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COMMISSION VIII – Health, safety and Environment

Hazardous substances in welding and allied processes

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ABSTRACT

The attached document is published by Berufsgenossenschaft Holz und Metall in 2012 with the title “BGI 593 Hazardous substances in welding and allied processes” in English and is submitted by the author with the scope of the development of an IIW booklet.

Berufsgenossenschaft Holz und Metall

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BGI 593

Hazardous substances in welding and allied processes

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Foreword to the 8. edition

Continuous progress in the development and sophistication of working methods in welding and allied processes, together with the use of new materials, make it necessary to continuously optimise measures for the protection of employees against accidents and damages to health at work and thus strive for an improvement of the occupational exposure situation on the whole.

Modern occupational health and safety does not only mean observation of regulations. The employer shall rather determine and assess the hazard for the employees related with their work and initiate relevant protective measures in accordance with the new law on occupational health and safety. It goes without saying that regulations and rules may be helpful in this context.

In the last four years, further changes on the field of health and safety legislation were made, both on national and on European level. The European Chemicals Act has experienced fundamental modifications which are mainly attributed to two new EC ordinances:

- the REACH Regulation (edition Dec. 2006) concerning the Registration, Evaluation, Authorisation and Restriction of chemical substances
- the CLP Regulation (edition Jan. 2009) concerning the classification, labelling and packaging of substances and mixtures.

As a consequence of this development in Europe and with respect to the handling of hazardous substances, the Ordinance for the protection against hazardous substances (Gefahrstoffverordnung) was adapted and published as edition Nov. 2010.

Besides generally applied basic obligations, further protective measures corresponding to the extent of the hazard are necessary.

By means of information contained in safety data sheets/product information sheets which are of primary importance for risk assessment (Evaluation of information according to GefStoffV), users in companies can implement the requirements of the GefStoffV.

Selection and determination of the required protective measures can be carried out with the help of TRGS 528 “Welding operations” and BG-Information booklet on “Hazardous substances in welding and allies processes”.

When determining protective measures, certain principles shall be taken as basis:

1. Work shall be so designed that hazards to life and health are avoided as far as possible and the residual risk is kept as low as possible.

2. Hazards shall be prevented at source.

3. The state of the art, occupational medicine and hygiene shall be taken into account as well as other firm knowledge in the field of occupational science.

4. Technology, work organisation, other work conditions, social relations and environmental influences shall be regarded as an entity and competently linked.

5. Individual protection measures are subordinate; mechanically operated collective protection measures are of prime importance.

6. Employees in need of special protection, e.g. young persons, shall be considered.

7. Employees shall be given instructions motivating them to behave in the desired way as far

as safety and health are concerned.

During welding, cutting and allied processes, gaseous or particulate substances are formed , which, according to composition, concentration and duration of exposure, present a hazard to the health of the employees (hazardous substances).

The determination of the concentration and the intensity of the effect of dominant hazardous substances (= key components) is a precondition for the assessment of the relevant work condition, for the determination and execution of the required measures and thus for successful health care as a whole.

The purpose of this booklet is:

- to provide information on the generation and the effects of hazardous substances produced during welding and allied processes (thermal cutting, thermal spraying, soldering and brazing etc.),
- to give guidance on the determination of hazardous substances,
- to simplify assessment of the hazard due to hazardous substances,

and

- to show possibilities of how to avoid or reduce the risk resulting from these substances.

1 General information on hazardous substances

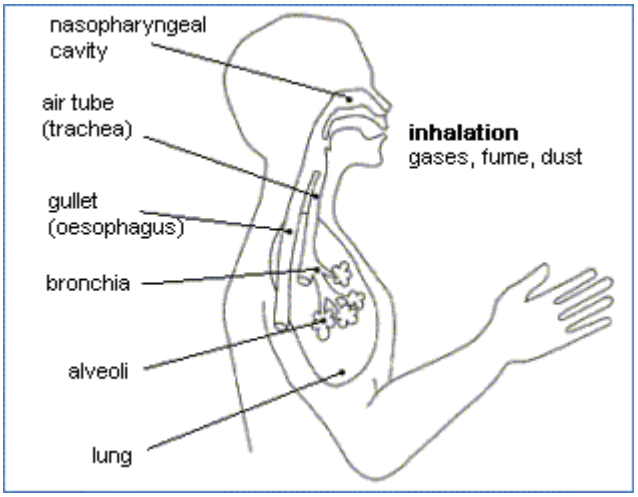
1.1 Definition

Hazardous substances in welding and allied processes are the inhalable/respirable substances generated, which are absorbed by the human body (figure 1-1). At a certain concentration, these substances may cause a hazard to health.

These substances have at least one of the properties listed in § 3, para 1 of the Chemicals' Act under numbers 6 to 14. They thus count among hazardous substances (Gefahrstoffe) within the meaning of the Hazardous Substances Ordinance (Gefahrstoffverordnung (GefStoffV)).

See as well TRGS “Welding operations” (TRGS 528)

Figure 1-1: Absorption of hazardous substances by the human body by inhalation [Source: zH1/223, 1995 Spiegel-Ciobanu, after Ruwac-Industrie- Sauger GmbH, 1993]



1.2 Classification

Hazardous substances generated during welding, cutting and allied processes can be classified according to their occurrence and effects (figure 1-2).

1.2.1 Occurrence

Hazardous substances are generated by welding, cutting and allied processes in the form of gases and/or particles (figure 1-5, page 13). Particulate substances are a dispersed distribution of minute solid particles in air. For all particles present in air, the following fractions are distinguished on the basis of particle size (according to DIN EN 481):

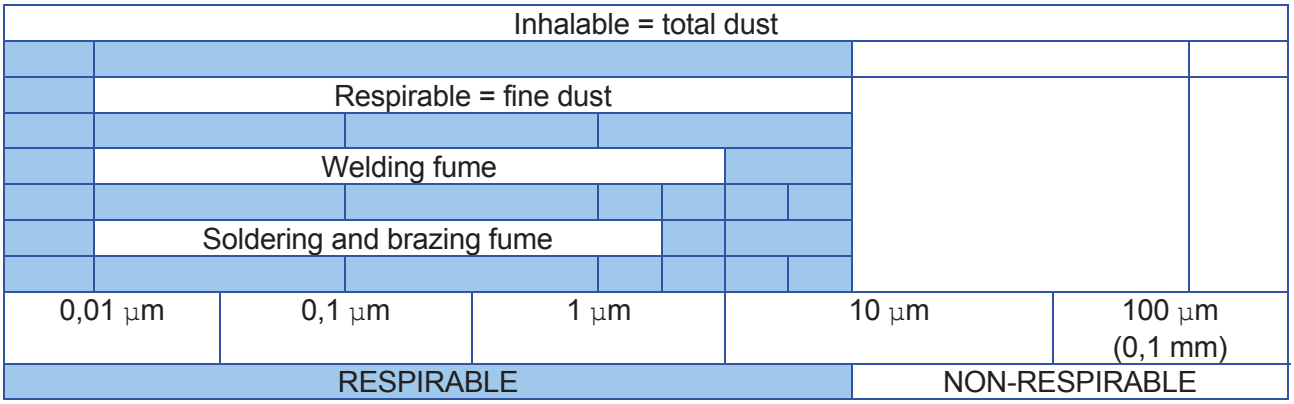
Inhalable fraction - The fraction of particles which is inhaled through mouth and nose into the body; it comprises particle sizes up to and exceeding 100 µm. In the past, this fraction was called "total dust".

Respirable fraction - The fraction of particles capable of penetrating into the alveoli (air sacs); it comprises particle sizes up to 10 µm. In the past, this fraction was called "fine dust".

Particulate substances generated during welding are very fine. In general, they have a diameter of less than 1 µm (in most cases less than 0,1 µm), therefore they are respirable and called "welding fume". Particles in the size range of < 0,1 µm are called “ultrafine particles”.

During thermal cutting and some allied processes, the particulate substances generated are only partially respirable.

Figure 1-2: Classification of particulate hazardous substances in welding and allied processes according to their particle size (occurrence)
[Source: Spiegel-Ciobanu, BGI 593, 2008]



Particle size and morphology (shape)

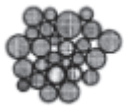
The quantity of particles depends on the combination of the processes and materials used.

Depending on the process group, different particle sizes with different particle morphology result (figure 1-3).

Morphological studies suggest that the individual welding fume particles do not have a homogeneous composition.

Besides primary particles (individual particles) chains and agglomerates are also formed by coagulation (figures 1-4 a and b).

Figure 1-3: Particle size, shape and morphology of welding fume (examples)
[Source: Spiegel-Ciobanu, BGI 593, 2008]

Process	Material	Particle			
		Shape of individual particles	Size of		
			Individual particles (diameter)	Chains (length)	Agglomerates (diameter)
Manual metal arc welding with covered electrodes (MMA)	Cr-Ni steel	ball shaped	up to 50 nm	several µm	up to 500 nm
			up to 400 nm	several µm	
Gas shielded arc welding (MAG/MIG)	Cr-Ni steel	ball shaped	up to 10 nm	up to 100 nm	up to 100 nm
	Aluminium alloys	ball shaped	10 to 50 nm	n.d.	n.d.
			up to 400 nm	n.d.	
					
n.d. = no data µm = micro metres (1 µm = 10^{-3} mm = 10^{-6}m) nm = nano metres (1 nm = 10^{-6} mm = 10^{-9}m)					

Figures 1-4 a and b:
Electron microscope photos of welding fume

Figure 1-4a: Particles of the fume generated during metal inert gas welding under carbon dioxide
[1]

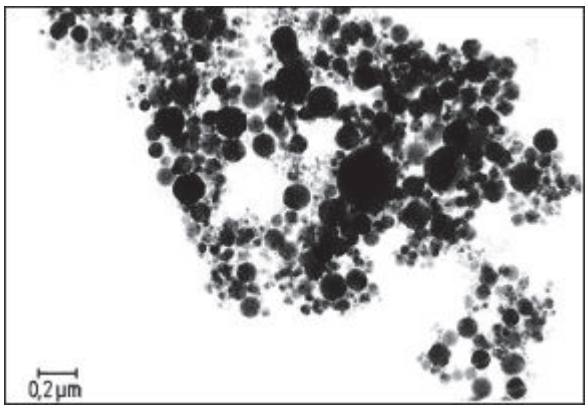
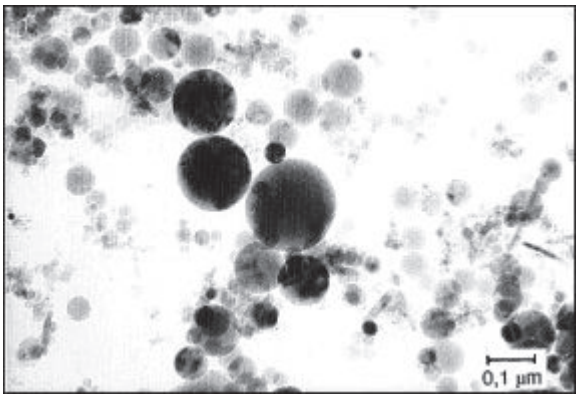


Figure 1-4b: Particles of the fume generated during metal active gas welding of aluminium alloys [3]



1.2.2 Effects

The gaseous and particulate substances generated during welding, cutting and allied processes can be classified according to their effect on the different organs of the human body as follows (figure 1-5 on page 13):

Substances stressing the respiratory tract and the lung - long-term intake of high concentrations may lead to stress of the respiratory tract and the lung. A long-term intake of high concentrations may e.g. lead to diseases of the respiratory tract (in the form of bronchitis up to obstructive bronchitis).

In addition, dust deposits in the lung may occur as siderosis (for iron oxides). Furthermore, at high concentrations, fibrogenous reactions (reproduction of the connective tissue) of the lung may occur (e.g. for aluminium oxide).

Toxic (poisonous) substances - have a toxic effect on the human body, if a certain dose (= amount per unit weight of the body) is exceeded. There is a dose-effect-relationship. Slight poisoning leads to mild health disorders; high concentrations of these substances in the inhaled air may cause very serious poisoning or be lethal.

Toxic substances are, for example, gases such as carbon monoxide, nitrogen oxides (monoxide and dioxide), ozone, as well as oxides of metals such as copper, lead, zinc in the form of fume and dusts.

Carcinogenic (cancer causing) substances - are substances which are known to cause malignant tumors. The risk of cancer generally depends on a number of factors, e.g. genetic predisposition, environmental pollution. There is no automatic effect, but the risk of cancer increases with the dose.

The latent period (interval between first contact and manifestation of the disease) may last for years or decades.

For these substances there is no known threshold value below which the hazard does no longer exist. In many cases these substances have an additional toxic effect.

Carcinogenic substances are listed in TRGS 905 and the “Amendment of the Regulation EC No. 1272/2008 of the European Parliament and of the Council on Classification, Labelling and Packaging of Substances and Mixtures” and classified into categories 1, 2 or 3 according to the

GefStoffV. The Deutsche Forschungsgemeinschaft (DFG; German Research Community), MAK und BAT-Werte-Liste (Maximum Workplace Concentration and Biological Tolerance Value list) 2011, classifies carcinogenic substances as follows:

Category 1
Substances which are known to be carcinogenic for human beings
(sufficient evidence).

Category 2
Substances which should be regarded as being carcinogenic for human beings (well founded presumption).

Category 3
Substances which give cause for concern due to evident or possible cancer-inducing effects, which can, however, not be finally judged due to insufficient information. The classification is preliminary.

A) Substances, for which the preconditions classifying them into categories 4 or 5 are given, for which there is, however, no sufficient information for the deduction of a MAK (maximum workplace concentration) or BAT (biological exposure tolerance) value.

B) There are indications for a carcinogenic effect from in-vitro or animal experiments, which are, however, not sufficient for a classification into another category. If other investigations show that the substance or its metabolites have no genotoxic effects, a MAK or BAT value can be laid down [4].

Category 4
Substances with carcinogenic and genotoxic effect, where a non-genotoxic mechanism of action is predominant and where genotoxic effects play no or only a subordinate role in the observance of the MAK or BAT value. Under these conditions no important contribution to the cancer risk for man has to be anticipated [4].

Category 5
Substances with carcinogenic and genotoxic effect, where no important contribution to the cancer risk for man has to be anticipated, provided the MAK and BAT value is observed [4].

For welding and allied processes, the substances to be considered among those listed in table 1-5 are especially nickel oxides, certain hexavalent chromium compounds, cadmium and its compounds, cobalt and its compounds and beryllium and its compounds [4].

Figure 1-5: Classification of hazardous substances according to their occurrence and effects [Source: Spiegel-Ciobanu, BGI 593, 2008]

Occurrence			Effects		
gaseous	particulate		lung stressing	toxic	carcino-genic
	inhalable	respirable			
nitrogen monoxide				X	
nitrogen dioxide				X	X[1)]
ozone				X	X[1)]
carbon monoxide				X	
phosgene				X	
hydrogen cyanide				X	
formalde-hyde					X[1)]
	aluminium oxide		X		
	iron oxide		X		
	magnesium oxide		X		
	barium compounds			X	
	lead oxide			X	
	fluorides			X	
	copper oxide			X	
	manganese oxide			X	
	molybdenum oxide			X	
	vanadium pentoxide			X	
	zinc oxide			X	
	titanium dioxide			X	X[1)]
	chromium (VI) compounds				X
	nickel oxide				X
	cobalt oxide				X[1)]
	cadmium oxide				X
	beryllium oxide				X

[1)] Suspected to have a carcinogenic effect

1.3 Generation

Hazardous substances generated during welding and allied processes arise from:

- filler materials
- parent materials
- shielding gases
- coatings
- contamination and
- ambient air

at high temperature (of the arc or flame) by physical and/or chemical processes (figure 1-6) such as

- evaporation
- condensation
- oxidation
- decomposition
- pyrolysis and
- combustion.

The type and amount of the hazardous substances generated depend on the material and the process. The chemical composition of the materials used has a direct influence on the chemical composition of the particulate hazardous substances. The processes used affect the generation of gaseous hazardous substances.

Figure 1-6: Generation of hazardous substances (examples)
[Source: Spiegel-Ciobanu, BGI 593, 2008]

Evaporation	metals	
	}	Fe, Cu, Mn, Ni, ..
Condensation	metals	
Oxidation	metals + O_2 = oxides $N_2 + O_2 \rightarrow 2NO$ $NO + 1/2O_2 \rightarrow NO_2$	FeO, Fe_2O_3, CuO, ...
Decomposition	$CO_2 \rightarrow CO + 1/2\ O_2$	
Pyrolysis	organic components $C_xH_y \rightarrow C_{x1}H_{y1}$ CO CH_2O	
Combustion	organic components + O_2 O_2 $C_xH_y \rightarrow CO + H_2O \rightarrow$ $CO_2 + H_2O$	

1.3.1 Gaseous hazardous substances

Carbon monoxide (CO) is generated in critical concentrations during metal active gas welding with carbon dioxide (MAGC) or during metal active gas welding with mixed gases (with a high

concentration of carbon dioxide) by thermal decomposition of carbon dioxide (CO_2).

Furthermore, carbon monoxide is generated during any form of combustion with an inadequate oxygen supply.

Nitrogen oxides (NO_x = NO, NO_2) are generated by oxidation of the atmospheric nitrogen (from the oxygen [O_2] and nitrogen [N_2] in the air) at the edge of the flame or the arc. Nitrogen monoxide is generated at temperatures exceeding 1000 °C. Nitrogen monoxide oxidises to nitrogen dioxide in the air at room temperature.

$$N_2 + O_2 \xrightarrow{T > 1000°C} 2\,NO$$

$$2\,NO + O_2 \xrightarrow{T_{Raum}} 2\,NO_2$$

In oxy-fuel processes (gas welding, flame heating, flame straightening, flame cutting, flame spraying), in plasma cutting with compressed air or nitrogen, and in laser beam cutting with compressed air or nitrogen, the predominant hazardous substances (key components) are nitrogen oxides (primarily nitrogen dioxide).

Ozone (O_3) is generated by ultraviolet radiation from the oxygen in the air, especially during inert gas shielded welding of materials reflecting radiation strongly, such as aluminium and aluminium silicon alloys. The presence of other gases, fume or dust in the air accelerates the decomposition of ozone into oxygen.

$$O_2 \xrightarrow{UV\ radiation} 2O$$
$$O + O_2 \longrightarrow O_3$$
$$O_3 \xrightarrow{gas\ and\ particles} O_2 + O$$

This explains why the ozone concentration is particularly high in processes with low fume generation.

Phosgene ($COCl_2$) is generated in addition to hydrogen chloride (HCl) during heating or by UV-radiation of degreasing agents containing chlorinated hydrocarbons.

Gases from coating materials are generated during welding of workpieces with shop primers (surface coatings preventing corrosion) or with other coatings (paints, lacquers). Depending on the chemical composition of the coatings, not only metal oxides are generated, which are particulate, but also gases, e.g. carbon monoxide (CO), formaldehyde (HCHO), toluylene diisocyanate, hydrogen cyanide (HCN), hydrogen chloride (HCl).

1.3.2 Particulate hazardous substances

Iron oxides (FeO, Fe_2O_3, Fe_3O_4) are generated from filler and parent material during welding and cutting of steels.

Aluminium oxide (Al_2O_3) is generated from filler and parent material during welding and cutting of aluminium base materials.

Manganese oxides (MnO_2, Mn_2O_3, Mn_3O_4, MnO) are generated by any arc process using manganese containing fillers. The concentration of manganese in the welding filler has a direct influence on the concentration of manganese oxide in the welding fume and always leads to enrichment in the welding fume. Analyses during hardfacing with core wires having high

manganese content revealed emission levels of up to 40 % manganese oxides in the welding fume.

Fluorides (CaF_2, KF, NaF, other) are generated from the covering of stick electrodes or from the filling of flux-cored wires when using lime-type coatings or fluxes containing fluorides.

In manual metal arc welding with basic covered unalloyed and low-alloy electrodes, for example, the concentration of fluorides in the welding fume reaches values between 10 % and 20 %.

Barium compounds ($BaCO_3$, BaF_2) are generated during welding with filler materials containing barium from the coating of covered electrodes or from the filling of the flux-cored wires, e.g.:

- electrodes for welding of cast iron and copper alloys,
- high and medium-alloy flux-cored wire electrodes or covered electrodes.

Thus, for example, during welding of cast iron and copper alloys with covered electrodes, the barium content in welding fume reached 40 %.

Potassium oxide, sodium oxide, titanium dioxide (K_2O, Na_2O, TiO_2) are generated from the coating when covered electrodes are used. Titanium dioxide may also occur in the fume of rutile-acid electrodes.

Chromium(VI) compounds
(chromates = Na_2CrO_4, K_2CrO_4, $ZnCrO_4$, etc)
(chromium trioxide = CrO_3)

Hexavalent chromium compounds are generated in critical concentrations when using high-alloy covered electrodes for manual metal arc welding and also when welding with high-alloy flux-cored wires containing chromium.

Chromium(VI) compounds may also occur in repair welding of materials coated with shop primers containing zinc chromates, which were common in the past.

Nickel oxides (NiO, NiO_2, Ni_2O_3) are mainly generated by:

- welding with pure nickel and nickel-base alloys (from the filler material)
- plasma cutting of high-alloy steel containing nickel (from the parent material)
- thermal spraying with nickel-base spraying materials (from the spraying material).

Cadmium oxide (CdO) is generated:

- from the filler material when brazing with brazing alloys containing cadmium,
- during welding and cutting of cadmium coated material.

Beryllium oxide is generated from the parent material used in cutting of material containing beryllium.

Cobalt oxide (CoO) is generated from the:

- filler material used in weld surfacing with alloys containing cobalt,
- spraying material in thermal spraying with cobalt-containing alloys,
- parent material in cutting of steel containing cobalt as an alloying element.

Thorium dioxide (ThO_2) is generated from the thoriated tungsten electrode mainly during TIG welding of aluminium material.

Other metals in the oxide form
Lead oxide, copper oxide, zinc oxide, tin oxide, vanadium pentoxide are generated during processing and manufacturing welding operations (e.g. from metallic coatings during repair welding, from the spraying material during thermal spraying, from the flux/filler material during soldering and brazing) using materials containing the above metals.

Fumes from coating materials
A great number of hazardous substances consisting of organic components are generated by welding and cutting processes from metallic materials having organic base coatings (e.g. paints, lacquers, primers).

1.3.3 Hazardous substances from organic based coating materials

Studies using pyrolysis of organic coatings used in shipbuilding, which are partly still applied today, revealed the decomposition products as shown in figures 1-7a and 1-7b (on pages 18 and 19):

Figure 1-7.a: Recommendations for key components related to decomposition products of organic based coating materials during pyrolysis (t = 350 °C)
[Source: Spiegel-Ciobanu, BGI 593, 2008, following publication Bernt Engström, Finland [5]

Decomposition products (Hazardous substances)	Key components[1] for different coating materials							
	Intermediate coat (binder base)						Finishing coat[2] (binder base)	
	Shop primer[3]			Primer[4]				
	epoxy resin	ethyl silicate	PVB	epoxy resin	chlori-nated rubber	alkyd resin	chlori-nated rubber	alkyd resin
aliphatic alde-hydes[5]			L_2		L_3	L_4	L_3	L_4
aliphatic alcohols (C_2-C_4)[6]	L_4	L_2	L_3	L_4				
aliphatic carboxylic acids						L_2		L_2
alkyle benzenes (C_7-C_8)[7]	L_3			L_3	L_4		L_4	
hygrogen chloride (HCl)					L_1		L_1	
carbon monoxide (CO)	L_2	L_1	L_1	L_2	L_2	L_3	L_2	L_3
phenols (incl. bisphenol A)	L_1			L_1				
phthalic anhydride						L_1		L_1
fine dust (respir. fraction)	L	L	L	L	L	L	L	L

1) L: general key component. L_1, L_2, L_3, L_4: first, second, third, fourth key component.
2) Top coat is also called "finishing paint".
3) The intermediate coat which the manufacturer often applies on semi-finished products (tools, profiles) is called shop primer.
4) The intermediate coat which is applied on finished products by the process operator is called primer.
5) e.g. butyric aldehyde.
6) e.g. butanol
7) e.g. toluene, xylene

Note! From experience it is known that with increasing temperature, the spectrum of decomposition products moves towards low-molecular materials, e.g.:
aliphatic aldehydes ⇒ acrolein, formaldehyde
aliphatic alcohols ⇒ ethanol, methanol
aliphatic carboxylic acids ⇒ acetic acid, formic acid.

Figure 1-7.b: Decomposition products from organic based coating materials during pyrolysis (t = 800 °C)
[Source: Spiegel-Ciobanu, BGI 593, 2008, based on BG supported studies]

Coating (binder base)	Epoxy tar amide addition compound hardened	Poly-urethane tar	Epoxy tar amine hardened	Epoxy resin	Urethane alkyd resin	Epoxy tar	Alkyd resin	Vinyl/epoxy resin (tar containing)
Decomposition products (Hazardous substances)	**Detected substances**			**Key components**				
Acenaphthene	X							
Acetaldehydel								X
Benzaldehyde			X					
Benzene	X	X	X	X	X	X	X	X
Biphenyl	X							
Bisphenol-A	X		X	X		X		
Butene								X
4-tert, Butylphenol			X					
Dibenzofuran	X							
Dihydrobenzopyrane or isomers	X							
Diisocyanatetoluene		X						
Fluorene	X							
Cresols			X					
Methyl-methacrylate								X
α-Methylstyrene (Isopropenylbenzene)			X	X		X		
Dimers of α-Methylstyrene								
Methylnaphthaline	X							
Naphthaline	X							
4-core poly aromatic hydrocarbons (PAH)	X	X						
5-core polyaromatic hydrocarbons	X	X						
Phenantrene /Anthracene	X	X						
Phenol	X		X	X				X
Pyrene	X	X						
Styrene	X		X	X	X	X	X	X
Toluene	X	X	X	X	X	X	X	X
Xylene	X		X					

1.4 Influencing factors

Apart from the processes and materials used, the amount and kind of hazardous substances are also influenced by surface coatings and contaminations as well as by the following factors:

Current, voltage

For identical processes and materials, higher welding currents and welding voltages lead to higher emission rates of hazardous substances.

Type of current

Higher emission rates are observed with a.c. than with d.c.

Diameter of the electrode

Emission of hazardous substances increases with the electrode diameter.

Type of coating

Rutile coated electrodes have the lowest emission rates of hazardous substances while cellulose covered electrodes have the highest.

