Exposure Assessment in German Potash Mining

Dirk Dahmann, Christian Monz, Heinrich Sönksen

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D. Dahmann, C. Monz
Institut für Gefahrstoff-Forschung,
Waldring 97
D 44789 Bochum
Germany

H. Sönksen
K+ S Aktiengesellschaft
Bertha-von-Suttner-Str. 7
D 34131 Kassel,
Germany

D. Dahmann (communicating author):
email: dahmann@igf-bbg.de,
phone: +49234306412
fax: +49234306353

Abstract

Objective: Between 1995 and 2003 a longitudinal study on miners in two German potash mines was planned and performed by BAuA in collaboration with K+S and IGF. Aim was to correlate exposure data to the results of medical examination of the miners in the respective mines' workforce and to use the detailed exposure investigation as a tool for risk assessment by the company. In this time period a discussion about health effects and the corresponding necessity to lower the existing threshold limits for the components NO and NO_2 was started as well. Whereas the epidemiological aspects of this study are reported elsewhere [10], we discuss the exposure situation in detail in this paper.
Methods: In two potash mines in Germany the shift and short time exposure for the components respirable dust, inhalable dust, diesel particulate matter, nitrogen monoxide, nitrogen dioxide, and carbon dioxide was investigated in four separate campaigns. The results are reported and discussed.
Results: The miners especially in the production areas of the mines are exposed to a highly correlated mixture of the components though the exposure situation can be regarded as state of the art and representative for the industry.
Conclusion: All dose-response-discussions must take into account that never only one of the components can be made responsible for an eventually occurring respiratory effect. For reasons of availability of proper measurement equipment limitations for a possible lowering of indicative limit values of the EU are to be observed.

Keywords

Exposure assessment, potash mining, nitrogen oxides, diesel exhaust, dust

Introduction

The study of negative health effects of air pollution components requires the availability of solid exposure data in well defined cohorts of exposed persons [6]. We report here the results of exposure assessment of two different cohorts in German potash mines. The respective study was initiated by Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, BAuA, and the medical examinations as well as the epidemiological investigation were also performed by this institution. The respective results are published elsewhere [10]. As the exposure assessment was performed for several different substances which resulted from different industrial processes, we here give a complete description of that aspect of the study in order to allow for a deeper insight into the complex exposure situation in potash mining.
An additional reason and the main motivation for participation of the mining company was to gain valuable data for risk assessment and to provide solid information for the currently pending discussion on revised threshold limits especially for the gaseous components.

Description of the technical processes

In Germany a potash production of about 40 million t crude ore a year is done by 5 mines. Due to the complicated geological situation mining is done predominantly by drill and blast while worldwide cutting methods are more common.
For the various mining processes and the subsequent support and logistic functions a fleet of, about 1700 mainly diesel powered equipment with an installed total power of the diesel engines of 135 MW is in operation. The loaders for face haulage are of decisive importance

for the diesel fuel consumption and thus for the diesel emissions due to their high power and utilisation time. Dependent on the deposit loaders with payloads of 9 to 20 t and rated power of 187 to 320 kW are in operation. In the mines with suitable conditions also electric powered loaders are in operation, in two mines the proportion of haulage with these loaders is in the range of more than 40 %. The working process of the most other production machines, i.e. auger and blast-hole drilling, roof bolting and explosive loading is already electrified, thus the diesel engine is only in operation for translocation from one workplace to the other. By contrast the diesel engine is essential for cleanup-loaders and scaling machines due to the requirements of the working process. For the transport of men and material mainly modified standard off-road vehicles with four-wheel drive are in operation. Mounting and dismounting of the stationary equipment is done with various service machines, i.e. fork lifts, cranes, etc. For roadway maintenance different construction machines, i.e. road cutting machines, graders, dozers, etc. are employed. For all the latter machine groups the diesel engine is essential due to the increasing distances of more than 10 km between the shafts and the production areas.
The two mines investigated in this project can be regarded as representative for the industry. In both mines state-of-the-art conditions are realized with respect to the exposure situation. Due to the flat up to steep structure of the potash layers the room and pillar method is prevailing. In the production areas drifts with a width of 9 to 16 m and a height corresponding to the layer are established in rectangular way, thus square shaped pillars with a width of 26 to 50 m remain for a safe support of the overlying structures (Fig. 1)
The dilution of the diesel engine exhaust components and explosives to a harmless level is guaranteed by proper ventilation. For this purpose the fresh air from the intake shafts is guided in canalized drifts to the individual production areas, where the air stream is guided by ventilators and walls to the several working places at the face. The exhaust air stream loaded with the hazardous substances is then returned back to the exhaust shafts in isolated drifts.

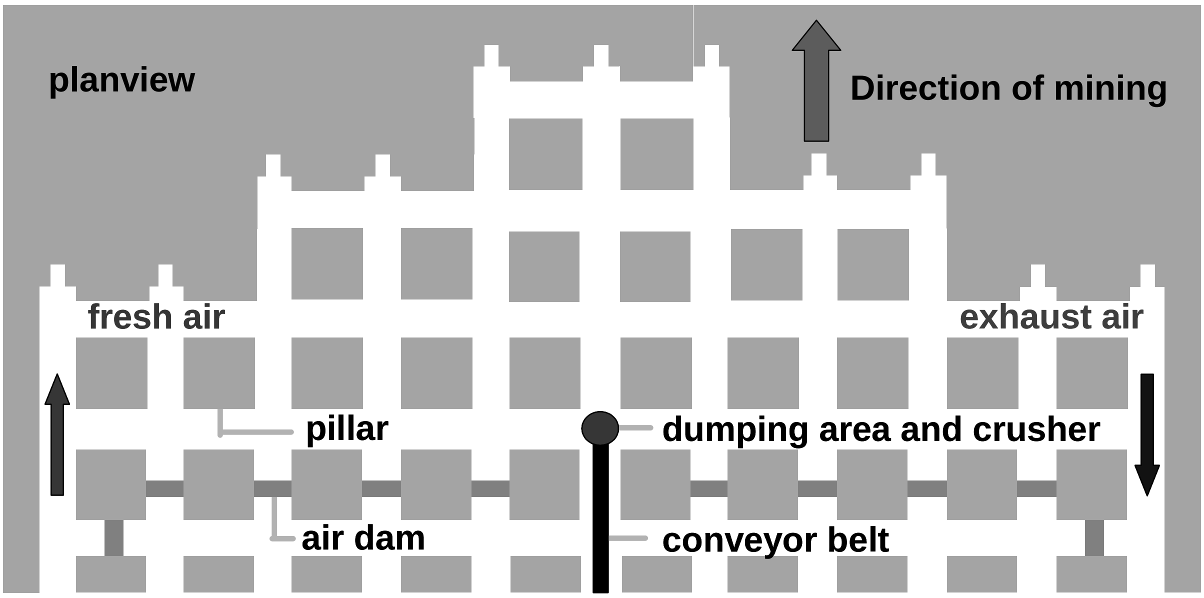

Fig. 1: Production area

Production is running in a 3 shift system with 15 to 18 regular shifts per week. Working time at the face is about 5.5 to 5.8 hours of an 8 hour shift.

