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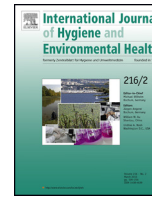

15 years of monitoring occupational exposure to respirable dust and quartz within the European industrial minerals sector

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ABSTRACT

Introduction: In 2000, a prospective Dust Monitoring Program (DMP) was started in which measurements of worker's exposure to respirable dust and quartz are collected in member companies from the European Industrial Minerals Association (IMA-Europe). After 15 years, the resulting IMA-DMP database allows a detailed overview of exposure levels of respirable dust and quartz over time within this industrial sector. Our aim is to describe the IMA-DMP and the current state of the corresponding database which due to continuation of the IMA-DMP is still growing. The future use of the database will also be highlighted including its utility for the industrial minerals producing sector.

Methods: Exposure data are being obtained following a common protocol including a standardized sampling strategy, standardized sampling and analytical methods and a data management system. Following strict quality control procedures, exposure data are consequently added to a central database. The data comprises personal exposure measurements including auxiliary information on work and other conditions during sampling.

Results: Currently, the IMA-DMP database consists of almost 28,000 personal measurements which have been performed from 2000 until 2015 representing 29 half-yearly sampling campaigns. The exposure data have been collected from 160 different worksites owned by 35 industrial mineral companies and comes from 23 European countries and approximately 5000 workers.

Conclusion: The IMA-DMP database provides the European minerals sector with reliable data regarding worker personal exposures to respirable dust and quartz. The database can be used as a powerful tool to address outstanding scientific issues on long-term exposure trends and exposure variability, and importantly, as a surveillance tool to evaluate exposure control measures. The database will be valuable for future epidemiological studies on respiratory health effects and will allow for estimation of quantitative exposure response relationships.

1. Introduction

Occupational exposure databases are valuable instruments in the field of occupational hygiene (Kromhout et al., 1993; Kauppinen, 2000; Flanagan et al., 2006). Data derived from industry-wide occupational databases could in potential provide highly reliable and accurate information regarding workers' exposures and workplace exposure conditions. Numerous industry-specific exposure databases have been developed during the last two decades, for instance, PAPDEM for the paper and pulp industry (Kauppinen et al., 1997), AWE for the asphalt industry (Burstyn et al., 2000a,b) and EXASRUB for the rubber manufacturing industry (De Vocht et al., 2005).

Numerous mineral extraction and processing activities generate respirable dust in which crystalline silica dust is often an important constituent (Brown and Rushton, 2005). Silica occurs naturally in a crystalline or amorphous form and is one of the most common and abundant minerals largely present in the Earth's crust (Rees and Murray, 2007). Within a large variety of mineral industries exposure to respirable crystalline silica (RCS) can occur in almost all stages of the production processes (Kachuri et al., 2014). Epidemiological studies have found that occupational exposure to silica dust is significantly associated with adverse health effects as silicosis (Wilson et al., 2002), chronic obstructive pulmonary disease

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(COPD) (Rees and Murray, 2007) and lung cancer (Steenland et al., 2001).

In 1987, 1997 and 2011 the International Agency for Research on Cancer (IARC) reviewed the carcinogenicity of crystalline silica, inhaled in the form of quartz from occupational sources. In 1997 IARC changed its classification of crystalline silica from probably carcinogenic to humans (group 2A), mainly based on animal experiments, to carcinogenic to humans (group 1) mainly based on additional evidence from human observational studies. IARC upheld this classification in the most recent evaluation in 2011 (IARC, 1987; Wilbourn et al., 1997; Guha et al., 2011).

Minerals which are not chemically modified but occur naturally (e.g. crystalline silica) are excluded from REACH registration despite the unequivocally well-known occupational risks of RCS (Friede and Wyart-Remy, 2013).

In 2000, the European Industrial Minerals Association (IMA-Europe) representing the European producers of andalusite, bentonite, borates, calcium carbonate, cristobalite, diatomite, dolomite, feldspar, kaolin, kaolinitic clays, lime, mica, quartz, sepiolite, talc, vermiculite and wollastonite – i.e. around 500 mineral companies or groups operating more than 700 mines and quarries and 750 plants throughout Europe, recognized the vital need to monitor occupational respirable dust and quartz exposures and initiated a prospective Dust Monitoring Program (DMP). Since 2006, the resulting IMA-DMP database is hosted by the Institute for Risk Assessment Sciences (IRAS) of Utrecht University, The Netherlands, in collaboration with The Netherlands Expertise Center for Occupational Respiratory Disorders (NECORD).

Participation in the IMA-DMP is open to all IMA-Europe member companies any time. In recent years, acknowledging the value of the IMA-DMP for the sector and their own company, several new members have started to participate in the project. At the time of the launch of the Program, a training workshop was organized to attract participants, and such meetings dedicated to the IMA-DMP have been organized every two years since and are open to all IMA member companies.

In 2006, 15 European industry sectors (the European Federations of producers of Glass Fibre, Precast Concrete, Foundry, Cement, Ceramics, Mortar, Mines, Natural Stones, Insulation Mineral Wool, Expanded Clay, Container Glass, Flat Glass, Calcium Silicate, Industrial Minerals (IMA-Europe) and Aggregates, and their European trade union (industriALL) with the notable exception of the construction industry) in which exposure to respirable silica is likely, signed a so-called tripartite Social Dialogue Agreement (SDA) with the aim of protecting their workers from health risks resulting from exposure to RCS. As part of this SDA they agreed on appropriate and credible measures for the improvement of working conditions, written down in a NEPSI good practice guide. NEPSI is the acronym for the resulting European Network for Silica formed by the employee and employer sectoral associations, which signed the Agreement on 25 April 2006 (NEPSI-EU, 2006). Besides providing information, instruction and training to the workforce, personal dust exposure monitoring is seen as one of the essential tools of the SDA.

