites owing to methodological limitations. The FIOH has also measured the concentrations of respirable crystalline silica during numerous research projects, for example in foundries, in the cement industry and during construction work, with the aim of monitoring and controlling workers' exposure. The results of those measurements can also be found in the Finnish database of occupational exposures.

4 Sampling

Sampling is carried out by means of defined standard methods. The methods satisfy the requirements of EN 13205 [8], EN 481 [9], EN 482 [10] and EN 689 [5]. Sampling systems are used in accordance with standard operating procedures and can be found for example in the CEN/TR 15230 Technical Report [11].

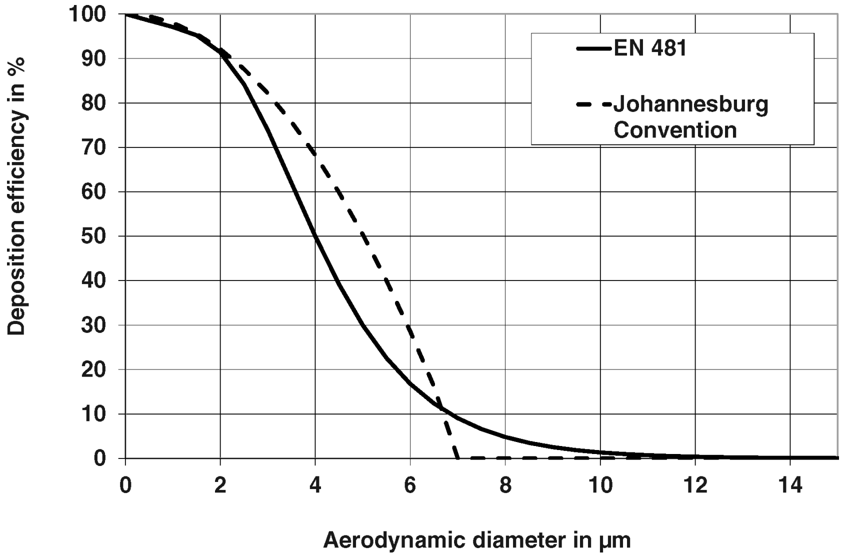

Figure 1. Deposition efficiency for the respirable dust fraction in accordance with the Johannesburg Convention („fine dust") and EN 481 („respirable dust") [9; 12].

4.1 Definition of the collected dust fraction

The respirable dust fraction was historically defined as fine dust in accordance with the 1959 Johannesburg Convention. The pre-separation integrated into the sampling instrument follows a function obtained by a sedimentation device ("elutriator").

Since 1994, the EN 481 [9] European standard has formed the basis for definition of the respirable fraction. The two conventions – the Johannesburg Convention and EN 481 – are not identical (see **Figure 1**); the differences are however relatively minor with regard to the dust particle distributions occurring in practice [13]. In addition, as stated by EN 481, the Johannesburg Convention samplers would oversample slightly in most cases. EN 481 therefore explicitly permits the use of elutriator-type pre-separators in accordance with the Johannesburg Convention for determining the respirable fraction. The definitions of the inhalable and respirable fractions set out in EN 481 are also identical to those used in ISO 7708 which concerns airborne dust in ambient air. The sampling devices with the pre-separator employed to date for measurement of the respirable fraction are listed in **Table 2**.

4.2 Sampling systems

The results compiled for the comparison of the exposure data were obtained from personal or static dust measurements. Measurements of dust concentrations conducted with personal and static instruments generally yield different results. The concentrations determined by personal sampling are in some cases higher than those obtained by static sampling and are generally more representative of workers' exposure. Personal measurements are therefore generally preferred, and complementary static measurements can be performed in Germany only if justified in the individual measurement report.

The measurement systems listed in Table 2 were used by these institutes for quartz sampling. The measurement systems are described and characterised in various sources [14 to 18].

[1] The European Network on Silica, www.nepsi.eu

Table 2. Sampling systems for the respirable dust fraction with indication of the flow rate.

