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European Commission

Third study on collecting most recent information for a certain number of substances with the view to analyse the health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC

(Ref: VC/2017/0011)

Final report for chromium(VI) in fumes from welding, plasma cutting and similar processes

FoBiG Forschungs- und Beratungsinstitut Gefahrstoffe GmbH

RPA Risk & Policy Analysts

COWI

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Third study on collecting most recent information for a certain number of substances with the view to analyse the health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work

Chromium(VI) in fumes from in welding, plasma cutting and similar processes

8 February 2018

Final Report

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List of acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
ACSH	Advisory Committee on Safety and Health at Work
BAR	Biological Reference Value (German: Biologische Arbeitsstoff-Referenzwerte)
BAuA	The German Federal Institute for Occupational Safety and Health
BGHM	(German: Berufsgenossenschaft Holz und Metall)
BLV	Biological limit value
BR	Better regulation
CAS no	Chemical Abstract Service number
CAPEX	Capital expenditure
CBA	Cost-Benefit Assessment
CDB	Current disease burden
CLH	Harmonised classification and labelling
CLP	Classification, Labelling and Packaging
CMD	The Carcinogens and Mutagens Directive
COSHH	Control of Substances Hazardous to Health
CPWR	The Center for Construction Research and Training
Cr(VI)	Hexavalent chromium
DALY	Disability adjusted life years
DECOS	The Dutch Expert Committee on Occupational Safety
DFG	German Research Foundation (German: Deutsche Forschungsgemeinschaft)
DGUV	Employers' Liability Insurance Association (German: Deutsche Gesetzliche Unfallversicherung)
DVS	German Welding Institute (German: Deutscher Verband für Schweissen)
ECHA	European Chemicals Agency
ERR	Exposure-risk relationship
EWA	European Welding Association
EWF	European Welding Federation
FCAW	Fluxed-Cored Arc Welding
FER	Fume Emission Rate
FDB	Future Disease Burden
FME	Dutch employers' association for the technology industry
FNV	Dutch Trade Union Federation
GESTIS	Substance Database on limit values for chemical agents by the DGUV
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GM	Geometric mean
GMAW	Gas Metal Arc Welding
GSD	Geometric standard deviation
GTAW	Gas Tungsten Arc Welding
GTS	German association for thermal spraying (German: Gemeinschaft Thermisches Spritzen)
HSE	Health and Safety Executive
HVBG	Association of professional associations (German: Hauptverband der gewerblichen Berufsgenossenschaften)
HVOF	High Velocity Oxygen Fuel (thermal spraying process)
IA	Impact assessment
IARC	International Agency for Research on Cancer
IFA	German Social Accident Insurance
IGF	German Federation of Industrial Research Associations (German: Industrielle Gemeinschaftsforschung)
IOM	Institute of Occupational Medicine
ISO	The International Organization for Standardization
LEV	Local exhaust ventilation
LOD	Level of detection

LOQ	Limit of quantification
MAG	Metal Active Gas
MAGC	Metal Active Gas with Carbon dioxide
MAGM	Metal Active Gas with Gas mixture
MEGA database	German exposure database (German: Messdaten zur Exposition gegenüber Gefahrstoffen am Arbeitsplatz)
MCA	Multi-Criteria Analysis
MIG	Metal Inert Gas
MMA	Manual Metal Arc
MS	Member States
Nd:YAG laser	Neodymium-doped Yttrium Aluminium Garnet laser
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OELV	Occupational exposure limit value
OR	Odds ratio
OPEX	Operating expenditure
OSHA	Occupational Safety and Health Administration
PAW	Plasma Arc Welding
PEL	The permissible exposure limit
PPE	Personal protective equipment
ppb	*parts per billion*
ppm	*parts per million*
PV	Present value
RAC	Committee for Risk Assessment
PVC	Polyvinyl chloride
REACH	Registration, Evaluation and Restriction of Chemical Substances
REL	Recommended Exposure Limit
RMM	Risk management measure
RPE	Respiratory Protective Equipment
SAW	Submerged Arc Welding
SCC	Strictly controlled conditions
SCOEL	Scientific Committee on Occupational Exposure Limits
SMAW	Shielded Metal Arc Welding
SME	Small and medium-sized enterprises
SMR	Standardised mortality ratio
STEL	Short-Term Limit Value
STT	Surface Tension Transfer
TIG	Tungsten Inert Gas
TLV	Threshold limit value
TNO	The Netherland Organisation
tpa	*Tonne per annum*
TSSEA	UK Thermal Spraying and Surface Engineering Association
TWA	Time weighted average
TWI	The Welding Institute
VMBG	The German Association of metal professionals' associations (German: Vereinigung der Metall-Berufsgenossenschaften)
VSL	Value of a statistical life
VSLY	Value of a statistical life year
WEA	Working Environment Authority
WIG	Wolfram Inert Gas
WHO	World Health Organization
WTP	Willingness to pay

Executive summary

The Carcinogens and Mutagens Directive (Directive 2004/37/EC), hereinafter the CMD, protects workers from exposure to carcinogens or mutagens at work by setting out minimum requirements to reduce exposure, including the so-called Binding Occupational Exposure Limit Values (OELVs). The specific objective of this report is to assess the impacts of the established OELV of 0.025 mg/m³ and of an OELV of 0.005 mg/m³ for "Chromium (VI) compounds in welding or plasma cutting processes or similar work processes that generate fume". The OELV of 0.005 mg/m³ will enter into force after 5 years after the transition date of the compromise recently reached by Council and the European Parliament on the Commission proposal COM(2016)248 final.

Exposure sources - Cr(VI) compounds from welding, plasma cutting and similar processes are not used intentionally, but may develop and be emitted from these processes. Workers may be exposed to Cr(VI) compounds in fumes from welding, thermal cutting or thermal spraying if there is chromium present in the base metal or metal consumable, and if the process conditions (temperature, dispersion, oxygen availability) allow oxidation of elemental or trivalent chromium to hexavalent chromium. Often, the designation 'stainless steel' is used for chromium-containing steels.

Data on exposure concentrations of Cr(VI) are available from the literature. The data document a high variability in Cr(VI) concentrations in air both in between the different welding, thermal cutting and thermal spraying processes and also within the same process. Exposure concentrations commonly exceed the OELVs of both 5 µg/m³ and 25 µg/m³ in the welding processes manual metal arc welding and flux-cored arc welding. Occasionally, exposure concentrations in gas metal welding (MIG/MAG) with solid wire and thermal cutting appear to exceed the OELV of 5 µg/m³. Exposure concentrations commonly exceed the OELVs of both 5 µg/m³ and 25 µg/m³ inside the spraying cabin in thermal spraying. Often, but not always, the worker will be placed outside the spraying cabin during the process, where exposure concentrations do not exceed the OELVs. The reported exposure concentrations do often not specify to what extent they reflect actual exposure concentrations or if respiratory protection equipment (RPE) is used, which would reduce actual exposure concentrations. According to information obtained during stakeholder consultation, local exhaust ventilation (LEV) is the most common risk management measures (RMM) used to reduce exposure. In certain high exposure concentrations, RPE is required to enable compliance with an OELV of 0.005 mg/m³. Large differences between companies exist in the availability of RMM, the awareness and feasibility of correct use, and the efficiency of LEV solutions.

Estimates on exposed workforce of welders have been obtained from the European Welding Association based on consumption of welding consumables. Estimates on exposed workforce of thermal cutters and sprayers were not readily available and have be derived based on information from national trade organisations and industry. In total, it is estimated that in the EU28 about 51,100 workers are exposed to Cr(VI) from thermal metal works with stainless steel.

The costs and benefits (relative to the baseline) estimated in this report for the different reference OELVs are summarised overleaf.

Table 0-1: Cr(VI) in fumes from welding, plasma cutting and similar processes. Summary of monetised costs and benefits		
Reference OELV	**PV benefits over 60 years (€2017)***	**PV costs over 60 years (€2017)**
A: 5 µg/m³	€5,507 million	€8,983 million
B: 25 µg/m³	€4,391 million	€3,496 million
Monetised costs and benefits	*Avoided lung cancer vis-à-vis the baseline*	*RMMs* *Measurements*
Significant non-monetised costs and benefits	*None*	*None*
*Method 1		

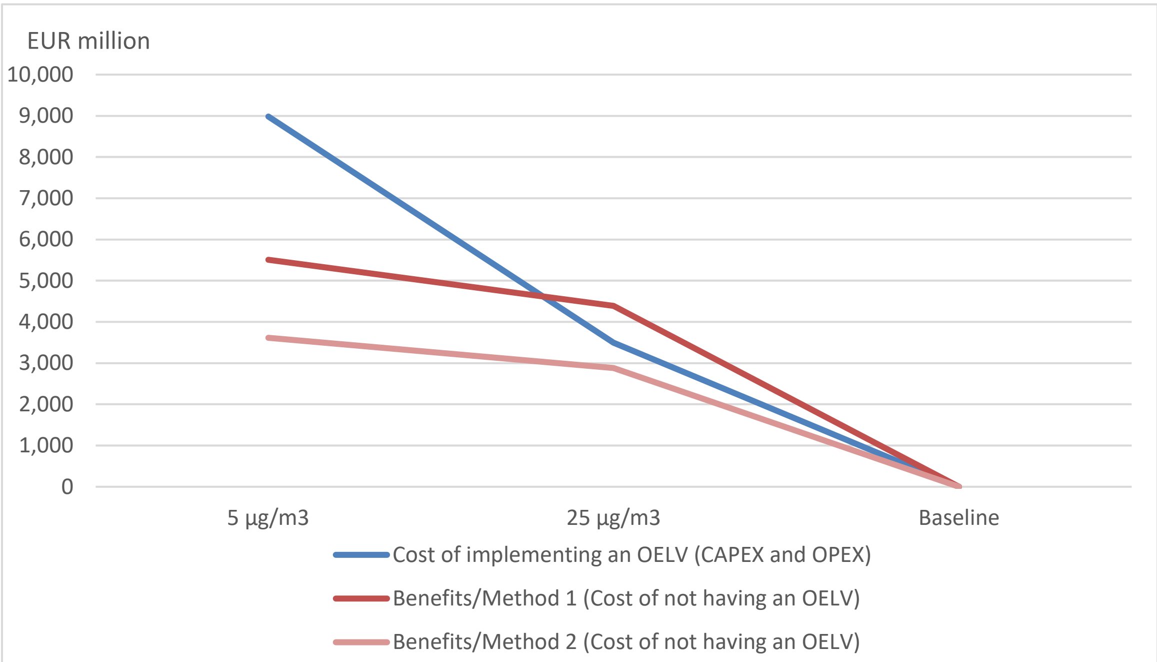


Figure 0-1: Costs/benefits of establishing an OELV for Cr(VI) in fumes from welding, plasma cutting and similar processes in the EU. Estimated costs (CAPEX AND OPEX) for 60 year and benefits (costs of not having an OELV) for a static baseline with a declining discount rate.

The table below summarises both the monetised impacts as well as those that are assessed qualitatively.

Table 0-2: Cr(VI) in fumes from welding, plasma cutting and similar processes. Multi-criteria analysis, €. Source: Modelling by COWI/RPA			
Impact	**Stakeholders affected**	**Reference OELV A: 5 µg/m³**	**Reference OELV B: 25 µg/m³**
		Economic impacts	
Compliance and administrative costs	Companies exposing their workers	€ 8,983 million	€ 3,496 million
Increased business	RMM suppliers	Increased business for RMM supplies – reduced business across all other industries	
Enforcement costs	Public sector	€0.25 million	€0.25 million
Benefits from reduced ill health	Employers	€28 million	€23 million
	Public sector	€63 million	€51 million

Table 0-2: Cr(VI) in fumes from welding, plasma cutting and similar processes. Multi-criteria analysis, €. Source: Modelling by COWI/RPA			
Impact	Stakeholders affected	Reference OELV A: 5 µg/m³	Reference OELV B: 25 µg/m³
Single-market: competition	Business	Some negative impacts	Some negative impacts
Single-market: consumers	Consumers	Limited impacts	Limited impacts
Single-market: internal market	Business	All companies will face same OELVs	All companies will face same OELVs
International competitiveness	Business	Some negative impacts	Some negative impacts
SMEs	Business	Some negative impacts	Some negative impacts
Specific MS/regions	Business	21 Member States have OELs > 5 µg/m3	14 Member States have OELs >25 µg/m3
Social impacts			
Ill-health avoided	Workers & families	€5,439 million	€4,337 million
Employment	Workers	Limited impacts	Limited impacts
Environmental impacts			
Environmental releases		No impact	No impact
Recycling – loss of business	Recycling companies	No impact	No impact
Recycling – durability of consumer goods, etc.		No impact	No impact
Notes: All costs/benefits are relative to the baseline (PV over 60 years).			

The benefits are avoided ill health cases and they are overall estimated at an order comparable to the costs. The reduced number of ill health cases are avoided lung cancer cases. There are no other significant benefits.

A significant **uncertainty of the benefits assessment** includes the calculation of cancer cases based on the exposure risk relationship (ERR, see section 2.4 Exposure-Risk-Relationship). The ERR was developed based on exposure to Cr(VI) via inhalable particles, while fumes from welding or plasma cutting processes and similar work processes mostly contain respirable particles. Given the carcinogenic potency of the respirable particle fraction is higher than of the inhalable particle fraction, the number of cancer cases may be underestimated, leading to a potential underestimation of the benefits estimate. Further uncertainties with the establishment of a reliable ERR for Cr(VI) from welding, thermal cutting and thermal spraying are related to:

- co-exposure with other carcinogens
- the high variability in exposure between and within the same processes
- the influence of the solubility of the Cr(VI) compounds on the toxicokinetics
- the variable particle size distribution

Further uncertainties of the benefits assessment are related exposure concentrations used in the calculation, the number of exposed workers, the temporal trends in exposure concentrations, the 60-

year period which is used for the modelling and the monetary valuation. The sum of these factors may have no, an over- or underestimating effect on the benefits estimate.

The key **uncertainty in the cost assessment** relates to the cost model that applies generic assumptions about what measures would be needed to insure compliance. There are some uncertainty about the whether there could be individual companies facing either larger or lower costs. Furthermore, the cost estimate is sensitive to some of the same parameters as the benefits estimate, i.e. exposure concentrations, the number of exposed workforce, as well as assumptions regarding number and distribution on sizes of companies and the assumption that monitoring of the workplace concentration will be required in all member states. Overall, the uncertainty of the costs assessment might be in the order of 50%.

1 Introduction

1.1 Background

The Carcinogens and Mutagens Directive (Directive 2004/37/EC), hereinafter the CMD, aims to protect workers against health and safety risks from exposure to carcinogens or mutagens at work. To this end, it sets out the minimum requirements for protecting workers who are exposed to carcinogens and mutagens, including the so-called Binding Occupational Exposure Limit Values (OELVs)[1]. For each OELV, Member States are required to establish a corresponding national occupational limit value (OEL), from which they can only deviate to a lower but not to a higher value.

1.2 Objectives

This report is one of eight reports elaborated within the framework of a study undertaken for the European Commission by a consortium comprising Risk & Policy Analysts (RPA) (United Kingdom), FoBiG Forschungs- und Beratungsinstitut Gefahrstoffe (Germany), COWI (Denmark), and EPRD Office for Economic Policy and Regional Development (Poland). The eight reports are:

- Methodological note
- OEL/STEL deriving systems
- Report for cadmium and its inorganic compounds;
- Report for beryllium and its inorganic compounds;
- Report for inorganic arsenic compounds including arsenic acid and its salts;
- Report for formaldehyde;
- Report for 4,4'-Methylene-bis(2-chloroaniline) (MOCA); and
- Report for Chromium (VI) in fumes from welding, plasma cutting and similar processes.

The specific objective of this report is to assess the impacts of the established OELV of 0.025 mg/m^3 and of an OELV of 0.005 mg/m^3 for "Chromium (VI) compounds in welding or plasma cutting processes or similar work processes that generate fume". The OELV of 0.005 mg/m^3 will enter into force after 5 years after the transition date of the compromise recently reached by Council and the European Parliament on the Commission proposal COM(2016)248 final.

[1] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV:c11137

1.3 Structure of the report

The report is organised as follows:

- Section 2 sets out the background (SCOEL/RAC[2], ACSH[3] documents) and the scope of the assessment for chromium (VI);
- Section 3 sets out the baseline;
- Section 4 sets out the benefits of the relevant measures;
- Section 5 sets out the costs of the relevant measures;
- Section 6 summarises the market effects;
- Section 7 describes the environmental impacts;
- Section 8 describes the distribution of any impacts;
- Section 9 provides the conclusions; and
- Section 10 provides the sensitivity analysis.

2 RAC (Committee for Risk Assessment)

3 ACSH (Advisory Committee on Safety and Health at Work)

2 Background and scope of the assessment

This section comprises the following subsections:

- Section 2.1: Background
- Section 2.2: Study scope
- Section 2.3: Summary of epidemiological and experimental data (cancer and non-cancer effects)
- Section 2.4: Deriving an Exposure-Risk-Relationship (carcinogenic effects) and Dose-Response-Relationship (non-carcinogenic effects)
- Section 2.5: Reference OELVs)

2.1 Background

The Scientific Committee on Occupational Exposure Limits (SCOEL) has adopted a recommendation on chromium (VI) compounds in 2017 and summarises (SCOEL, 2017):

"The critical effect of the occupational inhalation of hexavalent chromium (Cr(VI)) -containing compounds is lung cancer. In addition, occupational exposure can lead to nephrotoxicity, hypersensitivity (sensitisation), corrosion of the skin, irritation of the respiratory tract and gastrointestinal tract. Cr VI compounds have been classified as a carcinogen, in Category 1 based on both humans and animal data by IARC. Most Cr VI compounds are classified by the European Union in Category 1B (substance presumed to be carcinogenic to humans). The exceptions are chromium trioxide, zinc chromate and zinc potassium chromate which are classified in Category 1A (substance known to be carcinogenic to humans). […] Cr VI acts as a directly genotoxic carcinogen for which no threshold can be assumed and for which, linear extrapolation is commonly applied by SCOEL in this situation if the available data permits."

The SCOEL (2017) calculated the excess cancer risks as shown in Table 2-1.

Table 2-1: Number of excess lung cancer cases / 1000 (SCOEL, 2017)

Exposure 8 hour time weighted average	Point estimate combined exposure response slopes	Confidence interval	(Crump *et al.*, 2003)	(Park *et al.*, 2004)
0.1 µg/m³	0.4	0.3-0.5	0.2	0.6
1 µg/m³	4	3.2-4.8	2	6
5 µg/m³	20	16-24	8	32
10 µg/m³	39	31-47	15	62
25 µg/m³	94	76-112	38	146

The SCOEL neither recommends a short-term limit value (STEL), a biological limit value (BVL), nor a skin notation. The recommendation contains the additional categorisation as "Carcinogen group A (genotoxic carcinogen without a threshold)" and a sensitisation (respiratory and dermal) notation. The SCOEL recommendations do not differentiate between exposure to Cr(VI) from fumes in welding, plasma cutting and similar processes.

2.2 Study scope

The scope of this report is to assess the impacts of the established OELV of 0.025 mg/m³ and of an OELV of 0.005 mg/m³ for "Chromium (VI) compounds in welding or plasma cutting processes or similar work processes that generate fume".

Cr(VI) compounds are not intentionally used or actively added to the mentioned processes, but can form in and emit from these processes. The approach to the analysis of Cr(VI) compounds therefore differs from the other chemical agents in this study, leading to minor changes in the structure of this report.

The following processes have been considered to be within the definition "*welding/plasma cutting/and similar work processes that generate fumes*":

- Welding
- Thermal cutting, *e.g.* plasma cutting
- Thermal spraying, *e.g.* plasma spraying

The processes, their subprocesses and the potential for emitting chromium (VI) are described in the section 3.3.

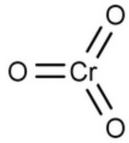
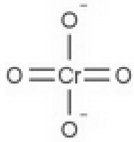
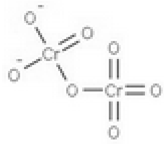
2.3 Summary of epidemiological and experimental data (cancer and non-cancer effects)

2.3.1 Identity and classification

Chromates and dichromates exist as a wide variety of 20-30 compounds of major industrial importance. The water solubility of Cr VI compounds can be defined as: poorly soluble (<1g/l), sparingly soluble (1-10g/l); highly soluble (>100g/l) (SCOEL, 2017). Some examples for hexavalent chromium compounds are given in the following table, but the chromium species released during welding or plasma cutting processes and similar work processes that generate fumes are not specified to date. This document covers the toxicological properties of Cr(VI) compounds, but not those of metallic chromium. They may differ in their classification, but within the scope of this project there is no discrimination with regard to possible slight quantitative differences in carcinogenic and non-carcinogenic potency.

Table 2-2: Identity and classification

Chemical Substance	Chromium (VI) trioxide	Sodium chromate	Sodium dichromate
CAS-Number	1333-82-0	7775-11-3	7789-12-0, 10588-01-9
EC-Number	215-607-8		234-190-3
Sum Formula	CrO_3		$Na_2Cr_2O_7$
Synonyms	Chromic anhydride, Chromium(VI) oxide	Disodium chromate	Disodium dichromate

Table 2-2: Identity and classification			
Chemical Structure		 Na^+	 2 Na^+
Classification (ECHA, 2017)	Ox. Sol. 1 H271, STOT SE 3; H335, Acute Tox. 3 * H301, Acute Tox. 3 *, H311, Skin Corr. 1A H314, Skin Sens. 1 H317, Acute Tox. 2 * H330, Resp. Sens. 1 H334, Muta. 1B H340, Carc. 1A H350, STOT RE 1 H372 **, Aquatic Acute 1 H400, Aquatic Chronic 1 H410, Repr. 2 H361f***	Acute Tox. 3 * H301, Resp. Sens. H334, Skin Sens.; H317, Acute Tox. 4 H312, Skin Corr. 1B H314, Skin Sens. 1 H317, Acute Tox. 2 * H330, Resp. Sens. 1 H334, Muta. 1B H340, Carc. 1B H350, STOT RE 1 H372**, Aquatic Acute 1 H400, Aquatic Chronic 1 H410, Repr. 1B H360FD	Ox. Sol. 2 H272, Skin Sens. 1 H317, Resp. Sens. 1 H334, STOT SE 3 H335, Acute Tox. 3 * H301, Acute Tox. 4 * H312, Skin Corr. 1B H314, Skin Sens. 1 H317, Acute Tox. 2 * H330, Resp. Sens. 1 H334, Muta. 1B H340, Carc. 1B H350, STOT RE 1, H372**, Aquatic Acute 1 H400, Aquatic Chronic 1 H410, Repr. 1B H360FD
Sources	Data from ECHA (2017) and NLM (2017)		

*: Minimum classification according to the criteria in Directive 67/548/EEC

** and ***: classifications under Directive 67/548/EEC translated

2.3.2 General toxicity profile, critical endpoints and mode of action

Cr(VI) compounds are used as pigment for textile dyes, for paints, inks, and plastics, corrosion inhibitors, wood preservatives, metal finishing and chrome plating, and leather tanning. Cr(VI) may be present as an impurity in Portland cement, and it can be generated and given off during casting, welding, and cutting operations, even if it was not originally present in its hexavalent state (ECB, 2005; IARC, 2012; SCOEL, 2017). Cr(VI) compounds, relevant for this assessment, are listed in Table 2-3. The Cr(VI) release during plasma cutting may even be higher than in welding fumes (Wang *et al.*, 2017).

Table 2-3: Cr(VI) compounds in fumes from welding and similar thermal processes covered in this impact assessment (assessed as Cr(VI))

Compound	Formula	CAS No.	Classification Carc./Muta.
Sodium chromate	*Na_2CrO_4*	7775-11-3	CLH Carc. 1B, Muta. 1B
Potassium chromate	*K_2CrO_4*	7789-00-6	CLH Carc. 1B, Muta. 1B
Calcium chromate	*$CaCrO_4$*	13765-19-0	CLH Carc. 1B
Zinc chromate	*$ZnCrO_4$*	13530-65-9	CLH Carc. 1A
Zinc chromates including zinc potassium chromate	-	-	CLH Carc. 1A

Table 2-3: Cr(VI) compounds in fumes from welding and similar thermal processes covered in this impact assessment (assessed as Cr(VI)			
Compound	**Formula**	**CAS No.**	**Classification Carc./Muta.**
Potassium dichromate	$K_2Cr_2O_7$	7778-50-9	
Tripotassium sodium chromate	$K_3Na(CrO_4)_2$		
Tripotassium sodium dichromate	$K_3Na(Cr_2O_7)_2$		

Absorption of inhaled Cr(VI) from the respiratory tract varies according to the solubility of the compound. High or sparingly soluble compounds absorbed more rapidly than poorly soluble or insoluble compounds. After repeated inhalation chromium accumulates in lung tissue, especially poorly soluble compounds. Reduction from hexavalent to trivalent chromium can already occur in the lung and also after oral exposure in the stomach to chromium (III), which is absorbed. At low concentrations, most Cr(VI) is reduced to Cr(III) in the extracellular space, but this reduction may be saturated at higher concentrations. Inhaled Cr(VI) is excreted in the urine or faeces, varying with compound solubility.

Aqueous Cr(VI) trioxide is a corrosive substance due to its low pH. Highly water-soluble Cr(VI) compounds can cause very severe skin and eye lesions and irritate the respiratory tract. Skin sensitisation resulting from contact with Cr(VI) compounds is relatively common in workers. Inhaled Cr(VI) compounds can also provoke occupational asthma. The main occupational non-carcinogenic effects reported are irritant and corrosive responses in relation to inhalation and dermal exposure, and kidney toxicity. Cr(VI) compounds are genotoxic *in vitro* and *in vivo* and are also considered to be germ cell mutagens. Besides direct interaction with DNA there are further indirect mechanisms of carcinogenicity, *e.g.* ternary chromium-DNA adducts, where chromium bridges DNA and small molecules such as cysteine, histidine, glutathione or ascorbate, induction of genomic instability, oxidative DNA damage, activation of transcriptions factors and protein kinases. The induced DNA damage lesions appear to depend strongly on the cellular reductant involved. Under physiological conditions with ascorbate as the major reductant, the generation of premutagenic ternary chromium-ascorbate-DNA adducts appears to be of major relevance, which may be linked to the increased number of mismatch-repair-resistant cells observed in chromate-induced lung tumours (ECB, 2005; IARC, 2012; SCOEL, 2017).

The large majority of studies on occupational Cr(VI) exposure indicate that there is an excess risk of lung cancer among workers, particularly in chromate production, chromate pigment production, and chromium electroplating. Increased lung cancer rates were also observed at welding workplaces. The main non-carcinogenic endpoints are irritant and corrosive effects. Water soluble Cr(VI) compounds caused fertility effects and developmental toxicity in animal studies (ECB, 2005; IARC, 2012; SCOEL, 2017).

Cancer endpoints – toxicological and epidemiological key studies (existing assessments)

Cr(VI) and lung cancer risk

The OELs are based on different key studies, which are shortly reported below.