The production cycle is based on the following steps (Fig. 2):

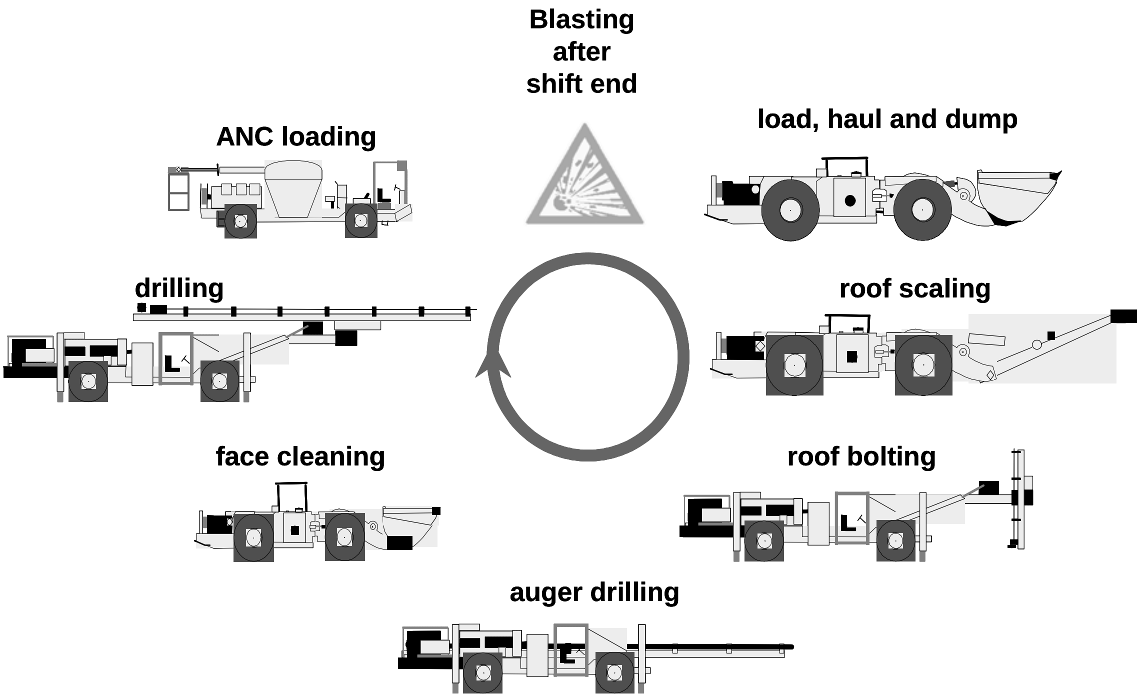

Fig. 2 Production cycle

- Auger drilling: Drilling of 3 parallel holes of 280 mm diameter each with a length of 7 m
- Face Cleaning: Cleaning the face from the auger drilling material
- Drilling : Drilling of blast holes with a diameter of 37 mm and a length of 7m
- ANC loading: Pneumatic filling of the blasting holes with explosives
- Blasting: Remote controlled blasting at the end of the shift with no personnel in the production areas
- Load, Haul, Dump: Haulage of the crude ore to the crusher in the central drift, from there the ore is transported to the hoisting shaft with belt conveyors
- Roof scaling: Scaling of the roof to prevent falling of loosed ore
- Roof bolting: Fixing of the roof layers with roof bolts

The health protection of the employees is guaranteed with proper threshold limit values respectively minimizing requirements in combination with intensive control and assessment of the air quality (Tab. 1).

Component	Main Source	Threshold limit values
Diesel particulate matter DPM (« elemental carbon »)	Diesel engines	0.3 mg/m³
Respirable dust	Mining process	3 mg/m³ (not valid for “soluble dust”)
Inhalable dust	Mining process	10 mg/m³ (not valid for “soluble dust”)
Carbon monoxide CO	Explosives / Diesel engines	30 ppm
Nitrogen monoxide NO	Diesel engines	25 ppm
Nitrogen dioxide NO_2	Explosives	5 ppm
Carbon dioxide CO_2	Natural sources / Diesel engines	5000 ppm

Tab. 1: Threshold limit values (valid at the time of the investigations) [19]

A typical concentration curve of the gaseous components over the shift time in the exhaust air stream of a production area with room and pillar mining method is shown in Fig. 3. The concentration peaks due to blasting at the end of the preceding shift is diluted reasonably fast within the first hour. Via the chart shown in Fig. 3, the development of CO-, NO- und CO_2-concentrations can be related to the beginning of machine operations (especially the diesel loader operations) as well as stopping the machines at the break in the middle of the shift and at the end of the shift.

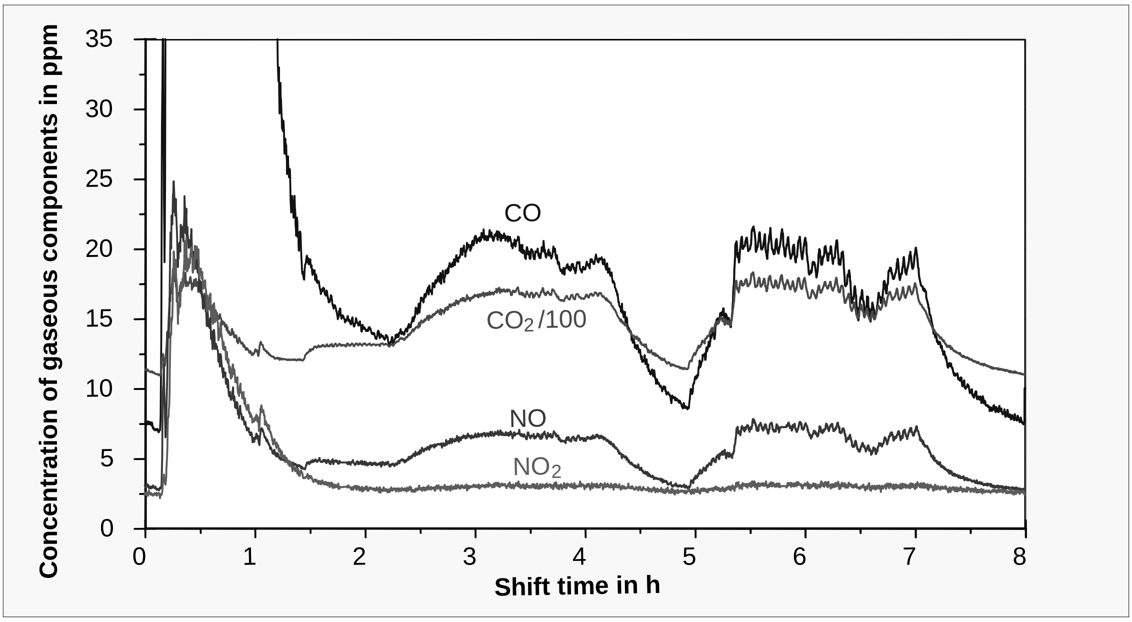

Fig. 3 Concentration of gaseous components at the exit of a production area

From these curves two fundamental conclusions with respect to the two possible sources can be taken:

- The NO_2 emission is mainly influenced by the use of explosives. Due to the slow release of the residual gases while loading the crude ore and from rear mining drifts a comparatively constant level is generated during the whole shift.