The IMA-DMP aimed to collect representative occupational exposure data from a wide variety of workplaces to determine existing exposure levels and to monitor exposure trends over time. In addition, the DMP allows companies to check compliance with national occupational exposure limits, to have a complete picture of existing exposure levels at their sites, to identify situations requiring further investigation or implementation of additional control measures to reduce workers' exposure, and monitor effectiveness of implemented dust control measures. Moreover, this initiative is also intended to put the mineral industries in a better position to discuss with regulatory authorities on setting future occupational exposure limits.

The aim of this paper is 1) to describe the details of the IMA-DMP and the content of the resulting IMA-DMP database, 2) to illustrate the process of elaborating and maintaining such an industry-wide occupational exposure database, 3) to discuss its current state, its utility and the future of the IMA-DMP.

2. Methods

2.1. IMA-DMP protocol and sampling strategy

At the start of the IMA-DMP project in 2000 a standardized protocol was developed and submitted to each of the participating companies. This sampling protocol included all requirements related to how measurements should be performed in order to quantitatively determine exposure levels for standardized jobs present at the sites of participating companies. The protocol described strict criteria for the sampling strategy, the jobs classification and nomenclature, sampling procedure, number of measurements, duration of measurements, campaigns and which sampling equipment and analytical methods had to be used. Participating companies were supposed to follow this protocol with strict quality criteria (Lesley and Danielle, 1997) to yield representative and reliable information on respirable dust and quartz exposure levels of their workers. For inclusion in the resulting IMA-DMP database the measurements data had to fulfill the minimum requirements for the following items: 1) sampling of pre-defined exposure groups, 2) personal sampling, 3) availability of a unique worker code and 4) sampling duration.

Re (1): The IMA-DMP industry-specific standardized nomenclature for jobs was created based on an industry-specific generic job classification. The sampled population was selected according to the entire company workforce subdivided into standardized exposure groups corresponding to executed tasks and activities of the workers. Hence, standardized exposure groups were defined according to standardized jobs (Appendix, Supplementary data). The standardized job was used as a sampling unit and was defined as the set of activities carried out by a worker during his daily working time.

Re (2): The IMA-DMP database considered exclusively personal measurements which were representative of the exposure a worker received during a single shift. All sampling was undertaken during regular working conditions.

Re (3): Individual workers were coded with a unique worker code in order to distinguish between measurements performed on different individuals and by doing so allowing estimation of variability in exposure concentrations between workers and from day-to-day within workers. Most companies consisted of production facilities located at multiple sites, sometimes in more than one country. Complementary information concerning number of employed workers and type of minerals mined or used in their production processes was collected in the beginning and when new companies and sites entered the DMP.

Re (4): The IMA-DMP protocol requires personal samples to be collected during a full working shift which is defined as between 7 and 8 h. However, in the database measurements with a duration between 4 and 10 h were accepted as personal measurements representative for an 8-h shift. It should be noted that each 8-h TWA concentration of respirable dusts and respirable quartz in the IMA-DMP database, is estimated on the basis of the actual sampling duration during the measurement (as long as the sampling duration was within 4–10 h).

In addition, per campaign a minimum of six dust samples per standardized job per site is collected. All sampling equipment has been in conformity with the European standard EN 481 (NEN-EN 481, 1993) and the applied sampling devices were able to measure the respirable fraction. Several respirable dust samplers were allowed by the sampling protocol (e.g. Higgins-Dewell cyclone, Dorr-Oliver 10 mm nylon-cyclone, FSP-10, CIP 10-R).

Initially, the participating companies were instructed to complete two campaigns per year at each site i.e. one campaign during the summer period and one campaign during the winter period in order to account for potential effects of weather conditions on the exposure data. After the year 2005, participating companies whose data would demonstrate negligible seasonal effects were no longer required to perform measurements every summer and winter period but were supposed to sample at least once a year and in alternating seasons in subsequent years.

The respirable dust concentrations are determined quantitatively by gravimetric analysis following the procedures and standards described in the protocol. The sample collection materials are weighed before and after sampling on the same balance. The net change in weight enables the determination of the dust concentration. During weighing, all data were recorded in a weighing record sheet. For quartz analyses, the analytical techniques, either X-Ray Diffraction (XRD) or Fourier Transform InfraRed spectroscopy (FT-IR) should be used as required in standard methods of NIOSH (1984), NIOSH (1990), HSE (1988) and OSHA (1981).

In the year 2006 collection of field blanks during each sampling campaign was introduced. Information on field blanks should be entered in the collection sheet. Field blanks were used to calculate the limits of detection (LoD) for respirable dust. Field blanks were in addition used to adjust all gravimetric and quartz (and other analytes) analyses for contamination during sampling and analytical procedures.

The sampling exposure data were collected via a Microsoft Excel© standardized collection sheet and consequently converted into a SAS (version 9.4) dataset.

Table 1
List of core characteristics coded in the IMA-DMP database.

