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Technical Rules for Hazardous Substances	Welding Work	TRGS 528

The Technical Rules for Hazardous Substances (TRGS) reflect the state of the art, the state of occupational health and occupational hygiene as well as other sound work-scientific knowledge relating to activities involving hazardous substances, including their classification and labelling. They are developed by the

Committee on Hazardous Substances (AGS)

with the participation of the Committee on Occupational Medicine (AfAMed) and published by the Federal Ministry of Labour and Social Affairs (BMAS) in the Joint Ministerial Gazette (GMBl).

This TRGS specifies, within the scope of its application, the requirements of the Hazardous Substances Ordinance (GefStoffV) and the Ordinance on Preventive Occupational Health Care (ArbMedVV). By complying the Technical Rules, the employer may therefor assume that the corresponding requirements under the ordinances have been fulfilled. Should the employer choose another solution, he must than achieve at least the same level of safety and health protection for employees.

Content

**) Note: TRGS 528 has been completely revised, including*
- Updating to the current status of the rules and regulations,
- Consideration of experience and suggestions from practice, the state of the art, findings from expert and prevention research communities,
- Inclusion of the air limit values relevant for welding work, e.g. for chromium(VI) compounds, nickel, cobalt, manganese or nitrogen oxides in the risk assessment,
- Consideration of the risk to other workers in the hazardous area,
- New Annex 2 "Decision-making aids for the selection of protective measures" and new Annex 3 “Specific information for selected sectors" to assist practitioners.

Content

1 Scope

(1) This TRGS apply to welding work on metallic materials during which gaseous and particulate hazardous substances may be generated. These are assigned to the following processes in particular:

1. Welding,
2. Thermal cutting and gouging,
3. Thermal spraying,
4. Soldering,
5. Flame straightening,
6. additive manufacturing processes with metal powders.

(2) For details of these processes see Annex 1.

(3) In addition to these TRGS, TRGS 407 "Activities involving gases - risk assessment" and TRBS 3145/TRGS 745 "Transportable pressurized gas cylinders - filling, holding, in-house transport, emptying" apply to the handling of process gases. The requirements of TRGS 510 "Storage of hazardous substances in transportable containers" apply to the storage of process gases.

2 Definitions

For the purposes of these TRGS, the following terms are defined:

(1) Welding work is work involving the procedures described in Annex 1 and related procedures. Incidental work, e.g. grinding, which is directly related to the application of these procedures is also part of the welding work.

(2) According to these TRGS, welders are all persons carrying out welding work. Welders also include persons operating welding devices.

(3) Base material is the material to be processed in the framework of welding work.

(4) Addition material is the material added and melted off within the scope of welding work, e.g. welding filler metal, which, together with the base material, forms a substance-to substance or positive-locking connection. Filler metals can be in the form of rods, wires, strips or powders.

(5) According to this TRGS, welding fumes are the particulate substances arising during welding work.

(6) Gaseous hazardous substances are the gases produced or used during welding work, e.g. nitrogen oxides, ozone, carbon monoxide, aldehydes or carbon dioxide, hydrogen.

(7) Limit values according to these TRGS are occupational exposure limits according to TRGS 900 and risk-based assessment standards according to TRGS 910.

(8) Extraction is the capture of hazardous substances at their respective source or escape, in order to minimize their spread to the breathing zone of the welder.

(9) Ventilation: Technical ventilation (mechanical room ventilation) is the exchange of room air against outside air by flow machines, e.g. fans, blowers. Natural ventilation is the exchange of room air against outside air by pressure differences due to wind or temperature differences; the air exchange usually takes place via open windows and doors.

(10) Air recirculation is the recirculation of air collected by extraction and cleaned in separators into working spaces. Depending on the effectiveness of the separator system, a certain proportion of hazardous substances is also returned to the work area.

(11) Confined spaces are areas surrounded on all sides or predominantly surrounded by solid walls and areas with little air exchange (i.e. which can only be poorly ventilated even with technical ventilation) in which, due to their spatial confinement and the hazardous substances arising, special hazards exist or can arise which clearly exceed the hazard potential normally prevailing at workplaces. Confined spaces are, for example, windowless rooms, tunnels, pipe trenches, pipes, shafts, tanks, vessels, chemical apparatus, cofferdams and double bottom cells in ships, as a rule with dimensions (length, width, height or diameter) of less than 2 m or a volume of less than 100 m^3.

(12) Stationary process: The application of a process is considered to be stationary if it is repeatedly carried out at the same workplace set up for this purpose, e.g. welding cabin, welding table.

(13) High alloy steel contains at least 5% by weight of an alloying element such as chromium, nickel, manganese.

(14) Non alloy or low alloy steel contains in total less than 5 % by weight of all alloying elements such as chromium, nickel, manganese.

(15) Spatial separation is the complete separation of spaces from each other, i.e. not only by side walls, but fully enclosing and with technically tight walls, floors and ceilings.

(16) Spatial partition of a work area from the rest of the room can be realised, for example, by means of individual walls, partition walls, curtain systems. Individual areas of the room remain connected**.** As a rule, these partitions are used in combination with extraction and/or ventilation measures.

(17) Spatial demarcation of a work area is achieved, for example, by marking the work areas and maintaining appropriate distances.

(18) Forced posture exists if welding fumes reach the breathing zone of the welder directly during welding work (welder must bend down into the plume of fumes). Ergonomic aspects have to be taken into account within the framework of the risk assessment in accordance with article 5 of the Occupational Safety and Health Act.

3 Information gathering and risk assessment

3.1 Information gathering

3.1.1 General notes for the release of hazardous substances

(1) Hazardous substances consisting of particulate (welding fumes, soldering fumes) or gaseous hazardous substances are released during welding work.

(2) The particulate hazardous substances are mixtures of substances whose chemical compositions and concentrations depend on the materials used and the processes applied.

The released particles may belong to the alveolar dust fraction (A-dust) as well as to the inhalable dust fraction (E-dust), see Figure 1 and sections 3.1.2 to 3.1.7. Furthermore, the fumes may also contain ultrafine particles whose diameter is below 100 nm.

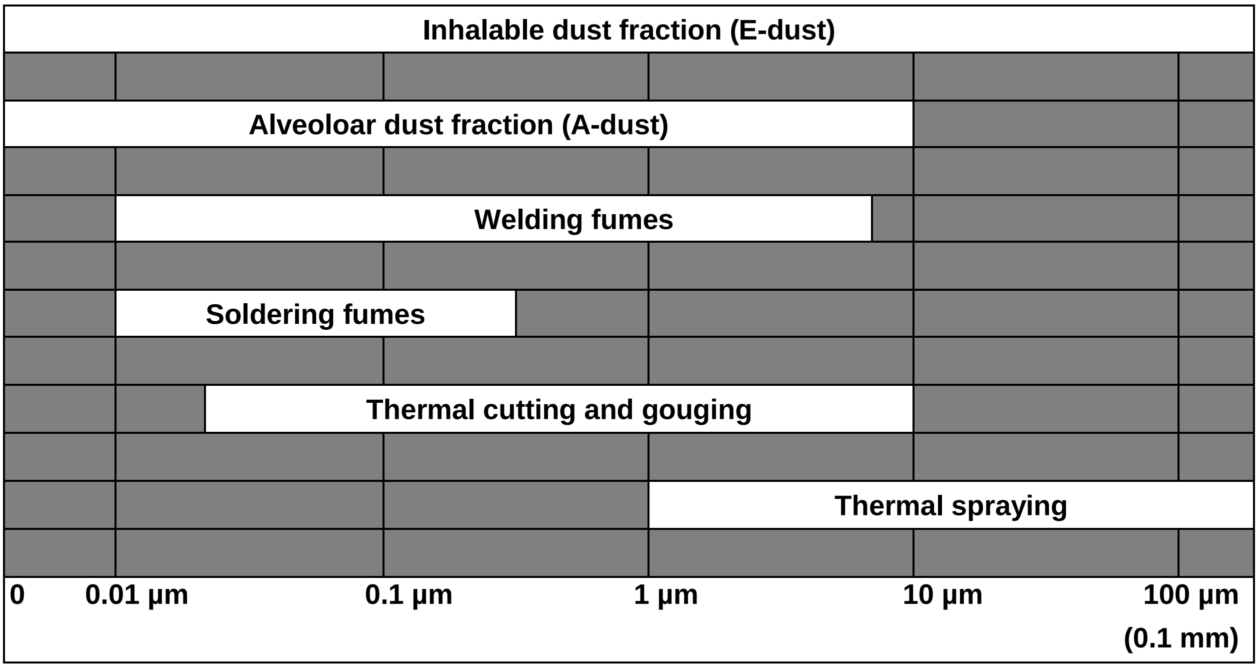


Figure 1: Size of particulate hazardous substances from welding processes in relation to dust fractions according to DIN EN 481

(3) The fumes and gases generated during welding work consist of hazardous substances, some of which have different effects on health. According to their effects, these are divided into:

1.	substances harmful to the respiratory tract and lungs	e.g. iron oxides, aluminium oxide,
2.	toxic or toxic-irritating substances	e.g. fluorides, manganese oxides, zinc oxide, copper oxide, aldehydes (when soldering with fluxes containing rosin),
3.	carcinogenic substances	e.g. chromium-(VI)-compounds, nickel oxide.

See also section 3.2.2.

(4) The safety data sheet or the fume data sheet according to DIN EN ISO 15011-4 provide information on the addition material used (see Annex 6).

(5) If applicable, also released hazardous substances from surface contaminations or coatings, such as pyrolysis products, e.g. isocyanates, aldehydes, epoxides, PAHs from organic coatings or released hazardous substances from inorganic coatings e.g. red lead, zinc chromate, asbestos-containing paints have to be considered.

3.1.2 Hazardous substances during welding

(1) The following processes in particular are used for welding (main groups according to DIN EN ISO 4063):

1. gas fusion welding,
2. arc welding (manual arc welding/MAG/MIG/TIG/plasma/submerged arc welding),

3. resistance welding,
4. electron beam welding/laser beam welding,
5. pressure welding, e.g. friction stir welding, magnetic pulse welding, diffusion welding.

For notes on these main groups, see also Annex 1.

(2) During welding, usually more than 95 % of the welding fumes are generated from the addition material and only about 5 % from the base material. The individual particles are predominantly smaller than 1 µm and therefore alveolar. Agglomerates and aggregates with larger diameters are also formed.

(3) In particular, the following resulting gaseous hazardous substances have to be taken into account:

1. ozone in MIG welding of aluminium materials, TIG welding of aluminum materials and high alloy steels,
2. carbon monoxide in MAGC welding of non alloy and low alloy steel,
3. nitrous gases (NO, NO_2) in autogenous processes and in plasma processes,
4. pyrolysis products from adhesives during spot-weld bonding and over-welding of organic coatings.

(4) Chromium(VI) compounds (alkali chromates and alkali dichromates, e.g. Na_2CrO_4, K_2CrO_4, $K_2Cr_2O_7$) in the welding fume predominantly occur during manual metal arc welding of chromium-nickel steel with coated stick electrodes as well as during metal inert gas welding of chromium-nickel steel with high-alloy flux-cored wires. In MAG welding of chromium-nickel steel with high-alloy wires, chromium(III) compounds (Cr_2O_3, spinels of the $Ni(Cr,Fe)_2O_4$ type) occur predominantly, see Table 5. Chromium trioxide (CrO_3) does not usually occur in welding fumes.

(5) Nickel oxide (NiO) in welding fume occurs mainly in MIG welding, but also in manual metal arc welding, TIG welding and laser cladding of nickel and nickel-based alloys. Nickel spinels e.g. Fe_2NiO_4 in the welding fume mainly occur during MAG welding and flux-cored arc welding without shielding gas of high-alloy chromium-nickel steels (see Table 5). As with nickel oxides, a carcinogenic effect can be assumed for nickel spinels (footnote 24 TRGS 900, IFA Arbeitsmappe Kennzahl 0537).

(6) When welding galvanized materials or alloys containing zinc, e.g. brass, the release of zinc oxide fume has to be taken into account. If addition materials containing copper are used, e.g. alloy "$CuSi_3$", copper oxide fume has to be taken into account in addition to zinc oxide fume.

(7) If ancillary work such as grinding, cutting, fettling, polishing, etc. is also carried out at welding workplaces, additional particulate emissions arise from the workpieces to be machined and the abrasives used due to mechanical removal.

(8) When grinding non-melting electrodes, e.g. TIG electrodes, the release of harmful dusts is to be expected so that suitable extraction is required. This applies in particular to the grinding of electrodes containing thorium dioxide, here extraction with dust extractors of dust class H is required, see also section 4.2 paragraph 7.

3.1.3 Hazardous substances during thermal cutting and gouging

(1) The following processes in particular are used for thermal cutting and gouging (main groups according to DIN EN ISO 4063):

1. autogenous flame cutting and flame gouging,
2. metal arc cutting and metal arc gouging,
3. plasma cutting and plasma gouging,
4. laser beam cutting.

(2) During thermal cutting and gouging, the fumes are generated from the base material. The fume composition depends on the chemical composition of the base material and on any coatings or impurities that may be present. The particles contained in the fume have diameters between 0.03 and - in agglomerated form - about 10 µm. They are predominantly alveolar. Hazardous substances from old coats of paint, e.g. coatings containing lead (red lead), zinc chromate, coatings containing asbestos, must also be taken into account.

(3) In particular, the following resulting gaseous hazardous substances have to be taken into account:

5. nitrous gases during autogenous flame cutting/flame gouging, plasma cutting/plasma gouging and laser beam cutting, each with compressed air or nitrogen,
6. ozone during plasma cutting/plasma gouging and laser beam cutting (when using UV light emitting lasers) of aluminium materials,
7. aldehydes during flame cutting/flame gouging due to pyrolysis products of coats of paint,
8. dioxins during flame cutting/flame gouging of materials with coatings containing organic chlorine compounds, see also TRGS 557.

3.1.4 Hazardous substances during thermal spraying

(1) The following processes in particular are used for thermal spraying (main processes according to DIN EN ISO 14917):

1. Flame spraying,
2. Cold gas spraying,
3. Arc spraying,
4. Plasma spraying,
5. Laser beam spraying,
6. Plasma surface treatment with plasma transferred arc (PTA).

(2) The fumes and gaseous hazardous substances generated during thermal spraying are formed from the spraying material and the fuel and carrier gases used. The chemical composition of these fumes depends on the composition of the spraying material used. The base material is not melted and is only subjected to a low thermal load.

(3) Spraying materials are in wire or powder form and consist of metals/metal alloys, e.g. zinc, tin, nickel, copper, nickel/chromium, nickel/copper, oxide ceramic materials, e.g. aluminium oxide, zirconium dioxide, chromium(III) oxide, titanium dioxide or carbide materials, e.g. tungsten carbide with cobalt and/or nickel and, where applicable, chromium contents. During thermal spraying, particles are usually formed in the inhalable range. In special cases, however, alveolar particles may also occur.

(4) In the case of flame spraying and plasma spraying, in particular nitrous gases are to be taken into account as gaseous hazardous substances.

3.1.5 Hazardous substances during soldering

(1) The following processes in particular are used for soldering (main processes according to DIN ISO 857-2):

1. soft soldering (working temperature T ≤ 450° C),
2. brazing (working temperature T > 450 °C), including flame brazing, arc brazing, laser beam brazing).

(2) In soft soldering and brazing, only the solders and brazing alloys are melted, not the base material. The chemical compositions of the fumes in soft soldering and brazing therefore depend on the solders, brazing alloys and fluxes used. The particles produced in the process are predominantly between 0.01 and 0.15 µm in diameter. They are alveolar.

(3) In the case of soft soldering, essentially tin-based solders are used, e.g. alloys "Sn99Cu1", "Sn95Ag4Cu1", lead-containing solders contain lead in addition to tin, e.g. alloy "Sn60Pb40". In the case of soft soldering, tin and tin oxide are the main fume components of the solder, while tin, lead and their oxides occur when leaded solders are used. In addition, depending on the composition of lead-free solders, copper, silver and their oxides cannot be excluded. Fluxes mainly used are natural resins, e.g. rosin, organic acids, e.g. adipic acid, and chlorides, e.g. zinc chloride, ammonium chloride. In particular aldehydes (from rosin) and hydrogen chloride, e.g. from ammonium chloride, must be taken into account as gaseous hazardous substances. Furthermore, evaporating solvents from fluxes, e.g. isopropanol, occur. Soft solders (with the exception of tin solder bars) already contain approx. 2 to 3 % flux. In various applications, however, flux pins, soldering fluid and soldering grease are additionally used.