- The operation of diesel engines is determining the CO-, NO- und CO_2-concentration, but contributes only a small amount to the NO_2-concentration.

A total of about 2600 miners are working in the two mines.

In addition to the crude ore production both mines operate an underground waste disposal in particular disused mine areas, organisationally separated in proper manner.

Methods

General remarks: The concentrations of the following components have been measured during three of the four different measurement campaigns: nitrogen monoxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), diesel particulate matter (“dpm”, “elemental carbon”), respirable dust, and inhalable dust, the latter two according to the European Standard EN 481 [7]. Due to experimental limitations in the very first campaign in 1995 only the particulate components (“dpm”, respirable and inhalable dust) could be measured.
The measurements have been performed according to the following timetable

Coding		Mine	Time of sampling
A1		Mine A	1994/1995
A2		Mine A	2000
B1		Mine B	1999
B2		Mine B	2003

General aspects of measurement strategy: For all the components time weighted eight-hour shift values were determined according to the German regulation TRGS 402 [17], which is in its procedures in line with the European Standard EN 689 [8]. As it was generally not possible to run the samplers on a whole shift base, i.e. from entry of the miners into the mine to exit, time weighting was done by measuring during time of exposure and numerical calculation including “exposure-free” time periods (e.g. travelling to the worksite). This is exactly the required procedure for the German compliance process, thus the results give a good description of the exposure situation in legal terms. As a rule of thumb personal sampling was generally preferred, but for several reasons in some cases stationary samplers had to be applied as well. So, in low-exposure situations, for example in the work shops, which were located near the intake shafts of the mines in both cases, the personal samplers for the four gaseous components were generally not suitable because of their insufficient lower detection limits (see below). As a consequence and because the concentrations especially of the nitrogen oxides were required for comparison purposes in these settings, stationary instruments had to be applied[1] as well. In a former study we could show, that under the conditions of underground mining with directed ventilation present in all workplaces, the differences for diesel particulate matter between personal and stationary sampling results tend to be very small, if the stationary sampling is performed “near the source” (as required by German regulation) [1] because of the ultrafine nature of that particulate aerosol. The same

[1] It is NOT recommended to use the environmental monitors (chemoluminescence) for these purposes, as the instruments need special maintenance procedures in salt mines and are in severe danger of malfunction after only a few uses underground due to their fragility.

can not safely be said for respirable dust and inhalable dust. Therefore the latter two components were only measured by personal sampling.
Instruments used: The following instruments have been applied (table 2).

Component	Name	Manufacturer	Personal/stationary	Principle
NO	Multiwarn	Draeger, Lübeck	personal	Electrochemical cell, direct reading
NO	CLD 700 AL	TECAN	stationary	chemoluminescence
NO_2	Multiwarn	Draeger, Lübeck	personal	Electrochemical cell, direct reading
NO_2	CLD 700 AL	TECAN	stationary	chemoluminescence
CO	Multiwarn	Draeger, Lübeck	personal	Electrochemical cell, direct reading
CO_2	Multiwarn	Draeger, Lübeck	personal	Infrared, direct reading
„dpm“	MPG II	DEHA, Friolzheim	stationary	Respirable dust fraction, elutriator pre-separator
„dpm“, respirable dust	PGP FSP	GSM, Neuss	personal	Cyclone pre-separator
Inhalable dust	PGP GSP	GSM, Neuss	personal	

Table 2: Measurement and sampling instruments

Whereas the dust sampling equipment (PGP, MPG II) could be used according to well-established standard operation procedures [5], the same is not true for the person carried gas sensors (Multiwarn). As mentioned above, the chemoluminescence monitors were only used in low-exposure situations of workshops, where otherwise relatively undemanding environmental conditions could be guaranteed. Even under these conditions, the equipment needed special cleaning after each single use underground in order to guarantee its functionality. We do not recommend their use in salt or potash mines, because of their general fragility.
The Multiwarns are characterized by relatively sturdy design but low sensitivity. In addition they need very high quality control efforts to guarantee their proper use. There is clear evidence, that cross sensitivities between some of the components (e.g. NO and CO, humidity) may play a part. Therefore it was necessary to put special emphasis on the calibration procedures applied. Commercially available calibration gases were used to calibrate the instruments in the laboratory. However, because of the special influence of moisture a one-point calibration with calibration gases within the underground mines themselves, i.e. under the specific respective humidity (very low) and atmospheric pressure conditions (variable depending on the site within the mine) was necessary. Even under these circumstances, we have to comment the measurement results according to our own validation results. Not all of the Multiwarn results can be classified as belonging into the same high validity category. Table 3 reports the analytical properties of the methods and our validation ranking)[2].

[2] Note that the manufacturer classifies the Multiwarn not as a measurement instrument but as a surveillance instrument.

Component	**Instrument**	**Validity category**	**Remark**	**Lower Detection limit (LDL)**
NO	Multiwarn	Medium	Cross sensitivity CO, large scale range	*1 ppm*[3]
NO	Chemoluminescence	Very high	Fragile and not suited for “routine”	0.002 ppm
NO_2	Multiwarn	high	Relatively small measurement range and high specifity	*1 ppm*[3]
NO_2	Chemoluminescence	Very high	Fragile and not suited for “routine”	0.002 ppm
CO	Multiwarn	Medium	Large scale range	*1 ppm*[3]
CO_2	Multiwarn	Low	Very large scale range, high environmental background[4]	- (not determined)
“dpm”,	All samplers,	Very high		0.01 mg/m³
respirable dust,	All samplers,	Very high	LDL for membrane filters	0.15 mg/m³
inhalable dust	All samplers,	Very high	LDL for membrane filters	0.1 mg/m³

Table 3:
Validity categories of the instruments/procedures (qualitative ranking with respect to this specific study) and analytical data

As a consequence the results for the component CO_2 are not given in this paper. Also, they are of only minor significance for the epidemiological study.
The direct reading instruments were set to a recording time of 1 minute. As a consequence all exposure data for the gaseous components are available as a sequence of 1-minute values from which shift values have been numerically calculated. This could be of high significance when irritant components like NO_2 are discussed. Especially in this case short time exposure and less dose-related effects can be important for eventually detected health effects. We have developed a specific evaluation tool for the discussion of short time values, the so-called workplace-exposure profiles (WEP), which have been reported elsewhere [4]. This procedure is discussed in detail below
Analytical procedures: The analytical methods of the direct reading instruments have already been described above. Diesel particulate matter was measured as elemental carbon using the coulometric method [3].This method has been demonstrated to yield well comparable data to the so-called thermo-optical method, standardized in NIOSH 5040 [2, 13] under mining conditions and has been tested extensively in a series of European round robin tests [9]. Because of the large number of samples only gravimetrically determined respirable dust and inhalable dust results are presented here. A special procedure for the determination of soluble (salt) percentages of the dust was also developed in IGF and has been published in

[3] 1 minute average, only a rough estimation can be given, as the LDLs vary according to the environmental conditions
[4] One of the mines has a considerable influx of geological CO_2 deposits from former volcanic activity.

