Identification of work-related exposure to carcinogenic substances in Germany

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Abstract

Occupational exposures to carcinogenic substances like benzo[a]pyrene, ethylenoxide, trichlorethene or butadiene occur in variety fields of industry. The risk strategy for carcinogenic substances in Germany entails a system for assessing hazards due to exposure at the workplace.

Substance-specific concentration values were determined to which a certain risk of contracting work-related cancer as a result of exposure on a day-to-day basis at work is assigned. Below an acceptance concentration, exposure is deemed acceptable; above a tolerance concentration, it is no longer deemed tolerable. Ranges of low, medium and high risk can thus be distinguished and subsequently linked to measures for minimization of the exposure which are not specific to a particular substance.

The data is recorded in the measurement system for exposure asssessment – MGU and is documented in the MEGA exposure database. By comparing the sub-stance-specific acceptance or tolerance concentrations with data from MEGA it is possible to identify workplaces at which employees are exposed to a higher than the accepted risk of contracting occupationally induced cancer.

Evaluations show that over 50% of the values measured in each case for ethylene oxide and trichlorethene are above the respective acceptance concentration. In many cases, the tolerance concentration is exceeded by the 75th or even the 50th percentiles of sectoral groups or groups of working areas. For example, for benzo[a]pyrene, 662 measured values lie above the analytical limit of detection, 246 of these in the medium-risk range, 414 in the high-risk range. Only 132 measured values can be clearly assigned to low-risk exposure. In contrast, for 1,3-butadiene all measured values with just one exception lie below the analytical limit of detection.

Keywords: exposure data, carcinogenic substances, acceptance concentration, tolerance concentration,benzo[a]pyrene, ethylenoxide, trichlorethene, butadiene.

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1 Risk concept for carcinogenic hazardous substances and exposure-risk ratios

Occupational exposures to carcinogenic substances occur in variety fields of industry. The risk strategy for carcinogenic substances in Germany entails a system for assessing hazards due to exposure at the workplace.

Under the German Dangerous Chemicals Ordinance (GefStoffV), employers are obliged to exclude risks to workers' safety and health during activities involving hazardous substances or to reduce such hazards to a minimum (Section 7 (4)). Where an occupational exposure limit (OEL) exists, it can be used as a basis for assessment of the risk presented by a hazardous substance. The GefStoffV defines an OEL as the concentration of a substance in the workplace atmosphere below which acute or chronic harmful effects to the health of workers need not generally be anticipated.

For carcinogenic hazardous substances with a genotoxic mechanism of action however, it is not generally possible to define a threshold value based upon occupational medical and toxicological findings which can serve as a basis for an OEL. An alternative method has been used to define maximum permissible exposure concentrations for these substances where their observance has been considered achievable by means of technical measures for the minimization of exposure (TRK technical reference concentrations). Since amendment of the GefStoffV in 2005, this is however no longer permissible, since limit values must now be set with reference to their impact upon human health. Consequently, a scientifically substantiated system for assessing carcinogenic substances at the workplace is now urgently needed which closes the resulting gap in the regulations. Against this background, the AGS Committee for Hazardous Substances in Germany developed the risk concept which, provided it proves effective in practice, is to be integrated into the GefStoffV [1].

A new aspect of this concept is that the measures required for worker protection are defined with reference to the associated increase in risk of occupationally induced cancer at a given exposure to the carcinogenic substance concerned during the working day. The concept essentially employs two risk limits: the acceptable risk of 4:10,000 (which is expected to be reduced to 4:100,000 in 2018, statistical probabilities: four additional cases of cancer per 1,000/10,000/100,000 workers at 40 years of daily exposure), i.e. the level below which a risk is accepted (low risk), and the tolerable risk of 4:1,000, i.e. the level above which the risk is not tolerated (high risk). These two risk limits form the boundaries of the medium-risk band within which the risk is tolerated but the hazard must be reduced by means of a catalogue of measures. For this concept to be implemented, two atmospheric concentrations corresponding to the two risk limits stated above must be determined for each individual carcinogenic substance. These concentrations are described accordingly as the acceptable and tolerable concentrations. As described in the BekGS 910 announcement on hazardous substances, this can be achieved by the determining of exposure-risk ratios [2]. Data from human epidemiological studies or from animal testing may be used for this purpose. The AGS in Germany has already drawn up exposure-risk ratios for certain substances and has published the corresponding substance-specific concentrations in the BekGS 910 [3].