Information	Core characteristics
General information	Country Company Site Mineral Date
Standardized jobs	Unique worker code Standardized job Sample ID
Sampling and measurements data	Sampler Sample collection material Sampling duration (min) (start time, stop time) Flow rate (l/min), (at start, at end, average) Sampling volume (m^3) Filter Weight (mg) (before and after sampling) Calculated dust concentration (mg/m^3) Below Limit of detection (yes/no) both for dust and analyte 8-h TWA dust concentration (mg/m^3) Type of analyte (quartz, cristobalite, tridymite) Analytical techniques (FT-IR/XRD) Analyte (mg) Calculated analyte concentration (mg/m^3) 8-h TWA[a] analyte concentration (mg/m^3)
Additional information	Shift & shift length Smoking during sampling Weather conditions (1): dry, wet Weather conditions (2): windy, not windy personal protective equipment during sampling

[a] TWA = Time Weighted Average.

2.2. IMA-DMP database

IMA-DMP aimed at creating a database with a uniform exposure data structure. The exposure data covers the following core characteristics: 1) general data, 2) standardized jobs, 3) sampling and measurements data. The IMA-DMP database includes 4) additional information such as shift & shift length, smoking and weather conditions, during sampling collection, as well as use of personal protective equipment during sampling (for details see Table 1).

2.3. Organizational structure and data processing

Fig. 1 illustrates the organizational structure and lines of communication within the IMA-Europe Dust Monitoring Program.

The exposure data are submitted by the participating companies and comprise personal exposure measurements and auxiliary information on work and other conditions during the measurements. The utilized quality control procedure consists of verification and checking data completeness and consistency before inclusion into the IMA-DMP database. This procedure also includes sorting the data according to its quality, in order to define its suitability for further statistical analysis. After each measurement campaign, company reports are written and provided to the individual companies. These reports contain chapters describing in detail the evaluation of all measurements data, including data characteristics, quality control, sampling results and interpretation of data (compliance with national occupational exposure limits; temporal trends in exposure concentrations) for each of the companies' sites. Further, jobs not in compliance are highlighted with an advice to reduce the exposure using adequate risk reduction measures.

Besides these individual company reports, a biannual report based on analyses of the full IMA-DMP database is produced and provided to each participating company. These reports are discussed in debriefing meetings with representatives of the companies, IMA-Europe and the researchers of IRAS and NECORD. Focus of these meetings is the state of the IMA-DMP program and long-term trends in dust and quartz exposure concentrations across the industry.

The (raw) data are not shared between companies in order to maintain confidentiality. The overall results and statistical analyses, however, are discussed during biannual debriefing meetings with representatives from each participating company. Exposure data are sometimes shared externally for specific purposes, e.g. on request of regulators. Again, such shared data always relate to pooled anonymous data, not company specific data.

3. Results

The measurements present in the IMA-DMP database version (as of 1 May 2015) presented here were collected starting from the winter season of 2000/2001 until the winter season of 2014/2015 representing 29 campaigns, monitoring data from 160 different worksites owned by 35 industrial mineral companies in 23 countries across Europe. IMA-DMP database includes a total of 27,832 observations. It includes 27,697 respirable dust measurements and 23,480 respirable quartz measurements. Measurements are representative for a total workforce of >5000. Fig. 2 shows the number of sites and samples collected in each campaign.

In the period from campaign 1 (2001) to campaign 9 (2005) companies were requested to collect exposure data two times a year i.e. every summer and winter. The drop in numbers of site and samples at the beginning of campaign 10 is due to the relaxed criterion of sampling once a year; either in the winter or in the summer period. From campaign 19 (2010) new participants and new sites entered the DMP which resulted in an increase in numbers of sites and sam-

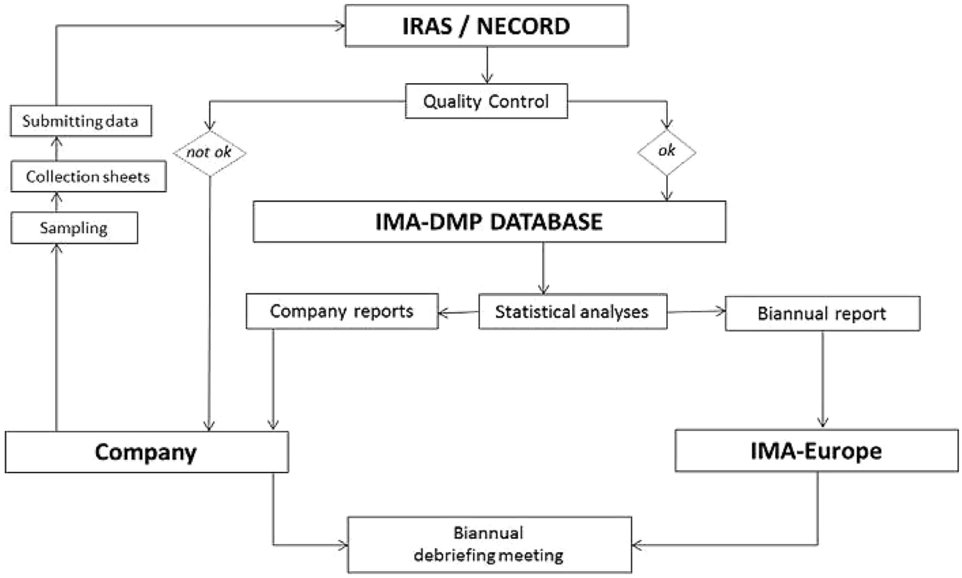

Fig. 1. Lines of communication within the IMA dust monitoring program.