[11]. Because of the considerable additional effort it would have required, and because it only was available in later stages of the study, only few filter samples have been investigated with this method.

Results

Shift value data

Table 4 details the total numbers of measurements for the various different workplaces and mines. The measurements have been performed over a period of almost 10 years, therefore certain changes in the measurement methods, the measurement strategies and the sites of measurements have been inevitable. One example is the change of analyte for diesel particulate matter. Whereas in 1994/1995 dpm has been measured and evaluated as “total carbon”, it was determines as “elemental carbon (“ec”) since then. Elemental carbon is still the currently used analyte and therefore only these results have been included in this paper[5]. Some of the workplaces where classified with different formerly used denominations in the campaigns A1, A2, and B1. They have been reclassified according to the most recently used notification as of campaign B2. Great care has been taken, however, to guarantee comparability with respect to the real workplace situation of the miners involved. So, as an example “small transportation vehicle” jobs are the ones of supervisors or other persons with a more mobile work style using small diesel engine driven cars to move around in the production areas proper. The rationale behind the grouping was to have as many different groups as reasonably possible but to have as many measurement results as necessary behind each group for a statistically meaningful evaluation.
Three main regions have been identified within the mines because a functionally different level of exposure was suspected. They are the main production areas, relatively far off the intake shafts, where higher exposure levels were expected, the areas near the intake shafts where the work shops are located in both mines, and the area where an underground waste disposal is operated in both mines. In addition the personnel working in both of the first two areas (“mobile repair”) have been separately treated as well.

[5] The total carbon exposure situation in German potash mines during the time in question is described in [15]

	Workplace-Type	Inhalable Dust				Respirable dust				DPM				Nitrogen Dioxide				Nitrogen Monoxide				Carbon Monoxide			
		A1	**A2**	**B1**	**B2**	**A1**	**A2**	**B1**	**B2**	**A1**	**A2**	**B1**	**B2**	**A1**	**A2**	**B1**	**B2**	**A1**	**A2**	**B1**	**B2**	**A1**	**A2**	**B1**	**B2**
Production area	**Diesel loader**	66	32	32	21	66	33	36	21	20	30	31	21	-	22	31	21	-	22	31	21	-	22	31	21
	Electric loader	-	13	13	19	-	13	11	19	-	13	13	19	-	8	14	16	--	8	14	16	-	8	14	16
	Scaling machine	36	16	13	8	36	16	14	8	2	16	13	8	-	9	12	9	-	9	12	9	-	9	12	9
	Drilling jumbo	27	24	19	29	27	23	23	29	6	23	19	29	-	23	25	21	-	23	25	21	-	23	22	20
	Explosives vehicle	-	10	3	10	-	10	3	10	-	10	3	10	-	7	6	7	-	7	6	7	-	7	6	7
	Small transportation vehicle	37	14	12	11	37	15	11	10	11	15	12	10	-	10	10	13	-	10	10	12	-	10	10	13
	Administration area	-	13	-	16		15	-	16	-	15		16	-	6	3	16	-	6	3	11	-	6	3	16
Work shops	**Main work shop**	-	21	4	9	-	33	8	9	4	21	8	9	-	12	7	20	-	12	7	19	-	12	6	20
	Electrical work shop	-	-	-	8	-	-	-	8	-	-	-	8	-	-	-	6	-	-		6	-	-		6
	Small work shop	-	-	2	10	-	-	7	10	-	-	2	10	-	-	0	8	-	-	0	8	-	-	-	8
UWD	**UWD**	-	34	-	8	-	41	10	8	-	35	-	8	-	9	-4	6	-	9	4	6	-	9	4	6
	Belt-repair site/mobile repair personnel	-	12	-	8	-	12	12	8	11	12	16	8	-	9	-	6	-	9		5	-	9		6

UWD= Underground waste disposal
A1, A2, B1, B2 see above

Table 4: Number of Shift-Measurements

Tables 5 to 10 give the results for the indicated groups. The results of campaign A1 have not been included here because they are already published and are restricted only to particulate compounds. The data are given in the following format. The arithmetic mean of the respective set is followed by its geometric mean, the standard deviation and the highest measured result which includes at least 95% of all results. This excludes extremely high and possibly outlying results. For sets of 10 or fewer results it is identical with the maximum result. This convention is used because at least in Germany the 95percentile of measurements is relevant for threshold limit discussi

Tables 5 to 10 (Respirable dust, inhalable dust, diesel particulate matter (“dpm”), CO, NO, NO_2)

Type of workplace	Respirable dust (mg/m³) campaign A2				Respirable dust (mg/m³) campaign B1				Respirable dust (mg/m³) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	3.41	3.10	1.24	4.49	1.33	1.23	0.44	2.09	1.16	0.97	0.67	2.1
Electric loader	3.05	2.38	1.95	5.12	1.38	1.17	0.65	2.17	1.58	1.44	0.70	2.8
Scaling machine	5.43	4.96	2.51	8.4	2.16	1.85	1.41	3.77	2.72	2.50	1.13	2.0
Drilling jumbo	3.56	3.21	1.64	7.18	1.06	0.98	0.39	1.65	1.54	1.27	0.93	3.90
Explosives vehicle	2.74	2.62	0.73	3.65	0.83	0.82	0.13	0.95	0.64	0.46	0.28	1.22
Small transportation vehicle	2.53	2.44	0.76	3.45	0.82	0.78	0.25	0.99	0.63	0.57	0.25	0.98
Administration area	2.04	1.78	1.09	3.42	-	-	-	-	0.48	0.36	0.46	1.00
Main work shop	0.36	0.32	0.17	0.80	0.42	0.33	0.37	1.38	0.07	0.06	0.04	0.13
Electrical work shop	-	-		-	-	-	-	-	0.23	0.22	0.06	0.29
Small work shop	-	-		-	0.75	0.74	0.11	0.78	0.35	0.20	0.42	0.56
UWD	0.78	0.74	0.28	1.13	0.43	0.40	0.18	0.90	0.19	0.17	0.10	0.39
Belt-repair site/mobile repair personnel	1.22	1.16	0.40	1.57	1.28	1.10	0.83	2.01	0.38	0.32	0.19	0.63

Table 5: 8 h shift exposure data for campaigns A2, B1, and B2 per job category, Respirable Dust