Gibb *et al*. (2000) updated the lung cancer risk of the Baltimore (MD, USA) cohort, formerly examined by Braver *et al*. (1985), up to the end of 1992. The cohort included 2357 male workers with 122 cases of lung cancers. The cancer risk estimate was divided into four exposure categories of 0.00045, 0.0042, 0.030 and 0.449 mg/m^3 x years, for which standardised mortality ratios (SMR) for lung cancer of 0.96 (95% confidence interval (CI) 0.63-1.38), 1.42 (0.95-2.01) 1.57 (1.07-2.20) and 2.24 (1.60-3.03) were calculated. However, the median duration of employment of the workers was only 0.39 years, and a continuous exposure measurement was lacking.

A cohort of 482 workers with 51 cases of lung cancer (as at end of 1997) from the Painesville plant (OH, USA) was examined by Luippold *et al*. (2003). Workers of this plant have already been studied by Mancuso *et al*. (1997). The SMR were calculated for four exposure categories and were 0.67 (0.14-1.96) for 0-0.19 mg/m^3 x years, 1.84 (95% CI 0.79-3.62) for 0.20-0.48 mg/m^3 x years, 0.91 (95% CI 0.25-2.34) for 0.49-1.04 mg/m^3 x years, 3.65 (95% CI 2.08-5.92) for 1.05-2.69 mg/m^3 x years and 4.63 (95% CI 2.83-7.16) for 2.7-23 mg/m^3 x years. Exposure measurement was also limited in this study. Smoking as non-controlled confounder was discussed by AGS (2014), as cardiovascular causes of mortality were also increased with a SMR of 143 (96-204).

In a study by Birke *et al*. (2006), 739 workers of the German chromate production and 22 cases of lung cancers were analysed within the scope of the "Multiplant Study" (Mundt *et al*., 2002). A SMR of 2.09 (95% CI 1.08-3.65) was attributed to the highest exposure category of ≥200 µg/L x years chrome in urine. The authors discussed a median urine concentration of 400 µg/L x years (10 µg/L) as representative for this group and interpreted this result as the threshold of carcinogenicity, because the lung cancer risk was not increased below 200 µg/L x years. AGS (2014) estimated from this data a cumulative exposure in air of about ≤ 1000 µg/m^3 x years. Smoking was excluded as a relevant confounding factor.

Several meta-analyses of these data sets have been performed, *e.g.* the risk analysis by Crump *et al*. (2003), Goldbohm *et al*. (2006), Park *et al*. (2004) and Seidler *et al*. (2013). They all resulted in risk estimates within a narrow range of 2-6 x 10^{-3} at workplace concentrations of 1 µg/m^3.

Latency: Long term exposure (years) to inorganic chromium compounds may be needed for carcinogenic outcome. Reported latency time for chromium-induced tumours is 37.6 years (Butz, 2012). For different cancer sites different latency periods are provided. The estimate of a peak latency of solid tumors at 35 years (Hutchings and Rushton, 2012) appears to be adequate for lung cancer.

Welding and lung cancer risk

The amount of emitted or generated Cr(VI) and the ratio of total Cr/Cr(VI) formed in welding fumes varies widely with the treated material (content of chromium in, *e.g.*, stainless steel), the welding technique employed, and the composition of the consumables (IARC, 1990).

A comprehensive multicentre cohort study (Simonato *et al*., 1991) examined the carcinogenic effects in 11092 male welders from 135 companies in nine European countries to investigate the relationship between the different types of exposure occurring in stainless steel, mild steel and shipyard welding ("IARC-cohort"). The lung cancer mortality was significantly increased in the total cohort (SMR 134, 95% CI 110-160). The only statistically significant SMR was for mild steel-only welders (SMR 178, 95% CI 127-243). Results for the other subgroups were: shipyard welders (SMR 126, 95% C: 88-174); ever stainless steel welders (SMR 128, 95% CI 91-175), and predominantly stainless steel welders (SMR 123, 95% CI 75-190). The SMRs increased over time for every group except for the shipyard welders. For the predominantly stainless steel welder subcohort, the trend to increase with time was statistically significant ($p < 0.05$). In a subsequent publication, an exposure matrix was applied to these data to relate estimated cumulative Cr(VI) exposure and lung cancer risk among stainless steel welders, resulting in a not significantly increased SMR of 130-133 (95% CI 36-339) in workers with individual work history at exposures >1.5 mg x years/m^3, but higher risks with SMRs of 214-230 (95% CI 44-589) and 252-258 (95% CI 69-661) at lower cumulative exposures of 50-500 and 500-1500 mg x years/m^3, respectively (Gérin *et al*., 1993). However, the results were criticised because they were not based on

Cr(VI) air measurements and exposure misclassification in the cohort and co-exposure to nickel may obscure an exposure-response relationship for Cr(VI) (OSHA, 2006). Using their own risk model, OSHA (2006) estimated a dose related increase with SMRs of 119-194 (95% CI 111-260), 168-441 (95% CI 140-677) and 270-941 (95% CI 201-1510) for 275, 1000 and 2500 mg x years/m^3, respectively. However, finally this study was not applied by US-OSHA to calculate lung cancer risk from Cr(VI) because of too many associated uncertainties.

Moulin *et al*. (1993) examined the mortality from 1975 to 1988 in 2721 welders with and an internal comparison group of 6683 manual workers employed in 13 factories in France. The distribution of welders and controls according to smoking was not statistically different. The overall mortality was slightly higher for welders (SMR 1.02, 95% CI 0.89-1.18) than for controls (SMR 0.91, 95% CI 0.84-0.99). For lung cancer, the SMR was 1.24 (95% CI 0.75-1.94) for welders, whereas the corresponding value was lower for controls (SMR 0.94, 95% CI 0.68-1.26). The SMR for lung cancer was 1.59 among non-shipyard mild steel welders (95% CI 0.73-3.02). This contrasted with the results for all stainless steel welders (SMR 0.92, 95% CI 0.19-2.69), and for stainless steel welders predominantly exposed to Cr(VI) (SMR = 1.03, 95% CI 0.12-3.71). Moreover, SMRs for lung cancer for mild steel welders tended to increase with duration of exposure and time since first exposure, leading to significant excesses for duration > or = 20 years and latency > or = 20 years. Such a pattern was not found for stainless steel welders.

Ambroise *et al*. (2006) found no substantial differences in lung cancer risks from mild steel and stainless steel welding, which differ considerably in the release of Cr(VI) during welding. They concluded that this contradicts the hypothesis that the probable exposure to chromium and nickel compounds in welding fumes of stainless steel might predominantly be responsible for lung cancer.

A recent comprehensive analysis of lung cancer risk in welders comes from Kendzia *et al*. (2013). Within the SYNERGY project data 15483 male lung cancer cases (18388 male controls) were analysed, which were examined in 16 studies in Europe, Canada, China and New Zealand conducted between 1985 and 2010. 568 cases (427 controls) had ever worked as welders and had an odds ratio of developing lung cancer of 1.44 (CI: 1.25-1.67) with the odds ratio increasing for longer duration of welding. In never and light smokers, the odds ratio was 1.96 (1.37-2.79). Occasional welding was attributed with lower risks. Different welding types were not separated in this publication.

In 1990, IARC classified welding fumes as group 2B, *i.e.* possibly carcinogenic to humans, mainly based on cohort and case-control studies on lung cancer in welders (IARC, 1990).

A recent re-evaluation by IARC classified welding fumes (and also UV radiation from welding) into group 1, *i.e.* carcinogenic to humans (Guha *et al*., 2017), based on several recent studies which included exposure measurements. A positive association between welding and kidney cancer is also addressed in Guha *et al*. (2017), but with uncertainties due to lacking consideration of confounders (*e.g.* solvents) and little evidence of an exposure-risk relationship. However, details of the updated classification will be presented only in the IARC Vol. 118, which is still in press (status: November, 2017). From preliminary results, one group which participated, in the IARC update analysis concluded: "*The IARC evaluation of carcinogenicity did not differentiate between exposure to stainless steel welding and mild steel welding, although some previous studies explain the carcinogenic effects as being predominantly related to stainless steel welding. A slight excess risk of lung cancer was suggested in most of the studies among welders, including stainless steel, mild steel, and unspecified welding*" (Siew *et al*., 2008).

The key studies used for the re-classification by IARC were:

(Sørensen *et al.*, 2007): Standardised Incidence Ratio (SIR) of 1.35 (95% CI 1.06-1.70) among 4539 welders, with an SIR of 1.59 (95% CI 1.14-2.16) for mild steel welders never occupied in stainless steel welding were observed. A significant increased risk with increasing exposure duration was found only for stainless steel workers (adjusted for age, smoking and asbestos exposure). No exposure data were provided.

(Siew *et al.*, 2008): About 3000 workers exposed to welding fumes had increased Relative Risks (RR) for lung cancer of 1.15 (95% CI 0.90-1.46) in the highest exposure category of ≥ 200 mg x years/m^3 (no clear dose-response relationship compared to lower exposures). If squamous lung carcinoma were examined separately, a clear dose response-relationship was established with RR of 1.07 (95% CI 0.99-1.15), 1.26 (95% CI 1.04-1.53) and 1.55 (95% CI 1.08-2.24) for cumulative exposures of 0.1-10, 10.1-49.9 and ≥ 50 mg x years/m^3, respectively, adjusted for age, smoking, asbestos and silica exposure, socioeconomic status and period of follow-up. The authors concluded: "*In our study, we found a higher standardized incidence ratio for mild steel welders in comparison with stainless steel welders*." (Siew *et al*., 2008).

('t Mannetje *et al*., 2012): A Case-control study on 2197 lung cancer cases with occupation in welding or flame cutting and 2295 controls observed an Odds Ratio (OR) of 1.36 (95% CI 1.00-1.86), corrected for age, smoking and asbestos exposure. Sole exposure to welding fume resulted in an OR of 1.18 (95% CI 1.01-1.38), increasing to 1.38 (95% CI 1.09-1.75) for more than 25 years of occupation. In this study mild steel welding was associated with lower risks (1.14, 95% CI 0.95-1.36) compared to stainless steel welding (1.34, 95% CI 1.04-1.71).

(Matrat *et al*., 2016): An OR of 1.6 (95% CI 1.11-2.49) for lung cancer in regular welders was observed amongst 2276 cases and 2780 controls, adjusted for smoking and exposure to asbestos. The OR increased to 1.96 (95% CI 0.98-3.92) for occupation > 10 years. The risk was more pronounced in case of gas welding, when the workpiece was covered by paint, grease, or other substances and when it was cleaned with chemical substances before welding. Occasional welders had no increased risks. The authors discuss the hypothesis that Cr(VI) was a relevant cause of the elevated risk found from gas welding: "Our results showed that welding exclusively with gas was associated with a higher risk of lung cancer…. One hypothesis to support this result would be an exposure to higher Cr (VI) levels with gas welding as compared with arc welding, when separating the subcategories MIG, MAG, TIG or MMA is unreachable."

Non-cancer endpoints – toxicological and epidemiological key studies (existing assessments)

Beyond carcinogenicity Cr(VI) exerts relevant non-cancer effects from occupational exposure:

- Skin sensitisation and corrosion from dermal exposure
- Respiratory effects including effects in the upper and lower respiratory tract from inhalation exposure
- Reproductive effects at elevated exposure levels or from oral exposure.

It is currently not possible to link non-cancer effects from welding or plasma cutting processes and similar work processes that generate fume to Cr(VI) exposure in a quantitative way, as similar effects may also occur from other components within the welding/thermal cutting process and an additivity assumption (providing an attributable fraction of the effects to the single components of such fumes) appears not to be justified. This is specifically true for non-cancer respiratory effects. For skin-sensitisation also no sufficient potency assessments are available. Therefore studies reporting non-cancer effects from Cr(VI) or from, *e.g.* welding exposures, respectively are not reported in this section, because those cannot be used (and have not been used within OEL assessments) to derive an effect incidence for Cr(VI) welding or plasma cutting processes and similar work processes that generate fume.

Biological monitoring – toxicological and epidemiological key studies (existing assessments)

Total chromium in urine is generally used as a biological indicator (ACGIH, 2004; ANSES, 2017; Drexler and Hartwig, 2009). With regard to the local effects considered within the scope of this project, this biological monitoring is not considered to be a reliable measure of exposure.

Differentiating Cr(VI) compounds

The welding fumes contain insoluble as well as soluble Cr(VI) compounds (IARC, 1990), which may be associated with different cancer risks. However, to date there are no data to discriminate between these different chromium species and their specific carcinogenic potency when contained in welding or plasma cutting processes and similar work processes that generate fumes.

2.4 Deriving an Exposure-Risk-Relationship (carcinogenic effects) and Dose-Response-Relationship (non-carcinogenic effects)

2.4.1 Starting point

Starting point is the recently adopted EU binding OELV of 5 µg/m^3 for Cr(VI). An excess risk of 4 x 10^{-3} / µg/m^3 is reported by SCOEL (2017). Therefore, at the starting point, the associated excess risk at OELV-level is 2 x 10^{-2}. No explicit link to particle sizes is reported. However, from the background data of the respective epidemiological studies this risk estimate is linked to the inhalable fraction.

SCOEL (2017) provide a notation for respiratory and dermal sensitisation; but no skin notation.

No short-Term Limit Value (STEL) and no Biological Limit Value (BLV) are recommended (SCOEL, 2017).

Discussion:

Risk quantification for Cr(VI) may not be adequate for Cr(VI) excess cancer risk from welding or plasma cutting processes and similar work processes that generate fume. Although welding is associated with an elevated cancer risk, as recently confirmed by IARC (Guha *et al*., 2017), mode of action and contributing substances and factors are currently not sufficiently elucidated and the associated excess risk attributable to Cr(VI) is not known. Moreover, the excess risk reported above is associated to the inhalable fraction, but for welding or plasma cutting processes and similar work processes that generate fume, most relevant is the respirable fraction. For further discussion see Section 2.4.2. Therefore, the potential health impact described in this assessment is subject to the hypothesis that the Cr(VI) content in fumes from welding or plasma cutting processes and similar work processes (respirable fraction) is decisive for lung cancer with equal potency as is Cr(VI) exposure, *e.g.*, from chrome plating (inhalable fraction).

No starting point was established for non-carcinogenic endpoints.

2.4.2 Carcinogenic effects

Approach:

An excess risk of 4 x 10^{-3} / µg/m³ is reported by SCOEL (2017) and is adapted in this assessment. Because of the linear ERR at the recently established OELV of 5 µg/m³ an excess risk of 2% is calculated.

The applicability domain of this assessment should be limited to exposures of ≥ 0.1 µg/m³.

The respective ERR is shown in Figure 2-1.

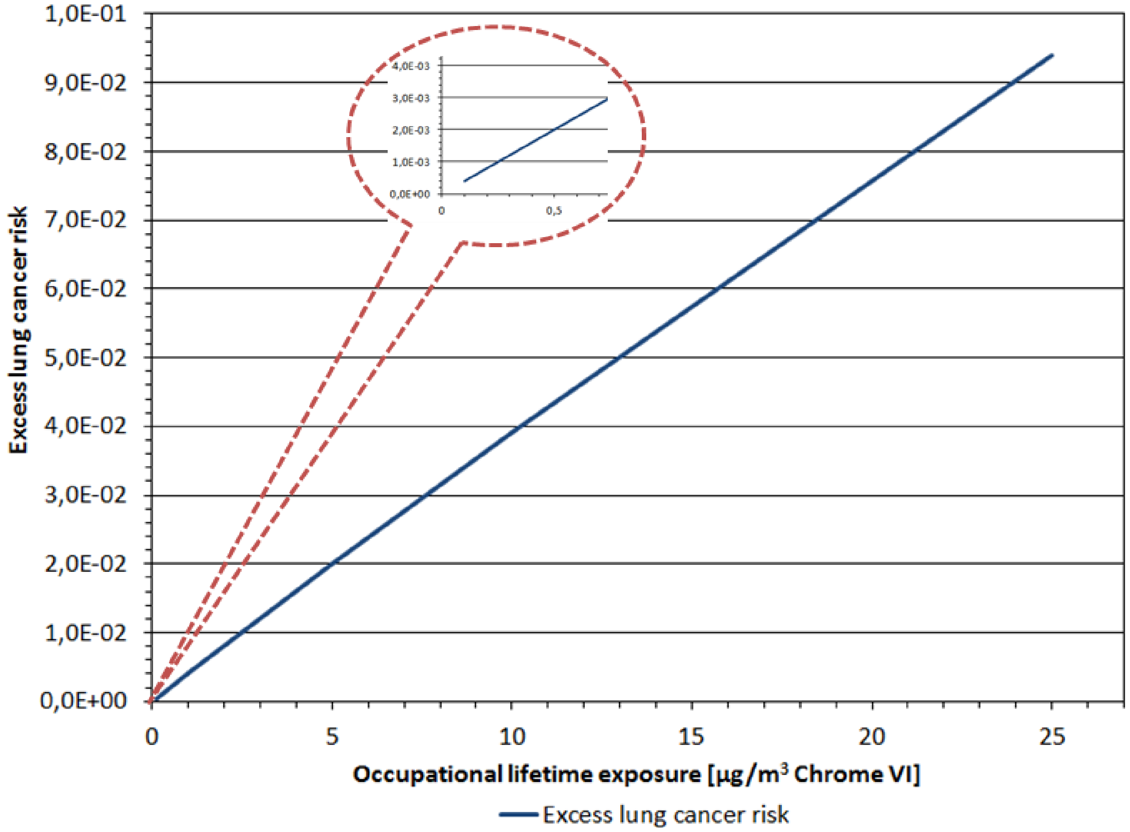


Figure 2-1: Exposure Risk Relationship (ERR) for lung cancer from occupational exposure to Cr(VI)

Discussion:

There are reasons to consider a sublinear dose response (see mechanistic aspects in chapter 2.3.2) and a linear extrapolation applied may be regarded as a conservative approach. However, all occupational risk assessments are based on linear extrapolation, as it is also suggested by SCOEL (2017). However, some assessments find it too uncertain to apply linear extrapolation to low concentrations (*e.g.*, AGS, 2014, who limit the risk quantification to concentrations ≥ 1 µg/m³).

SCOEL (2017) document this risk without explicit limiting the range, for which linear extrapolation is regarded to be justified. However, in their recommendation they focus on exposures above 0.1 µg/m³ (SCOEL, 2017, page 9; Table). From the discussion in Germany (AGS, 2014) it is concluded that lower exposure levels, in general, will clearly be more protective than elevated exposure levels, but that it may not be feasible to quantify excess risk at those low exposure levels (*e.g.*, for the purposes of an impact assessment). Considering:

- the high uncertainty of risk quantifications at low exposure levels,

- the associated small risk at 0.1 µg/m³ (*i.e.*, 4 x 10^{-4}) from linear extrapolation, and
- the plausibility of a sublinear exposure response relationship at low exposure levels

It is therefore suggested to limit the range of applicability of this ERR to > 0.1 µg/m³. Though there are sufficient data to consider welding as the cause of increased lung cancer rates, there are no reliable quantitative exposure data in these studies to establish exposure risk relationships for Cr(VI) from welding activities. Despite recent comprehensive data on Cr(VI) exposures emitted during welding operations (Pesch *et al*., 2015; Vincent *et al*., 2015; Weiss *et al*., 2013), the high variability within the same welding method and the co-exposure to other metals, salts and gases (IARC, 1990; 2012) preclude the establishment of a reliable exposure risk relationship with respect to a single substance within this mixture.

There is also uncertainty about the particle size distribution. Fumes contain a larger fraction of respirable dust compared to *e.g.* chromate production, where inhalable dust predominates.

Though there are some studies indicating a lower risk for mild steel welders in comparison to stainless steel welders (IARC, 1990), there are qualified indications on an similar carcinogenic potency of mild steel welding compared to stainless steel welding. This strongly indicates other relevant causes for carcinogenicity in addition to the amount of chromium released (*e.g.* Ambroise *et al*., 2006; OSHA, 2006 and the references provided there; Simonato *et al*., 1991). Therefore, the potential health impact described in this assessment is subject to the hypothesis that the Cr(VI) content in fumes from welding or plasma cutting processes and similar work processes (respirable fraction) is decisive for lung cancer with equal potency as is Cr(VI) exposure, *e.g.*, from chrome plating (inhalable fraction), which, however, is yet to be examined.

2.4.3 Non-carcinogenic effects

SCOEL (2004; 2017) addressed irritant and corrosive effects of the skin and respiratory tract as the "main health effects" from exposure to hexavalent chromium compounds. However, as welding is associated with an exposure to several further aerosolic or gaseous chemical substances with heterogeneous composition, which might cause different interactions with chromium, no quantitative risk assessment for non-carcinogenic endpoints is possible.

2.4.4 Short-term limit value (STEL)

There is no reliable data with regard to carcinogenic excess risk increase due to short-term occupational peak exposures. SCOEL (SCOEL, 2017) do not recommend a STEL. Establishing an ERR on short term effects is not feasible.

2.4.5 Biomonitoring values

Due to the local effects of Cr(VI), biological monitoring in urine is not regarded meaningful to quantify exposure of the respiratory tract. Moreover, no link between biomonitoring results and cancer risk from Cr(VI) exposure from welding or thermal cutting has been established.

2.5 Reference OELVs

The reference point for this report is given through the compromise recently reached by the Council and the European Parliament on the Commission proposal COM(2016)248 final. The reference points are the established OELV of 0.025 mg/m^3, which is a derogation for welding, and the OELV of 0.005 mg/m^3, which will enter into force 5 years after the transition date.

3 The baseline scenario

3.1 Introduction

This section comprises the following subsections:

- Section 3.2: Existing national limits
- Section 3.3: Relevant processes, sectors and compounds
- Section 3.4: Exposed workforce
- Section 3.5: Exposure concentrations
- Section 3.6: Current Risk Management Measures (RMMs)
- Section 3.7: Voluntary industry initiatives
- Section 3.8: Best practice
- Section 3.9: Standard monitoring methods/tools
- Section 3.10: Relevance of REACH Restrictions or Authorisation
- Section 3.11: Market analysis
- Section 3.11: Alternatives
- Section 3.12: Current and future burden of disease

3.2 Existing national limits

3.2.1 OELs

A summary of OELs in EU- and non-EU countries for Cr(VI) compounds is presented in Table 3-1. Most OELs for Cr(VI) and inorganic compounds refer to inhalable or total dust and most of them are not specifically linked to specific exposure scenarios. The range is from 0.001 mg/m³ to 0.5 mg/m³, with most of the values from 0.01 to 0.05 mg/m³). A specified OEL for welding fumes of 4 mg/m³ is available from China. No background document is available, so it is not known, which chemical compounds and which endpoints are covered. Therefore, it is not directly comparable to the OEL for Cr(VI) compounds. Few other OEL address explicitly Cr(VI) in welding. These are the OEL from Austria, Slovakia, Slovenia and USA/ACGIH.

If the intended change by ACGIH (envisaged threshold limit value (TLV): 0.0002 mg/m³) is included and if national OELs are linked to small excess cancer risks, this range may be even larger. The highest OEL for Cr(VI) compounds are from Austria with 0.5 mg/m³ for the inhalable fraction of other Cr(VI) compounds and Greece with an OEL of 0.5 mg/m³ for total dust.

An OELV for Cr(VI) as well as Cr(VI) during welding and plasma cutting will be set finally at 0.005 mg/m³ in the EU (details see below). Lower levels are discussed by USA/ACGIH (0.0002 mg/m³; intended change, not yet implemented, for Cr(VI), inhalable fraction, also suggested by NIOSH as REL) and are established in Germany and in France (0.001 mg/m³). In Germany, this is not exactly an OEL. Because of the uncertainties for further extrapolations into the low exposure range (< 1 µg/m³) no extrapolation was performed (no defined acceptable risk level) and the 1 µg/m³ at a risk level of 4:1000 is regarded as an "assessment value". This value is risk based and no effect threshold. Further minimization of exposure is demanded.

Some, but not all of the OELs distinguish between soluble and poorly soluble Cr(VI) compounds. However, no apparent and unambiguous discrimination of OELs can be observed with regard to the critical target organs, toxicological endpoints or potency (see *e.g.* ACGIH, 1991; 2004).

The background of most OELs is not known, as only few background documents could be traced within the framework of this analysis. Moreover, many countries do not establish their own OEL, but adapt an OEL from other countries and therefore would not be in the position to provide background documents. However, most – if not all – of the existing OELs apparently find carcinogenicity of Cr(VI) compounds one of the critical health endpoint and, accordingly, link their OEL to cancer risk, but partially also with additional endpoints, *e.g.* respiratory tract irritation, asthma, dermatitis and possible kidney damage (ACGIH, 2004; 2016; 2017). ACGIH has included carcinogenicity of (insoluble) Cr(VI) compounds as critical endpoint in the derivation of the TLV already a long time ago (ACGIH, 1991), and the differentiation between soluble and insoluble compounds as well as a lowering of the ACGIH-TLV is not yet implemented.

As several countries (*e.g.* Belgium, Ireland, Spain, and also non-European countries, see Table 3-1, have the same TLV as ACGIH, split into a value of 0.05 and 0.01 mg/m^3 for soluble and insoluble compounds, respectively, they may have adopted this TLV. Clearly, the more recent evaluation by ACGIH results in a lower OEL compared to the still implemented TLV.

ECHA, SCOEL, the Netherlands and Germany provided ranges of concentrations associated with differing cancer risk levels, which may be linked to an OEL, or to a "tolerable" or "acceptable" risk level, or just provide potency information. All these risk estimates based on the same methodology of the assumption of a linear exposure risk relationship (despite some mechanistic uncertainties) and resulted in an identical risk of 4 x 10^{-3} per 1 µg/m^3, based on the Baltimore and the Painesville cohort studies, or meta-analysis of them (Germany additionally on data from two German chromate plants). Therefore, no systematic difference in the methodology of deriving OEL based on risk estimates is observed in Europe. OSHA and NIOSH OEL are also based on quantitative risk estimates, which resulted in slightly (about 1.5-fold) higher risks compared to the European estimates.

Carcinogenic effects for Cr(VI) from chromate production

As background documents are available only for few of the OELs, the basis for most of them is unknown. Amongst these documents there are only OELs for Cr(VI) based on epidemiological data on chromate production. The available background documents consistently assumed a linear dose-response relationship, at least down to concentrations of 1 µg/m^3. As can be seen in the following chapter, all risk estimates are based on only few studies with similar outcome, and they are therefore very similar.

EU (2017)[4]

A stepwise reduction of chromium exposure was stipulated in the Proposal for a Directive of the European Parliament and of the Council amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work (June 2017). There will be an exposure limit value of 0.010 mg/m^3 for a period of 5 years after the date of transposition of the directive; after that period a limit of 0.005 mg/m^3 will apply. There is derogation for welding or plasma-cutting processes or similar work processes that generate fumes: for them the exposure limit value is 0.025 mg/m^3 until 5 years after the transposition date and after that period the limit will be 0.005 mg/m^3. This overview document (and also a related link[5]) do not address the size fraction of the dust, but as all the other risk assessments (below) are based on epidemiological data, *i.e.* inhalable dust, it can be assumed with sufficient certainty that it refers also to inhalable dust. Therefore the OELV for Cr(VI) as well as Cr(VI) during welding and plasma cutting will be finally 5 µg/m^3. No backgrounds to the health risk (risk for carcinogenic and/or non-cancer effects associated with this OELV) are provided.