(4) For flame brazing (working temperature > 450 °C), e.g. of copper-brass, copper-steel, mainly brazing alloys based of brass are used, which also contain additives of silver ("silver brazing alloys"). The fluxes used for brazing contain boron compounds, chlorides and fluorides. Depending on the brazing alloys and fluxes used, brazing fumes consisting of copper oxide, zinc oxide, silver oxide, chlorides and fluorides can be produced during brazing. Hydrogen chloride and hydrogen fluoride must be taken into account here as gaseous hazardous substances. In flame brazing for the production of copper-copper compounds, copper-phosphorus brazing alloys, where applicable also with silver content, are used; here, no flux is required. When brazing aluminium, appropriate aluminium brazing alloys (aluminium-silicon alloys) are used at working temperatures of up to 600 °C.

(5) In arc brazing (MIG, MAG, TIG, plasma brazing) and laser beam brazing, working temperature 900-1100 °C, predominantly wire-shaped copper-based alloys are used as addition material, e.g. alloy "CuSi3", "CuAl8" or "CuSn6", here essentially copper oxide occurs in the soldering fume. Zinc oxide can additionally occur in galvanised sheets.

3.1.6 Hazardous substances during flame straightening

During flame straightening, nitrous gases in particular must be taken into account.

3.1.7 Hazardous substances in additive manufacturing processes with metal powders

(1) Metal powders are used in some additive manufacturing processes. Depending on their composition, the powders consist of iron, chromium, nickel, cobalt, titanium and aluminium, for example. The metal powders predominantly have grain sizes in the range of 20 to 60 µm, but may also contain portions with significantly lower diameters. Handling metal powders, especially during the process steps before and after the construction process (see also Annex 3), can lead to exposure to metal dusts (A- or E-dust fraction).

(2) As the metal powders are generally made of non-oxidised metal, they may also present fire and explosion hazards.

3.2 Risk assessment

3.2.1 General information on risk assessment

(1) In accordance with article 5 of the Occupational Safety and Health Act and article 6 of the Hazardous Substances Ordinance, the employer has to carry out a risk assessment prior to the commencement of the activity in which the hazards associated with the work of the employees are determined and measures to protect their health are specified. The possible risk to other employees who may be exposed to the welding fumes and gases must also be taken into account.

(2) Information on how to carry out the risk assessment is given in TRGS 400, for carcinogenic substances additionally in TRGS 910. Within the framework of the risk assessment, all routes of exposure (oral, dermal, inhalation) must be taken into account. In the case of welding work, it is mainly the inhalation exposure which must be assessed, taking into account other relevant boundary conditions, as well as the type of work, e.g. heavy physical work or the wearing of stressful PPE. The following guidelines also provide assistance in assessing the risks associated with soft soldering "Recommendations for risk assessment by the occupational accident insurance institutions (EGU) in accordance with the Hazardous Substances Ordinance Manual Piston Soldering with lead-containing solder alloys in the electrical and electronics industry" (DGUV Information 213-714) and the "Recommendations for risk assessment by the occupational accident insurance institutions (EGU) in accordance with the Hazardous Substances Ordinance Manual Piston Soldering with lead-free solder alloys in the electrical and electronics industry" (DGUV Information 213-725).

(3) Information on how to perform the metrological investigations are described in section 5.2 and in Annex 4 of this TRGS.

(4) The assessment of inhalation exposure is to be carried out in accordance with TRGS 402, taking into account the occupational exposure limits published in TRGS 900. In the case of welding work involving the release of carcinogenic substances with risk-based assessment standards, e.g. chromium(VI) compounds, nickel oxides, in particular during the welding of high-alloy materials and nickel-based alloys, the risk-based assessment standards of TRGS 910 are to be taken into account for the assessment of inhalation exposure.

(5) Within the framework of the risk assessment, the material-, process- and workplace-specific factors through which the exposure at the workplace is essentially determined must also be taken into account.

(6) The results of the risk assessment and of the effectiveness review are to be documented. The results of workplace measurements have to be retained and made available to the employees. The documentation has to state which measures are taken to eliminate or reduce to a minimum the hazards caused by hazardous substances.

(7) If an assessment standard according to TRGS 910 is exceeded during activities involving carcinogenic hazardous substances, a plan of action must be drawn up, see TRGS 910.

(8) In accordance with article 14 paragraph 3 of the Hazardous Substances Ordinance, the employer has to keep a register of employees who carry out activities with carcinogenic or mutagenic hazardous substances of categories 1A or 1B and for whom there is a risk to health or safety and they have to retain this register for 40 years after the end of the expo-

sure. The register must be updated regularly. TRGS 410 provides further details. This applies in particular to employees who carry out welding work and are exposed to welding fumes containing carcinogenic substances of categories 1A or 1B.

(9) In addition, the employer has to take account in the risk assessment of the findings obtained from preventive occupational medicine, in particular from biomonitoring, insofar as these are available, and of generally accessible, published information. However, the employer cannot derive the right to inspect individual examination results from this requirement.

(10) The employer has to examine the necessity of involving the company physician in the risk assessment. In the case of processes which are likely to result in the release of carcinogenic substances, the company physician has to be involved in the risk assessment. This also applies to the assessment of hazard prevention measures if occupational accidents or occupational diseases typical for welding work have occurred. The involvement of the physician can vary depending on the circumstances and ranges from short written or oral statements to carrying out the risk assessment on behalf of the employer (see AMR 3.2). The involvement of the company physician in the risk assessment focuses on the contribution of occupational medical expertise. The physician advises the employer in particular

1. on the properties and significance of alveolar and inhalable dust,
2. on carcinogenic properties of particles and gases, for example chromium(VI) compounds, nickel oxides, cadmium oxide, cobalt metal,
3. on toxic or toxic-irritant properties of particles and gases, e.g. fluorides, copper oxide, aluminium oxide, iron oxides, manganese oxides, isocyanates, epoxides, dioxins, aldehydes, hydrogen chloride, carbon monoxide, nitrous gases, ozone,
4. on radioactive properties of particles, e.g. thorium dioxide,
5. to acute and chronic consequences of exposure, e.g. causing pulmonary oedema, metal fume fever, cancer, pulmonary fibrosis and chronic obstructive bronchitis,
6. on occupational health screening in accordance with section 6, including biomonitoring (see AMR 6.2) and vaccination (see AMR 6.7),
7. with regard to possible cut-off criteria for preventive occupational healthcare for exposure to carcinogenic particles and gases (see AMR 3.2),
8. on special issues for special groups of people, such as adolescents, pregnant or breastfeeding women.

3.2.2 Material-specific factors in risk assessment

The welding fumes and gases generated during welding work consist of hazardous substances, some of which have different harmful effects. According to their effects, these are classified according to Table 1:

Table 1: Classification of hazardous substances arising during welding work according to their harmful effect

Occurring hazardous substance	**Effects**			
Gaseous / particulate	**Respiratory and pulmonary stress**[1)]	**Toxic**[2)]	**Carcinogenic**	**Toxic for reproduction**
nitrogen monoxide		X		
nitrogen dioxide		X		
ozone		X	X[4)]	
carbon monoxide		X		X[5)]
phosgene		X		
hydrogen cyanide		X		
formaldehyde		X	X[3)]	
aluminium oxide	X			
iron oxides (e.g. Fe_3O_4)	X			
magnesium oxide	X			
barium compounds (e.g. $BaCO_3$)		X		
lead(II) oxide		X		X[5)]
fluorides (e.g. NaF, KF, CaF_2 BaF_2)		X		
copper oxide		X		
manganese oxides (e.g. MnO, Mn_3O_4)		X		
molybdenum(VI) oxide		X	X[4)]	
vanadium pentoxide		X		
chromium compounds		X		
zinc oxide		X		
titanium dioxide	X			
chromium(VI) compounds (e.g. Na_2CrO_4)		X	X[3)]	
nickel oxides (e.g. NiO)		X	X[3)]	
cobalt metal			X[6)]	
cobalt oxides (e.g. CoO, Co_2O_3)		X	X[7)]	
cadmium oxide		X	X[3)]	
beryllium oxide		X	X[3)]	

1) Respiratory and pulmonary stress means here that effects in the sense of chronic inflammation (chronic bronchitis) due to particle overload are in the foreground. As a consequence, an obstructive respiratory disease, mostly in the form of a chronic obstructive pulmonary disease (COPD) can result. The general dust limit value applies to these substances.
2) Toxic here means acute or chronic toxic effects described in the literature, usually also a corresponding classification according to the CLP Regulation (Regulation (EC) No 1272/2008). Therefore, unlike in the case of hazardous substances identified as causing respiratory and pulmonary stress, compliance with the general dust limit value (A fraction) is insufficient.

3) Classified according to CLP Regulation (Regulation (EC) No 1272/2008) as a carcinogen, category 1A or 1B.
4) Classified according to the CLP Regulation (Regulation (EC) No 1272/2008) in the hazard class carcinogenicity, category 2.
5) Classified according to CLP Regulation (Regulation (EC) No 1272/2008) as a reproductive toxicant, category 1A.
6) Classified according to TRGS 905 as carcinogenic, category 1B.
7) Classified according to TRGS 905 as carcinogenic, category 2.

See also section 3.1.1, paragraph 3.

3.2.3 Process-specific risk assessment factors

(1) Depending on the process used, welding fumes are released to different extents. A measure for the release is the respective emission rate (emitted particulate mass of a process per time in mg/s or g/h). Typical emission rates of welding processes are listed in Table 2.

(2) The processes shall be classified into the following 4 emission groups according to their emission rates of particulate matter:

1. low (< 1mg/s)
2. medium (1 to 2 mg/s),
3. high (2 to 25 mg/s) and
4. very high (> 25 mg/s).

As a general rule, the higher the emission group, the higher the requirements for exposure reduction measures at the workplace.

(3) The emission rates describe the release of welding fumes during welding processes and thus provide indications of the possible exposure of employees at the workplace.

(4) Informations on emission rates can also be taken from the fume data sheets according to DIN EN ISO 15011-4 (see Annex 6).

Table 2: Assessment of the processes on the basis of emission rates. Assignment to emission groups.

Process (sample list)	**Emission rate[1] (mg/s)**	**Emission group**
submerged arc welding	< 1	low
gas fusion welding (autogenous process)	< 1	low
TIG	< 1	low
laser beam cutting without addition materials	1 to 2	medium
MIG/MAG (low-energy protective gas welding)	1 to 4	medium to high
laser beam cutting with addition materials	2 to 5	high
MIG (solid wire, nickel, nickel-based alloys)	2 to 6	high
MIG (aluminium materials)	0.8 to 29	low to very high
MAG (solid wire)	2 to 12	high
MMA	2 to 22	high
MAG (flux-cored arc welding with shielding gas)	6 to > 25	high to very high
MAG (flux-cored arc welding without shielding gas)	> 25	very high
soft soldering	< 1	low
Brazing	1 to 4	medium to high
MIG soldering	1 to 9	medium to high
laser beam cutting	9 to 25	high to very high
autogenous flame cutting	> 25	very high
plasma cutting	> 25	very high
arc spraying	> 25	very high
flame spraying	> 25	very high

1) Empirical values, which can still be reduced in individual cases by optimising the process parameters.

(5) In addition to welding fumes (particles), the following welding processes also release gaseous hazardous substances which must be taken into account in the risk assessment:

1. MIG welding of aluminium materials: ozone; it is formed from atmospheric oxygen by the action of UV radiation from the arc,
2. MAGC welding of non alloy and low alloy steel: carbon monoxide
3. autogenous welding, arc, plasma and laser beam processes: nitrous gases (NO, NO_2),
4. soft soldering: aldehydes,
5. brazing: hydrogen chloride,
6. spot-weld bonding: pyrolysis products during adhesive burn-off

See also sections 3.1.2 to 3.1.6.

3.2.4 Workplace and activity-specific risk assessment factors

(1) Workplace and activity-specific factors, such as spatial conditions, ventilation situation and in particular the arc burning time per shift, additionally influence the concentration of hazardous substances in the air at the workplace and thus also the level of exposure. The exposure is also determined by the head and body position of the welder.

(2) Very high exposure is to be expected during welding work in confined spaces or in areas with low air exchange.

(3) If welding work is carried out in a forced posture, high to very high exposure must also be assumed.

(4) Low exposure may be present if welding work is performed only for a short period of time (no more than half an hour per shift). Typical examples are:

1. repair welding work in vehicle construction, in building yards, in mechanical workshops,
2. tacking work and execution of short interrupted welds,
3. brazing work in heating system construction.

(5) Low exposure cannot be present in confined space welding operations.

(6) Depending on the type and extent of the ancillary work, e.g. grinding, it has to be checked whether additional protective measures are required or whether the protective measures already taken at the welding workplaces are also suitable for these emissions (note: welding fume extraction systems are generally not suitable for extracting combustible dusts, e.g. aluminium dust). If additional measures are required, these must be determined within the framework of the risk assessment. For grinding of the electrodes, see also sections 3.1.2 paragraph 8 and 4.2 paragraph 7.

(7) Gases escaping unintentionally from compressed gas cylinders or defective supply lines can displace the atmospheric oxygen in work areas, so that there is a risk of suffocation. This applies in particular to work in confined spaces and below ground level. If combustion gases or shielding gases/forming gases with a high hydrogen content escape in an uncontrolled manner, explosive gas mixtures can form.

(8) If oxygen escapes into the environment, there is an increased risk of fire. Even materials that are normally flame-resistant can catch fire if the oxygen content in the atmosphere is increased.

3.2.5 Overall risk assessment

The employer must identify and evaluate the material-specific, process-specific and workplace- and activity-specific factors and combine them in an overall assessment and determine the necessary protective measures in accordance with section 4 of this TRGS. In the overall assessment, the risk to other employees must also be taken into account.

4 Protective measures

4.1 Basic requirements

(1) As a result of the risk assessment, the employer shall specify the necessary protective measures in accordance with section 4 and Annexes 2 and 3 of this TRGS. The specified protective measures are generally also suitable to minimize exposure to ultrafine particles.

(2) If exposure of employees to hazardous substances cannot be avoided during welding work, suitable protective measures are required to eliminate or minimize the resulting hazard.

In accordance with the Hazardous Substances Ordinance, the following measures are to be taken into account in the listed order of priority on the basis of the risk assessment:

1. substitution testing: selection of low hazard processes and base materials/addition materials (section 4.2),
2. ventilation and structural measures (sections 4.3 to 4.5),
3. organisational and hygiene measures (section 4.6) and
4. personal protective measures (section 4.7).

(3) The measures are to be designed such that at least the limit values are complied with. In addition, it has to be examined whether the exposures can be further reduced according to the state of the art, in compliance with the minimisation requirement. If the effectiveness of one protective measure is not sufficient, a combination of measures has to be taken. If compliance with the limit values cannot be ensured through extraction at the source, the welder must wear suitable respiratory protection. In order to protect the other employees in the hazardous area, it must be checked whether structural and organisational measures can be implemented if the limit values are exceeded. If these measures are not suitable, room ventilation measures must be taken. If these measures are not effective, the other employees in the hazardous area must also wear suitable respiratory protection. See also Annex 2.

(4) In principle, the measures specified in TRGS 500 have to be inducted. In particular, reference is made to the special regulations on shift work, rest break regulation and night work according to TRGS 500.

(5) If activities involving hazardous substances are carried out by an employee alone (i.e. outside the hearing and visual range of other persons), the employer has to specify additional protective measures or ensure adequate supervision, see also TRGS 500.

(6) In the case of welding work in which carcinogenic substances with risk-based assessment standards, e.g. chromium(VI) compounds, nickel oxides, may be released, in particular in the welding of high alloy materials and nickel-based alloys, the staged measures concept of TRGS 910 are to be taken into account. For the preparation of a plan of measures, see also section 3.2.1 paragraph 7.

(7) In the case of processes with the emission groups "low" or "medium", at least an effective extraction system in the source area is generally required. In the case of processes with emission groups "high" and "very high", as a rule, additional protective measures are required for welders and other employees in the hazardous area. In the case of welding work in accordance with section 3.2.4 paragraphs 2 and 3, welders are generally required to wear suitable respiratory protection, irrespective of the welding process.