Sampling system	Description Flow rate/type of measurement	SUVA	ÖSBS	FIOH	IGF	IFA
FSP-BIA	With use of the Casella cyclone; 2 l/min, personal	X	X		X	X
FSP-10	With 10 l cyclone and SG 10 pump; 10 l/min, personal	X	X		X	X
MPG II	With sedimentation pre-separation*; 2.8 m³/h, static				X	X
PM 4F	Cyclone pre-separation; 4 m³/h, static	X	X		X	X
VC 25F	Pre-selection by impaction; 22.5 m³/h, static	X**	X***			X
Cyclone (SKC)	Cyclone and SKC pump; 2.5-2.75 l/min, 37 mm cassette, personal/static			X		
IOM foam sampler (SKC)	Foam pre-separation, SKC pump, 2.0 l/min, personal/ static			X		

* In accordance with the Johannesburg Convention
** SUVA: no pre-impactor, fine dust inlet only
*** ÖSBS: no pre-impactor, fine dust inlet only; in use until approximately 2002

Table 3. Analytical methods applied and their detection limits.

Analytical method	SUVA**	ÖSBS	FIOH	IGF	IFA
X-ray diffraction	X	X	X	X	X
Relative detection limit* in mg/m³ (10 l/min, 2 h sampling time)	0.0004 to 0.0008	0.025 to 0.050		0.008 to 0.024	0.017 to 0.033
Relative detection limit* in mg/m³ (2 l/min, 2 h sampling time)	0.002 to 0.004	0.125 to 0.250		0.042 to 0.120	0.083 to 0.167
Infrared spectroscopy			X	X	X
Relative detection limit* in mg/m³ (10 l/min, 2 h sampling time)			0.0054	0.003	0.008
Relative detection limit* in mg/m³ (2 l/min, 2 h sampling time)			0.027	0.012	0.042

* Under optimum conditions; increases at higher dust concentrations (see Section 5.3); range: values for different evaluated peaks.
** See section 5.3.

5 Analytical methods

The sampling systems listed in Table 2 all collect the respirable dust fraction on membrane filters. Besides the concentration of respirable dust, the concentration of respirable quartz dust must be determined from the dust collected on these filters. The analytical methods available for this purpose are in principle X-ray diffraction (XRD), infrared spectroscopy and, to a lesser degree, phase-contrast microscopy (estimation of the mass fraction of quartz in the respirable dust). **Table 3** provides an overview of the analytical methods used within the institutions.

5.1 X-ray diffraction (indirect method)

Based upon a known mass of respirable dust on the sampling filter, a specific portion of the loaded filter is used for quartz analysis. Incineration of the membrane filter substance in porcelain crucibles at a maximum of 550 °C and subsequent treatment of the glowing residue with hydrochloric acid in an ultrasonic bath causes the components soluble in hydrochloric acid, such as carbonates and iron oxides, to be dissolved. At SUVA, PVC filters with a sufficient dust load are dissolved in tetrahydrofuran. The residual suspension is transferred to the analysis filter (e.g. silver membrane filter) on which a thin, homogeneous particle layer is obtained (elimination of the effect of the mass attenuation coefficients in the mineral mixture). The analysis filter is then subjected to X-ray analysis.
For quantitative quartz analysis, the strongest interference at d = 0.334 nm initially appears to be the most suitable. However, it may be subject to considerable disturbance if micas, for example, are present. The second- and third-strongest interferences, those at d = 0.426 nm and d = 0.182 nm respectively, are also analysed. The third-strongest interference has proved to be largely free of disturbance. A comprehensive description of the analytical method can be found in the literature [19]. The general requirements for the XRD analysis of quartz can be found in [20].

5.2 Infrared spectroscopy (indirect method)

The dust-loaded filter or a defined portion of it and a known quantity of potassium bromide (KBr) are homogenised by milling and incinerated in steps up to a maximum temperature of 550 °C. A defined portion of this is used to produce a KBr pellet. A ratio of 1 mg substance to 250 mg KBr must not be exceeded. The integral extinction of the two infrared bands at 779/798 cm^{-1} is employed for the quantitative analysis of quartz. If the quartz component is high, the weaker band at 695 cm^{-1} can also be used [9; 14; 21].