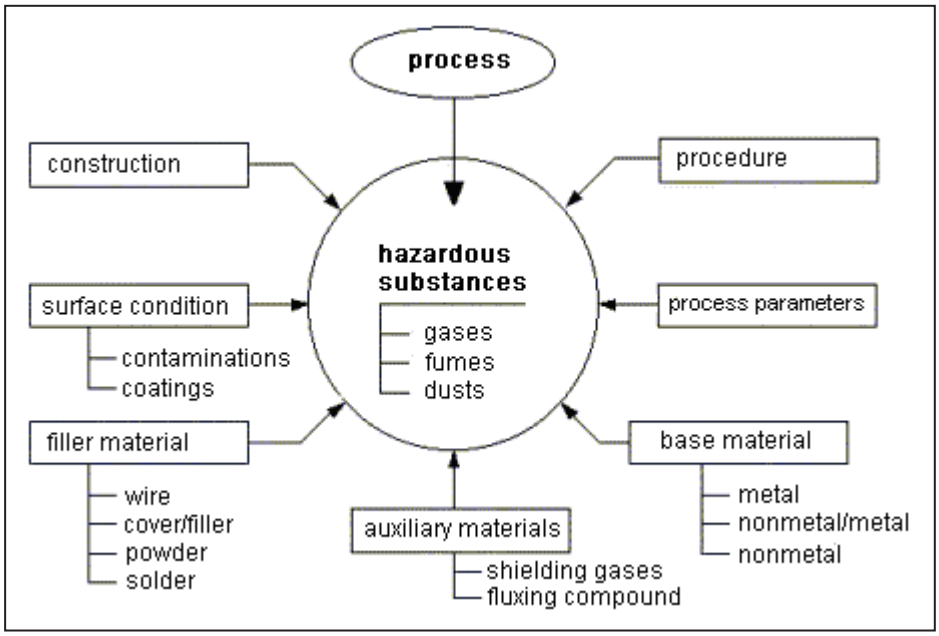
Inclination angle of the electrode

At flat angles of inclination of the electrode, emission rates are lower than at steep inclination angles.

Type of welding

Overlaying produces higher emission rates of hazardous substances than joint welding.

Figure 1-8: Influencing factors



1.5 New Hazardous Substances Ordinance

On 02.12.2010 the actually valid ordinance for the protection against hazardous substances Hazardous Substances Ordinance has come into force.

The most important modifications compared to the former edition of the Hazardous substances Ordinance with impact on welding and allied processes include:

- The **rules for classification, labelling and packaging (§ 4 GefStoffV)** should be adapted to the CLP regulation taking into account transition periods until 1 June 2015.

- **Documentation of the risk assessment (§ 6 GefStoffV)** shall now contain the result of the substitution test as well as the justification for doing without substitution, provided protective measures have to be taken according to §§ 9 or 10.

- Where no test data on the acute-toxic, irritating, skin-sensibilising, mutagenic effect as well as on the effect of repeated exposure are available, the hazardous substances in question shall be deemed to have this effect when making the risk assessment **(§ 6 GefStoffV)**

- **The required protective measures are no longer a result of the former known intrinsic protection classes but result from concrete hazards**. This means that depending on the severity of the hazard different basic obligations (§ 7 GefStoffV) and packages of protective measures (§§ 8 to 15 GefStoffV) are to be applied

- The substitution principle is now a basic obligation even in case of minor hazards (§ 7 GefStoffV)

- When wearing stressed personal protective equipment (PPE), the minimization principle shall be observed (§ 7 GefStoffV)

- Activities with toxic, very toxic, CMR (carcinogenic, mutagenic, reprotoxic) hazardous substances and those sensibilising the respiratory tract shall only be performed by skilled or specially instructed persons (§ 8 GefStoffV)

- Additional protective measures shall be applied according to § 9 GefStoffV (e.g. wearing of PPE) in case the AGW (occupational exposure limit values) or BGW (biological limit values) are exceeded or there is a residual risk for hazardous substances without AGW/BGW or in case of skin-resorptive/skin- or eye damaging hazardous substances where a risk by contact with the skin or eyes is expected (i.e. when §§ 7 and 8 are not sufficient). These protective measures are also necessary for closed systems where substitution is technically not feasible and where an increased hazard of inhalation exists

- For activities involving class 1 or 2 carcinogenic, mutagenic and reprotoxic hazardous substances, other suitable determination methods are possible (§ 10 GefStoffV) in addition to measurements

- Instruction now includes obligatory advice on occupational health and toxicology (§ 14 GefStoffV)

- For activities involving class 1 or 2 carcinogenic, mutagenic or reprotoxic hazardous substances, the employment register shall be kept for 40 years after the end of exposure (§ 14 GefStoffV)

1.6 Mandatory limit values (according to TRGS …)

TRGS 900 "Arbeitsplatzgrenzwerte" (AGW) (Occupational Exposure Limit Values) contains limit values for the time weighted average concentration of substances in air at the workplace with reference to a given period of time.

The AGW determines the concentration of a substance that is not expected to induce acute or chronic detrimental health effects (§ 3 para 6 GefStoffV). They are established by the Ausschuss für Gefahrstoffe (Committee for Hazardous Substances (AGS)).

In order to limit the exposure of welders to hazardous substances at the workplace, i.e. to minimise the effects of these substances on the human body, substance-specific limit values have been established. These limit values are periodically checked on the basis of technical conditions at the workplace and analytical and occupational medical findings.

1.6.1 Occupational exposure limit value (AGW) in accordance with TRGS 900

material

Occupational exposure limit values in their new meaning are conceived such that acute or chronic effects have not to be expected when they are observed,

TRGS 900 "Arbeitsplatzgrenzwerte" contains occupational exposure limit values on the basis of medical findings for numerous substances.

General dust limit value

The general dust limit value distinguishes between:

- the limit value for the respirable fraction (A-Fr) of 3 mg/m³ and
- the limit value for the inhalable fraction (E-Fr) of 10 mg/m³.

If the general dust limit value is observed, impairment to health is unlikely, if pertinent tests ensure that no mutagenic, carcinogenic, fibrogenic or allergenic effects of the dust are to be expected.

The general dust limit value also applies to

- aluminium oxide (except for fume),
- iron oxides,
- magnesium oxide (except for fume) and
- titanium dioxide.

The general dust limit value is specified as a TWA value and shall be applied to hardly soluble or insoluble dusts which cannot be regulated otherwise. The limit value is considered as general upper limit, in addition, the substance specific air limit values shall, however, be complied with as well.

The limit value does not apply to soluble dusts, ultrafine and coarsely dispersed particle fractions.

For dusts with ultrafine particle fractions and for welding activities, the general dust limit is the

upper limit; ultrafine particles shall be specifically considered following availability of relevant assessment criteria (limit values).

If a dust concentration of 3 mg/m³ (A-Fr) cannot be observed at workplaces, preventive occupational medical examinations shall be provided for the employees.

Impairment of the function of respiratory organs by the above dust and fume is the result of long-term effects and mainly depends on the dose of dust, which is determined by the mean fine dust concentration acting over a longer period.

The values shall prevent impairment of the function of the respiratory organs due to a general dust effect.

1.6.2 Biological limit value (Biologischer Grenzwert, BGW) in accordance with TRGS 903

BGW is the limit value for the concentration of a substance, its metabolite (transformation product within the body) or a stress indicator in the corresponding biological material on a toxicological and occupational medical basis at which the health of an employee is not impaired [TRGS 903].

According to this definition, the former MAK-values correspond to the AGW and the former BAT-values to the BGW.

1.6.3 Exposure-risk relationships (Exposition Risiko-Beziehungen, ERB)

[Source: AGS]

According to § 10 para 2 GefStoffV the employer shall ensure that AGW are observed. No AGW or MAK can be derived for most of the carcinogenic substances. Therefore, the AGS (Committee on Hazardous Substances) has elaborated a general concept for determining risk-based limit values for carcinogenic substances. In the “Announcement on Hazardous Substances 910 “Risk figures and exposure-risk relationships in activities involving carcinogenic hazardous substances (Announcement 910)” risk limits for a broad variety of substances and substance-specific concentration value as well as exposure-risk-relationships specified by the AGS are presented. Acceptance and tolerance concentrations are listed for 11 substances (e.g. for benzol or benzo(a)pyrene as key component in certain PAH mixtures) including their justification which stands for a social-political convention. The second part of Announcement 910 describes the scientific methods in the disciplines “toxicology” and “epidemiology” for detecting risks related to substances and for deriving exposure-risk-relationships. With this concept the hazard given by carcinogenic substances at the workplace shall be reduced to a minimum.

The 3 risk intensities (low, medium, high risk) defined by acceptance and tolerance risk were assigned to preventive measure options (classified preventive measure concept for risk reduction).

1.6.3.1 Risk estimation for substances without exposure-risk-relationships (ERB)

[Source: Dr. Nies, Dr. Steinhausen, IFA]

Exposure-risk-relationships (ERB) have already been elaborated by the Committee on Hazardous Substances for certain substances and the associated substance-specific acceptance and tolerance concentrations published in the Announcement on Hazardous Substances 910 - Announcement 910 (see list of substances). However there are still no values available for many substances. As long as no workplace exposure limit exists for a substance, the employer shall

refer to other assessment criteria on his own authority (see TRGS 400).

The estimated concentrations given in the following table may help for assigning the workplace exposures to a risk intensity according to Announcement 910. They have been established following the risk concept of the AGS (Announcement 910) from older unit-risk estimations (IFA Handbook, code number 120120. 42. LfgXII/2002).

Substance	Estimated concentration Risk 4:1000 for 40 years of Workplace concentration (in µg/m³)	Estimated concentration Risk 4:10000 for 40 years of Workplace concentration (in µg/m³)
Chromium (VI)	0.5 to 2	0.05 to 0.2
Cobalt	3.5 to 6	0.35 to 0.6
Nickel (NiO)	90	9
(Extract from IFA table. Dr. Nies, Dr. Steinhausen		

1.7 Limit values of the German Research Community (Deutsche Forschungsgemeinschaft, DFG)

1.7.1 Maximum workplace concentration (Maximale Arbeitsplatzkonzentration, MAK)

These values are established by the senate commission of the DFG and annually published in the MAK list of the Senate Commission. A great number of these values are integrated into the TRGS 900 "Occupational Exposure Limit Values" after discussions in the Committee for Hazardous Substances (AGS).

MAK is the concentration of a substance in the air at the workplace at which the health of the employees is generally not affected. Scientific criteria of health and safety rather than technical and economical possibilities of realisation in practice are taken as basis.

As a general rule, MAK only applies to individual substances (pure substances) and is a long-term value, namely a time-weighted average concentration, normally for a daily eight-hours exposure and an average of 40 hours of work a week (in four-shift companies 42 hours a week for four successive weeks) [4].

Due to the fact that the concentration of different substances at the workplace may vary, short-term values are established in order to be able to evaluate short-term exceeding of the time-weighted average concentration (exposure peaks). They are limited with respect to dose, duration, frequency and time intervals.

Limit values for substance mixtures shall be determined in accordance with TRGS 403 "Bewertung von Stoffgemischen in der Luft am Arbeitsplatz" (Evaluation of substance mixtures in the air at the workplace).

During welding and allied processes, hazardous substances always occur in the form of mixtures. Therefore, the determination of the limit values is very complex. In practice, process- or material-specific key components are therefore often used.

1.7.2 Biological tolerance value for working substances (Biologischer Arbeitsstofftoleranzwert (BAT value))

The BAT value is the concentration of a substance or its metabolites in the body or the resulting deviation of a biological indicator from the norm at which the health of the employee is generally not impaired. BAT values are listed in TRGS 903. The BAT values for some hazardous substances in welding are listed in figure 1-9 (on page 25). BAT values are intended to be maximum values for a healthy individual. The values are specified on the basis of medically and toxicologically founded criteria of health protection. As a rule, BAT values apply to an exposure to single substances.

BAT values can be defined as concentrations, formation or excretion rates (amount/unit of time), generally in the blood and/or urine. Like MAK values, they are normally related to an exposure to a substance of a maximum of 8 hours per day and 40 hours per week.

BAT values are intended to protect health at the workplace, especially within the scope of special preventive medical examinations. They serve as a basis for the assessment of whether the amounts of substances taken in by the organism are critical or non-critical.

Monitoring may be carried out by a periodic quantitative determination of a substance in biological material or a biological parameter. The measurement strategy should take into account the exposure conditions at the workplace. Observation of the BAT values does not imply that monitoring the concentration of hazardous substances in the air can be neglected.

Figure 1-9: Biological limit values (BGW)/biological tolerance values for working materials (BAT)/ biological reference values for working materials for some hazardous substances in welding and allied processes

Hazardous substance	Parameter	BGW/BAT-/BAR-value	Test material	Sampling time
1 Gaseous				
Carbon monoxide (CO)	CO-Hb	5 %	blood (B)	B
2 Particulate				
Aluminium	Aluminium	60 µg/g creatinine	urine (H)	A
Barium compounds, soluble	Barium	10 µg/l (BAR)	Urine (H)	c, b
Cadmium and its compounds	Cadmium	1 µg/l (BAR)	Blood (B)	A
		0.8 µg/l (BAR)	Urine (H)	A
Chromium and its compounds	Total chromium	0.6 µg/l(BAR)	Urine (H)	B
Manganese and its compounds	Manganese	20 µg/l	blood (B)	c, b
Fluorides (inorganic fluorine compounds)	Fluoride	7,0 mg/g creatinine	urine (H)	B
		4,0 mg/g creatinine	urine (H)	D
Lead and its compounds	Lead	400 µg/l (BLW)[1] 70 µg/l (BAR)[2]	blood (B)	A

a - no limit
b - end of exposure or end of shift
c- for long-term exposure following several preceding shifts
d - before next shift
[1] - for women > 45years and for men [2] - for women

1.7.3 Biological guideline values (Biologische Leitwerte, BLW)

The BLW is the quantity of a working material or working material metabolite or the deviation it initiates of a biological indicator from its standard for human beings, which shall be taken as a lead for the protective measure to be taken. Biological guideline values are only given for hazardous substances for which no biological tolerance values (BAT values) on the basis of toxicological and occupational medical findings can be established (i.e. for carcinogenic or cancer suspicious substances of categories 1 to 3 and for non-carcinogenic substances, for which no sufficient toxicological data are available).

For the BLW, generally an exposure to working substances of 8 hours a day and 40 hours a week at maximum over the working life is taken as basis.

When the biological guideline value is observed, the risk of an impairment of health cannot be excluded.

The technical conditions and the technical, hygienic and organisational protective measures shall be so improved that concentrations are reached which are as far below the biological guideline value as possible.

Due to the frame conditions at the workplace it is not necessarily correct to derive the substance concentration in the air at the workplace from the biological value specific for a substance and vice versa in the actual case.

Important influencing factors are physically heavy work, work in constrained posture and temperature at the workplace.

1.7.4 Biological reference values for working material (Biologische Arbeitsstoff-Referenzwerte, BAR)

These values (reference values) describe the stress of a reference population at a given period of time under working material contained in the environment. Persons belonging to the reference population of working age are not occupationally exposed to the working material.

The extent of occupational exposure to a working material can be obtained by comparison between bio-monitoring, measured in occupationally exposed persons, and the biological reference value for the working material, measured in the reference group.

1.7.5 Exposure equivalents for carcinogenic working substances (Expositionsäquivalente für krebserzeugende Arbeitsstoffe (EKA))

For some carcinogenic substances - such as alkali chromates, cobalt, nickel and nickel compounds - correlations can be established between the concentration of hazardous substances in the air and in the biological material (blood or urine). These correlations are called exposure equivalents (figure 1-10).

Figure 1-10: Exposure equivalents for carcinogenic working substances (EKA) for some hazardous substances in welding and allied processes

Alkali chromates Cr(IV)	**Air CrO_3 (mg/m³)**	**Sampling time: for long-term exposure after several preceding shifts**	**Sampling time: end of exposure or end of shift**
		Erythrocytes[1]) Chromium (µg/l whole blood)	**Urine[2]) Chromium (µg/l)**
	0,03 0,05 0,08 0,10	9 17 25 35	12 20 30 40
Cobalt and its compounds	**Air Cobalt (mg/m³)**	**Sampling time: not limit Urine/Cobalt (µg/l)**	
	0.010 0,025 0,05 0,10 0,50	6 15 30 60 300	
Hydrazine	**Air Hydrazine (mg/m³)**	**Sampling time: End of exposure or end of shift Urine µg Hydrazine/ g Creatinine**	**Plasma Hydrazine (µg/l)**
	0,013 0,026 0,065 0,104 0,130	35 70 200 300 380	27 55 160 270 340
Nickel (Nickel metal, -oxide, -carbonate, -sulphide, sulphide ores)	**Air Nickel (mg/m³)**	**Sampling time: For long-term exposure after several preceding shifts Urine Nickel (µg/l)**	
	0,10 0,30 0,50	15 30 45	

[1]) not applicable to welding fume exposure [2]) also applicable to welding fume exposure

1.8 EU values

EU values are limits set by the European Union (obligatory limit and indicative values) for occupational exposure. In analogy to the AGW, MAK or old TRK values, these values are time-weighted average concentrations for an 8 hours exposure.

In figures 1-11 a and 1-11 b and 1-12 a and 1-12 b on pages 29 - 37, the hazardous substances in welding and allied processes, their limit values and classifications are given in tabular form.

1.9 Limit values according to the radiation protection ordinance

(Strahlenschutzverordnung, StrlSchV)

The StrlSchV of 1 August 2001 specifies new limit values for the handling of radioactive substances

The following dose limit values apply:

- 6 mSv for persons not occupationally exposed to radiation during “work activities”,
- 20 mSv for persons occupationally exposed to radiation,
- 400 mSv for the total occupation related dose,
- 6 mSv for persons under the age of 18.

Technical guidance concentration (Technische Richtkonzentrationen, TRK)

The TRK values were deleted from TRGS 900 in accordance with the new GefStoffV. As in practice the old definition of the TRK still is of some relevance, it is described at this point.

According to the old GefStoffV, TRK was the concentration of a substance in air at the workplace, which could be attained by the state of the art. Generally, TRK are time weighted average concentrations for a daily 8 hour exposure and an average work schedule of 40 hours a week. The limitation of the upper deviations from the mean value was as well determined by short-term values. TRK were only established for substances, for which no toxicologically and occupational medically founded MAK could be established. TRK were also given for carcinogenic substances; when observing them at the workplace the risk of damage to health was reduced but not completely excluded.

Figure 1-11a: Hazardous substances in welding and allied processes, limit values, classification, status January 2003
[Source: Spiegel-Ciobanu following editions 2003 of [4] and [10]

1 Gaseous hazardous substances												
I			II						III	IV	V
Hazardous substance		Classification K	Air limit value						Value in biol. mat.	G-Prin-ciples	Relev. Regul./ Literature
			mg/m³	ml/m³	Type (origin)	Peak-limit/ Categ.	Short-time value level	Short-time value durat.[1)]			
1.1 Toxic											
Carbon monoxide	(CO)		35	30	MAK (DFG)	2	2 · MAK	15 min, MiW	BAT	7	
Carbon dioxide	(CO_2)		9100	5000	MAK (DFG, EU)	4	4 · MAK	15 min, MiW			
Phosgene (Carbonyl chloride)	($COCl_2$)		0,082	0,02	MAK (DFG)	= 1 =					ZH1/298
Nitrogen monoxide	(NO)		30	25	MAK (EU)						
Nitrogen dioxide	(NO_2)		9,5	5	MAK (DFG)	=1=	MAK				ZH1/214
1.2 Carcinogenic											
Formaldehyde	(CH_2O)	3	0,62	0,5	TRK (AGS)	=1=	TRK				TRGS 513, 607 ZH1/296
Ozone	(O_3)	3	0,2	0,1	MAK (DFG)	=1=	MAK				
[1)] The duration of increased exposure shall not exceed a total of one hour within a shift											

Figure 1-11b: Hazardous substances in welding and allied processes, limit values, classification, status January 2003
[Source: Spiegel-Ciobanu following editions 2003 of [4] and [10]

2 Particulate hazardous substances										
I		**II**						**III**	**IV**	**V**
Hazardous substance	**Classifi-cation K**	**Air limit value**						**Value in biol. mat.**	**G-Prin-ciples**	**Relev. Regul./ Literature**
		mg/m³	**ml/m³**	**Type (origin)**	**Peak limit/ Categ.**	**Short-time value level**	**Short-time value durat.[1)]**			
2.1 Lung-stressing[2])										
Aluminium oxide		3A/6A[2])		MAK (DFG)	4	4 MAK	15 min, MiW	BAT		
Iron oxides		3A/6A[2])		MAK (DFG)	4	4 MAK	15 min, MiW			
Magnesium oxide		3A/6A[2])		MAK (DFG)	4	4 MAK	15 min, MiW			
Molybdenum compounds, insoluble (calculated as Mo)		15 E[2])		MAK (DFG)	4	4 MAK	15 min, MiW			
Titanium dioxide[9)]		3A/6A[2])		MAK (DFG)	4	4 MAK	15 min, MiW			
2.2 Toxic										
Barium compounds, soluble		0,5 E		MAK (DFG, EU)	4	4 MAK	15 min, MiW			
Lead oxide		0,1 E		MAK (DFG)	4	4 MAK	15 min, MiW	BAT		
Calcium oxide		5 E		MAK (DFG)	= 1 =	MAK	15 min, MiW			
Fluorides (calculated as fluorine)		2,5 E		MAK (DFG)	4	4 MAK	15 min, MiW	BAT		ZH 1/161
Copper oxide		0,1 A		MAK (DFG)	4	4 MAK	15 min, MiW			
Manganese oxides		0,5 E		MAK (DFG)	4	4 MAK	15 min, MiW			
Molybdenum compounds, soluble (calculated as Mo)		5 E		MAK (DFG)	4	4 MAK	15 min, MiW			
Silver compounds		0,01 E		MAK (EU)						
Vanadium pentoxide		0,05 A		MAK (DFG)	4	4 MAK	15 min, MiW			
Zinc oxide		5 A		MAK (DFG)	4	4 MAK	15 min, MiW			
Tin compounds, inorganic		2 E		MAK (DFG, EU)	4	4 MAK	15 min, MiW			

1) The duration of increased exposure shall not exceed a total of one hour within a shift

2) see clause 1.5 Limit values, general dust limit value, BGI 593

2 Particulate hazardous substances										
I		II						III	IV	V
Hazardous substance	Classifi-cation K	Air limit value						Value in biol. mat.	G-Prin-ciples	Relev. Regul./ Literature
		mg/m³	ml/m³	Type (origin)	Peak limit/ Categ.	Short-time value level	Short-time value durat.[1]			
2.3 Carcinogenic										
Beryllium oxide	2	0,002 E		TRK (AGS)	4	4 TRK	15 min, MiW		40	
Cadmium oxide	2	0,03 E[2]/ 0,015 E[3]		TRK (AGS)	4	4 TRK	15 min, MiW		32	ZH 1/136 Bundesarbeits-blatt (1991), Nr. 9, S. 76
Chromium(VI) compounds including lead chromate (in the form of dusts/aerosols excluding those practically insoluble in water, such as barium chromate)	2[4]	0,1 E[5]/ 0,05 E[6]		TRK (AGS)	4	4 TRK	15 min, MiW	EKA[7]	15	TRGS 602, 613 ZH 1/88 BIA-Arbeitsm. KZ 1010
Cobalt oxide	3[8]	0,1 E		TRK (AGS)	4	4 TRK	15 min, MiW	EKA	40	
Nickel oxide	1	0,5 E		TRK (AGS)	4	4 TRK	15 min, MiW	EKA	38	

1) The duration of increased exposure shall not exceed a total of 1 hour per shift

2) for welding of cadmium containing alloys

3) for all other processes

4) Lead chromate: classification = 3; chromium trioxide: classification = 1; zinc chromate: classification = 1; zinc potassium chromate classification = 1; strontium chromate: classification =2

5) for manual metal arc welding with covered electrodes

6) for all other processes

7) for alkali chromates

8) classification according to lists B and C (see explanations to column “classification”)

Key to symbols

A ***Key to column "Air limit values" (see TRGS 900)***

A	Respirable fraction (former fine dust)
E	Inhalable fraction (former total dust)
MAK	Maximum occupational exposure concentration
TRK	Technical guidance (reference) concentration
(AGS)	Ausschuß für Gefahrstoffe (Committee for hazardous substances)
(DFG)	Senatskommission der Deutschen Forschungsgemeinschaft (Senate Commision of the German Research Council)
(EU)	Commission of the European Union
MiW	Mean value

B ***Key to column "Classification" (see TRGS 905)***

K Classification as carcinogenic (see lists A, B and C)
Category 1, 2 or 3 according to Annex I GefStoffV.

- List A: Here, all substances classified by the European Union (EU) and all substances listed in §§ 15a and 35 of the GefStoffV are given.
- List B: The substances given here have not yet been classified by the EU
- List C: Here, all substances are given, the national evaluation by the AGS of which differs from the EU classification. A modification of the legal classification by the EU is aspired for these substances

C ***Key to assignment in column "Type (origin)"***

Comparison of classifications of carcinogenic substances DFG - TRGS 900

DFG	TRGS 900	
III	**K**	Certain special substance groups (carcinogens), listed in Notice 28 of the Senate Commission in paragraph III "Carcinogenic working substances" and/or in Directive 90/394/EWG "Cancer Directive" (Article 2, letter C).
III A1	**1**	Working substances clearly identified as carcinogenic, which are known to be capable of causing malignant tumors in human beings.
III A2	**2**	Working substances clearly identified as carcinogenic, which up to now, according to the Commission, have only proved to be carcinogenic in animal experiments under conditions comparable to a possible human exposure at the workplace or from which comparability can be derived.
III B	**3**	Substances with well-founded suspicion of being potentially carcinogenic.

D ***Key to column "Value in biological material"***

BAT	Biological tolerance values for working substances
EKA	Exposure equivalents for carcinogenic working substances

Figure 1-12a: Hazardous substances in welding and allied processes, limit values, classification, ***status May 2012*** *in accordance with the new GefStoffV*

[Source: Spiegel-Ciobanu following TRGS 900 Ed. 2012 and MAK- and BAT-value list of DFG Ed. 2011]

1 Gaseous hazardous substances											
I			**II**						**III**	**IV**	**V**
Hazardous substance		**Classification K**	**Air limit value (AGW, MAK)**						**Value in biol. mat.**	**G-Prin-ciples**	**Relev. Regul./ Literature**
			mg/m³	**ml/m³**	**Type (origin)**	**Peak-limit/ Categ.[2] Excess factor**	**Short-time value level[3]**	**Short-time value durat.[1]**			
1.1 Toxic											
Carbon monoxide	(CO)		35	30	AGW (DFG)	(II)1	1 · AGW	15 min, MiW	BAT	7	
Carbon dioxide	(CO_2)		9100	5000	AGW (DFG, EU)	(II)2	2 · AGW	15 min, MiW			
Phosgene (Carbonyl chloride)	($COCl_2$)		0.41	0,02	MAK (DFG)	(I)2	2 · AGW	15 min, MiW			BGI 615
Nitrogen monoxide	(NO)		0.63				2 · MAK	15 min, MiW			
1.2 Carcinogenic											
Formaldehyde	(CH_2O)	4 (DFG)	0.37	0.3	MAK (DFG)	(I)2	2 · MAK	15 min, MiW			TRGS 513, 607, BGI 614
Ozone	(O_3)	3 B (DFG)			(DFG)						
Nitrogen dioxide	(NO_2)	3 B (DFG)	0.95	0.5	MAK (DFG)	(I)1	2 · MAK	15 min, MiW			BGI 591

Extract from MAK- and BAT-value list 2011 of DFG and TRGS 900:

[1]) The duration of increased exposure shall not exceed a total of one hour within a shift

[2]) Category I Substances whose local effect determines the limit value or respiratory sensitive substances

Category II Resorptively acting substances

Excess factor: basic value for category I, generally factor 1; basic value for category 2, generally factor 2:

[3]) Short-time value concentration results from the product of the workplace limit value and the excess factor.