USA/ACGIH

The ACGIH TLV is 0.05 µg Cr/m^3 for water soluble Cr (VI) compounds and 0.01 µg/m^3 for insoluble Cr (VI) compounds. The latter also covers fumes from stainless steel welding. The values have been derived to minimise the potential for respiratory tract irritation and cancer, dermatitis and possible kidney damage, but are not based on quantitative risk assessments (ACGIH, 2004; 2016).

However, the ACGIH intends to change the TLV to 0.0002 mg/m^3 for Cr(VI) compounds as inhalable matter, but welding fumes are no longer addressed. The TLV is based on the endpoints lung and sinonasal cancer, respiratory tract irritation and asthma. ACGIH stated that the TLV should minimize respiratory sensitisation and reduce the likelihood of asthmatic responses in already sensitised individuals, but severe reactions may still occur (ACGIH, 2017). The TLV is not associated formally with a specified risk. The authors refer to the studies by Gibb *et al*. (200), Park *et al*. (2004) and Luippold *et al*. (2003), Crump *et al*. (2003) with risk estimates of 1 per 1000 workers at 0.0002 mg/m^3 and 2 per 1000 at 0.001 mg/m^3, respectively.

AGS (2014)

The risk estimate by AGS (2014) is based on a weight-of-evidence approach using epidemiological data, especially from the Baltimore cohort (Gibb *et al*., 2000), the Painesville cohort (Luippold *et al*., 2003), and from 2 German chromate plants (Birk *et al*., 2006). A doubling of the SMR at about 12.5 µg/m^3 workplace exposure was attributed to an excess risk of about 5/100, resulting in the excess risk estimate of 4 x 10^{-3} at a workplace exposure to 1 µg/m^3. Due to the uncertainties with regard to a linear exposure risk relationship, the AGS did not extrapolate risks to levels below 1 µg/m^3. 1 µg/m^3

4 See http://www.consilium.europa.eu/en/press/press-releases/2017/07/11-carcinogens-mutations-at-work/ accessed October 2017

5 See http://www.consilium.europa.eu/en/press/press-releases/2017/07/pdf/st10803-ad01_en17_pdf / accessed October 2017

formally is not called a "tolerable risk" level and is not called OEL ("Arbeitsplatzgrenzwert"). Instead the term "judgment value" ("Beurteilungsmaßstab") is used to refer to the uncertainties in the risk quantification process[6].

ECHA (2013a)

ECHA (2013a) used the risk analysis by Seidler *et al*. (2013) to derive a "key reference point" of an excess lifetime (up to an age of 89 years) lung cancer risk of 4 x 10^{-3} for workers exposed to an 8h-time-weighted average (TWA) concentration of 1 µg Cr(VI)/m^3 for 40 years, with a linear dose-response relationship at least down to 1 µg/m^3. A range of risks at air concentrations of 0.01-25 µg/m^3 was provided and the risk estimates at concentrations below 1 µg/m^3 are marked as questionable, because "exposures below 1 µg Cr(VI)/m^3 might well greatly overestimate the real cancer risks and from about 0.1 µg/m^3 downwards), cancer risks may be negligible" (ECHA, 2013a).

HCN (2016)

Point risk estimates for lung cancer of 4 x 10^{-5} and 4 x 10^{-3} for 40 years of exposure to concentrations of 0.01 and 1 µg/m^3, respectively, were derived by the Dutch authorities. These estimates were also based on the risk analysis by Seidler *et al*. (2013) and were recalculated with Dutch mortality data and up to a lifetime of 100 years.

OSHA (2006)

OSHA (2006) calculated a unit excess lifetime lung cancer risk of 2.1-9.1 x 10^{-3} for 45 years of occupational exposure to 1 µg/m^3. This range corresponds to the maximum likelihood estimates based on the studies by Luippold *et al*. (2003) and Gibb *et al*. (2000), respectively. A linear relationship was assumed. The final rule establishes an 8-hour time-weighted average (TWA) exposure limit of 5 µg Cr (VI)/m^3, which was associated by OSHA (2006) with a risk of 1.0-4.5 x 10^{-2}.

NIOSH (2013)

NIOSH (2013) estimated a slightly higher risk of 6 x 10^{-3} for 40 years of exposure to a concentration of 1 µg/m^3, based on the risk assessment by Park *et al*. (2004). The authors stated that although a threshold could not be ruled out because of the limitations of the analysis, the best estimate at this time is that there is no concentration threshold for the Cr (VI)-induced lung cancer. As the risk at 0.16 µg/m^3 is 1/1000 (level considered significant and worthy of intervention by OSHA), a Recommended Exposure Limit (REL) of 0.2 µg Cr (VI)/m^3 was derived.

The assessments mentioned above use a similar set of epidemiological studies with identical conclusions on the excess risk for workers exposed over working lifetime to hexavalent chromium. Differences exist in the approaches to estimate these risks. However, AGS (2014) refrained from extrapolation to exposures below 1 µg/m^3, whereas ECHA (2013a) and HCN (HCN, 2016) extended the applicability domain of this risk estimate to 10 ng/m^3 and above, but marked as increasingly uncertain at concentrations < 1 µg/m^3 by ECHA (2013a).

6 https://www.baua.de/DE/Aufgaben/Geschaeftsfuehrung-von-Ausschuessen/AGS/Beurteilungsmassstaebe.html

SCOEL (2004; 2017)

SCOEL (2017) does not derive an OEL for Cr(VI) but recommends to consider recent cancer risk estimates (Crump *et al*., 2003; Park *et al*., 2004; Seidler *et al*., 2013) for regulation. They refer to other national risk assessments with similar risk quantifications (AGS, 2014; HCN, 2016). The respective excess risk is 4:1000/ µg/m³. The former risk assessment by SCOEL (2004) used a meta-analysis of 10 studies involving chromate production workers, chromate pigment production workers and chromium platers (Steenland *et al*., 1996), which resulted in a roughly 10-fold lower risk (0.1-0.6 x 10^{-3} at 1 µg/m³) compared to the more recent risk estimates. It was considered by ECHA (2013a) as less reliable, because it did not include more recent publications and actual exposure data.

IOM (2011)

IOM (2011) reported no numeric excess risk for working life exposure per µg/m³, but relative risks (RR) from occupational exposure to hexavalent chromium with respect to lung cancer (key studies: Cole and Rodu (2005), Crump *et al*. (2003) and also to sinonasal cancer (Rosenman and Stanbury, 1996), which was not considered in other risk analyses. The respective relative risks for lung cancer were quantified to 1.18 (1.12-1.25) at "high" exposures (Cole and Rodu, 2005) and 1 at "low" exposures (Crump *et al*., 2003). The respective relative risks for sinonasal cancer were quantified to 5.18 (2.37-11.3) at "high" exposures (Rosenman and Stanbury, 1996) and 3.42 (0.42-10.52) at "low" exposures ("harmonic mean" estimate). IOM regarded 5-16 µg hexavalent chromium/m³ as "high" exposures in 1995, "low" exposures would be in the range of 0.02-0.63 µg/m³ (IOM, 2011).

Registration dossiers

Some Cr (VI) compounds have an assigned DNEL. For example, REACH[7] registrants derived DNELs of 10 µg/m³ for chromium trioxide, sodium and potassium chromate and sodium and potassium dichromate (ECHA Dissemination, 2017). However, no further details are provided. Therefore the excess risk linked to this DNEL is not known.

Carcinogenic effects of welding fumes

The ACGIH TLV is 0.05 µg Cr/m³ for water soluble Cr (VI) compounds and 0.01 µg/m³ for insoluble Cr (VI) compounds. The latter also covers fumes from stainless steel welding. The values have been derived to minimize the potential for respiratory tract irritation and cancer, dermatitis and possible kidney damage, but are not based on quantitative risk assessments (ACGIH, 2004; 2016).

However, the ACGIH intends to change the TLV to 0.0002 mg/m³ for Cr(VI) compound as inhalable matter with welding fumes are no longer explicitly mentioned.

Non-carcinogenic effects

The ACGIH TLV is 0.05 µg Cr/m³ for water soluble Cr (VI) compounds and 0.01 µg/m³ for insoluble compounds. In addition to cancer, it has been derived to minimize the potential for respiratory tract irritation, dermatitis and possible kidney damage. No STEL was derived (ACGIH, 2004; 2016).

[7] Registration, Evaluation and Restriction of Chemical Substances, Regulation (EC) No 1907/2006

However, the ACGIH intends to change the TLV to 0.0002 mg/m^3 for Cr(VI) compound as inhalable fraction. ACGIH stated that the TLV should minimize respiratory sensitisation and reduce the likelihood of asthmatic responses in already sensitised individuals, but severe reactions may still occur (ACGIH, 2017).

Other up-to-date values based on non-carcinogenic effects of chromium are not available. Specifically, a non-cancer occupational exposure limit from exposure to welding fumes has not been derived and linked to the respective Cr(VI) fraction.

Table 3-1: OELs and STELs in EU Member States and selected non-EU countries for Chromium(VI) and inorganic compounds.

Member State	Value [mg/m^3] I=inhalable; R=respirable; T=total dust	Specification of values ‡ (year)	OEL definition	Study details	STEL [mg/m^3]	Specification of STEL‡
Austria[5]	0.1 (I) 0.05 (I)	-manual arc welding -other uses	SE/T		0.4 (I) 0.2 (I)	-manual arc welding -other uses
Belgium	0.05 0.01	-water soluble -water insoluble	SE/T		-	n.a.
Bulgaria	0.05	-including chromic acid	SE/T		-	n.a.
Croatia	0.05		SE/T		-	n.a.
Cyprus	-		n.a.		-	n.a.
Czech Republic	0.05		HB		0.1	
Denmark[5]	0.5 0.005	-powder and soluble chromium and chromium salts -chromic acid and chromates	SE/T	Not known or not reported	0.01	
Estonia	2 0.02	-except for chromic acid and chromates -chromic acid and chromates	SE/T		-	n.a.
Finland[5,10]	0.005		SE/T		-	n.a.
France[§§]	0.001		SE/T		0.005	
Germany[3]	0.001 -“tolerable risk”* Excess cancer risk: 4 x 10^{-3} - 0.001 mg/m^3	-doubling SMR at about 12.5 µg/m^3 workplace exposure was attributed to excess risk of about 5/100 (2014)	HB	Endpoint: lung Species: human for (Gibb *et al.*, 2000) Luippold *et al.*	0.008	

Table 3-1: OELs and STELs in EU Member States and selected non-EU countries for Chromium(VI) and inorganic compounds.						
Member State	**Value [mg/m³] I=inhalable; R=respirable; T=total dust**	**Specification of values ‡ (year)**	**OEL definition**	**Study details**	**STEL [mg/m³]**	**Specification of STEL‡**
				(2003) Luippold *et al.* (2003) Birk *et al.* (2006)		
Greece	0.5		SE/T	Not known or not reported	-	n.a.
Hungary	0.05 0.01	-sodium chromate, potassium chromate and other soluble Cr VI compounds -slightly soluble	HB		-	
Ireland	0.05 0.01	-water soluble -water insoluble	HB		-	n.a.
Italy	-		n.a.			n.a.
Latvia	0.01	-chromium trioxide, dichromium tris(chromate) Me_2CrO_4 or $Me_2Cr_2O_7$	SE/T		-	n.a.
Lithuania	0.005		SE/T		0.015	
Luxembourg	-		n.a.		-	n.a.
Malta	-		n.a.		-	n.a.
Netherlands[8]	0.001 [Excess cancer risk: 4 x 10^{-3} – 0.001 mg/m³]		SE/T	Seidler *et al.* (2013) Endpoint: lung Species: human	-	n.a.
Poland	0.1	-chromate, dichromate	HB	Not known or not reported	0.3	-chromate, dichromate
Portugal	-		n.a.		-	n.a.
Romania	0.05		Not known		-	n.a.
Slovakia	0.1 (I) 0.05 (I)	-manual welding, production of in water soluble CrVI compounds -other	SE/T		-	n.a.

Table 3-1: OELs and STELs in EU Member States and selected non-EU countries for Chromium(VI) and inorganic compounds.						
Member State	**Value [mg/m³] I=inhalable; R=respirable; T=total dust**	**Specification of values ‡ (year)**	**OEL definition**	**Study details**	**STEL [mg/m³]**	**Specification of STEL‡**
Slovenia	0.1 (I) 0.05 (I)	-manual arc welding, soluble -others	SE/T		0.4 0.2	-manual welding, preparation of soluble Cr -other
Spain	0.05 0.01	-soluble+ -insoluble+	SE/T		-	n.a.
Sweden	0.005 (T)		SE/T		0.015	total aerosol
United Kingdom[9]	0.05		SE/T		-	n.a.
SCOEL[5]	- [estimated excess risk: 4 x 10^{-3} - 0.001 mg/m³]		HB	(Crump *et al.*, 2003) (Park *et al.*, 2004) (Seidler *et al.* 2013)	-	n.a.
EU[12]	0.005		n.a.		-	n.a.
ECHA[7]	- [estimated excess risk of 4 x 10^{-3} - 0.001 mg/m³]	(2013)	HB	Seidler *et al.* (2013) Endpoint: lung Species: human	-	n.a.
Selected non-EU countries						
Australia	0.05		Not known	Not known or not reported	-	n.a.
Brazil	-		Not known			
Canada, Ontario	0.05 0.01	-water soluble -water insoluble	Not known		-	n.a.
Canada, Québec[5]	0.05 0.01	-water soluble -water insoluble	Not known		-	n.a.
China	4 (T) 0.05	-welding fumes -chromium trioxide, chromate, dichromate	SE/T		-	n.a.
India	0.05	-water soluble	Not known		-	n.a.
Japan	0.05 0.01	-water soluble -certain compounds	HB		-	n.a.
South Korea[5]	0.05 0.01	-water soluble -water insoluble	SE/T		-	n.a.

Table 3-1: OELs and STELs in EU Member States and selected non-EU countries for Chromium(VI) and inorganic compounds.						
Member State	**Value [mg/m³] I=inhalable; R=respirable; T=total dust**	**Specification of values ‡ (year)**	**OEL definition**	**Study details**	**STEL [mg/m³]**	**Specification of STEL‡**
USA; ACGIH[6~]	0.05 0.01 0.0002 (I) ~	-water soluble -water insoluble, addresses also fumes from welding -intended change: chromium (VI), inhalable particulate matter ~ (2004 and 2016)	HB	Endpoints: respiratory tract irritation, cancer, dermatitis and possible kidney damage	- 0.0005 ~	n.a. -intended change (2017) draft~
USA, OSHA	0.005 [Excess cancer risk: 1.0-4.5 x 10^{-2}] Excess cancer risk: 2.1-9.1 x 10^{-3} - 0.001 mg/m³	for 45 years of exposure	SE/T	Luippold *et al.* (2003) (Gibb *et al.*, 2000)	-	n.a.
USA, NIOSH[11, $]	# Excess cancer risk: 6 x 10^{-3} - 0.001 mg/m³		n.a.	Not known or not reported	-	n.a.

‡ chromium (VI) and inorganic compounds, all occupations, if not stated otherwise (*i.e.*, different applicability domain, specific occupations)
- not established/assigned
~ Intended changes are not implemented, yet.
+ Contradictory data from questionnaire responses or GESTIS database.
n.a. = not applicable
SE/T = influenced by socio-economic and/or technical considerations; HB = health or risk-based

§§ Limit values are recognised values – not according to decree modified on 30 June 2004 – thus not legally binding.
*This concentration is not regarded as a fixed OEL (AGS; TRGS 910; https://www.baua.de/DE/Angebote/Rechtstexte-und-Technische-Regeln/Regelwerk/TRGS/pdf/TRGS-910.pdf?__blob=publicationFile&v=4), but as an upper limit and called « Beurteilungsmaßstab » (« judgment value ») associated with a risk of 4/1000 at 1 µg/m³
$ “For NIOSH RELs, "TWA" indicates a time-weighted average concentration for up to a 10-hour workday during a 40-hour workweek.“; Online: https://www.cdc.gov/niosh/npg/pgintrod.html#exposure assessed December 2017; however, more recently this REL was withdrawn:
 # No recommended exposure limits (RELs) established - Reference to "Appendix A - NIOSH Potential Occupational Carcinogens". NIOSH has changed policy with regard to carcinogenic substances. Under the old policy, RELs for most carcinogens were non-quantitative values labelled "lowest feasible concentration (LFC)." The effect of the new policy will be the development, whenever possible, of quantitative RELs that are based on human and/or animal data, as well as on the consideration of technological feasibility for controlling workplace exposures to the REL. Changes in the RELs and respirator recommendations that reflect the new policy will be included in future editions.

References:
Data was collected from responses of Member States questionnaires, GESTIS database[1], or country specific lists of OEL from web-

Table 3-1: OELs and STELs in EU Member States and selected non-EU countries for Chromium(VI) and inorganic compounds.						
Member State	**Value [mg/m³] I=inhalable; R=respirable; T=total dust**	**Specification of values ‡ (year)**	**OEL definition**	**Study details**	**STEL [mg/m³]**	**Specification of STEL‡**
search, if not stated otherwise (references 2-12, below). 1: IFA (2017) Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung. GESTIS - International limit values for chemical agents. 2: ANSES (2017) Valeurs limites d'exposition en milieu professionnel. Evaluation des indicateurs biologiques d'exposition et recommandation de valeurs biologiques pour le Chrome VI et ses composes, Rapport d'expertise collective, 26/07/2017 3: AGS (2014) Ausschuss für Gefahrstoffe. Begründung zu Expositions-Risiko-Beziehung für Chrom(VI)-Verbindungen in TRGS 910. 4: Drexler and Hartwig (2009) Biologische Arbeitsstoff-Toleranz-Werte (BAT-Werte), Expositionsäquivalente für krebserzeugende Arbeitsstoffe (EKA), Biologische Leitwerte (BLW) und Biologische Arbeitsstoff-Referenzwerte (BAR). 5: SCOEL (2017) Recommendation from the Scientific Committee on Occupational Exposure Limits for Chromium VI compounds. 6: ACGIH (2004; 2016) American Conference of Governmental Industrial Hygienists. Chromium and Inorganic Compounds. 7: ECHA (2013b) Application for Authorisation: Establishing a Reference Dose Response Relationship for Carcinogenicity of Hexavalent Chromium. 8: HCN (2016) Health Council of the Netherlands. Health-based recommendation on occupational exposure limits. Hexavalent chromium compounds 9: HSE (2013) EH40/2005 Workplace exposure limits, EH40 (Second edition, published 2011, update March 2013) 10: Ministry of Social Affairs and Health, Finland (2016) HTP-arvot 1214/2016 11: NIOSH (2013) Criteria for a Recommended Standard - Occupational Exposure to Hexavalent Chromium. DHHS (NIOSH) Publication No. 2013–128. September 2013 ; (#, see above, for recent NIOSH changes) 12: European Union (2017) Directive (EU) 2017/2398 of the European parliament and of the council of 12 December 2017 amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work. Online: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017L2398&qid=1515769801913&from=en, assessed January 2018.						

3.2.2 Short term limit values (STEL)

SCOEL (2017) does not recommend a STEL for Cr(VI). Only few other STELs are reported with no background documents available.

3.2.3 Biomonitoring values

The French OEL committee has recommended biological values for hexavalent chromium: a Biological Limit Value of 2.5 µg/L (1.8 µg/g creatinine at the end of a working week was derived, based on exposure to the 8-hour OEL (1 µg/m^3), and a Biological Reference Value of 0.65 µg/L or 0.54 µg/g creatinine was established (ANSES, 2017).

Drexler and Hartwig (2009) derived a Biological Reference Value (BAR) of 0.6 µg/L total chrome in urine. This value for Germany represents the upper 95th percentile of the background burden of the general population. There is no German Biological Limit Value.

The Biological Exposure Index (BEI) of the ACGIH for Cr(VI) as water-soluble fumes at a post shift at the end of a working week is 25 µg/l urine (and an increase per shift of 10 µg/L urine). The BEI is consistent with an exposure to 0.05 mg/m^3, the TLV for water-soluble Cr(VI) compounds (ACGIH, 2016).

3.3 Relevant sectors, uses and operations

Cr(VI) compounds in fumes from thermal metal works can only form if there is chromium present in the base metal or metal consumable, and if the process conditions (temperature, dispersion, oxygen availability) allow oxidation of elemental or trivalent chromium to hexavalent chromium. The composition of a welding consumable is adapted to the composition of the steel, meaning that, chromium containing steels require the use of chromium containing welding consumables. In welding, appr. 95% of the fume originates from the welding consumable and only about 5% from the base metal (BGHM, 2013).

Mild steels, also known as plain-carbon steel and low-carbon steel, is now the most common form of steel. Mild steels contain approximately 0.05-0.25% carbon and do not contain any chromium. Therefore, emissions of Cr(VI) compounds are not expected in thermal metal works with mild steel.

Unalloyed or low-alloy steels contain less than 5% alloys such as manganese, nickel and chromium. Emissions of Cr(VI) compounds in thermal metal works with low-alloy steels are expected to be very low (HVBG, 2006).

High-alloy steels contain more than 5% alloys such as manganese, nickel and chromium. Considerable emissions of Cr(VI) compounds in thermal metal works with high-alloy steels can be expected (HVBG, 2006).

In the literature, the designations **stainless steel and high alloyed steel** may be used interchangeably or differently. Scheepers *et al*. (2008) differentiates by defining high-alloyed steel as containing 5-26% alloys and stainless steel more than 26% alloys. In other sources, stainless steel is considered as one type of high-alloyed steel, or high-alloy steels are simply referred to as chromium nickel steels (*e.g.* HVBG, 2006).

The literature investigating the emissions from welding and other hot metal works, commonly differentiates between mild and stainless steel only (*e.g.* Leonard *et al*., 2010). Literature concerned with emissions of Cr(VI) commonly focuses on stainless steel only (*e.g.* HSE, 2010), as exposures to Cr(VI) from mild or low alloyed steels have been shown to be very low/under the detection limit (*e.g.* Edmé *et al*. 1997; Meeker *et al*. 2010). Therefore, the present report uses the designation "stainless steel" as well. For more information on exposures, see section 3.5.

3.3.1 Demarcation of processes

The definition "Welding, plasma cutting and similar processes" requires a more precise demarcation of relevant processes.

The metal working processes soldering and grinding, are often mentioned in relation to stainless steel metal works, but have not been evaluated in this study. Soldering and grinding are reported to have a low to negligible potential of yielding Cr(VI) emissions (*e.g.* IFA, 2012), while stakeholders from the industry often mention it as a process significantly contributing to exposures to fumes in general. Soldering and grinding are activities which are linked to the hot metal works evaluated here, but they are not considered relevant for the scope of the current study. In any case, these processes are relevant in assessments of overall occupational exposures of welders and other metal workers.

The present study focusses on: i) welding and its subprocesses, ii) thermal cutting and its subprocesses (*e.g.* plasma cutting), and iii) thermal spraying and its subprocesses.

3.3.2 Welding

Welding processes are distinguished based on the energy source used, the materials worked with, the purpose of the welding, the physical processes in the welding and the degree of mechanisation of the process. Welding is most commonly used to join metal pieces, but welding techniques can also be used to apply a surface to a given work piece (cladding). Welding always generates gaseous and particulate hazardous substances, with varying amounts depending on the process. The particulate substances have a particle size (aerodynamic diameter) of less than 1 µm, they are respirable and are normally called ”welding fume“ (VMBG, 2007). Generally, more than 95% of the welding fume is generated from the filler metal and only about 5% from the parent/base metal (HVBG, 2006). Thus air concentrations are mainly predicted by the metal content in electrodes or base material in addition to the welding technique (Weiss *et al*., 2013).

Table 3-2 lists relevant welding processes and their abbreviations. For most processes, several abbreviations and designations are commonly used in European literature, originating from diverging designations in British and American English. The following sections shortly describe the welding processes, their application range, the potential for Cr(VI) exposure as well as prevalence and trends in use of processes.

Table 3-2: Abbreviation and names of main welding processes. The bold printed abbreviations are primarily used in this study	
Abbreviation(s)*	**Process designation(s)**
MMA SMAW	Manual Metal Arc Shielded Metal Arc Welding
GMAW - **MIG** - **MAG**	Gas metal arc welding - Metal Inert Gas - Metal Active Gas
TIG GTAW WIG	Tungsten Inert Gas Gas Tungsten Arc Welding Wolfram Inert Gas (mostly German)
FCAW	Fluxed-Cored Arc Welding
SAW	Submerged arc welding
PAW	Plasma arc welding
-	Laser welding
-	Hybrid welding
*The bold abbreviations are used in this report.	

Summary of relevant welding processes

The German Association of metal professionals' associations, VMBG[8] (2007), defines key components as the dominant hazardous substances and lists the key components emitted from the different welding processes (Table 3-3). The table also displays several other hazardous compounds deriving from welding. From the welding processes below, MMA and FCAW (MAGM with flux-cored wires) in stainless steel welding are the most relevant welding processes with potentially high Cr(VI) emissions.

Table 3-3: List of welding processes with Cr(VI) as key component[1] in welding fume (modified from VMBG, 2007)		
Process	**Filler metal**	**Welding fume/key components[1]**
Manual metal arc welding (MMA)	unalloyed, low-alloy steel	welding fume
	chromium-nickel-steel (≤ 20% Cr and ≤ 30% Ni)	**Cr(VI) compounds**
	nickel, nickel alloys (> 30% Ni)	nickel oxide or copper oxide
Metal active gas welding with gas mixture (MAGM)	unalloyed, low-alloy steel	welding fume
	chromium-nickel-steel solid wire (≤ 20% Cr and ≤ 30% Ni)	nickel oxide
	chromium-nickel-steel flux-cored wire (≤ 20% Cr and ≤ 30% Ni)	**Cr(VI) compounds**
Tungsten inert gas welding (TIG)	unalloyed, low-alloy steel	welding fume, ozone
	chromium-nickel-steel (≤ 20% Cr and ≤ 30% Ni)	welding fume
	nickel, nickel alloys (> 30% Ni)	ozone
	pure aluminium, aluminium-silicon alloys	welding fume,
	other aluminium alloys	ozone
Laser welding (Laser cladding,	cobalt base alloys (> 60% Co, > 20% Cr)	cobalt oxide
	nickel base alloys (> 60% Ni)	nickel oxide

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Table 3-3: List of welding processes with Cr(VI) as key component[1] in welding fume (modified from VMBG, 2007)		
Process	Filler metal	Welding fume/key components[1]
hardfacing, laser beam surfacing)	**iron base alloys (< 40% Cr, > 60% Fe)**	welding fume
	complex aluminium bronzes (75% Cu)	copper oxide
[1] defined as the dominant hazardous substance		

Manual Metal Arc (MMA) Welding

MMA or "stick welding" is commonly used for mild steel, low-alloy steel, and stainless steel welding. In MMA, the electrode is held manually, and the electric arc flows between the consumable electrode and the base metal. Nowadays, the electrodes in MMA welding are always coated with a flux material, which decomposes to provide a shielding gas to protect the weld deposit from impurities (Figure 3-1). The available electrodes can be divided into the following main groups:

- Cellulosic electrodes, contain a high proportion of cellulose in the coating
- Rutile electrodes, contain a high proportion of titanium oxide (rutile)
- Basic electrodes, contain a high proportion of calcium carbonate and calcium fluoride
- Metal powder electrodes, contain an addition of metal powder to the flux coating[9].