A comparison follows of the tolerable and acceptable concentrations of some of these substances with exposure data from the MGU Measurement system for exposure assessment of the German Social Accident Insurance Institutions. Exposure data from 2000 to 2010 were evaluated. The acceptable concentrations are abbreviated below as AC I (4:10,000) and AC II (4:100,000, the target value for 2018), the tolerable concentration as TC. Unless specified further, the terms acceptable concentration, acceptable risk and mean risk refer to the currently applicable risk limit of 4:10,000.

1.1 Determining, documentation and evaluation of exposure

The workplace exposure measurement data which are evaluated below were determined and documented in accordance with the criteria of the MGU [4]. The MGU is a measurement system for exposure assessment which has been operated jointly for over four decades by the German statutory accident insurance institutions and the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA). It employs quality-assured procedures. The standards of the MGU are assured by a quality management system that essentially implements the requirements of EN ISO 9001. The test laboratories are operated in accordance with EN ISO 17025, “General requirements for the competence of testing and calibration laboratories”. Descriptions of the measurement methods can be found in [5].

All data recorded in the MGU are stored in the MEGA database of measured data on workplace exposure to hazardous substances. Should discrete values fail to reach the analytical quantification limit (a. q.) of the measurement method used, half of the value is considered during statistical interpretation. The data in the MEGA exposure database can be evaluated statistically according to a range of selection criteria and evaluation strategies. Data collectives for example can be differentiated according to the associated industrial sector or working area. Mean values and percentiles are used below to describe the collectives. At an x^{th} percentile (or x% value), x percent of all available measured data lie below the value concerned, the remainder (100 – x) above it. Should the number of measured values below the analytical quantification limit (a. q.) be greater than the number of measured values represented by this cumulative frequency (x% value), “a. q.” is stated instead of the value in question. Collectives are evaluated only if at least ten measured values from at least five different companies exist.

2 Substances with acceptable and tolerable concentrations

At the time of production of the present publication, the BekGS 910 contains acceptable and tolerable concentrations for nine different substances. In accordance with the TRGS 400 technical rule for hazardous substances No 6.4 Paragraph 5, these concentrations are to be used as metrics for the risk assessment. For four of these substances, Table 1 states the number of workplace measured values with reference to the exposure which are documented in the MEGA database for the data period from 2000 to 2010. The table also shows the distribution of these measured values in percent in the areas of low, medium (light-grey shading) and high (dark-grey shading) risk. Measured values which lie below the relevant analytical quantification limit and have an analytical quantification limit greater than the acceptable concentration cannot be assigned to any risk range. The proportion of these measured values is also stated [6].

Table 1: Measurements from 2000 to 2010 with distribution in the risk band.

	Benzo[a]pyrene	Ethylenoxide	Trichlorethene	1,3-Butadiene
Number of measured data, total	2.193	223	624	257
Number of measured data with high risk (measurement value > tolerance concentration (TC)) in %	20	21.5	40.5	0
Number of measured data with average risk (tolerance concentration ≥ measurement value > acceptance concentration (AC I)) in %	118	35	9.9	0.4
Number of measured data with low risk (measurement value ≤ acceptance concentration (AC I)) in %	6,2	25.6	45.7	0
Not allocated measurement values in %	62	17.9	3.9	99.6

Substances exhibiting a high proportion of measured values with exposures above the acceptable concentration are benzo[a]pyrene, ethylene oxide and trichloroethylene. These substances are evaluated further; depending upon the available data, differentiation is made according to the duration of exposure, sectors of industry and working areas, kind of sampling, and whether a collection facility (exhaust) is present. The table shows percentiles in the medium and high-risk ranges by a light-grey and dark-grey background respectively. For 1,3-butadiene, only a small number of available measured data lie above the acceptable concentration, or the available data are not sufficient. For this reason, the information is limited in these cases to a list of the sectors of industry and working areas for which measurement was performed. The evaluations of the exposure data are preceded by a brief description of the adverse effects to health of the carcinogenic substance concerned together with the concentrations (tolerable concentration, acceptable concentration) of the individual substances [3]. The TRK (technical exposure limit) values cited can be found in the 2004 version of the TRGS 900 technical rules [7]. The associated GHS classifications can be found in the GESTIS substance database [8].

3 Benzo[a]pyrene

3.1 Carcinogenic action and risk limits

Benzo[a]pyrene (B[a]P) is a polycyclic aromatic hydrocarbon (PAH). It is formed by incomplete combustion of carbon compounds, and always constitutes one component within a complex mixture of highly diverse PAHs. The PAHs include several hundred discrete compounds. The carcinogenic action of these mixtures is attributed primarily to the various polycyclic aromates consisting of four to seven rings. B[a]P, being a highly carcinogenic example of these PAHs, served as an indicator substance during risk quantification. The exposure-risk ratio determined for B[a]P therefore relates to the "total PAH". For this purpose, a PAH mixture was employed with a composition similar to the emissions from coking plants, gasworks and aluminium smelters. Like B[a]P, PAHs can be detected ubiquitously; their presence is often in the order of magnitude of the target value (for 2018) of the acceptable concentration of 4:100,000.