In any case the time-weighted average shall be observed. As a total four short-time value phases are allowed during one shift [Source: TRGS 900]

Figure 1-12b: Hazardous substances in welding and allied processes, limit values, classification, ***status May*** *2012 – in accordance with the new GefStoffV*

[Source: Spiegel-Ciobanu following TRGS 900 Ed. 2012 and MAK- and BAT-value list of DFG Ed. 2011]

2 Particulate hazardous substances										
I		**II**						**III**	**IV**	**V**
Hazardous substance	**Classifi-cation K**	**Air limit value (AGW, MAK)**						**Value in biol. mat.**	**G-Prin-ciples**	**Relev. Regul./ Literature**
		mg/m³	**ml/m³**	**Type (origin)**	**Peak limit/ Categ.[2] Excess factor**	**Short-time value level[3]**	**Short-time value durat.[1]**			
2.1 Lung-stressing[4]										
Aluminium oxide		3A[5]/10E[4])		AGW (AGS)	(II)2	2 AGW	15 min, MiW	BAT	7	
Iron oxides	3B (DFG)[7]	3A/10E[4])		AGW (AGS)	(II)2	2 AGW	15 min, MiW			
Magnesium oxide		3A/10E[4])		AGW (AGS)	(II)2	2 AGW	15 min, MiW			
Titanium dioxide[9]	3A (DFG)[8]	3A/10E[4])		AGW (AGS)	(II)2	2 AGW	15 min, MiW			
2.2 Toxic										
Barium compounds, soluble		0,5 E		AGW (EU)	(I)1	1 AGW	15 min, MiW	BAR		
Chromium (III) compounds		2,0 E		AGW (EU)	(I)1	1 AGW	15 min, MiW			
Fluorides (calculated as fluorine)		1,0 E		AGW (AGS)	(II)4	4 AGW	15 min, MiW	BAT		BGI 576
Copper oxide		0,1 A		MAK (DFG)	(II)2	2 MAK	15 min, MiW			
Manganese oxides		0,5 E[6]		AGW (DFG)				BAR		
Silver compounds, inorganic		0,01 E		AGW (DFG, EU)	(I)2	2 AGW	15 min, MiW			
Zinc oxide[3]		O,1 A / 2 E		MAK (DFG)	(I)4 /(I)2	4 MAK/ 2 MAK	15 min, MiW			

Extract from MAK- and BAT-value list 2011 of DFG and TRGS 900:

[1]) The duration of increased exposure shall not exceed a total of one hour within a shift

[2]) Category I Substances whose local effect determines the limit value or respiratory sensitive substances

Category II Resorptively acting substances

Excess factor: basic value for category I, generally factor 1; basic value for category 2, generally factor 2:

[3]) Short-time value concentration results from the product of the workplace limit value and the excess factor.

2	Particulate hazardous substances										
I		II						III	IV	V	
Hazardous substance	Classifi-cation K	Air limit value (AGW, MAK)						Value in biol. mat.	G-Prin-ciples	Relev. Regul./ Literature	
		mg/m³	ml/m³	Type (origin)	Peak limit/ Categ.[2] Excess factor	Short-time value level[3]	Short-time value durat.[1]				
	In any case the time-weighted average shall be observed. As a total four short-time value phases are allowed during one shift [Source: TRGS 900]										
4)	see clause 1.5 Limit values, general dust limit value, BGI 593										
5)	The MAK- and BAT-value list 2001 of DFG gives a MAK value for the inhalable fraction of dust of 0,3 mg/m³ for dusts having a density of 1 g/cm³ .										
6)	The MAK- and BAT-value list 2001 of DFG gives MAK values: 0,02 mg/m³ for the inhalable fraction and 0, 2 mg/m³ for the respirable faction of dust. Ultrafine particles are excluded.										
7)	Excluded are iron oxides biologically not available.										
8)	Respirable faction; ultrafine particles are excluded										

Figure 1-12b continued: **Status January 2006**

2 Particulate hazardous substances											
I		II						III	IV	V	
Hazardous substance	Classifi-cation K	Air limit value						Value in biol. mat.	G-Prin-ciples	Relev. Regul./ Literature	
		mg/m³	ml/m³	Type (origin)	Peak limit/ Categ.[2] Excess factor	Short-time value level[3]	Short-time value durat.[1]				
2.3 Carcinogenic											
Beryllium oxide	1[2]			(DFG)				EKA BAR			
Lead oxide	2			(DFG)				BLW	Lead oxide		
Cadmium oxide	1[3]			(DFG)				BLW BAR	32		
Chromium(VI) compounds	1 1A[4] 1B[5]			(DFG) (EU) (EU)				EKA[6]	15	TRGS 602, 613	
Cobalt oxide	2[3]			(DFG)				EKA	40		
Nickel oxide	1			(DFG)				EKA	48		

[1]) The duration of increased exposure shall not exceed a total of one hour within a shift

[2]) Hazard of sensibilising the respiratory tract and the skin

[3]) Hazard if skin resorption

[4]) For zinc chromate, zinc potassium chromate, chromium trioxide according to the amendment of 20.01.2011 of the Regulation (CE) No. 1272/2008 of the EU. This corresponds to the former classification according to EC Directive RL 67/548/EEC, category 1 as carcinogenic.

[5]) Sodium-/potassium chromate and sodium- /potassium dichromate according to the amendment of 20.01.2011 of the Regulation (CE) No. 1272/2008 of the EU. This corresponds to the former classification according to EC Directive RL 67/548/EEC, category 2 as carcinogenic.

[6]) For alkali chromates.

Key to symbols

A ***Key to column "Air limit values" (see TRGS 900)***

C ***Key to assignment in column "Type (origin)"***
See Clause 1.2.2 of this BGI

	A	Respirable fraction (former fine dust)
	E	Inhalable fraction (former total dust)
	MAK	Maximum occupational exposure concentration
	TRK	Technical guidance (reference) concentration
	(AGS)	Ausschuß für Gefahrstoffe (Committee for hazardous substances)
	(DFG)	Senatskommission der Deutschen Forschungsgemeinschaft (Senate Commision of the German Research Council)
	(EU)	Commission of the European Union
	MiW	Mean value
B	***Key to column "Classification" (see TRGS 905)***	
	K	Classification as carcinogenic (see lists A, B and C) Category 1, 2 or 3 according to Annex I GefStoffV. List A: Here, all substances classified by the European Union (EU) and all substances listed in §§ 15a and 35 of the GefStoffV are given. List B: The substances given here have not yet been classified by the EU List C: Here, all substances are given, the national evaluation by the AGS of which differs from the EU classification. A modification of the legal classification by the EU is aspired for these substances
D	***Key to column "Value in biological material"***	
	See clause 1.7 of this BGI	

1.10 Test methods

Reliable evidence of the risk which the welder encounters at the workplace through hazardous substances can be obtained from application of different test methods, primarily:

- laboratory emission measurements
- workplace exposure measurements - measurements of concentrations
- analyses of biological material
- epidemiological studies.

Laboratory emission measurements determine the amount per unit time (mg/s) and the chemical composition of emitted hazardous substances for several processes and materials using the fume box method.
Examples see Figure 1-13.

Thus, basic data are obtained for comparison of different processes and materials and for the evaluation of the hazard to the welder (see clause 5). Emission measurements also provide a basis for calculating ventilation systems and for other necessary protective measures.

As an additional example for the results of emission measurements, see also figure 3-1 on page 37 "Analysis of welding fume generated by manual metal arc welding with covered electrodes, according to DIN 1913".

Figure 1-13: Results of emission measurements (examples)
[Source: Spiegel-Ciobanu, analysis of research results according to [1],[2],[3],[6],[7],[8],[9],[11].]

Example 1: Emissions during different welding processes from high-alloy chromium-nickel steel

Welding process	**Emission rate (mg/s)**				
	Welding fume	**Total chromium**	**Chromium(VI)-compounds**	**Nickel oxide**	**Manganese oxide**
MMA[1)]	2 - 16	0,04 - 1,3	0,01 - 1,2	0,03 - 0,5	0,04 - 1,1
MAG[2)]	1,5 - 8	0,1 - 1,3	0 - 0,05	0,05 - 0,6	0,1 - 1,2
Laser beam welding	1,3 - 2,0	0,16 - 0,26	0,003 - 0,007	0,05 - 0,08	0,09 - 0,16

[1)] MMA = manual metal arc welding with covered electrodes [2)] MAG = metal active gas welding

Example 2: Emissions during different welding processes from unalloyed and low-alloy steel

Welding process		Emission rate in mg/s	
Manual metal arc welding with covered electrodes (MMA)			
MAG	with solid wire		
	with flux-cored wire and shielding gas	6,7 ÷ 54	
	with selfshielded flux-cored wire	up to 97	

Example 3: Emissions during MIG welding with different high nickel filler materials and different shielding gases

Filler material	Shielding gases	Emission rate in mg/s

		Welding fume	Nickel	Total chromium	Molybdenum	Copper	Titanium
SG-NiTi4	Four substances gas[1)]	2,82	1,94	--	--	--	0,03
SG-NiCr23Mo16	Four substances gas[1)]	2,23	0,98	0,26	0,19	--	--
SG-CuNi30Fe	Four substances gas[1)]	3,58	0,67	--	--	2,2	--
SG-NiMo28Cr	Four substances gas[1)]	1,97	0,99	--	0,1	--	--
	Argon	1.05	0,53	--	0,05	--	--
	Two substances gas[2)]	1,57	0,88	--	0,18	--	--
	Three substances gas[3)]	1,02	0,53	--	0,11	--	--

[1)] Four substances gas: 0,05% CO_2; 30% He; 2% H^2; Rest Ar
[2)] Two substances gas: 50% He; 50% Ar;
[3)] Three substances gas: 0,05 CO2; 50% He, Rest Ar

Workplace exposure measurements are intended to show the real external exposure of the welder. Sampling takes place in the welder's breathing zone. Details on the quantitative and qualitative evaluation of the sample are described in clause 6.1 (Measuring methods for gaseous substances) and in clause 6.2 (Measuring methods for particulate substances). **The measured concentrations** (mg/m³) are compared with the relevant limit values and determine the protective measures to be taken. The accuracy of the measurement primarily depends on whether the sampling is actually effected within the breathing zone. There are a number of approaches in this field at present, with corresponding specifications for measuring techniques (sampling).

Analyses of biological material, i.e. body fluids (urine, blood) taken from the welder, show the concentrations of critical substances they contain. These values give information on the level of the welder's internal stress caused by exposure at the workplace and are compared with normal values or BAT values.

Epidemiological studies are carried out to clarify the frequency of diseases and mortality in different groups of persons, e.g. to clarify the welder’s pulmonary cancer risk. Epidemiological studies are based on comparisons between "test persons (probands)" (e.g. welders) and a control group (employees not involved in welding activities and hence considered to be unexposed).

Many epidemiological studies have been carried out with regard to health hazards caused by the exposure of arc welders to chromium and nickel.

They revealed a slightly increased cancer risk for manual metal arc welders working with stainless steel.

However, recent epidemiological studies also indicate a slightly increased risk of pulmonary cancer for arc welders in general.

2 Effects of specific hazardous substances

2.1 Toxic gaseous hazardous substances

2.1.1 Carbon monoxide (CO)

Very poisonous, odourless gas. In higher concentrations the oxygen transport in the blood is impeded by the great affinity of carbon monoxide to haemoglobin (haemoglobin is necessary for transporting oxygen in the body). The result is a lack of oxygen in the tissues.

Concerning pregnancy, carbon monoxide is assigned to group B, i.e. according to available information a reprotoxic effect is expected even when the MAK and BAT value is observed.

Dizziness, lassitude and head ache occur at a concentration of 150 ml/m³ of CO in the breathing zone. A level of 700 ml/m³ of CO causes fainting, increased pulse and breathing rates, finally leading to unconsciousness, respiratory paralysis, cardiac arrest and death.
MAK value = 33 mg/m³, 30 ml/m³.

2.1.2 Nitrogen oxides (NO_x = NO, NO_2)

Also called nitric oxides or nitrous gases. Nitrogen monoxide (NO) is a colourless, poisonous gas. Nitrogen dioxide (NO_2) is a brown-red, poisonous gas causing oxidation. Nitrogen dioxide is much more toxic than nitrogen monoxide and acts as an insidious irritant gas even in relatively low concentrations. The first stage of intoxication comprises irritation of the air passages and dyspnoea and is followed by an asymptomatic state lasting from some hours to several days. The second stage leads, in severe cases, to fatal pulmonary oedema (accumulation of fluid in the lungs).
MAK value for NO_2 = 0,95 mg/m³; 0,5 ml/m³
MAK value for NO = 0,63 mg/m³; 0,5 ml/m³

NO_2 has been classified into category 3 B carcinogenic by the DFG .

2.1.3 Ozone (O_3)

In high concentrations this is a deep blue gas having a penetrating smell and being highly toxic. It acts as an irritant gas on respiratory organs and eyes. It causes an irritation of the throat, dyspnoea and possibly pulmonary oedema.
MAK value = cancelled

More recent studies do not exclude the possibility that ozone has a carcinogenic potential. Therefore ozone has been classified into category 3 B (substances suspected to have a carcinogenic potential)

2.1.4 Phosgene ($COCl_2$)

(Carbonyle chloride or carbon dichloride oxide) - is an odourless, extremely poisonous gas with a musty smell. Initially (3 to 8 hours) there are only slight symptoms which may be followed by heavy irritations of the respiratory tract ending in pulmonary oedema (accumulation of fluid in the lungs).
MAK (DFG) value = 0,41 mg/m³; 0,1 ml/m³

Concerning pregnancy, phosgene is assigned to group C, i.e. a risk of damage to the embryo is not suspected when the MAK and BAT value is observed.

2.1.5 Gases from coating materials

Hydrogen cyanide (HCN) (hydrocyanic acid) - has a smell of bitter almonds and is a very weak, not very stable acid, which is among the strongest and quickest-acting poisons. Similar to carbon monoxide, it impedes the transport of oxygen in the blood, but to a much greater extent.
MAK value = 2,1 g/m³; 1,9 ml/m³

Concerning pregnancy, here again group C is assigned, i.e. a risk of damage to the embryo is not suspected when the MAK and BAT value is observed.

Formaldehyde (CH_2O) - is a pungently smelling colourless gas having a strongly irritant effect on the mucous membranes. It causes inflammation of the respiratory tract and is suspected to be mutagenic and carcinogenic.
MAK value = 0,37 mg/m³; 0,3 ml/m³

Toluylene diisocyanate (TDI) - has a strong irritant effect on the respiratory tract; it may cause asthma-like attacks and may lead to "bronchial asthma" by sensitisation.

Classified into category 3 A as carcinogenic by the DFG (see Clause 1.2.2 Effects)

Figure 2-1 on page 41 shows a summary of the effects of important gaseous hazardous substances on the human body in a table.

Figure 2-1: Effects of specific gaseous hazardous substances in welding and allied processes
[Source: Spiegel-Ciobanu according to clause 12.1]

Hazardous substance	Effect
1.1 Toxic	
Hydrogen cyanide (HCN)	toxic - impedes oxygen transport in the blood poisoning respiratory paralysis
Carbon monoxide (CO)	toxic - impedes oxygen transport in the blood headache poisoning respiratory paralysis possibly unconsciousness
1.2 Carcinogenic	
Formaldehyde (CH_2O)	Suspicion of carcinogenic effect - strong irritation of the mucous membrane
Ozone (O_3)	Suspicion of carcinogenic effect - toxic - irritation of the mucous membrane acute irritant gas intoxication pulmonary oedema
Phosgene (Carbonylchloride) ($COCl_2$) Nitrogen dioxide (NO_2)	Suspicion of carcinogenic effect - toxic - irritation of the mucous membrane irritant gas intoxication delayed pulmonary oedema (danger to life)
Toluylene diisocyanate (TDI)	Suspicion of carcinogenic effect - irritation of respiratory tract (bronchial asthma)

2.2 Particulate hazardous substances

2.2.1 Lung-stressing substances

Iron oxides (FeO, Fe_2O_3, Fe_3O_4) - are considered to be substances without any toxic or carcinogenic effects. Long-term intake of high concentrations may result in a dust deposit in the lungs. This deposit is also known as siderotic pneumoconiosis or siderosis. It is also called "tattooing of the lungs".

When the exposure has ended the iron deposits generally are reversible. In very high and extreme concentrations under very poor confined ventilation conditions a fibrotization of the lung (siderofibrosis) may occur in rare cases and after long-time exposure.
AGW = 3 mg/m³ A/10 mg/m³ E.

Aluminium oxide (Al_2O_3) - may lead to a dust deposit in the lungs. Under certain circumstances an aluminosis (pneumoconiosis) may occur which is not reversible like siderosis. In this case intensity of the aluminium oxide exposure rather than its duration is important. Irritation of the respiratory tract may also occur.
AGW = 3 mg/m³ A/10 mg/m³ E.

Potassium oxide, sodium oxide, titanium dioxide (K_2O, Na_2O, TiO_2) - should be classified as lung-stressing, because they may result in dust deposits in the lungs.
AGW = 3 mg/m³ A/10 mg/m³ E.

2.2.2 Toxic substances

Manganese oxides (MnO_2, Mn_2O_3, Mn_3O_4, MnO) in high concentrations may have irritant effects on the respiratory tract and may result in pneumonia. Permanent exposure can impair the nervous system and lead to paralysis agitans (unknown in welders up to now)
AGW = 0,5 mg/m³ E for Mn compounds

Fluorides (CaF_2, KF, NaF and others) - high concentrations lead to irritation of the gastric mucous membrane and of the respiratory tract. In severe cases, i.e. constant intake of high amounts, chronic general and bone damages are observed (unknown in welders up to now).
AGW = 2,5 mg/m³ E.

Barium compounds ($BaCO_3$, BaF_2) - in the welding fume are mainly present in water-soluble form and have a toxic effect when taken in by the human body. If the MAK values for soluble barium are exceeded, slight accumulation of barium cannot be excluded. In some cases the organism may suffer from a lack of potassium (hypokalemia). A clear correlation between external and internal barium exposure has been established.
MAK value (DFG) = 0,5 mg/m³ E

Chromium(III) compounds (Cr_2O_3, $FeCr_2O_4$, $KCrF_4$) - are considered, according to general occupational experience, as having a very low toxicity. There is no information on local irritations or intoxications caused in human beings. Even available animal studies do not provide information on clear acute effects.
AGW = 2mg/m³ E

Other metallic oxides - with toxic effects

Copper oxide, zinc oxide - may cause metal (welding) fume fever.

2.2.3 Carcinogenic substances

Chromium(VI) compounds - in the form of chromates (especially those which are slightly soluble) and chromium trioxide may have carcinogenic effects on the human body, particularly on the respiratory organs. They are classified as category 1, 2 or 3 carcinogens (see figure 1-12b on page 34, "limit values, classification").

Especially chromium trioxide is classified as a carcinogenic substance in category 1. This means that exposure may cause malignant tumours in humans.

Chromium(VI) compounds can also irritate the mucous membrane and be caustic.

Nickel oxides (NiO, NiO_2, Ni_2O_3) - may have a carcinogenic effect on the respiratory tract and are classified as carcinogenic substance in category 1.

Cadmium oxide (CdO) - is classified as carcinogenic substance in category 1 (DFG). It acts as a strong irritant and results, similar to nitrous gases, in possibly severe pulmonary oedema, often after slight symptoms and a stage of many hours (20 to 30 hours) without symptoms. If high amounts of cadmium are inhaled, changes may appear in the upper respiratory tract after approximately two years and pulmonary emphysema and disorders similar to rheumatism may occur.

Lead oxide - is classified by DFG as carcinogenic substance in category 2 and may cause blood and nerve poisoning.

Beryllium oxide (BeO) - is classified as carcinogenic substance in category 1 (DFG). Beryllium generally has a considerable toxic effect. The inhalation of fume and dust containing beryllium causes severe irritant effects in the upper respiratory tract and acute metal fume fever. Severe cases may result in chronic inflammation of the respiratory tract (chronic pneumonia).

Cobalt oxide (CoO) - is classified as carcinogenic substance in category 2 (DFG). At higher exposures, damages to the respiratory organs cannot be excluded.

Vanadium pentoxide - is classified by DFG as carcinogenic substance in category 2 (see item 1.2.2 on page 11 of this BGI). DFG has established EKA values (correlations between the concentrations of the substances in air at the workplace and in biological material). It is toxic and has irritant effects on the eyes and the respiratory tract. High concentrations exceeding the MAK value may result in impairments of the lung functions.

2.2.4 Thorium dioxide (ThO_2)

Thorium dioxide (ThO_2) - is a radioactive substance. The inhalation of fume and dust containing thorium dioxide leads to an internal radiation exposure.

Damages may occur through deposition of thorium in the bones, radiation of the bronchial tubes and the lungs.

For non radiation workers at “work” (i.e. during TIG welding) the limit value for the effective dose of 6 mSv per year is valid. Figure 2-2 on page 44 shows a table summarizing the effects of the most important particulate hazardous substances on the human body.

Figure 2-2: Effects of specific particulate hazardous substances in welding and allied processes [Source: Spiegel-Ciobanu according to clause 12.1]

Hazardous substance	**Effect**
2.1 Lung stressing	
Aluminium oxide	dust deposits in the lung, aluminosis
Iron oxide	dust deposits in the lung, siderosis
Potassium oxide	dust deposits in the lung
Sodium oxide	
Titanium dioxide	
2.2 Toxic	
Barium compounds, soluble	toxic - nausea possible potassium deficiency
Fluorides	toxic - irritation of the mucous membrane bone damage
Copper oxide	toxic - metal fume fever (copper fume fever)
Manganese oxide	toxic - irritation of the mucous membrane nerve damages
Zinc oxide	toxic - metal fume fever (zinc fume fever)
2.3 Cancerogenic	
Beryllium oxide	carcinogenic - metal fume fever chronic pneumonia
Lead oxide	suspicion of carcinogenic effect toxic - nausea gastrointestinal disorders nerve and kidney damage
Cadmium oxide	carcinogenic - irritation of the mucous membrane pulmonary emphysema
Chromium(VI) compounds	carcinogenic (respiratory system) - irritation of the mucous membrane
Cobalt oxide	carcinogenic - damage to respiratory system
Nickel oxides	carcinogenic (respiratory system)
Titanium doixide	Suspicion of carcinogenic effect (as respirable fraction); excluded are ultrafine particles
Vanadium pentoxide	toxic - irritation of eyes and respiratory system lung damages
2.4 radioactive	
Thorium dioxide	radioactive - radiation of the bronchial tubes and the lungs can have carcinogenic effects

3. Assignment of hazardous substances to welding processes and materials

The studies described in clause 1.10 have yielded the following important results:

- the chemical composition of gaseous and particulate hazardous substances depends on the process and material used;
- hazardous substances never occur as a single component but always as a mixture of several components;
- depending on the process and material, one, two or even three components (gases and particles) may be predominant as far as their concentration and efficacy is concerned (e.g. the relevant limit values are the first to be exceeded).

Any predominant hazardous substance is called a **key component** (for a specific combination of process and material) (see as well clause 8 of this BG Information). A **main component** of the welding fume is a component of occupational medical importance, the fraction of which in the welding fume is not predominant, i.e., this component is no key component of the welding fume. Main components shall not be equated with key components.

In the following text the processes are divided into four main groups:
- welding;
- thermal cutting;
- thermal spraying;
- soldering and brazing.

3.1 Welding

Welding always generates gaseous and particulate hazardous substances. The particulate substances have a particle size (aerodynamic diameter) of less than 1 μm, they are respirable and are normally called "welding fume". From the occupational health point of view, the respirable fraction (A fraction) is of special importance. This fraction, formerly called fine dust, is usually measured with the sampling head for the inhalable fraction (formerly called total dust; E dust) during personal measurements carried out in welding. The reason is that at present it is still difficult to position the sampling head for the A fraction behind the welder's shield (lack of space)

Since welding only produces very fine particles, all of which are included in the "respirable fraction", measurements of “E dust” instead of “A dust” are always on the safe side. The amount of hazardous substances generated in different welding processes is different. Today is often measured with the PGP-EA system. (A and E fraction are simultaneously captured (see clause 6.2)

Fume emission (mg/s) in welding is usually lower than fume and dust emission in cutting or spraying.

Studies on the emission of hazardous substances in welding have shown that approx. 95 % of the welding fume is generated from the filler metal and only less than 5 % from the parent metal.

3.1.1 Gas welding

Gas welding of unalloyed and low-alloy steel mainly produces nitrous gases (nitrogen oxides). Here as for other oxy-fuel gas processes, e.g. flame heating and flame straightening, where an

even larger amount of nitrogen oxides is generated, the key component is nitrogen dioxide.

The concentration of nitrogen dioxide in the air at the workplace increases with the length of the flame and hence with the size of the torch and the distance between tip and sheet.

The concentration of nitrogen dioxide becomes critical for operations in confined spaces without adequate ventilation measures. With a freely burning flame, it can reach 10 times the value produced by a flame with a length of 15 mm.

Measurements of emissions in gas welding and heating revealed the following approximate values for nitrous gases:

Process	**NO_x emission rates (mg/s)**
Gas welding	0,8 - 40
Heating	up to 75

Problems with respect to generated airborne particles can only arise from the treatment of non-ferrous metals (e.g. lead, copper) and from coatings containing such metals.

3.1.2 Manual metal arc welding with covered electrodes

Unalloyed, low-alloy steel
(alloying components < 5 %)
Compared with gas welding, this process generates high amounts of airborne particles.
Hazards caused by nitrous gases are unlikely.

In manual metal arc welding with unalloyed or low-alloy electrodes, the welding fume (total) shall be considered.

The chemical composition of the welding fume reflects the chemical composition of the core wire and of the covering. In this case, the main constituents of the welding fume are iron oxide (Fe_2O_3), silicon dioxide (SiO_2), potassium oxide (K_2O), manganese oxide (MnO), sodium oxide (Na_2), titanium dioxide (TiO_2), alumunium oxide (Al_2O_3).

Dependent on the type of covering (acid, rutile, basic, cellulosic) these components occur in different proportions. The fume from basic covered electrodes also contains calcium oxide (CaO) and fluorides (F^-). Here, fluorides should be considered as another main component (figure 3-1).