Principally, all types of electrodes can be used for stainless steels. The choice of electrode depends on other weld properties.

The presence of alkaline (earth) metals contributes to the stabilization of Cr(VI) compounds in the fumes. Apart from calcium carbonate and calcium fluoride, basic covered electrodes also contain higher proportions of potassium dioxide and calcium oxide compared to rutile covered electrode (VMBG, 2007). Therefore, the alkaline (earth) metals in fumes from MMA welding with basic electrodes cause higher proportions of Cr(VI) compounds than in fumes from rutile electrodes.

By MMA welding with high-alloy electrodes, welding fume may contain up to 16% of chromium. Up to 90% of these chromium compounds are present as chromates (Cr(VI)). Other carcinogenic substances in the welding fume, such as nickel oxide (present with 1% and seldom up to 3%) do not present the main concern in this process (VMBG, 2007; HVBG, 2006).

[9] http://www.twi-global.com/technical-knowledge/job-knowledge/the-manual-metal-arc-process-mma-welding-002/

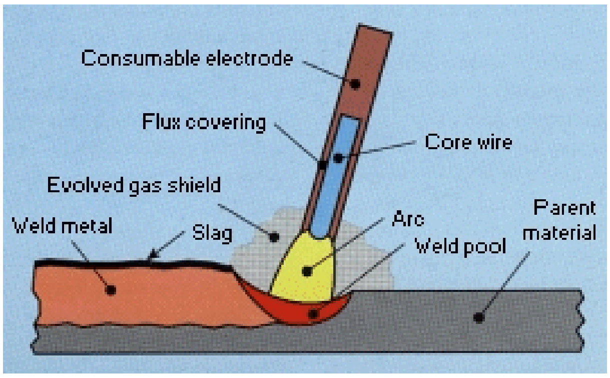

Figure 3-1: MMA weld area (picture by Courtesy of TWI Ltd.)

According to communication with the industry and welding associations, the use of MMA has been decreasing over the last decades (estimates ranging between reductions of 4-22% per decade). Informal expert judgements estimate the use of MMA at appr. 5%, 12% and 35% out of all welding processes for France, Poland and Romania for the period 2001-2010, respectively. Possibly 10-29% of all MMA welding is done on stainless steel (informal estimates for Romania and France for the period 2001-2010, respectively) (DGUV, 2017, pers. communication).

Fluxed-Cored Arc Welding (FCAW)

FCAW is commonly used for mild steel, low alloy steel, and stainless steel. The consumable electrode is continuously fed from a spool and an electric arc flows between the electrode and base metal. The electrode wire has a central core containing fluxing agents, which form a protective slag over the weld. Flux-cored wires may be self-shielding or shielding gas may be supplied externally. FCAW with external shielding gas supply may also be considered as MIG/MAG welding (see section below). Usually, solid wires are used in MIG/MAG welding. In some publications, FCAW is called for MAG welding with flux-cored wires or filler wires. Flux-cored wires for stainless steels commonly contain between 12 and 30% Cr. Depending on the welding consumables, shielding gas (composition), wire feed speed and other technical welding parameters, welding fumes containing Cr(VI) compounds may be released. The use of self-shielded flux-cored wire electrodes generates considerably higher welding fume emissions than the use of flux-cored wire electrodes under externally supplied shielding gas.

No information indicating a clear trend with respect to the use of this welding technique has been obtained. Informal expert judgements estimate the use of FCAW at appr. 6%, 10% and 1% out of all welding processes for Romania, Poland and France for the period 2001-2010, respectively. Possibly 5 – 60% of all FCAW welding is done on stainless steel (informal estimates for Romania and France for the period 2001-2010, respectively) (DGUV, 2017, pers. communication).

Gas metal arc welding - Metal Inert Gas and Metal Active Gas Welding (GMAW – MIG and MAG)

GMAW is used for most types of metal. This process involves the flow of an electric arc between the base metal and a continuously spool-fed solid-core consumable electrode. Shielding gas is supplied externally and the electrode has usually no flux coating or core (Figure 3-2). Typical inert shielding gases are argon and helium (MIG). MAG can be further subdivided in metal active gas welding with carbon dioxide (MAGC) and metal active gas welding with gas mixture (MAGM).

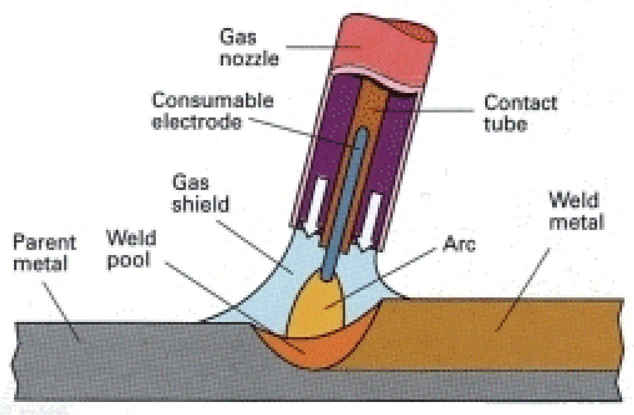

Figure 3-2: MIG/MAG welding area (picture by Courtesy of TWI Ltd)

In processes with active gas (MAGC, MAGM), generation of large quantities of particulate hazardous substances (welding fume) can be expected.

The use of chromium nickel steel filler wires (≤20% Cr and ≤30% Ni) in MAGM welding of chromium nickel steels leads to emissions of Cr(VI) in the welding fume. The welding fumes contain up to 17% chromium compounds and up to 5% nickel oxide, but the chromium compounds are almost exclusively composed of the trivalent form Cr(III) (VMBG, 2007).

MAGC welding is primarily used for unalloyed and low-alloyed steels. The emission of carbon monoxide is a major concern in MAGC.

In contrast, processes using inert gas (MIG) are mainly used with aluminium-base materials (*e.g.* aluminium-silicon alloys), nickel and nickel-base alloys (alloy elements are typically copper, chromium, cobalt and/or molybdenum), and generally exhibit a lower fume generation than MAG processes.

Larger amounts of welding fume are generated when MAG/MIG welding with flux-cored wire electrodes than when welding with solid wire electrodes. Therefore, MAG welding with a high-alloy flux-cored wire will cause Cr(VI) compounds to be the key component in the welding fume (HVBG, 2006; VMBG, 2007).

Fume emission and composition also depends on the shielding gas composition, gas flow, the weld mode, wire feed rate, voltage and current (*e.g.* Keane *et al.*, 2009, 2016).

MIG/MAG welding is widely used in most industry sectors and accounts for more than 50% of all weld metal deposited. Compared to MMA, MIG/MAG has the advantage in terms of flexibility, deposition rates and suitability for mechanisation and has therefore substituted MMA in some applications. However, it should be noted that a high degree of manipulative skill is demanded of the welder (TWI, n.y.).

Informal estimates indicate that the use of this welding technique has become more widespread during the past decade (growth of 3-20% per decade). Informal expert judgements estimate the use of GMAW at appr. 42, 60 and 17% out of all welding processes for Romania, Poland and France for the period 2001-2010, respectively. Possibly 5-60% of all MIG/MAG welding is done on stainless steel (informal estimates for Romania and France for the period 2001-2010, respectively) (DGUV, 2017, pers. communication).

Tungsten Inert Gas Welding (TIG)

TIG welding is an arc welding process used on metals such as aluminium, magnesium, mild steel, stainless steel, brass, silver and copper-nickel alloys. This technique uses a non-consumable tungsten electrode. The filler metal is fed manually and the shielding gas is supplied externally. TIG produces very little fumes. The shielding gas consists of an inert gas (such as argon or helium), which can create an oxygen-deficient atmosphere. Therefore, even when working with chromium containing base metal and consumable, Cr(VI) compounds are not accounted as key components in the welding fume (HVBG, 2006).

According to communication with the industry and welding associations, the use of TIG welding has been quite stable over the last decades. Informal expert judgements estimate the use of TIG at appr. 6, 10 and 14% out of all welding processes for Romania, Poland and France for the period 2001-2010, respectively. TIG welding on stainless steel is estimated to make up at least 50% of TIG welding with all materials (DGUV, 2017, pers. communication).

Laser welding

The use of lasers in welding and allied processes represents a relatively new and complex process. The high energy of the laser source causes evaporation from the parent metal.

Among the laser welding techniques, CO_2-laser and Nd:YAG laser are available. The processes are always automated.

The amounts of total dust emissions formed during CO_2-laser welding <u>without</u> filler metal are comparable to those formed during metal active gas welding (appr. 1.2 to 2 mg/s of total dust for chromium nickel steels).

Emissions rates of total dust are generally lower at optimum (welding) parameters when using Nd:YAG-Lasers than when using CO_2-lasers (appr. 1.5 mg/s for total dust for chromium nickel steels; VMBG, 2007).

Laser cladding (also called hardfacing) is a form of laser welding <u>with</u> filler metal, where the filler metal in the form of wire or powder is welded on the surface of a given component to improve surface properties (*e.g.* anticorrosion). Mainly particulate hazardous substances (fume) are generated. If the filler metal is added in the form of powder, partially inhalable but non-respirable particulate substances are produced besides the fume. Laser welding may be used for chromium-nickel steel and iron-based alloys. In laser welding with iron alloys containing a high level of chromium, iron oxide is considered the key component in the welding fume, while chromium is mainly present in the metallic or trivalent oxide form. Measured Cr(VI) compound levels have been reported to account for 5% of total chromium (VMBG, 2007).

According to communication with the industry and welding associations, the use of laser welding has become more popular and is thus increasing. Informal expert judgements estimate the use of laser welding at appr. 1%, 3% and 34% out of all welding processes for Romania, Poland and France for the period 2001-2010, respectively. Laser welding on stainless steel is estimated to make up appr. 5-10% of laser welding with all materials (informal estimates for Romania and France for the period 2001-2010, respectively) (DGUV, 2017, pers. communication).

Other welding processes

Oxy-fuel welding is also described as oxyacetylene welding, oxy welding, or gas welding. The welding is done by use of a torch fed by a combination of acetylene (or another fuel) and oxygen and an additional filler metal (depending on the steel to be welded). Oxy-fuel welding is mainly used for unalloyed and low-alloy steel, where emission of nitrous gases (nitrogen oxides) is the principal concern (VMBG, 2007). The process is therefore less relevant with respect to Cr(VI) exposure.

Plasma arc welding (PAW) is very similar to TIG as the arc is formed between a pointed tungsten electrode and the workpiece. However, plasma welding can be seen as advancement from TIG due to deeper penetration and high welding speeds. It can be applied on many metals, also stainless steel (TWI, n.y.).

Submerged arc welding (SAW) involves formation of an arc between a continuously-fed bare wire electrode and the workpiece. The process uses a flux to generate protective gases and slag, and to add alloying elements to the weld pool. Prior to welding, a thin layer of flux powder is placed on the workpiece surface. Hence, the arc is completely covered by the flux layer, preventing heat loss, visible arc light, and fume emission. Most commonly welded materials are carbon-manganese steels, low alloy steels and stainless steels (TWI, n.y.).

Electric resistance welding or spot welding is a process where the metal pieces are connected to electrodes and in which the heat obtained from the resistance to the electric current when joining is used. Resistance spot welding is used extensively in the automotive industry to produce lap type joints in a range of components. Emissions of Cr(VI) are not a major issue (TWI, n.y.).

Hybrid welding designates a novel technique where two welding processes are combined in one automated operation in order to improve mechanical weld parameters and increase welding speed. The best known hybrid processes are:

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

These techniques may save consumption of filler material due to better penetration and thus reduce exposures (Force, 2017). However, as during the above processes the melting capacity and the feed rate are much higher than for the individual processes, higher emissions rates of hazardous substances may also be expected.

3.3.3 Thermal cutting

Thermal cutting processes are similar to welding in principle, however, the parameters governing fume and Cr(VI) emissions differ from welding. In most welding techniques, the majority of fumes come from the vaporization of the consumables (wires/electrodes). In cutting processes, no consumables are used, therefore emissions, come from the base metal.

Summary of relevant thermal cutting processes

Of the thermal cutting processes reviewed, plasma and laser cutting of chromium-nickel steels are the most relevant processes with respect to Cr(VI) exposure.

Table 3-4: List of thermal cutting processes with Cr(VI) (modified after VMBG, 2007)		
Process	**Parent metal**	**fume/key components**
Plasma cutting, Laser cutting	unalloyed, low-alloy steel (alloy components < 5%)	welding fume nitrogen dioxide

Table 3-4: List of thermal cutting processes with Cr(VI) (modified after VMBG, 2007)

Process	Parent metal	fume/key components
	chromium-nickel steel (≤ 20% Cr und ≤ 30% Ni)	nickel oxide, **(Cr(VI) compounds)** *
	nickel, nickel compounds (> 30% Ni)	nickel oxide
	aluminium-base materials	welding fume ozone

* Cr(VI) compounds mentioned as a main component, but not as a key component

Plasma cutting

Plasma is an ionized gas that conducts electricity, and it is created by adding energy to an electrically neutral gas. The energy is electricity and the gas is typically compressed air. The plasma arc moves across the workpiece surface and produces cuts in a short time (Figure 3-3).

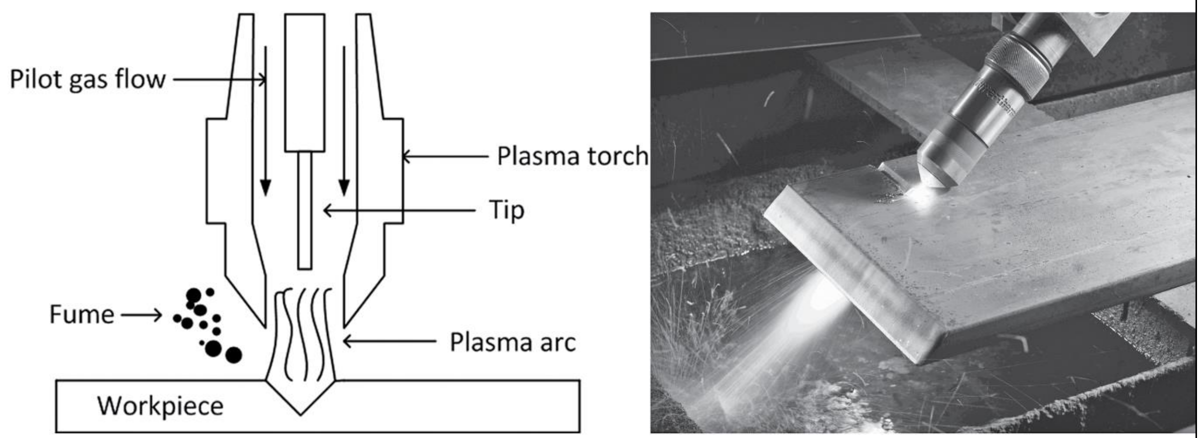

Figure 3-3: The structure of plasma cutting torch in schematic and real-world images (from Wang *et al.*, 2017).

Compared with other thermal or non-thermal cutting processes (*e.g.* oxyfuel, laser and water jet cutting) plasma cutting is considered more versatile with higher penetration ability, less energy consumed and low consumable cost. Moreover, it is highly mobile to perform work on different locations. Many plasma cutting applications are performed on thick mild steel or stainless steel plates, where the capability of conventional cutting techniques is limited (Wang *et al*., 2017).

The hazardous substances emitted mainly depend on the parent metal being cut (*i.e.* on its chemical composition) and on the cutting parameters such as arc current and cutting speed (*i.e.* lower cutting speed lowers emissions) (Wang *et al*., 2017; VMBG, 2007). Wang *et al*. (2017) states that the oxidation reactions in the plasma cutting arc zone are not oxygen restricted, since there is no shielding barrier (shielding gas) to prevent oxygen entry as is the case in MIG/MAG welding. Therefore, a potentially higher fraction of chromium present in the base material can oxidise to Cr(VI).

In plasma cutting of chromium-nickel steel, nickel oxide is generated as a key component. In addition Cr(VI) compounds are generated as another main component (VMBG, 2007).

Laser cutting

Laser cutting comprises a complexity of processes and equipment, and the generation of hazardous substances in laser cutting is determined by many characteristics, such as thickness of the workpiece, the lens focal length, the cutting gas pressure, the laser beam power, and the cutting speed. On the whole, laser cutting produces relatively large amounts of dust, which are, however, smaller than in oxy-fuel or plasma cutting (VMBG, 2007).

As for laser welding, the different laser techniques (CO_2 laser, Nd:YAG laser) are available for cutting chromium nickel steels.

Oxy-fuel cutting

The process is also described as oxyacetylene cutting, flame cutting or torch cutting.

The base metal is cut by use of a torch fed by a combination of acetylene (or another fuel) and pure oxygen. The process produces high fume emissions as a function of different parameters, such as sheet thickness, fuel gas, cutting gas pressure and cutting speed.

Oxy-fuel torches are normally only used for cutting low alloyed steels, as oxidation of the steel is a principle reaction in the cutting process. Since stainless steels is not prone to oxidation, this process is less relevant with respect to Cr(VI) exposure (VMBG, 2007).

3.3.4 Thermal spraying

Thermal spraying is a coating process that consists of a heat source (flame or other) and a coating material in a powder or wire form, which is literally melted into tiny droplets and sprayed onto surfaces at high velocity. Thermal spraying is thus a surface treatment process that is either used to provide the component surface with certain properties or in repair of components.

Thermal spraying produces large amounts of particulate hazardous substances, depending on the process used, see descriptions below. Emissions of hazardous substances are significantly lower in flame spraying than in arc spraying. Plasma spraying produces the largest emissions of hazardous substances compared to flame or arc spraying (VMBG, 2017).

The hazardous substances generated depend on the material and are exclusively emitted from the spraying material. The parent metal has no influence on the amount and the composition of the hazardous substances produced.

The list of thermal spray methods in the following sections is not exhaustive, but comprises the methods described by the German association of metal professionals' associations related to emission of hazardous compounds (VMBG, 2007).

According to communication with the industry, there is a growing number of applications and a growing demand of thermal spraying. For the purpose of the cancer incidence calculations, it is anticipated that workforce will increase with 0.5% p.a.

Summary of relevant thermal spraying processes

Table 3-5: List of thermal spraying processes with Cr(VI) (modified after VMBG, 2007)		
Process	**Spaying material**	**fume/key components**
Flame spraying	unalloyed, low-alloy steel	Respirable and inhalable dust, nitrogen dioxide
	chromium-nickel steel (≤ 27% Cr und ≤ 22% Ni)	nickel oxide, nitrogen dioxide **(Cr(VI) compounds)***
	nickel and nickel alloys (> 60% Ni)	nickel oxide, nitrogen dioxide
	aluminium-base materials3)	nitrogen dioxide
	lead alloys	lead alloys, nitrogen dioxide
	copper and copper alloys	copper oxide, nitrogen dioxide
	other non-ferrous metals and alloys	Respirable and inhalable dust, nitrogen dioxide
Arc spraying	unalloyed, low-alloy steel (alloying components < 5%)	Respirable and inhalable dust,
	chromium-nickel steel (≤ 27% Cr and ≤ 22% Ni)	nickel oxide **(Cr(VI) compounds)***
	nickel und nickel alloys (> 60% Ni)	nickel oxide
	aluminium-base materials3)	Respirable and inhalable dust
	copper and copper alloys	copper oxide
	other non-ferrous metals and alloys	Respirable and inhalable dust,
Plasma spraying	copper aluminium and copper tin alloys	copper oxide
	chromium-nickel steel (≤ 27% Cr and ≤ 22% Ni)	nickel oxide ozone **(Cr(VI) compounds)***
	nickel und nickel alloys (> 60% Ni)	nickel oxide
	cobalt base alloys (> 50% Co)	cobalt oxide
* Cr(VI) compounds not mentioned as the key component, but the generation of a mixture of Cr(VI) is assumed (VMBG 2017).		

Plasma spraying

Plasma spraying produces higher emissions of hazardous substances than flame or arc spraying with the same spraying materials, due to the use of a much higher spraying rate. Most of the plasma spraying processes are therefore carried out in enclosed systems (encapsulated systems). Nevertheless, there is still a health risk for the operator for the few manual spraying processes, if the high hazardous substance concentrations are not exhausted at source.

Arc spraying

VMBG (2007) states that arc spraying produces large emissions of particulate substances. During arc spraying with chromium-nickel or nickel-base spraying materials, nickel oxide is to be considered as key component. The diameter of particles is usually smaller in arc spraying than in flame spraying, resulting in a larger respirable fraction (VMBG, 2007). No statements regarding Cr(VI) are made.

Flame spraying

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

In flame spraying, as in other oxy-fuel processes, generation of nitrous gases should be taken into account. During flame spraying with high-alloy spraying material (*e.g.* chromium < 27%, Ni < 22%) high levels of dust emissions include also high proportions of nickel oxide. Cr(VI) compounds may be generated, assumedly a mixture of different chromium oxides is produced.

3.3.5 Summary of relevant processes

Based on a large number of measurements carried out within the framework of a measuring program by the German Association of metal professionals' associations, the association VMBG (2007) concludes that the limit values for Cr(VI) compounds of 0.1 mg/m³ for MMA and 0.05 mg/m³ for all other processes (indicative values with respect to the state of the art, Dec. 2004) are often exceeded when no or insufficient ventilation measures are used for works with chromium steels and chromium nickel steels (Table 3-6).

The data indicate that the compliance with the established and future OELVs of 0.025 and 0.005 mg/m³ (25 and 5 µg/m³), respectively, may be especially challenging in MMA, MAG/FCAW, plasma and laser welding, and thermal spraying, and requires good ventilation or other RMM. Exceedance of the OELVs cannot be excluded for the other processes either.

Table 3-6: Exposure to Cr(VI) compounds for chromium and chromium-nickel steels in processes without or with insufficient extraction (VMBG, 2007)

Process	No. of personal samples	No. of stationary samples *n*	> indicative OEL *	< indicative OEL *
Manual metal arc welding with covered electrode	186	41	always	-
MAG welding with solid wire	544	110	-	often
MAG welding with flux-cored wire			often	-
MIG welding	176	52	-	-
TIG welding	149	35	-	always
Plasma cutting	18	13	often	-
Laser cutting			often	-
Flame cutting			-	-
Thermal spraying	1	0	often	-
* Indicative OEL for Cr(VI) of 0,05 mg/m³ for all processes, except MMA: indicative OEL of 0,1 mg/m³ for MMA				

3.3.6 Relevant sectors

European and national associations (EWA, EWF, DVS, TWI, GTS, TSSEA), as well as ventilation companies, have been consulted about the sectors application areas of stainless steel welding, cutting and spraying. For more details on the stakeholder consultation, please see Annex 1.

Containers, tubes, pipes and other components of stainless steel are high-value products, which are used in all industry applications with high requirements towards corrosivity, precision, material fatigue and cleanability of the components.

Welding, cutting and thermal spraying of stainless steel is mainly relevant for manufacture and repair of components for the following industrial sectors:

- Chemical equipment (reactors, heat exchangers, storage tanks, food industry)
- Furniture (tables, cabinets, kitchen equipment)
- Oil and gas transportation systems
- Shipbuilding and off-shore
- Handling of minerals (hardfacing)
- Aviation
- Automobile
- Wind energy
- Military equipment

Thermal spraying with Cr-containing coatings may be applied on components with requirements towards high temperature corrosion, thermal insulation and wear, *e.g.* turbine blade, hydraulic cylinders and shaft sleeves. Such components are primarily used in the following sectors (Mathesius and Krömmer 2014):

- Aviation
- Chemical installation engineering
- Electricity generation
- Mining
- Printing industry
- Pumps
- Textile industry

Fume emitting metal works with stainless steels are thus found in a wide range of industries and therefore cannot be demarcated to a specific number of applications and/or sectors.

3.3.7 Cr(VI) compounds in fumes from welding, plasma cutting and similar processes

Most of the fumes generated during welding originate from the welding consumable, which therefore is the primary source of hexavalent chromium in welding fume. Chromium may occur as Cr(III) and Cr(VI) in the fumes.

The analytical methods used to determine Cr(VI) concentrations in workplace air quantify the presence of the Cr(VI) ion and not the specific compounds. Some methods differentiate between Cr(VI) in water soluble (*e.g.* potassium chromate) and insoluble/ poorly soluble compounds (*e.g.* lead chromate). Therefore, limited knowledge about the compounds is available. Knowledge about the presence of other elements in the consumables and base metal, knowledge about the stability of Cr(VI) compounds at high temperatures and some experimental data allow for conclusions about the presence of certain compounds (Floros, 2017, pers. communication).

The Cr(VI) compounds mainly occur as chromates, generated during MMA welding with basic covered electrodes or flux-cored wires that contain Na and/or K. The chromates or dichromates that can be observed are Na_2CrO_4, K_2CrO_4, $K_2Cr_2O_7$, $K_3Na(CrO_4)_2$, $K_3Na(Cr_2O_7)_2$.

Cr(VI) compounds are also formed during welding of formerly common primer coatings containing zinc chromate (DGUV, 2008). Chromium compounds and metallic chromium are also used as corrosion inhibitors for metal alloys, as primers and top coats in aerospace applications as well as pigments in paints. Welding works with chromium-treated materials have the potential to form Cr(VI) containing fumes (DGUV, 2008). However, it is regarded as exceeding the scope of this study to investigate this potential exposure source further.

In welding, fumes from other processes with high-alloyed steels, *e.g.* MIG/MAG, Cr(VI) concentrations are also reported. This may be surprising because the consumables used in MIG/MAG welding do not contain alkali metals in significant amounts to stabilise Cr(VI) in alkaline chromates. Until now, there is no experimental evidence explaining the presence of Cr(VI) in fumes from welding where no alkaline cations are present. However, based on stability considerations, relevant candidates that could explain Cr(VI) presence could be nickel or manganese, supporting the formation of $NiCrO_4$ and $MnCrO_4$, respectively. Another possible explanation is that some of the Cr(III) is converted to Cr(VI) during sample preparation (see section 3.9 Standard monitoring methods/tools; Floros, 2017; DGUV, 2017, pers. communication).

Several reports mention the presence of chromium trioxide, CrO_3, in the fumes, *e.g.* BGHM (2013). CrO_3 decomposes at appr. 200 °C into Cr_2O_3 and O_2, which is why it is not likely to form during welding and related processes at much more elevated temperatures (Floros, 2017a; DGUV, 2017, pers. communication). A possible explanation why CrO_3 is reported to be present in the fumes, may be from a misunderstanding of earlier (German) reports, where Cr(VI) concentrations commonly were recalculated and reported as CrO_3 concentrations in order to allow comparison with the an OEL that was defined for CrO_3 (*e.g.* IFA, 2012; Emmerling *et al.*, 1989; Angerer *et al.*, 1987).

Table 3-7 lists the known/most common Cr(VI) compounds but may not be exhaustive for possible Cr(VI) compounds in fumes from welding and related processes.