Epidemiological findings reveal a clear relationship between occupational B[a]P/PAH exposure and the incidence of lung cancer. In addition, evidence suggests that exposed individuals face a greater risk of contracting bladder and skin tumours. A relationship is however also suspected between occupational B[a]P/PAH exposure and the incidence of other tumour types. Like all PAHs, B[a]P is absorbed by inhalation, dermally and via the gastrointestinal tract.

The tolerable concentration (4:1,000) of 700 ng/m³ and the acceptable concentrations AC I (4:10,000) of 70 ng/m³ and AC II (4:100,000) of 7 ng/m³ are calculated from the exposure-risk ratio based upon the incidence for lung cancer. This represents a substantial reduction in the target maximum exposure quantities compared to the TRK (technical exposure limit) values, now suspended, of 5 µg/m³ for the production and charging of extruded pitch, furnace area of coking plants, and 2 µg/m³ for other areas [3]. Strict rules for the wearing of respiratory protective equipment in critical working areas were and still are in place however in the form of the TRGS 551 technical rules [9].

3.2 Application of the exposure-risk ratio of B[a]P

The overall carcinogenicity associated with exposure to PAHs containing B[a]P is dependent not only upon the concentrations of the discrete substances, but also upon the strength of their carcinogenic action. Acenaphthene, naphthalene, phenanthrene and pyrene are assumed to be much weaker in their action than B[a]P. Conversely, certain dibenzopyrenes are considered to be ten times as carcinogenic [10]. Even minor fluctuations in the concentration of these highly carcinogenic substances could therefore have a substantial influence upon their hazard potential.

At present, 16 PAHs are detected on a specimen holder as standard in the MGU. This enables the relative distribution of the individual PAHs in each sample to be calculated compared to the B[a]P indicator component (provided the measured values lie above the analytical limit of detection). The figure shows

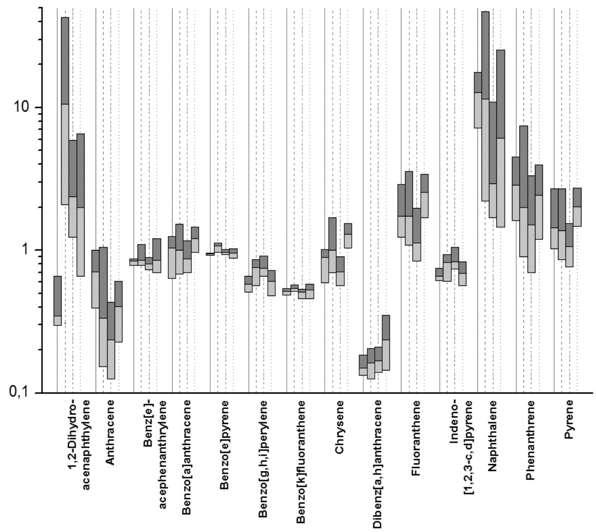

Figure 1: Concentration in relation to benzo[a]pyrene.

the 25th, 50th and 75th percentiles of the concentrations of the measured PAHs as multiples of the B[a]P concentrations measured on the same specimen holders [11].

The evaluation was performed separately for coking plant emissions (unbroken vertical lines) and for the measurements from the three sectors of construction (dots), electrical engineering/precision engineering/optics (dots/dashes) and the stone and ceramics industry (short dashes). It can be seen that the ratio of the atmospheric concentrations of many PAHs to the concentration of B[a]P measured at the same time are in similar orders of magnitude in the different sectors. The ranges are greatest here for substances which generally have a lower strength of action (acenaphthene, naphthalene, phenanthrene, pyrene). For coking plant emissions, it can be seen that for a given B[a]P concentration, the additional proportion of the exposure accounted for by other PAHs is often comparable to or if anything lower than that in other sectors. Accordingly, the available data in no way warrant the conclusion that when B[a]P is used as an indicator substance for the evaluation of PAH exposure in sectors other than coking plants, gasworks and aluminium smelters, the risk for the employees in these sectors is over-evaluated.