Figure 3-1: Analysis of welding fume [1] generated by manual metal arc welding with unalloyed/low- alloy electrodes (according to DIN 1913)

Hazardous substances	Type of covering			
	acid %	rutile %	basic %	cellulose %
Na_2O	2 - 4	2 – 4	2 – 4	2 - 4
Al_2O_3	1 - 2	1 - 2	1 - 2	1 - 2
SiO_2	30 - 40	30 - 40	~ 10	~ 10
K_2O	10 - 20	10 - 20	20 - 30	–
CaO	1 - 2	1 - 2	15 - 20	–
TiO_2	< 1	~ 5	~ 1	~ 1,5
MnO	~ 10	~ 7	~ 6	~ 5
Fe_2O_3	~ 40	20 - 30	20 - 30	70 - 80
F^-	–	–	12 - 16	–

Fume of electrodes with acid covering contain up to 10 % of manganese oxide. Thus, **manganese oxide** may become an additional main component of the welding fume in this case.

The following approximate emission values for welding fume are the result of many measurements carried out during manual metal arc welding with unalloyed/low-alloy electrodes:

Process	**Welding fume emission rates (mg/s)**
Manual metal arc welding	- 18

For special electrodes containing copper, copper oxide (CuO) may be an additional main component.

Chromium-nickel steel
(≤ 20 % Cr and ≤ 30 % Ni)

In addition to iron and substances from the coating (as above), high alloy covered electrodes contain up to 20 % of chromium and up to 30 % of nickel in the core wire.

During manual metal arc welding with high-alloy electrodes, welding fume is generated, the chemical composition of which may contain up to 16 % of chromium compounds. Up to 90 % of these chromium compounds are present as chromates (chromium(VI) compounds) which in most cases are classified as carcinogenic. Here, nickel oxide with 1 % and seldom up to 3 % is clearly under-represented.

For this process with the above materials, the key component in the welding fume is "chromate". The fume from basic covered electrodes contains much higher proportions of chromium(VI) than those from rutile electrodes.

Examination of biological material and epidemiological studies indicate that the strongest risk to a welder's health is produced by manual metal arc welding with high-alloy electrodes. Specific protective measures should be provided at the workplace, e.g. exhaust of welding fume at the

point of origin. In addition, preventive occupational medical examinations shall be carried out.

Emission measurements made during manual metal arc welding with high-alloy electrodes gave the following approximate emission values for welding fume:

Process	**Welding fume emission rates (mg/s)**
Joint welding	2 - 16
Cladding	3 - 22

Nickel, nickel alloys (> 30 % Ni)

In manual metal arc welding with pure nickel or with nickel-base alloys, nickel oxide is the key component, even though the welding fume only contains a maximum of 5 % of nickel oxide. Nickel oxides are classified as carcinogenic substances into category 1. Specific protective measures should therefore be provided at the workplace.

Apart from nickel oxide in the welding fume copper oxide may be generated - depending on the type of alloy (with copper components) – as another main component. When cladding with electrodes containing cobalt, attention should be paid to cobalt oxide (CoO).

Emission measurements made during manual metal arc welding with pure nickel and nickel-base alloys gave the following approximate welding fume emissions:

Process	**Welding fume emission rates (mg/s)**
Manual metal arc welding	approx. 7

3.1.3 Gas-shielded arc welding

In processes with active gas (MAGC, MAGM) primarily generation of large quantities of particulate hazardous substances (welding fume) can be expected. The amount of hazardous substances is of the same order as in manual metal arc welding with covered electrodes.

In contrast, processes using inert gas (MIG, TIG) exhibit a significantly lower fume generation.

Subject to the consumables and shielding gases used, gases and welding fume are generated, from which the key components are chosen. Figure 3-2a on page 52 gives some examples.

3.1.3.1 Gas-shielded metal arc welding (MAG/MIG)

- Influence of the shielding gas used on the fume generation

Metal active gas welding with carbon dioxide (MAGC)
In metal active gas welding with carbon dioxide (MAGC) of unalloyed and low-alloy steel, carbon monoxide is a key component besides welding fume. By thermal decomposition of the carbon dioxide which is used as shielding gas, carbon monoxide is generated. Here, the welding fume is mainly composed of iron oxides.

Emission measurements made during MAGC welding of unalloyed/low-alloy steel gave the following approximate emission values for welding fume and carbon monoxide:

Hazardous substance	Emission rates (mg/s)
Welding fume	2 - 12
Carbon monoxide (CO)	2 – 12,5

Metal active gas welding with gas mixture (MAGM)
In metal active gas welding with gas mixture (MAGM) of unalloyed and low-alloy steel, a gas mixture is used as shielding gas. If the gas mixture contains carbon dioxide, formation of a certain amount of CO is to be expected. Here, the welding fume is composed of iron oxides.

During MAGM welding of chromium-nickel steels, nickel oxide should be considered as possible key component. Although the welding fume contains up to 17 % of chromium compounds and up to 5 % of nickel oxide, the chromium compounds are almost exclusively composed of the trivalent form, which is not regarded as being carcinogenic.

Metal inert gas welding (MIG)
In metal inert gas welding (MIG) of aluminium-base materials, formation of ozone (from UV-radiation and from strongly reflecting materials) should be taken into account in addition to the welding fume (in the form of aluminium oxide). In most cases fume generation is, however, lower than in MAG welding.

Ozone concentrations are higher with aluminium-silicon-alloys than with pure aluminium and considerably higher than with aluminium-magnesium alloys.

When MIG welding nickel and nickel-base alloys, nickel oxide is the important key component in the welding fume.

Due to the high nickel proportion in the filler metals the content of nickel oxide in the welding fume may reach values between 30 and 87 %.

Emission measurements made during MIG welding of nickel and nickel-base alloys gave the following approximate emission values for welding fume and nickel oxide:

Hazardous substance	Emission rates (mg/s)
Welding fume	2 – 6
Nickel oxide	up to 5

Higher emission values of welding fume are generally to be expected for nickel base alloys containing copper (e.g. Nicorros) than for nickel base alloys with other alloy elements such as Cr, Co, Mo. Here, copper oxide shall be considered as key component instead of nickel oxide.

Protective measures shall be provided as for all other carcinogenic substances. Checking of ozone concentrations may also be necessary.

- Influence of electrode type on the fume generation

Larger amounts of welding fume are generated when MAG/MIG welding with flux-cored wire electrodes than when welding with solid wire electrodes.

The use of self-shielded flux-cored wire electrodes generates considerably higher welding fume emissions than the use of flux-cored wire electrodes under shielding gas.

For example, metal active gas welding of unalloyed and low-alloy steel gave the following emission values:

Filler metal	**Welding fume emission rates (mg/s)**
Solid wire	2 - 12
Flux-cored wire with shielding gas	6 - 54
Self-shielded flux cored wire	up to 97

In principle, the flux core of the wires contains components similar to those in the covering of a corresponding electrode.

Depending on the type of filler metal, the following constituents may be key components of the welding fume:

Filler metal	**Key component**
a) unalloyed/low-alloy basic flux-cored wire (with shielding gas)	Manganese oxide
b) high-alloy flux-cored wire	Chromium(VI)compounds or manganese oxide[1)]
c) unalloyed/low-alloy self-shielded flux-cored wire	Manganese oxide or barium compounds (depending on filler wire)
[1)] see also Figure 3-2a	

3.1.3.2 High performance MAG welding

The wire feed rate for this process is above 15 m/min. At the same time, the deposition rate is above 8 kg/h.

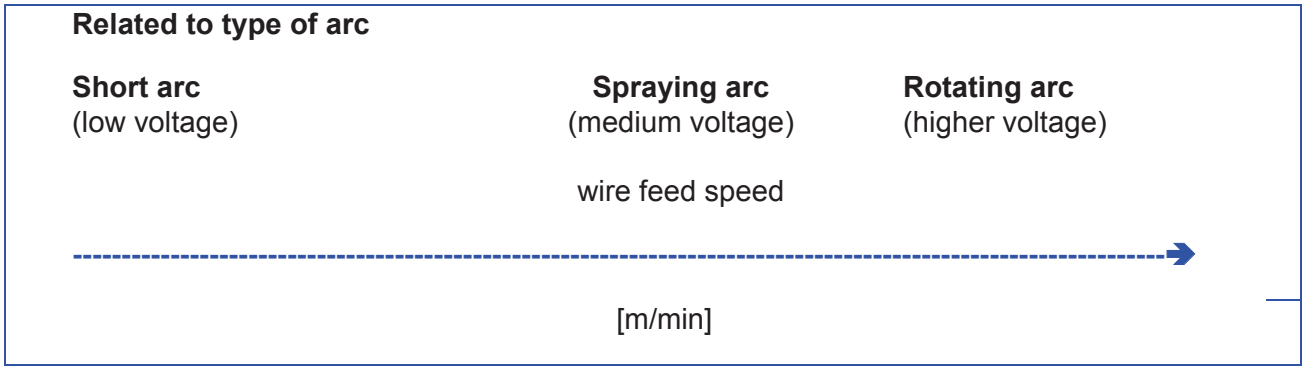
The higher the deposition rate or the wire feed rate, the higher the emissions of hazardous substances.

The higher the heat (energy) fed into the process, the higher the emissions of hazardous substances. As during high power MAG welding with massive wire the energies fed in are lower than during high power MAG welding with band, the emissions of hazardous substances are also higher for the latter process (see diagram below).

Hazardous substance emissions increase with increasing voltage and wire feed rate.

Thus, the highest emission rates are to be anticipated for rotating arcs, the lowest, by contrast, for short arcs.

Here as well the key components are the same as for MAG welding - depending on the materials used.



3.1.3.3 Tungsten inert gas welding (TIG)

In tungsten inert gas welding (TIG), the formation of ozone is promoted by the reduced level of fume generation. Ozone values are especially high (but lower than for MIG) with pure aluminium and - even more so - with aluminium-silicon alloys. If pure nickel and nickel alloys are welded, nickel oxide may be the key component.

When using thoriated tungsten electrodes in TIG welding, especially when welding aluminium materials, a radiation exposure by inhalation of fume containing thorium dioxide can be expected. Limit values for persons not occupationally exposed to radiation during “work activities” are in general exceeded. Therefore effective protection measures shall be provided at the workplace (e.g. use of non-thoriated tungsten electrodes).

Figure 3-2a: Assignment of key components to processes and materials used in welding
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008]

Process	Filler metal	Welding fume/key component(s)
Gas welding	unalloyed, low-alloy steel (alloy components < 5%)	nitrogen dioxide
Manual metal arc welding	unalloyed, low-alloy steel (alloy components < 5%)	welding fume[1)] manganese oxide[4)]
	chromium-nickel steel (≤ 20% Cr and ≤ 30% Ni)	chromium(VI) compounds or manganese oxide[4)]
	nickel, nickel alloys (> 30% Ni)	nickel oxide or copper oxide[2)]
Metal active gas welding with carbon dioxide (MAGC)	unalloyed, low-alloy steel (alloy components < 5%)	welding fume[1)] carbon monoxide
Metal active gas welding with gas mixture (MAGM)	unalloyed, low-alloy steel (alloy components < 5%)	welding fume[1)]
	chromium-nickel steel solid wire (≤ 20% Cr and ≤ 30% Ni)	nickel oxide or manganese oxide[4)]
	chromium-nickel steel flux-cored wire (≤ 20% Cr and ≤ 30% Ni)	chromium(VI) compounds or manganese oxide[4)]
Metal inert gas welding (MIG)	nickel, nickel alloys (> 30% Ni)	nickel oxide or copper oxide[2)], ozone
	pure aluminium aluminium-silicon-alloys	ozone welding fume[1)]
	other aluminium alloys[3)]	ozone welding fume[1)]
Tungsten inert gas welding (TIG)	unalloyed, low-alloy steel (alloy components < 5%)	welding fume[1)] ozone
	chromium-nickel steel (≤ 20% Cr and ≤ 30% Ni)	welding fume[1)] ozone
	nickel, nickel alloys (> 30% Ni)	ozone welding fume[1)]
	pure aluminium aluminium-silicon-alloys	welding fume[1)] ozone
	other aluminium alloys[3)]	welding fume[1)] ozone

[1)] Limit value for the A fraction of the dust
[2)] Limit value for copper fume, depending on type of alloy, with/without copper
[3)] Aluminium materials (pure aluminium, aluminium alloys) limit value for aluminium oxide fume
[4)] When the manganese percent in the alloy or the sum of percents (alloy and cover/filling) is ≥ 5%

3.1.4 Resistance welding

In resistance welding with different materials, welding fume concentrations (metal oxides from spatter or evaporation of the material) are generated, which under normal operation and ventilation conditions, are below the MAK or old TRK values for the corresponding hazardous substances (figure 1-11b on page 30 to 32).

Welding of oiled or greasy sheet steel should be avoided in practice, if possible. Thick layers of oil or grease lead to higher fume concentrations including proportions of organic substances.

When welding without spatter, about 30 % more fume are generated from greased sheet than from non-greased sheet.

Compared to other resistance welding processes (e.g. spot welding), flash welding produces greater amounts of fume which usually necessitate exhaust at the machine.

3.1.5 Laser beam welding with CO_2-laser

The use of lasers in welding and allied processes represents a relatively new and complex process. Special advice, particularly on ventilation and filter techniques, is offered by the Laser Zentrum (Laser Centre) Hannover (LZH), Hollerithallee 8, 30419 Hannover, Germany.

3.1.5.1 Laser beam welding without filler metal

The high energy of the laser source causes evaporation from the parent metal (fused metal).

This leads to emissions of hazardous substances (welding fume), the chemical composition of which approximates that of the parent metal.

The amounts of hazardous substances formed during laser welding without filler metal are comparable to those formed during metal active gas welding. For example, laser welding of chromium-nickel steel produces emissions of 1,2 to 2 mg/s for total dust.

Emission measurements made when laser welding different metallic materials showed the following emission values for constant welding parameters (thickness of material = 1 mm, laser power = 2900 W, focal length = 200 mm, feed rate = 50 mm/s, process gas = Ar):

Material	**Emissions of particulate hazardous substances [mg/s] (above processing side)**
unalloyed steel	1,5
X 5 CrNi 18 9	1,2
galvanized steel	7
titanium	0,9

The highest emissions of hazardous substances are observed for galvanised steel, where fume is essentially generated from the zinc coating.

Material	Emissions of gaseous hazardous substances (µg/s)		
	NO_x	CO	O_3
unalloyed steel	200	56	53
X 5 CrNi 18 9	350	28	19
galvanized steel	800	56	<

The results show lower emission rates for gaseous hazardous substances.

3.1.5.2 Laser beam overlaying

In laser beam overlaying, the filler metal can be added in the form of wire or powder. Mainly particulate hazardous substances (fume) are generated. If the filler metal is added in the form of powder, partially inhalable but non-respirable particulate substances are produced besides the fume. Total emissions of particulate substances during laser cladding are less than 5 mg/s.

Gaseous hazardous substances do not present a problem. The chemical composition of the welding fume is roughly similar to the chemical composition of the filler metal, elements with a low boiling temperature being overrepresented in the fume.

Apart from the key component (corresponding to the basic alloying element) oxides of other alloying elements (more than 10 %) may also reach critical values after different periods of operation. These are the main components.

Laser cladding with cobalt based alloys produces welding fume and dust in which cobalt oxide is considered to be the key components.

For nickel based alloys which also include more than 10 % of cobalt, nickel or cobalt oxide may be the key component in the welding fume – depending on the respective percentage in the welding fume. The welding fume also contains aluminium oxide.

For laser cladding of iron-based alloys containing a high level of chromium, welding fume (iron oxide) shall be considered. Total chromium in the welding fume is mainly present in the metallic or trivalent oxide form. Measured chromium(VI) compound levels are very low (≤ 5% of total chromium).

Copper oxide should be considered as key component for complex aluminium bronze, due to the high content of copper (approx. 75 % Cu). Besides, aluminium oxide is a main component.

3.1.6 Laser beam welding with Nd:YAG-laser

Emissions of hazardous substances (emission rate, [mg/s]) are generally lower at optimum (welding) parameters when using solid state lasers (Nd:YAG-Laser) than when using CO_2 lasers, as, at present, the obtainable welding speeds are lower for the Nd:YAG laser than for the CO_2

laser.

The absorbed intensity (power density) in the interaction zone is decisive for the amount of particulate substances.

With an increase in intensity, the melting temperature and thus the evaporation rate increases.

Emission measurements made during welding of chromium nickel steel and galvanised steel as a function of the absorbed beam intensity gave the following welding fume emission rates:

Material	**Welding fume emission rates [mg/s]**
chromium-nickel steel (s = 3mm, v_s = 600 mm/min)	~ 1,5
galvanised steel (s = 1mm, v_s = 400 mm/min)	~ 2,7

The beam intensity varies between 3,18 x 10^5 and 6,67 x 10^5 W/cm^2.

Figure 3-2 b: Assignment of key components to processes and materials used in laser welding
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008]

Process	**Parent metal**	**Welding fume/ key component(s)**
Laser beam welding[1)]	unalloyed, low-alloy steel	welding fume[2)]
	chromium-nickel steel (≤ 20% Cr and ≤ 30% Ni)	nickel oxide
	galvanised steel	zinc oxide
Process	**Filler metal**	**Key component(s)s**
Laser beamoverlaying	cobalt base alloys (> 60% Co, > 20% Cr)	cobalt oxide
	nickel base alloys (> 60% Ni)	nickel oxide
	iron base alloys (> 40% Cr, > 60% Fe)	welding fume[2)]
	complex aluminium bronzes (≈ 75% Cu)	copper oxide[3)]
[1)] here without filler metal [2)] the limit value for the A fraction of the dust should be taken [3)] limit for copper fume		

3.1.7 Hybrid welding

Hybrid welding (= combination of two individual processes) gains increasing importance for welding fabrication. The best known hybrid processes are:

- laser beam MIG,
- laser beam TIG,
- plasma MIG,
- plasma TIG and
- laser beam plasma welding

As during the above processes the melting capacity and the feed rate are much higher than for the individual processes, it has to be expected that the hazardous substances generated (mg/s) are somewhat higher than for simple MIG or TIG welding.

For all hybrid welding processes, it is thoroughly recommended to use an integrated extraction in the generation zone of the hazardous substances.

For a correct design of the ventilation system, examinations for the determination of emission rates specific to process/material are advisable.

Laser beam plasma welding of aluminium materials

This process combination enables a significant increase in welding speed and is used for aluminium materials both with CO_2 and with Nd:YAG lasers. Here as well, higher emissions of hazardous substances have to be expected than for simple laser beam welding. The choice of the key components also depends on the materials used. In this case, the key components ozone and aluminium containing welding fume – which occur at the same time – should be considered. An effective extraction should be installed directly in the generation zone of the above hazardous substances.

3.2 Thermal cutting

This process group includes oxygen cutting, plasma cutting and laser cutting (figure 3-2d on page 51). The composition of the parent metal determines the chemical composition of the particulate substances (fume), the diameter of which is larger than in fume from welding but which are nevertheless respirable.

3.2.1 Flame cutting (unalloyed and low-alloy steel)

This process produces high fume emissions as a function of different parameters

- sheet thickness
- fuel gas
- cutting gas pressure
- cutting speed.

In addition to welding fume - which is important in this process - generation of nitrous gases shall be considered, i.e. nitrogen dioxide shall be considered as key component besides welding fume.

In this process, the welding fume emission rate is about 10 to 50 mg/s.

3.2.2 Plasma cutting

This process is usually accompanied by a substantial emission of particulate substances.

The hazardous substances emitted mainly depend on the parent metal being cut (i.e. on its chemical composition), on the cutting parameters chosen, and on the kind of plasma gas used.

An increase in cutting speed (mm/min) leads to a reduction of the hazardous substances emitted (g/min).

For the processing of unalloyed and low-alloy steel welding fume is important (mainly iron oxides). In plasma cutting of chromium-nickel steel, however, nickel oxide is generated as key component. In addition chromium(VI) compounds are generated as main component.

Nickel and nickel base alloys which are processed by plasma cutting produce high levels of nickel oxide in the welding fume.

For aluminium-base materials where the parent metals are strongly reflective (e.g. aluminium-silicon alloys) ozone may be a key component in addition to welding fume.

If no technical protective measures, for example down-draught exhaust, are provided, it can be assumed that the limit value for the A fraction of the dust (3 mg/m³) is exceeded at workplaces at the machine, independent of the chemical composition of the materials . If the materials contain more than 5 % of chromium and nickel (high-alloy materials) this also applies to the former limit values for chromium(VI) compounds and nickel oxide, nickel oxide being the key component.

If compressed air or nitrogen is used as plasma gas, nitrogen dioxide should be considered as additional key component.

3.2.3 Laser beam cutting

Due to the complexity of processes and equipment, generation of hazardous substances in laser cutting is determined by many characteristics.

In addition to the material and the parameters determined by the process, the laser source plays an important role in the generation and composition of hazardous substances.

3.2.3.1. Laser beam cutting with CO_2-laser

Parameters which have a great influence on the amount of hazardous substances emitted are the thickness of the workpiece, the lens focal length, the cutting gas pressure, the laser beam power, and the cutting speed.

Dust emissions (mg/m) increase with increasing workpiece thickness and/or with an increasing lens focal length and/or with an increasing cutting gas pressure and/or with an increasing laser beam power.

With increasing cutting speed, dust emissions (mg/s) increase per time unit (mg/s) and decrease per cutting length (mg/m).

On the whole, laser cutting produces relatively large amounts of dust, which are, however, smaller

than in oxygen or plasma cutting.

The largest emissions of hazardous substances occur in laser cutting of chromium-nickel steel.

The cutting of galvanised steel results in higher emission rates than the cutting of unalloyed steel.

During cutting with CO_2-laser (power = 1 kW) the following welding fume emissions were obtained for equal workpiece thicknesses:

Material	**Welding fume Emission rates [mg/s]**
unalloyed steel	16 - 24
chromium-nickel steel	14 - 35

With regard to the problem of hazardous substances, it is possible to differentiate between

- high-pressure laser cutting (with nitrogen) and
- laser cutting (with oxygen).

The use of nitrogen as cutting gas reduces the emissions of hazardous substances from chromium-nickel steel and galvanised steel by half compared to cutting with oxygen.

Welding fume emissions in high-pressure laser cutting and laser cutting (example):

(Power = 1 kW, focal length of lens = 63,5 mm, thickness of workpiece = 1 mm)

Material	**Welding fume emission rates (mg/s)**	
	High-pressure laser cutting	Laser cutting
low-alloy steel	-	17
chromium nickel steel	8	20
galvanised steel	4,5	9

Without adequate exhaust systems, the MAK and old TRK values (see figure 1-11b in clause 1.8) for the corresponding key components are exceeded in laser cutting, irrespective of the parent metal.

3.2.3.2 Laser beam cutting with Nd:YAG-laser

Here again (as in clause 3.1.6) the total emissions of hazardous substances are lower for the use of solid state lasers (Nd:YAG lasers) than for the use of CO_2 lasers (figure 3-2c on page 59), whereas the cutting speed which can presently be reached is lower for Nd:YAG lasers than for CO_2 lasers.

During cutting with an Nd:YAG laser the following welding fume emissions were obtained for a material thickness of 1 mm:

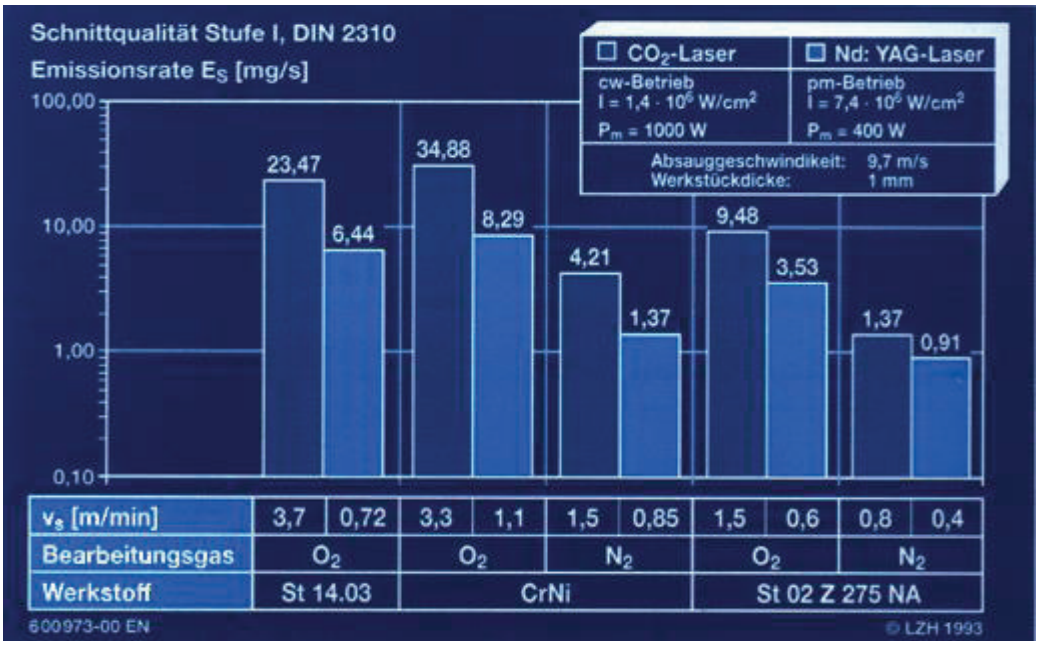
Material	Welding fume emission rates (mg/s)	
	Processing gas	
	N_2	O_2
chromium-nickel steel ($I = 2{,}98 \times 10^6$ W/cm^2)	(v_s = 850 mm/min) ~ 2	(v_s = 400 mm/min) ~ 2,7
AlMg 3 ($I = 1{,}89 \times 10^6$ W/cm^2)	(v_s = 200 mm/min) ~ 0,3	-

Here as well, welding fume emission (mg/m) increases with the increase of the material thickness. If nitrogen is used as processing gas (cutting gas), welding fume (mg/s) is as well considerably reduced.

The parameters having an essential influence on the amount of emitted hazardous substances are the following: absorbed intensity (power density), processing gas pressure, cutting speed, processing efficiency degree, thickness of the workpiece.

Maximum emission rates of gaseous hazardous substances are generated during cutting of 1 mm chromium-nickel-steel at a cutting speed of 400 mm/min and oxygen as processing gas. i.e.: 0,17 ppm/s of ozone, 0,00155 ppm/s of nitrogen monoxide, 0,041 ppm/s of carbon monoxide.

Figure 3-2c:
Comparison of emissions generated during laser cutting with CO_2 and Nd:YAG lasers
(Source: Engel, page 92, figure 44)



When using other Nd:YAG laser systems with higher power outputs (e.g. 1000 W) in the future, emissions (emission rates mg/s) will exceed those of CO_2 lasers at optimised parameters.