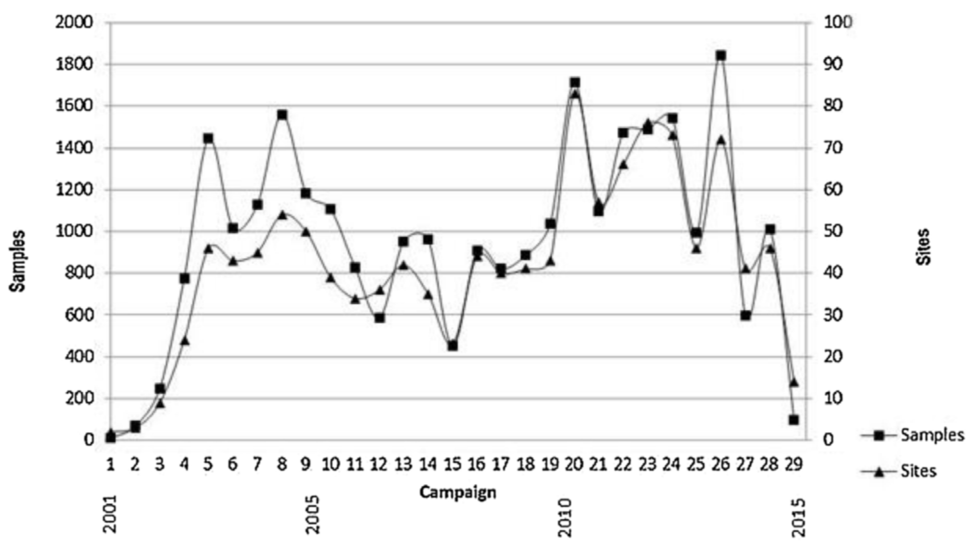

Fig. 2. Trends in number of sites and number of measurements per sampling campaign.

ples. The numbers for campaigns 27, 28 and 29 are incomplete due to data processing still ongoing.

At the start of the project, the IMA-DMP database contained exposure data from predominantly Western-European countries. In more recent years new participating and existing companies extending their production in eastern direction has resulted in a more complete coverage of Europe. Fig. 3 displays the current geographical distribution of the participating companies. The time period of participation is presented in the legend of Fig. 3. Table 2 shows the year data collection started for each country.

An overview of number of respirable dust and quartz observations categorized by country is presented in Table 2. The majority (66%) of the measurements were collected in just four countries: United Kingdom, France, Spain and Germany. Collection of measurements in the nine more recently enrolled countries started in the summer of 2010: Austria, Russia, Ukraine, Turkey, Bosnia, Czech Republic, Hungary, Poland and Slovakia. The total number of measurements in these nine recently enrolled countries currently makes up only a relatively small part (5%) of the database.

Table 2 also presents an overview of respirable dust and quartz observations categorized by mineral category and by standardized job. The companies are producing silica, kaolin, talc, feldspar, clay and bentonite. An additional category ‘mixed minerals’ was created for sites that reported the production of multiple minerals during a single sampling campaign and a category ‘other minerals’ was created for sites reporting production of minerals other than the six minerals categories mentioned above. Table 4 shows that about half of the measurements have been performed on sites where silica was being produced, processed or worked with. From Table 2 it can be seen that the majority (55%) of the dust monitoring has taken place among transport workers, maintenance workers, bagging operators and quarry operators.

Table 3 shows the type of samplers and the mean flow rates of samplers during sampling per country. Exposure measurements were restricted to personally measured respirable fractions collected with cyclones with a filter or with multi-fraction samplers containing a foam matrix for size-selective collection of dust. The mean flow rates appear to be in line with the

Fig. 3. Geographical distributions of the represented countries.

corresponding advised standard flow rates for the specific samplers. National preferences and traditions explain the differences between countries/companies in samplers used. For instance, CIP 10-R, containing a foam matrix for size-selective collection of respirable dust, is by far the most used sampler in France. On the other hand, several other countries like Germany, United Kingdom and Spain have a preference for using respirable dust cyclones.

Table 4 provides an overview of the applied analytical techniques for quartz per country and per mineral. The analytical techniques XRD and FT-IR are used almost equally (respectively 45% and 55% of the samples). The accessibility and costs of the analytical techniques as well as the expected level of respirable crystalline silica present will most likely play a role in choosing which method to use. FT-IR is generally recognized as being less expensive and faster than the XRD methods (Verpaele and Jouret, 2013) and has a lower limit of detection. XRD is an order of magnitude less sensitive but enables differentiation between quartz and cristobalite and tridymite. (HSE, 2014). When higher concentrations quartz in respirable dust are expected because of the type of mineral produced the less sensitive XRD analytical technique could be utilized without problems considering the limit of detection. The opposite using the more sensitive FT-IR method for situation with lower expected quartz concentrations would then be seen as well. The quartz percentages in the samples analyzed with XRD were twice as high as those in the samples that were analyzed with FT-IR (12% and 6% respectively). So next to availability of a specific analytical method the expected quartz concentration also seems to play a role in the applied analytical method.

Table 5 presents average sampling duration (in min) per country and overall. Only 34% of all measurements were within the range of 7–8 h as defined as full shift in the protocol (Table 5). In France almost 1300 samples were collected with a sampling duration exceeding 10 h. In 2006, the definition of a measurement duration representative for a full 8-h shift was relaxed to measurements with a duration between 4 and 10 h. As a result, the number of full-shift measurements increased to 86%.