3.3 Exposure

3.3.1 Available data

The following descriptions of exposure (Table 2) are based upon the 2,012 shift-based measured values from among the 2,193 measured values in total from the data period under evaluation; the mean duration of exposure at the workplaces at which measurement was performed was 7.99 hours. 662 measured values are above the analytical quantification limit (a. q). 246 of these (12%) in the medium-risk and 414 (20%) in the high-risk range. Only 132 measured values can be assigned clearly to the low-risk exposure band. 1,359 measured values fail to exceed the corresponding analytical quantification limit, which is generally higher than the acceptable concentration (91% of the measured values are below the analytical quantification limit; in only five cases is the analytical quantification limit also higher than the tolerable concentration). The actual proportion of exposure associated with medium risk will therefore be substantially higher. Accordingly, under no circumstances should a harmless exposure level generally be assumed for collectives for which statistical parameters are not stated owing to the high proportion of measured values below the analytical quantification limit.

Table 2: Data of benzo[a]pyrene.

Data set	Number of data	Number of data < a. q.	Arithmetic mean in ng/m³	Geometric meam in ng/m³	50th Percentile in ng/m³	75th Percentile in ng/m³	90th Percentile in ng/m³	95th Percentile in ng/m³
Total	2 021	1 359	4 130	182	a. q. !	360 +	2 700	11 500
Stationary sampling	1 282	1 007	3 500	116	a. q. !	a. q. !	898	2 790
Personal sampling	739	352	5 230	400	200 +	1 380	7 710	23 700
Working area with local exhaust ventilation	733	440	1 750	214	a. q. !	638 +	2 370	5 500
Working area without local exhaust ventilation	718	503	4 990	184	a. q. !	295 +	5 060	23 400

\+ The distribution value is below the largest analytical quantification limit in the data set.
! The number of measured values below the analytical quantification limit (a. q.) is greater than the number for measured values represented by this cumulative frequency value. No concentration is therefore given for this cumulative frequency value.

At 2,700 ng/m³, the 90th percentile of all B[a]P exposure measurements is substantially above the tolerable concentration of 700 ng/m³. The 75th percentile exceeds the acceptable concentration of 70 ng/m³ by over a factor of five. If only the measurements obtained by means of personal sampling are considered, even the 50th percentile, at 200 ng/m³, is in the medium-risk range.

3.3.2 Sectors of industry

Exposures exhibiting statistical parameters in the high-risk range were measured in numerous sectors of industry (Table 3).

Table 3: Benzo[a]pyrene – sector of industry.

Data set	Number of data	Number of data < a. q.	Arithmetic mean in ng/m³	Geometric mean in ng/m³	50th Percentile in ng/m³	75th Percentile in ng/m³	90th Percentile in ng/m³	95th Percentile in ng/m³
Waste disposal and buildings cleaning	145	114	608	74.2	a. q. !	a. q. !	385 +	1 450
Construction sector	319	110	22 100	1 100	885	15 800	47 300	89 400
Chemical industry	48	40	270	103	a. q. !	a. q. !	276 +	544 +
Electrical engineering, precision engineering, optics	198	54	1 890	603	720	1 790	5 180	6 540
Energy development	65	28	1 780	428	440 +	1 210	5 320	7 400
Glas industry	50	50	79.4	78.2	a. q. !	a. q. !	a. q. !	a.q. !
Rubber manufacture	21	21	89.8	71.5	a. q. !	a. q. !	a. q. !	a. q. !
Wood and paper	37	34	180	81.6	a. q. !	a. q. !	a. q. !	270
Plastic industry	28	27	78.9	75.2	a. q. !	a. q. !	a. q. !	a. q. !
Processing metals and mechanical engineering	363	346	830	80.7	a. q. !	a. q. !	a. q. !	a. q. !
Manufacture of metals	261	202	724	113	a. q. !	a. q. !	449	1 400
Shipping	73	73	55.9	38.2	a. q. !	a. q. !	a. q. !	a. q. !
Stone and ceramics industry	338	189	622	190	a. q. !	465	1 600	2 500
Transport	109	107	62.1	45	a. q. !	a. q. !	a. q. !	a. q. !

Explanations, see table 2

The 50th percentile of the values measured in the construction sector and in the sectoral group of electrical engineering, precision engineering and optics lie above the tolerable concentration. In waste disposal and buildings cleaning, energy development, manufacture of metals and the stone and ceramics industry, this is still the case at least for the 95th percentile. Foci of medium- and high-risk exposure are seen in the following sectors: work in contaminated areas (waste disposal and buildings cleaning), redevelopment, corrosion protection, construction of stoves and industrial ovens (construction sector), general working areas in electrical engineering (the sectoral group of electrical engineering, precision engineering and optics), coking plants (energy development), aluminium smelters, foundries and electric steel works (metals production), and the manufacture of refractory goods (stone and ceramics industry).