The amounts of particulate hazardous substances generated during the use of Nd:YAG lasers are in the order of magnitude of those generated during metal inert gas welding (MIG). Technical ventilation measures, especially effective extraction systems, are necessary here as well to avoid exceeding the limit values for the relevant key components.

Figure 3-2d:
Assignment of key components to process and material used in thermal cutting
[Source: Spiegel-Ciobanu, BGI 593, Ed. 2008]

Process	Parent metal	Welding fume/key components
Oxygen cutting	unalloyed, low-alloy steel (alloy components < 5 %)	welding fume[2)] nitrogen dioxide
Plasma cutting[1)] Laser cutting	unalloyed, low-alloy steel (alloy components < 5 %)	welding fume[2)]
	chromium-nickel steel (≤ 20% Cr and ≤ 30% Ni)	nickel oxide
	nickel, nickel compounds (> 30% Ni)	nickel oxide
	aluminium-base materials[3)]	welding fume[2)] ozone

1) When compressed air or nitrogen is used as plasma gas, nitrogen dioxide should also be considered as key component!
2) Limit value for the A fraction of the dust
3) Aluminium-base materials (pure aluminium, aluminium alloys)
limit value for aluminium oxide fume

3.3 Thermal spraying

Thermal spraying produces large amounts of particulate hazardous substances, depending on the process used (figure 3-2e on page 62). Thus, emissions of hazardous substances are significantly lower in flame spraying than in arc spraying.

Plasma spraying produces the largest emissions of hazardous substances compared to flame or arc spraying.

Furthermore, the hazardous substances generated depend on the material and are exclusively emitted from the spraying material.

The parent metal has no influence on the amount and the composition of the hazardous substances produced.

In all spraying processes, welding fume and dust concentrations in the breathing zone exceed the general dust limit value for both A and E fractions, if there is no or insufficient capture and separation of hazardous substances. In general, spraying processes (especially plasma spraying)

should be carried out in closed booths so that the exposure of welders and other persons to fume, dusts and noise is reduced to a minimum.

3.3.1 Flame spraying

Flame spraying using wires and powder as spraying materials generates gaseous and particulate substances. The chemical composition of the particulate substances in fume/dust corresponds to the composition of the spraying material.

In flame spraying, as in other oxy-fuel processes, generation of nitrous gases should be taken into account.

During flame spraying with high-alloy spraying material (e.g. chromium < 27%, Ni < 22%) high levels of dust emissions include also high proportions of nickel oxide.

In this process, nickel oxide concentrations considerably exceed 0,5 mg/m³ (old TRK value for nickel oxide, see Figure 1-11b on page 30).

Chromium(VI) compounds may in addition be generated. It is assumed that a varied mixture of different chromium oxides is produced.

This mixture is hardly soluble, also contains chromium(VI) compounds and is regarded as carcinogenic.

Nickel oxide is the key component when nickel and nickel alloys are used. Here again, 0,5 mg/m³ (old TRK value for nickel oxide, see Figure 1-11b on page 30) is expected to be exceeded frequently.

At the same deposition rate, chromium-nickel alloys produce higher emissions than zinc or aluminium alloys.

3.3.2 Arc spraying

Arc spraying produces large emissions of particulate substances. For comparable spraying parameters and at approximately the same deposition rate, the emission of hazardous substances from aluminium wire is higher than that from zinc, chromium, nickel and aluminium bronze wires, where the emissions of hazardous substances are comparable. During arc spraying with chromium-nickel or nickel-base spraying materials, nickel oxide should be considered as key component. The old TRK values (Figure 1-11b on page 30) were proved to be exceeded here.

The diameter of particles is usually smaller in arc spraying than in flame spraying, resulting in a larger respirable fraction.

3.3.3 Plasma spraying

Plasma spraying produces higher emissions of hazardous substances than flame or arc spraying with the same spraying materials, due to the use of a much higher spraying rate.

Most of the plasma spraying processes are therefore carried out in enclosed systems (encapsulated systems). Nevertheless, there is still a health risk for the operator for the few

manual spraying processes, if the high hazardous substance concentrations are not exhausted at source.
Practice shows that the old TRK and MAK values can be substantially exceeded during plasma spraying with materials having higher proportions of critical materials (chromium, nickel, cobalt, etc.) (see Figure 1-11b on page 30) if no effective exhaust system is in operation.

Figure 3-2e: Assignment of key components to processes and materials used in thermal spraying [Source: Spiegel-Ciobanu, BGI 593, Ed. 2008]

Process	**Spraying material**	**Welding fume/ key component(s)**
Flame spraying	unalloyed, low-alloy steel (alloying components > 5 %)	A, E dust[1)] nitrogen dioxide
	chromium-nickel steel (≤ 27% Cr and ≤ 22% Ni)	nickel oxide nitrogen dioxide
	nickel and nickel alloys (> 60% Ni)	nickel oxide nitrogen dioxide
	aluminium-base materials[3)]	A, E dust[1)] nitrogen dioxide
	lead alloys	lead oxide nitrogen dioxide
	copper and copper alloys	copper oxide[2)] nitrogen dioxide
	other non-ferrous metals and alloys	A, E dust[1)] nitrogen dioxide
Arc spraying	unalloyed, low-alloy steel (alloying components < 5 %)	A, E dust[1)]
	chromium-nickel steel (≤ 27% Cr and ≤ 22% Ni)	nickel oxide
	nickel and nickel alloys (> 60% Ni)	nickel oxide
	aluminium-base materials[3)]	A, E dust[1)]
	copper and copper alloys	copper oxide[2)]
	other non-ferrous metals and alloys	A, E dust[1)]
Plasma spraying	copper aluminium and copper tin alloys	copper oxide[2)]
	chromium nickel steel (≤ 27 % Cr and ≤ 22 % Ni)	nickel oxide ozone
	nickel and nickel alloys (> 60 % Ni)	nickel oxide
	cobalt base alloys (> 50% Co)	cobalt oxide

1)	Limit value for A dust (respirable dust)/welding fume and E dust (inhalable dust)
2)	Limit value for copper fume
3)	Aluminium-base materials (pure aluminium, aluminium alloys) limit value for aluminium oxide fume

3.4 Soldering and Brazing

Here again, the emission of hazardous substances is related to the process and the material used. The amount and the chemical composition of hazardous substances generated (soldering or brazing fume) depend on the materials used (solder and brazing alloys, flux, binder) (figure 3-5 on page 64) and on the process parameters (brazing or soldering temperature [figure 3-7 on page 67], soldering and holding time).

Soldering and brazing are principally classified according to process temperature.

3.4.1 Soldering (T < 450 °C)

The generation of hazardous substances first of all depends on the soldering temperature.

An example is given by measurements made during manual soldering with a colophony-containing cored solder (1,5 DIN 8516-L-Sn 60 PbCu 2 zh) and flux F-SW 32 3,5.

The hazardous substances produced in soldering are mainly colophony and its decomposition products, since many fluxes are based on colophony.

In addition, hydrazine, lead, hydrogen chloride and bromide or tin compounds may occur, according to the solder and flux used. This is mainly the case for soldering operations in installations.

3.4.2 Brazing (T > 450 °C)

For brazing, mainly copper-zinc alloys are used, which can also contain nickel, tin, silver and cadmium additives.

The fluxes used in brazing contain mixtures of boric acids, single and complex fluorides, oxyfluorides and borax.

Depending on the brazing alloys and flux, brazing produces the following hazardous substances: cadmium oxide, copper oxide, zinc oxide, silver oxide, fluorides, boron oxides, etc.

From the occupational health point of view, cadmium compounds and fluorides in brazing fume are especially important.

During **brazing with alloys containing cadmium** an extraction of the fume is indispensable.

For **copper base alloys** an extraction in the area of generation is recommended because of the varying measuring results at the workplace (concentration of copper fume above/below the limit value).

Figure 3-3: Emission of hazardous substances as a function of the soldering temperature
[Source: Spiegel-Ciobanu, BGI 593, Ed. 2008 according to [8]

Soldering temperature [°C]	Emission			
	Total fume [mg/g flux]	Colophony [mg/g solder]	Aldehyde [mg/g solder]	Tin [µg/g solder]
250	40	1	2×10^{-3}	8
450	102	4,2	$12,5 \times 10^{-3}$	30

Figure 3-4: soldering workplace with extraction
[Source: Böckler, BGETEM]

According to DIN 29454-1 soft soldering fluxes are divided into three groups (Figure 3-5 on page 64)

Figure 3-5: Classification of fluxes into groups
[Source: BGI 593, Ed. 2008 according to Böckler, BGETEM

Group	Flux
1	natural resins (colophony) or modified natural resins with or without addition of organic or halogen containing activators
2	organic acids (e.g. citric, oleic, stearic, benzoic acid), amines, diamines, urea and organic halogen compounds
3	zinc and other metal chlorides, ammonium chloride (in aqueous solution or in organic preparations)

Due to the solders and brazing alloys used during soldering and brazing, a variety of hazardous substances may be generated. The following hazardous substances were found in soldering and brazing fumes, among others:

Aldehydes (especially formaldehyde, acetaldehyde, acrylic aldehyde), antimony oxide, inorganic

and organic tin compounds, lead oxide, boron oxide, boron trifluoride, cadmium oxide, chlorides/hydrogen chloride, fluorides, hydrogen fluoride, hydrazine, copper oxide, colophony, phosphorous pentoxide, silver oxide, zinc oxide.

In figures 3-6 and 3-7 on pages 66/67, the hazardous substances generated during soldering and brazing, which have to be taken into account in the framework of the hazard determination and evaluation, are listed.

See as well:
BG/BGIA Recommendation “Weichlöten mit dem Lötkolben an elektrischen und elektronischen Baugruppen oder deren Einzelkomponenten (Kolbenlöten)” (Soldering with soldering gun at electric and electronic component groups or their single components (gun soldering)) (BGI 790-014).

Figure 3-6: Key components during soldering (table 5 of BGR 220)
[Source: BGI 593, Ed. 2008 according to Böckler, BGETEM]

Soldering (temperature < 450° C)			
Solders		**Fluxes** (flux basis)	**Key components**
Field of application	**Type of solder**		
Heavy metals	antimony-containing, low-antimony, antimony-free lead-tin and tin-lead solders	Group 1	A dust aldehyde[1)] lead oxide
		Group 2	A dust lead oxide[1)]
		Group 3	A dust lead oxide[1)]
	tin-lead solders with copper, silver or phosphorus additions	Group 1	A dust aldehyde[1)] lead oxide
		Group 2	A dust lead oxide[1)]
		Group 3	A dust lead oxide[1)]
	tin solders with silver, copper, bismuth, indium, antimony and zinc additions	Group 1	A dust aldehyde[1)]
		Group 2	A dust
		Group 3	A dust
	cadmium solders with zinc, tin, silver and lead additions	Group 1	A dust aldehyde[1)] cadmium oxide
		Group 2	A dust cadmium oxide
		Group 3	A dust cadmium oxide
Light metals	solders on the basis of: - tin-zinc - zinc-cadmium - zinc-aluminium - lead-tin-silver	organic compounds, e.g. amines, organic halogen compounds	A dust cadmium oxide
		chlorides, fluorides, e.g. zinc chloride	A dust cadmium oxide chlorides fluorides
[1)] Except for workplaces, where electric and electronic component groups or their individual components are soldered or at the repair workplaces in these areas			

Table 3-7: Key components during brazing (Table 6 of BGR 220)
[Source: BGI 593, Ed. 2008 according to Böckler, BGETEM]

Brazing (Temp. ≥ 450° C)			
Brazing alloys for brazing		Flux (flux basis)	Key component
Field of application	Type of brazing alloy		
Heavy metals	silver containing brazing alloys, cadmium free	boron compounds with additions of single and complex fluorides, phosphates and silicates	A dust chlorides fluorides silver oxide
	silver containing brazing alloys, cadmium-containing		A dust chlorides fluorides silver oxide cadmium oxide
	phosphorous brazing alloys		A dust chlorides fluorides
	zinc and zinc containing brazing alloys		A dust chlorides fluorides zinc oxide
	copper and copper based brazing alloys[1)]		A dust chlorides fluorides copper oxide
	nickel base brazing alloys[1)]		A dust nickel oxide
	palladium containing brazing alloys[1)]		A dust
	gold containing brazing alloys[1)]		A dust
Light metals	aluminium base brazing alloys	chlorides and fluorides	A dust chlorides fluorides
[1)] In general, these brazing alloys are used in shielding gas ovens or in vacuum ovens without fluxes			

3.4.3 MIG brazing, laser brazing, plasma brazing (T > 900 °C)

For these processes mainly copper base alloys in the form of wire are used as filler metal with a melting zone lower than that of the parent metal, e.g. CuSi3 (Si 3%, Mn 1%, rest Cu), AlBz 8 (Al 8,2%, rest Cu).

The particulate hazardous substances emitted are generated from the filler metal. The parent metal is not melted.

Galvanized steel

During processing of galvanized steels, the fume contains high proportions of zinc oxide generated by vaporization and oxidization of the coating.

In addition, high amounts of copper oxide are generated from the filler metal.

The highest emission rates have to be anticipated for MIG brazing, while the lowest emission rates are generated during plasma brazing.

Thus during MIG brazing with CuSi 3 (wire diameter of 1 mm) and a zinc layer of 45 µm, about 4,7 mg/s are generated.

High alloy steel

Here, the key component in the welding fume is determined by the filler metal, i.e. copper oxide. The parent metal has no influence on the generation of hazardous substances.

During MIG brazing with a wire diameter of 1 mm, the fume generation is about 2,4 mg/s.

During plasma brazing and laser brazing with the same filler metal, the welding fume emission is much lower than during MIG brazing.

Figure 3-8: Assignment of main and key components to the processes and materials during soldering/brazing

[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008 following [13]

Process	Parent metal	Filler metal	Main component	Key component
MIG brazing	Galvanized steel	CuSi 3	Zinc oxide	Copper oxide
	Chromium nickel steel	AlBz 8		Copper oxide
Laser brazing	Galvanized steel	CuSi 3	Zinc oxide	Copper oxide
	Chromium nickel steel	AlBz 8		Copper oxide
Plasma brazing	Galvanized steel	CuSi 3	Zinc oxide	Copper oxide
	Chromium nickel steel	AlBz 8		Copper oxide
Chromium nickel steel: ≤ 20 % Cr and ≤ 30 % Ni AlBz 8: Al 8,2 %, rest Cu CuSi: Si 3 %, Mn 1 %, rest Cu				

4 Ultrafine particles (UFP)

4.1 Findings from studies on toxicity of UFP

Epidemiological studies and animal tests with ultrafine particles are in principle inhalation tests with rats or other rodents exposed to diesel soot, technical soot and with titanium oxide. They show that, depending on the particle surface in contact with the lung, inflammatory, fibrotic (hardening of the lung tissue) or carcinogenic effects may occur.

Studies show that particle size, structure and shape of the ultrafine particles contained in the welding fume can influence potential effects on the human organism. In addition, the chemical composition of the particles is of great importance.

The particle concentration (particle/cm³), the specific particle surface as well as the chemical composition have influence on the probability of deposits in the lung, the cleaning behaviour of the lung and the resulting staying time, thus determining the damage to the lung.

The largest damaging potential is assigned to particles having a size between 20 and 50 nm. [Source: Spiegel-Ciobanu, Publication [14]]

4.2 Findings from research on the characteristics of UFP

Physico-chemical processes such as vaporization, condensation, oxidation, pyrolysis caused by high temperatures during welding processes generate ultrafine particles.

The processes applied and their parameters (current, voltage, electrode diameter, type of welding), the filler and parent metal used with their chemical composition, the shielding gases or the flux material as well as the surface quality of the materials play an important role. The nature and amount of particles generated are mainly influenced. Furthermore, workplace specific factors shall be named: ventilation, head/body position, duration of welding, shape/construction of the workpiece which determines the welding fume concentration in the welders' breathing zone [19].

4.3 Results from studies on welding processes

The ISF of RWTH Aachen has examined together with ITEM Hannover welding, cutting and soldering processes with unalloyed, low-alloy and high-alloy materials as well as aluminium-based

and copper-based alloys with respect to their emission rates, chemical composition, diffusion equivalent diameter of the agglomerates and the geometrical diameter of primary particles and with respect to “biologically active surface” of particles. The results are summarized in Figure 4-1 to Figure 4-7 [15] and are presented as follows.

With time, increasing sizes of particles and agglomerates are generated so that an “ageing process” of the welding fume can be expected during measurements of welding fume concentrations at the workplace.

Mass and number size distributions, agglomerate number emission rates (number of agglomerates per second), mean primary particle number per agglomerate are subjected to changes by ageing.

Manual metal arc welding

Pr. #	Parent metal	Electrode	Gas	Mass-emission rate [mg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Meanprimary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
3	1.0038	Rutile basic, low alloy.	no gas	5,8	0,37	3,0	129	1,8	4,2E+11	91	3,8E+13	7	2,1
4	1.0038	Rutile basic, low alloy	no gas	3,9	0,35	1,9	126	1,7	4,44E+11	89	4,0E+13	9	2,3
5	1.0038	basic, low alloy	no gas	7,6	0,45	1,5	135	1,6	5,2E+11	24	1,2E+13	15	2,2
6	1.0038	Cellulose	no gas	4,4	0,34	4,2	117	1,7	7,76E+11	76	5,9E+13	6	1,9
7	1.4301	basic, high alloy	no gas	5,5	0,44	1,6	142	1,7	3,57E+11	37	1,3E+13	13	2,2

Metal active gas welding / build-up welding

Pr. #	Parent metal	Electrode	Gas	Mass-emission rate [mg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Meanprimary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
8	1.0038	Solid wire, low alloy	100% CO_2	9,6	0,37	1,7	156	1,6	8,59E+11	343	3,0E+14	15	2,1
9	1.0038	rutile cored wire, low alloy.	100% CO_2	12,9	0,40	1,5	142	1,6	6,88E+11	159	1,1E+14	13	2,1
10	1.0038	solid wire, low alloy	82% Ar, 18% CO_2	2,5	0,39	1,9	129	1,6	4,83E+11				
56	primed sheet	solid wire, low alloy	82% Ar, 18% CO_2	2,9	0,21	2,3	152	1,8	3,25E+11	138	4,5E+13	11	1,6
11	1.0038	metal powder cored wire, low alloy	82% Ar, 18% CO_2	12,7	0,30	1,6	152	1,6	1,18E+12	330	3,9E+14	13	2,0
12	1.0038	rutile cored wire, low alloy.	82% Ar, 18% CO_2	16,3	0,37	1,4	149	1,5	1,3E+12	37	4,8E+13	33	1,6
13	1.4541	Solid wire, high alloy	90% Ar, 10% CO_2	3,7	0,19	1,8	149	1,7	5,09E+11	93	4,7E+13	8	1,9
14	1.4541	Solid wire, high alloy	97,5% Ar, 2,5%CO_2	2,9	0,13	1,5	129	1,6	7,05E+11	353	2,5E+14	11	1,7
15	1.4301	Solid wire, high alloy	90% Ar, 10% CO_2	2,5	0,45	3,3	120	1,6	1,24E+12				
16	1.4301	Solid wire, high alloy	97,5% Ar, 2,5%CO_2	3,2	0,20	2,1	138	1,6	1,1E+12	334	3,7E+14	13	1,6
17	1.4541	Cored wire, high alloy	90% Ar, 10% CO_2	3,1	0,27	1,9	129	1,6	6,47E+11				
18	1.4541	Cored wire, high alloy	97,5% Ar, 2,5%CO_2	4	0,27	2,0	126	1,6	5,51E+11	69	3,8E+13	23	1,7
19	1.0038	Metal powder cored wire, high alloy	kein Gas	30,4	0,35	1,6	144	1,9	1,69E+12				
20	1.0038	Cored wire, low alloy.	82% Ar, 18% CO_2	24,8	0,39	3,0	152	1,6	1,13E+12	185	2,1E+14	22	1,7

Figure 4-1: Characteristics of UFP in manual metal arc welding and metal active gas welding [Source: Pohlmann, G. [15]]

Metal inert gas welding

Pr. #	Parent metal	Wire	Gas	Mass emission rate [mg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Mean primary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
35	Al 99.5	S-Al 99.5	100% Ar	5.27	0.32	2.5	181	1.7	3.44E+11	264	9.1E+13	9	1.7
36	Al 99.6	S-Al 99.5	50% Ar, 50% He	6.9	0.36	2.0	194	1.7	2.85E+11	809	2.3E+14	7	1.6
37	AlSi1Mg	AlSi 5	100% Ar	9.28	0.37	1.9	190	1.7	3.67E+11	1535	5.6E+14	16	1.7
38	AlSi1Mg	AlSi 5	50% Ar, 50% He	7.54	0.42	1.8	164	1.7	2.74E+11	86	2.4E+13	9	1.9
39	AlSi1Mg	AlSi 12	100% Ar	3.16	0.33	1.9	154	1.7	3.35E+11	480	1.6E+14	14	1.6
40	AlSi1Mg	AlSi 12	50% Ar, 50% He	3.03	0.38	1.6	92	1.8	2.24E+11	295	6.6E+13	9	1.7
41	AlMg3	Al Mg 3	100% Ar	23.82	0.38	1.8	208	1.6	5.24E+11	1393	7.3E+14	14	1.7
42	AlMg3	Al Mg 3	50% Ar, 50% He	31.96	0.40	1.7	199	1.7	4.17E+11	189	7.9E+13	13	1.8
43	AlMg3	Al Mg 5	100% Ar	11.42	0.34	2.1	178	1.6	2.6E+11	1850	4.8E+14	16	1.7
44	AlMg3	Al Mg 5	50% Ar, 50% He	6.62	0.33	2.0	160	1.7	2.44E+11	973	2.4E+14	15	1.8
45	Nickel	Alloy 617	100% Ar	1.45			60	1.7	3.93E+11	116	4.5E+13	12	1.5

Metal inert gas soldering

Pr. #	Parent metal	Wire	Gas	Mass emission rate [mg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Mean primary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
47	DX53	AlBz5Ni2	97.5% Ar, 2.5%CO2	2.6	0.32	2.0	149	1.7	3.17E+11	571	1.8E+14	19	1.5
48	DX53	AlBz5Ni2	99.5% Ar, 0.5%O2	2.6	0.22	2.9	138	1.7	4.31E+11	499	2.2E+14	9	1.5
49	DX53	CuSi3	97.5% Ar, 2.5%CO2	2.3	0.17	2.0	129	1.7	2.91E+11	180	5.2E+13	11	1.6
50	DX53	CuSi3	99.5% Ar, 0.5%O2	1.9	0.16	1.9	135	1.7	3.84E+11	308	1.2E+14	13	1.5
51	DX53	CuAl8	97.5% Ar, 2.5%CO2	3.9	0.33	1.6	164	1.7	3.29E+11	735	2.4E+14	10	1.6
52	DX53	CuAl8	99.5% Ar, 0.5%O2	4.9	0.29	1.8	152	1.6	3.67E+11	149	5.5E+13	8	1.6

Figure 4-2: Characteristics of UFP in metal inert gas welding and metal inert gas soldering [Source: Pohlmann, G. [15]]

Tungsten inert gas welding

Pr. #	Parent metal	Wire	Gas	Mass emission rate [mg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Mean primary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
64	1.4541	High alloy rod	100% Ar	0.0144			23	1.7	3.69E+11	17	6.2E+12	22	1.4
65	2.0090	copper rod	100% Ar	0.0142			24	1.6	6.14E+11				
66	AlMg3Mn	AlMg-alloy	70% Ar, 30% He	0.0276			32	1.6	4.04E+11	31	1.2E+13	15	2.0
67	AlSi1MgMn	AlSi-alloy	70% Ar, 30% He	0.0377			63	1.9	4.14E+11	120	5.0E+13	10	1.5

Laser beamwleding without filler metal

Pr. #	Parent metal	Wire	Gas	Mass emission rate [mg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Mean primary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
74	DX53	no wire	100% He	7.8	0.1	2.75	152	1.6	7.23E+11	477	3.5E+14	12	1.48
75	DX53	no wire	100% He	8	0.15	3.9	181	1.6	5.94E+11	2603	1.5E+15	13	1.5
76	AlSi1MgMn	no wire	100% He	2.6	0.25	5.8			2.14E+12	1375			
77	AlMg3Mn	no wire	100% He	6.5	0.15	2.6						18	1.5

Laser MIG hybrid welding

Pr. #	Parent metal	Wire	Gas	Mass emission rate [mg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Mean primary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
78	AlMg3Mn	AlMg5	50% Ar, 50% He	4.3	0.40	1.8	157	1.7	6.81E+11	366	2.5E+14	12	1.7
79	AlSi1MgMn	AlSi12	50% Ar, 50% He	1.2	0.40	2.7	97	1.7	9.96E+11	510	5.1E+14	13	1.6
80	DX53	Solidwire, low alloy	100% He	18.5	0.36	2.2	184	1.7	8E+11	202	1.6E+14	18	1.6
81	1.0038	Solidwire, low alloy	100% He	10.4			160	1.6	1.06E+12	2606	2.8E+15	20	1.4

Figure 4-3: Characteristics of UFP in tungsten inert gas welding, laser welding and laser MIG hybrid welding [Source: Pohlmann, G. [15]]

Electron beam welding at atmosphere													
	Parent metal	Wire	Gas	Mass emission rate [mg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Mean primary particle number per agglomerate	Calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
53	AlMg3Mn	no wire	He, air in addition	6.1	0.28	1.8	237	1.4	2.65E+12	138	3.7E+14	11	1.6
54	Mg-Al 3	no wire	He, air in addition	31.7	0.27	-	201	1.5	2.75E+12	704	1.9E+15	25	1.6
55	AlSi1MgMn	no wire	He, air in addition	22.2	0.17	1.9	124	1.5	3.65E+12	43	1.6E+14	19	1.7

Figure 4-4: Characteristics of UFP in electron beam at atmosphere [Source: Pohlmann, G. [15]]

Resistance spot welding and resistance spot weld bonding													
Pr. #	Parent metal	Wire	Gas	Mass emission rate [µg/s]	MMAD [µm]	GSD (average)	Number median of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Mean primary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
90	DX51 D+Z	no wire	no gas	23.2			47	2	8.20E+09	20	1.7E+11	14	1.6
91	DC01	no wire	no gas	37.7			54	2	4.55E+09	569	2.6E+12	12	1.4
92	organic coated	no wire	no gas	49.7	0.39	5.0			1.53E+11	201	3.1E+13	9	1.5
93	organic coated	no wire	no gas	50.1					2.11E+11	184	3.9E+13	10	1.5
94	DX51 D+Z	no wire	no gas	22.6						78		12	1.6
95	DC01	no wire	no gas	37.8					1.47E+10	123	1.8E+12	24	1.7

Figure 4-5: Characteristics of UFP in resistance spot welding and spot weld bonding [Source: Pohlmann, G. [15]]

Soldering and brazing

Pr. #	Parent metal	Wire (Lot)	Gas	Mass emission rate [mg/s]	MMAD [µm]	GSD (average)	Numbermedian of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Meanprimary particle number per agglomerate	calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
82	2.0090	Sn99Cu1	no gas	1	0.45	2.6	58	1.5	3.25E+12				
83	2.0090	Sn95.5Ag3.8Cu0.7	no gas	0.8	0.56	4.3	65	1.5	4.35E+12				
84	1.8814	Ag55ZnCuSn	no gas	0.4	0.40	1.8	39	1.8	8.54E+11	12	1.0E+13	32	1.8
85	1.8814	Ag40CuZnSn	no gas	0.5	0.34	1.7	44	1.7	9.15E+11	9	8.4E+12	32	1.7

Figure 4-6: Characteristics of UFP in soldering and brazing [Source: Pohlmann, G. [15]]

Plasma, flame, laser beam cutting

Pr. #	Parent metal	Wire	Gas	Mass emission rate [mg/s]	MMAD [µm]	GSD (average)	Numbermedian of mobility distribution [nm]	GSD (average)	Agglomerate emission rate (1/sec)	Mean p rimary particle number per agglomerate	Calculated primary particle emission rate [1/sec]	Median value of primary particle size distribution [nm]	GSD (average)
86	1.4301	no wire	O2	0.66	0.12	2.1	172	1.6	1.1E+12	162	1.8E+14	9	1.5
87	1.0038	no wire	O2	0.21	0.35	11.9			4.75E+11	186	8.9E+13	8	1.5
88	1.4301	no wire	no gas	0.43	0.39	2.6			9.11E+10	202	1.8E+13	9	1.5
89	1.0038	no wire	no gas	0.21	0.12	3.0			2.58E+11	115	3.0E+13	7	1.4

Figure 4-7: Characteristics of UFP in plasma, flame and laser beam cutting [Source: Pohlmann, G. [15]]

4.4 Findings from research on identification of particle characteristics in welding of galvanized sheet

By means of the fume box method (see also clause 1.10 of this BGI) and on the basis of DIN EN 15011, fire and electroplated hot dipped and electrolytic galvanized sheets were soldered and welded during MIG-soldering, resistance spot welding and CO_2 laser beam welding in the ISF section of RWTH Aachen [16] in order to identify here again ultrafine particles and their particle characteristics.