(8) In individual cases, the risk assessment (in particular for procedures with the emission group "low" such as submerged arc welding, TIG welding without filler metal or for work with low exposure in accordance with section 3.2.4 paragraph 4 may show that natural room ventilation is sufficient.

(9) Thermal spray work is to be carried out in suitable enclosed booths, where possible, see CEN/TR 15339-6.

(10) If thermal spray work cannot be carried out in enclosed spray booths, suitable semi-enclosed booths are to be used wherever possible. It must be ensured that the workplace is located in the inflow area of the ambient air.

(11) The required protective measures for additive laser sintering/laser melting with metal powders are described in Annex 3, section 7.

(12) The necessary protective measures for manual piston soldering are contained in the two process- and substance-specific criteria (VSK) DGUV information documents 213-714 and 213-725.

4.2 Substitution: Selection of low-hazard processes and base materials/addition materials

(1) The employer has to check, taking into account the state of the art, whether processes can be used in which hazardous substances are not released or are released only to a small extent. These include mechanical joining processes, e.g. clinching, riveting, screwing or welding work in closed systems, e.g. automated welding in welding cabins, automated spraying in spray cabins, additive manufacturing in closed automated manufacturing machines.

(2) If these processes cannot be used, such welding processes are to be applied and base materials/addition materials used where the release of hazardous substances is as low as possible, as far as this is technically possible and suitable for the task, see also section 3.2.3. Preference is to be given to procedures with a low emission group.

(3) Processes where the release of hazardous substances is low include:

1. submerged arc welding (SAW),
2. tungsten inert gas welding (TIG welding) with thorium dioxide-free tungsten electrodes,
3. plasma cutting with water bath cover,
4. welding processes without addition materials, e.g. friction stir welding, magnetic pulse welding.

(4) The composition and quantity of hazardous substance emissions are influenced, among other things, by the selected welding parameters, e.g. welding current, welding voltage, shielding gas type and shielding gas composition. To minimise the emission of hazardous substances, the welding parameters recommended by the manufacturers of the electrodes or gases must be observed. In the case of MIG/MAG welding, a reduction in welding fume emissions can be achieved by controlling the welding current waveform and the selection of the corresponding process control variants (e.g. controlled short arc).

(5) During gas-shielded welding with high alloy welding wire, the release of carcinogenic chromium(VI) compounds in the fume is considerably lower than during manual arc welding with coated high-alloy stick electrodes or with high alloy flux-cored wires.

(6) If, on the other hand, nickel-based materials or pure nickel are used as addition material, the release of carcinogenic nickel oxide in the welding fume is lower in manual arc welding than in MIG/MAG welding.

(7) As a rule, tungsten electrodes without thorium addition are to be used, such as electrodes without oxide addition or electrodes with cerium(IV) oxide (CeO_2), lanthanum oxide (La_2O_3) or zirconium(IV) oxide (ZrO_2). The technological necessity of using tungsten electrodes containing thorium dioxide for TIG welding has to be justified and documented in the risk assessment. Reference is made to the necessary measures according to radiation protection law, see also DGUV Information 209-049. If the use of electrodes containing thorium dioxide is unavoidable, an extraction system with dust extractors of dust class H must be used for grinding these electrodes.

(8) Only beryllium-free electrodes, e.g. alloys of WCu, $CuNi_2Si$, CuCrZr, are to be used for resistance welding.

(9) When welding, barium-free welding consumables are to be used if possible.

(10) Arc brazing is often lower in emissions and less problematic in terms of fume composition than arc welding and should be used in these cases.

(11) The lists in paragraphs 1 to 10 are not exhaustive. In individual cases, further low-hazard processes may be used.

(12) For the performance and documentation of the substitution check, the requirements of TRGS 600 apply in all other respects.

4.3 Ventilation and structural measures

(1) As a matter of principle, ventilation measures in accordance with the state of the art are to be taken for welding work, see also section 4.1 paragraph 7.

(2) Ventilation measures are to be selected such that the protection of the welder and other employees is ensured and a spread of welding fumes and gases from the work area is prevented as far as this is possible in accordance with the state of the art.

(3) The extraction of hazardous substances must primarily take place in the source area. The closer the extraction is to the source, the more efficient the collection of the hazardous substances. Information on this is provided in DGUV Rule 109-002.

(4) The spread of welding fumes and gases beyond the working area also has to be prevented, above all, by suitable structural and technical measures. Depending on the boundary conditions (material-, process-, workplace- and activity-specific factors), the spectrum of suitable structural measures comprises welding in separate rooms (spatial separation), partitions with intermediate walls (spatial partition) and measures for ventilation and air conditioning to separate the welding area from other (manufacturing) areas. For welding work with low exposure, a spatial demarcation is usually sufficient.

(5) Depending on the boundary conditions, technical room ventilation may be required as an additional ventilation measure to ensure compliance with the limit values also for those employees who do not perform welding work but are exposed to welding fumes and gases.

(6) In rooms or in partial areas of rooms in which welding work is performed, the supply and exhaust air of room ventilation systems has to be generally conducted in such a way that it supports the thermal flows generated during welding and that hazardous substances not captured are displaced from the breathing zone of the employees. Displacement ventilation with the associated stratified flow has proven to be particularly suitable for this purpose. For information on the design of room ventilation systems, see VDI 2262 Part 3 and VDI 3802.

(7) With regard to the effectiveness review of the measures taken, the requirements of section 5 of this TRGS apply.

4.4 Extraction in the source area

4.4.1 Air volume flow rates

The air volume flow rates required for effective extraction must be determined when planning the extraction systems and ensured for the duration of the hazardous activities.

4.4.2 Extraction for manual welding

(1) In the case of manual welding, suitable capture of the hazardous substances in the source area is required as a matter of principle, unless the risk assessment arrives at a different result in the individual case.

(2) Depending on the welding process, the type of workplace (mobile or stationary) and the size of the workpieces to be processed, the following ventilation measures are suitable for the capture of hazardous substances in the source area, if necessary in combination:

1. extraction integrated in the welding torch or directly fitted to the welding torch,
2. stationary or mobile extraction systems with fixed or tracking capturing elements.

(3) The volumetric flow range required for the extraction is to be requested from the manufacturer and is to be observed during the welding work. Information on the dimensioning of capturing elements is contained in DIN EN ISO 21904 Part 1, DIN EN ISO 21904 Part 4 and VDI 2262 Part 4. For low-vacuum spot extraction systems with a nominal diameter of 160 mm, an air volume flow rate in the range of 800 to 1000 m^3/h has proven to be suitable.

(4) When using welding torch-integrated extraction systems, the minimum and maximum air volume flow rate as well as the vacuum required to generate the flow rate has to be requested from the manufacturer of the welding torch and has to be observed during the welding process. A too low air volume flow rate results in a higher exposure of the welder, a too high air volume flow rate extracts the shielding gas to an unacceptable extent and thus impairs the weld seam quality.

(5) A prerequisite for effective extraction in the case of tracking capturing elements is that the welder always positions the capturing elements as closely as possible to the source. Since the effectiveness of the protective measure is significantly influenced by the knowledge and behaviour of the employees, they must be trained and instructed regularly, see also section 7. Care must be taken to ensure that easy and precise positioning of the capturing elements is possible. The closer the extraction system is to the source, the more efficient the capture of the hazardous substances. A low-vacuum spot extraction system still captures the welding fumes well up to a distance of 30 to 40 cm, a high-vacuum spot extraction system up to a distance of 15 cm.

(6) Ventilation processes without capturing elements in the vicinity of the welding point are not permitted as the sole protective measure for the welders. These processes only contribute to the purification of the air in the ambient area, i.e. they are only a supplementary measure to room ventilation.

4.4.3 Extraction during fully mechanised and automated welding

(1) In the case of fully mechanized and automated welding processes, the operator is usually not in the immediate vicinity of the welding point. Therefore, closed or at least semi-closed capturing systems are to be used as far as possible for the extraction of emissions. These enclose the entire area and thus prevent the release of welding fumes and gases. Such capturing systems are characterised by a lower air volume flow rate with a considerably better capture efficiency than the open capturing systems used in manual welding when the thermal effect is utilised. Further information on capturing systems can be found in DGUV Rule 109-002 and VDI 2262 Part 4.

(2) If the enclosed or semi-enclosed collection systems are large enough to be accessible, the risk assessment is to specify the conditions under which it is safe to enter the facility. Parameters to be taken into account here are the frequency of access, ventilation and exposure peaks.

4.5 Air recirculation

(1) Extracted air may only be returned to the work area if it has been sufficiently cleaned. Sufficient purification of welding fumes without substances that are carcinogenic, mutagenic or toxic to reproduction is, e.g., given if air handling systems for the separation of welding fumes are used which comply with the standard DIN EN ISO 21904 Part 1. In addition, section 4.5 paragraph 4 applies to installations used for the separation of smoke containing substances that are carcinogenic, mutagenic or toxic for reproduction.

(2) The capture rate of open capturing elements is usually less than 100 %. The uncaptured fumes and gases can accumulate in the working area, just like the residual fumes let through by the filter. For this reason, the capture rate of the extraction system must be optimised and a sufficient supply of outside air must be ensured during air recirculation. The determination of the required outside air volume flows must be carried out according to the rules of technology, including DGUV Rule 109-002 and VDI/DVS 6005.

(3) Gases generated or released during welding are not separated by filters normally used for welding fume separation. These gases may accumulate in the entire workshop, e.g. during air recirculation or also during work without extraction. In order to comply with the limit values for gaseous hazardous substances (e.g. MAGC welding: carbon monoxide, carbon dioxide), a fresh air volume flow of 200 m³/h per welder must generally be available for welding work. In the case of autogenous welding processes (gas welding, flame cutting, flame heating and flame straightening), a higher fresh air volume flow is required due to the emissions of nitrogen monoxide in particular, but also of nitrogen dioxide, which must be determined as part of the individual risk assessment**.** The same applies to MIG welding of aluminium materials (occurrence of ozone).

(4) At workplaces where welding work involving the emission of substances that are carcinogenic, mutagenic or toxic to reproduction of category 1A or 1B is performed (in particular where materials containing chromium and nickel are used), the extracted air may generally not be recirculated. If possible, the extracted air must be conducted in exhaust air mode in these cases, e.g. in the case of stationary workplaces. If welding fume extraction devices have to be operated in recirculation mode, e.g. in the case of mobile workplaces, only devices approved by the authorities or by the statutory occupational accident insurance institutions may be used which have been tested in accordance with DIN EN ISO 21904 Parts 1 and 2 and are marked W3. These welding fume extraction devices must also be used for radioactive substances in the welding fumes (thorium dioxide). Filter towers are generally unsuitable for capturing these hazardous substances, see also section 4.4.2 paragraph 6.

(5) If a room ventilation system is used in addition to extraction at the source in accordance with the state of the art, the room ventilation system may also be operated with air recirculation. In this case, it must be ensured that in the case of welding fumes with substances that are carcinogenic, mutagenic or toxic to reproduction of category 1A or 1B, the hazardous substance concentration in the recirculated air does not exceed 1/10 of the acceptable concentration, the assessment standard or the occupational exposure limit. Proof of this can also be provided by means of suitable balances, e.g. calculations based on the room air concentration and the separating capacity of the filter.

(6) If a system for room ventilation is used as the only ventilation measure because extraction at the source is technically not possible, this system shall not be operated with air recirculation in the case of welding fumes containing substances that are carcinogenic**,** mutagenic or toxic to reproduction of category 1A or 1B.

4.6 Organisational measures

(1) Prior to commencing welding work, care shall be taken to remove residues on workpiece surfaces, e.g. from cold cleaners.

(2) The employer has to keep tools, machines and ventilation equipment in a technically good order and condition. The employees have to use them in accordance with their intended purpose.

(3) During work interruptions and before the end of work, the valves on compressed gas cylinders and gas tapping points must be closed (do not just close the valves on the pressure reducers!).

(4) The employer has to ensure that only effective equipment for the capture and separation of hazardous substances is used. Proof of sufficient effectiveness (compliance with the limit values) is to be provided when these facilities are commissioned for the first time and during the periodic inspections in accordance with section 5.

(5) The devices in accordance with paragraph 4 are to be tested at least once a year by a person qualified to perform such tests. The tests must be documented. See TRBS 1203 and DGUV Rule 109-002.

(6) The number of workers exposed to welding fumes and gases and the duration of exposure are to be minimised as far as possible. The presence of employees in the hazard zone who do not carry out welding work themselves must be avoided, if possible, or at least reduced to the absolutely necessary number and to the necessary duration. Polluted work areas must be spatially delimited and may only be accessible to employees who carry out work there.

(7) Welding work with high exposure are to be performed at the end of the working day, if possible.

(8) The exposure of welders may be reduced by limiting the time of the respective welding work. Corresponding individual regulations on the maximum exposure time may be a supporting measure to comply with the limit values.

(9) As far as possible, the working positions of the employees are to be designed in such a way that the exposure to hazardous substances is minimised by exploiting thermal effects, e.g. by ergonomically favourable positioning of the workpieces by means of rotating and swivelling work tables.

(10) If an unfavourable working position cannot be avoided, special attention should be paid to placing the welding shield close to the face.

(11) Employees who are exposed to hazardous substances in their work area may not consume any food or beverages there (eating, drinking and smoking ban at the workplace). Likewise, no food or beverages may be stored there. Appropriate break rooms are to be provided for this purpose, which employees have to use.

(12) Contaminated areas are to be cleaned regularly. The cleaning intervals are to be determined on the basis of the risk assessment. The cleaning work is to be carried out in such a way that the release and stirring up of dust is avoided, e.g. with damp or wet methods or by suction using suitable and tested industrial vacuum cleaners or state of the art sweeping suction machines.

(13) In the case of metal dusts that do not contain carcinogenic hazardous substances, industrial vacuum cleaners of dust class M are to be used; in the case of metal dusts with carcinogenic hazardous substances, industrial vacuum cleaners of dust class H are to be used. A positive list of tested industrial vacuum cleaners has been published in the IFA manual, code 510210/1.

(14) Dry sweeping or blowing off dust deposits with compressed air is generally not permitted. The ban on the use of compressed air also applies to the cleaning of work clothing.

(15) The employer has to provide separate storage facilities for work and protective clothing on the one hand and for street clothing on the other, e.g. double lockers. The employer ensures that employees do not carry contaminated work clothing into other areas, e.g. break and stand-by rooms. Contaminated work clothing remains in the company and is cleaned appropriately by the employer.

4.7 Personal protective measures (respiratory protection)

(1) Insofar as the protective measures listed in sections 4.1 to 4.6 are not sufficient or their implementation is not technically possible, the employer must provide suitable respiratory protective equipment to protect the employees. Employees are obliged to use this equipment.

(2) For the selection of suitable respiratory protection, the regulations of DGUV Rule 112-190 have to be observed. The following respiratory protective devices may be used to protect against welding fumes:

1. ventilated helmets/hoods with blower and particulate filters TH2P or TH3P,
2. masks with blower and particle filter TM1P, TM2P, TM3P,
3. full-face masks or mouthpiece sets with P2 or P3 filters,
4. half/quarter masks with P2 or P3 filters, particle filtering half masks FFP2 or FFP3, or
5. insulating devices, e.g. ventilated helmets/hoods with external compressed air supply.

In the case of carcinogenic substances, respiratory protection of the highest filter class, i.e. with P3 filters, must always be provided and used.

(3) If gaseous hazardous substances in concentrations hazardous to health are also generated during welding, suitable combination filters are to be used when filtering respiratory protection is used.

(4) The use of heavy respiratory protection (weight of equipment > 3 kg or breathing resistance) may not be a permanent measure (longer than 120 hours in a period of 3 months). An exception to this is only possible with the approval of the competent authority and with the involvement of the employees and their representatives at the company level. It must be limited to the absolutely necessary minimum for each employee. When selecting respiratory protection equipment, preference must therefore be given to the selection and use of non-incriminating respiratory protection equipment. When using low-weight respiratory protection (equipment weight < 3 kg and no breathing resistance, e.g. ventilated welding helmets/hoods with blowers according to section 4.7 paragraph 2 No.1) is used, the preventive occupational healthcare requirements set out in Annex Part 4, paragraph 1, No. 1 of the ArbMedVV and Annex Part 4 paragraph 2 No. 2 of the ArbMedVV, as well as the time limits for using low-weight respiratory protection equipment laid down in DGUV Rule 112-190, are no longer applicable. In the case of additional loads on the device carrier due to work loads, e.g. also harmful protective clothing and ambient climate, the baseline value for the calculation of the carrying time is 220 minutes. The wearing time must then be determined on a case-by-case basis with the assistance of the company physisian. More detailed rules are contained in DGUV Rule 112-190.