3.3.3 Working areas

Table 4 shows groups of working areas that can be formed from the available exposure data. Where possible, these groups also have been formed based upon personal measurements, which generally exhibit higher measured values than the undifferentiated collective. It can be seen that workplaces associated with an

Table 4: Benzo[a]pyrene – working area.

Data set	Number of data	Number of data < a. q.	Arithmetic mean in ng/m³	Geometric mean in ng/m³	50th Percentile in ng/m³	75th Percentile in ng/m³	90th Percentile in ng/m³	95th Percentile in ng/m³
Remediation, redevelopment work	104	76	3 210	103	a. q. !	140 +	3 570	11 100
Remediation, redevelopment work (personal sampling)	24	7	12 800	1 310	700	7 160	47 700	65 900
Construction, miscellaneous work	25	3	8 680	1 610	2 010	7 310	24 400	38 500
Preparing for firing	56	12	1 400	543	730	1 400	2 600	3 760
Grinding	36	19	2 420	192	a. q. !	490	6 140	11 200
Grinding personal sampling)	11	7	5 960	351	a. q. !	2 140	23 300	28 200
Casting, smelting	150	128	1 040	104	a. q. !	a. q. !	180 +	1 430
Casting, smelting (personal sampling)	30	22	3 940	185	a. q. !	110 +	4 570	6 260
Hardening	31	31	68.9	65.3	a. q. !	a. q. !	a. q. !	a. q. !
Mixing	104	22	2 350	659	680	2 520	5 440	7 980
Mixing (personal sampling)	69	3	3 330	1 340	1 280	3 960	6 440	10 400
Installation	23	21	66.7	60.8	a. q. !	a. q. !	a. q. !	149 +
Kiln	49	38	307	117	a. q. !	a. q. !	793	1 090
Kiln (personal sampling)	23	15	493	148	a. q. !	295	1 090	1 950
Pressing	190	94	770	257	150 +	905	2 400	4 110
Pressing (personal sampling)	96	23	1 280	560	770	1 300	3 700	5 010
Cleaning	20	15	1 090	271	a. q. !	670 +	2 700	5 580
Cleaning (personal sampling)	12	9	892	278	a. q. !	670 +	1 750	3 340
Forging	26	21	190	108	a. q. !	a. q. !	388	682
Welding	99	99	70.4	67	a. q. !	a. q. !	a. q. !	a. q. !
Impact drilling, chiselling	37	2	10 400	1 960	1 290	15 700	34 200	37 700
Impact drilling, chiselling (personal sampling)	28	2	12 000	2 320	1 430	16 900	35 100	40 500
Control / operating panel	45	21	1400	354	320 +	1070	3640	5360
Control / operating panel (personal sampling)	32	8	1930	636	690	1300	4960	5440
Blasting	100	13	59600	6940	19400	58500	141000	300000
Blasting (personal sampling)	44	10	43100	3510	2500	33300	86400	127000

Explanations, see table 2

elevated health risk frequently involve mechanical tasks: blasting (various methods) in corrosion protection, milling in road construction, impact drilling and chiselling during redevelopment work, and mixing and pressing during the manufacture of electrical carbon and refractory goods. This is also the case for the groups of redevelopment/remediation and of construction/miscellaneous work. Values above the acceptable concentration for the control/operating panel group are measured for the most part in coking plants.

4 Ethylene oxide

4.1 Carcinogenic action and risk limits

Ethylene oxide is distributed well within the body following intake by inhalation. Owing to its genotoxic properties, it is therefore suspected of being able to exert a carcinogenic effect in a number of tissues. The exposure-risk ratio was based upon the formation of lung tumours in experiments performed on mice. The incidence of brain tumours in rats following inhalative administration is also considered relevant to human beings. The tolerance risk (4:1,000) equates to an approximate tolerable concentration of 2 mg/m³ (= 1.1 ppm), the acceptable risk to approximate acceptable concentrations of 0.2 mg/m³ (= 0.11 ppm) for AC I and 0.02 mg/m³ (= 0.01 ppm) for AC II. Like the tolerable concentration, the 2004 TRK value was in the order of 2 mg/m³ [2].

4.2 Exposure values

4.2.1 Available data

Shift-based and non-shift-based values are relevant to ethylene oxide (Table 5).

Table 5: Data of ethylenoxide.