Regarding

- emission rates
- percentage of particle fraction D < 100 nm
- particle number concentration
- particle surface concentration

the results are presented as follows:

Results from MIG soldering of galvanized sheets [16]

Depending on the materials and parameters chosen:

- the emission rates are between 1.3 and 9.0 mg/s
- the zinc percentage is between 30% and 60%
- the particle fraction having a mobility diameter < 100 nm is between 28% and 55%
- the mean particle number concentration is in the order of 10^6 - 10^7 [particle/cm³]
- the mean particle surface concentration is in the order of 10^{12} - 10^{13} [nm²/cm³]

Results from resistance spot welding of galvanized sheets [16]

Depending on the materials and parameters chosen:

- the emission rates are between 0.07 and 0.43 mg/s
- the particle fraction having a mobility diameter < 100 nm is approx. 99%
- the mean particle number concentration is in the order of 10^5 - 10^6 [particle/cm³]
- the mean particle surface concentration is in the order of 10^{10} - 10^{11} [nm²/cm³]

Results from CO_2 laser welding of galvanized sheets [16]

Depending on the materials and parameters chosen:

- the emission rates are between 2,56 and 4,97 mg/s
- the particle fraction having a mobility diameter < 100 nm is between 40% and 60%.the mean particle number concentration is in the order of 10^7 [particle/cm³]
- the mean particle surface concentration is in the order of 10^{12} - 10^{13} [nm²/cm³]

A reduction of the emission rates - for processes with emission rates above 1 mg/s - by means of targeted protective measures implies at the same time a reduction of the primary particle emission rate and the agglomerate emission rate.

The well-directed use of effective exhaust systems, their capturing elements are positioned in the generation area of welding fume, lead to a shortfall of the statutory workplace limit values and hence to a reduction of the initially high hazard by welding fume in processes with medium, high and very high emission rates.

	MIG-soldering of galvanized sheets	Resistance spot welding of galvanized sheets	CO_2 laser welding of galvanized sheets
Average of mass emission rates	1,3 - 9,1 [mg/s]	0,07 – 0,18 [mg/s] 16,2 – 83,7 [µg/point]	2,56 - 4,97 [mg/s]
Average of portions of particle fraction D < 20 nm	8,2 – 12,8 %	39,05 – 78,65 %	9,00 – 12,11 %
D < 50 nm	10,65 – 16,78 %	81,56 – 95,88 %	12,99 – 14,98 %
D < 100 nm	26,49 – 55,14 %	96,66 – 99,55 %	40,38 – 55,16 %
Average of mean particle-number concentration	5,03E+06 – 2,56E+07 [particle/cm³]	5,70E+05 – 1,75E+06 [particle/cm³]	1,21E+07 – 2,22E+07 [particle/cm³]
Average of mean particle surface concentration	2,85E+12 – 2,61E+13 [nm²/cm³]	1,92E+10 – 1,12E+11 [nm²/cm³]	9,09E+12 – 1,50E+13 [nm²/cm³]
Average from agglomerate number emission rates identified from exhaust volume flow and particle number concentration	1,91E+11 – 9,73E+11 [particle/s]	1,51E+11 – 5,28E+11 [particle/point] 6,88E+11 – 1,89E+12 [particle/s welding current time]	4,59E+11 – 8,44E+11 [particle/s]

Figure 4-8: Survey of particle characteristics measured [Source: Lenz, K. [16]]

5 Hazard evaluation during welding

For the determination of measures for health protection, an evaluation of the occupational hazards for the employed persons in compliance with § 5 Arbeitsschutzgesetz (ArbSchG, labour protection law) shall be carried out.

Knowledge of the “emission rate” and the “chemical composition” of the welding fume is a precondition for the hazard evaluation (see also TRGS 400) and for the choice of suitable protection measures (see also TRGS 500) for each process/material combination.

The following factors are part of the hazard evaluation:

Process specific factors

- The welding processes may be classified into four classes according to emission rates (mg/s) (emission classes 1 to 4) with respect to particles.

Effect specific factors

- The welding fume may be classified into three classes (effect classes A, B, C) with respect to the specific effect of their components on the human body.

The extent of health hazard (low up to very high) depends on process-specific and effect-specific factors (figure 5-1).

Figure 5-2 on page 80 contains an assignment to the welding fume classes on the basis of emission rates and effect (A 1 to C 4).

Workplace specific factors

- They include especially:
  spatial conditions, ventilation situation, head and body position during welding.

For **medium, high and very high emission rates (emission classes 2 to 4)** - without ventilation measures -, **concentrations of hazardous substances** occur in the breathing zone of the welder**,** which **exceed the limit values by far.**

For **low emission rates (emission class 1)**, the concentrations of hazardous substances in the breathing zone of the welder are by experience known to be on the level of the limit value or slightly below.

Without ventilation measures and due to additional circumstances at the workplace the health hazard is in some cases increased, e.g. in confined spaces.

Therefore, besides considerations concerning

1. selection of low emission processes
2. selection of low emission materials

best possible solutions for ventilation – as far as technically possible - shall as well be found and used.

It may be assumed that there is “no health hazard” if the substance specific limit values of the lung damaging and toxic substances contained in the welding fume are not exceeded and the values of the carcinogenic substances are clearly below the relevant limit values. The old TRK values should clearly be fallen below by protective measures. Attention is paid to the efficiency checks of protective measures according to No. 7 TRGS 400.

Through the choice of effective ventilation measures the health hazard is reduced or even excluded.

The classification of the hazard in the table in Figure 4-2 is effected on the basis of process and material specific factors and shall not be coupled to the protection steps of the GefStoffV at this place.

It is the basis for further evaluation at the workplace and for the choice of the relevant protective measures

Figure 5-1: Classification of the hazards into the welding fume categories

[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008 according to [17]]

Hazard	Welding fume category
I low health hazard	A1
II medium health hazard	A2, B1, C1
.**III** high health hazard	A3, B2, B3, C2, C3
IV very high health hazard	A4, B4, C4

Figure 5-2: Hazard evaluation on the basis of emission rates and effect; classification into the welding fume classes

[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008 according to [17]]

Welding fume: Emission classes/ emission rates [mg/s]		Process examples	Welding fume: effect		
			Effect class A	Effect class B	Effect class C
			Substances straining respiratory tract and lung[1]) e.g. Fe_2O_3	Toxic or toxic irritating substances[2]) e.g. F^-, MnO, CuO	Carcinogenic substances[2]) e.g. Cr(VI), NiO
			Hazard	Hazard	Hazard
1	< 1	e.g. UP[3)]	I (A1)	I (B1)	I (C1)
	< 1	e.g. TIG[4)]	I (A1)	II (B1)	II (C1)
2	1 to 2	e.g. laser welding	II (A2)	III (B2)	III (C2)
3	2 to 25	e.g. MMA, MAG (solid wire)	III (A3)	III (B3)	III (C3)
4	> 25	e.g. MAG	IV (A4)	IV (B4)	IV (C4)

I = low health hazard II = medium health hazard III = high health hazard
IV = very high health hazard;

A1 to C4: welding fume classes

1) If alloying or cover/filler components each are < 5%.

2) If alloying or cover/filler components each are > 5%.

3) Automated

4) See BG Information “Welding activities with chromium and nickel alloy filler and parent materials” (BGI 855) and “BG/BGIA Recommendations for Hazard Evaluation according to the Hazardous Substances Ordinance – Tungsten Inert Gas Welding (TIG Welding)” (BGI 790-012)

5.1 BGHM software

Evaluate welding fume exposure

The Berufsgenossenschaft Holz und Metall (BGHM - German Social Accident Insurance Institution for the woodworking and metalworking industries) now offers on its website a software for evaluating welding fume exposure by means of a hazard number.

The program is based on the model presented in the expert magazine “Schweißen und Schneiden” (“Welding and Cutting”), edition 09/11 under the title “Arbeitsschutzregelungen beim Schweißen” (“Health and Safety Regulations for Welding”). The main emphasis is on the comparison between processes, materials and workplace specific factors and not on occupational medical-toxicological evaluation. At the same time it becomes apparent why a health hazard remains for certain welding operations which points out that carrying respiratory equipment is a

necessary supplementary protective measure.

The software leads the user step by step into the description of the relevant workplace situation. This is done on the basis of hazard groups and special factors based on the interpretation of laboratory and practical measurement results and ending in a hazard number. Its level gives the final decision what protective measure package will have to be assigned to the described workplace situation. The software also provides the user with tailor-made proposals for improvement. By repeating the calculations with the factors of the individual proposals, the user can find out from which of the proposals made he/she gets the most profit. The evaluation of welding fume exposure by means of this software puts the requirements of GefStoffV and TRGS 528 as well as the procedures describes in BGIs 593 and 616 in concrete terms.

The program is given under

http://www.bghm.de Webcode 802

6 Measurement methods

Measurement of hazardous substances at the workplace has the purpose of obtaining a clear picture of the actual situation regarding hazardous substances, in order to allow appropriate decisions to be made on protective measures.

For this reason, a particular measurement should be carefully planned, prepared and carried out in such a way that the result really represents the situation.

Different measurement strategies have been developed over the course of time, differing in cost and effort according to the level of confidence required from the result.

Measurement methods for hazardous substances at the workplace usually consist of several individual steps, i.e.:

- arrangement for sampling
- sampling
- handling and storing of the sample
- preparation of the sample
- analytical determination
- calculation of the result.

Sampling is carried out by collecting hazardous substances on a sample carrier, where they cause changes to a chemical agent.

Sample carriers can roughly be classified into:
- sample carriers for gases
  (ozone, nitrogen oxides, carbon monoxide)
- sample carriers for airborne particles (fume, dusts)

The level of emissions of hazardous substances (mg/m³) at the workplace and the corresponding exposure experienced by the welder are determined by different measurement methods.

In analogy to the sample carriers, the differentiation is made between:
- measurement methods for gaseous substances (gases) and
- measurement methods for airborne particles (fume, dusts)

These measurements are basically carried out in such a way that the concentration of hazardous substances present in the welder's breathing zone can be assessed.

6.1 Measurement methods for gaseous substances

Personal exposure is, in general, determined by (figure 6-1):
- continuous measurement methods with direct reading measurement instruments (direct reading electrical apparatus, detector tubes),
- discontinuous measurement methods.

Continuous measurement methods

Direct reading electrical apparatus

The use of mobile infrared analysers for determining CO concentrations or of direct reading apparatus for measuring nitrogen oxides and ozone, which operate according to the chemiluminescence method, makes it possible to indicate the amount and time of potential

exposures to hazardous substances directly at the workplace. This apparatus is useful for screening measurements of: variation of concentration in time, time weighted average concentration as well as for comparison with limit values and periodic measurements. Their use and maintenance calls for qualified personnel. Attention shall be paid to cross sensitivities.

*Figure 6-1: Measurement of individual gases and organic vapours (Excerpt from DIN EN ISO 10882 *); Annex B)*

Measurement method	Gases and vapours				
	ozone (O3)	carbon monoxide CO	carbon dioxide CO_2	nitrogen oxide (NO)+ nitrogen dioxide (NO_2)	organic vapours
	0,01 ppm to 3 ppm	3 ppm to 500 ppm	500 ppm to 10 %	0,3 ppm up to 250 ppm	-
Direct reading electrical apparatus	generally used	generally used	generally used	generally used	available, but usefulness limited by poor specificity
Detector tubes	available, but not recommended	generally used	generally used	generally used	available, but usefulness limited by poor specificity
indirect methods involving laboratory analysis	not generally applicable	not generally applicable	not generally applicable	available but not generally used	generally used

*) DIN EN ISO 10882 Sampling of airborne particles and gases in the operator's breathing zone (Part 2: Sampling of gases)

Detector tubes

A defined volume of air is aspirated from the open detector tube by a suitable manual or battery-driven pump. The concentration can be read from the change in colour of the filler compound, which is specific for a hazardous substance or a group of substances. There are short and long term detector tubes.

Detector tubes are most useful for screening measurements of time weighted average concentration rather than for comparison with limit values or periodic measurements.

Figure 6-2: Direct reading detector tubes: accuro 2000 one hand-operated gas detector pump and automatic pump with detector tube for the measurement of gaseous hazardous substances [Source: Spiegel-Ciobanu, BGI 593 Ed. 2008 according to Dräger]

Discontinuous methods

The sampled air is drawn by a motor-driven pump through a suitable sorption tube, such as e.g. activated carbon or silica gel tubes. The absorbing capacity of the absorber shall be sufficiently high. Sampling can be made at fixed points or directly at the person.

The use of passive samplers is also possible. Evaluation is exclusively made in laboratories. These methods have separate steps of sampling and analysis.

6.2 Measurement methods for particulate substances

When concentrations of particulate hazardous substances are measured, a distinction is made between:

- sampling systems for measurements made on the person (PAS) with a personal dust collector,
- sampling systems for fixed point measurements with a stationary dust collector (figure 6-11 on page 89).

Sampling on the person
Sampling on the person with the personal dust collector (Personal Air Sampler = PAS) is carried out in the welder's breathing zone (figure 6-3 and figure 6-4 on page 85) with a "sampling head" for the inhalable fraction, which collects airborne particles on a filter.

With the aid of a pump, attached to the welder's body by a belt, a certain volume of air is aspirated. A more suitable method for correct assessment of the welder's exposure at the workplace is sampling directly on the person (during welding behind the welder's helmet/face shield).

The determination of the welding fume concentration is done in compliance with the standard – mostly with a sampling head capturing the inhalable fraction (E dust), e.g. BIA-GSP-system (see clause 3.1 of the present BG Information)

After sampling and transport of the filter to the laboratory, a quantitative (mg/m³) and qualitative (chemical composition) analysis of the sample is made in the laboratory. The analytical determination by weighing and chemical analysis usually is restricted to the relevant key components.

The European/International Standard EN ISO 10882-1 “Sampling of airborne particles and gases in the operator's breathing zone” Part 1 specifies procedures for the personal sampling of airborne particles during welding and allied processes.

According to the standard the sampler shall be located behind the welder’s face shield. It can have different positions: to the left or right of the face or under the chin. The measurement is carried out by the sampling head for the E fraction of the dust.

Figure 6-3:
Measurement of airborne particles with a personal dust collector (PAS) and check for gaseous hazardous substances by means of detector tubes
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, Messtechnik NMBG]

Figure: 6-4 Personal measurement with PAS for the determination of particulate hazardous substances
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, Messtechnik NMBG]

Figures 6-5 to 6-7: Examples of arrangements for mounting samplers behind the welder's face shield; Annex A (informative) from EN ISO 10882-1, see clause 12.3.

Figure 6-5:
Welder's face shield with a sampler attached by means of a removable clip
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008 according to DIN EN ISO 10882-1]

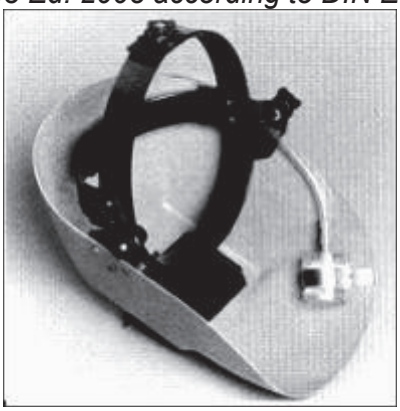


Figure 6-6:
Welder wearing a sampler attached to a sportsperson's headband
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008 according to DIN EN ISO 10882-1]

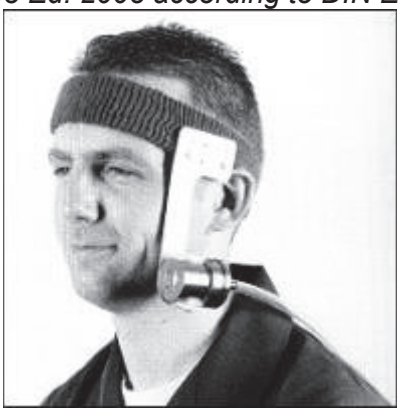
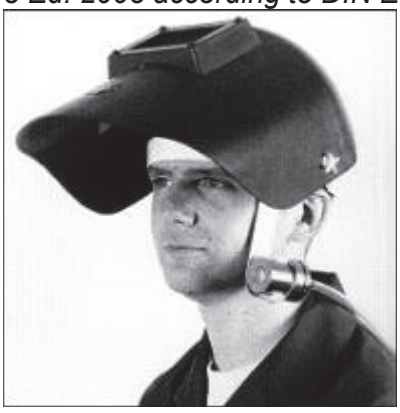


Figure 6-7:
Welder wearing a sampler attached to a sportsperson's headband and a welder's face shield
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008 according to DIN EN ISO 10882-1]



Sampling head PGP-EA

A newly developed sampling head PGP-EA supplements the sampling system mentioned above (PGP) and enables simultaneous sampling of the inhalable and the respirable dust fractions. The PGP-EA can be used for the determination of the mass concentrations of A and E dust and the substance concentrations in the A dust during welding and allied processes as a standard system in the measuring system of the Berufsgenossenschaften for hazardous substances (BGMG).

In analogy to the sampling head GSP 3,5 the inhalable fraction (E dust) is captured by a suction cone with a volume flow of 3,5 l/min. Inside the sampling head PGP-EA the aerosol is divided into two fractions. For this purpose, an open pore polyurethane foam as size selective and collecting element is used together with a downstream plane filter. The porosity and the geometry of the polyurethane foam are chosen such that respirable dust particles according to the definition in EN 481 may pass.

The foam is inserted into an annular holder, the plane filter with a diameter of 37 mm is inserted into the usual capsule in connection to the universal mounting device of the PGP system (see figures 6-8 and 6-9). Both filter elements shall be transported together in a tin, inserted into the sampling head on site and mounted with the special suction cone to the filter mounting device of the PGP system.

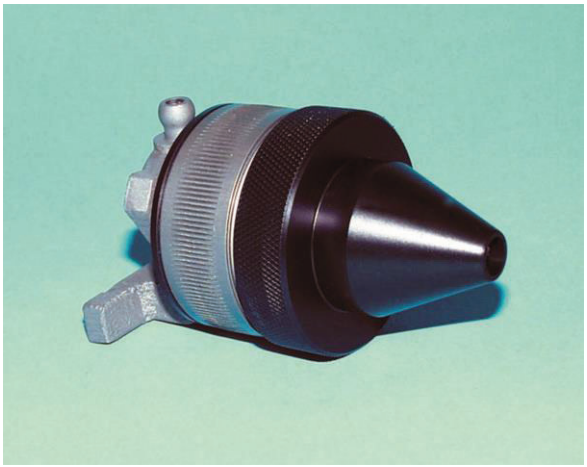


Figure 6-8: Sampling head PGP-EA (Source: IFA)

Figure 6-9: Dismounted sampling head PGP-EA (Source: IFA)

The E-dust concentration is determined by weighing both filter elements (foam and plane filter) and the A-dust fraction by weighing only the plane filter. The elementary analysis of dust in the plane filter (A-dust) is possible by means on standard methods [22]

Figure 6-10: Welder's safety helmet with integrated sampling heads PGP-EA and GSP for simultaneous sampling
[Source: Messtechnik BHGM/Fiegehenn]

Stationary sampling

Sampling with a stationary dust collector (figure 5-10) is made at a fixed point in the vicinity of the welder (working area). The sampling position in the room is chosen such that it is suitable for determining the general concentration of welding fume in the workplace atmosphere. It is also used for evaluating the ventilation conditions in the room.

Figure 6-11:
Stationary dust collector (VC 25) for fixed point sampling (measurement) of particulate hazardous substances
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, Messtechnik NMBG]

7 Assessment of airborne particles during welding and allied processes

- During all processes with unalloyed/low alloy material (parent and filler materials), where the portions of chromium, nickel, cobalt, manganese, copper, barium, fluoride are individually below 5 % by weight and where no mutagenic, carcinogenic, fibrogenic, toxic or sensitising substances are contained in the welding fume, it is in most cases sufficient for the evaluation of the welder's exposure at the workplace to determine the concentration of the welding fume/respirable fraction and comparison with the relevant limit value.

  Here, the limit value for the A fraction of 3 mg/m³ is the upper limit and is decisive.

  During thermal spraying or for mixed workplaces (welding and grinding) the inhalable fraction (E dust) can be important in addition to the respirable one. Here, the determination of the inhalable dust concentration is also recommended.

- During all processes with high-alloy materials (parent and filler material), where the individual portions of chromium, nickel, cobalt, manganese, copper, barium, fluoride are at least 5 % by weight and where mutagenic, carcinogenic, fibrogenic, toxic or sensitising substances are contained in the welding fume, the limit values of the relevant key component shall be observed. For the specified key components see as well figures 3-2a to 3-2e and figures 3-5, 3-6, 3-8 on pages 52 to 69 of the present BG Information.

  The welding fume concentration is subject to compliance with the key component and therefore depends on the

a) processes and materials,
b) chemical composition of the welding fume,
c) concentration of the key component in the welding fume and its limit value.

In this case, the welding fume concentration is below 3 mg/m³ A.

Here, compliance with the **limit value for the A fraction is not sufficient, but the limit value of the relevant key component is decisive** (see examples in figure 7-1).

- For all processes, where compliance with the valid air limit value for welding fume or the respirable fraction of the dust is not possible – in spite of ventilation measures- in certain areas, as confined spaces (e.g. boilers, containers, ship raised access floors) as well as other areas with low/insufficient air exchange, additional protection measures (e.g. organisational measures and use of personal protective equipment) are necessary.

Compliance with the limit value for the key component – consequently compliance with the calculated welding fume concentration according to “Health and Safety Executive” with the formula:

$$LV_{WF} = \frac{100 \cdot LV_i}{C}$$

with
LV_i = substance specific limit value, mg/m³
C = percentage (%) of the key component in the welding fume
LV_{WF} = limit value for welding fume/welding fume concentration, mg/m³

- means at the same time compliance with the limit values of all substances contained in the welding fume. See also BGI 616, [18]

For carcinogenic substances, for which at present no AGW (see 1.6.1) is specified the minimisation obligation according to the hazardous substances ordinance applies. The upper limit for the measured hazardous substances concentrations are the old TRK, which reflect the state of the art until end 2005.

As soon as new guiding values, describing the state of the art, such as according to TRGS 528, are specified and published (e.g. for chromium(VI)-compounds/nickel oxide), these should be taken as upper limit for the corresponding concentrations (see example)

Figure 7-1: Examples
[Source Spiegel-Ciobanu, BGI 616 Ed. 2005 [18]

Process	First key component	Limit value of key component or value according to state of the art	Welding fume concentration when complying with the limit value of the key component
Manual metal arc welding with high-alloy 18% Cr and 8% Ni covered electrodes (here: with 6% Cr(VI) in welding fume)	Cr-IV compounds	0,03 mg/m³	0,5 mg/³
Metal inert gas welding with nickel base filler metal (here: with 50% Ni in welding fume)	NiO	0,5 mg/m³	1,0 mg/m³
Metal arc welding with low-alloyed self-shielded flux-cored wire electrodes (here: with 20 % Mn in welding fume)	Manganese oxide	0,5 mg/m³	2,5 mg/m³

8. Identification and evaluation of the hazardous substances concentration

For the determination of the exposure of the welder to welding fume and comparison with the air limit value for welding fume (at present air limit value for the A fraction of the dust) sampling shall be carried out behind the welder's face shield or hand screen. This is also true for confined spaces like containers, boilers or raised access floor cells on ships (see as well clause 5 Measuring methods).

If – in exceptional cases – the sampling of welding fume is only possible outside the welder's face shield (in front of or beside the protective shield or screen), the measured hazardous substances concentration does not give any information on the exposure of the welder, even if compared with the relevant limit value. In this case, only a statement concerning the direct ventilation situation is possible.

For the determination and evaluation of the hazardous substances concentration at the workplace, TRGS 402 is used.

It contains a description of how to verify compliance with the air limit values for hazardous substances at the workplace, the exposure evaluation and the efficiency of protective measures.

Exposure determination can be made by workplace measurements and by equal determination methods. For substances with AGW, the evaluation of the exposure is made by comparison with the limit values: for substances without AGW other criteria are mentioned, e.g. VSK-, BG-/IFA recommendations; as e.g. BG/IFA recommendation for certain soldering work with electrically heated soldering bits at electrical or electronic assemblies and their individual components (bit soldering)

For the "Bewertung von Stoffgemischen in der Luft am Arbeitsplatz" (Evaluation of mixed substances in the air at workplaces) during welding and allied processes reference is made to clause 3.3 "Vereinfachtes Bewertungsverfahren anhand von Leitkomponenten" (Simplified evaluation procedure on the basis of key components) (see as well clause 3 of the present BG Information).

If the limit value(s) valid for the key component(s) or values according to the state of the art (e.g.

Cr(VI), Ni) is (are) observed in the breathing zone of the welder, the concentrations of all other hazardous substances in the hazardous substances mixture are below their relevant limit values.