(5) If carcinogenic hazardous substances are released as a result of the welding work, in particular during the welding of high alloy steels and nickel-based alloys, suitable respiratory protection in accordance with section 4.7 paragraph 2 is to be provided for the welders except for processes of the "low" emission group such as submerged arc and TIG welding processes. It is mandatory that respiratory protection be worn when the respective tolerable concentration is exceeded, otherwise during exposure peaks. In all other respects, the wearing

of respiratory protection is recommended when the acceptable concentration is exceeded, especially during exposure peaks. In the case of carcinogenic chromium(VI) compounds, suitable respiratory protection must be worn if the assessment standard is exceeded.

(6) If filter devices with blowers are used during work with an open flame or during activities in which welding spatter or flying sparks may occur, there is a risk that the respiratory protection filters may catch fire - usually unnoticed at first. Fatal flue gases (especially carbon monoxide and carbon dioxide) can then be produced in the filter. Therefore, only filter devices are to be used for such work, where constructive measures, e.g. close-meshed metal screens in front of the intake openings or "spark traps" prevent weld spatter and sparks from entering the filter; alternatively, insulating devices can be used.

(7) For welding work in confined spaces, e.g. in shipbuilding, in box girders or in double floors, the following procedure applies to the selection of respiratory protective devices:

1. If possible, ventilation measures have to be installed in accordance with section 4.3.
2. If this is not possible or not sufficient for spatial reasons, ventilated hoods or helmets should preferably be worn.
3. If ventilated hoods and helmets are not applicable for spatial reasons, FFP3 masks are to be worn during welding.
4. If the occurrence of nitrous gases is to be expected, e.g. during flame straightening, suitable respiratory protection (half/quarter masks with combination filter of filter class NO-P3) must be used, see DGUV Rule 112-190.
5. If there is a risk of oxygen deficiency, use ambient air independent respirators (insulating devices).

(8) When thermal spraying with mechanised or automated spraying processes, suitable respiratory protection must be worn when entering the spray cabin if the spray cabin air is not sufficiently cleaned, e.g. due to insufficient follow-up times of the extraction system. Respiratory protection must always be worn when spraying manually. Respiratory protection must also be worn when charging or cleaning the powder containers.As a rule, a class P3 filter is required. For flame spraying and plasma spraying, a combination filter of filter class NO-P3 may be required.

5 Effectiveness check

5.1 Basic requirements on effectiveness check

(1) The effectiveness of the protective measures taken is to be checked by workplace measurements or by other suitable identification methods before the workplace is put into operation and then regularly within specified periods. The protective measures are sufficient if the relevant limit values are complied with and, in addition, a corresponding finding can be made in accordance with TRGS 402.

(2) The methods, timing and frequency of the effectiveness review are to be determined by the employer on his own responsibility within the framework of the risk assessment, see section 7 TRGS 400. An effectiveness check is required in the event of a change in relevant boundary conditions, e.g. in the event of a process change. Otherwise, an effectiveness check must be repeated at regular intervals. An effectiveness check by means of control measurements is carried out according to the specifications of TRGS 402.

(3) Effectiveness checks can also be carried out by measuring technical parameters in accordance with TRGS 402. If extraction systems or systems for room ventilation are used as a protective measure, it is recommended that the corresponding air volume flows of the extraction system or room ventilation be determined in parallel with workplace measurements in accordance with TRGS 402 when the workplace is put into operation. Later effectiveness checks can then be carried out on the basis of air volume flow measurements.

(4) Technical protective measures, e.g. ventilation and exhaust systems, must be checked for adequate functioning and effectiveness in accordance with section 4.6 paragraphs 4 and 5 on a regular basis, for welding fumes at least once a year.

(5) If a process- and substance-specific criterion (VSK), a substance- or process-specific TRGS or a sector-specific guidance document exists, the specifications for effectiveness control provided there must be observed. Examples of this are DGUV Information 213-714, DGUV Information 213-725 and TRGS 505.

5.2 Additional requirements and notes on effectiveness check by workplace measurements

(1) In the case of welding work, representative measured quantities according to Tables 5 to 8 may be used for the metrological determination of the inhalation exposure or for the effectiveness check of the protective measures taken by exposure measurements, see Annex 4 paragraph 6.

(2) The limit values from TRGS 900 and TRGS 910 regarding the representative measurement parameters in accordance with paragraph 1 that are relevant and binding for welding work are listed in Table 3. For ozone, zinc and its inorganic compounds as well as copper and its inorganic compounds, no binding limit values in accordance with TRGS 900 or TRGS 910 are currently available. For these substances, Table 3 contains, in accordance with section 5.4.2 of TRGS 402, MAK values of the DFG Senate Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area of the Deutsche Forschungsgemeinschaft or foreign limit values to be used for assessing exposure and the effectiveness of protective measurands (assessment standards in accordance with section 5.4 TRGS 402).

Table 3: Limit values from TRGS 900 and TRGS 910, MAK values or international limit values for representative measurands for welding work

Substance	Limit value/ assessment standard according to section 5.4 TRGS 402	Excursion factor	Source
general dust limit value	OEL 1.25 mg/m³ (A) Density 2.5 g/m³ OEL 10 mg/m³ (E)	8 2	TRGS 900
aluminium oxide (Al_2O_3)	general dust limit value		TRGS 900
ozone	0.1 mg/m³	2	LIG GESTIS
chromium(VI) compounds (e.g. sodium-chromate Na_2CrO_4, potassium chromate	BM 1.0 µg/m³ (E)	8	TRGS 910
cobalt and cobalt compounds, classified as Carc. 1A, Carc.1B (e.g. cobalt metal (Co))	TK 5.0 µg/m³ (A) AK 0.5 µg/m³ (A)	8	TRGS 910
nickel compounds, classified as Carc. 1A, Carc. 1B (e.g. nickel(II)-oxide NiO, nickel spinels)	TK 6.0 µg/m³ (A) AK 6.0 µg/m³ (A)	8	TRGS 910
nickel and nickel compounds	OEL 30 µg/m³ (E)	8	TRGS 900
manganese and its inorganic compounds (e.g. MnO, Mn_3O_4)	OEL 0.2 mg/m³ (E) OEL 0.02 mg/m³ (A)	8	TRGS 900
nitrogen(II) oxide (NO)	2.5 mg/m³	2	TRGS 900
nitrogen(IV) oxide (NO_2)	OEL 0.95 mg/m³	2	TRGS 900
fluorides (sodium fluoride (NaF), calcium fluoride (CaF_2), barium fluoride (BaF_2), sodium calcium fluoride ($NaCaF_3$))	OEL 1 mg/m³ (E)	4	TRGS 900
zinc and its inorganic compounds (ZnO)	MAK 0.1 mg/m³ (A), MAK 2 mg/m³ (E)	4 2	MAK list
barium compounds, soluble (BaO)	MAK 0.5 mg/m³ (E)	8	MAK list
copper and its inorganic compounds (CuO)	MAK 0.01 mg/m³ (A)	2	MAK list
carbon monoxide	OEL 35 mg/m³	2	TRGS 900

Explanations:
TK: Tolerable concentration
AK: Acceptable concentration
OEL: Occupational exposure limit
MAK: Maximum workplace concentration
BM: Assessment standard, risk-based
LIG GESTIS: List of International Limits for Chemical Substances in the GESTIS Substance Database
(A): Alveolar fraction (respirable fraction)
(E): Inhalable fraction

(3) Control measurements according to TRGS 402 may be dispensed with if the effectiveness of the protective measures taken can be demonstrated by other test parameters, e.g. checking of the ventilation parameters. For further information on the identification and assessment of exposures, see Annex 4.

(4) Findings from biomonitoring obtained within the framework of occupational health screening taking into account AMR 6.2 may be used for the effectiveness check (see also section 3.2.1 paragraph 9).

5.3 Documentation

The results of the effectiveness check must be recorded, retained and made available to the employees and their representatives. The results of the effectiveness check must be documented in the risk assessment. Measurement records may be part of the risk assessment.

5.4 Consequences of the effectiveness check

(1) If the effectiveness check shows that limit values are not complied with and thus that the protective measures taken are not sufficient, further exposure-reducing measures are to be arranged without delay and the risk assessment then has to be carried out again (see also TRGS 402). For provision and wearing of respiratory protection see section 4.7 paragraph 1.

(2) If risk- based assessment standards according to TRGS 910 are not complied with, a plan of action must be drawn up in which it is specifically described on the basis of which measures, in which periods of time and to what extent a further reduction of exposure is to be achieved. Further details can be found in TRGS 910. For provision and wearing of respiratory protection see section 4.7 paragraph 1.

5.5 Establishment of findings

At regular intervals or where appropriate, e.g. in the event of changes in relevant boundary conditions, changes in limit values, it has to be checked in accordance with section 6 of TRGS 402 check whether the derived finding is still valid. The intervals for the check are to be determined depending on the operational conditions in the findings. An annual interval is recommended.

6 Preventive occupational healthcare

(1) The general requirements in section 4 of AMR 3.2 are to be taken into account. The following paragraph contains specific explanations in this regard. The requirements of other occupational health rules, in particular AMR 11.1, remain unaffected.

(2) Reasons for preventive healthcare in connection with the activities and hazards addressed in this Technical Rule include in particular

1. Mandatory healthcare

a) in the case of activities involving a hazardous substance listed in the Annex in part 1 paragraph 1 number 1 of the ArbMedVV (for example fluorides or carbon monoxide), if the occupational exposure limit (AGW) is not complied with (Annex part 1 paragraph 1 number 1 letter a of the ArbMedVV);

b) in the case of activities involving a hazardous substance listed in the Annex part 1 paragraph 1 number 1 of the ArbMedVV which is classified as a carcinogen or mutagen of category 1A or 1B within the meaning of the Hazardous Substances Ordinance, for example chromium(VI) compounds or nickel oxides, or activities which are designated as carcinogenic activities or processes of category 1A or 1B within the meaning of the Hazardous Substances Ordinance, if repeated exposure cannot be ruled out (Annex part 1 paragraph 1 number 1 letter b of the ArbMedVV);

c) in the case of activities involving exposure to welding fumes (welding and cutting of metals), if an air concentration of 3 mg/m3 (A dust fraction) is exceeded (Annex part 1 paragraph 1 number 2 letter b of the ArbMedVV);

d) in the case of activities requiring the wearing of respiratory protective devices of groups 2 and 3 (Annex part 4 paragraph 1 number 1 of the ArbMedVV; AMR 14.2).

2. Optional healthcare

a) in the case of activities involving a hazardous substance listed in the Annex Part 1 Paragraph 1 Number 1 of the ArbMedVV, e.g. fluorides or carbon monoxide, if the occupational exposure limit (AGW) is complied with;

b) in the case of activities involving a hazardous substance which is not listed in Annex 1 part 1 paragraph 1 number 1 of the ArbMedVV but which is classified as carcinogenic or mutagenic of category 1A or 1B within the meaning of the Hazardous Substances Ordinance, e.g. cobalt metal, or activities which are designated as carcinogenic activities or processes of category 1A or 1B within the meaning of the Hazardous Substances Ordinance, if repeated exposure cannot be ruled out (Annex part 1 paragraph 2 number 2 letter d of the ArbMedVV);

c) in the case of activities involving exposure to welding fumes (welding and cutting of metals), if an air concentration of 3 mg/m^3 (A-dust fraction) is observed (Annex part 1 paragraph 2 number 2 letter f of the ArbMedVV);

d) in the case of activities requiring the wearing of group 1 respiratory protective equipment (Annex part 4, paragraph 2, number 2 ArbMedVV; AMR 14.2).

3. Follow-up healthcare

After termination of exposure to carcinogenic or mutagenic hazardous substances of category 1A or 1B, e.g. chromium(VI) compounds, nickel oxides, cobalt metal or activities involving hazardous substances that are designated as carcinogenic activities or processes of category 1A or 1B within the meaning of the Hazardous Substances Ordinance (Annex part 1, paragraph 3, number 1 ArbMedVV).

7 Operating instructions and oral instruction

(1) The employer has to draw up written operating instructions for welding work in accordance with the Hazardous Substances Ordinance. The written operating instructions are to be made known to the employees in a comprehensible form and language.

(2) In accordance with article 14 of the Hazardous Substances Ordinance, work area- and substance-related hazards are to be taken into account when preparing written operating instructions.

(3) See TRGS 555 for guidance on the preparation. Examples of a written operating instruction for "Manual metal arc welding with coated chromium/nickel-containing stick electrodes in a tank" and for "Flame heating and straightening in a ship's tank" are given in Annex 5.

(4) The employer has to instruct employees on safe welding practices. This oral instruction must include the following aspects:

1. the hazardous substances released during the welding process used and the hazards involved; in the case of carcinogenic constituents in the welding fume, also the exposure level and the assigned risk area,
2. the implications of welding parameters,
3. the welding position,

4. the working position (posture),
5. the correct use of the ventilation equipment (including the tracking of the capture elements),
6. the personal protective equipment to be used, including possible wear time limitations,
7. general occupational health toxicological counselling, including an explanation of preventive occupational healthcare (see paragraph 5),
8. hygiene measures,
9. behaviour in the event of temporary disruptions in operation and
10. First aid.

It must be taken into account that the welder is usually unable to see his workplace and the load on him occurring due to the dazzling effect.

(5) In the case of welding work, the employer has to ensure that the employees receive general occupational medical and toxicological advice as part of the instruction. Whether the physician in charge of preventive occupational healthcare is to be involved in the advice is to be decided within the framework of the risk assessment. The involvement of the physician in charge of preventive occupational healthcare is generally required if the risk assessment indicates that mandatory healthcare is to be arranged or that optional healthcare is to be offered. The "involvement of the physician in charge of preventive occupational healthcare" does not necessarily mean that he or she must personally provide the advice throughout. The requirement for participation can be fulfilled, for example, by providing medical training for the persons carrying out the advice or by participating in the preparation of suitable advice materials (see AMR 3.2). In the counselling, the possible health consequences of the hazard and how to avoid them, including immediate measures and special first aid measures, are to be explained to the employees in a form that is comprehensible to the layperson, and they are to be informed about their entitlements to preventive occupational healthcare.

For the hazards addressed in this Technical Rule, counselling therefore includes, in particular, information on

1. the inhalation route of welding fumes and gases,
2. the increased intake in the event of increased work load,
3. conductive and main components of the welding fumes and gases and, if applicable, further components, e.g. from coatings, as well as their effects,
4. the influence of tobacco smoking on the health of welders,
5. medical factors that may lead to an increase in risk, e.g. certain pre-existing conditions, particularly of the respiratory tract, or dispositions such as hypersensitivity of the bronchial tubes,
6. clinical pictures e.g. pulmonary oedema, metal fume fever, chronic bronchitis, asthma, lung cancer and symptoms e.g. cough,
7. temporal correlation of health problems with the corresponding activity e.g. metal fume fever,
8. the content and aim of occupational health screening (see section 6), including any elective healthcare,

9. other preventive measures such as vaccination against pneumococci (see AMR 6.7).