Data set	Number of data	Number of data < a. q.	Arithmetic mean in ng/m³	Geometric mean in ng/m³	50th Percentile in ng/m³	75th Percentile in ng/m³	90th Percentile in ng/m³	95th Percentile in ng/m³
shift: exposure duration ≥ 6 Stunden (average exposure duration 8.083 hours)								
Total	144	55	3.351	0.479	0.4 +	1 +	4	8
Stationary sampling	82	25	2.234	0.533	0.4 +	1.25	4	7.8
Personal sampling	62	30	4.83	0.416	0.3 +	0.9 +	2.48	8.18
Non-shift-based: exposure duration < 6 hours (average exposure duration 1.465 hours)								
Total	76	30	12.30	1.282	1 +	3	9.76	28.8

Explanations, see table 2

Altogether, 144 shift-based values are available, with a mean exposure duration of approximately 8 hours; substantial differences in the measurement results are not observed between static and personal sampling. Even the 50th percentile values are above the acceptable concentration; the 90th percentile values (between 2.5 and 4 mg/m³, depending upon the form of sampling) indicate exposure in the high-risk range. Evaluation of the 76 items of non-shift-based measured data, for which the mean exposure duration was approximately 1.5 hours, reveals that overall the values of the corresponding percentiles are higher and that the tolerable concentration is often exceeded several times. The 90th percentile value for example is almost 10 mg/m³. Atmospheric concentrations of ethylene oxide in this order of magnitude may represent a high risk even at short durations of exposure. In the associated working areas, ethylene oxide is used for sterilization purposes, or is released for example from products (medical devices) in storage which had previously been fumigated at a different location for the purpose of sterilization.

4.2.2 Sectors of industry and working areas

The majority of exposure measurements were performed in plants in the chemical industry and the electrical engineering, precision engineering and optics group of sectors. In both cases, affected working areas are primarily associated with the sterilization and storage of medical devices. For the values measured for sterilization work, the 90th percentile lies above the tolerable concentration; for those for storage work, this is also the case for the 75th percentile. The statistical parameters are summarized in Table 6.

Table 6: Ethylenoxide – sector of industry and working area.

Data set	Number of data	Number of data < a. p.	Arithmetic mean in ng/m³	Geometric Mean in ng/m³	50th Percentile in ng/m³	75th Percentile in ng/m³	90th Percentile in ng/m³	95th Percentile in ng/m
Chemical industry	79	31	3.765	0.418	0.35 +	0.8 +	2.61	6
Electrical engineering, precision engineering, optics	25	3	3.84	1.0464	1	2.3	4.25	24.375
Storage	47	11	3.043	0.885	1	2.6	6.6	8
Sterilization work	41	14	6.485	0.584	0.45 +	0.875 +	2.63	5.86

Explanations, see table 2

5 Trichloroethene

5.1 Carcinogenic action and risk limits

Trichloroethene has a genotoxic effect upon the kidneys. In addition, inducing of liver cancer and non-Hodgkin's lymphoma tumours owing to local genotoxicity cannot be excluded. The risk limits were derived from epidemiological studies and experimental findings on male rats for the incidence of kidney tumours. The tolerance risk (4:1,000) equates to an approximate tolerable concentration of 60 mg/m³, the acceptable risk to approximate acceptable concentrations of 33 mg/m³ for AC I and 3.3 mg/m³ for AC II. The TRK technical reference concentration was 165 mg/m³. In the case of contact of liquid trichloroethene with the skin, the dermal intake path yields a clear contribution to the exposure [3].

5.2 Exposure values

5.2.1 Available data

Altogether, a total of 624 measured values were evaluated (Table 7).

Measurements at workplaces at which the employees were exposed for only part of the time are also available for trichloroethene. Evaluation of these non-shift-based measured values yields a 75th percentile of 285 mg/m³. In

Table 7: Data of trichlorethene.

Data set	Number of data	Number of data < a. p.	Arithmetic mean in ng/m³	Geometric mean in g/m³	50th Percentile in ng/m³	75th Percentile in ng/m³	90th Percentile in ng/m³	95th Percentile in ng/m³
Shift: exposure duration ≥ 6 hours (average exposure duration 7.881 hours)								
Total	469	112	110.001	22.556	24 +	92.75	192.2	308.4
Stationary sampling	240	76	125.778	17.338	17 +	82	177	293
Personal sampling	229	36	93.467	29.718	37 +	94	201.1	339.95
Working area with local exhaust ventilation	273	69	109.973	20.603	21 +	87.25	160	237.1
Working area without local exhaust ventilation	98	23	133.325	28.506	30 +	126.5	283.2	701.8
Non-shift-based: exposure duration < 6 hours (average exposure duration 2,182 hours)								
Total	103	17	282.143	64.564	87	284.5	543.7	1089.35
Exposure peaks (no exposure duration documented)								
Total	52	20	186.288	75.898	78	179	422.2	816