5.3 Detection limits and influence of the dust concentration

Besides being influenced by the analytical method used, the duration of sampling and the sampler flow rate, the relative detection limit for the respirable quartz dust concentration in air measurements depends directly on the concentration of respirable dust. In general it cannot be lower than one-hundredth of the respirable dust concentration in the working area under evaluation (see **Figure 2**) [22].
The relative detection limits for analysis of the respirable quartz dust concentration of air samples are a function of the

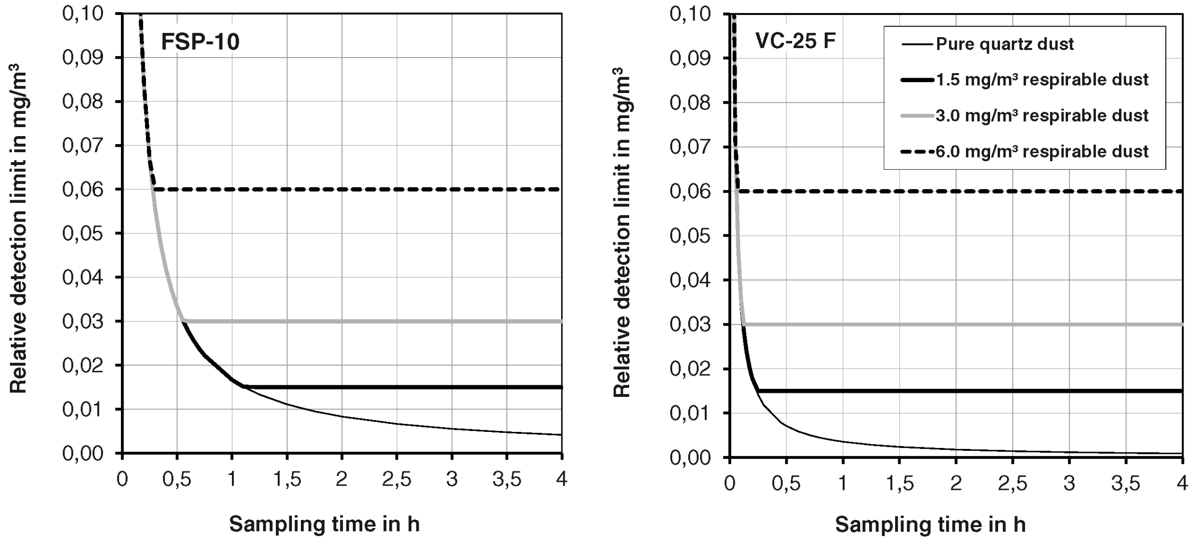

Figure 2. Relative detection limits.

respirable dust concentration and the duration of sampling. Two examples are shown within the sampling systems VC 25F and FSP 10.
To permit estimation of the quartz concentration at low dust concentrations and small sample volumes, SUVA extrapolates the quartz content (% quartz in respirable dust) from evaluable filters in the same working area to obtain that on filters with an excessively low dust load:

$$c_{\text{quartz, filter weighable but insufficient dust for X-ray diffraction}} = c_{\text{respirable dust}} \times f$$

f = average quartz percentage of the working area
The SUVA detection limit is therefore determined almost exclusively by gravimetry.