Table 3-7: Cr(VI) compounds in fumes from welding, plasma cutting and similar thermal processes

Compound	Formula	CAS No.*	Classification Carc./Muta.
Sodium chromate	Na_2CrO_4	7775-11-3	CLH Carc. 1B, Muta. 1B
Sodium dichromate	$Na_2Cr_2O_7$	7789-12-0, 10588-01-9	CLH Carc. 1B, Muta. 1B
Potassium chromate	K_2CrO_4	7789-00-6	CLH Carc. 1B, Muta. 1B
Potassium dichromate	$K_2Cr_2O_7$	7778-50-9	CLH Carc. 1B, Muta. 1B
Tripotassium sodium dichromate	$K_3Na(CrO_4)_2$	-	-
Tripotassium sodium di-dichromate	$K_3Na(Cr_2O_7)_2$	-	-
Calcium chromate	$CaCrO_4$	13765-19-0	CLH Carc. 1B
Zinc chromate	$ZnCrO_4$	13530-65-9	CLH Carc. 1A
Zinc chromates incl. zinc potassium chromate	-	-	CLH Carc. 1A
Nickel chromate	$NiCrO_4$	14721-18-7	CLH Carc. 1A
Manganese chromate	$MnCrO_4$	-	-
Lead chromate	$PbCrO_4$	7758-97-6	CLH Carc. 1B

* Chemical Abstract Service number used for identifying chemicals.

According to the Classification, Labelling and Packaging regulation (CLP), all Cr(VI) compounds have a CLH Carc., 1A or 1B with the exception of zinc chromate, which has a notified classification of Carc. 1A. Chromium trioxide and most of the chromate are also classified as Muta 1B.

3.4 Exposed workforce

In order to derive estimates on the number of welders, thermal cutters and sprayers exposed to Cr(VI) in fumes from thermal metal works, firstly the total number of workers in these processes (section 3.4.1) and secondly the number of workers working with stainless steels is investigated (section 3.4.2).

3.4.1 Number of workers exposed to fumes in welding, plasma cutting and similar processes

The German Welding institute (DVS) made an investigation of the number of welders in Europe by conducting a survey with 19 welding technology societies and institutes in Europe (DVS, 2009). In the survey, the DVS points out that welding activities are carried out by various groups of people. There are employees performing welding as a full-time activity specifying welding as their occupational profile. These may be "qualified" welders (certified through *e.g.* the national welding institutes), who prove their ability regularly (as a rule, every two years) in recurring qualification tests. There are also full-time welders, who are not certified. Moreover, there are employees in manufacturing companies, who carry out welding work occasionally in addition to their main activity, for example, as a fitter or a mechanic. These "occasional welders" can be qualified through recurring qualification test or not.

For the survey, numbers of qualified welders were easily obtained from most welding institutes. The number of non-certified welders was accounted for. The number of occasional welders was recalculated as full-time welders (method for calculation not further specified in the publication). Furthermore, the survey collected or estimated specific figures for further welding professionals, such as welding supervisors, welding designers or robot operators (DVS, 2009).

The DVS (2009) estimated a total of **841,635 full-time welders for 19 countries in the EU** in 2007 (welding of all types of steel) (Table 3-8).

In 2013, the DVS published a study on the value created by the joining and cutting sector (DVS, 2013). The figures for number of welders in this publication were a little lower, accounting for **156,000 and 647,000 full-time welders in Germany and the EU27**, respectively.

According to TWI (The Welding Institute), the official number of welders in the UK in 2017 was 73,000. However, the TWI also suggests that the number of qualified (code) welders is close to 50,000, while accounting for non-qualified welders as well, the figure is estimated by expert judgement at **up to 100,000 welders in the UK** (TWI, 2017, pers. communication). These estimates exemplify the uncertainty related to the estimates of numbers of workers obtained.

The vast majority of welding companies are small or medium-sized enterprises (SMEs; DVS, 2017, pers. communication; HSE, 2010).

The data provided by DVS (2009) appears to be the most comprehensive and unambiguous, why it is used for the estimation of exposed workers. Comparing the number of welders with the populations of the reported countries, the fraction of the population working as welders is on average 0.21%, ranging from 0.09 to 0.43% for France and Croatia, respectively. Using the average fraction of welders in the population and an EU population of 510.5 Mio., the **number of welders (fte) in the EU28 can be estimated at appr. 1 Mio** (Table 3-8).

The number of thermal cutters cannot be estimated based on consumables consumption, as no consumables are applied in the process. Based on currently available knowledge, the number of thermal cutters working with stainless steels is lower than the number of welders. Only very limited quantitative information has been obtained on the number of thermal cutters during consultation and literature search. Generally spoken, thermal cutting activities occur in two types of companies; Specialised cutting companies, who as sub supplier’s process metal sheets for manufacturers of metal components and other industrial clients. These companies often offer a range of different cutting and possibly other related sheet processing techniques. The other type of company are metal component manufacturers, who may work with only one or a few cutting processes adapted to their production. Workers in this type of companies will often also have other jobs than cutting, *e.g.* welding. As for welding, the cutting of stainless and mild steel types is usually sharply separated, *e.g.* by separate workrooms.

Informal estimates account for 3000-4000 cutting companies (all steels, both thermal and non-thermal processes) in Germany with typically 25-50 employees (but ranging between 5-250 employees), thereof 20-25% cutting operators.

Estimates on thermal spraying have been obtained for Germany and Denmark only.

The German thermal spraying association (GTS) estimates that in Germany there are about 400 companies and about 200 in-house companies working with thermal spraying with about 5,000 – 6,000 workers employed in total. Most of these companies are SMEs (possibly 90-95%). About half of the workers can be anticipated working with operations involving stainless steel works (GTS, 2017, pers. communication). Furthermore, in the majority of companies, the spraying processes are automated, leading to lower exposure concentrations for the operators than manual thermal spraying.

In Denmark there are about 10-20 companies, accounting for about appr. 300 workers working with thermal spraying (not full-time).

In Europe, the majority of thermal spraying companies is found in Germany, United Kingdom and France. Surface treatment by thermal spraying is the final step in the production of workpieces and the end users (*e.g.* automotive industry, paper industry, aerospace industry) prefer to be in the vicinity of the surfacing works (GTS, 2017, pers. communication). Based on linear extrapolation of the figures and population sizes from Denmark and Germany, there may be **about 30,000 thermal sprayers in EU28**. The figure is most likely too large, as thermal spraying may be less common in many of the MS compared to Germany and/or Denmark.

Table 3-8: Number of workers exposed to fumes from welding and thermal spraying.

Country	Welding[1]	Thermal spraying[2]
Austria	14,954	
Belgium	28,000	
Bulgaria	13,313	
Croatia	18,020	
Cyprus	-	
Czech Republic	-	
Denmark	8,000	300

Table 3-8: Number of workers exposed to fumes from welding and thermal spraying.		
Country	**Welding[1]**	**Thermal spraying[2]**
Estonia	-	
Finland	9,666	
France	60,000	
Germany	168,000	5,000 – 6,000
Greece	-	
Hungary	-	
Ireland	-	
Italy	150,000	
Latvia	-	
Lithuania	-	
Luxembourg	-	
Malta	-	
Netherlands	30,273	
(Norway)	8,389	
Poland	75,000	
Portugal	15,000	
Romania	37,600	
Slovakia	19,700	
Slovenia	-	
Spain	73,860	
Sweden	25,000	
(Switzerland)	13,860	
U.K.	73,000	
Estimate EU28	**1,048,210**	**30,000**

[1] Figures for the single countries from DVS (2009). For derivation of EU28 estimate, see text.
[2] See text for derivation of estimate.

3.4.2 Number of workers exposed to Cr(VI) in fumes from in welding, plasma cutting and similar processes

Only a certain proportion of workers in welding, plasma cutting and similar processes will be exposed to Cr(VI), notably workers working with high-alloyed and stainless steels.

Only limited information on numbers of stainless steel welders has been obtained by national associations. The Latvian Association of Mechanical Engineering and Metalworking Industries notes that difficulties with estimating the number of stainless steel workers are also related to the fact that many companies work as subcontractors for *e.g.* the automotive industry, and do not regularly work on contracts involving stainless steel works (Association of Mechanical Engineering and Metalworking Industries, 2017, pers. communication). The Greek Welding institute estimates that there are 200 welders working with stainless steel in Greece (Welding Greek Institute, 2017, pers. communication).

The European Welding Association has been consulted with respect to estimation on numbers of workers exposed due to stainless steel metal works. Statistical data on sales of stainless steel welding consumables are registered by the European Welding Association (EWA, 2017, pers. communication).

Under consideration of the consumables used for the different welding processes, consumable consumption and welding duty cycles, estimates were derived for the single welding processes. The number of welders based on consumable sales in 2016 is **appr. 31,000 stainless steel welders (fte) for EU28** (Table 3-9).

A total of 31,000 stainless steels welders corresponds to 3.0 to 4.8% of the total number of welders in Europe, using the estimates of 1,050,000 and 647,000 from derived DVS (2009, 2013), respectively. EWA recognises these figures as realistic, but notes that more workers will be exposed than the calculated 31,000 due to the fact that not all welders are working full-time as welders (EWA, 2017, pers. communication). According to communication with the DVS and the German Welding Electrode Association, the fraction of stainless steel welders compared to total welders appears to be somehow low, even when accounting for that stainless steel welding maybe more common in some of the older MS such as Germany, Italy and France compared to some of the newer MS such as Croatia and Romania. The Welding Electrode Association in Germany estimates the consumption fraction of electrodes for high-alloyed steel (containing > 5% Cr) at 10-15% (Welding Electrode Association, 2017, pers. communication), but highlights, that this fraction cannot be translated directly into the fraction of stainless steel welders. It has not been possible to receive other/more updated figures from other sources within the timeframe.

Assuming that the fraction of stainless steel workers from welding also applies to cutting, the fraction of stainless welders of total welders and the fraction of German welders of European welders has been used to derive an estimate for EU28. Thus, the **number of workers in thermal stainless steel cutting is estimated to be in the range of 2,800 – 7,400, averaging 5,100 workers in EU28**.

With respect to thermal spraying, according to communication with the German GTS association, it is estimated that 50% of the thermal sprayers work with Cr-containing consumables, resulting in **15,000 thermal sprayers potentially exposed to the Cr(VI) in Europe**.

Table 3-9: Number of workers in stainless steel works (EWA, 2017, pers. communication). See text for derivation of estimates.

Process	Subprocess	Workers
Stainless steel welders (EWA, 2017, pers. communication)	SMAW/MMA	8,000
	GMAW[1]	13,000
	FCAW[1]	4,000
	TIG	5,000
	SAW[2]	1,000
	Total	**31,000**
Stainless steel thermal cutters		**5,100**
Stainless steel thermal sprayers		**15,000**

[1] GMAW and FCAW includes a substantial percentage of automated welding stations with a limited fume exposure for the welder [2] With SAW there is no exposure to welding fumes

The figures of 31,000 welders, 5,100 thermal cutters and 15,000 thermal sprayers thus constitute the exposed workforce subject to the calculation of the current and future burden of cancer cases (section 3.13). The numbers of workers will be distributed on the single MS by using the proportional share of the welder distribution by country as reported by DVS (2009). For the MS, where DVS (2009) does not provide an estimate on the number of welders, the population share of the MS will be used.

3.5 Exposure concentrations

3.5.1 Stakeholder consultations and site visits

Very limited data on exposure concentrations of Cr(VI) have been received from the company consultations by questionnaires, interviews or site visits. According to communication with the industry, exposure concentrations of Cr(VI) are not measured on a regular basis since the national or regional responsible authorities do not control compliance with the national OEL. Therefore, companies do generally not know the Cr(VI) exposure levels in their facility. A few companies consulted within this assessment were not even aware of the potential presence of Cr(VI) in fumes from hot works on stainless steel.

Commonly, the national or regional WEAs control emissions from welding and similar processes visually and/or olfactory, and by inspecting the ventilation system. In some cases, measurements of fume concentrations may be taken and several companies stated that they had data on fume particle concentrations. In special cases, the samples may be taken for the respirable and inhalable fume fraction, as well as analysed for elemental composition (total Cr).

A single medium-sized company working with welding, plasma and laser cutting in production of stainless steel parts in Finland reported compliance with the national OEL, as the highest out of 8 measured values was 10% of the national OEL of 5 µg/m³.

A few more medium-sized companies reported exposure concentrations in the questionnaire, but did not specify the substance (Cr(VI), Cr(total, or fume particles) nor the number of samples, process nor method of derivation. The information is therefore not used in the current assessment.

Several stakeholders (from Denmark, Finland and Germany) reported, that measured workplace concentrations were considered to be in compliance with the national OEL when being at maximum 10% of the OEL.

The site visits and the stakeholder consultation indicate that there are large differences in exposure potentials between companies and that the differences can be related to the origin of company/type of production rather than to a geographical region. As an example, two manufacturers were visited on the Iberian Peninsula. The manufacturers did not have measured data on exposure concentrations of Cr(VI), and the exposures could therefore not be compared with an OEL(V). However, the manufacturers exhibited large differences in the occupational environment. Apart from considerable differences in the workers ear and eye protection, different exposure situations to fumes (and thus also to Cr(VI)) could be identified through diverging availability of local exhaust ventilation (LEV), the use of available LEV, the dustiness and cleanliness of the workroom, as well as the segregation of working processes. In the company with "advanced" RMM, the characteristic smell of hot metal works could hardly be detected, even though the production was running on 3 shifts/day, which demonstrates a very efficient application of extraction systems. The company was using LEV from stationary and mobile filter units, no general room ventilation and had several cutting/welding machines with partial of complete enclosure of the process.

The company with the "less advanced" RMM had a few mobile filter units available.

Further company characteristics, which influence the exposure potential, are:

- thickness of materials – thicker steel sheets require more energy for welding or cutting and result in higher emissions
- type of production – in standardized mass production it is easier to install and maintain LEV and/or automated solution, than in manufacture of specialty components or in repair

Exposure concentrations of Cr(VI) are available in the literature. These data are commonly compiled by national bodies concerned with occupational health such as the British Health Safety Executive or the German Employers' Liability Insurance Associations and/or have been measured within scientific studies. These data are presented in the following sections.

3.5.2 Exposure data on welding

German MEGA database 1994 - 2009

The exposure data from the MEGA database (database with measurement data relating to workplace exposure to hazardous substances) as analysed and published by Pesch *et al*. (2015) contains 3695 personal measurements of Cr(VI) in the inhalable fraction of particles in fumes from welding and other metal works from the period of 1994 - 2009. For the registration in the MEGA database, occupational settings with anticipated high Cr(VI) exposures were chosen. However, no detailed information is available on how the study population was selected. Therefore, the number of measurements in the single processes is not necessarily representative for the distribution of processes in the industry. The study by Pesch *et al*. (2015) does not provide details on use of LEV or other RMM.

The 3695 measurements, hereof 2048 for welders, cutters and thermal sprayers, have been collected on the same type of filter (quartz-fibre filters) analysed with the same method in a central laboratory to limit additional influences of the analytical procedure. Measurements compiled in the MEGA database were on average based on sampling for 2 hours.

Pesch *et al*. (2015) report the concentrations as median, imputed (modelled) median, P75, P90, and P95 values (Table 3-10).

Generally, about 2/3 of the measurements were below the limits of quantification (LOQ)[10], and measurements indicate low median concentrations, but comparatively high 95th percentiles. MMA and FCAW show the highest concentrations with median concentrations exceeding the recently adopted OELV of 5 µg/m³. For TIG and Laser welding, the majority of measurements were below the LOQ. However, a few measurements of TIG exceed the recently adopted OELV of 5 µg/m³.

Table 3-10: Distribution of personal measurements of hexavalent chromium in µg/m³ in the MEGA database, 1994-2009, by selected occupations with anticipated high exposure levels (Pesch *et al*., 2015)

Occupation	N	% <LOQ	Median (µg/m³)	Median with imputed data* (µg/m³)	P75 (µg/m³)	P90 (µg/m³)	P95 (µg/m³)
Welder, total	1898	61	<LOQ	2.84	6.76	28.08	67.60
GMAW	616	47	3.64	3.64	9.88	23.92	43.68
FCAW	25	44	5.72	5.72	41.60	57.20	62.40
TIG	581	88	<LOQ	0.20	<LOQ	5.20	6.76

[10] LOQs for the measurements in the MEGA database were reported in IFA (2012): The LOQs for the personal and stationary samples were 2.6 µg/m³ and 0.052 µg/m³, respectively.

Table 3-10: Distribution of personal measurements of hexavalent chromium in µg/m³ in the MEGA database, 1994-2009, by selected occupations with anticipated high exposure levels (Pesch *et al.*, 2015)							
Occupation	N	% <LOQ	Median (µg/m³)	Median with imputed data* (µg/m³)	P75 (µg/m³)	P90 (µg/m³)	P95 (µg/m³)
MMA	279	34	6.76	6.76	37.96	145.61	348.41
Laser welding	23	96	<LOQ	0.07	<LOQ	<LOQ	<LOQ
Others or not specified	374	64	<LOQ	1.37	7.80	36.92	79.04
* Median of the modelled data.							

The German institute for research and testing of the German Social Accident Insurance (IFA) regularly publishes data from the MEGA database. In 2012, exposure data for Cr(IV) for the period 2000 - 2009 were published for a wide range of sectors and working areas, amongst them welding, cutting and thermal spraying. For several welding processes, cutting and thermal spraying, the IFA (2012) lists the results differentiated for personal and stationary samples. The LOQs for the personal and stationary samples were 2.6 µg/m³ and 0.052 µg/m³, respectively. The large difference in LOQ is caused by the difference in sampled air volumes (0.42 m³ and 45 m³ for personal and stationary samples, respectively).

For MMA, the geometric mean of 76 personal measurements (6.3 µg/m³) exceeds the OELV of 5 µg/m³ with, while the geometric mean of the stationary measurements (3.8 µg/m³; n=23) does not. The 95th percentiles are exceeding the OELV of 5 µg/m³ in personal and stationary samples from all welding processes, except of samples from laser and TIG welding and stationary samples of MIG welding. The stationary measurements thus indicate that not only the welders, but also other persons working in the same workroom may be exposed to elevated concentrations. The data are not presented separately here, since they are partly contained in the data in Table 3-10 above as published by Pesch *et al*. (2015).

HSE survey in the UK (2010)

A survey of exposure to stainless steel welding fume conducted by the HSE (2010) identified 150 welding companies in the UK of which 52 welded stainless steel and were willing to contribute to the survey by telephone interviews about RMM, materials welded, number of workers and health surveillance. Eight companies were visited and concentrations of inhalable fume, Cr and Cr(VI) were measured from personal samples (Table 3-11). Several sites used more than one welding technique. Furthermore, existing exposure data collected in earlier reports in the U.K. was summarised and is also presented below.

Table 3-11: Exposure data from the sites visited; 8-hr TWA inhalation exposure range (µg/m³) (from HSE, 2010)					
Process	N	Concentration[1]	LEV/RPE[2]	Comment	Reference
MIG	5	n.d.	-	Site 1, visit in 1999	HSE, 2010[3]
MMA	5	n.d. - 210	-	Site 2, visit in 1998/9	HSE, 2010[3]
MMA	5	1 - 420	-	Site 3, visit in 1998/9	HSE, 2010[3]
MIG	9	n.d. - 40	-	-	HSE, 2010[3]
TIG	16	n.d.	-	-	HSE, 2010[3]
Other welding process	11	n.d. - 49	-	-	HSE, 2010[3]

Table 3-11: Exposure data from the sites visited; 8-hr TWA inhalation exposure range (µg/m³) (from HSE, 2010)					
Process	N	Concentration[1]	LEV/RPE[2]	Comment	Reference
85% MIG, 15% TIG	7	1.2 - 7.5	YES/YES	Site 1, visit Dec 2006	HSE, 2010
85% MIG, 15% TIG	8	<1 - 27	YES/YES	Site 1, visit Nov 2007	HSE, 2010
85% MIG, 15% TIG	8	<1 - 1.3	YES/YES	Site 1, visit Dec 2007	HSE, 2010
FCAW	8	<1 - 1.3	NO/YES	Site 2	HSE, 2010
TIG	8	<1	NO/NO	Site 3	HSE, 2010
90% TIG, 10% MMA	6	<1 - 2	NO/YES	Site 4, LEV for MMA but no LEV for TIG	HSE, 2010
85% TIG, 15% FCAW	8	2 - 5	NO/NO	Site 5, LEV for FCA, but none for TIG;	HSE, 2010
TIG	1	3	NO/NO	Site 5, RPE available, but not used	HSE, 2010
TIG	2	<2	YES/YES	Site 6, RPE used by one of two weld-ers	HSE, 2010
TIG	1	<2	YES/NO	Site 7, RPE available, but not used	HSE, 2010

[1] Not detected.
[2] LEV – locale exhaust ventilation, RPE – respiratory protection equipment, "-" – not reported
[3] Original data from an earlier survey from 2002 with partly the same sites.

MIG welding resulted in exposure concentrations from below limit of detection (LOD < 1 µg/m³) of up to 27 µg/m³ and can thus exceed the OELV of 5 µg/m³. Apparently, the company performing MIG welding (site 1) introduced TIG welding after the first measurements in 1999. However, there is not enough information available in order to make any conclusions about substitution of processes and exposure.

MMA welding showed the highest exposure concentrations from below LOD of up to 42 µg/m³ and can thus exceed the OELV of 5 µg/m³.

TIG welding showed the lowest exposure concentrations and did not exceed the OELV in any measurement.

In measurements at a company with 85% TIG welding and 15% FCAW, the OELV was reached.

Among the main findings of the survey were:

- 92% of these companies carried out TIG welding and at least 75% of the stainless welding carried out was TIG, which is less critical with regards to Cr(VI) exposure.
- 59% of the companies reported some use of MMA welding. MMA, where Cr(IV) is a key component of MMA welding fume, accounted for less than 15% of their total stainless welding.
- 90% of the companies reported some use of MIG welding, four of these companies said MIG represented more than 75% of the total stainless welding.
- 3 (8%) of the companies reported use of FCAW, only one company said it constituted more than 75% of their total stainless work. FCAW has the potential of emitting Cr(IV) compounds.

- The average number of employees potentially exposed to stainless steel welding fume was 6, range 1 – 25. These numbers confirm the widespread application of welding in SME.
- 48 companies responded regarding the use of LEV systems, and 33 (69%) reported to use LEV of some type.
- Breaches of occupational exposure limits were uncommon, even where exposure control strategies were judged to be inadequate.
- A significant proportion of companies were not controlling stainless welding fume exposures in accordance with COSHH[11] essentials welding guidance.
- A significant proportion of sites welding stainless steel have adequate exposure controls available, but for various reasons these controls are not used or are used incorrectly.

French survey on occupational exposures to Cr(VI)

Vincent *et al*. (2015) performed a survey on occupational exposure to Cr(VI) compounds in France for a wide range of sectors (sectors not reported here). Personal and stationary samples of the inhalable particle fraction were taken in the period of 2010-2013 over durations which could be less than the duration of a normal work shift. The technicians responsible for sampling were asked to evaluate whether the measurement was representative of actual worker exposure over a full working day and only measurements, which were considered representative, were used to describe exposure. No detailed information on whether the reported concentrations are from stationary or personal samples, from which welding technique, nor on the use on PPE are given. The results are presented in Table 3-12. Mean values are below the OELV of 5 µg/m³, but the upper limit of the geometric standard deviation is twenty times the OELV.

Table 3-12: Exposure levels of Cr(VI) welding from the period 2010 - 2013

Process	n	Arithm. mean (µg/m³)	Geom. mean (µg/m³)	GSD Range (µg/m³)	Reference
TIG, MAG, Arc welding	104	2.81	0.42	< 0.02-97.43	Vincent *et al.*, 2015

Comparison of several datasets by Meekers et al. (2010)

The goal of the study was to characterise breathing zone air concentrations of Cr(VI) during welding tasks and primary contributing factors by use of data from four datasets (US-OSHA, TWI, CPWR and CPWR(LEV))[12].

In the US-OSHA compliance dataset, 181 samples were analysed for Cr(VI) covering the years 2006-2008. Among these 181 samples, 66% of the samples were above the LOD (LOD concentration not reported). Only 8.8% of the samples exceeded the US-OSHA permissible exposure limit (PEL) of 5 µg/m³.

The TWI dataset consists of 124 samples. Approximately 13% of TWI samples exceeded the 5 µg/m³. The type of metal being welded and welding process were both significant factors.

[11] COSHH – Control of Substances Hazardous to Health from the British Health and Safety Executive.

[12] CPWR - The Center for Construction Research and Training (located in the United States of America).

Concentrations of Cr(VI) measured in the CPWR field surveys were considerably higher than those reported in the US-OSHA and TWI datasets. Approximately 25% of the samples exceeded the 5 μg/m³. The type of welding performed had a significant influence on Cr(VI) concentrations. Plasma arc welding (PAW) was associated with the highest single exposure level (21.9 μg/m³), and 2 of 20 MIG welding samples exceeded the PEL of 5 μg/m³.

The CPWR (LEV) dataset showed that LEV use reduced mean and median breathing zone Cr(VI) concentrations by 55% and 68%, respectively.

Table 3-13 provides a summary of the Meeker *et al*. (2010) analysis.

Table 3-13: Cr(VI) Exposure data (μg/m³) by task variables (Meeker *et al.*, 2010.)

Variable	N	Median [A]	P25 [A]	P75 [A]	Maximum	p-value
Material						<0.0001[B]
Stainless steel/Inconel	75	0.60	<LOD	4.0	426	
Low alloy steel/other materials	49	<LOD[A]	<LOD	0.6	2.20	
Process (SS/Inconel only)	75					<0.0001[D]
MMA[c]	30	5.00	1.80	18.0	107	
MIG	22	0.70	0.40	1.2	2.20	
TIG	21	<LOD	<LOD	<LOD	0.40	
PAW	1	426	-		426	
SAW	1	<LOD	-		-	
LEV (SS/Inconel only)	75					0.095[E]
No	69	0.70	<LOD	4.0	426	
Yes	6	0.13	<LOD	0.6	2.20	

A For samples<LOD, LODs ranged between 0.1 and 0.2 μg/m³ in TWI dataset.
B Wilcoxon rank-sum test.
C Also includes 10 shifts coded as a combination of both SMA and GMA welding.
D Kruskal-Wallis test comparing multiple groups. P < 0.0001 in a Wilcoxon rank-sum test comparing SMA welding with all other processes among stainless steel samples.
E P = 0.05 in a two-tailed Student's t-test using ln-transformed Cr(VI) concentrations.

Survey in the Netherlands by Scheepers et al. (2008)

Scheepers *et al*. (2008) investigated inhalation exposure to Cr and Cr(VI) by personal air sampling and biological monitoring in 53 welders from 13 industrial facilities working with mild steels, high-alloy and stainless steels in the Netherlands. The results were reported according to steel type, but not according to process (Table 3-14).

The determination of the air concentrations of total Cr in the welding helmets showed that the welders of stainless and high-alloyed steels as a group were four-fold higher exposed in the breathing zone than welders of mild steels (data not shown here). Median concentrations of Cr(VI) were highest in welding mild steel and comparatively high in high-alloyed steel (0.23 and 0.20 μg/m³), but still below the adopted OELV of 5 μg/m³. The highest upper range was reported for stainless steel welding.