Explanations, see table 2

consideration of the mean exposure duration of around two hours, a high risk cannot be excluded at these and higher concentrations of hazardous substances. Workplaces primarily affected are laboratory workplaces in educational establishments and asphalt laboratories. The same applies to further 52 measured values which were documented as exposure peaks. Of the 469 shift-based measured values (mean exposure duration: 7.881 hours), 112 are below the analytical quantification limit. The 75th percentiles are substantially above the tolerable concentration. The following differentiations by sector of industry and working area relate only to the shift-based measurement data.

5.2.2 Sectors of industry

The 75th percentiles of all sectoral groups (Table 8) are above the acceptable concentration.

Table 8: Trichlorethene – sector of industry.

Data set	Number of data	Number of data < a. q.	Arithmetic mean in mg/m³	Geometric mean in mg/m³	50th Percentile in mg/m³	75th Percentile in mg/m³	90th Percentile in mg/m³	95th Percentile in mg/m³
Construction sector	19	5	325.874	84.662	167.5	386.75	701.8	773
Educational establish-ments	81	4	59.94	26.621	45	75	112.7	228.5
Electrical engineering, precision engineering, optics	18	8	43.275	11.127	6	48.5	116.8	145.6
Rubber manufacture	28	0	274.357	80.649	110	270	773.8	1192.6
Plastic industry	22	4	44.925	9.422	13	39.5	79.8	88.2
Processing metals and mechanical engineering	50	14	38.431	14.723	11	60	98	128.5
Stone and ceramics industry	203	54	75.0667	24.874	21 +	109.25	169.5	256

Explanations, see table 2

The highest exposure levels are found in the construction sector and rubber manufacture. All 81 measurements in educational establishments relate to laboratory workplaces. The focus of the measurement activities in the stone and ceramics industry (173 data records among a total of 203 measured values) lay in asphalt plants and for the most part also concerned measurements in these plants' laboratories.

5.2.3 Working areas

Several groups can be formed from the various working areas (Table 9); laboratory workplaces are significantly more numerous than the other groups.

Table 9: Trichlorethene – working area.

Data set	Number of data	Number of data < a. q.	Arithmetic mean in ng/m³	Geometric mean in ng/m³	50th Percentile in ng/m³	75th Percentile in ng/m³	90th Percentile in ng/m³	95th Percentile in ng/m³
Fat removal system	36	5	82.715	21.741	19	57	114.4	163.2
Fat removal system (personal sampling)	21	4	100.502	19.215	13.5	48.75	112.9	127.35
Gluing	28	2	136.732	31.238	38	123	319.2	642.8
Gluing (personal sampling)	18	2	160.372	30.818	23	111	555.6	751.9
Laboratory (total)	248	52	85.245	29.7	37 +	104	173	304.4
Laboratory (total) (personal sampling	129	20	72.259	32.718	45	91.75	156.8	237.2
Laboratory (asphalt and construction material)	156	42	81.625	26.119	23 +	112	171.4	270.6
Laboratory (asphalt and construction material) (personal sampling)	63	15	66.192	25.587	23.5 +	109.75	154.2	171.85
Laboratory (scientific research)	71	4	61.79	35.831	46.5	75.25	112.5	213.5
Laboratory (scientific research) (personal sampling)	55	2	70.596	43.499	51	83.5	131	231.25
Surface treatment	23	4	215.783	51.00935	53	234.75	686.5	715.3
Surface treatment (personal sampling)	13	4	267.385	45.151	49.5	357.5	699.1	940.95
Cleaning	18	5	22.231	8.342	10	27.5	45.2	94.4

Explanations, see table 2.

The acceptable concentration is exceeded by over 50% of the measurements in the working area groups of gluing, laboratory and surface treatment; over 25% of the measured values in these working areas are also substantially above the tolerable concentration.

6 Butadiene (1, 3-butadiene)

6.1 Carcinogenic action and risk limits

Owing to its genotoxic properties, 1,3-butadiene is carcinogenic. Numerous epidemiological studies exist concerning the carcinogenicity of 1,3-butadiene; these were performed on workers in both the synthetic rubber and monomer production sectors. An increase in the incidence of leukaemia and the formation of malignant lymphatic and hematopoietic tissue was observed among the affected individuals. The exposure-risk ratio was formed based upon leukaemia fatality rates in a North American cohort of workers involved in synthetic rubber production. It reveals substance-specific concentrations of 5 mg/m^3 for the tolerable risk and of 0.5 mg/m^3 and 0.05 mg/m^3 for the acceptable risks I and II respectively. The upper exposure limits governed by the TRK technical reference concentration values were around 34 mg/m^3 for post-polymerization processing and for charging, and around 11 mg/m^3 for other cases [3].