Type of workplace	Inhalable dust (mg/m³)campaign A2				Inhalable dust (mg/m³) campaign B1				Inhalable dust (mg/m³) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	19.13	13.34	12.00	35.13	12.93	11.23	6.76	25.26	8.04	4.76	5.94	18.1
Electric loader	23.18	12.73	17.83	41.67	17.36	15.25	9.19	23.96	25.11	18.43	16,45	41.50
Scaling machine	34.04	29.67	19.64	76.01	18.48	15.84	10.63	28.06	38.71	36.56	12.35	58.70
Drilling jumbo	21.94	17.55	16.54	60.11	7.13	5.95	4.12	13.79	11.18	8.09	8.85	33.9
Explosives vehicle	9.34	8.10	4.58	18.46	2.53	2.31	1.01	3.77	2.61	2.40	1.23	5.91
Small transportation vehicle	11.65	8.50	5.24	19.08	4.82	4.08	2.56	10.29	4.05	3.62	1.78	6.24
Administration area	5.76	4.49	3.65	10.81	-	-	-	-	0.91	0.61	1.00	2.1
Main work shop	1.43	1.1	0.88	3.16	0.60	0.60	0.06	0.67	0.27	0.24	0.13	0.44
Electrical work shop	-	-	-	-	-	-	-	-	0.31	0.30	0.05	0.38
Small work shop	-	-	-	-	1.34	1.32	-	1.51	0.31	0.19	0.25	0.79
UWD	2.22	1.80	1.57	4.46	0.75	0.57	0.66	2.54	2.07	0.59	3.13	8.30
Belt-repair site/mobile repair personnel	6.36	5.79	2.39	8.94	-	-	-	-	1.15	1.00	0.67	2.72

Table 6: 8 h shift exposure data for campaigns A2, B1, and B2 per job category, Inhalable Dust

Type of workplace	Dpm (mg/m³) campaign A2				Dpm (mg/m³) campaign B1				Dpm (mg/m³) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	0.14	0.12	0.06	0.24	0.19	0.17	0.07	0.31	0.14	0.11	0.07	0.25
Electric loader	0.08	0.08	0.03	0.11	0.09	0.07	0.04	0.14	0.14	0.13	0.05	0.22
Scaling machine	0.13	0.12	0.04	0.20	0.18	0.17	0.07	0.30	0.18	0.16	0.08	0.28
Drilling jumbo	0.13	0.11	0.06	0.21	0.14	0.12	0.08	0.31	0.13	0.12	0.05	0.24
Explosives vehicle	0.11	0.10	0.03	0.15	0.11	0.11	0.01	0.12	0.11	0.08	0.06	0.22
Small transportation vehicle	0.09	0.08	0.02	0.11	0.09	0.09	0.02	0.11	0.10	0.09	0.05	0.19
Administration area	0.05	0.05	0.02	0.07	-	-	-	-	0.08	0.07	0.04	0.14
Main work shop	0.04	0.03	0.02	0.07	0.05	0.04	0.04	0.06	0.03	0.02	0.01	0.05
Electrical work shop	-	-	-	-	-	-	-	-	0.03	0.03	0.01	0.04
Small work shop	-	-	-	-	0.05	0.05	-	0.06	0.03	0.03	0.01	0.04
UWD	0.06	0.06	0.02	0.09	0.04	0.03	0.03	0.09	0.06	0.05	0.03	0.11
Belt-repair site/mobile repair personnel	0.09	0.09	0.03	0.11	0.09	0.09	0.03	0.12	0.08	0.08	0.01	0.10

Table 7: 8 h shift exposure data for campaigns A2, B1, and B2 per job category, Diesel particulate Matter

Type of workplace	CO (ppm) campaign A2				CO (ppm) campaign B1				CO (ppm) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	2.94	0.70	2.72	6.59	2.42	1.47	1.92	5.47	5.40	4.87	2.27	9.26
Electric loader	1.84	0.28	1.56	4.96	3.86	3.55	1.56	6.79	6.14	5.50	2.38	8.77
Scaling machine	2.73	0.47	1.98	5.66	2.53	2.35	0.84	3.37	5.19	4.90	1.78	8.84
Drilling jumbo	2.66	0.82	2.37	7.94	2.59	2.14	1.37	3.84	4.32	4.00	1.65	7.53
Explosives vehicle	2.39	1.31	2.32	6.48	2.61	2.56	0.52	3.62	5.04	4.94	1.06	7.26
Small transportation vehicle	1.43	0.25	1.16	3.46	1.70	1.40	1.08	4.23	4.23	3.78	1.62	5.84
Administration area	0.84	0.00	1.13	2.96	1.23	1.12	0.46	1.71	3.83	0.02	3.21	8.41
Main work shop	0.00	0.00	0.01	0.01	1.20	0.22	1.50	3.44	0.30	0.00	0.92	1.45
Electrical work shop	-	-	-	-	-	-	-	-	0.08	0.00	0.13	0.34
Small work shop	-	-	-	-	-	-	-	-	0.80	0.00	1.31	3.31
UWD	0.60	0.19	0.84	2.70	2.58	1.58	2.35	6.51	3.76	2.84	2.68	9.01
Belt-repair site/mobile repair personnel	1.76	1.15	1.07	2.81	-	-	-	-	5.25	4.51	3.27	12.05

Table 8: 8 h shift exposure data for campaigns A2, B1, and B2 per job category, Carbon Monoxide

Type of workplace	NO (ppm) campaign A2				NO (ppm) campaign B1				NO (ppm) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	4.70	4.02	2.58	8.69	2.90	2.59	1.28	5.14	4.76	4.34	1.86	7.23
Electric loader	3.00	2.69	1.36	5.80	2.92	2.58	1.28	4.09	3.07	2.82	1.12	4.49
Scaling machine	4.41	4.17	1.59	8.18	3.65	3.50	1.02	5.03	4.09	3.92	1.20	5.73
Drilling jumbo	3.64	3.22	2.07	5.63	1.91	1.22	1.42	4.31	2.63	2.41	1.14	3.82
Explosives vehicle	2.21	1.78	1.16	3.71	3.40	3.11	1.47	6.17	3.22	3.11	0.79	4.30
Small transportation vehicle	2.87	2.05	3.35	12.71	1.21	1.13	0.45	2.16	2.29	2.11	0.79	3.26
Administration area	1.17	0.10	0.97	2.89	1.85	1.85	0.06	1.92	1.57	0.10	1.50	4.29
Main work shop	0.36	0.02	0.41	0.60	1.47	0.79	1.17	3.40	0.34	0.05	0.26	0.79
Electrical work shop	-	-	-	-	-	-	-	-	0.34	0.03	0.23	0.52
Small work shop	-	-	-	-	-	-	-	-	0.40	0.03	0.25	0.78
UWD	0.52	0.30	0.39	1.17	1.79	1.41	1.00	3.11	1.46	1.23	0.87	3.05
Belt-repair site/mobile repair personnel	2.28	2.08	0.98	4.16	-	-	-	-	1.73	1.70	0.40	2.52

Table 9: 8 h shift exposure data for campaigns A2, B1, and B2 per job category, Nitrogen Monoxide