Annex 1: Glossary

Process name	Explanation
Submerged arc welding	In submerged arc welding, one or more metal wires are melted under powder cover as an electrode in the arc that forms between the end of the wire and the workpiece. The process can only be carried out in a mechanized way in tub position (PA), horizontal position (PB) or in transverse position (PC). Due to the powder covering of the arc, there is only a low emission of hazardous substances. After the welding has been carried out, the powder is extracted.
Gas welding (autogenous processes)	The energy source used in gas fusion welding is usually acetylene as the fuel gas together with oxygen. The welding addition material - bare wire - is supplied separately and melted in the welding flame at a temperature of approx. 3100 °C.
TIG welding with and without addition material	Tungsten inert gas welding (TIG) is an inert gas welding process in which the arc between the workpiece and a tungsten electrode burns in an inert gas. Due to the high melting point of tungsten, the electrode does not melt. Argon, helium or their mixtures are used as shielding gases. The TIG welding process can be used with or without addition material. The addition material is usually fed in by hand. With this welding process, many types of weld seams can be produced in all positions. Direct or alternating current is used. The weldable workpiece thicknesses range up to approx. 4 mm for steel and up to approx. 5 mm for aluminium.
MAG welding (solid wire) with shielding gas	Metal active gas welding (MAG) is a shielded arc welding process in which the arc burns between a consumable wire electrode and the workpiece in a shielded gas atmosphere. The wire electrode is continuously fed, adequate to the melting rate, as an addition material with a wire feed device. Argon-carbon dioxide mixtures are usually used as shielding gases. The MAG process is particularly suitable for welding non alloy, low alloy and high alloy steels.
MAG welding (cored wire) with/without shielding gas	Flux-cored wires are increasingly used in MAG welding. Flux cored wires are "tubular" welding wires filled with powders that either have the properties of the coating of stick electrodes or improve other characteristics of the weld. The process can be used both with and without the addition of shielding gases (self-protecting flux cored wires - metal arc welding). In the latter, the powder melts and forms a gaseous protective bell over the weld pool. The resulting slag must be removed.
MAGC welding	MAGC welding is a gas shielded metal arc welding process with a consumable wire electrode and non-inert (active) shielding gas. The active shielding gas in the MAGC process consists of carbon dioxide (CO_2). The MAGC process is used for welding non alloy and low alloy steels, since with the prevailing high temperatures the decomposition of carbon dioxide to carbon monoxide and oxygen results in an undesired high burn-up of alloying elements in the weld pool, which in the case of high alloy steels can no longer be compensated by the normal addition material (solid wire electrode).

Process name	Explanation
MIG/MAG welding (process control variants)	Electronically controlled MIG/MAG process control variants can be assigned in their essential characteristics to the known arc types short arc, mixed arc, spray arc and pulse arc. In contrast to classical MIG/MAG welding, however, MIG/MAG process control variants specifically modify the properties in order to open up certain advantages. These relate on the one hand to quantitative aspects, such as the expansion of the process window possible for the specific arc type, and on the other hand to qualitative aspects, such as process stability and error. prevention. The following options are predominantly used with regard to the material transition: - Change of time duration and frequency of the material transition in the short circuit - Limitation of causes for the formation of spatter in the case of short-circuited material transition - Influencing the beginning and end of the material transition - Changing the direction of movement of the melting electrode - Shortening of the predominantly short-circuit-free controllable arc length in the spray arc - Timing of different types of material transition - Influencing weld penetration and seam geometry by means of material transition The following arc types are used: - Regulated short arc - Low splash short arc - Energy-reduced short arc - Performance-enhanced short arc - Modified spray arc - pulsed arc - Modified pulsed arc - AC process - Combined process variant - Cyclic wire movement
MIG welding	Metal inert gas (MIG) welding is closely related to MAG welding; however, inert gases such as argon, helium or their mixtures are used as shielding gases. The process is used in particular for welding non-ferrous metals.
MMA welding	In manual metal arc welding (MMA), rutile, basic, acidic or cellulose coated rod electrodes are melted in the arc. The coating has both metallurgical (addition of alloying elements) and process engineering functions (formation of a protective atmosphere above the melt, stabilisation and alignment of the arc). The melting of rutile, basic or acid coated electrodes leads to the formation of slag, which must be removed from the weld seam after the welding process and after the seam has cooled down.
Resistance Welding	Resistance welding is a mechanized electric welding process especially for joining thin-walled workpieces such as sheet metal. The workpieces are first pressed together with a welding tong or rollers. By applying a current pulse to the electrodes of the welding tong, the workpieces are selectively heated in the area of the electrodes and fuse together under the pressure exerted by the welding tong.

Process name	Explanation
Pressure welding	In pressure welding, the components are joined at the joint in a doughy state by pressing them together. No auxiliary materials (e.g. welding wire) are required. The components are heated with the aid of another mechanical, chemical or electrical energy resource, since most materials lose strength as the temperature rises. Pressure welding represents a non-detachable connection of the materials. Almost all materials can be welded with the large number of pressure welding processes. Welding of different materials is possible with some processes, e.g. friction stir welding or friction welding.
Laser beam welding with and without filler metal	Laser beam welding is a welding process in which the required heat is generated by a laser beam. The laser beam penetrates the material surface and the energy of the laser is absorbed in the material, converted into heat and used for the welding or cutting process. There are a large number of different laser beam sources and processes, which are increasingly specializing in specific applications. Gas lasers, such as fast flow or diffusion cooled CO_2 lasers, or solid state lasers, such as Nd:YAG, disk, fiber or diode lasers are used. Depending on the laser beam intensity/power density used, a distinction is made between heat conduction welding and deep penetration welding. In combination with other welding processes, the laser beam-arc hybrid welding process, for example, can also be used to exploit the advantages of both processes.
Soldering	Joining process primarily for joining different metallic materials with the aid of a molten addition material (solder) whose melting temperature is below that of the base materials; the base materials are wetted without being melted. In some cases, fluxes in paste or powder form are added to clean the workpiece surface, improve wettability and prevent the formation of surface films. In soft soldering, the solder melts at working temperatures below 450°C, in hard soldering above 450°C, e.g. flame brazing at about 700°C. For TIG, MIG, MAG, laser beam brazing and plasma brazing, the working temperature is 900° to 1100 °C. A distinction is made between joint brazing and surface brazing depending on the type of brazing joint.
Autogenous flame cutting	An oxygen fuel gas flame serves as the heat source for autogenous flame cutting. Acetylene, propane or natural gas are used as fuel gases. A heating flame heats the material to ignition temperature and cleans the surface from rust, scale and other impurities. The material is burnt to slag along the cutting oxygen jet. The resulting combustion heat enables continuous combustion in the depth and feed direction. The thin slag is blown out of the kerf. The prerequisite for autogenous flame cutting is that the ignition temperature of the material to be cut and the melting temperature of its slag are lower than the melting temperature of the material. The slag produced during combustion must be thin and the material should have low thermal conductivity. This is the case, for example, with structural steels, low alloy steels, cast steel and titanium. Advantages - low investment and operating costs - flexible use, e.g. on construction sites - largest application range in relation to the workpiece thickness - good suitability for bevel cutting Disadvantages - Material selection severely limited - high thermal load of the material

Process name	Explanation
Plasma cutting	Plasma cutting can be used to prepare weld seams and form cuts on materials that are not suitable for flame cutting. These are for example alloyed steel, aluminium, copper and grey cast iron. The plasma gas - nitrogen, nitrogen-hydrogen mixtures, argon-hydrogen mixtures and compressed air are used - flows through the water-cooled cutting nozzle. The arc burning between the electrode and the workpiece heats the plasma gas to a plasma jet with a temperature of about 45,000°C. The material melts along the plasma jet and is blown out of the joint. The cutting result is influenced by the parameters cutting current, cutting speed, distance of the plasma torch to the workpiece, gas pressure and gas quantity. Due to high noise pollution and hazardous substance emissions, plasma cutting is often carried out industrially with under water cover of the workpiece. Advantages - Only thermal process for cutting high alloy steels and aluminium materials in the medium and larger thickness range - excellent for structural steel in the thin sheet range - Cutting of high-strength structural steels with low heat input - higher cutting speeds compared to oxyfuel flame cutting Disadvantages - wider kerf compared to autogenous flame cutting - non-parallel cutting edges- very high noise pollution when dry cutting - high pollutant emission during dry cutting

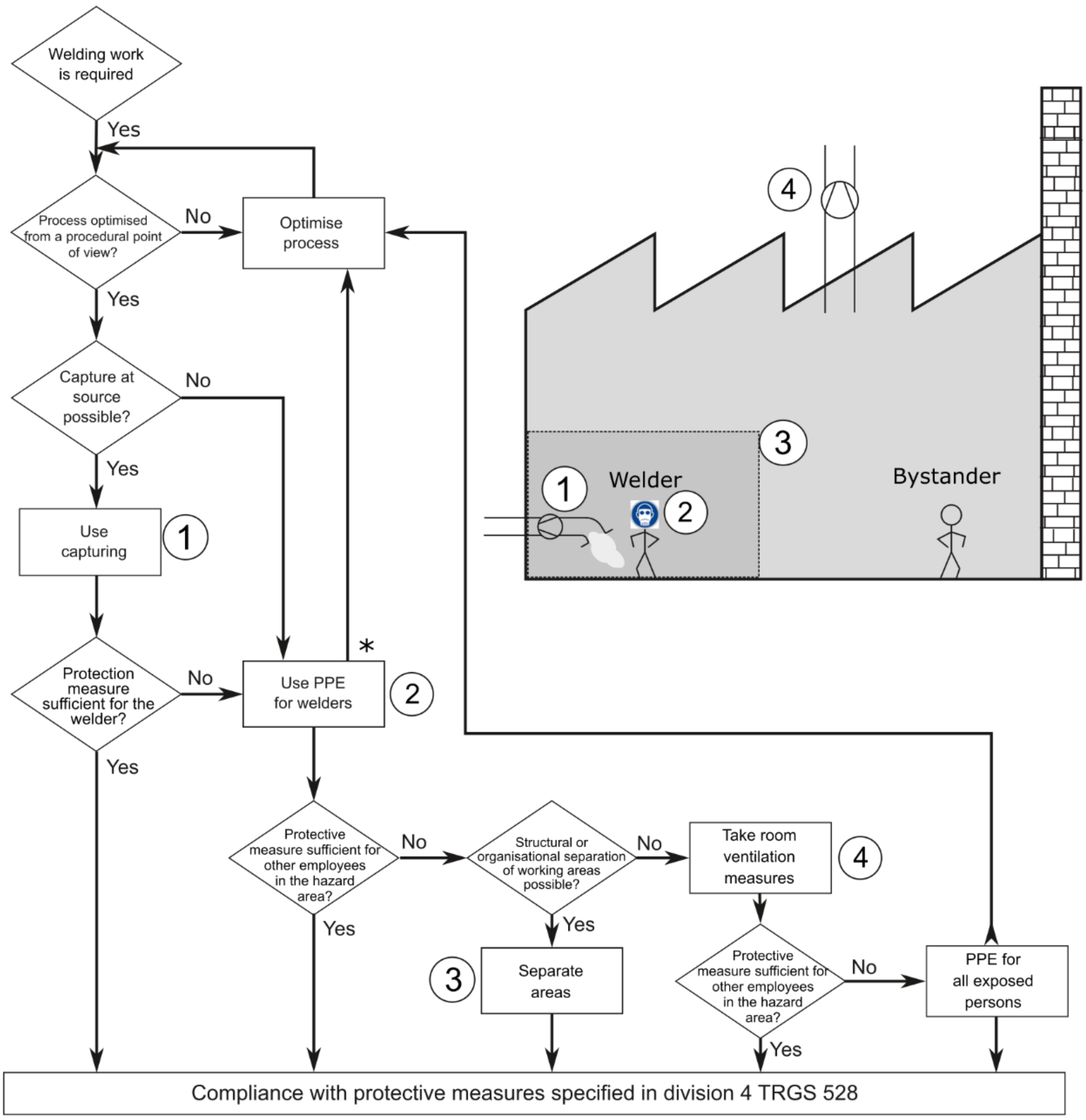
Process name	**Explanation**
Laser beam cutting	Laser beam cutting is suitable for cutting different materials, e.g. steels, non-ferrous metals, plastics, ceramics or wood. For ferrous materials it is mostly used for workpiece thicknesses of up to 25 mm. Both CO_2 gas lasers and solid-state lasers in the form of a disk or fiber laser are used. High electrical/optical efficiency can be achieved today with the diode-pumped solid-state laser. For material processing, e.g. for cutting transparent materials such as displays, drilling nozzles or ablating channels, ultrashort pulse lasers are also used today or when other technologies are no longer suitable. Three process variants are distinguished according to the type of transformation of the material in the kerf: - In laser beam flame cutting, the material to be cut is heated to ignition temperature by the focused laser beam. The cutting oxygen burns the material at the cutting point and forms a thin slag, which is blown out of the kerf by the kinetic energy of the oxygen jet. The cutting process corresponds to the combustion process during flame cutting. The most common application is therefore the cutting of non alloy and low alloy steels. - In laser beam fusion cutting, the material is melted by the laser beam over the entire thickness of the workpiece. Instead of cutting oxygen, an inert gas, usually nitrogen, is used and blows the melt out of the kerf. Laser beam fusion cutting is preferably used for cutting high alloy steels and for non-ferrous metals. The particular advantage of cutting high alloy steels with nitrogen are the resulting metallically bright cutting edges. - In laser beam sublimation cutting, the material to be cut is vaporized (sublimated) by the high energy density of the laser beam. The vaporized material is blown out of the kerf by the vapour pressure and by an inert cutting gas. Laser beam sublimation cutting is used for cutting wood, leather, textiles and plastics. Advantages - high cutting speed - process-dependent rework-free, metallically bright cutting edges - precise cutting contours with almost parallel kerfs - depending on the system, a high variety of materials is possible, e.g. non-ferrous metals can also be cut - low heat-affected zones Disadvantages - High investment costs compared to other thermal separation processes - limited range of sheet thicknesses (up to 50 mm high alloy steel, up to approx. 25 mm non alloy steel)

Process name	**Explanation**
Thermal spraying	The spray additive is fed to a nozzle in the form of powders, wires or rods. In the nozzle it is partially or fully melted in the flame of a fuel gas/air or fuel gas/oxygen mixture, in an electric arc or in a plasma and accelerated in a carrier gas flow at high speed onto the surface of the workpiece to be coated. The most commonly used procedures include: - flame spraying - high velocity flame spraying - arc spraying - plasma spraying - cold spraying Thermally sprayed coatings are used to improve workpiece and component properties, for example with regard to wear, corrosion, tribological behaviour, heat transfer or insulation, electrical conductivity or insulation, appearance and/or to restore serviceability for new production and repair. In addition, they create the conditions for solderability for certain applications.
Flame straightening	Flame straightening is a manufacturing process in autogenous technology. The heat source is usually an oxygen-acetylene flame. Welding on steel and metal structures creates residual stresses in the multiaxial stress state. A basic distinction is made between four types of shrinkage (longitudinal, transverse, angular and thickness shrinkage). However, little importance is attached to the latter. Flame straightening eliminates the shrinkage and stresses created during welding.
Additive manufacturing	Additive manufacturing refers to manufacturing processes in which a component is produced layer by layer by adding the material. Due to the layer-by-layer structure, complex structures can be produced that cannot be realized with machining or casting processes. With regard to welding technology, metals, plastics or ceramics are used as common materials. The materials are usually melted in powder form by a laser beam and joined together. Additive manufacturing processes that are within the scope of this TRGS include laser cladding, selective laser melting and selective laser sintering with metal powders.

Annex 2: Decision-making aids for the selection of protective measures

This Annex describes the basic approach to selecting the necessary protective measures in the case of welding. The following flow chart shows the general procedure.

1 Protective measures in the case of welding



* further process optimisation is required because of the of PPE

Figure 2: Flow chart for the selection of protective measures for welding work**.**

2 Selection of capturing system

Criteria for the selection of capturing systems are:

1. welding process
2. type of process
3. position of weld seams
4. number of pieces
5. size of components
6. length of weld seams

1. Welding processes

MIG/MAG	• Welding torch integrated capture • HV[1] -/LV[2] - point capture
TIG, MMA	• HV-/LV- Point capture
Autogenous process	• HV-/LV- Point capture
Thermal cutting	• Table extraction

2. Type of process

Automated procedures	• If possible, carry out with closed capture system (keeping under pressure, defined flushing of the system) • Machining in fixtures with permanently installed,
Manual procedures	• Consideration of the following criteria

3. Position of weld seams

predominantly tub position Components can be rotated, for example	• Welding torch-integrated capture • HV/LV point capture
frequently changing welding positions (see also size of components)	• HV/LV point capture • Welding torch-integrated capture

4. Number of pieces

large machining in fixtures	• Machining in fixtures with permanently installed, adapted capture elements
medium processing at stationary work-places	• HV/LV point capture • Burner integrated capture
small processing at changing work-places	• HV point capture • Welding torch-integrated capture

[1] HV = high vacuum extraction using a vacuum of at least 8 000 Pa, typical diameter of extraction hoses 60-80 mm.