6.2 Exposure values

For the data period under evaluation, 257 measured values were documented for 1,3-butadiene exposure. Of these, only one measured value lay above the analytical quantification limit, which varies according to the duration and volume of sampling and is generally around 1 mg/m^3. Accordingly, it can be concluded for the measured values below the analytical quantification limit only that the tolerable concentration is not exceeded. A medium risk caused by exposure to 1,3-butadiene cannot therefore be excluded. Further evaluation of the measured values would not therefore appear beneficial. Consequently, only the sectors of industry and working areas in which sampling was performed are listed.

- The most common sectors are: the plastics industry (94 – number of measurements); metalworking and machine construction (49); electrical engineering, precision engineering, optics (30); leather industry, textile industry (28).
- The most frequent working areas are: extruders (34); mouldings (46); plastics welding (10); laboratory (9).

7 Discussion

The exposure-risk ratios of the BekGS 910 serve as new assessment metrics for exposure to carcinogenic substances. Comparison of the resulting risk limits with the exposure data from the MEGA database enables workplaces to be identified at which the workers are potentially exposed to a risk higher than the acceptable risk of contracting occupational cancer. Over 50% of the measured values for ethylene oxide and trichloroethene are for example seen to lie above the respective acceptable concentrations (AC I). In many cases, the tolerable concentration (TC) is also exceeded by the 75th percentiles and in some cases even by the 50th percentiles of sector of industry or working area groups.

Exposure to B[a]P and PAHs is of particular relevance in these analyses, since in some cases it arises inadvertently and unmonitored, which makes emission-reducing measures difficult. Even though the acceptable and tolerable concentrations employed for evaluation were explicitly formulated only for emissions at coking plants, gasworks and aluminium smelters, exposure to B[a]P exceeding these concentrations should be taken seriously, since as has been shown, the distribution patterns of PAH exposure in the sectors studied do not differ fundamentally from those at coking plant workplaces. Unfortunately, the atmospheric concentrations were not routinely recorded for the PAHs suggested as having a stronger carcinogenic effect than that of B[a]P (such as various dibenzopyrenes [10]. The reason for this is that the individual compounds analysed as being representative of the substance group are selected with reference to the list of "priority pollutants" [12] of the United States Environmental Protection Agency (US EPA), and that this selection is based upon environmental toxicology. The PAHs relevant to routine measurement are however currently the subject of discussion [10]. Accordingly, until new findings are available, exposure should be reduced and adequate measures taken to protect the workers at workplaces notable for increased B[a]P concentrations.

The examples described here show that the exposure situation and where appropriate also the state of the art must be determined with reference to the industrial sector and in some cases to the specific process. As a general rule, existing measures which contribute to the values remaining below the acceptable concentration should be maintained in accordance with the principle of minimizing exposure. Regular monitoring should be performed in order to prevent the exposure situation from deteriorating [13]. The in-plant measures to be taken in response to exceeding of the acceptable concentration are of key importance in industrial practice. These measures concern the consideration of substitute substances and comprise technical, organizational and occupational medical measures.

With regard to the exposure data presented here, and also in consideration of exposure-risk ratios that have yet to be formulated, it is seen that in many cases, the atmospheric concentrations to be monitored require substantially lower the analytical quantification limits than those routinely achieved at present. This particularly applies to 1,3-butadiene, for which the measured values are almost all below the analytical quantification limit, which in turn however is higher than the acceptable concentration. Over 60% of the measurements of B[a]P, too, cannot be assigned reliably to the low-risk range. The performance of measurements in the range of the acceptable concentration presents problems. Consideration must be given to adjusting existing measurement methods to the requirements, or to developing new methods [13].

Acceptable concentrations may under certain circumstances be so low as to lie below the external background exposure level. Guidance on risk assessment is required in this case. This could ultimately result in background exposure not caused by the employer being deducted for assessment purposes [13].

The procedure to be followed when several substances occur simultaneously at a workplace must also be discussed. Can the effect of substances with the same target organ be linked additively [13]?

For some substances for which exposure-risk ratios exist, few or no exposure data are available. In these cases, it is advisable to examine whether these gaps in the knowledge concerning possible risks to the workers can be closed, for example by the imposition of measurement programmes.

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