Type of workplace	NO_2 (ppm) campaign A2				NO_2 (ppm) campaign B1				NO_2 (ppm) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	1.06	0-86	0.70	2.41	0.90	0.86	0.27	1.19	1.43	1.28	0.61	2.60
Electric loader	0.63	0.34	0.47	1.29	0.63	0.60	0.26	0.91	1.34	1.28	0.39	1.89
Scaling machine	0.98	0.97	0.16	1.19	0.88	0.77	0.50	1.87	1.14	1.05	0.45	1.87
Drilling jumbo	0.83	0.61	0.50	1.68	0.51	0.41	0.34	1.24	1.04	0.95	0.41	1.59
Explosives vehicle	0.92	0.81	0.43	1.58	0.84	0.79	0.26	1.19	1.10	1.03	0.32	1.46
Small transportation vehicle	0.44	0.32	0.27	0.89	0.58	0.47	0.27	0.91	0.94	0.90	0.25	1.23
Administration area	0.36	0.01	0.33	0.96	0.52	0.50	0.11	0.62	0.78	0.11	0.46	1.29
Main work shop	0.06	0.01	0.07	0.19	0.35	0.10	0.45	1.17	0.01	0.00	0.02	0.04
Electrical work shop	-	-	-	-	-	-	-	-	0.01	0.00	0.01	0.02
Small work shop	-	-	-	-	-	-	-	-	0.12	0.00	0.11	0.29
UWD	0.13	0.11	0.05	0.19	0.21	0.09	0.24	0.62	0.21	0.15	0.16	0.51
Belt-repair site/mobile repair personnel	0.48	0.43	0.24	1.01	-	-	-	-	0.82	0.73	0.43	1.62

Table 10: 8 h shift exposure data for campaigns A2, B1, and B2 per job category, Nitrogen Dioxide

At a first glance the provisional grouping into the four mine regions does display in the data set. Therefore the regions are outlined with a differently shaded background to highlight the intrinsically different exposure situation. For the epidemiological study a high correlation between the 6 analytes displayed here was found. It was impossible to differentiate between selectively high exposure for example to nitrogen dioxide and particulate components. High exposure to one of the components usually means high exposure to the others as well. This is in line with expectation and therefore plausible.
As the results of this study were also meant to produce valid data for a threshold discussion the complete set of results was also compiled for each mine.
A simple two-sided t-test showed no difference between the three different campaigns for each component. Therefore Table 11 gives the complete summarized exposure data for the three campaigns which can be taken as representative for the whole potash mining industry in Germany.

Respirable dust (mg/m^3)	
Number of measurements	557
Average	1.57
Standard deviation	1.52
95 percentile	4.66

Inhalable dust (mg/m^3)	
Number of measurements	516
Average	10.76
Standard deviation	13.86
95 percentile	36.74

Diesel particulate matter (mg/m^3)	
Number of measurements	546
Average	0.10
Standard deviation	0.07
95 percentile	0.24

CO (ppm)	
Number of measurements	407
Average	2.70
Standard deviation	2.34
95 percentile	7.39

NO (ppm)	
Number of measurements	409
Average	2.57
Standard deviation	1.93
95 percentile	5.73

NO_2 (ppm)	
Number of measurements	417
Average	0.74
Standard deviation	0.56
95 percentile	1.78

Table 11 Cumulated 8 h Shift data for all components and mines

Short time exposure data

While for shift exposure the time period of eight hours as a base for averaging the concentrations has been generally accepted, the situation for short time exposure is quite different. Nevertheless, short time exposure is a very significant situation with respect to the health of workers, especially for irritant agents. In the campaigns described above it was decided at an early stage to monitor the gaseous components in a way that would allow for significant information to be obtained in this respect. Earlier IGF had developed a novel tool for the description of short time exposure situations in cases where it is not known beforehand at exactly which time period during the shift the periods of high exposures are observed. The tool is called “workplace exposure profile (“WEP”) [4]. For this model the direct reading results (in these cases one-minute-averages) are transferred into a spreadsheet. After the measurements a 15-minute sliding average filter is run over the data set to identify the one 15-minute-period of highest exposure. The average concentration for this period is recorded and removed from the data set. Then the procedure is repeated. One receives a decreasing set of 15 minute average concentrations for the shift which is guaranteed to identify the peak exposure periods without knowing the relevant moments of high exposure beforehand.
An example of the procedure is shown in Figures 4 and 5.

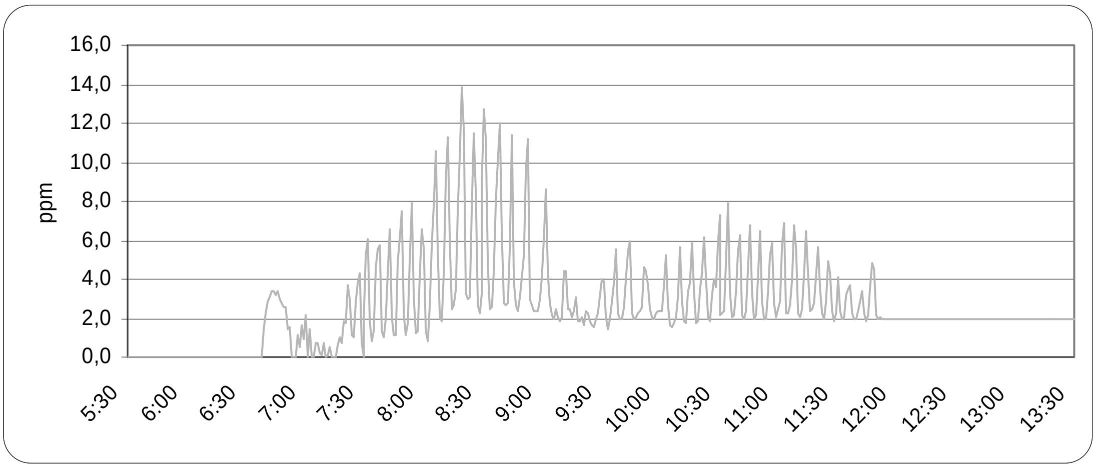

Figure 4: Plot of the CO-concentration during the shift of a loader driver (concentration versus time).

Figure 4 shows the typical plot of the carbon monoxide concentration of a loader driver’s exposure. The concentration is increasing after the driver has taken up a load of salt and drives it in line with the ventilation air (the relative velocity of the vehicle and the ventilation air are not very different). Then he dumps the salt and drives back into the direction of the fresh ventilation air in lower exposure concentrations. Each driving cycle can so be identified (together with the tea break). Depending on the direction of the fresh air flow the periods of high and low exposure may of course change respectively.
Figure 5 demonstrates which kind of information can be generated by the WEP process. It uses the example of Figure 4.