[2] LV = low-vacuum extraction, uses vacuums of up to 3000 Pa, typical diameter of extraction hoses 150-160 mm.

5. Size of components

small	• Table extraction • LV point capture • Welding torch-integrated capture
medium	• HV/ LV point capture • Welding torch-integrated capture
large	• Welding torch-integrated capture

6. Length of weld seams

≤ approx. 300 mm	• LV point capture • Welding torch-integrated capture
> approx. 300 mm	• HV point capture with adapted capture elements • Welding torch-integrated capture

3 Selection of welding smoke separators

Criteria for the selection of welding smoke separators are

1. Number of workplaces
2. Location of workplaces
3. Size of the workshop/work station

1. Number of workplaces

≤ 3	• mobile single workplace separators
> 3	• stationary multi-workplace separators

2. Location of workplaces

many workplaces of the same type, arranged next to each other.	• stationary multi-workplace separators
different distributed workplaces	• mobile single workplace separators • Central HV separator with distributed connection points for point capture and welding torch-integrated capture

3. Size of the workshop/work station

With increasing workshop size, the costs for central extraction systems increases. Especially with HV systems, leakages play an increasing role.

Solution approach: form smaller systems, islands.

4 Ventilation

As the volume of workshops increases, the costs for indoor ventilation increases, too. his involves high investment costs and even higher operating costs.

Solution: Optimize capture at the source.

Annex 3: Specific information for selected sectors

The requirements of section 4 Protective Measures remain unaffected in the following selected sectors. The measures listed in this annex represent a supplement or concretization for the respective sector**.**

1 Shipbuilding

1.1 Description of the sector and typical products

In shipyards, ships made of steel or aluminium are newly built or maintained.

1.2 Description of typical workplaces

The welding work is carried out on or in ships and on ship components in halls, in docks and on slipways.

1.3 Description of activities

In particular, the employees carry out joint welding on steel or aluminium materials and cutting of steel or aluminium materials by means of flame or plasma cutting.

Welding processes used include in particular MIG/MAG welding, manual metal arc welding, submerged arc welding and TIG welding.

Operating times (welding time)

Welders working at shipyards generally perform welding work all the time. Locksmiths, pipe fitters and shipbuilders, on the other hand, also perform other work activities. Their share in welding and flame-cutting work is usually up to 20 %.

Base materials

Mainly non alloy steels are processed in plate thicknesses of between 5 and 30 mm. In the case of special ships and e.g. in ship superstructures and equipment, aluminium materials are processed in a thickness range of 3 to 20 mm. Chrome-nickel steels and copper alloys are used on a case by case basis.

Addition materials

The addition materials are used in accordance with the base materials.

1.4 Exposure situation

The exposure situation in shipbuilding is characterised by constantly changing workplaces. When welding in confined spaces and when welding complex component geometries, difficult ambient air conditions occur because extraction at the source is often not possible. In these cases it is usually necessary to wear suitable respiratory protection.

1.5 Protective measures Substitution

Priority is to be given to welding processes with low emission rates such as submerged arc welding and TIG welding, if this is possible according to the state of the art.

Technical/structural protective measures

The welding fumes always have to be extracted at the source by means of suitable welding torch-integrated extraction systems or tracking extraction elements above the welding point.

In working areas, e.g. workshops, additional technical room ventilation may be necessary to protect other employees in the hazard area if limit values cannot be complied with by other measures (extraction at the source, structural and organisational measures).

Organizational protection measures

Wherever possible, welding and burning work should be separated from other activities in space or time.

The effectiveness of the protective measures taken must be checked regularly, see section 5. All extraction equipment (ventilation and extraction systems as well as the extraction units) must be maintained regularly in accordance with the manufacturer's instructions and checked for full functionality at least once a year.

Preventive occupational healthcare of employees is to be carried out in accordance with the provisions of section 6.

Personal protective measures

Suitable respiratory protection must be worn at all times if the technical and organisational measures are not sufficient, e.g. if the extraction equipment cannot be used effectively due to poor accessibility, see section 4.7 paragraph 7.

In shipbuilding, fan-assisted welding helmets, welding helmets with external compressed air supply (insulating devices) or filtering FFP3 face masks have proved their worth, see also section 4.7 paragraph 7.

2 Automotive engineering - body shell construction

2.1 Description of the sector and typical products

Depending on the vertical range of manufacture, all vehicle manufacturers have their own body shell construction, while other assemblies relevant to welding technology, such as exhaust silencers, chassis parts, etc., are often manufactured as purchased parts from suppliers.

Whereas standard steel sheets used to be joined ungalvanized, and from the 80s increasingly galvanized, by resistance spot welding or MAG welding, combinations of various materials (mainly aluminium-steel composite structures) are now common. Welding has therefore been partly replaced by other joining methods such as clinching or self-pierce riveting.

Epoxy resin-based body adhesives are also used to increase crash resistance.

2.2 Description of typical workplaces

Car body production usually takes place in a hall with technical ventilation and heat recovery, in which the heat is transferred from the exhaust air to the supply air via heat exchanger.

2.3 Description of activities

At the workplace, the pre-assembled components are inserted into fixtures, which are joined together by the robot during the next work cycle through bead application of the body adhesive and/or by resistance spot welding or by inert gas welding.

Resistance spot welding with the hand-held spot welding gun or MAG welding with the hand-held welding torch is usually still used as an "emergency strategy" in the event of a system malfunction or as rework.

The laser beam welding processes or laser beam brazing that occur in some special areas are carried out in closed systems with direct extraction also for reasons of protection from laser radiation.

Operating times (welding time)

The welding time for resistance spot welding is in the fraction of a second range.

The duty cycle of the MIG/MAG welder is limited due to its design and is only relevant in the special cases described (emergency strategy and rework).

Base materials

The following base materials are used in the production of car bodies:

- Body panels made of galvanised, non alloy steel in a thickness of 0.6 to 0.8 mm,

- Body reinforcement sheets (cross members/ longitudinal members) in a thickness of usually 2 mm,

- Outer skin sheets made of various aluminium alloys in a thickness of usually 1.5 mm.

Addition materials

The following addition materials (electrodes) are commonly used in automotive body manufacturing:

- For non alloy and low alloy steels gas metal arc welding electrodes with the abbreviation G3Si1 according to DIN EN ISO 14341,

- for aluminium components TIG welding electrodes with the abbreviation S Al 4043 (AlSi5) according to DIN EN ISO 18273,

- for laser beam brazing electrodes with the abbreviation S Cu 6560 (CuSi3Mn1) according to DIN EN ISO 24373,

- for resistance spot welding welding electrodes made of CuCrZr (CuCr1Zr).

2.4 Exposure situation

While the breathing zone of the system/robot operator is outside the source area of the welding fumes, the welder is directly exposed during rework or emergency strategy in case of system malfunction.

2.5 Protective measures

Plant and robot operation - Requirements for the ventilation system

The hazardous substances are to be captured directly at the source or with a hood extraction system. A directed air flow from the work areas to the extraction areas must be ensured.

Leakages and overflows at heat recovery systems from exhaust air to supply air are to be minimized. The maximum proportion of exhaust air in the supply air must remain below 1 % during normal operation. During welding operation, the extraction system is to be operated permanently in exhaust air mode. Recirculated air operation is only permitted during welding-free periods.

Rework and emergency strategy in case of plant malfunction - Requirements for the workplaces

In the case of smaller components, a welding booth with a welding table and adjustable extraction element must be set up.

When working on the car body outside a welding booth, the employee must wear a welding helmet with a separate air supply in addition to the running-hall extraction system.

3 Plant, container and pipeline construction

3.1 Description of the sector and typical products

The main areas of activity are the manufacture of large containers (silos), intermediate storage containers and smaller apparatus as well as pipeline construction. The containers are often equipped with agitators, e.g. for discharge, and screw conveyors in the pipelines may be required for transport.

Sheets and profiles in the thickness range of 3 to 30 mm are usually processed, with individual profile dimensions of up to 12 m.

The operating temperatures range from low temperatures to high temperatures in the power plant sector, and the variety of materials is correspondingly large.

3.2 Description of typical workplaces

Due to the size and shape of the components, the welding workplaces are, with a few exceptions (automatic welding processes), set up as assembly and welding workplaces decentrally at changing locations in the workshop. Due to their heavy weights, the components often cannot be positioned without aids (crane), and welding is mainly carried out in forced postures.

3.3 Description of activities

In addition to the machining processes, conventional and automatic fusion welding processes (submerged arc, MIG/MAG and partly TIG welding) are carried out. The focus is on MAG welding of non alloy and high alloy steels. The operating times can vary considerably. In addition, cutting processes of steel materials by means of flame and plasma cutting are used.

The base materials used are non alloy or high-strength structural steels, pressure vessel steels and high alloy steels for low- and high-temperature applications. Welding is carried out with addition materials of the same type, and with nickel-based materials for special applications.

3.4 Exposure situation

The exposure situation is characterised by constantly changing workplaces, except in the case of small apparatus construction. The room air conditions are difficult in complex component geometries because it is often not possible to extract at the source. In these cases it is usually necessary to wear suitable respiratory protection.

3.5 Protective measures Substitution

Welding processes with low emission rates are to be used as a matter of priority, also with regard to the choice of addition material in coordination with the base material (low manganese content).

Technical/structural protective measures

The welding fumes must be extracted at the source. Preferably, welding torch-integrated extraction systems with exhaust air filtering or mobile extraction tracking elements to be installed above the welding point are suitable.

In working areas, e.g. halls, additional technical room ventilation may be necessary to protect other employees in the hazard area if limit values cannot be complied with by other measures (extraction at the source, structural and organisational measures).

Organizational protection measures

Welding and flame-cutting work is to be separated from other activities as far as possible either in terms of space or time. Likewise, the processing of structural steels and high alloy steels is to be spatially separated, if possible.

Personal protective measures

If the technical and organisational protective measures are not sufficient, suitable respiratory protection must be provided and worn.

Suitable respiratory protective devices are fan-assisted welding helmets or forced ventilation welding helmets. For short periods of use it is also possible to use, filtering respirators with filter class FFP2 or, in the case of welding fumes with carcinogenic content substances, filter class FFP3.

4 Steel construction

4.1 Description of the sector and typical products

In steel construction, large supporting structures such as road or railway bridges are made of steel.

4.2 Description of typical workplaces

The welding workplaces are usually located in large workshops with floor areas of over 2,000 m^2.

4.3 Description of activities

For joint welding on steel materials mainly MIG/MAG and TIG welding are used.

Operating times (welding time)

Welders working in steel construction usually perform welding-related work all the time.

Base materials

The base materials used are mainly non alloy steels with the abbreviations S 235 to S 460, S 690, S 960 and chrome-nickel steels in plate thicknesses of up to 200 mm.

Addition materials

Addition materials are used in accordance with the base materials, i.e. addition materials with a slight overalloying compared to the base material.

4.4 Exposure situation

The exposure situation of the welders is characterized by constantly changing workplaces. The components are placed in corresponding ergonomically favourable positions for optimum processing.

4.5 Protective measures Substitution

In principle, it has to be checked whether processes with low emission rates, e.g. TIG welding, can be used. These processes are then to be used accordingly.

Technical/structural protective measures

The welding fumes must always be extracted at the source by means of suitable welding torch-integrated extraction systems or tracking extraction elements above the welding point.

In working areas, e.g. halls, additional technical room ventilation may be necessary to protect other employees in the hazard area if limit values cannot be complied with by other measures (extraction at the source, structural and organisational measures).

Organizational protection measures

If possible, the materials or components should be positioned in such a way that work does not have to be carried out in forced postures.

Personal protective measures

If the technical and organisational protective measures are not sufficient, suitable respiratory protection must be provided and worn.

Suitable respiratory protective devices are fan-assisted welding helmets or forced ventilation welding helmets. For short periods of use, filtering face masks of filter class FFP2 or, in the case of welding fumes with carcinogenic content substances, filter class FFP3 are also applicable.

5 Metal construction

5.1 Description of the sector and typical products

Welding and related processes are usually applied in the field of structural metal engineering. The focus of activity is the manufacture and assembly of products made of steel and/or aluminium. Typical products are stairs, railings, canopies, balconies, gates, grilles or fences, some of which are also assembled on site. Sheets and profiles in the thickness range 3 to 25 mm are usually processed, with dimensions of up to 6000 mm. Due to their relatively low weights, the components can usually be handled without aids (crane) and can be easily positioned.

5.2 Description of typical workplaces

Due to the size and shape of the components, welding workplaces are set up decentrally - as assembly and welding workplaces - at changing locations in the workshop. If, in addition to the non alloy standard materials, stainless CrNi- or aluminium materials are processed, a local separation of the welding areas is usually carried out.

5.3 Description of activities

In addition to machining processes, conventional fusion welding (MMA, MIG/MAG and TIG) plays the most important role. The focus here is on MAG welding of non alloy steels.

Operating times (welding time)

The individual processes are applied in metal construction averaged over the sector as follows:

Table 4: Processes used in metal construction

Process	Scope (frequency of use)	Material	Arc burning time (hrs/day)
MAG (manufacturing)	80 %	non alloy steel	1.0-1.5
MMA (assembly)	10 %	non alloy steel chrome-nickel steel	0.5
MIG/MAG (manufacturing)	5 %	aluminium chrome-nickel steel	0.5
TIG (manufacturing)	5 %	aluminium chromium-nickel steel	0.5

Base materials

A typical non alloy steel is structural steel with the abbreviation S 235 (material number 1.0038) with approx. 80 %, for chrome-nickel steels with the abbreviation X5CrNi18-10 (material number 1.4301) and X6CrNiMoTi 17-12-2 (material number 1.4571) with approx. 15 % as well as aluminium and its alloys with approx. 5 %.

Addition materials

The addition materials used are in accordance with the base materials and contain similar chemical compositions.

5.4 Protective measures

In principle, it should be checked whether welding can be replaced by other joining methods such as gluing, folding or mechanical joining (screws, rivets).

Automated welding processes with integrated extraction (if necessary enclosed) are preferable to conventional welding processes.

If one of the conventional welding processes is selected, it should be optimised so that lower-pollution welding processes are preferably used, e.g. TIG instead of MMA welding or MAG solid wire welding instead of MAG flux cored wire welding.

Unless welding work with low exposure is involved (see section 3.2.4 paragraph 4), the welding fumes must be captured as far as possible at the source as set points. For this purpose, the welding torch-integrated extraction system is suitable, e.g. for long weld seams and large components. Table extraction is suitable for fixed welding stations, e.g. for small parts, or separate LV/HV spot extraction with mobile individual station separators.

If extraction at the source is not sufficient for the welder, suitable personal protective equipment, e.g. a ventilated helmet, must be used both for the welding activities and for ancillary work, e.g. plastering of seams.

In the case of small and medium-sized components, other employees in the hazard area are to be protected by spatial partition of the welding shop from other manufacturing areas. If spatial partition is not possible, suitable room ventilation measures have be taken to protect other workers in the hazard area.

6 Manual commercial vehicle production and repair

6.1 Description of the sector and typical products

The main focus of activity is the manufacture and repair of special vehicles or of individual superstructures with which series chassis for commercial vehicles have been fitted, with a total weight of usually more than 3.8 tons.

6.2 Description of typical workplaces

Usually, metal sheet and profiles in the thickness range of 3 to 30 mm are processed, with dimensions of up to 6000 mm. Due to the size and shape of the components, welding workplaces are set up decentrally - as assembly and welding workplaces - at changing places in the workshop. Due to their heavy weights, the components often cannot be positioned without aids (crane), and welding is mainly carried out in forced postures.

6.3 Description of activities

In addition to machining processes, conventional fusion welding (MIG/MAG and in some cases TIG welding) is of the greatest importance. The focus here is on MAG welding of non alloy steels. The operating times can vary considerably. In addition, cutting processes of steel materials by means of flame and plasma cutting are used.

Typical non alloy steels are steels with the abbreviation S 235JR or S 355J2. Welding is carried out with similar, slightly higher alloyed addition materials.

6.4 Exposure situation

The exposure situation is characterized by constantly changing workplaces. The room air conditions are difficult in the case of complex component geometries, because it is often not possible to extract at the source. In these cases it is usually necessary to wear suitable respiratory protection.

6.5 Protective measures

Substitution

Welding processes with low emission rates are to be used as a matter of priority, also with regard to the choice of addition material in coordination with the base material (low manganese content).