The survey does not offer any discussion on the diverging results concerning total Cr and Cr(VI), even though it may be surprising that Cr(VI) median concentrations are lower in welding with stainless steel compared to mild steel. Possible explanations could be:

- processes used - the major parts of processes in stainless steel welding was TIG welding, with generally very low emissions of Cr(VI)
- possibly higher awareness of correct use and higher availability of efficient LEV in stainless steel welding
- analytical uncertainties

Table 3-14: Cr(VI) exposure concentrations (µg/m³) from processes with mild, high-alloyed and stainless steels

Activity	N	Steel type	Median	Range
MIG/MAG	4	Stainless	0.084	<0.02–19.0
FCAW	4			
MMA	2			
Gas welding, plasma cutting and laser cutting	3			
TIG	6			
MIG/MAG	6	High-alloyed	0.20	<0.02–0.35
MIG/MAG	7	Mild	0.23	<0.02–2.38
FCAW	7			
MMA	6			
Gas welding, plasma cutting and laser cutting	4			
TIG	4			

German survey of 210 workers, 1985 – 1988

The survey by Emmerling *et al*. (1989) investigated air concentrations of respirable dust, Cr, Cr(VI) and Ni (personal samples), as well as Cr and Ni in biological samples (blood and urine) of 210 stainless steel welders from 29 companies in the period from 1985 – 1988 in Germany. The results are presented in Table 3-15. Cr(VI) emissions were highest in MMA with covered electrodes, followed by MAG and TIG. The median levels of MMA and MAG, but not of TIG, exceeded the past national OEL of 5 µg/m³.

Table 3-15: Cr(VI) concentrations (µg/m³) from personal samples collected during 1985 – 1988 (recalculated from Emmerling *et al*. (1989), where concentrations were reported as CrO_3)

Process	n	Median	68% Range
MMA with coated electrodes	61	18.1	2.3 - 186.6
MAG	46	8.3	0.8 - 32.5
TIG	16	1.5	n.d. - 6.0

3.5.3 Exposure data on thermal cutting

Exposure data for thermal cutting are limited.

The IFA (2012) lists the data from the MEGA database for thermal cutting differentiated for personal and stationary samples, but contains no information on how the concentrations are distributed on the different cutting processes (plasma cutting, laser cutting, flame cutting). About 71% of the samples were below the LOQ[13]. Exposure concentrations for both the personal and the stationary samples are generally below the OELV of 5 µg/m³ with geometric means of 2.6 and 0.9 µg/m³, respectively. The stationary samples show considerably lower concentrations. However, the large standard deviations and the P95 for the personal samples show that the OELV is exceeded in some cases (Table 3-16). There is no information on whether the personal samples are taken from manual cutters or from operators of automated cutting.

The IFA (2012) also lists the results of the samples from thermal cutting differentiated according to presence of LEV (data not shown here, but in section 3.5.5). The arithmetic and geometric mean for samples with LEV were 5.1 and 1.3 µg/m³, respectively (n=83). The arithmetic and geometric mean for samples without LEV were about twice as high with 11.9 and 2.4 µg/m³, respectively (n=17).

Table 3-16: Exposure levels of Cr(VI) from cutting from the period 2000-2009, recalculated from Table 5.2, p. 16 in IFA, 2012

Process	Type of sample	n	n <LOQ*	Arithm. mean (µg/m³)	Std. dev.	Geom. mean (µg/m³)	P75 (µg/m³)	P90 (µg/m³)	P95 (µg/m³)	Reference
Cutting	Personal	79	71%	10.7	26.8	2.6	2.8	27.6	45.2	IFA, 2012
Cutting	Stationary	94	71%	2.1	6.2	0.9	1.3	1.8	3.8	IFA, 2012

* values < LOQ were included by calculating with ½ of the respective LOQ

Pesch *et al*. (2015) analysed the results of 115 personal measurements for cutters from the period 1994 – 2009 (Table 3-17). The percentile concentrations for this period are slightly higher than for the period 2000 – 2009 (shown in Table 3-16), indicating that concentrations may have been reduced over time.

Table 3-17: Distribution of personal measurements of hexavalent chromium in µg/m³ in the MEGA database, 1994-2009, by selected occupations with anticipated high exposure levels (Pesch *et al.*, 2015.)

Occupation	n	% <LOQ	Median (µg/m³)	Median with imputed data (µg/m³)*	P75 (µg/m³)	P90 (µg/m³)	P95 (µg/m³)
Cutter	115	60	<LOQ	1.53	9.36	32.24	67.60

* Median of the modelled data.

Wang *et al*. (2017) performed a study to evaluate the effects of operation parameters (arc current and arc time) on the fume formation rates, Cr(VI) and other oxides concentrations, particle size distributions, and particle morphology. Wang *et al*. (2017) do not report air concentrations, but report total fume and Cr(VI) emission rates. Generally, emission rates and oxidation increased with arc current. Cr(VI) emission rates averaged 220 ± 24 µg/min at 20 A arc current to 480 ± 50 µg/min at 50 A arc current. Cr(VI) emissions from the plasma cutting in the referred study were higher than Cr(VI) emissions from welding fume in a previous study conducted by Wang and co-workers with a comparable experimental setup. A high concentration of a fine fraction of particles with geometric mean sizes from 96 to 235 nm was observed, facilitating alveolar exposure to Cr(VI). Higher arc current yielded more particles, while lower arc current was not able to penetrate the metal plates. Workers should therefore optimise the arc current to balance cut performance and fume emission.

13 The LOQs for the personal and stationary samples were 2.6 µg/m³ and 0.052 µg/m³, respectively (recalculated from IFA, 2012).

Consultations with national experts confirm, that thermal cutting, especially plasma cutting, is a high-emission process, where emissions may not always be adequately controlled (Schneidforum, 2017; Floros, 2017, pers. communication). However, it has to be emphasized that high emissions do not equal high exposure concentrations since high-emission processes often are automated or encapsulated. Plasma cutting, high-definition plasma cutting, CO_2-laser cutting (older laser technique) and fibre laser cutting (more recent laser technique, after 2009) are the main techniques for thermal cutting of stainless steel. Flame cutting may only be used exceptionally on stainless steel, *e.g.* in construction. Plasma and laser cutting techniques for stainless steels are always automatized, meaning the operator programs and starts the cutting machine, whereafter the operator often will move away from the machine. In some situations, *e.g.* in short-time or difficult cutting operations, the welder may choose to stay at the machine. This behaviour was also observed during at site visit. According to an older study on emissions from cutting machines and spatial distribution of exposure concentrations referred to by an industry contact, the exposure concentrations are decreasing drastically with increased distance (few meters) to the source (Schneidforum, 2017, pers. communication).

For the calculation of cancer cases, it is therefore anticipated that 50% of the exposed thermal cutters will be exposed to concentrations corresponding to the personal measurements, while the other half will be exposed to concentrations corresponding to the stationary measurements.

3.5.4 Exposure data on thermal spraying

Exposure data for thermal sprayers are not abundantly available.

In 2014, two German research institutions, the Surface Engineering Institute and the Institute of Hygiene and Environmental Medicine in Aachen, jointly published a report on the development of a suitable measuring method for airborne substances in thermal spraying (IGF, 2014). Furthermore, the report contained an assessment of emissions of a system in operation and formed the basis for derivation of guidelines for safe operation of thermal spraying.

Plasma and arc spraying resulted in the highest emissions (Table 3-18), exceeding the OELV of 5 µg/m³ by a factor of up to several hundreds. Apart from consumables used, the emissions also depended on the cabin design, the measuring position, the extraction system, the powder/wire feed rate and the selected process parameters. The influence of the parameters is not further described in the report.

It has to be noted, that in the case of thermal spraying, the measured concentrations in the spray cabin do not represent the exposure concentrations as in most cases the worker will not be inside the cabin while the process is on-going. Only in certain cases, the process will be performed manually with the worker being located within the cabin. According to information from industry, PPE and LEV are always used in such cases.

Table 3-18: Measured concentrations in different thermal spraying processes (from IGF, 2014)

Process	Concentration of Cr(VI) (µg/m³)	Concentration of Cr(total) (µg/m³)	Spraying consumable	Feeding rate (g/min)	Extraction (m³/h)	Site of measurement
Arc spraying	223	387	NiCr 80/20	Not specified	Not specified	Experimental spray cabin
HVOF	n.d.	20	NiCr 80/20	Not specified	Not specified	Experimental spray cabin

Table 3-18: Measured concentrations in different thermal spraying processes (from IGF, 2014)						
Process	**Concentration of Cr(VI) (µg/m³)**	**Concentration of Cr(total) (µg/m³)**	**Spraying consumable**	**Feeding rate (g/min)**	**Extraction (m³/h)**	**Site of measurement**
HVOF	n.d.	n.d.	WC/Co	Not specified	Not specified	Experimental spray cabin
Plasma spraying	n.d.	n.d.	NiCr 80/20	Not specified	Not specified	Experimental spray cabin
Plasma spraying	7	15	Cr_2O_3	Not specified	Not specified	Experimental spray cabin
Plasma spraying	2,500	5,800	Cr_2O_3	30	9,300	Industrial spray cabin
Plasma spraying	300	400	Cr_2O_3	60	15,000	Industrial spray cabin
HVOF	400	33,300	CrC-NiCr**	80	15,000	Industrial spray cabin
Flame spraying	200	400	SF20**	70	8,000	Industrial spray cabin
Plasma spraying	600	4,500	NiCr 80/20	50	8,600	Industrial spray cabin
Plasma spraying	-	100	NiCr 75/25	60	15,000	Industrial spray cabin
HVOF	-	100	WC-CrCNi*	60	15,000	Industrial spray cabin
HVOF	600	4,000	WC-CoCr*	100	15,000	Industrial spray cabin
n.d.: not detected * Cr content not reported.						

In the report by IGF (2014), available studies on emissions to hazardous substances due to thermal spraying are summarised. The essential information with regard to Cr(VI) with reference to the original studies are given in Table 3-19.

Table 3-19: Summary of studies on Cr(VI) emissions from thermal spraying (from IGF, 2014)		
Study description	**Results**	**Original reference**
Personal and biological samples were taken from 34 workers in six companies during one working week including several methods of thermal spraying.	Levels of exposure to cobalt, chromium and nickel were highest in plasma sprayers and, on occasions exceeded UK OEL. Certain activities were identified as being particularly critical. These include manual or not fully automated spraying, where entering the spray cabin is required, the handling of the powder, and cleaning works inside the spray cabin. Exposure to metals during detonation gun and electric arc spraying was better controlled and levels remained below the relevant UK OELs throughout the study period. The measuring methodology of the investigations did not allow a distinction of the chromium species contained.	(Chadwick *et al.*, 1997)

Table 3-19: Summary of studies on Cr(VI) emissions from thermal spraying (from IGF, 2014)		
Study description	**Results**	**Original reference**
	The findings clearly indicate that exposure to and uptake of metals may exceed UK Occupational Limits or standards when spraying is performed manually or semi-automatically.	
Personal samples were taken in one company every day during one month and analysed for nine metals, amongst them Cr.	Considered limit values for dust particles and nickel were exceeded only in exceptional cases, related to maintenance, cleaning or open operation processes. Cr(VI) was not evaluated separately.	(Petsas *et al.*, 2007)
Investigation of emissions during HVOF spraying with WCCoCr (containing 4% Cr) powder as a spraying additive.	In stationary and personal measurements, the concentrations of Cr(VI) were below the detection limit and thus also below the considered limit values. Despite enhanced ventilation in the spray cabin, high dust concentrations were measured and during prolonged operation, dust accumulated on the floor. This reflects that the extraction system does not remove the particles efficiently.	(Legoux *et al.*, 2006)

Vincent *et al*. (2015) included a few samples of the inhalable fraction from 2 sites in the thermal spraying sector in their survey on occupational exposure to Cr(VI) compounds in France. The measurements were performed during 2010 – 2013 by personal or area sampling over durations which could be less than the duration of a normal work shift. The technicians responsible for sampling were asked to evaluate whether the measurement was representative of actual worker exposure over a full working day and only measurements, which were considered representative, were used to describe exposure. No detailed information on whether the reported concentrations are from stationary or personal samples, nor on the use on PPE are given. The results are presented in .

Table 3-20: Exposure levels of Cr(VI) in thermal spraying from the period 2010 - 2013.						
Process	**n**	**Arithm. mean (µg/m³)**	**Geom. mean (µg/m³)**	**GSD**	**Range (µg/m³)**	**Reference**
HVOF and arc plasma spray	8	7.01	5.27	2.28	1.82-15.34	Vincent *et al.*, 2015

IFA (2012) lists the results from the MEGA database for thermal spraying differentiated for personal and stationary samples, of which 36% and 44% were below the LOQ[14], respectively. Both the personal and the stationary samples appear to often exceed the OELV of 5 µg/m³ with geometric means of 28 and 1.3 µg/m³, and P75 of 161 and 5 µg/m³, respectively. Personal samples are considerably higher than stationary samples (Table 3-21). No data on whether the samples were taken inside or outside the spraying cabin, are given. The magnitude of the personal samples indicates measurements inside the spraying cabin, corresponding to manual spraying. Still, it is considered very likely that actual

[14] The LOQs for the personal and stationary samples were 2.6 µg/m³ and 0.052 µg/m³, respectively (recalculated from IFA, 2012).

exposure concentrations will be lower as the personal sampling do not seem to account for the use of PPE such as respiratory masks.

Table 3-21: Exposure levels of Cr(VI) in thermal spraying from the period 2000 - 2009*.											
Process	**Type of sample**	**n**	**n <LOQ**	**Arithm. mean (µg/m³)**	**Std. dev.**	**Geom. mean (µg/m³)**	**P50 (µg/m³)**	**P75 (µg/m³)**	**P90 (µg/m³)**	**P95 (µg/m³)**	**Reference**
Spraying	Personal	25	36%	323	776	28	37	161	832	1027	IFA, 2012
Spraying	Stationary	44	20%	11	29	1.3	0.8	5.0	24	45	IFA, 2012
*recalculated from CrO3 concentrations reported in IFA (2012).											

The exposure levels reported by Vincent *et al*. (2015) correspond to the levels of the stationary samples reported in Table 3-21 by IFA (2012), even though the range is considerably narrower. This can be reasonably explained by the smaller number of samples. Since the samples in Vincent *et al*. (2015) have been selected according to representativeness for worker exposure and their correspondence to the stationary samples by IFA (2012), the concentrations from the stationary samples from IFA are chosen for the calculation of the cancer burden.

Furthermore, the concentrations from the personal samples are applied for 10% of the workforce, conservatively accounting for that a certain fraction of thermal sprayers may be exposed to concentrations corresponding to the personal samples (without any use of respiratory PPE) by manual thermal spraying.

3.5.5 Influence of LEV and other RMM on exposure concentrations

Lehnert *et al*. (2014) investigated changes in air-borne and internal metal exposure following improvements of LEV and RPE in a plant where FCAW was applied to stainless steel. Twelve welders were examined before (2008) and after (2011) introduction of LEV and RPE. Exposure measurement was performed by personal sampling of respirable welding fume inside the welding helmets during one workshift, biological samples were taken after the shift. The geometric mean of all samples of respirable particles could be reduced from 4.1 mg/m³ in 2008 to 0.5 mg/m³ in 2011. Exposure to airborne chromium was reduced from 187 to 6.3 µg/m³. Reduction according to welding technique and compartment can be seen in Table 3-22. The study demonstrated a distinct reduction in the exposure of welders using improved LEV and RPE. Data from area sampling and biomonitoring indicated that the background level may add considerably to the internal exposure (Lehnert *et al*., 2014).

Table 3-22: Effects of RMM on exposure concentrations (Lehnert *et al*., 2014)						
Process	**Description of exposure situation**	**RMM introduced**	**Sample**	**GM* before (no. of samples)**	**GM* after (no. of samples)**	**GM after/GM before***
FCAW with consumable steel wires with a	Personal sampling of respirable fumes of welders from the	• Improvement and extension of LEV	Respirable particles (mg/m³)	5.6 (n = 9)	0.4 (n = 7)	7%

Table 3-22: Effects of RMM on exposure concentrations (Lehnert *et al.*, 2014)						
Process	**Description of exposure situation**	**RMM introduced**	**Sample**	**GM* before (no. of samples)**	**GM* after (no. of samples)**	**GM after/GM before***
content of Cr of 18.5-24%	container section in a plant before and after introduction of RMM. Work includes welding in confined spaces	• Torches with integrated extraction • Change from dry to wet floor cleaning method • Helmets with purified air supply for working in confined spaces	Cr (µg/m³)	243 (n = 9)	3.8 (n = 7)	1.5%
GMAW with consumable steel wires with a content of Cr of 19-24%	Personal sampling of respirable fumes of welders in the workshop section before and after introduction of RMM.	• Improvement and extension of LEV • Torches with integrated extraction • Change from dry to wet floor cleaning method	Respirable particles (mg/m³)	1.6 (n = 3)	0.8 (n = 4)	50%
			Cr (µg/m³)	86.0 (n = 3)	17.2 (n = 4)	20%
* GM – geometric mean						

Accordingly, Meeker *et al.* (2010) found that LEV reduced median Cr(VI) concentrations by 68%.

The MEGA data from 2000-2009 (IFA, 2012) are listed differentiated according to presence of LEV. No information on type and efficiency of LEV, if and how it was used is provided. Still, the data allow for a rough comparison and are presented in Table 3-23. In most cases, the data indicate a reduction in exposure concentrations through the use of LEV. Generally, there are more data available for processes with LEV than without LEV, even though the sampling sites have been selected with anticipations about high exposures. The fraction of samples below the quantification limit is higher for processes with LEV (61%) than for processes without LEV (49%).

The reduction of exposure concentrations given through the presence of LEV is most pronounced for MMA with covered electrodes and thermal cutting. However, even in MMA, which is the process yielding the highest Cr(VI) emissions, at sites without LEV, the concentrations where often below the quantification limit (usually ≤2.6 µg/m³). With respect to MIG and PAW, Cr(VI) exposure concentrations are slightly higher in situations with LEV compared to without.

This indicates that there are a number of parameters apart from the process and the presence of LEV that determine exposure concentrations. Generally spoken, the presence of LEV appears to have a positive effect on exposure concentrations. The data support the conclusions of the British welding survey (HSE, 2010), saying that a significant proportion of sites in stainless steel welding have adequate exposure controls available, but for various reasons these controls were not used or were used incorrectly, leading the diverse exposure concentrations within the same process. With respect to MMA, the choice of electrode has a considerable impact on Cr(VI) emissions.

Table 3-23: Comparison of exposure concentrations with and without LEV (IFA, 2012)							
Process	LEV			No LEV			Concentrations LEV/no LEV (Geom. mean)
	n	n <LOQ	Geom. mean (µg/m³)	n	n <LOQ	Geom. mean (µg/m³)	
Welding in general	35	24	1.9	14	6	2.1	90%
MMA with covered eletrodes	38	33	4.7	12	1	11.5	41%
MAG	269	141	2.3	92	44	2.8	82%
MIG	70	38	2.8	24	11	2.1	133%
PAW	19	15	0.8	19	12	0.7	114%
Thermal cutting	143	102	1.3	25	18	2.4	54%
Sum of samples	**574**	**353 (61%)**		**186**	**92 (49%)**		

According to expert communication, welding fume emissions can often be reduced significantly (up to 50%) solely by the adjustment of welding parameters. The optimisation of welding parameters with respect to emission reduction, while still maintaining high-quality welds, is a matter of training of the welder (Floros, 2017, pers. communication).

3.5.6 Relationships between concentrations of fume particles, total chromium and Cr(VI)

A survey by Emmerling *et al.* (1989) investigated the relationship between Cr(VI) and total Cr depending on welding method. The survey reports concentrations of respirable dust, total Cr concentrations, Cr(VI) and the fraction of Cr(VI) of total Cr. The results are presented in Table 3-24 below. Whilst emissions of respirable dust and total Cr were highest for MAG, Cr(VI) emissions were highest in MMA with covered electrodes. A large proportion of the chromium found in fumes from MMA welding can be expected to be hexavalent (15-88%), while the fractions are smaller for TIG and MAG welding (7-40% and 2-17%, respectively).

Table 3-24: Concentrations from personal samples collected during 1985 – 1988 (recalculated from Emmerling *et al.*, 1989, where concentrations were reported as CrO_3)									
Process	n	Respirable dust mg/m³		Total Cr µg/m³		Cr(VI) µg/m³		Cr(VI)/total Cr	
		Median	68% Range	Median	68% Range	Median	68% Range	Median	68% Range
MMA with coated electrodes	61	2.7	1.4 – 9.2	118.6	30.9 – 456	18.1	2.3 – 186.6	48%	15 – 88%
MAG	46	5.3	1.6 – 8.2	358.6	83.5 – 1260	8.3	0.8 – 32.5	5%	2 – 17%
TIG	16	1.5	0.7 – 2.4	26.5	6.7 – 61.6	1.5	n.d. – 6.0	19%	7 – 40%

Meeker *et al.* (2001) examining several datasets on welding fume exposure (see section 3.5.2), found only weak-to-moderate correlations between total particulate matter and Cr(VI), suggesting that total particulate matter concentrations are not a good surrogate for Cr(VI) exposure in retrospective studies.

The two studies exemplify that the presence of Cr(VI) in the welding fumes is highly dependent on the welding process and even varies considerably within the same process. Therefore, no general conclusion on a relationship between concentrations of particles, total chromium and Cr(VI) can be drawn.

Data analyses of welding fume measurements from the national Dutch IRAS database showed significant correlation between the concentrations of fume particles and Cr(VI) (n = 65), with Cr(VI) fractions of 0.26% (arithmetic mean), 0.6% (P95) and 2.3% (P99), leading to the practical consideration that if the limit value for welding fume (1 mg/m³) is complied with, the metal exposure will also be under the respective Cr(VI) limit values (Kanters and van de Werken, 2012)[15].

3.5.7 Trends in exposure concentrations

The extractions from the MEGA database published by Pesch *et al*. (2015) are reported for four times periods in the years from 1994 – 2009 in Germany. The major part of the data presented in Table 3-25 originates from measurements from welders (1898 out of 3659, corresponding to 52% of the measurements), further occupations with Cr(VI) exposure included cutters (3%), thermal sprayers (1%) and other occupations (electroplaters, foundry workers and related occupations, workers in pigments or other chromium-containing chemicals, spray painters and chemical workers, all corresponding to 44%). Concentrations (expressed as P75, P90 and P95) were highest for the period 1994-1997 and lowest in the period 2002-2005. Concentrations from the two remaining intervals from the period, 1988 – 2001 and 2006 – 2009, show values in between. Pesch *et al*. (2015) did not observe a statistical significant influence of the year of measurement in the time period 1994 to 2009.

Table 3-25: Distribution of personal measurements of hexavalent chromium in µg/m³ in the MEGA database, 1994-2009, by sampling years

Time of measurement (years)	N	% <LOQ	Median (µg/m³)	Median with imputed data (µg/m³)*	P75 (µg/m³)	P90 (µg/m³)	P95 (µg/m³)
Total	3659	67	<LOQ	0.90	5.20	22.88	57.20
Time of measurement (years)							
1994-1997	981	68	<LOQ	0.94	5.72	30.68	83.20
1998-2001	1111	66	<LOQ	0.76	6.76	23.40	51.48
2002-2005	908	69	<LOQ	0.96	4.68	16.64	41.08
2006-2009	659	66	<LOQ	0.95	5.04	19.76	62.40
*Median of modelled data.							

In the Netherlands, an annual decline of -3 to -4% in measured concentrations of welding fumes over the period 1983-2008 has been observed, suggesting that Cr(VI) exposure concentrations are

[15] The Dutch OEL for Cr(VI) has been reconsidered and lowered to 1 µg/m³ since the year of the references, see Table 3-1

declining likewise (Kanters and van de Werken, 2012). However, the awareness and activities for lowering exposures are not considered to be representative for all European MS.

According to communication with the ventilation, welding and thermal spraying industry, the use of LEV and PPE becomes more widespread. Furthermore, awareness about using available LEV and PPE, as well as using the equipment correctly, is increasing, leading to a reduction in exposure concentrations. Therefore, a trend of declining exposures of 1% p.a. will be anticipated for the estimation of cancer cases.

3.5.8 Challenges in compliance with the OELV of 5 µg/m³

The data from the literature illustrate, that exposure concentrations exceed the OELVs of both 5 µg/m³ and 25 µg/m³ in several processes, most pronounced in MMA and FCAW.

The stakeholder consultation revealed that companies do generally not know their exposure concentrations of Cr(VI), as its monitoring is not required by the relevant labour inspection authorities.

In the case of welding work in confined spaces, in areas with a low air exchange and/or welding jobs in a constrained posture, where the welding fumes pass directly into the welder's respiration zone, higher exposures must be expected (Weiss *et al*. 2013; BAuA, 2009).

The topic of challenging exposure situations has been discussed by personal communication with a number of experts from the industry[16].

Most experts support the notion that challenges are difficult to identify due to the lack of descriptive data, the wide ranges in reported exposure concentrations, the missing clear link between use of LEV/PPE and exposure levels, and the considerable uncertainties related to chemical analysis of Cr(VI).

Identification of exposure situations, where compliance would be challenging, is therefore a matter of qualitative assessment. Some experts recognize difficulties with the compliance with the national OELs of 1 µg/m³ in France and Germany, but partly also with the OELV 5 µg/m³ (Floros, 2017; DVS, 2017, personal communication). However, information about specific exposure situations and/or company types with concentrations exceeding the OELV has been sparse.

Generally spoken, repair works with a little degree of standardisation and works with very large items make automated solutions with integrated extraction system less feasible, leading to manual operations with potentially higher exposure.

Examples of exposure concentrations in confined spaces could be in the production or repair of vessels or boilers, which require that the welder is located inside the vessel in order to carry out the work. This could for example happen during application of a cladding to the whole inner surface to achieve resistance to corrosive fluids. The surface cladding may be applied by MMA (mainly repair), FCAW and/or MIG (mainly in production) and would usually be applied manually. The use of mobile filter units would typically be unfeasible in such situations. Therefore, RPE would be the control measure of choice. General room ventilation would still be required in order to protect workers performing

[16] Amongst others: TWI; Floros; Schneidforum GmbH; DVS; Force technology; DVS, 2017, personal communication.

other tasks in the same workroom. Exposure situations with confined spaces are primarily found in the manufacture of stainless steel apparatuses, pipes and ducts, vessels, boilers and similar.

A single company interviewed in the consultation exercise noted that improving the ergonomics of RPE would be beneficial, since the wearing of RPE may be impractical in very confined spaces forcing the worker to crouch or to lie down in order to complete the work. National regulations about the allowed duration of use of such masks have to be considered. The use of cladding robots would be another – typically more costly measure – to reduce exposures.

Elevated exposure situations may also arise in plasma cutting, if the cutting table is only provided with extraction from below the table or with no extraction at all. Extraction systems for cutting machines are available at reasonable prices, why compliance with the OELV should not be a major challenge. The worker should still reduce his/her personal exposure by leaving the cutting table after starting the machine and rotation of tasks.

3.5.9 Summary on exposure concentrations

No data on exposure concentrations of Cr(VI) have been received from the company consultations by questionnaires, interviews or site visits. According to communication with the industry, exposure concentrations of Cr(VI) are not measured on a regular basis and MS OELs are not enforced by the national authorities.