In addition, Table 5 shows the four a priori defined weather conditions ‘dry’, ‘wet’, ‘windy’ and ‘not windy’ during sampling. Almost three quarters of the measurements in the IMA-DMP database were collected under dry (76%) and not windy (72%) conditions. For the three countries with the largest amount of measurements United Kingdom, France and Spain, monitoring in dry conditions took place for respectively 73%, 75% and 80% of the measurements for which this information was available.

4. Discussion

The IMA-DMP program aimed to collect representative data on occupational exposure to respirable dust and quartz from various workplaces at sites from member companies of the European Industrial Minerals Association. As a result, a unique occupational exposure database has been created with a wealth of information during the last 15 years which due to continuation of the IMA-DMP is still growing. To the best of our knowledge, this is currently the largest industrial personal occupational exposure database with

Table 2
Number of observations within IMA DMP database categorized by country, by mineral category and by standardized job for respirable dust and respirable quartz.

Country	Year started	Respirable dust (freq. %)	Respirable quartz (freq. %)
Austria	2010	67 (<1)	36 (<1)
Belgium	2002	1,833 (6.6)	1,559 (6.6)
Bosnia	2012	18 (<1)	18 (<1)
Czech Rep.	2011	192 (<1)	192 (<1)
Denmark	2006	174 (<1)	174 (<1)
Finland	2002	702 (2,5)	449 (1.6)
France	2001	4,679 (17)	3,577 (13)
Germany	2002	2,897 (10)	2,873 (10)
Greece	2002	408 (1.5)	156 (<1)
Hungary	2012	23 (<1)	24 (<1)
Italy	2002	1,635 (5.9)	1,098 (3.9)
Netherlands	2002	1,838 (6.6)	1,077 (3.9)
Norway	2001	794 (2,9)	277 (1.0)
Poland	2013	159 (<1)	60 (<1)
Portugal	2003	355 (1.3)	355 (1.3)
Russia	2010	150 (<1)	150 (<1)
Slovakia	2011	161(<1)	161 (<1)
Spain	2002	5,048 (18)	4,717 (17)
Sweden	2003	359 (1.3)	359 (1.3)
Switzerland	2008	0 (0)	84 (<1)
Turkey	2010	316 (1.1)	301 (1,1)
Ukraine	2010	282 (1.1)	280 (1.0)
United Kingdom	2000	5,607 (20)	5,503 (20)
Total		27,697	23,480
Mineral		**Respirable dust (freq %)**	**Respirable quartz (freq %)**
Silica		12,889 (46.5)	12,704 (54.1)
Kaolin		1,166 (4.2)	1,048 (4.5)
Talc		2,276 (8.2)	100 (0.4)
Feldspar		1,163 (4.2)	1,156 (4.9)
Clay		3,443 (12.4)	3,444 (14.7)
Bentonite		275 (1.0)	23 (1.0)
Mixed minerals		2,671 (9.6)	2,543 (10.8)
Other minerals		3,814 (13.8)	2,462 (10.5)
Total		27,697	23,480
Standardized job		**Respirable dust (freq %)**	**Respirable quartz (freq %)**
Bagging operator		3,603 (13.0)	2,953 (12.6)
Crusher operator		744 (2.7)	457 (1.9)
Dry process operator		3,077 (11.1)	2,554 (10.9)
Foreman		2,529 (9.1)	2,278 (9.7)
Laboratory		1,658 (6.0)	1,528 (6.5)
Lime Hydration operation		33 (0.1)	33 (0.1)
Maintenance worker		3,915 (14.1)	3,093 (13.2)
Miller operator		1,332 (4.8)	1,050 (4.5)
Multi-skilled		1,103 (4.0)	867 (3.7)
Plastification		139 (0.5)	139 (0.6)
Quarry operator		3,058 (11.0)	2,834 (12.1)
R&D		8 (0.03)	8 (0.03)
Transport worker		4,636 (16.7)	3,955 (16.8)
Wet process operator		1,862 (6.7)	1,731 (7.4)
Total		27,697	23,480

approximately 28,000 personal measurements collected specifically within one industrial sector.

A standardized protocol including sampling strategy, sampling methods, data management and quality control underlies the prospective dust monitoring program. This is a notable difference with other industry-specific exposure databases like for instance

PAPDEM (Kauppinen et al., 1997), EXASRUB (De Vocht et al., 2005), and AWE (Burstyn et al., 2000a,b) which collected exposure measurement data retrospectively. The IMA-DMP contains personal exposure measurements including auxiliary information collected by the participating companies according to the standardized protocol. Furthermore, all auxiliary information was coded using an *a priori* standardized format. The collected data meet the minimal requirements for core information proposed by Rajan et al. (1997). For example, the work force within a company was subdivided into standardized jobs corresponding to executed tasks and activities of the workers. The approach of using standardized jobs to collect measurements data proved to be successful to provide researchers with an opportunity to model the effect of job characteristics on exposure levels within the European rubber manufacturing industry (Burstyn et al., 2000a,b). Alongside standardization of jobs, a unique worker code was registered in the IMA-DMP database in order to identify monitored workers and to identify repeated measurements performed on the same worker. This allows for merging data across measurement campaigns and enables estimation of within (temporal) – and between (personal) – worker variability in exposure concentrations (Kromhout et al., 1993).

The protocol described strict criteria for sampling duration. However, only 34% of all observations were within the range of the original full shift definition of 7–8 h. During the course of the IMA-DMP the situation improved due to better quality control. When in 2006 the definition of full shift was further relaxed to all measurements with a duration between 4 and 10 h the number of full-shift measurements increased to 86%. In France, for instance, the num-

Table 3
Respirable Dust Samplers used per country.