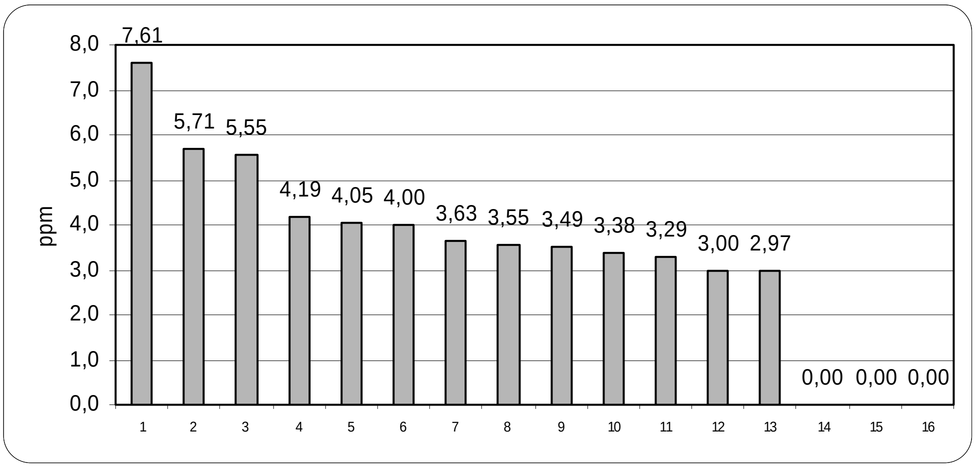

Figure5: Workplace exposure profile of the workplace given in figure 4 (15 minute averages sorted in descending order)

A wealth of short time exposure data was received by this process. For the purpose of this study only the highest short time exposure value for the three gaseous components during the shifts which gave rise to the shift-data presented before are reported here. Further evaluation of the WEP data is planned and will be reported elsewhere. For example, in the case of the loader driver as of picture 1 and 2 a short time value of 7.61 ppm would be transferred to the data base (in this case table 12).
Tables 12 to 14 give the results for the maximum short time exposure values for the components CO, NO and NO_2. The respective numbers of measurements are similar to the ones given in Table 4, but not completely identical because of practical reasons.
No difference was found for the three campaigns in the case of short time maximum exposure and therefore only the combined data are given in Table 15 as well.

Type of workplace	CO (ppm) campaign A2				CO (ppm) campaign B1				CO (ppm) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	6.93	4.35	5.16	16.12	7.36	5.22	5.76	16.80	9.40	8.63	3.72	15.90
Electric loader	5.77	4.94	2.85	9.35	0.39	7.93	5.17	17.82	11.11	10.02	4.47	17.10
Scaling machine	7.45	6.70	2.79	10.40	6.08	5.72	1.96	10.47	11.21	10.69	3.49	13.79
Drilling jumbo	5.38	3.60	3.83	13.24	6.99	6.10	3.68	13.27	8.13	7.30	4.00	14.65
Explosives vehicle	5.13	4.21	2.98	10.22	5.87	5.42	2.48	10.53	8.77	8.54	2.09	10.33
Small transportation vehicle	5.68	4.81	3.45	10.69	6.00	5.57	2.15	10.30	8.48	7.84	3.29	14.44
Administration area	2.20	0.93	1.82	4.43	1.76	1.70	0.43	2.29	7.89	6.98	2.96	10.18
Main work shop	0.28	0.25	0.14	0.48	1.85	1.62	1.01	3.27	3.04	0.58	5.14	9.46
Electrical work shop	-	-	-	-	-	-	-	-	0.27	0.16	0.22	0.58
Small work shop	-	-	-	-	-	-	-	-	1.68	0.74	1.40	3.44
UWD	3.41	2.55	1.86	4.94	6.82	5.74	3.49	11.90	11.92	11.80	1.60	13.69
Belt-repair site/mobile repair personnel	6.59	5.22	4.39	14.87	14.81	10.25	14.94	47.50	8.76	7.02	5.95	20.30

Table 12: Maximum Short Time (15 min) exposure data Carbon Monoxide for the shifts and workplaces as of table 7.

Type of workplace	NO (ppm) campaign A2				NO (ppm) campaign B1				NO (ppm) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	9.80	8.32	5.53	19.84	7.19	6.77	2.31	10.41	8.79	8.40	2.50	12.05
Electric loader	5.32	5.09	1.59	8.78	5.91	5.60	1.88	9.00	4.59	4.45	1.02	5.83
Scaling machine	14.63	13.32	6.72	28.56	9.51	9.33	1.72	11.94	12.62	12.06	3.96	12.50
Drilling jumbo	7.21	6.33	3.68	12.98	5.78	4.56	2.84	9.36	5.08	4.65	2.45	7.36
Explosives vehicle	4.74	4.39	1.75	6.96	8.53	8.31	2.13	12.67	5.65	5.56	0.94	7.03
Small transportation vehicle	6.78	5.48	5.66	10.23	4.95	4.82	1.12	7.04	4.83	4.64	1.24	6.09
Administration area	2.66	1.81	2.20	6.71	2.84	2.63	1.18	4.52	0.65	0.22	0.56	1.50
Main work shop	1.32	0.73	0.76	2.47	2.61	2.28	1.37	4.52	0.71	0.57	0.41	1.30
Electrical work shop	-	-	-	-	-	-	-	-	0.49	0.47	0.12	0.66
Small work shop	-	-	-	-	-	-	-	-	0.56	0.37	0.28	1.00
UWD	1.58	1.42	0.75	2.99	6.55	6.33	1.55	7.91	2.75	2.69	0.55	3.48
Belt-repair site/mobile repair personnel	7.14	6.55	2.70	11.39	4.25	4.13	1.04	5.94	2.94	2.89	0.50	3.58

Table 13: Maximum Short Time (15 min) exposure data Nitrogen Monoxide for the shifts and workplaces of table 8.

Type of workplace	NO_2 (ppm) campaign A2				NO_2 (ppm) campaign B1				NO_2 (ppm) campaign B2			
	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile	Average	Geom. mean	Standard Deviation	95-percentile
Diesel loader	2.09	1.69	1.16	4.04	2.28	2.12	0.87	3.54	2.00	1.83	0.79	3.63
Electric loader	1.31	1.08	0.61	2.13	1.37	1.19	0.66	2.62	1.82	1.75	0.44	2.41
Scaling machine	2.75	2.64	0.87	4.80	1.89	1.71	0.69	2.79	2.33	2.24	0.73	1.91
Drilling jumbo	1.84	1.49	0.91	3.01	1.49	1.09	1.02	3.69	1.63	1.57	0.47	2.34
Explosives vehicle	1.86	1.76	0.60	2.74	2.40	2.16	1.01	4.05	1.84	1.75	0.50	2.14
Small transportation vehicle	2.00	1.63	1.21	3.62	1.89	1.71	0.69	2.79	1.73	1.64	0.51	2.30
Administration area	0.59	0.30	0.46	1.19	0.64	0.64	0.06	0.70	0.78	0.73	0.25	1.13
Main work shop	0.31	0.25	0.12	0.44	0.32	0.08	0.31	0.63	0.08	0.02	0.10	0.24
Electrical work shop	-	-	-	-	-	-	-	-	0.03	0.02	0.02	0.07
Small work shop	-	-	-	-	-	-	-	-	0.22	0.21	0.07	0.30
UWD	0.65	0.55	0.35	1.16	0.83	0.41	0.99	2.52	0.43	0.43	0.01	0.43
Belt-repair site/mobile repair personnel	1.61	1.43	0.91	3.60	2.63	2.52	0.72	3.64	1.31	1.13	0.72	2.62

Table 14: Maximum Short Time (15 min) exposure data Nitrogen Dioxide for the shifts and workplaces of table 9.