Generally, the results on exposure concentrations from the different studies reported in literature are consistent and generally provide the same levels with considerable variation of emissions that can be found in between and within the processes. Variation increases generally with increasing sample size.

Exposure concentrations commonly exceed the OELVs of both 5 µg/m³ and 25 µg/m³ in MMA and FCAW. Exposure concentrations in MIG/MAG welding with solid wire and thermal cutting appear to exceed the OELV of 5 µg/m³ occasionally.

The main welding process carried out in stainless steel is TIG welding, which is a low emission technique not leading to exposure concentrations above 5 µg/m³ when LEV is used. Exposure concentrations from laser welding or SAW are also well below 5 µg/m³.

Exposure concentrations commonly exceed the OELVs of both 5 µg/m³ and 25 µg/m³ inside the spraying cabin in thermal spraying. Outside the spraying cabin or RPE applied, exposure concentrations do not exceed the OELVs.

Exposure concentrations are lower when extraction measures are used, however, large differences in LEV efficiency are observed and many other welding parameters influence exposure levels.

Available data do not indicate a clear trend towards exposure reductions. Some data indicate that the concentrations have not changed substantially within a certain welding technique. However, the application of high-emission processes such as MMA welding is declining, while low-emission processes such as laser welding are becoming more wide-spread. According to communication with the ventilation, welding and thermal spraying industry, the use of LEV and PPE becomes more and more widespread leading to lower exposure concentrations. Therefore, a trend of declining exposures of 1% per year is used in the estimation of burden of disease.

The data collected in the MEGA database (as published by Pesch *et al*., 2015; IFA, 2012) is the most comprehensive and representative dataset available. The measurements have been taken in the period of 1994 – 2009 and are therefore thought to be a good surrogate of the various exposure situations that may exist currently in Europe. The sampling sites are selected according to anticipated high exposures, meaning the data provide a protective basis for further calculations. The data are reported differentiated for sample type, process and use of LEV. Furthermore, the analytical variation within the dataset is anticipated to be small due to standardised sample handling, preparation and analytical methods applied.

3.5.10 Distribution of workers across exposure concentrations

The distribution of exposed workers according to concentrations in the different processes is based on Cr(VI) exposure data from the MEGA database. For every process, the number of workers exposed to a given concentration is estimated using a lognormal distribution fitted to the median and the percentiles (P75, P90, and P90) data from the MEGA dataset, and using the number of exposed workers according to section 3.4.2. For thermal cutting and thermal spraying, the number of workers was distributed on the dataset of the personal and stationary measurements in order to approach actual exposure situations (see section 3.5.3 and 3.5.4, respectively). See Annex 2 for method and indication of fit of the distribution for the different processes.

An example of the fitted probability density distribution for the GMAW process in the concentration range 0.1-15 µg/m³ can be seen in Figure 3-4.

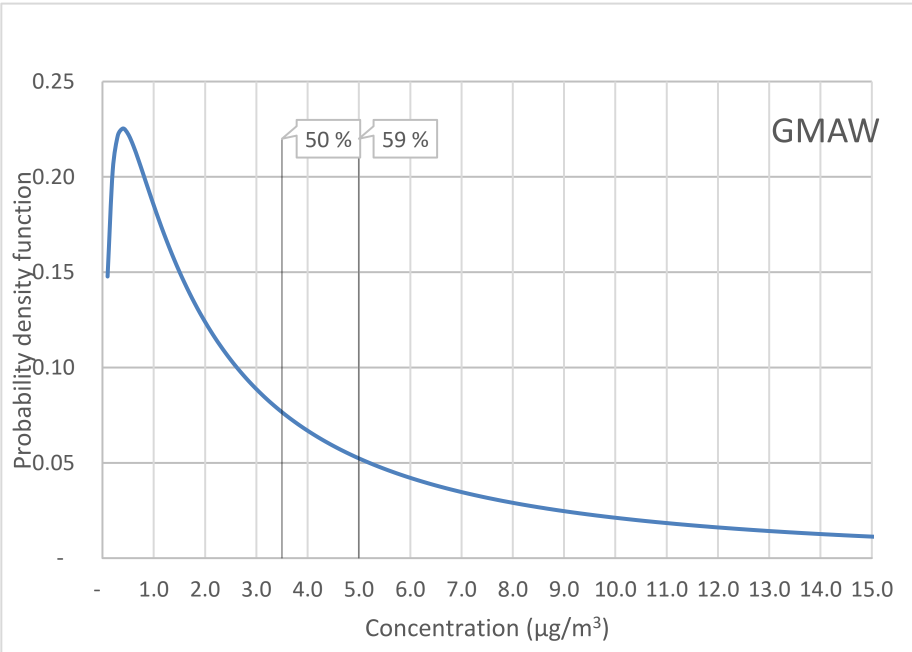

Figure 3-4: Probability density distribution fitted to the exposure concentrations provided from the MEGA database (Pesch *et al.* 2015) for the GMAW process. 50% of the GMAW welders are estimated to be exposed to concentrations ≤3.5 µg/m³, while 41% are estimated to be exposed to concentrations > the OELV of 5 µg/m³ (Source: Modelling by COWI).

The number of exposed workers has been distributed on eight concentration intervals as shown in Figure 3-5. The figure illustrates that 64% of workers are estimated to be exposed at concentrations below 5 µg/m³, 10% are exposed at concentrations between 5 and 25 µg/m³ and 16% are exposed at concentrations above 25 µg/m³. The figure also illustrates the GMAW, MMA and thermal spraying are the processes most significantly contributing to the number of exposed workers at high concentrations (> 5 µg/m³). The data shown in Figure 3-5 are used as input data for the calculation of cancer cases in section 3.13.

Please note that the data from the MEGA database do not contain any information about use of PPE. Therefore, there may be concentrations in the figure below (especially at high concentrations), who do not represent actual exposure concentrations, because the workers may be wearing breathing apparatus in some situations.

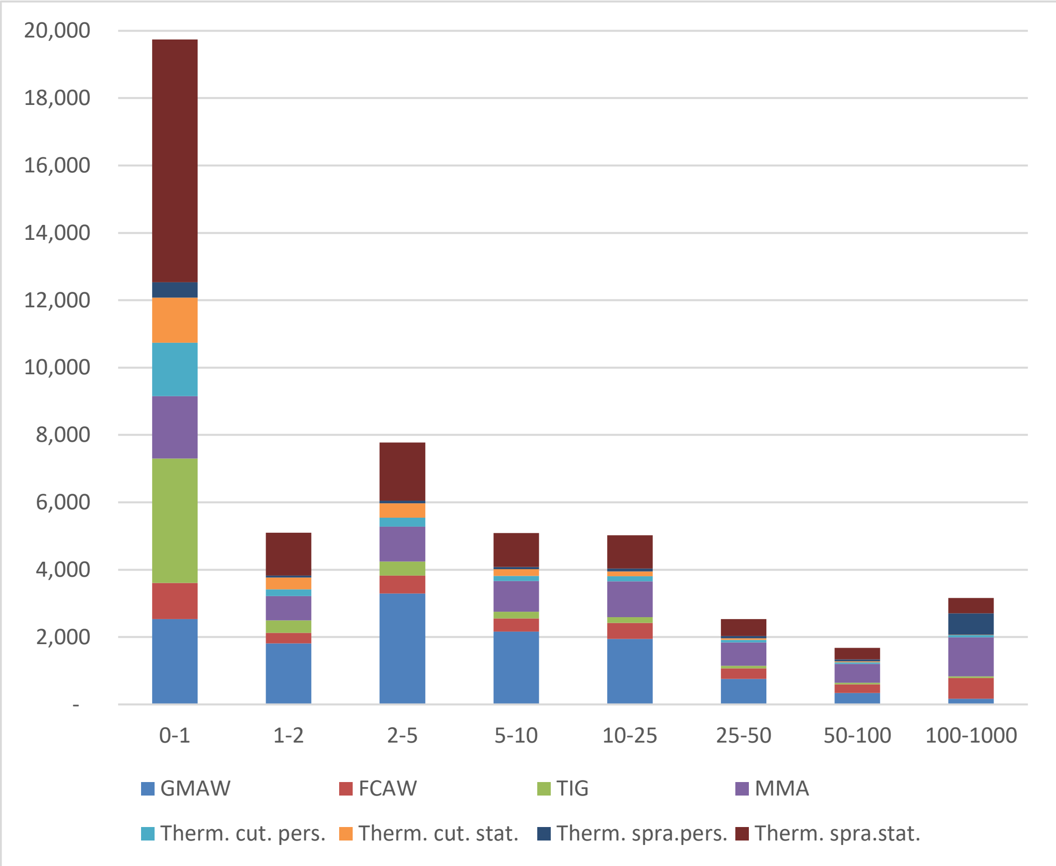

Figure 3-5: Number of exposed workers per concentration interval. Note that the concentration intervals are not equally large.

3.6 Current Risk Management Measures (RMMs)

3.6.1 Overview of current RMM and their costs

The industry, the national and European associations and experts have been consulted about the current use of RMM in welding, thermal cutting and spraying operations in Europe. The results are presented in below.

Six companies answered the RMM section of the Cr(VI)-questionnaire. Further information about RMM was also obtained from interviews and site visits with seven companies working with welding, thermal cutting and/or spraying.

Most companies involved in welding, thermal cutting and spraying are SMEs. No differences in use of RMM have been identified for different companies' sizes.

According to communication with the ventilation industry, the requirements to and capacity of the ventilation system is calculated on the basis of:

- the workroom volume,
- number of workstations,
- possible combination of different extraction systems,
- the fume emission rates of the processes,
- the frequency and the duration of fume emitting operations,
- the assumptions about extraction efficiency,
- workplace requirements by the relevant OELs.

Hence the costs of ventilation depend on many parameters of the specific application, which complicates the derivation of generally valid cost estimates.

No definite differences in use of RMM could be identified between the MS. Some communication with the ventilation industry indicates that the use of on-torch extraction is quite uncommon in most countries, while there are a number of users in Germany, France, the Netherlands and Sweden. Furthermore, the low OEL of 0.001 mg/m³ in France promotes the use of respiratory helmets in France to a higher degree than in other MS. The type of ventilation system does also depend on the national regulations regarding recirculation of process air. Recirculation is currently prohibited in Denmark, France, Germany and Italy.

Communication with the industry indicates that more attention is paid to use local exhaust ventilation (LEV) and respiratory protection equipment (RPE) compared to earlier times, leading to increased use of these RMM.

Table 3-26: Current risk management measures			
Type of measure	**Measure**	**Extraction efficiency**	**Costs**
Reducing the number of workers exposed	Rotation of workers is not a common measure in order to reduce worker exposure, because the single operations are usually only ongoing for a limited period of time and the works require special capabilities. Therefore, rotation is not feasible for welding. Rotation may be feasible in thermal cutting and is also used by companies with automated cutting machines. Generally, there is a trend towards automatization and robotic operators in applications, where this is possible. *E.g.* in the repair of some smaller components or tools, automatized laser welding can substitute manual micro-welding.	-	-

Table 3-26: Current risk management measures				
Type of measure		**Measure**	**Extraction efficiency**	**Costs**
2. Reduce the concentration at the workplace	General ventilation	Natural or mechanical ventilation is commonly used in workrooms depending on the processes and requirements by the national authorities. In France, for instance, mechanical general ventilation always has to be combined with LEV in order to comply with the national OEL. In Germany or Denmark, natural ventilation combined with LEV is often regarded as a sufficient measure for fume extraction in work hops. Mechanical ventilation systems usually create a directed airflow through positioning of the fresh air intake and the workshop air exhaust. Often the intake and exhaust are located in the ducting below the ceiling of the workshop. Mechanical ventilation systems, which are recirculating the air, *e.g.* by ducting on opposite walls of the work room, are also known as push-pull systems. Furthermore, ventilation suppliers do also offer filter towers as stand-alone installations to reduce air contaminant concentrations in a radius, *e.g.* 5 m, within a certain area of the work shop (only in MS where recirculation of air is allowed).	General ventilation is not effective for protecting workers of manual welding processes as the fumes are not removed at the source where exposures are higher. General ventilation reduces exposure *i.e.* welding robot operators or other staff working in the workroom. The air exchange rates are typically dimensioned at 5-8 times the work shop volume/h.	Highly dependent on workshop design, number of work stations, type of process, duration of use and availability of further RMM such as LEV. According to communication with industry, the cost of a general ventilation system in a "typical" workshop of 5000 m³ would be: • investment appr. 65,000 - 93,000 EUR • maintenance and service 3,000 - 4,000 per year (rough estimate) • additional costs for energy consumption (appr. 32 kW) and energy loss, if air is not recirculated
	Local exhaust ventilation (LEV)	Low-vacuum extraction (ca. 700-1000 m³/h) by means of fume hoods/funnels on flexible arms are the most common LEV. This extraction measure is commonly used at welding stations, and also at some cutting tables. Furthermore, high-vacuum spot extraction systems (ca. 100-150 m³/h) are available. These solutions are typically used in situations, where a very close location of	The efficiency highly depends on the location and nearness of the fume hood towards the source. The shape of the fume hood (funnel, with or without flange, rectangular or circular flange) also influences the extraction efficiency. Flanges always improve the efficiency. Efficiencies of low-	Highly dependent on workshop design, number of work stations, type of process, duration of use and availability of further RMM such general ventilation. According to communication with industry, the cost of a general ventilation system + low-pressure LEV at 5

Table 3-26: Current risk management measures				
Type of measure		Measure	Extraction efficiency	Costs
		the extraction to the source is desired (*e.g.* in static, robotic welding situations). On-torch spot extraction is available for certain welding processes (MIG/MAG), where the extraction in integrated in the welding torch (ca. 50-100 m³/h). Cutting tables for automatized metal cutting are commonly provided with extraction from below the grid on which the workpiece is placed. Extraction/welding tables are also available for smaller/manual processes, where the table may be provided with moveable sides and/or extraction in the back panel. LEV solutions may be installed stationary in a work shop or connected to mobile filter units for *e.g.* repair on large work pieces.	vacuum spot extraction are estimated at 80 - 99% at correct positioning. Efficiencies of on-torch spot extractions vary significantly depending on gas nozzle shape, shape of the contact tip, suction speed and welding direction. The highest estimates available state an efficiency of 90-98%. Efficiencies of high-vacuum spot extraction are estimated at 50 - 99% at correct positioning. Extraction tables with extraction from below are considered to be very efficient for larger particles but less efficient for smaller particles and gases.	workstations in a "typical" workshop of 5000 m³ would be: • investment appr. 70,000 - 95,000 EUR • maintenance and service 3,000 - 4,000 per year (rough estimate) • additional costs for energy consumption (appr. 27 kW) and energy loss, if air is not recirculated Investment costs for other RMM: • Mobile extraction and filter unit 1,000 - 5,000 EUR per work station • Extraction torches 500 - 4,000 EUR • Extraction/welding tables 1,000 - 5,000 EUR Investment cost per welding station: • 2000 - 5000 EUR (fume extraction torch, ducting to room or local ventilation unit) Investment for extraction and filter unit for one cutting table: • 10,000 - 25,000 EUR
	Water tables	Plasma cutting tables with water in order to cut under water are available and used by a smaller fraction of the cutting companies. Slag and particles from the cutting are caught in the water, sediment and removed from the water. Depending on elemental composition,	Water tables are considered to be very efficient for larger particles and partly for smaller particles. Supplementary LEV is recommended for extraction of gases and small particles.	Water can be reused after sedimentation. The containment of particles in the water prolongs the filter life, which are more costly to maintain/clean/exchange. Investment per water cutting table from 20,000 EUR.

Table 3-26: Current risk management measures				
Type of measure		Measure	Extraction efficiency	Costs
		the slag can even be sold and reused in metal fabrication.		
	Modification of working processes	Only very limited information has been obtained during consultation. Emission reduction is possible through optimization of operation parameters, *e.g.* voltage, arc length or shielding gas composition. None of the companies, who answered the questionnaire, has provided information on modification of processes. For more information on the topic, see section 3.8 Best practice.	-	'-
	Substitution of working processes	Only very limited information has been obtained during consultation. Emission reduction is possible through substitution of processes, *e.g.* MMA may be replaced with FCAW or GMAW in certain applications. A single company, who answered the questionnaire, stated that they introduced SPOT (resistance) welding instead of MAG welding in order to reduce exposure. For more information on the topic, see section 3.8 Best practice.	-	-
	Substitution of consumables	Only very limited information has been obtained during consultation. A few companies answered that the choice of electrode does not depend on emission potential. The choice of consumable in welding or thermal spraying highly depends on the base metal and the quality requirements of the weld or the surface, limiting the potential for substitution of consumables. For more information on the topic, see section 3.8 Best practice.	-	-

Table 3-26: Current risk management measures				
Type of measure		Measure	Extraction efficiency	Costs
	Detect unusual exposures	Only very limited information has been obtained during consultation. Sensors that monitor the particle burden continuously in the work shop air, indicate air quality visually by green/amber/red lights and may be linked to the ventilation system and the operator's computer/smartphone, are available. However, no information on how common or efficient these systems are has been retrieved.	-	Appr. 1000 EUR investment.
	Cleaning of base metal surfaces of any coating or paint	Common recommendation from working environment authorities. In thermal spraying, surface are often cleaned/prepared by sandblasting. Only very limited information has been obtained for welding or cutting during consultation. The information indicates, that cleaning of base metal surfaces is not necessarily a standard procedure.	-	-
	Cleaning of dust and work shop surfaces after operations	According to industry information, cleaning is commonly done after finishing the work task or by the end of the day, either by vacuum-cleaning, or as wet-cleaning.	-	-

Table 3-26: Current risk management measures				
Type of measure		Measure	Extraction efficiency	Costs
3. Reduce worker exposure:	Information of workers on working with hazardous materials	Instruction courses, handbooks and training are commonly available for welding operators. The degree of worker safety instruction varies considerable between different companies. The communication with some stakeholders indicated a certain reluctance about distributing information about a relationship between stainless steel welding and cancer.	-	
	Personal protection equipment (PPE) to reduce inhalation exposure to workers	Fresh-air supplying masks or filter masks with battery-powered filter-ventilation-unit (turbo-unit) are used in confined spaces, where LEV is not available, *e.g.* inside pipes or vessels. A single company consulted for this study also stated the use of battery operated masks in automated plasma cutting.	95-99.9%	Appr. 1000 EUR investment.
	Containment	The processes are in many cases entirely or partly segregated from other processes. Manual or robotic welding stations are commonly separated from each other by plastic curtains and/or partition walls. Cutting tables may be located in a segregated space in the workroom. Certain cutting machines may be partly (*e.g.* high-definition plasma cutting) or entirely enclosed (fiber laser cutting). Thermal spraying is always separated from the surroundings by containment in cabins. The segregation of processes is in most cases essential for visual protection of by-passer as well as noise and contamination control.	-	Cabin from appr. 20,000 EUR.

Low pressure extraction, provided by fume hoods or funnels on flexible and moveable arms, are by far the most common RMM and used in almost all manual working processes and often also for automated processes. According to communication with the industry, the use of processes such as TIG welding, with considerable lower and less visible emissions than *e.g.* GMAW, may lead to the conclusion, that no LEV is needed for these low-emission processes.

According to communication with the industry, several technical advances of RMM in order to reduce worker exposure are commonly available. For example, the LEV may be connected to the welding machine, thus being activated at the same time when the welder starts welding. Thus the worker does not have to remember to switch on the LEV and the company saves energy as the LEV is only in operation when actually needed (during the working process).

Another example for reducing worker exposure has been mentioned from a company working with thermal spraying in the aviation industry. The company uses automatic door locks for the spray cabins, which are first unlocked after the ventilation system has extracted the contaminated air in order to prevent the worker from entering the spray cabin directly after the spraying process has ended.

3.6.2 Recommendations by authorities and industry associations on RMM

A few examples of recommendations and guidelines regarding the use of RMM from authorities and associations are mentioned in this section.

The German Federal Institute for Occupational Safety and Health (BAuA) has in 2009 released a Technical Rule for Hazardous Substances for welding and related works (TRGS 528), which reflects the state of technology, occupational safety and health and occupational hygiene as well as other scientific knowledge for activities involving hazardous substances including their classification and labelling (BAuA, 2009).

The TRGS 528 obliges the employer to perform a risk assessment prior to commencement of the work and gives instructions for categorisation of a hazard class of a given working process.

The Danish WEA recommends LEV in combination with general ventilation. The ventilation system must be equipped with a control device indicating insufficient function by visual or acoustic signalling.

Low pressure extraction (1000 m^3/h) is usually regarded as providing sufficient protection (Danish WEA, 2014). High pressure extraction (150 m^3/h) is highly dependent on the movement of the extraction unit with the working process and usually needs additional measures such as general ventilation, separation of work place from others by means of screens/curtains and/or respiratory protection.

Furthermore, the Danish WEA (2014) has the following requirements with regard to reducing inhalation exposure:

- PPE: has to be CE-certified
- Cleaning: Surface-treated working pieces have to be cleaned off before welding/cutting
- Education: All workers exposed to fumes from welding or cutting must have received special education approved by the Danish WEA director
- Electrodes: If coated electrodes are used, the electrode with the lowest fume generation class (among the electrodes has meeting the technical requirements) has to be chosen. There are 7 classes, 1 indicates the lowest and 7 the highest fume generation.

Many MS have developed recommendations and guidance documents on use of RMM in welding and thermal cutting.

In specific applications, the national WEAs may not have developed guideline. In such cases, guidelines or recommendations may be available from industry associations. In Germany, a guideline on all aspects of thermal spraying, including requirements and detailed recommendations about RMM in thermal spraying has been developed by the Thermal Spray Association GTS (Mathesius and Krömmer, 2014). Amongst others, the GTS recommends ventilations rates of min. 8000 m^3/h per workplace, as well as wearing PPE including respiratory helmets in case the thermal spray operator has to enter the spray cabin.

3.6.3 Costs and efficiency of RMMs

Information about costs and efficiency of various RMMs used as background for the costs assessment (chapter 5) have been derived from manufacturers of RMM, industry consultation and RPA, and are shown in Table 3-27 and percentage reduction in exposure achieved with RMM in Table 3-28.

Table 3-27: Cost of various RMMs in €									
Size of company	Small 7 workers exposed Exposed workers on 1 machine			Medium 37 workers exposed 4 machines			Large 63 workers exposed 8 machines		
Type of RMM	CAPEX 2017	Life-span years	OPEX (% of CAPEX)	CAPEX 2017	Life-span years	OPEX (% of CAPEX)	CAPEX 2017	Life-span years	OPEX (% of CAPEX)
RWK: Rework	25,000			100,000			200,000		
LEV 3: Full enclosure	45,000	20	10%	440,000	20	10%	1,700,000	20	10%
LEV 2: Partial enclosure	31,000	20	10%	240,000	20	10%	650,000	20	10%
LEV 1: Open hood	7,000	20	10%	94,000	20	10%	264,000	20	10%
WE2: Pressurised or sealed	20	10%	240,001	20	10%	650,001	20	10%	31,001
WE1: Simple enclosure	20	3%	94,001	20	3%	264,001	20	3%	7,001
RPE 3: Powered helmets or full face mask	7,375	2	30%	37,375	2	30%	62,500	2	30%
RPE 2: HEPA filter - unpowered	1,106	Mask: 1 month, Filter: 1 month	50%	5,606	Mask: 1 month, Filter: 1 month	50%	9,375	Mask: 1 month, Filter: 1 month	50%
RPE 1: Simple mask	1,918	Not relevant, 1 per day	0%	9,718	Not relevant, 1 per day	0%	16,250	Not relevant, 1 per day	0%
OH 1: Organisational measures	7,375		50%	37,375		50%	62,500		50%
GDV 1: General dilution ventilation	50,000	20	10%	75,000	20	10%	150,000	20	10%
Source: RPA									

Table 3-28: Percentage reduction in exposure achieved with RMM	
Type of RMM	**% reduction in exposure**
Discontinuation	100%
Rework	50%
Full enclosure	99.5%
Partial enclosure	90%
Open hood	80%
No LEV	0%
Pressurised or sealed cabin	99.5%
Simple enclosed cab	80%
No enclosure	0%
Powered helmets or full face mask	97.5%
HEPA filter	95%
Simple mask	60%
No mask	0%
Organisational measures	30%
No organisational measures	0%
General dilution ventilation	30%
No general ventilation	0%
Source: RPA and manufacturers of RMMs	

3.7 Voluntary industry initiatives

Several national and European associations have been consulted regarding voluntary industry initiatives. Even though there has been a lot of attention about the exposure to Cr(VI), EWA states that it is not possible to substitute consumables or processes emitting Cr(VI) with consumables or processes emitting less Cr(VI) without significant losses in functionality (EWA, 2017, pers. communication).

In the Netherlands, the Metal Union (FNV), the employers' association for the technology industry (FME), the Professionals and the Workers Union (CNV) have joined to the industry initiative "5xbeter"[17] ("five times better") with the aim of reducing occupational exposures to hazardous substances in the metal working sectors, hereunder welding fumes. The 5xbeter initiatives provide companies with advice on how to reduce occupational exposures by means of digital improvement checks, educational materials and personal coaching. No further information has been received upon contacting the organisation.

In 2013, The Netherland Organisation (TNO), being an applied scientific research organization, launched a project for the transfer and exchange of knowledge about dust-free working and the use of dust-free tools with contractors in the building industry. According to communication with several stakeholders, performance and efficiency test of various welding and extraction technologies were performed within this initiative. However, no further information has been received upon contact to the organisation.

17 https://www.5xbeter.nl/site/nl

No further voluntary industry initiatives or Social Partner Agreements at European or national level with the aim of reducing exposure to Cr(VI) in fumes from welding, plasma cutting and similar processes have been identified.

3.8 Best practice

3.8.1 Risk Management Measures

Exposure concentrations at the workplace and of the worker are highly correlated. Most of the following measures (apart from PPE) will contribute to reduction of exposures both of the workplace in general, and of the worker.

Ventilation

On-torch spot extraction is advocated as the best available extraction method by the German BGHM as the fumes are removed as close to the source as possible. Differently shaped nozzles for on-torch extraction are available (Figure 3-6). Since the extraction unit is integrated in the torch, this method is only available for processes, where the consumable is provided continuously, *i.e.* MIG/MAG. Due to (earlier) challenges with the concurrent suction of the shielding gas (leading to unacceptable welding results), inefficient fume extraction and onerous handling of the bigger and heavier torches with extraction pipe attached to the torch, the extraction integrated torches are not commonly used yet. The larger torches may also impede the sight on the welding, especially in confined spaces where movement is limited. However, within the automobile industry, on-torch extraction systems are used in certain applications[18]. According to communication with the ventilation industry, the design of extraction torches and the welding quality documentation for extraction torches has been improved considerably, making earlier reservations unfounded. At least in a few MS (France, Germany, Netherlands, Sweden), on-torch extraction is used in industrial applications, *e.g.* in the automotive industry (not necessarily for stainless steel, though).