Technical/structural protective measures

The welding fumes must always be extracted at the source, preferably by means of suitable welding torch-integrated extraction systems or also by means of trackable extraction elements above the welding point.

In working areas, e.g. workshops, additional technical room ventilation may be necessary to protect other employees in the hazard area if limit values cannot be complied with by other measures (extraction at the source, structural and organisational measures).

Organizational protection measures

Welding and flame-cutting work are to be separated from other activities as far as possible, either spatially or temporally.

Personal protective measures

If the technical and organisational protective measures are not sufficient, suitable respiratory protection must be provided and worn.

Suitable respiratory protective devices are fan-assisted welding helmets or forced ventilation welding helmets. For short periods of use, filtering respirators with filter class FFP2 or, in the case of welding fumes with carcinogenic content substances, filter class FFP3 can also be used.

7 Additive manufacturing

Additive manufacturing processes (see also Annex 1) are relatively new technologies whose applications are becoming increasingly important. The processes described here use metal powders that are introduced layer by layer into a closed space (installation space) with the aid of a charging device and selectively melted with a laser beam.

Exposure to hazardous materials or fire and explosion hazards may occur during the following operations:

- Quality inspections (incoming goods inspection)
- Storage of metal powders
- Powder preparation including reprocessing
- Plant preparation
- Printing of the component (building process)
- Component removal and cleaning (powder removal)
- Cleaning the installation space
- Component reworking
- Waste disposal
- Filter changes

7.1 Quality inspections (incoming goods inspection)

Description of activities

Metal powders are usually supplied in closed containers with appropriate stability during transport. For quality tests, they must be opened and samples taken. In the process, the metal powder may be stirred up and inhaled and there may be skin contact. Metal powders finely dispersed in the air can create an explosive atmosphere at the workplace.

Protective measures

Low-dust working method, wear chemical protective gloves e.g. disposable nitrile gloves, approx. 0.2 mm thickness and approx. 300 mm length and protection goggles. Suitable respiratory protective equipment has to be worn when working with carcinogenic metal powders. DGUV Rule 112-190 contains notes to select suitable respiratory protective equipment.

To prevent metal powder adhering to clothing from being carried to other areas, working clothes, e.g. a smock, must be worn and removed when leaving the work area.

7.2 Storage of metal powders

Description of activities

Metal powders are usually stored in closed containers. Powders are a fire load.

Protective measures

Adjust storage quantity to the process. The requirements of TRGS 510 must be taken into account.

7.3 Powder preparation including reprocessing

Description of activities

Before a metal powder is used, its flow behaviour is usually determined. A powder that does not meet the requirements is either not used and returned to the supplier, or the flow behaviour of the powder is adjusted to the desired properties by a sieving process.

Whether powder used once in a printing process is used a second time depends on the quality requirements. Often the powder is disposed of as waste. If a second use is possible, the powder must be sieved before it is used again. The sieving process should be carried out in closed sieving equipment. Hazards may arise from skin contact, inhalation or the formation of explosive atmospheres.

Protective measures

Vacuuming of the screening machines with dust extractors (dust class M, for carcinogenic metals dust class H), which are also suitable for vacuuming combustible dusts. These devices are marked “type 22” or “ExHexagon II 3D”. In all other cases, the measures listed in section 7.1 apply.

7.4 Plant preparation

Description of activities

Before the printing process, the equipment must be filled with the respective metal powder. Depending on the type of system, filling can be carried out with a shovel, by an open pouring process or by connecting the powder container.

Protective measures

Open pouring operations are to be avoided. If this is not possible, the protective measures listed in section 7.1 are to be implemented.

7.5 Printing the component (construction process)

Description of the activity

Laser beam melting systems are closed systems. Before and during the printing process, the installation space is flooded with inert gas. Since the installation spaces have only a low leakage rate, only small amounts of inert gas or fumes (smoke/condensate) escape from the installation space.

Protective measures

Since the printing process is automated and is usually only checked occasionally, protective measures for employees are usually not required.

7.6 Component removal and component cleaning (powder removal)

Description of the activity

After the printing process is finished, the powder and the components inside must cool down before the installation space is opened and the unmelted powder is removed with an extractor. After removing the powder, the components are removed from the installation space with the working platform. Metal powder adhering to components is roughly removed with spatulas, brushes or similar tools.

Protective measures

Exposure to metal powders may occur during the work steps. In this respect, the protective measures mentioned in section 7.1 also apply here. If the components are removed while still warm, suitable heat-resistant protective gloves must be worn.

7.7 Cleaning the installation space

Description of activities

Before the next printing process, the installation space is cleaned, specifically condensate/smoke adhering to the walls is extracted with wet separators or dry extractors and then wiped with damp cloths. Special lens cleaning cloths are usually used for cleaning the laser optics. When cleaning the interior, there is an increased risk of explosion due to condensed dusts. If the cleaning cloths dry, they can ignite themselves. They therefore present an increased fire load.

Protective measures

The hazards described in section 7.1 can occur during the work steps. Therefore, the protective measures mentioned also apply here. In particular, suitable protective gloves must be worn. For cleaning the installation space, some manufacturers of filtering devices offer special filtering devices which generally have a multi-stage filter system. For reasons of explosion protection, the pre-filter usually consists of a wet separator, e.g. a water bath. Cloths used for manual cleaning must be collected in closed containers made of non-flammable material and disposed of.

7.8 Component finishing

Description of activities

The printed components are firmly attached to the working platform and must be separated mechanically using a saw or by breaking them off. These work steps and the further component cleaning takes place outside the installation space, often on special work tables with extraction or in enclosed cleaning chambers.

If the component surfaces have to be sandblasted or ground, this is done in cabins.

Protective measures

Wearing of suitable protective gloves, provision and wearing of suitable respiratory protection, if necessary.

7.9 Waste disposal

Description of activities

Metal powders and wastes may tend to react strongly in air and sometimes self-ignite. Mixing of different metal powder residues must be avoided. Sludges from wet separators and flooded air filters may react in air and release hydrogen (explosion hazard).

Protective measures

Store waste in containers made of non-combustible material and, if possible, outdoors or in well-ventilated rooms with direct air exchange through fresh air.

Annex 4: Notes for measurements

- **for the determination of exposure to hazardous substances**
- **for checking the effectiveness of ventilation equipment**

for welding work

1 Determination of exposure to hazardous substances

(1) TRGS 402 is to be taken into account for measurements to determine hazardous substance exposures. Anyone carrying out workplace measurements must be competent and have the necessary equipment. If the measurements are carried out by measuring bodies accredited for measuring hazardous substances at workplaces, the employer can generally assume that the findings obtained by this measuring body are accurate.

Information on suitable measuring bodies can be found on the DGUV homepage at: http://www.dguv.de/ifa/fachinfos/arbeitsplatzgrenzwerte/messstellen-fuer-gefahrstoffe/index.jsp.

If measurements are to be carried out by a measuring body which is not accredited for workplace measurements, the employer must check whether the measuring body meets the relevant requirements.

The finding is then the result of the evaluation of a measurement according to TRGS 402.

The finding may be (except for carcinogenic substances with risk-based assessment criteria): "protective measures sufficient" or "protective measures not sufficient".

The substance index is formed for a single substance. If several substances contribute to exposure in the working area simultaneously or successively during a shift, the evaluation index is calculated for substances with an OEL by adding the substance indices of the individual substances. If the substance or evaluation indices are less than or equal to 1, and if the short-term value requirements are met and it can also be justified that the substance or evaluation indices will also be complied with in future, the finding is "protective measures sufficient".

Due to the different effects, the gaseous hazardous substances (NO_x and ozone) are assessed separately from the particulate hazardous substances in welding work and are thus not included in the evaluation index. This does not apply to manganese and other substances with OEL.

If substance indices for A and E dust fractions are available for a hazardous substance, the higher substance index is to be taken into account when calculating the evaluation index. If only one substance index is available, this is to be used.

Compliance with the general dust limit value (A and E dust fraction) must be determined separately on the basis of the substance indices.

In the case of carcinogenic hazardous substances with risk-based assessment standards according to TRGS 910, the findings may be:

1. Tolerable or acceptable concentration is complied with, or
2. Tolerable concentration exceeded.

In the case of carcinogenic chromium(VI) compounds, the finding may be:

1. Assessment criterion met, or
2. Assessment criterion exceeded.

If there is exposure to several carcinogenic substances, these are assessed separately as individual substances on the basis of their substance indices. An evaluation index does not have to be calculated in these cases. In the case of carcinogenic substances, the measures to be taken are based on TRGS 910 and this TRGS.

(2) In the case of hazardous substance measurements, a distinction shall be made between dust and gas measurements. In the case of dust and welding fume measurements, an air sample is drawn in by means of a sampling pump. The particles contained therein are deposited on a filter that has previously been inserted into a sampling head. The sampling head ensures that the system only detects the dust fraction to be considered (alveolar or inhalable fraction). For gas measurements, direct-reading gas meters are preferably used, which selectively measure the concentration of the gas in question.

(3) For welding fume measurements, measuring systems are to be used which detect both the inhalable (E-dust) and the alveolar dust fraction (A-dust). If the exposure of a welder is to be determined, the measurement should be carried out with personal measuring systems in the breathing zone of the welder, i.e. the sampling should be carried out behind the welding shield or screen which the welder uses to protect himself against optical radiation.

(4) The same applies to the measurement of gas exposures. Gas measurements should be performed either with portable gas measuring devices or with stationary operated ones with sufficiently long hose lines that make sampling in the breathing zone possible. For the sampling of welding fumes, the use of the PGP-EA sampling system has proven to be effective. The system simultaneously captures the alveolar and the inhalable dust fraction and, due to its small dimensions, allows sampling behind the welding shield. However, the system only allows the analytical determination of hazardous substances in the A-dust fraction, e.g. nickel oxide. If the concentrations of hazardous substances in the E-dust fraction have to be determined, e.g. for chromium(VI), cadmium, manganese or fluorine compounds, an E-dust sampling system (PGP-GSP) must also be used. The E-dust concentration is then determined gravimetrically, the concentrations of the individual hazardous substances are determined with chemical analysis methods from the filter exposed. As an alternative to the PGP-EA sampling system, the PGP-GSP and PGP-FSP sampling systems can also be used with an appropriately modified welding helmet to determine the E-and A-dust fractions and the hazardous substances they contain.

(5) If the welding fume or gas concentration in the work area is to be determined, e.g. for assessing the hazard to other employees in the hazard area or for assessing welding procedures and/or welding positions, stationary measuring systems are to be used or person-carried systems are to be used in a stationary manner.

(6) In the case of welding work, representative measured quantities can be used for the metrological determination and assessment of exposure, see Tables 5 to 8 below. For soft soldering, see the "Recommendations for risk assessment by the occupational accident insurance institutions (EGU) in accordance with the Hazardous Substances Ordinance Manual Piston Soldering with lead-containing solder alloys in the electrical and electronics industry" (DGUV Information 213-714) and/or "Recommendations for risk assessment by the occupational accident insurance institutions (EGU) in accordance with the Hazardous Substances Ordinance) Manual Piston Soldering with lead-free solder alloys in the electrical and electronics industry" (DGUV Information 213-725).

Table 5: Welding processes and hazardous substances to be measured (representative measurands)

Process	Material	Hazardous Substance						
		A dust fraction	**Manganese oxide (A-and E-dust fraction)**	**Cr(VI) compounds (E-dust fraction)**	**Nickel oxide and nickel spinels (A-dust fraction)**	**Ozone**	**Nitrogen monoxide and nitrogen dioxide[6)]**	**Others**
Autogenous welding	unalloyed steel, low alloy steel[4)]						X	
	non-ferrous metals [3)]						X	zinc oxide[11)] copper oxide[12)]
Manual metal arc welding	non alloy steel, low alloy steel[4)]	X	X[13)16)]				X	
	high alloy steel CrNi steel[5)]	X		X[16)]			X	
	nickel, nickel alloys (Ni > 30 %)	X			X[16)]		X	copper oxide[7)]
	copper copper alloys (Cu > 50%)	X	X[8)]		X[9)]		X	copper oxide [16)]
MAG (flux-cored arc welding without shielding gas)	non alloy steel, low alloy steel[4)]	X	X[13)16)]				X	barium oxide[2)]
	high alloy CrNi steel[5)]	X	X[13)]	X[16)]	X[15)]		X	barium oxide[2)]
MAG (flux-cored arc welding with shielding gas)	non alloy steel, low alloy steel[4)]	X	X[13)16)]				X	carbon monoxide[1)]
	high alloy CrNi steel[5)]	X	X[13)]	X[14)16)]	X[15)]		X	carbon monoxide[1)]
	nickel, nickel alloys (Ni > 30 %)	x			X[16)]		X	carbon monoxide[1)]
Metal Active Gas welding (MAG) with carbon dioxide	non alloy steel, low alloy steel[4)]	X	X[13)16)]				X	carbon monoxide[1)]
Metal Active Gas Welding (MAG) with mixed gas	non alloy steel, low alloy steel[4)]	X	X[13)16)]				X	
	high alloy CrNi steel[6)]	X	X[13)]	X[14)]	X[15)16)]		X	
Metal-Inert Gas Welding (MIG)	aluminium materials	X[16)]				X[16)]		aluminium oxide
	nickel, nickel alloys (Ni > 30 %)	X		X[10)]	X[16)]			
	copper, copper alloys (Cu > 50 %)	X			X[9)]			copper oxide [16)]

Table 5: Welding processes and hazardous substances to be measured (representative measurands)

Process	Material	Hazardous substance						
		A dust fraction	Manganese oxide (A-and E-dust-fraction)	Cr(VI) compounds (E-dust-fraction)	Nickel oxide and nickel spinels (A-dust-fraction)	Ozone	Nitrogen monoxide and nitrogen dioxide[6)]	Others
Tungsten inert gas welding (TIG) with addition material	non alloy steel, low alloy steel [4)]	X						
	high alloy CrNi steel[6)]	X			X[16)]	X		
	aluminium materials	X[16)]				X		aluminium oxide
	nickel, nickel alloys (Ni > 30%)	X			X[16)]			
Laser beam welding (without addition material)	non alloy steel, low alloy	X	X[16)]					
	galvanized base material	X	X[16)]					zinc oxide[16)]
	high alloy CrNi steel[6)]	X	X	X	X[16)]			
Laser beam cladding	cobalt, cobalt alloys (Co > 60 %)	X		X[10)]				cobalt oxide[16)]
	nickel, nickel alloys (Ni > 30%)	X			X[16)]			
	iron, iron alloys (Fe > 60 %; Cr < 40 %)	X	X	X[16)]				
	copper, copper alloys (e.g. aluminium multi-alloy bronzes) (Cu > 50 %)	X						copper oxide [16)] aluminium oxide

1) Consider carbon monoxide (CO) only if carbon dioxide is used as shielding gas.
2) Consider barium oxide only if barium compounds are part of the addition material.
3) Non-ferrous metals: copper, aluminium, zinc, bronze, brass and metal alloys with Fe < 50 %
4) Non alloy, low alloy steel: alloying constituents < 5 %
5) High alloy CrNi steel: Cr 5-20%; Ni 5-30%.
6) NO and NO2 occur in all autogenous and arc processes. High concentrations are to be expected during gas welding.
7) Only for addition materials with copper contents > 20 %.
8) Only for addition materials with manganese contents > 10 %.
9) Only for addition materials with nickel contents > 30 %.
10) Only for addition materials with chromium contents > 20 %.
11) When non-ferrous metal zinc
12) When non-ferrous metal copper
13) Manganese iron spinel ($MnFe_2O_4$)
14) Mainly Cr(III) compounds
15) Nickel-chromium-iron spinels ($Ni(Cr,Fe)_2O_4$)
16) Usually individual substance with the highest substance index

Table 6: Cutting processes and hazardous substances to be measured (representative measurands)

Process	Material	Hazardous substance: A-dust fraction	Manganese oxide (A-and E-dust-fraction)	Cr(VI) compounds (E-dust-fraction)	Nickel oxide and nickel spinels (A-dust fraction)	Ozone	Nitrogen monoxide and nitrogen dioxide	Others
flame cutting	non alloy steel, low alloy steel[2)]	X	X[4)]				X	
thermal cutting with oxygen lance plasma cutting laser beam cutting	non alloy steel, low alloy	X	X[4)]				X[1)]	
	high alloy CrNi steel[3)]	X	X	X	X[4)]		X[1)]	
	nickel, nickel alloys (Ni > 30 %)	X			X[4)]		X[1)]	
	aluminium materials	X[4)]				X	X[1)][4)]	aluminium oxide

1) When using compressed air or nitrogen as cutting gas

2) Non alloy, low alloy steel: alloying constituents < 5 %

3) High alloy CrNi steel: Cr 5-20%; Ni 5-30%.