	Cyclones														Multifraction samplers			
Mean flowrate l/min (std)	HD(pl) (adv. flow: 2.2)* 2.2 (0.09)		HD (met) (adv. flow: 2.2) 2.2 (0.06)		DO (adv. flow: 1.9) 1.8 (0.18)		GS (adv. flow: 2.0) 2.0 (0.17)		FSP 2 (adv. flow: 2.0) 2.0 (0.02)		SKC (adv. flow: 2.5) 2,0 (0.02)		FSP 10 (adv. flow: 10) 10 (0.0)		CIP-10R (adv. flow: 10) 10 (0.07)		IOM (adv. flow: 2.0) 2.0 (0.03)	
Country	*resp.dust*	*resp.quartz*	*resp.dust*	*resp.quartz*	*resp.dust*	*resp.quartz*	*resp.dust*	*resp.quartz*	*resp.dust*	*resp.quartz*	*resp.dust*	*resp.quartz*	*resp.dust*	*resp.quartz*	*resp.dust*	*resp.quartz*	*resp.dust*	*resp.quartz*
Austria	30	0	0	0	0	0	0	0	0	0	0	0	37	36	0	0	0	0
Belgium	336	295	112	74	933	933	0	0	0	0	0	0	0	0	256	257	0	0
Bosnia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	18	0	0
Czech-Republic	0	0	108	108	0	0	0	0	0	0	0	0	0	0	84	84	0	0
Denmark	0	0	0	0	0	0	148	148	0	0	26	26	0	0	0	0	0	0
Finland	0	0	0	0	0	0	340	334	0	0	115	115	0	0	0	0	247	0
France	0	0	0	0	26	22	0	0	0	0	0	0	0	0	4,849	3,555	0	0
Germany	0	0	1,315	1,294	8	8	574	571	822	822	0	0	156	156	22	22	0	0
Greece	389	137	19	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	24	0	0
Italy	716	717	18	18	320	320	0	4	0	0	0	0	0	0	581	39	0	0
Netherlands	930	485	668	364	229	217	0	0	0	0	0	0	0	0	11	11	0	0
Norway	702	183	92	94	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poland	0	0	159	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Portugal	0	0	0	0	355	355	0	0	0	0	0	0	0	0	0	0	0	0
Russia	150	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slovakia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	161	161	0	0
Spain	5,048	4,717	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sweden	51	51	0	0	0	0	200	200	0	0	108	108	0	0	0	0	0	0
Switzerland	0	0	0	0	0	84	0	0	0	0	0	0	0	0	0	0	0	0
Turkey	316	301	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ukraine	91	90	191	190	0	0	0	0	0	0	0	0	0	0	0	0	0	0
United Kingdom	601	593	5,006	4,910	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (%)	9,360	7,719	7,688	7,131	1,871	1,939	**1,262**	**1,257**	**822**	**822**	**249**	**249**	**193**	**192**	**6,005**	**4,171**	**247**	**0**
	(34%)	(33%)	(28%)	(30%)	(7%)	(8%)	**(5%)**	**(5%)**	**(3%)**	**(4%)**	**(1%)**	**(1%)**	**(1%)**	**(1%)**	**(22%)**	**(18%)**	**(1%)**	**(0%)**

*adv. Flow = advised flow rate (l/min) (Ref: P. Stacey et al., 2013. Differences Between Samplers for Respirable Dust and the Analysis of Quartz. STP 1565, 73–102).
1. HD (pl): Higgins-Dewell (plastic cyclone).
2. HD (met): Higgins-Dewell (metal cyclone).
3. DO: Dorr-Oliver 10 mm Nylon Cyclone.
4. GS: GS 1 Cyclone.
5. FSP 2.
6. SKC aluminium cyclone.
7. FSP 10.
8. CIP 10 R: CIP 10 Respirable.
9. IOM (sampler with foam insert for respirable dust sampling).

Table 4
Analytical techniques for respirable quartz per country and per mineral.

Country	Analytical techniques (resp. quartz)	
	FT-IR	XRD
Austria	0 (0%)	36 (100%)
Belgium	352 (23%)	1,207 (77%)
Bosnia	18 (100%)	0 (0%)
Czech-Republic	192 (100%)	0 (0%)
Denmark	174 (100%)	0 (0%)
Finland	449 (100%)	0 (0%)
France	3,577 (100%)	0 (0%)
Germany[a]	2,260 (79%)	603 (21%)
Greece	156 (100%)	0 (0%)
Hungary	24 (100%)	0 (0%)
Italy	0 (0%)	1,098 (100%)
Netherlands	993 (92%)	84 (8%)
Norway	277 (100%)	0 (0%)
Poland	60 (100%)	0 (0%)
Portugal	0 (0%)	355 (100%)
Russia	0 (0%)	150 (100%)
Slovakia	161 (100%)	0 (0%)
Spain	3,836 (81)	881 (19%)
Sweden	359 (100%)	0 (0%)
Switzerland	0 (0%)	84 (100%)
Turkey	4 (1%)	297 (99%)
Ukraine	0 (0%)	280 (100%)
United Kingdom	0 (0%)	5,503 (100%)
Total (%)	12,892 (55%)	10,578(45%)

Mineral	FT-IR	Median % quartz	XRD	Median % quartz
Silica	6,160 (48%)	7	6,544 (52%)	13.0
Kaolin	341 (33%)	1.6	707 (67%)	3.6
Talc	61 (61%)	0.1	39 (39%)	0.1
Feldspar	775 (67%)	5	381 (33%)	4.9
Clay	1,981 (58%)	7	1,463 (42%)	11.8
Bentonite	18 (78%)	2.7	5 (22%)	0.2
*Mixed minerals	1,833 (72%)	10	700 (28%)	12.2
Other minerals	1,723 (70%)	1	739 (30%)	14.5
Total (%)	12,892 (55%)	6.3	10,578 (45%)	11.9

[a] For 10 observations information on analytical techniques is missing.

ber of observations within the range 7–8 h was 25% before 2006 and this increased to 74% after 2006.