CO (ppm)	
Number of measurements	331
Average	7.08
Standard deviation	5.14
95 percentile	15.90

NO (ppm)	
Number of measurements	347
Average	4.15
Standard deviation	4.28
95 percentile	12.45

NO_2 (ppm)	
Number of measurements	344
Average	1.66
Standard deviation	1.01
95 percentile	3.60

Table 15: Cumulated short time exposure of CO, NO, NO_2 in German potash mining (highest 15 minute exposure episodes during shift).

Discussion

As stated above, the campaigns had several aims. They should describe the current situation in potash mining with respect to risk assessment and general compliance to the threshold limits valid at the time of measurements. In addition and in cooperation with an epidemiological study they should indicate the exposure situation of the miners and compare it to the outcome of medical examinations of lung function data. In case of a risk to the respiratory tract of the miners as a possible medical outcome of the epidemiological study immediate measures would have been necessary. As a final consequence the results of this and the epidemiological study were meant to provide solid data foundation for a future European threshold limit policy.

As a first consideration, because of the very high numbers of measurements which cover all the relevant workplaces in the mines under conditions of daily exposure the usual limitations of compliance measurements for the description of a representative exposure situation do not apply in this study. The character of the measurements as being representative was the topmost consideration for their performance in all cases.

The study showed a remarkable exposure situation as the miners were jointly exposed to several gaseous and particular components with a potential for harmful effects on the airways. Though in the vast majority of cases the threshold limits were complied with for the single components as well as the sum of the mixture as demanded in German contemporary legislation [18], the fact of a high joint and highly correlated exposure remains. This is different for differing regions of the mine but it is possible to discriminate between a low exposure situation for example in the work shops and a high one in the production area. The data were introduced into the epidemiological study and the respective consequences are reported there. However, even under these conditions no immediate action for a further reduction of exposure levels were required by the outcome of the medical study. This is true even for the joint exposure of several components with a suspected capacity of being harmful to the respiratory system of the miners. In any case, further activities for lowering exposure would have been difficult to implement as the mines of the study do represent the state of the art of exposure control [12], as has been shown already above.

Several theoretical possibilities in this direction remain and will be discussed in detail in the following [16].

The currently required ventilation rate is determined by the various diesel engine types. Due to the fact that there is virtually no corrosion because of the very low humidity in the mines, the machines and vehicles reach a remarkable service lifetime. The standard off-road vehicles are dominated by EURO 0- to III-engines with the first EURO IV-engines being continuously introduced in these days. In contrast the production machines are equipped with special power reduced, air cooled DEUTZ-engines because of their excellent exhaust quality. Since end of the nineties also modern water cooled engines are available, which achieve even better exhaust quality based on all technical measures like turbo chargeing, air intake cooling, high pressure injection system, etc. Within the usual machine replacement procedures a medium term emission reduction and exposure situation improvement can and will be achieved.

Also of interest are the fuel quality and the development of devices for exhaust gas treatment. The mining industry has always taken special efforts to get low sulphur fuels to reduce the sulfate particle emissions but only since 2003 in general fuel with less than 10 ppm sulphur is available in Germany. In order to further reduce harmful substances investigations set focus on renewable fuels but they were not *yet* found to be applicable under mining conditions.

Also particulate filters were tested since the early nineties using several different systems. Especially the low exhaust temperature of the power reduced engines makes it more difficult to regenerate the filter by initiating the process of burning off the collected diesel particulate matter. In addition the common filter systems of vehicles intended for the use in public traffic caused a dramatic NO_2-concentration increase because of the oxidation of NO due to the catalytic coating of the filter elements. This study clearly demonstrates that a further increase of NO_2 concentrations can not be tolerated.

Besides of the particulate filter systems the development of DENOX-systems for the reduction of nitrogen oxides are in the focus. Such systems, i.e. systems with injection of aqueous urea liquid in a special down stream selective catalytic reduction catalyst (“SCR”) are only at the beginning of the technical development. They are not available for the great variety of diesel engines in underground mining machines.

Further emission reduction measures by increasing the electrification of machines are currently not possible for logistical reasons. Workplaces where electric loaders are used show generally lower exposure levels for dpm, and the gaseous components as compared to diesel powered equipment in this study. Because of the fact that pure regions of electrically driven engines are very rare in the mines the effect is not more profound. The levels of dust exposure are of course not changed, as the main source of respirable and inhalable dust is not affected by different engine types.

The increase of the ventilation rate is technically and economically not feasible due to the limited cross-section and the according flow speed in the shafts.

With respect to the explosives a steady optimization has taken place in the last decade and a halving of the NO_2-emission has been achieved as can be qualitatively demonstrated by comparison to older spot measurements. The research efforts are going on, and minor regular improvements can reasonably be expected in the future. Also the use of emulsion explosives was thoroughly investigated, but a broad application can not be taken into account yet.

An important topic for the possible future European threshold limits needs to be stressed. Directive 98/24 EU [14] demands that indicative limit values be set under consideration of the available measurement technique. For underground salt and potash mining this study

describes the available equipment for routine investigation. As the chemoluminescence method can not be routinely applied in these environments it should not be further regarded (see table 3). Also, even under the high and joint exposure levels shown here, no immediate action for new and dramatically lower threshold limits can be deducted from the outcome of this study. The continuous and steady procedure of improvement of the situation which is underway as has been demonstrated should suffice.
Under all circumstances the short time exposure of the miners must be additionally taken into account as well.

Conclusions

In four major measurement campaigns in two large potash mines in Germany the levels of exposure for respirable dust, inhalable dust, diesel particulate matter ("elemental carbon"), nitrogen monoxide, nitrogen dioxide and carbon monoxide has been determined as eight hour shift values and maximum short term (15 minute) exposure values. Exposure has been shown to be high for all of the components especially in the production range of the mines. A differentiation for a single especially relevant component is not possible, as they are highly correlated in all workplaces. Therefore, all dose-response-discussions must take into account that never only one of the components can be made responsible for an eventually occurring respiratory effect.
The campaigns have been performed under conditions which can be considered as representative for the industry and state of the art of exposure control in underground mining. A steady and continuous process of improvement is performed, as described in this paper, however.
For reasons of availability of proper measurement equipment limitations for a possible lowering of indicative limit values of the EU are to be observed. This study describes the state of art of measurement especially of the gaseous components. Future threshold limits will have to take it into account.
The corresponding epidemiological study has shown only very minor effects [10] even in this high exposure situation and the production routines can be regarded as performed according to the state of art in connection with the currently taken measures of industrial hygiene and a well established medical surveillance system in the mines.

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