The result of the evaluation refers to “protective measures sufficient/not sufficient”. Verification of the efficiency of protective measures is taken for supporting the results.

9. Situation of hazardous substances at the workplace

9.1 Exposure to welding fume

An evaluation of the measurements of welding fume exposure at workplaces carried out by the Metall-Berufsgenossenschaften with respect to compliance with

- the limit value then valid of the respirable fraction of 6 mg/m³ and
- the indicative value for welding fume for preventive occupational medical examinations of 3 mg/m³

is represented in figure 9-1.

Figure 9-1: Exposure to welding fume[1], data period 1986-1996
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, following MEGA analysis, BGIA]

Procedure	Sampling: at the person (PAS)						Sampling: stationary					
	with capture[4]			without capture[4]			with capture[4]			without capture[4]		
	Number of measuring data	Frequency of exceeding for		Number of measuring data	Frequency of exceeding for		Number of measuring data	Frequency of exceeding for		Number of measuring data	Frequency of exceeding for	
		6 mg/m³ [2]	3 mg/m³ [3]		**6 mg/m³** [2]	3 mg/mm³ [3]		**6 mm/m³** [2]	3 mg/m³ [3]		6 mg/mm³ [2]	3 mg/mm³ [3]
		%	%		%	%		%	%		%	%
Manual metal arc welding	386	**19**	38	186	**49**	73	45	**4**	8	41	**4**	19
MAG welding	741	**31**	58	544	**69**	83	187	**5**	16	110	**14**	29
MIG welding	250	**22**	43	176	**43**	68	58	**2**	23	52	**7**	24
TIG welding	149	**5**	10	182	**5**	15	39	**0**	1	35	**4**	9
Thermal cutting (flame, plasma, laser cutting)	66	**14**	23	18	**52**	69	33	**0**	11	13	**18**	26
Thermal spraying (flame, arc, plasma spraying)	40	**14**	29	1	**0**	0	28	**15**	19	0	-	-

[1] welding fume = fine dust = total dust (see as well clause 3.1)
[2] 6 mg/m³ = limit value for respirable fraction in the period 1986-1996
[3] 3 mg/m³ = indicative value for preventive occupational medical examinations according to BGI 504-39 "Welding fume"
[4] with/without extraction system

9.2 Exposure to chromium(VI) compounds and nickel oxide

Research studies and occupational exposure measurements during processing of chromium-nickel steels and of nickel and nickel-base alloys without ventilation measures or with insufficient efficiency of ventilation measures reveal the situation represented in figure 9-2:

Figure 9-2: Exposure to chromium (VI) compounds and nickel oxide
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008]

Process	Exposure to Cr(VI) compounds for chromium and chromium-nickel steels		Exposure to nickel oxide For chromium-nickel steels		nickel and nickel-base alloys	
	above 0,1/0,05[1)]	below 0,1/0,05[1)]	above 0,5[2)]	below 0,5[2)]	above 0,5[2)]	below 0,5[2)]
Manuel metal arc welding with covered electrode	always	-	-	almost always		almost always
MAG welding with solid wire	-	often	-	often	almost always	-
MAG welding with flux-cored wire	often	-	-	almost always	-	-
MIG welding	-	-	-		almost always	-
TIG welding	-	always	-	always	-	almost always
Plasma cutting	often	-	always	-	always	-
Laser cutting	often	-	always	-	always	-
Thermal spraying	often	-	always	-	always	-

[1)] indicative value for chromium(VI) compounds with respect to the state of the art end 2004 (0,1 mg/m³ for manual metal arc welding; 0,05 mg/m³ for all other processes)

[2)] indicative value (i0,5 mg/m³ for all processes) for nickel oxide with respect to the state of the art in the end 2004

10 Protective measures against hazardous substances

In order to minimise the health hazard to the welder by hazardous substances at the workplace, technical, organisational and – in certain situations – also personal protective measures should be effected according to the GefStoffV and also specified by TRGS 500. GefStoffV, TRGS 528 and TRGS 500 indicate that efficiency of the implemented protective measures should be checked by verification of their efficiency.

As the magnitude of the emission rates is influenced by a number of factors (see clause 1.4) and, in addition, the concentration at the workplace depends on workplace specific factors (see clause 4), the necessary protection classes may also differ from those given in Figure 10-1.

A prevention concept has been developed with the purpose of obtaining compliance with the limit values and of reducing exposure at the workplace. The prevention concept has the following topics (see as well Annex):

Figure 10-1: State of the art from exposure data in welding operations[3,4]
The information refers to workplaces with welding fume extraction [Source. Table 2 TRGS 528]

Process	**Filler metal or material**	**Welding fume** in mg/m^3	**Chromium (VI) comp.** in mg/m^3	**Nickel and its comp.** in mg/m^3	**Ozone** in mg/m^3	**Nitrogen oxide** in mg/m^3
Gas welding (autogenous welding)	unalloyed, low alloy steels	particulate emissions not relevant			Not assignable[1)]	Not assignable[1)]
MMA	unalloyed, low alloy steels	≤ 3 (A) ≤ 10 (E)	Not relevant		Not assignable[1)]	No assignable[1)]
	high alloy steels	≤ 3 (A) ≤ 10 (E)	≤ 0,03 (E)	≤ 0,05 (E)		
MAG / MIG	unalloyed, low alloy steels	≤ 3 (A) ≤ 10 (E)	Not relevant		≤ 0,2	Not assignable[1)]
	high alloy steels	≤ 3 (A) ≤ 10 (E)	≤ 0,02 (E)	≤ 0,1 (E)		
UP-Schweißen		≤ 1 (A)	Not relevant		Not relevant	
TIG welding[2)]		≤ 1 (A) ≤ 2 (E)	≤ 0,01 (E)	≤ 0,01 (E)	≤ 0,1	Not assignable[1)]
Resistance welding		≤ 2 (A) ≤ 4 (E)	Not relevant		Not relevant	
Thermal spraying (flame, arc, plasma		≤ 2 (A) ≤ 10 (E)	≤ 0,01 (E)	≤ 0,05 (E)	Not assignable[1)]	Not assignable[1)]
Flame cutting		≤ 3 (A) ≤ 10 (E)	Not relevant		Not assignable[1)]	NO: ≤ 2,5 NO_2: ≤ 2

1) State of the art not assignable, because sufficient amount of data for specification of a value is not available. Number 5.1 para. 9 applies.
2) See also BGI 790-012
3) Industry and workplace specific deviations possible.
4 For information in Table 2 the following condition applies: Less than 5% exposure relevant extra work such as grinding, cutting, cleaning, polishing is performed.

10.1 Technical protective measures

The technical protective measures listed in the following should be chosen individually or in combination.

10.1.1 Selection of low fume emission processes

- High-alloy covered electrodes are used in manual metal arc welding of chromium-nickel steel. This process produces high amounts of fume which contain hexavalent - carcinogenic - chromium compounds (here: chromates) in critical concentrations. It is possible to convert to metal active gas welding (MAG). Although MAG welding produces more chromium compounds overall, these are, however, predominantly trivalent (non-carcinogenic) and seldom hexavalent (carcinogenic).

Figure 10-2: TIG welding, a process with low welding fume emission
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008]

Figure 10-3: Submerged arc welding with low emission of hazardous substances
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008]

- In comparison to manual metal arc welding, metal active gas welding (MAG) and metal inert gas welding (MIG), tungsten inert gas welding (TIG) generates much less fume (figure 10-2). For this reason, tungsten inert gas welding can be called a low fume emission process. It is especially recommended for welding materials which contain high quantities of chromium and nickel.

- In submerged arc welding the welding process is carried out under a blanket of granular flux

(figure 10-3). Thus, only small quantities of hazardous substances are generated. In addition, for procedural reasons, the operator is generally not very close to the weld. For these reasons, submerged arc welding is recommended as an alternative to other arc welding processes – if technically possible.

- Pulsed operation during gas-shielded arc welding (pulsed-arc welding) leads to a reduction of the welding fume emission by 50 % to 90 %.

- The application of energy reduced short arc processes as shown in the graphics (Figure 10-4 and 10-5 on page 98) lead to significantly reduced emission values.

  The measurement values refer to a uniform deposition rate of 4 m/min G3Si Ø 1.2 mm. The chemical composition of the shielding gases used is indicated as well as the nomenclature according to DIN EN ISO 141745 (welding materials - gases and mixed gases for arc welding and allies processes).

- With the same deposition rate, the ColdArc® process generates clearly less emission than the short arc process. The reduction of the welding fume emission is up to 75%.

- Laser flame cutting of unalloyed and low-alloy steel leads to lower hazardous substance emissions than flame cutting.

- High pressure laser cutting (with N_2) instead of laser flame cutting (with O_2). For the same material and the same sheet thickness, emissions of hazardous substances during high pressure laser cutting can be lower by a factor of 2 to 15 than those during laser flame cutting.

- Where possible, flame spraying should be preferred to arc spraying, because of the lower emissions. On the other hand, the risk of generation of nitrous gases shall not be neglected here.

10.1.2 Selection of low emission materials

- Fume generated in soldering and brazing and the related exposure can be reduced by a careful choice of materials (e.g. low melting point brazing alloys with high content of silver). Special attention shall be paid to brazing with nickel-base brazing alloys and brazing alloys containing cadmium (due to the carcinogenic effects of cadmium and nickel). In particular, the possibility of replacing nickel-base brazing alloys and brazing alloys containing cadmium by less hazardous solders should be explored.

- Low-emission materials, e. g. the application of high alloy stick electrodes in manual metal arc welding or flux-cored wires in shielding gas welding emitting small portions of chromium(VI) compounds into the welding fume.

The selection of filler materials containing small portions of potassium, calcium or sodium silicate as binding agent and using instead e.g. lithium waterglass, reduces the percentage of chromium(VI) compounds in the welding fume by approx.. 30-50%.

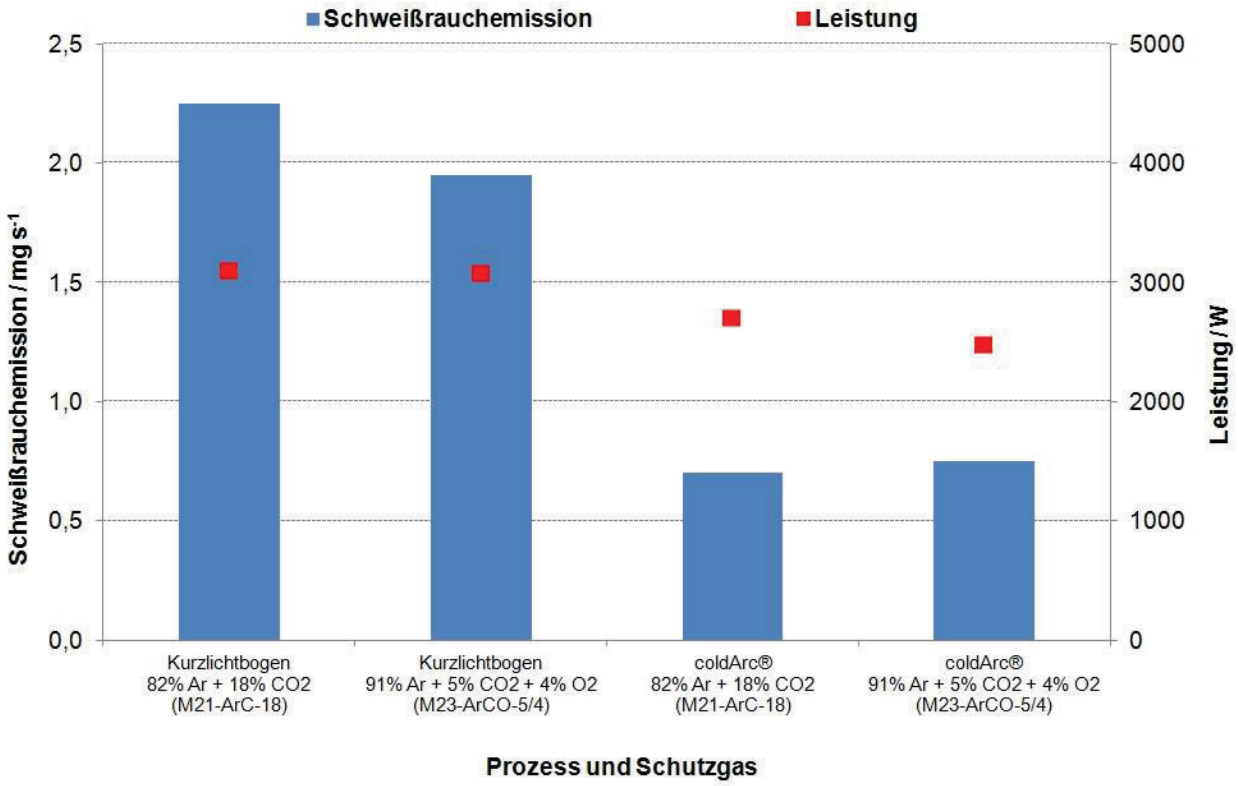


Figure 10-4: Comparison ColdArc® - short arc (4m/min) [Source: Rose, S. [26]]

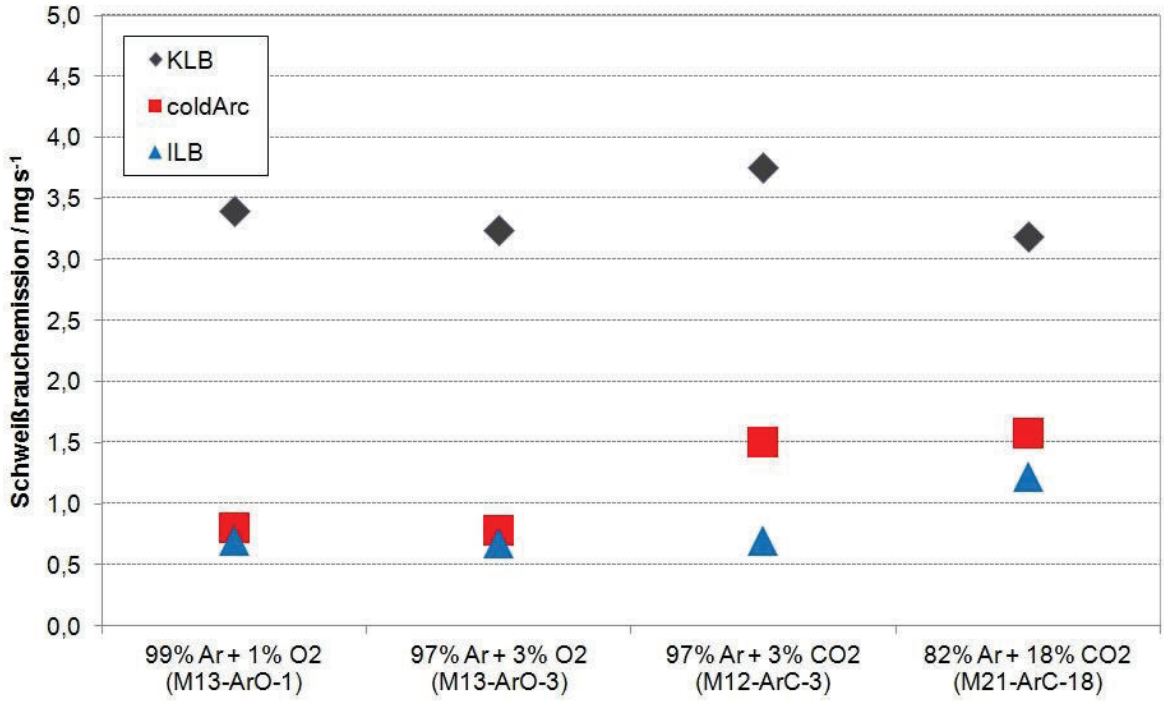


Figure 10-5: Comparison ColdArc® - short arc-pulsed arc; influence of shielding gas on welding fume emission [Source: Rose, S. [26]]

10.1.3 Improvement of the working conditions

The generation of hazardous substances and their penetration into the breathing zone can be reduced by selection of favourable welding parameters (figure 10-6) and by an improvement of other working conditions.

10.1.3.1 Selection of favourable welding parameters

The selection of favourable welding parameters may contribute substantially to minimising hazardous substances. It is advisable to avoid high levels of welding voltage, welding current and shielding gas flow rate.

10.1.3.2 Use of non-thoriated electrodes in TIG welding

Non-thoriated electrodes for TIG welding with other oxide additions (e.g. additions containing cerium or lanthanum) are already standardized in DIN EN 26848 and available on the market.

10.1.3.3 Selection of favourable parameters for laser cladding

In laser cladding, hazardous substances can be minimised by
- lowest possible energy per added powder in relation to the process result and
- best possible powder selection with respect to particle size distribution.

10.1.3.4 Selection of favourable parameters for laser cutting

In laser cutting, hazardous substances can be minimised within the optimum parameters by
- lower laser beam power
- short lens focal length for thin sheets and
- low cutting pressure.

Figure 10-6: Selection of favourable parameters for different processes
[Source: Spiegel-Ciobanu, BGI 593 Ed,. 2008]

Process Parameter	Oxyacetylene process	Manual metal arc welding	MAG/MIG welding
Torch size	small		
Oxygen consumption	limited		
Flame length	short		
Cutting speed (mm/s)	low		
Welding voltage		low*)	low*)
Welding current		low*)	low*)
Arc length		short	
Composition of shielding gas			higher contents of inert gas (e.g. Ar)
Flow rate of shielding gas			low*)

*) - with regard to manufacturer's data.

10.1.3.5 Surface condition of the workpiece

During welding and cutting operations on coated workpieces, additional hazardous substances are generated from the coating which can be avoided by the following measures:

- reduction of the coating thickness to 15 to 20 µm,
- removal of coatings in the welding area,
- removal of contamination on the workpiece surface (e.g. oil, grease, paint, residues of solvents).

10.1.3.6 Body posture of the welder

The welder's workplace and the positioning of the workpiece should be such that

- the horizontal distance between the welding location and the welder's head is as large as possible and
- the vertical distance is as short as possible.

This ensures that hazardous substances ascending with the thermal updraft can largely be kept away from the welder's breathing zone.

10.1.4 Technical safety devices

Special technical safety devices may be used to reduce the emission and immission of hazardous substances.

10.1.4.1 Torch holder with gas shut-up valve

At fixed workplaces for oxyacetylene operations it is possible to use torch holders fitted with automatic gas shut-off valves. This avoids the generation of large quantities of nitrous gases during breaks.

10.1.4.2 Plasma cutting with water protection device
(with water curtain/air-water shower or water protection bell)

Plasma cutting with a water curtain is usually carried out in conjunction with a water cutting table and a water injection cutting torch. The emission of hazardous substances is reduced but cannot be avoided.

10.1.4.3 Plasma cutting under water

Today, plasma cutting under water cover is carried out in numerous small and medium-sized plants. This process reduces the emission of hazardous substances and noise to a considerable extent.

Depending on the application (sheet thickness, type of material), emission of airborne particles can be reduced by a factor of up to 500 for comparable cutting operations. The emission of gases, especially nitrous gases (in plasma cutting with argon/nitrogen/ hydrogen as plasma gas), is reduced by about a half.

10.1.4.4 Flame cutting and plasma cutting on the water surface

The sheet is placed on the water surface of a cutting tank and a concentric exhaust can be installed around the torch so that the emission of hazardous substances is reduced.

A comparison between plasma cutting in atmosphere, plasma cutting above water bath and plasma cutting under water shows the following reduction in emission:

for dust = 100:10:1
for NO_x= 4 : 2 : 1

10.1.4.5 Flame cutting under water

Studies on flame cutting with a water cover have shown a radical reduction in the emission of hazardous substances compared to atmospheric flame cutting:

- particulate emissions are reduced by several orders of magnitude,
- emission of gaseous substances also decreases substantially.

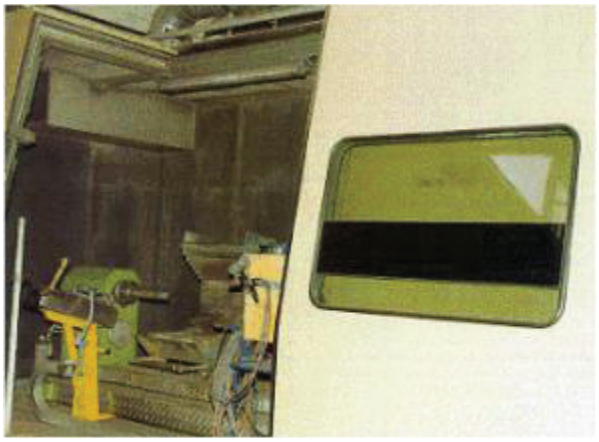
10.1.4.6 Operations in enclosed booths

Thermal spraying should be carried out in enclosed booths, if possible in automated mode (operators outside).

Plasma spraying in enclosed booths is standard practice today. (Figure 10-7).

Enclosure of the working area is also recommended for laser material processing. According to the state of the art, equipment for laser beam welding and cutting are enclosed and hence protect against laser radiation and hazardous substances.

Figure 10-7:
Enclosed booth for plasma spraying
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008]



10.1.5 Ventilation

Practical experience shows that ventilation often is the only possibility for minimising hazardous substances.

a) Free ventilation (natural ventilation)

Air is exchanged between the interior and the exterior as a result of a pressure gradient due to wind and temperature differences between the outside and the inside.

The exchange of air takes place through windows, doors, ridge turrets etc. Free ventilation can only be the solution for low hazard levels (determined by amount, concentration, type of hazardous substance).

An example is TIG welding with non-thoriated tungsten electrodes.

b) Forced (mechanical) ventilation

The exchange of air between the room and the outside realized by circulating units (e.g. fans or blowers) is called forced (mechanical) ventilation.

To obtain effective forced ventilation in rooms or halls, the air flow pattern, for example in welding - thermal uplift of hazardous substances from the bottom to the top - should be arranged so that the exhaust air is removed from the upper part of the room and fresh air flows in at the bottom.

10.1.5.1 Extraction

In welding processes where high concentrations of hazardous substances and/or critical substances are to be expected in the workplace atmosphere, the use of extraction systems (Figure 10-8) for a direct local capture of the generated hazardous substances is the most effective protective measure. All process/material combinations known to cause medium, high and very high hazards (see clause 4 of this BG Information) are addressed.

The purpose is optimum capture and exhaust of hazardous substances and high efficiency of the filter system.

The capture element is critical for the effectiveness of extraction (Figure 10-9 on page 103).

The choice of shape, the correct dimensioning and positioning of capture elements shall correspond to the thermal movement of the welding fume and their quantity and depends on the particular working situation (see Directive DVS/VDI 6005).

The capture element should always be placed as close as possible to the generation area of hazardous substances.

For flexible capture elements it is important that the welder is willing to position it correctly.

Capture elements with flange are more effective than the conventional types without flanges used previously (figure 10-10 on page 105)

Figure 10-8: Example of a stationary extraction
[Source: Spiegel-Ciobanu, BGI Ed. 2008, photo Fa. KEMPER]

Figure 10-9:
Gas-shielded metal arc welding (MIG/MAG) with extractor
[Source: Fa. KEMPER]

Tests on a test stand show that refitting of funnel guards with a flange of a width of 50 mm already may lead to an increase of suction reach of about 10 % in all directions or a reduction of air quantity demand of about 20 % (see as well “Gesund und Sicher” 9/2002, “Absaugtechnik – Teil 2”).

The filter system used plays a decisive role in the separation of hazardous substances.

Among other factors, the choice of these filter systems depends on the chemical composition of the hazardous substances.

For the filtration of metal dusts, self-cleaning surface filters (cleaned with compressed air) can be recommended.

Separation of gases and especially of organic components is very difficult and shall be adapted to each single case (process, material). The extraction equipment requires an efficient separation of the hazardous substances for the recirculation of the air and/or for the environment. Various filter systems - mechanical, electrostatic - are available.

Available **extraction equipment** may be differentiated into:

- static extraction equipment and
- mobile extraction devices.

Static extraction equipment is suitable for repetitive welding operations carried out at fixed locations (e.g. mass production). Extracted air is directed to the outside by ducting (e.g. within a larger centralised system). Depending on the task, the capture elements are fixed in position or can be guided by flexible hoses.

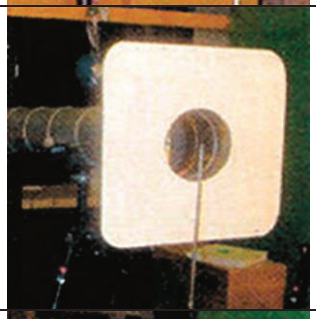
These units are available in different forms. Cutting tables are usually fitted with down-draught extraction (extraction below the table). Down-draught extraction acts in the direction opposite to the thermal up-current of hazardous substances. An additional extraction device can be fitted above the table and to the rear. Extractor tables fitted to flame and plasma cutting systems are intended to work in sections and hence concentrate on the respective dust generation area.

Example:
During laser cutting with down-draught extraction and optimum ambient air changes, emissions are 10 times less than the OEL value for the respirable fraction of the dust. This ensures continuous and reliable compliance with these limit values.

Booths with extraction for welding and thermal spraying:

Booths incorporating extraction have yielded very good results in practice. The walls of the booth enclose the working area as closely as possible. Air flowing in through the booth opening is exhausted on the opposite side. Inside these booths, hazardous substances should be captured and extracted directly at the area of generation by special capture devices.

Figure 10-10: Tests on the test stand;
Table of results for the measured suction reaches at 1200 m³/h (GS 9/2002 "Absaugtechnik – Teil 2")

Description	Figure	Suction range x at 1200 m³/h (w_x = 0,3 m/s)[1)]	Suction range x at 1200 m³/h (w_x = 0,5 m/s)[2)]	Required volume flow for w_x = 0,4 m/s x = 300 mm
Suction tube → 150 mm without flange		290 mm	217 mm	1705 m³/h
Suction tube → 150 mm with flange 400 x 400 mm		337 mm	255 mm	1270 m³/h
Funnel → 300 mm without flange		302 mm	240 mm	1580 m³/h
Funnel → 300 mm with flange 400 x 400 mm		335 mm	254 mm	1290 m³/h
Asymmetric inflow nozzle with flange 360 x 290 mm (Kemper)		343 mm	248 mm	1220 m³/h

Nozzle plate 400 x 400 mm, r 40 mm (Kessler+Luch)		344 mm	258 mm	1220 m³/h

1) Mean values from 30 measuring points in 2 axes displaced by 90°
2) Mean values form 26 measuring points in 2 axes displaced by 90°

Table of results with measured suction ranges at 1200 m³/h. For a simplified reading, the mean suction range is given.

In laser processes booths also offer a good protection against hazardous substances and optic radiation.

The separator may be connected to the central extraction system or the booth may have its own separator.