Several respirable dust samplers were allowed by the IMA-DMP sampling protocol all in compliance with the technical European standard EN 481 (NEN-EN 481, 1993). These samplers were described by Görner et al. (2001) and according to the authors; these samplers are suitable for a wide range of aerosol size distributions with an accuracy performance criterion (APC) of at least 80%. The sampler of preference differs considerably between countries due to the availability of the samplers and due to national traditions or pReferences

Recently, performances of low flow rate respirable dust samplers (< 2.5 l min $^{-1}$) and high flow rate samplers (>4 l min $^{-1}$) were evaluated. The sampling efficiency between samplers (i.e. ratios of respirable dust mass concentrations) has been compared under controlled laboratory-based facilities (e.g. wind tunnels) and under field conditions. The high flow rate size-selective foam samplers like CIP10-R collected approximately 50% more respirable dust mass than low flow rate samplers like Higgins-Dewell (HD) type cyclones. Differences in respirable dust concentrations between the samplers were minimal (Lee et al., 2015). The use of high flow rates samplers and collecting more respirable dust mass will result in a lower limit of detection In 2001, a study was conducted by Kenny et al. (2001) to compare respirable dust concentrations measured with the HD samplers and those measured with the IOM dual-fraction sampler, which is a size-selective foam sampler like CIP 10-R. The IOM dual-fraction sampler also yielded similar results in respirable dust concentrations as the HD cyclones. In conclusion, differences in respirable dust concentrations measured with (personal) cyclones and size-selective foam samplers used within IMA-DMP are generally considered to be very small.

Several published studies have assessed the differences in quartz concentration between measurements with cyclones and size selective foam samplers. Verpaele and Jouret (2013) showed that the CIP 10-R sampler significantly underestimated the quartz concentration (up to 26%) in the sampled respirable dust fraction when compared with HD cyclones. Lower quartz mass concentrations collected with CIP 10-R were also found by Stacey et al. (2016). De Vocht et al. (2009) also reported in a field study within the brick

Table 5
Sampling duration and weather conditions during sampling per country.

	Sampling duration								Weather conditions			
Country	Median(min)	<4 hr	4–7 hr	7–8 hr	8–10 hr	>10 hr	missing	4–10 hr (%)	Dry	Wet	Not windy	Windy
Austria	322	1	55	11	0	0	0	66 (<1)	65	2	67	0
Belgium	445	51	400	1,024	144	19	0	1,568 (7)	647	234	670	211
Bosnia	360	0	18	0	0	0	0	18 (<1)	15	3	18	0
Czech-Republic	420	0	119	73	0	0	0	192 (<1)	155	37	135	57
Denmark	433	6	66	69	31	2	0	166 (<1)	60	12	29	8
Finland	430	24	268	327	95	3	0	690 (3)	243	41	210	74
France	480	417	549	872	765	1,297	985	2,186 (9)	1,028	351	268	132
Germany	420	138	1,205	1,509	10	0	35	2,724 (11)	946	414	985	375
Greece	420	0	81	294	37	0	32	380 (2)	205	60	242	23
Hungary	360	0	24	0	0	0	0	24 (<1)	16	8	24	0
Italy	365	46	978	417	194	5	0	1,589 (7)	587	70	625	32
Netherlands	437	16	673	758	388	3	0	1,819 (8)	523	288	400	397
Norway	362	24	535	205	30	2	0	770 (3)	147	69	149	67
Poland	360	41	111	5	0	2	0	116 (<1)	128	31	117	42
Portugal	426	0	140	97	49	21	48	286 (1)	107	95	110	92
Russia	432	3	56	68	22	1	0	146 (<1)	118	32	90	60
Slovakia	450	0	1	108	52	0	0	161 (<1)	150	11	109	52
Spain	466	162	1,045	1,683	1,874	129	155	4,602 (19)	2,661	667	2,654	543
Sweden	300	11	253	40	53	2	0	346 (1)	111	26	42	89
Switzerland	470	0	17	41	26	0	0	84 (<1)	84	0	82	2
Turkey	415	11	157	116	30	2	0	303 (1)	251	65	262	54
Ukraine	430	1	119	85	49	28	0	253 (1)	187	95	5	277
United Kingdom	416	56	2,912	1,723	761	168	0	5,396 (23)	1,580	588	1,393	774
Total (%)		1,007 (4%)	9,782(35%)	9,525(34%)	4,610(17%)	1,684(6%)	1,223(5%)	23,917(86%)	10,014(76%)	3,199(24%)	8,686(72%)	3,361(28%)

manufacturing industry a considerable under-sampling (up to 50%) with the IOM dual-fraction size-selective foam sampler when compared to the HD cyclone. Based on these findings and the fact that CIP 10-R sampler and the IOM dual-fraction sampler are frequently used within IMA-DMP, an appropriate correction factor should be applied to adjust quartz measurements performed with samplers collecting dust with a foam matrix.