6 Collection of measurement data and company-related data

In addition to sampling, the participating institutions systematically determine and collect company and exposure data. Various systems are available to the institutions. The IGF and IFA use the OMEGA hazardous substances software developed in-house for collecting company related and exposure data within the social accident insurance institutions' MGU measurement system for exposure assessment [4].
SUVA also gathers exposure data and, to a limited extent, company data in an SAP-based database developed in-house. Further data are recorded in plain language in the measurement reports.
Before the introduction of the uniLIME 2006 laboratory information management system (LIMS) currently in use, the ÖSBS used Thermo Lab Systems' Nautilus software. This was used for storing data on the sampling systems employed, as well as data from sampling and laboratory analyses. In March 2008, the new uniLIME laboratory information system was introduced and the data from the legacy Nautilus system were transferred into the new LIMS. Since the end of 2008, exposure data from sampling assignments have also been integrated in the LIMS.
The FIOH's laboratory information management system (LIMS) was produced by White Lake Point Software Ltd. It is referred to as WilabLIMS and is tailored to the FIOH's purposes. Legacy data have been stored in an Oracle database. All data are now converted into an SQL database which is connected to the Microsoft AX system. The FIOH is currently developing an extranet ordering system and software for field measurements. WilabLIMS comprises three different systems: LimsKemia is used for occupational samples, LimsBio for biomonitoring samples, and the LimsHistoria database for older, non-active exposure data. Exposure data are gathered for LimsKemia from occupational measurements. Classification is performed by industry and occupation. All data from chemical, microbiological and aerosol samples are stored in the LimsKemia system. The stored data also contain information on the sample type, duration of exposure and personal protection. Annual statistics are generated from industry, job function and exposure data.
A portion of the data is documented with the aid of code lists, and another portion by defined plain-language fields. Different coding systems are used for sectors of industry, working areas and occupations/activities. SUVA and FIOH use the NACE system for classifying the sectors of industry. SUVA also has its own index of working areas. IFA and IGF use the "Index of branches of industry and similar nomenclatures" [23] for the coding of industrial sectors. Tables of NACE equivalents exist [24]. Working areas are classified by way of sector-related lists. The ÖSBS uses plain-language descriptions for sectors and working areas.
At all institutions, measured values are documented not in isolation, but always together with the recorded ambient conditions and other crucial workplace information. Efforts are made to determine and describe all factors that may have an effect on the measurement result and to store all data concerning the situation in the working area at the time of measurement. **Table 4** presents an overview of the company and exposure data that are gathered and documented alongside the measurement data.

7 Conclusion

The measurement conventions, sampling and analytics performed for the quantification of quartz exposure are comparable between Germany, Austria, Finland and Switzerland. Significant differences are however observed between measurement strategies. The exposure levels determined for comparable tasks can therefore also be expected to exhibit

Table 4. Measurement data and company-related data collected and documented.

Measurement data and company-related data	SUVA	ÖSBS	FIOH	IGF	IFA
Identification of sample	X	X	X	X	X
Hazardous substance (names of substances)	X	X	X	X	X
Industrial sector	X	X**	X	X	X
Working areas	X	X	X	X	X
Occupations/job titles			X	X	X
Type of sampling, e.g. static/personal	X	X**	X	X	X
Sampling duration in h	X	X	X	X	X
Exposure duration in h		X	X	X	X
Reason for measurement, e.g. survey, occupational disease, prevention, control measure after refurbishment	X		X	X	X
Operational situation, e.g. normal conditions, reasonable worst case	X	X		X	X
Representativeness (sampling duration is representative of exposure duration)	X	X	X	X	X
Measurement system, e.g. Gilian, VC25	X	X	X	X	X
Sample carrier, e.g. membrane filter	X	X	X	X	X
Flow rate in l/min; m³/h	X	X	X	X	X
Sampled volume in l; m³	X	X	X	X	X
Measurement location, e.g. indoors/outdoors	X	X	X	X	X
Spatial conditions, e.g. length, width, height, volume				X	X
Natural ventilation, e.g. open doors/windows	X			X	X
Mechanical ventilation, e.g. air-conditioning, supply air, exhaust air	X	X**	X	X	X
Local exhaust ventilation, e.g. hood, suction nozzle	X	X**	X	X	X
Emission control measures, e.g. wet processing, housing	X*	X**	X	X	X
Weather				X	X
Temperature outdoors in °C		X**		X	X
Indoor temperature in °C	X			X	X
Relative humidity in %	X	X**		X	X
Analytical method	X	X	X	X	X

X* Since 2013, X** Since 2008

differences between the different countries. In Part 2 of the publication, the deviations observed will be described and discussed with reference to certain working areas in the industrial sectors of the extraction of rock, processing of minerals and earths, and quarrying of gravel and sand. It will be shown that the exposure data obtained in different countries should not be pooled unchecked when used in epidemiological studies.

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