Mobile welding fume extraction devices
are suitable when the workplaces vary and can be used in many fields. These devices operate with air recirculation, i.e. the captured and filtered air is recirculated into the working area. Mobile extraction devices may be combined and operated with different capture devices:

- gas shielded torches with integrated extraction,
- hand shield with integrated extraction
- movable capture devices (extractor ducts)

Formerly, the extraction and its regulation were done by means of an annular nozzle; the new version, where the extraction device is attached to the torch so that it can be turned, is better adaptable to the local conditions and the welding situation. A larger degree of capture is reached without noteworthy adverse effect on the gas shielding.

Existing torches can also be refitted with it.

For recirculation of air a sufficient amount of fresh air shall be guaranteed. The proportion of the recirculated air shall have a maximum of 50 % in the fresh air.

Ventilation systems with recirculation may be used when they are type tested or when their required efficiency has been checked by individual measurements (see also TRGS 560).

The proportion of non-extracted hazardous substances is decisive in case less than 85% are extracted (see TRGS 560). For extraction of welding fume with carcinogenic or mutagenic or reprotoxic portions of category 1 or 2, recirculation of air shall only be made with type tested welding fume extraction devices of welding fume class W2 or W3. Requirements of TRGS 560 shall be considered here. Mobile welding fume extraction devices comply with the requirements if they have been tested by the Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA = Institute for Occupational Health and Safety) and published in the IFA handbook under the section “510215 – Mobile Schweißrauchabsauggeräte – Positivliste” (Mobile welding fume extraction devices – positive list).

Today, mobile filter extractors to the state of the art are successfully used for welding.

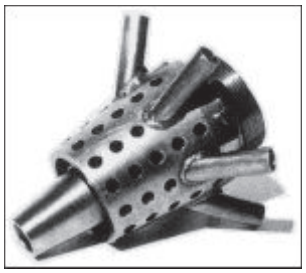
Figure 10-11: Capture element fixed to the torch
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, DINSE GmbH]

Torches with integrated extraction are suitable for MIG/MAG processes. They allow direct extraction at the point of generation of hazardous substances. They may be used in stationary and in mobile systems (figure 9-10)

Figure 10-12: Torch with integrated extraction
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, DINSE GmbH]

For Nd:YAG lasers working head integrated extraction nozzles were also developed.

Figure 10-13: Working head integrated extraction for Nd:YAG lasers (Source: Heinz-Piest-Institut, PHI extractor nozzle MK 5)



When designed for high vacuum, capture elements and piping/hoses only need small diameters as the air volumes required for ventilation are small.

Figure 10-14:
Torch for gas-shielded metal arc welding (MIG/MAG) with integrated extraction for automated systems
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, DINSE GmbH]

10.1.5.2 Supply air systems/room ventilation

Generally, for welding processes in halls supply air and exhaust air systems are required for the removal of hazardous substances. The air contaminated with hazardous substances shall be suitably replaced by uncontaminated air.

For process/material combinations, where a low hazard can be anticipated as e.g. submerged arc welding (see clause 5 of this BG Information) a technical room ventilation can generally be sufficient for welding activities taking a longer time.

Figure 10-15a: Torch-integrated extractor out of operation
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, DINSE GmbH]

Figure 10-15b:
Torch-integrated extractor in operation
[Source: Spiegel-Ciobanu, BGI 593 Ed. 2008, DINSE GmbH]

10.1.5.3 Assignment of ventilation measures to processes and materials used in welding

The old BG Rule “Welding fume” (BGR 220) contained ventilation requirements for normal cases of important welding processes, for which a differentiation was made between ventilation in rooms for processes in which the content of hazardous substances mainly depends on

- either the filler metal used
  or
- the parent metal used.

(figures 10-15 to 10-18 on pages 109-112).

Figure 10-16: Following the old BG Rule “Welding fume” (BGR 220, Table 8) Ventilation in rooms for processes with filler metal

Process	Filler metal		welding of coated steel
	unalloyed and low-alloy steel, aluminium materials	high-alloy steel, non-ferrous materials (except aluminium materials)	
Gas welding	T	A	A
Manual metal arc welding	A	A	A
MIG/MAG welding	A	A	A
TIG welding *with non-thoriated tungsten electrodes* *with thoriated tungsten electrodes*	T A	A/T A	T A
Submerged arc welding	T	T	T
Laser cladding	A	A	-
Thermal spraying	A	A	-
A = extraction at the point of generation of hazardous substances T = forced (mechanical) room ventilation			

Figure 10-17: Following the old BG Rule "Welding fume" (BGR 220, Table 9): Ventilation in rooms for processes without filler metal

Process	Parent metal		Welding of coated steel
	unalloyed and low-alloy steel, aluminium materials	high-alloy steel, non-ferrous materials (except aluminium-base materials)	
Flame heating, Flame straightening	T[1)]	T[1)]	T[1)]
Flame hardening	T[1)]	-	-
Flame priming	T[1)]	-	A
Flame cutting	T*[)1)]	-	T*[)1)]
Flame grooving	A	-	T[1)]
Scarfing	-	A	-
TIG welding *with non thoriated electrodes* *with thoriated electrodes*	T A	T A	T A
Laser welding	A	A	A
Laser cutting	A	A	A
Plasma cutting (without water cover)	A	A	A
Arc oxygen cutting Arc air gouging	A	A	A
Flash butt welding	A	A	A
Other resistance welding processes	F	T	T

*) Digressively, for automated flame cutting equipment A is valid.

1) For these operations the generation of nitrous gases is the main emphasis of the risk. For operations lasting more than half an hour and in rooms with less than 100m³ of available space per torch, A is required, unless random checks of concentration of nitrous gases (MAG value = 0.5 ppm for NO and NO_2 each) are made and immediate protection measures are taken (temporary stopping of work, use of breathing protection) when the air limit value in exceeded.

A = extraction at the point of generation of hazardous substances

F = free (natural) ventilation

T = forced (mechanical) room ventilation

Figure 10-18: Deviating from the data in figures 10-16 and 10-17, more intensive ventilation may be necessary; or less intensive ventilation may be adequate, if proved by measurements (old BGR 220, Table 10), e.g. for

more intensive ventilation necessary	less intensive ventilation sufficient
• especially high gas flow rates • especially high welding currents • contamination of work piece surfaces • unfavourable working conditions (e.g. confined spaces, unfavourable air flow conditions)	• especially low gas flow rates • especially low welding currents • favourable working conditions (e.g. high halls, favourable air flow conditions) • favourable air flow conditions (e.g. roof openings and air supply in the floor area) • coatings for which a neutral expert report has demonstrated that hazardous substances are only generated in a minor degree

10.2 Personal protective equipment (PPE)

Personal protective equipment is intended to protect the welder directly and, in many cases, is a necessary supplement to the technical protective measures:

10.2.1 Welder's hand and face shields

Hand and face shields with filter lenses with the appropriate protection level shall be used in arc welding. They provide protection from optic radiation, heat, sparks and, to some degree, from hazardous substances. The welder is responsible for their correct positioning.

10.2.2 Respiratory protective equipment

When ventilation measures used, especially extraction in the area where hazardous substances are generated, do not achieve that limit values are observed, or when concentrations of carcinogenic substances are not sufficiently minimized, respiratory protective equipment has to be selected as an additional measure.

Furthermore, the use of respiratory protective devices is only allowed if all organisational and technical measures have been exhausted. In general that means they shall only be used for short periods and only in confined spaces (e.g. boilers, containers, raised access floor cells in ships) or other areas with low/insufficient air exchange.

For certain process/material combinations as e.g. MIG welding of aluminium materials we know from experience that minimizing the hazardous substances concentration – by means of ventilation measures – does not suffice to achieve that both the concentrations of ozone and welding fume remain under the limit values. Here, forced draught respiratory protective equipment, e.g. forced draught air welding helmets, is recommended as a supplement to ventilation, as for these devices a G 26 test may be dispensed with and no limit of the wear time has to be

observed.

Even for low emission processes where welding fume contains carcinogenic substances such as Cr(VI) compounds or NiO, the residual risk in the welder's breathing zone should be reduced by wearing respiratory protective equipment.

Selection of respiratory protective equipment for welding activities

Up to 30fold overstepping of the limit values for the respiratory fraction the use of **half/quarter masks with P3 filters or particle filtering half masks FFP3** is recommended.

It shall, however, be noted that during special cutting and welding activities other gases, ozone and CO, and other gaseous or vaporous hazardous substances may be formed. In addition the aerial oxygen may be displaced by the above gases in the case of insufficient ventilation of the workplace and thus the concentration can fall below 17 percent by volume. For this reason, the following is recommended:

a) **In case of sufficient oxygen supply, a combination filter** which holds back organic and inorganic gases and vapours. Furthermore, the **filter** for gases should be suitable **for CO (lower limit is here 19 percent by volume of oxygen) and nitrous gases**. A combination filter is recommended, as the hazardous substances mentioned occur in different concentrations, but also collectively.

The generated **ozone** is retained by an **activated carbon filter**. Due to the high weight of such a filter only a full mask can be used as facepiece. A **better alternative** is **the choice of a force draught filtering device** incorporating a mask or a helmet/hood. If generation of CO or nitrous gases is likely, an A1B B 2 E2 K1 CO NO HG P3 filter should be used. If CO and nitrous gases are not assumed, an ABEK2 P3 filter is sufficient.

b) **In case of insufficient or uncertain oxygen content** of the ambient air **respiratory protective equipment without air recirculation** should be used.

Here, a compressed air line breathing apparatus incorporating a hood should be favoured.

For activities with open flame or where welding spatter may occur, the possible hazard by ignition of the filters (among others generation of high carbon monoxide and carbon dioxide concentrations) shall be taken into account when using respiratory protective equipment, especially with gas or combination filters, which are not directly connected to the facepiece.

Studies performed on glassfibre filters of various filter classes (P1, P2, P3) show that the relevant requirements of European Standards governing the permeability are reliably met for all three performance categories. The characteristics already known for particulate high efficiency air filters are thus also confirmed for respiratory protective devices. Random movement (diffusion) of the ultrafine particles causes them to deposit inside the filtering layer.

Where a suitable filter class is selected, well over 99% of the fine and ultrafine particles can be separated. By contrast, leakage-free fit of the breathing mask presents the real problem for the use of respiratory protective equipment.

For use of respiratory protective equipment, see BG Rule "Einsatz von Atemschutzgeräten" (use of respiratory protective equipment, BGR 190) and BG Information "Zertifizierte Atemschutzgeräte" (certified respiratory protective equipment, BGI 693).

Figure 10-19: Speedglas 9100 FX air with Adflo respiratory protection during works in constraint posture
[Source: Fa. 3M]

Figure 10-20: Speedglas 9100 Air with Adflo respiratory protection
[Source: Fa. 3M]

11 Preventive occupational medical care

11.1 General

Despite considerable technical and organisational efforts, absolute security against the effects of hazardous substances cannot be attained under today's operating conditions. Therefore, it is necessary and beyond dispute that, for certain operations, necessary technical prevention should be accompanied by preventive occupational medical care. Its purpose is avoidance and early detection especially of chronic diseases.

Employees at risk shall therefore be examined before starting work and then receive regular examinations by an authorized physician (occupational physician and additionally a company physician) (see "Verordnung zur Arbeitsmedizinischen Vorsorge" (Preventive Occupational Medical Care ordinance) (ArbMedVV). These requirements apply, among others, to employees who are exposed to higher doses of carcinogenic substances such as chromium(VI) compounds (chromates, chromium trioxide) or nickel oxide. This means that many welders are also affected.

“Bio-monitoring is part of preventive occupational medical examinations as long as analysis methods recognized in occupational medicine and suitable values for evaluation are available” (ArbMedVV). In this regard see also clause 1.7 of this BG information.

Occupational medical examinations shall be initiated during welding and cutting of metals, if the welding fume concentration exceeds 3 mg/m³; they shall, however, also be offered in the case of compliance with this concentration.

In case of exposure to carcinogenic substances as chromium(VI) and nickel oxide, occupational medical examinations shall be arranged and offered, depending on the level of exposure and according to Annex Part 1 of ArbMedVV, or the regular offer should be organized (G 15 “chromium(VI) compounds”, G 38 “Nickel and its compounds”). In this regard see also item 6 of TRGS 528.

According to Part 4 of Annex to ArbMedVV, compulsory examinations are required when respiratory protective equipment of group 2 and 3 are worn and examinations are offered when respiratory protective equipment of group 1 is worn. These should be carried out corresponding to G26 “Respiratory protective equipment” (for respiratory protective equipment having a weight > 3kg and a respiratory resistance)

11.2 Principles and selection criteria

The "Berufsgenossenschaftliche Grundsätze für arbeitsmedizinische Vorsorgeuntersuchungen (BG principles for occupational medical examinations)" (G...) give essential advice to the authorized physician how to proceed in practice (figure 11-1).

With regard to hazardous substances generated by welding, the principles G 15, G 38 and G 39 are of special importance.

The groups of persons who have to undergo a special occupational medical examination are listed in the BG Information "Handlungsanleitungen für die arbeitsmedizinische Vorsorge nach den Berufsgenossenschaftlichen Grundsätzen für arbeitsmedizinische Vorsorgeuntersuchungen" (Operational guidelines for occupational medical care according to the BG principles for occupational medical examinations) (BGI 504 und BGI 504-…)

*Figure 11-1: "Berufsgenossenschaftliche Grundsätze für arbeitsmedizinische Vorsorgeuntersuchungen (*BG principles for occupational medical examinations)*" (G...) and associated "operational guidelines for occupational medical care"*

BG principle	Title	Selection criteria
G 2	Blei oder seine Verbindungen (Lead or its compounds)	BGI 504-2
G 7	Kohlenmonoxid (Carbon monoxide)	BGI 504-7
G 15	Chrom(VI)-Verbindungen (Chromium (VI) compounds)	BGI 504-15
G 27	Isocyanate (isocyanates)	BGI 504-27
G 32	Cadmium oder seine Verbindungen (Cadmium or its compounds)	BGI 504-32
G 34	Fluor oder seine anorganischen Verbindungen (Fluorine or its inorganic compounds)	BGI 504-34
G 38	Nickel oder seine Verbindungen (Nickel or its compounds)	BGI 504-38
G 39	Schweißrauche (Welding fume)	BGI 504-39
G 40	Krebserzeugende Gefahrstoffe – allgemein (carcinogenic hazardous substances – general)	BGI 504-40c (Be) BGI 504-40f (Co)

11.3 Welding fume (general)

Principle G 39 applies to welding fume in general. For insured persons exposed during work to a concentration of A dust (respirable fraction) in the welding fume exceeding 3 mg/m³ as time weighted average concentration in the breathing zone, occupational medical examinations shall be carried out in accordance with G 39 "Schweißrauche" (welding fume).

According to the latest findings, it can generally be expected that the indicative value of 3 mg/m³ will be exceeded during the following welding and allied processes:

- manual metal arc welding, MIG, MAG welding without sufficient ventilation,
- plasma cutting without extraction and/or water cover,
- flame spraying, arc spraying, plasma spraying without enclosure,
- flame gouging,
- air arc gouging,
- flash butt welding
- automated flame cutting without extraction or without water cover
- welding with filler wire (MAG, MIG, MOG welding) without extraction
- laser welding (with/without filler metal) and cutting without extraction

Occupational medical examinations according to G 39 are generally not necessary (but can be offered) for the following welding and allied processes, where the indicative value is not reached:

- gas welding,

- flame heating,
- tungsten inert gas welding,
- micro plasma welding,
- plasma cutting with water cover,
- submerged arc welding,
- resistance welding (except flash butt welding),
- friction welding,
- thermal spraying in enclosed plants,
- stud welding,
- liquid metal welding (thermit welding),
- electro slag welding.

For other processes and working situations, measurements at the workplace shall be used as basis for the decision.

According to G 39, occupational medical examinations shall be carried out before starting work; re-examinations shall then take place at 36 months intervals.

11.4 Chromium(VI) compounds

Occupational medical examinations become necessary according to the principle G 15 and its operational guidelines in the BG Information “Chrom(VI)-Verbindungen” (chromium(VI) compounds) (BGI 504-15) if the exposure action value for chromium(VI) compounds is exceeded.

According to the latest findings it can be expected that the exposure action value will be exceeded in the following welding and allied processes:

- manual metal arc welding with high-alloy covered electrodes (with a chromium content of 5 % or more by mass),
- metal active gas welding with high-alloy filler wire (with a chromium content of 5% or more by mass in the alloy or in fluxes for making slag),
- plasma cutting and laser cutting of chromium nickel materials (with a chromium content of 5% or more by mass),
- flame spraying, arc spraying, plasma spraying with high-alloy spraying filler metals (with a chromium content of 5% or more by mass),
- welding, cutting and dry grinding of workpieces coated with materials containing chromium (VI).

Occupational medical examinations according to the principle G 15 usually are not necessary for the following welding processes, where the exposure action value is not reached:

- tungsten inert-gas welding,
- micro plasma welding,
- plasma fusion cutting with water cover.

For other processes and in special working situations, measurements at the workplace shall be used as basis for the decision.

Occupational medical examinations shall be carried out before starting work (initial examination). The first re-examination is due after 6 to 9 months, further re-examinations after 12 to 24 months.

In addition, extra re-examinations are necessary due to chromium (VI) being classified as

carcinogenic, i.e. even after termination of the hazardous activity occupational medical surveillance is carried out. In these cases, special notification to the Berufsgenossenschaft (ODIN) is necessary.

11.5 Nickel and nickel compounds

The principle "Nickel oder seine Verbindungen" (Nickel or its Compounds) (G 38) gives details on occupational preventive examinations for employees having carried out processes where the exposure action value for nickel and its compounds has been exceeded.

According to the latest findings it can be expected that the exposure action value will be exceeded in the following processes, according to the operational guidelines assigned to the principle G 38 in the BG Information "Nickel oder seine Verbindungen" (Nickel or its Compounds) (BGI 504-38):

- gas shielded metal arc and manual metal arc welding with high-alloy filler material (with a nickel content of 5% or more by mass),
- plasma cutting and laser cutting of materials with a nickel content of 5 % or more by mass,
- thermal spraying with spraying materials with a nickel content of more than 5 %.

Occupational medical examinations according to the principle G 38 are generally not necessary (but can be offered) for the following welding processes, since the exposure action value is not reached:

- tungsten inert-gas welding,
- micro plasma cutting,
- plasma cutting with water cover,
- thermal spraying in enclosed equipment.

For other processes or in special working situations, measurements at the workplace shall be used as basis for the decision.

According to G 38, an initial examination shall take place before starting work and re-examinations are prescribed after 36 to 60 months. Additional re-examinations are carried out at intervals of 36 to 60 months for working periods exceeding 5 years. In these cases, special notification to the Berufsgenossenschaft (ODIN) is necessary.

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12.2 Regulations and Rules

Summary of technical regulations to be considered for hazardous substances in welding and allied processes.

12.2.1 Ordinances and technical regulations

- „Verordnung zum Schutz vor Gefahrstoffen“ (Gefahrstoffverordnung - GefStoffV)
- „Verordnung über den Schutz vor Schäden durch ionisierende Strahlen“ (Strahlenschutzverordnung - StrlSchV)
- „Verordnung zur arbeitsmedizinischen Vorsorge“ (ArbMedVV)
- TRGS 400 "Gefährdungsbeurteilung für Tätigkeiten mit Gefahrstoffen“
- TRGS 402 "Ermitteln und Beurteilen der Gefährdungen bei Tätigkeiten mit Gefahrstoffen: Inhalative Exposition“
- TRGS 420 "Verfahrens- und stoffspezifische Kriterien (VSK) für die Gefährdungsbeurteilung“
- TRGS 500 „Schutzmaßnahmen“
- TRGS 528 „Schweißtechnische Arbeiten“
- TRGS 560 "Luftrückführung beim Tätigkeiten mit krebserzeugenden, erbgutverändernden und fruchtbarkeitsgefährdenden Stoffen"
- TRGS 900 "Grenzwerte in der Luft am Arbeitsplatz - Luftgrenzwerte"
- TRGS 903 "Biologische Grenzwerte"
- TRGS 905 "Verzeichnis krebserzeugender, erbgutverändernder und fortpflanzungsgefährdender Stoffe"

12.2.2 Accident Prevention Regulations

- "Grundsätze der Prävention" (BGV A 1)

12.2.3 BG Rules, BG Information and BG Principles

- "Arbeitsplatzlüftung – Lufttechnische Maßnahmen" (BGR 121)
- "Benutzung von Atemschutzgeräten" (BGR 190)
- "Handlungsanleitungen für die arbeitsmedizinische Vorsorge" (BGI/GUV-I 504)
- "Blei oder seine Verbindungen (mit Ausnahme der Bleialkyle" (BGI 504-2)
- "Kohlenmonoxid" (BGI 504-7)
- "Chrom-VI-Verbindungen" (BGI 504-15)
- "Isocyanate" (BGI 504-27)
- "Cadmium oder seine Verbindungen" (BGI 504-32)
- "Fluor oder seine anorganischen Verbindungen" (BGI 504-34)
- "Nickel oder seine Verbindungen" (BGI 504-38)
- "Schweißrauche" (BGI 504-39)
- "Beryllium" (BGI 504-40c)
- "Cobalt und seine Verbindungen“ (BGI 504-40f)
- "Von den Berufsgenossenschaften anerkannte Analysenverfahren zur Feststellung der Konzentrationen krebserzeugender Arbeitsstoffe in der Luft in Arbeitsbereichen" (BGI 505)
- "Bestimmung von sechswertigem Chrom" (BGI 505-5)
- "Bestimmung von Nickel und seinen anorganischen Verbindungen" (BGI 505-10)

- „Bestimmung von Cobalt und seinen Verbindungen“ (BGI 505-15)
- „Lichtbogenschweißer“ (BGI 553)
- „Gasschweißer“ (BGI 554)
- „Beurteilung der Gesundheitsgefährdung durch Schweißrauche – Hilfestellung für die schweißtechnische Praxis“ (BGI 616)
- „Zertifizierte Atemschutzgeräte“ (BGI 693)
- „Nitrose Gase beim Schweißen, Schneiden und bei verwandten Verfahren“ (BGI 743)
- „Umgang mit thoriumoxidhaltigen Wolframelektroden beim Wolfram-Intergasschweißen (WIG)“ (BGI 746)
- BG/BGIA-Empfehlung für die Gefährdungsbeurteilung nach der Gefahrstoffverordnung: Wolfram-Inertgas-Schweißen (WIG-Schweißen) (BGI 790-012)
- BG/BGIA-Empfehlung für die Gefährdungsbeurteilung nach der Gefahrstoffverordnung: Weichlöten mit dem Lötkolben an elektrischen und elektronischen Baugruppen oder deren Einzelkomponenten (Kolbenlöten) (BGI 790-014)
- „Schweißtechnische Arbeiten mit chrom- und nickel-legierten Zusatz und Grundwerkstoffen“ (BGI 858)
- „Berufsgenossenschaftliche Grundsätze für arbeitsmedizinische Vorsorgeuntersuchungen“ (BGG 904)
  - G 2 Blei oder seine Verbindungen
  - G 7 Kohlenmonoxid
  - G 15 Chrom(VI)-Verbindungen
  - G 27 Isocyanate
  - G 32 Cadmium oder seine Verbindungen
  - G 34 Fluor oder seine anorganischen Verbindungen
  - G 38 Nickel oder seine Verbindungen
  - G 39 Schweißrauche
  - G 40 Krebserzeugende Gefahrstoffe - Allgemein

12.3 DIN-Normen

- DIN EN 481 "Workplace atmospheres; size fraction definitions for measurement of airborne particles“
- DIN EN ISO 10882-1
  "Health and safety in welding and allied processes - Sampling of airborne particles and gases in the operator's breathing zone - Part 1: Sampling of airborne particles“
- DIN EN ISO 10882-2 Part 2: “Sampling of gases”.
- DIN EN ISO 15011-1 “Health and safety in welding and allied processes - Laboratory method for sampling fume and gases generated by arc welding Part 1: Determination of fume emission rate during arc welding and collection of fume for analysis”
- DIN EN ISO 15011-2)
  „Determination of emission rates of gases, except ozone”
- DIN EN ISO 15011-3)
  „Determination of ozone concentration using fixed point measurements”
- EN ISO 15011-4 „Fume data sheets”
- DIN EN 26848 „Tungsten electrodes for inert gas shielded arc welding and for plasma cutting and welding – codification”

12.4 Other technical rules

- DVS/VDI-Richtlinie 6005 "Lüftungstechnik beim Schweißen und bei verwandten Verfahren"
- DVS 2307 Blatt 2 "Arbeitsschutz beim Flammspritzen"
- DVS 2307 Blatt 3 "Arbeitsschutz beim Lichtbogenspritzen"
- DVS 2307 Blatt 4 "Arbeitsschutz beim Plasmaspritzen"

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14 Annex

Excerpt from the Hazardous Substances Ordinance 2010

§ 7 Basic duties

- Substitution principle (even in case of low hazards)
- Minimization principle
- Order of precedence of protective measures: TOP??
- Employees shall wear PSE
- Burdensome PSE no permanent measure, minimization required
- Functionality and efficiency of technical protective measures shall be regularly audited (every three years), documentation
- Determination by measurements or other suitable determination methods whether AGW are observed
- Competent performance of measurements by an accredited

§ 8 General protective measures

- Appropriate working methods, work material and working places …
- Limiting exposure, number of employees and hazardous substances at the workplace
- Hygiene measures, e.g. workplace cleaning
- Company related labelling according to CLP Ordinance or in keeping with the temporary provisions of the Dangerous Substances or Preparation directive
- Consummation of foodstuff of any kind in appropriate areas
- Storage only in such a way that health and environment are not at risk
- Hazardous substances container shall not be mistaken for foodstuff and shall be tightly closable
- Disposal of no longer needed hazardous substances
- Hazardous substances classified as very toxic, toxic, carcinogenic, mutagenic and reprotoxic shall be stored shut away
- Activities with toxic, very toxic, carcinogenic, mutagenic and reprotoxic hazardous substances and those sensible to the respiratory tract shall only be carried out by skilled or especially competent persons

§ 9 Additional protective measures

- If §§ 7 and 8 are not sufficient, particularly in case
  - of AG"/BGW being exceeded
  - of a residual risk related to hazardous substances without AGW/BGW
  - of skin resorptive/skin and eye damaging hazardous substances

  there is a danger by contact with the skin or the eyes.
- Closed system when substitution is technically not possible and when there is an increased hazard of inhalation. Where closed system is technically not possible, then exposure reduction according to the state of the art.
- In case of AGW being exceeded ("inhalative hazard") or hazard by skin resorptive/skin or eye damaging hazardous substances ("dermal" hazard): PPE
- Separate storage of work and protective clothing on one hand and street clothes on the other.
- Employer shall clean contaminated work clothing.
- Limitation on access
- Additional protective measures (supervision) when working alone.

§ 10 Special protective measures for activities with carcinogenic, mutagenic and reprotoxic hazardous substances

- Obligation for measurements replaced by obligation for determination.
- Reference to Annex II No. 6 (closed plant in case of carcinogenic substances such as dimethyl sulphate, HMPA etc.)