Within the IMA-DMP quartz concentrations have been determined with FT-IR or with XRD techniques. In one company in Germany the FT-IR analytical technique was preferable when the exposure levels were expected to be close to the limits of detection for quartz when analyzed with XRD. On the other hand XRD is known to produce more consistent results than FT-IR when analyzing for respirable quartz (Stacey et al., 2009). It is unlikely that the quartz concentrations within the IMA-DMP database are biased due to analytical method used since it is clear that differences in quartz concentration due to analytical method are non-significant. For instance no statistical difference in amount detected was found when quartz was analyzed with direct-on-filter XRD method compared to direct-on-filter FT-IR method (Stacey et al., 2003).

Within the IMA-DMP database, about 23% of the respirable dust measurements and 30% of the respirable quartz measurements are below the limit of detection. Appropriate imputation techniques should be applied for these measurements to end up with unbiased estimates of average exposures and measures of variability in exposure concentrations (Jin et al., 2011). In addition, these imputations should be adjusted for the fact that two analytical techniques with different analytical limits of detection are being used for quartz.

Several studies have stressed the potential influence of weather conditions as they might affect workers' exposure (Lumens and Spee, 2001; Peters et al., 2009; Nieuwenhuijsen and Schenker, 1998). Weather conditions as rain and wind were taken into account to assess their influence on the determinant 'working environment' for workers within the construction industry. As a result, minor negative contribution to the working environment in terms of dust concentration was found when it was raining and windy. Similar findings were noted by Peters et al. (2009), rain had a negative effect on dust (inhalable) concentration. Nieuwenhuijsen and Schenker (1998) reported that dry and warm weather conditions lead to high dust levels experienced by farmers and farm workers. Potential influence of climate changes on exposure of workers may lead to preferential sampling on bad (dry and not windy days) or good (wet and windy days) in outdoor situations. Therefore the question could be raised whether the sampling days in the IMA-DMP database are representative for the meteorological conditions encountered during a year at the various sites in the different countries. This will be a more important question for sites and jobs where most of the work is performed outdoors. Looking at the database we see an overall 24% of wet sampling days. According to the average annual precipitation for European cities (Current Results: Weather and Science Facts, 2016), approximately 29% of days per year are considered 'wet' days, averaged over all countries. Given that the sampling dates and locations within the IMA-DMP database are known and that it should be possible to reconstruct whether a job was inside or outside, the phenomenon of preferential sampling being an issue or not can be studied. When we compare the percentage of dry days per country with what is reported in the IMA-DMP database we see similar patterns: United Kingdom (65%) (73% in database), France (69%) (75% in database) and Spain (85%) (80% in database) (Current Results: Weather and Science Facts, 2016). Preferential sampling on dry days seems not to differ between countries.

It should be noted that although a standardized protocol within IMA-DMP was used, it is still possible that small or larger deviations in sampling procedures could have occurred as discussed above. Despite these limitations the overall IMA-DMP database contains highly comparable data on personal exposure to respirable dust and quartz due to the standardized protocol, the pre-scribed sampling strategy and the quality control system in place. Absence of quality control is thought of one of the major problems of occupational exposure databases. In the EXASRUB database, lack of occupational hygiene information in the original datasheets was the reason for the worse agreement in coding exercises (De Vocht et al., 2005). The lack of quality control was also raised as a problem in other (retrospective) studies of exposure assessment data (Rajan et al., 1997; Caldwell et al., 2001; Cherrie et al., 2001). Therefore, quality control is essential to ensure completeness and consistency of the data collection before the data from a company during a certain campaign can be included into the database. The downside of this approach is that some delay in data submission might occur when companies are requested to correct the collection sheets, which will cause delays in incorporation of measurement data into the IMA-DMP database.

The direct feedback to companies in the form of company reports prepared after each sampling campaign helps companies to identify problem areas and jobs with high exposure levels within their sites in order to develop prevention strategies to lower exposure levels. The feed-back at company level is one of the important benefits stimulating companies to participate in the IMA-DMP. Participation to the IMA-DMP can help companies to become aware, evaluate and understand workers' exposure to a hazardous substance. A recent study by Basinas et al. (2016) showed that simple feedback of measurements results to employers and employees lowered exposure concentrations between 20% and 30% and by doing so will reduce associated health risks of exposed workers.

5. Conclusions

This paper will help the scientific community and stakeholders better understand that initiatives as the IMA-DMP can serve as a tool to protect workers from health risks resulting from exposure to respirable dust and quartz via a dedicated exposure monitoring program. The resulting IMA-DMP database, exclusively based on personal exposure measurements, is a unique exposure database with valuable exposure information collected prospectively during the last 15 years. This program can serve as an example for other industrial sectors, showing that the use of a common standardized sampling protocol and adequate quality control is essential to have reliable exposure data. This could be used to identify situations requiring further investigation or implementation of additional control measures to reduce workers' exposure at the level of individual companies and of an entire industrial sector.

The large amount of measurement data systematically collected in the European Industrial Minerals industry will enable quantitative estimates of long term exposure to respirable dust and crystalline silica that can be used in future occupational epidemiological studies to estimates quantitative exposure response relationships between exposure to respirable quartz and respiratory health outcomes. This evidence from human observational studies will eventually allow for a much more accurate and precise deduction of occupational exposure limits for a very abundant occupational exposure.

Conflict of interest

The authors declare no conflict of interest relating to the material presented in this Article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

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Appendix A. Supplementary data

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