4) Usually individual substance with the highest substance index

Table 7: Spraying methods and hazardous substances to be measured (representative measurands)

Process	**Spray addition material**	**Hazardous substance**				
		A/E- dust fraction	**Cr(VI) compounds (E-dust fraction)**	**Nickel oxide and nickel spinels (A-dust fraction)**	**Nitrogen monoxide and nitrogen dioxide**	**Others**
Flame spraying	non alloy, low alloy steel[3)]	X[6)]			X[6)]	
	high alloy CrNi steel[4)]	X	X	X[6)]	X[6)]	
	nickel, nickel alloys (Ni > 30 %)	X		X[6)]	X[6)]	
	aluminium materials	X[6)]			X	aluminium oxide
	non-ferrous metals[2)], depending on material	X[6)]			X	copper oxide[5)6)]
Arc spraying	non alloy steel, low alloy steel[3)]	X[6)]				
	high alloy CrNi steel[4)]	X	X	X[6)]		
	nickel, nickel alloys (Ni > 30 %)	X		X[6)]		
	aluminium materials	X[6)]				aluminium oxide
	non-ferrous metals[2)] , depending on material	X[6)]				
Plasma spraying	copper, copper alloys	X				copper oxide [6)8)]
	high alloy CrNi steel[4)]	X	X	X[6)]		
	nickel, nickel alloys (Ni > 30 %)	X		X[6)]		
	cobalt, cobalt alloys (Co > 60 %)	X	X[1)]			cobalt oxide[6)]

1) If the Cr content is > 20 %, Cr(VI) compounds must also be determined.
2) Non-ferrous metals: copper, aluminium, zinc, bronze, brass, metal alloys with Fe < 50 %
3) Non alloy, low alloy steel: alloying constituents < 5 %
4) High alloy CrNi steel: Cr 5-20%; Ni 5-30%.
5) For copper as a non-ferrous metal
6) Usually individual substance with the highest substance index

Table 8: Brazing and hazardous substances to be measured (representative measurands)			
Process	**Material**	**Flux**	**Representative measurands**
Flame brazing	Hard solders containing copper and phosphorous	Boron compounds, chlorides, fluorides, phosphates as well as	A-dust, copper oxide, chlorides, fluorides
	Hard solders containing silver	Boron compounds, chlorides, fluorides, phosphates as well as	A-dust, silver oxide, chlorides, fluorides,
	aluminium hard solders	chlorides, fluorides (FL)	A-dust, chlorides, fluorides
	Hard solders containing zinc	Boron compounds, chlorides, fluorides, phosphates as well as	A-dust, zinc oxide, chlorides, fluorides,
	Hard solders containing copper	Boron compounds, chlorides, fluorides, phosphates as well as	A-dust, copper oxide, chlorides, fluorides
Furnace brazing	Hard solders containing nickel 2)	-	A-dust, nickel oxide
	Hard solders containing palladium2)	-	A-dust
	Hard solders containing gold2)	-	A-dust
Arc brazing	copper-based alloys3)	-	A-dust, copper oxide1)
Laser beam brazing	copper-based alloys3)	-	A-dust, copper oxide1)

1) In the case of galvanized base materials also zinc oxide.
2) As a rule, these solders are used flux-free in shielding gas furnaces and/or vacuum furnaces.
3) CuSi3, CuAl8, CuSn6

2 Verification of the effectiveness of ventilation equipment

If ventilation systems are used to reduce the exposure of employees to hazardous substances, their effectiveness must be checked regularly.

This verification can be carried out by measurements in accordance with TRGS 402, which may involve a considerable amount of work. In order to simplify or reduce the measurement effort, it is recommended to carry out a determination and assessment of the exposure according to the metrological determination methods according to TRGS 402 during the initial inspection and to additionally determine the performance characteristics of the ventilation equipment used at the workplace. Depending on the type of ventilation equipment, e.g. the air volume flow of the extraction unit/extraction system, the air velocity in the suction field of an extraction hood or the negative pressure in the suction hose of a welding torch with fume extraction should be determined.

If the assessment according to TRGS 402 results in the finding "protective measures sufficient", the performance data of the ventilation system can be used for effectiveness checks. If subsequent performance checks confirm the unchanged function of the ventilation system, it is possible, under the same working conditions (same material, same workload, same welding conditions, same working behaviour, e.g. when tracking the extraction) a sufficient effect of the protective measures can be assumed even without further workplace measurements according to TRGS 402.

Annex 5: Examples of operating instructions

(COMPANY NAME)	OPERATING INSTRUCTION [3]	NO:
WORKING AREA: Shipbuilding, Tank and apparatus building	WORKPLACE: Confined spaces, e.g. double bottom ACTIVITY: Flame heating, flame straightening	

HAZARDS TO MAN AND THE ENVIRONMENT

- poisoning through nitrous gases (the effects can occur up to 72 hours after the exposure!)
- suffocation due to lack of oxygen
- combustion through oxygen enrichment
- explosion hazard through fuel gas accumulation
- fire hazard through combustible materials in the rooms
- burns through heated parts, slag and burner flame
- noise

PROTECTIVE MEASURES AND RULES OF CONDUCT

- Always use room ventilation, start warming only when room ventilation is effective (check!). Do not keep your face over the flame. Do not allow the flame to burn unnecessarily. Never allow release of oxygen for "air improvement". Check welding torch accessories for porous hoses and fixed screw connections.
- Do not pull hoses over sharp edges.
- Remove welding torch accessories in breaks and at the end of the work from the room or remove hoses at the entry point.
- Remove combustible substances, such as fats, oils, paints, wood, paper, etc. from the working area. If this is not possible, cover substances and keep fire extinguisher ready.
- Do not put the fuel gas hoses around your body.
- Use flame-retardant welding suit. Pull trouser legs over your shoes.
- Use protective gloves, protective goggles and hearing protectors.

BEHAVIOUR IN CASE OF OPERATIONAL FAILURES

- In the event of ventilation failure, stop work immediately and leave the room.
- In the event of a hose fire, leave the room immediately and close gas valves at the entry point.
- Fight emerging fires by means of fire extinguishers, report fire (phone number: 112).

BEHAVIOUR IN CASE OF ACCIDENT, FIRST AID

- Stop working. - In the event of burns, cool affected parts of the body immediately under running water and call first responders. - Provide first aid.	In the case of cough irritation and when feeling unwell consult a physician and indicate nitrous gases - Get help, dial 112. - Inform superior.

MAINTENANCE, DISPOSAL

Maintenance and repair must only e performed by commissioned persons

CONSEQUENCES OF NON-COMPLIANCE

- Health damages - Material damages	- Labour law measures

Date:	Signature: Release:

[3] This operating instruction is an example and must be adapted to the specific needs.

(Name of company)	OPERATING INSTRUCTION[4] under section 14 of the Hazardous Substances Ordinance	No. ...
1. Scope of application		
Working area/workplace: shipbuilding, chemical apparatus building	Activity: Manual metal arc welding and MAG welding of chrome-nickel steels	
2. Name of hazardous substance		
welding fume with carcinogenic parts of chromium (VI) compounds and nickel oxide		
3. Hazards to man and the environment		
- Inhalation of these welding fumes can cause cancer. - Irritation of respiratory tract and stomach lining - Allergic reactions of the skin caused by nickel oxide.		
4. Protective measures and rules of conduct		
- Always extract welding fumes at the source. - Position capturing element above the welding point and always track. - Work in ventilated rooms only. - Use forced ventilation welding helmet. - Do not eat, drink or smoke at the workplace. - Clean your face and hands before breaks and after end of shift and change out of polluted working clothes. - Clean the workplace only by vacuum cleaning (no sweeping!).		
5. Behaviour in the event of danger	Emergency number:...	
- In case of failure of extraction system, ventilation or forced ventilation welding helmets immediately upon end of work and leave the working area. - Inform superior.		
6. First Aid	Emergency number:....	
In the event of allergical reactions or irritations of the respiratory tract stop working and consult physician		
7. Appropriate waste management		
- not applicable		
Date:	Signature/release:	

[4] This operating instruction is an example and must be adapted to the specific needs.

Annex 6: Information according to fume data sheet pursuant to DIN EN ISO 15011-4

Fume data sheet

Manufacturer/supplier:	Address:
Date of drafting or validation:	
Trade name of the addition material:	Type of addition material:
Standard(s) according to which the addition material was manufactured:	

Test laboratory	Publication date of test report:
Test conditions	Observations of the test laboratory:

Parameters	Test condition
Diameter of the addition material (mm)	
Current (A)	
Voltage (V)	
Polarity (d.c.+/a.c./d.c.-)	
Type of gas	
Gas flow (l/min)	
Welding speed (mm/min)	
Material of test piece	
Power source: Type, manufacturer, model and installation	
Welding torch: Manufacturer, type and inert gas jet diameter (mm)	
Distance between current contact tube and workpiece (mm)	
Wire feed speed (m/min)	

Fume emission rate and data about the chemical composition in accordance with ISO 15011-4

Fume emission rate (mg/s and g/h)	

Main welding fume constituents	Chemical composition % (mass content)

References

(1) Ordinances

1. Hazardous Substances Ordinance (GefStoffV)
2. Ordinance on Safety and Health Protection in the Use of Work Equipment (BetrSichV)
3. Ordinance on Preventive Occupational Health Care (ArbMedVV)

(2) Technical rules for hazardous substances

1. TRGS 400 "Risk assessment for activities involving hazardous substances"
2. TRGS 402 "Determination and assessment of hazards associated with activities involving hazardous substances: Inhalation exposure”
3. TRGS 407 "Activities involving gases - risk assessment"
4. TRGS 410 "Exposure register in the case of danger to carcinogenic or mutagenic hazardous substances of categories 1A or 1B"
5. TRGS 420 "Process- and substance-specific criteria (VSK) for the determination and assessment of inhalation exposure", Annex No. 1 Manual piston soldering with lead-containing solder alloys in the electrical and electronics industry and No. 12 Manual piston soldering with lead-free solder alloys in the electrical and electronics industry
6. TRGS 500 "Protective measures”
7. TRGS 505 "Lead”
8. TRGS 510 "Storage of hazardous substances in portable containers"
9. TRGS 561 "Activities involving carcinogenic metals and their compounds"
10. TRGS 557 "Dioxins”
11. TRGS 600 "Substitution”
12. TRBS 3145/TRGS 745 "Transportable pressure vessels - Filling, holding, internal transport, emptying"
13. TRGS 900 "Occupational exposure limits”
14. TRGS 910 "Risk-related concept of measures for activities with carcinogenic hazardous substances"

(3) Technical rules for industrial safety

1. TRBS 1203 "Qualified persons"

(4) Occupational health rules

1. AMR 2.1 “Time limits for initiating/offering occupational health screening”
2. AMR 3.2 "Preventive occupational health care”
3. AMR 5.1 "Requirements for the provision of occupational health care"
4. AMR 6.2 "Biomonitoring”
5. AMR 6.3 "Preventive occupational health care certificate”

6. AMR 6.4 "Notifications to the employer according to section 6 (4) ArbMedVV"
7. AMR 6.7 "Pneumococcal vaccination as part of preventive occupational health care for activities involving hazardous substances due to welding and cutting of metals"
8. AMR 11.1 "Deviations according to Annex Part 1 Paragraph 4 ArbMedVV regarding activities with carcinogenic or mutagenic hazardous substances of category 1A or 1B"
9. AMR 14.2 "Classification of respiratory protective equipment into groups"

(5) Occupational health recommendations

1. Occupational health recommendation "Elective health care”

(6) DGUV Rules

1. DGUV Rule 100-500 "Operation of work equipment", in particular Chapter 2.26 "Welding, cutting and allied processes"; for the online version see http://www.dguv.de
2. DGUV Rule 109-002 "Workplace ventilation - Ventilation measures"
3. DGUV Rule 112-190 "Use of respiratory protective equipment"
4. DGUV Rule 112-192 "Use of eye and face protection".
5. DGUV Rule 112-195 "Use of protective gloves"
6. DGUV Rule 113-004 "Containers, silos and confined spaces; Part 1: Work in containers, silos and confined spaces"

(7) DGUV Informations

1. DGUV Information 209-011 "Gas Welding”
2. DGUV Information 209-047 "Nitrous gases during welding and allied processes"
3. DGUV Information 209-049 "Handling of tungsten electrodes containing thorium oxide during tungsten inert gas welding (TIG)"
4. DGUV Information 209-058 "Welding work with chrome and nickel alloyed addition and base materials"
5. DGUV Information 240-390 "Instructions for occupational medical examinations in accordance with DGUV Principle G 39 "Welding fumes"
6. DGUV Information 213-714 "Recommendations for risk assessment by the occupational accident insurance institutions (EGU) in accordance with the Hazardous Substances Ordinance: Manual piston soldering with lead-containing solder alloys in the electrical and electronics industry"
7. DGUV Information 213-725 "Recommendations for risk assessment by the occupational accident insurance institutions (EGU) in accordance with the Hazardous Substances Ordinance: Manual piston soldering with lead-free solder alloys in the electrical and electronics industry"

(8) Standards

1. DIN EN 481: 1993-09, Workplace atmosphere; size fraction definitions for measurement of airborne particles
2. DIN 1910-100: 2008-02, Welding and allied processes - Vocabulary - Part 100: Metal welding processes with additions to DIN EN 14610:2005
3. DIN EN ISO 4063: 2011-03, Welding and allied processes - Nomenclature of processes and reference numbers (ISO 4063:2009, corrected version 2010-03-01)
4. DIN ISO 857-2: 2007-03, Welding and allied processes - Vocabulary - Part 2: Soldering an brazing processes and related terms (ISO 857-2:2005)
5. DIN EN 1045: 1997-08, Brazing - Fluxes for brazing - Classification and technical delivery conditions
6. DIN EN ISO 9453: 2014-12, Soft solder alloys - Chemical composition and forms (ISO 9453:2014)
7. DIN EN ISO 9454-1: 2016-07, Soft soldering fluxes - Classification and requirements - Part 1: Classification, labelling and packaging (ISO 9454-1:2016)
8. DIN EN 14610: 2005-02, Welding and allied processes – Definition of metal welding processes
9. DIN EN ISO 14917: 2017-08, Thermal spraying - Terminology, classification (ISO 14917:2017)
10. DIN EN ISO 15011-4: 2018-05, Health and safety in welding and allied processes - Laboratory method for sampling fumes and gases; Part 4: Fume data sheets (ISO 15011-4:2017)
11. DIN EN ISO 21904-1: 2020-06, Health and safety in welding and allied processes - Equipment for capture and separation of welding fumes - Part 1: General requirements (ISO 21904-1:2020)
12. DIN EN ISO 21904-2: 2020-06, Health and safety in welding and allied processes - Equipment for capture and separation of welding fumes - Part 2: Requirements for testing and marking of separation efficiency (ISO 21904-2:2020)
13. DIN EN ISO 21904-4: 2020-06, Health and safety in welding and allied processes - Equipment for capture and separation of welding fume - Part 4: Determination of the minimum air volume flow rate of capture devices (ISO 21904-4:2020)
14. DIN EN ISO 17672: 2017-1, Brazing – Filler metals (ISO 17672:2016)
15. DIN 31051: 2012-09, Fundamentals of maintenance
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17. DIN EN ISO 21904-2:2019-03 – Health and safety in welding and allied processes - Equipment for the capture and separation of welding fumes - Part 2: Requirements for testing and marking of separation efficiency (ISO/DIS 21904-2:2019)

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(9) VDI regulations

1. VDI 2262 Sheet 3: 2011-06, Air quality at the workplace - Reduction of the exposure to air pollutants - Ventilation measures
2. VDI 2262 Part 4: 2006-03, Workplace air - Reduction of exposure to air pollutants - Ventilation technical measures
3. VDI 3802 Part 1: 2014-09, Air conditioning systems for factories
4. VDI/DVS 6005: 2018-02, Hazardous substances and ventilation systems for welding workplaces

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