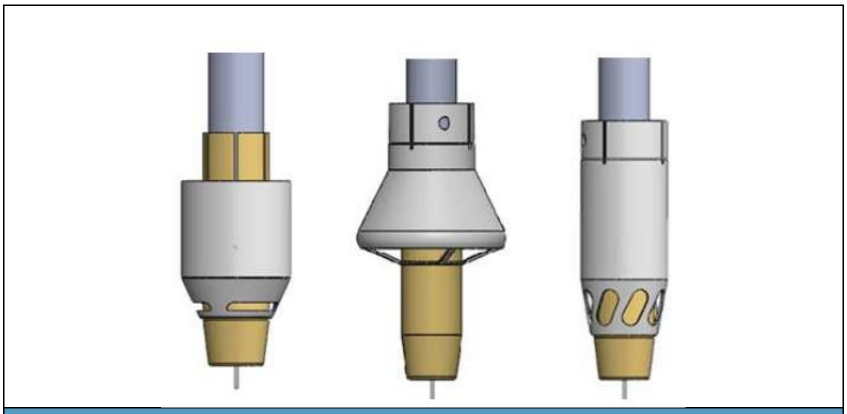

Figure 3-6: Different nozzle shapes of extraction torches (from IGF, 2016)

[18] Translas and Abicor Binzel, 2017, pers. communication.

The IGF (2016) has investigated the extraction efficiency of several available torches. The results show that torches with satisfying extraction efficiency are available, but that efficiencies are highly dependent on welding position, inclination angle, and suction strength. The estimated efficiencies varied between 9 and 99%. The choice of shielding gas does also influence fume emission (IGF, 2016).

According to communication with the ventilation industry, the Netherlands Organisation (TNO) has performed comprehensive and independent tests of extraction efficiency of extractions torches currently available on the market. This information could not be retrieved upon contact to the organisation.

Modification of processes

Information on process optimisation with regard to emission reduction is abundantly present from the literature and research projects.

The reduction of the current and voltage used in the welding or cutting process, is the parameter often advocated for reducing emissions (*e.g.* Wang *et al.*, 2017; Zschiesche, 2017), as high voltages are leading to higher emissions. However, as exemplified by Figure 3-7, also medium voltages may lead to high emissions.

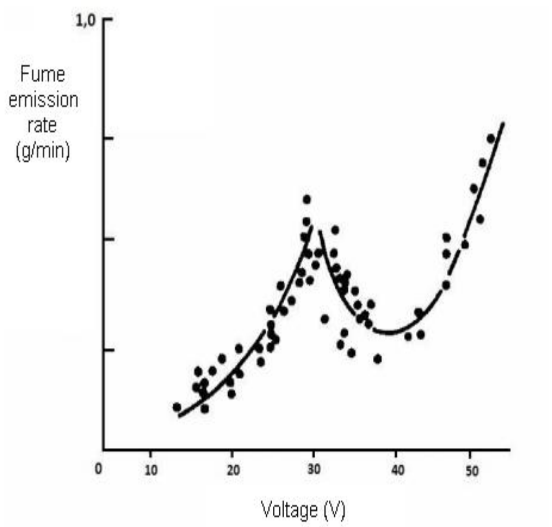

Figure 3-7: Principal relationship between voltage and fume emission rate (modified from IFG, 2017)

The IFG (2017) investigated the effects of different welding parameterisation in gas metal arc welding on the fume emission rates (FER). Figure 3-7 shows weld droplet transitions from two processes, V5_2 and V5_5, which are similarly parameterized, but differ slightly in applied current and voltage. V5_5 shows the ideal transition of a droplet in the pulse. In V5_2, the droplet transits in short circuit (against the ideal of pulsed arc welding), leading to increased fume formation as can be seen in the background of the pictures. This irregular appearance of process disturbances (here: short circuits) is decisive for the fume emission rate being a factor of about 3 times higher for V5_2 compared to V5_5 (IGF, 2017). The authors conclude that both exceeding and falling below the optimum voltage can increase the FER significantly. Special awareness should be paid to the choice of voltages higher than the optimum voltages, since the process here has no interferences and thus subjectively is not perceived as emission-intensive. The detailed understanding of the parametrization of welding processes is a useful approach to further develop computer-based control measures for welding power sources (IGF, 2017).

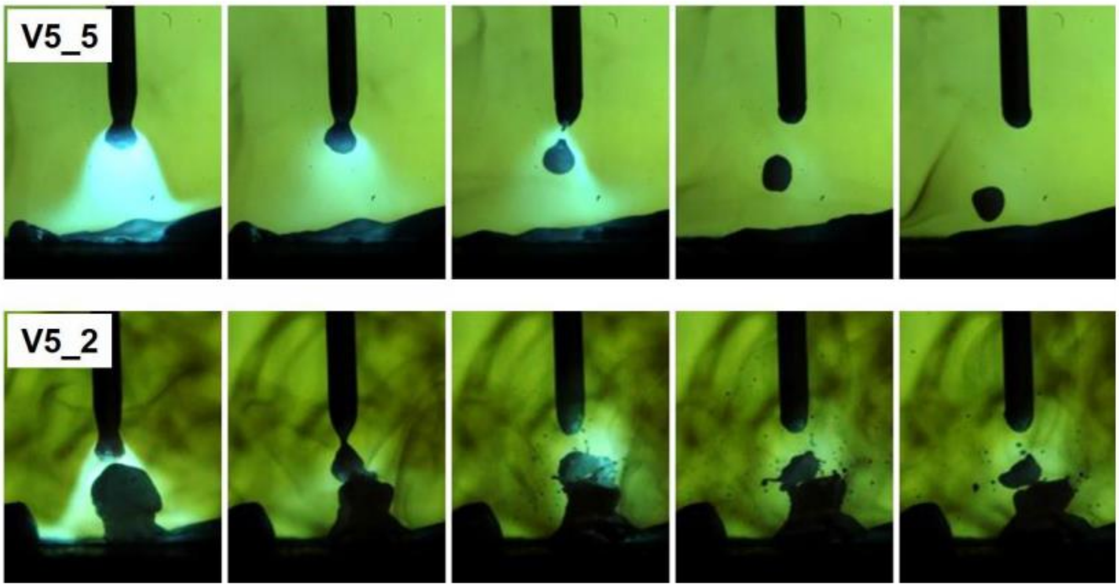

Figure 3-8: Comparison of exemplary droplet transitions of a lower emission (V5_5) and a more emission-intensive process (V5_2) in gas metal arc welding (from IFG, 2017). See text for further explanation.

Another IGF report (IGF, 2016) investigated the potential of emission reduction by partial separation of the CrNi consumable from the arc in GMAW processes. In the method, an additional hot-wire containing potentially hazardous substances, such as Cr and Ni, is applied in the welding of chromium nickel steels (Figure 3-8). The modified process renders a lower metal vaporization and hence a lower fume and Cr(VI) emission. In summary, by the use of additional wires containing the necessary alloys, the potential hazard of welding fumes in GMAW welding of high-alloy steel (X5CrNi18-10) can be significantly reduced. However, for the practical implementation of the process, it is imperative to supply all hazardous wire components through an additional wire. Presently, no commercially available wire fulfils the requirements to the chemical composition of such a wire (IGF, 2016).

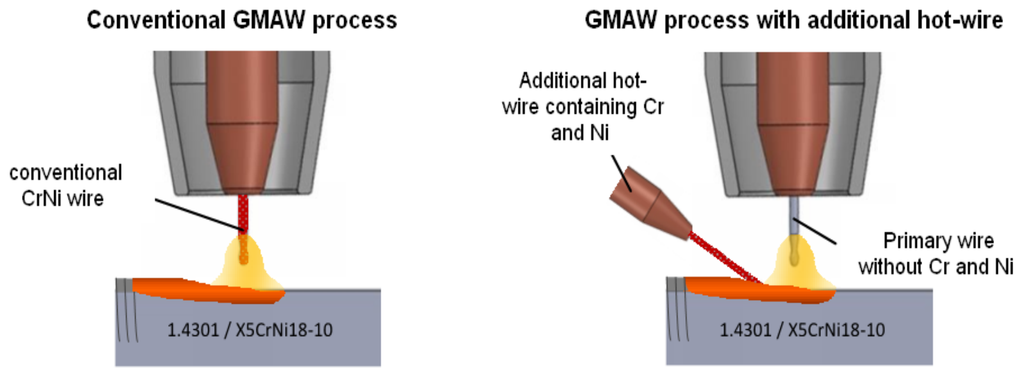

Figure 3-9: Schematic drawings of the conventional GMAW and the modified GMAW process with additional hot-wire (modified from IGF, 2016).

Knowledge on welding parameter optimisation with respect to fume emission reduction is available. However, the knowledge transfer into industrial applications appears fragmentary.

Substitution or modification of processes

General statements about possible substitutions of high-emission processes, *e.g.* MMA and FCAW, with low-emission technologies cannot be made. However, where technically possible, the use of the following processes should be considered and preferred (DGUV, 2017, pers. communication; Matusiak, 2011):

- TIG Welding (more time-consuming than many other techniques)
- Submerged Arc Welding (possible only in horizontal welding)
- Friction Stir Welding (possible only under particular conditions)
- Pulsed MIG/MAG welding
- Cold Metal Transfer (CMT, low energy welding process)
- ColdArc Welding (low energy welding process)
- Surface Tension Transfer (STT, low energy welding process)

Dennis *et al*. (2002b) has investigated the effect of shield gas composition in gas metal arc welding on Cr(VI) and ozone concentration in the fume. The article describes the application of a double shroud torch that allows use of concentric shield gases of different compositions. The Cr(VI) and ozone concentrations in the fume were measured and compared with results when using a single shield gas. The use of small amounts of the reducing agents NO and C2H4 in secondary shielding using the double shroud torch was found to offer advantages for ozone concentration reduction compared with use in a conventional torch, but this was not found to be an advantage for reducing Cr(VI) concentrations.

Substitution of consumables

Generally, there is an increasing awareness of differences in emission potential of electrodes, also within the same process.

In certain applications, substitution of the alkali metals in the electrodes by lithium may be possible (Floros, 2017, pers. communication; Dennis *et al*. 2002a).

Dennis *et al.* (2002a) found that the replacement of potassium by lithium in self-shielding flux-cored wire gave reductions in both Cr(VI) concentrations and in fume formation rate. Reductions in Cr(VI) concentration increased with increasing voltage, and at all voltages the concentrations of Cr(VI) were reduced well below the 1% level, thereby removing the possibility of Cr(VI) being the key component in determining fume concentrations.

In an earlier publication, Dennis *et al*. (1996) demonstrated a significant reduction of Cr(VI) in welding fume by the addition of 1% zinc to the flux-cored wire at a certain voltage.

However, the health risk associated with welding fume containing lithium, described as an extremely biologically active ion, has not been investigated in this publication. Weldability and mechanical strength of welds have also to be considered before substitution of potassium by lithium or addition of other metals commercially viable (Dennis *et al.*, 2002a).

Detect unusual exposures

Several ventilation suppliers offer sensors that monitor the particle burden continuously in the work shop air and can indicate air quality visually by green/amber/red lights and acoustically. These devices may be linked to the ventilation system and the operator's computer/smartphone in order to optimise the operational cost and efficiency of the ventilation system.

Cleaning of base metal surfaces of any coating or paint

Cleaning of base metal surfaces before doing hot metal work is a common recommendation from working environment authorities. In thermal spraying, surfaces are often cleaned/prepared by sand-blasting. Very limited information has been obtained for welding or cutting during consultation. The information indicates that the cleaning of base metal surfaces is not necessarily a standard procedure.

Further measures

Instruction courses, handbooks and training commonly available for welders and operators. Workers working as welders should be qualified through the educational centres of the national welding institutes.

Improving the **safety culture and behaviour** at companies working with welding, cutting and thermal spraying is a crucial measure for improving exposure situations and at least as important as technical measures. A good safety culture motivates workers to use available technical measures properly. Reluctance to fully inform workers about risks related to work with carcinogenic substances, has to be overcome in order to ignite behavioural changes. Exposure can be significantly reduced by small behavioural changes such as moving the head out of the welding fumes and adjusting the position of the LEV hood.

Fresh-air supplying masks or filter masks with battery-powered filter-ventilation-unit (turbo-unit) should be used when welding in confined spaces, where LEV is not available (*e.g.* inside pipes). Fresh-air supplying masks or filter masks with battery-powered filter-ventilation-unit should always be used in manual spray operations. Whenever possible, spray operations should be fully automated.

With respect to **containment**, the processes are in many cases entirely or partly segregated from other processes. Manual or robotic welding stations are commonly separated from each other by plastic curtains and/or partition walls. Thermal spraying is always separated from the surroundings by containment in cabins. Modern fibre laser cutting tables are always fully enclosed which simplifies extraction of polluted air. The containment of processes is in most cases essential for the visual protection of bypassers as well as noise and contamination control.

In plasma cutting, **cutting tables with water** combined with LEV are regarded as best practice with regard to exposures.

3.8.2 Conclusion on exposure and RMM

In some working situation, exposure concentrations may exceed the OELV of 5 µg/m³. There are challenges related to both the analysis of Cr(VI) and national/regional enforcement of existing OELs for Cr(VI) by the responsible authorities.

A wide range of RMM are available for basically all exposure situations, allowing for reduction of exposure to (Cr(VI) in) fumes from welding, plasma cutting and similar processes. Within this study, no exposure situations have been identified, which do not allow for use of RMM and PPE to significantly reduce exposure concentrations (and thus comply with the OELV). However, workers and employers may need encouragement in using and/or providing RMM and PPE, as well as improving health and safety culture at work.

In any case, an OELV for Cr(VI) may function as a driver for reduction of exposures to fumes from welding, thermal cutting and thermal spraying, thus protecting workers also for a number of other hazardous substances present in the fumes.

3.9 Standard monitoring methods/tools

Procedures for monitoring contaminants in the workplace are established by the National working environment authorities. The guidelines would typically make reference to European standards to be used for the monitoring.

As an example, in Denmark, the Danish Working Environment Authority specifies requirements to occupational hygiene measurements in the guideline: At-Vejledning D-7.2-2 "Arbejdshygiejniske dokumentationsmålinger" [Occupational hygiene documentation][19]. The guidelines define the documentation that concerns:

- The workplace air content of gases, vapours, dust and other particulate pollutants from substances and materials.
- The concentration of harmful substances or their metabolites in biological fluids.
- The extent of biochemical changes in biological fluids.

Monitoring substances in workplace air

As concerns the monitoring of substances in the workplace, two European standards are available:

[19] See https://arbejdstilsynet.dk/da/regler/at-vejledninger/a/d-7-2-arbejdshygiejniske-dokumentationsmaalinger

- EN 482:2012++A1:2015: Workplace exposure. General requirements for the performance of procedures for the measurement of chemical agents.
- EN 689:1995: Workplace atmospheres - Guidance for the assessment of exposure by inhalation to chemical agents for comparison with limit values and measurement strategy.

The latter is under revision and available as a draft: DSF/prEN 689: Workplace exposure - Measurement of exposure by inhalation to chemical agents - Strategy for testing compliance with occupational exposure limit values.

EN 482:2012+A1:2015 specifies general requirements for the performance of procedures for the determination of the concentration of chemical agents in workplace atmospheres as required by the Chemical Agents Directive 98/24/EC. The requirements given apply to all measuring procedures, irrespective of the physical form of the chemical agent (gas, vapour, airborne particles), the sampling method and the analytical method used and is applicable to all steps measuring procedures with separate sampling and analysis steps, and direct-reading devices.

EN 689:1995 provides guidance for the assessment of exposure by inhalation of chemical agents for comparison with limit values and measurement strategy. The standard refers to the latest update of EN 482 as concerns the General requirements for the performance of procedures for the measurement of chemical agents. The standard describes the monitoring strategy consisting of two phases:

An occupational exposure assessment where the exposure is compared with the OEL
Periodic measurements to regularly check if exposure conditions have changed

The manual outlines no formal procedure for deciding whether exposures are below the limit values within an occupational exposure assessment.

Analytical methods for Cr(VI) in workplace air

The SCOEL (2017) refers to several methods developed by various organizations (NIOSH, DFG, HSE, ISO, OSHA) to quantify Cr(VI) levels in workplace air. Recommended methods characterise time-weighted average (TWA), breathing zone exposure across full work shifts.

The respirable fraction, formerly called fine dust, is usually measured with the sampling head for the inhalable fraction (formerly called total dust) during personal measurements carried out in welding. The reason is that at present it is still difficult to position the sampling head for the respirable fraction behind the welder's shield (lack of space; VMBG, 2007). However, the SCOEL (2017) recommends that sampling should be based on inhalable dust sampling, since inhalable dust samplers capture dust particulates that can penetrate all parts of the respiratory organ. Welding only produces very fine particles, all of which are included in the" respirable fraction", thus measurements of inhalable fraction instead of the respirable fraction are always on the safe side.

In all methods, sampling is by trapping onto a filter, *e.g.* a PVC filter. This is followed by extraction with an inorganic buffer. Some methods involve extracting with a buffer for the direct determination of soluble Cr(VI) (only) and some others with the stronger digestion (wet ashing) for the determination of the soluble and insoluble chromium simultaneously. Possible reduction or oxidation reactions are always a concern during sampling and sample preparation.

Once solubilised, further steps can be enrichment (decrease the volume to increase the concentration) and/or separation from Cr(III). Subsequently, in several methods ion-chromatography and post-column derivatisation by diphenylhydrazine (DPH) are used. Other methods use direct derivatisation by

DPH. The coloured Cr(VI)-DPH complex can be determined by UV-VIS photometry or colorimetric comparison (SCOEL, 2017).

Details of two methods for analysing Cr(VI), as listed in the GESTIS analytical methods database[20], are shown in the Table 3-29 below. The 'GESTIS - Analytical methods' database contains 9 methods for 'Chromium VI compounds (as Cr)'. Of these, 2 are assigned an 'A' ranking, 7 a 'B' ranking and none a 'C' ranking.

Table 3-29: List No.: 116 in GESTIS analytical methods database; Substance: Chromium VI (as Cr), ('A' ranking methods)

No	Source and method name	Principle of the method	Flow rate/Recommended air volume	LOQ/ Validated working range	Indicative rating	Remarks
1	ISO 16740 Determination of hexavalent chromium in airborne particulate matter (published 2003, English)	Particulates trapped on a PVC membrane or QF filter in an inhalable sampler. *Soluble Cr(VI):* Extraction with H2O or 0,05 M (NH4)2SO4 + 0,05 M NH4OH. *Insoluble Cr(VI):* Hotplate or ultrasonic extraction with 20 g/l NaOH + 30 g/l Na2CO3. Analysis by IC with UV-vis detection after post column derivatisation with 0,5 g/l 1,5-diphenylcarbazide in 1+9 methanol and 0,5 M H2SO4.	Flow rate: Sampler–dependent Recommended sampling time: 15 min–8 h	LOQ: 0,7 µg/m³ 30 l, 0,04 µg/m³ 480 l	A	
4	MétroPol Fiche 084 Chrome hexavalent (published 2004, French)	Particulates trapped on a QF filter in a 37 mm cassette filter holder. *Soluble Cr(VI):* Extraction with 0,5 M (NH4)2SO4 + 0,5 M NH4OH inside the sampling cassette. Analysis by ETAAS or ICP-AES, or by UV-vis spectrophotometry after derivatisation with 0,5 g/l 1,5-diphenylcarbazide in acetone. *Insoluble Cr(VI)* Ultrasonic extraction with 20 g/l NaOH + 30 g/l Na2CO3 at 60°C. Analysis by ETAAS or ICP-AES.	1 l/min 15-240 l	LOQ: Soluble Cr(VI): 27 µg/m3 15 l 1,7 µg/m3 240 l Insoluble Cr(VI): 8 µg/m3 15 l 0,5 µg/m3 240 l	A	Inhalable sampler not used, but wall deposits analysed No performance data published in the method

Even though several standard methods are available, the analysis of Cr(VI) in fumes from hot metal works is still challenging, because so far, no method for chromium speciation in solid matrices can fully avoid interconversions with trivalent chromium during all steps of sampling and analysis (Pesch *et al.*, 2015; Floros, 2017).

[20] http://amcaw.ifa.dguv.de/WForm09.aspx

Wang *et al*. (2017) realized that emission of nitrogen oxides in plasma cutting fumes can be a good indicator of Cr(VI) formation (R = 0.93). Since the analytical methods for estimations of nitrogen oxides are less costly and more reliable, NO_X monitoring could be developed as an alternative to Cr(VI) measurements.

3.10 Relevance of REACH Restrictions or Authorisation

Cr(VI) compounds are subject to restriction under REACH. Thus leather articles containing Cr(VI) may not be placed on the market.

3.11 Market analysis

Several European and national associations (EWA, EWF, DVS, TWI, GTS, TSSEA), as well as ventilation companies, have been consulted about the sectors of stainless steel hot metal works.

The majority of companies are SMEs. Some companies are only concerned with manufacture, other only with repair of components. Larger companies may have in-house workshops for the repair and/or production of components. More specific information about the number and size of metal work companies could not be obtained by the European welding organisations (EWA, EWF).

Main industries using stainless steel for are located in Germany, followed by Italy, France, UK, Spain, Netherlands, Portugal, Poland, Sweden, Finland and Romania (sequence only roughly indicative and not exhaustive, based on qualitative experts' judgements).

Assuming that about 25% of the employees in a company are welders or operators and that the distribution of companies on sizes (small, medium, large enterprise) is 50%, 49% and 1%, the number of companies can be calculated as shown in Table 3-30. Accounting for the number of welders, who are not working full-time but part-time, would result in higher figures. Accounting for that some companies work in 2-3 shifts/day, would result in lower figures. It is here anticipated that the mentioned two effects level each other out.

Table 3-30: Cr(VI) – Number of companies

Process	No. of welders/operators	No. of small enterprises	No. of medium enterprises	No. of large enterprises
Welding	31,000	2,102	406	5
Thermal cutting	5,100	346	67	1
Thermal spraying	15,000	1,017	197	2
Total	**51,100**	**3,464**	**670**	**8**

Both small to large entities will be expected to invest in improved fume extraction systems upon introduction of an OEL of 0.005 mg/m³. However, experiences from the ventilation suppliers and industry associations do also indicate that national guidelines for exposure reduction are neither consequently followed by the employers, nor are national limit values on Cr(VI) consequently enforced.

3.12 Alternatives

Cr(VI) in fumes from welding, thermal cutting and spraying will be present, if chromium is contained in the base metal and/or consumable and the process favours oxidation of chromium to the hexavalent state. The opportunities to reduce or substitute chromium in the base and/or consumables are limited and not the primary means to reduce exposure.

Alternative processes, process modifications and alternative consumables have been addressed in section 3.8.

3.13 Current and future burden of disease

3.13.1 Data from the literature

No literature on current or future number of cancer cases related to exposure to Cr(VI) in fumes from welding, thermal cutting or thermal spraying has been identified.

3.13.2 Input data for calculation of disease burden

The German MEGA dataset as described in section 3.5 is the most comprehensive and representative dataset available and is therefore used for the estimation of cancer cases. The exposure data differs significantly for the different welding, thermal cutting and spraying processes; hence the number of cancer cases is estimated separately for the different processes. The concentration input data for the model calculations is divided into eight bands (Table 3-31). For every process, the number of workers exposed to a given concentration was estimated using a lognormal distribution fitted to the data from the MEGA dataset (see section 3.5.).

Table 3-31: Exposed workers input data for calculation of cases at baseline and target OEL at current, future and past exposures of welders (Source: Study team estimates).

Concentration ranges (µg/m³)		Exposed workforce in EU28 (No.)							
		MMA	FCAW	GMAW	TIG	Th. cutting, pers.	Th. cutting, stat.	Spraying, pers.	Spraying, pers.
Band 1	0 - 1	1,848	1,078	2,531	3,691	984	1,334	462	7,205
Band 2	1 - 2	719	318	1,808	368	195	347	56	1,279
Band 3	2 - 5	1,038	530	3,296	418	298	427	78	1,726
Band 4	5 - 10	910	388	2,164	203	204	204	61	1,005
Band 5	10 - 25	1,071	480	1,941	167	242	151	82	985
Band 6	25 - 50	691	318	757	72	157	52	62	509
Band 7	50 - 100	564	264	337	41	130	23	62	337
Band 8	100 - 1000	1,159	624	166	40	341	13	636	454
Total No.		**8,000**	**4,000**	**13,000**	**5,000**	**2,550**	**2,550**	**1,500**	**13,500**

For the calculation of cancer cases, the trend of exposure concentrations has been set to - 1% for past and future exposures. The workforce trend has been anticipated to remains unchanged (0%). The applied Exposure Risk Relationship (ERR) has been described in section 2.4.

The total number of workers in EU for a single process (*e.g.* 8,000 workers in MMA welding) was distributed on the single MS by using the distribution of welders on the MS as reported by DVS (2009; see section 3.4.1). For MS where estimates were missing, the contribution according to population size was accounted for.

Table 3-32: Input data for calculation of cases at baseline and reference OEL at current, future and past exposures of welders		
Parameter	**Unit**	**Value**
OELs and exposure trends		
Reference OELV	µg/m³	5 and 25
Reference % compliance with OELV	%	100
MS OEL	µg/m³	See Table 3-1
Exposure concentration trend - future	%pa	- 1
Exposure concentration trend - past	%pa	- 1
Health Endpoints		
ERR	/µg/m³	4.00E-03
Effect threshold	µg/m³	0
Time periods		
Period for baseline cases	a	50
Future period	a	40
Past period	a	50
Workforce trend – future and past		
MMA	%pa	-2
FCAW	%pa	0
GMAW	%pa	1
TIG	%pa	0
Thermal cutting	%pa	0
Thermal spraying	%pa	0

3.13.3 Current burden of disease due to past exposure

The model calculations have been performed separately for the welding processes MMA, FCAW, GMAW and TIG welding, as well as thermal cutting, and thermal spraying. The exposures from laser welding and SAW are very low (below the LOQ) and are therefore omitted here.

The current burden of disease due to past exposure (Table 3-33) has been estimated using the data in the preceding sections and assuming that the number of workers in the relevant processes remained unchanged and that the exposure concentrations have been decreasing by 1% each year.

Table 3-33: Current burden of disease due to past exposure to Cr(VI) from welding, thermal cutting and thermal spraying (Source: Modelling by COWI/RPA)		
Endpoint	**Number of cases in 2017 due to past exposure**	**Number of cases over average working life period (40 years)**
Lung cancer	132	5,274

3.13.4 Future burden of disease

The total number of cases expected to occur in the future derived from all process-differentiated calculations is given in Table 3-35. These estimates are based on the assumption that the number of workers exposed to Cr(VI) in fumes from welding, thermal cutting and thermal spraying will remain unchanged and that the associated exposure concentrations will decrease by 1% each year.

Table 3-34: Future burden of disease due to exposure to Cr(VI) from welding, thermal cutting and thermal spraying (Source: Modelling by COWI/RPA)			
Endpoint	**Number of cases over 40 years**	**Number of cases over 60 years**	**Monetary value PV 60 years**
			Static discount rate (method 1)
Lung cancer	4,444	7,619	6,200 EUR millions
Note: PV – Present value			

3.13.5 Summary and discussion on disease burden

The number of cases reported should not be taken as a definite estimate of cancer cases, but merely as an indication of magnitude. However, the estimates may be regarded as protective or overestimated regarding to the following reasons:

- The exposure concentrations used for the calculations originate from measurements in working environment with anticipated high/measurable exposures.
- The exposure concentrations used for the calculations (MEGA data as published by Pesch *et al*., 2015, and IFA, 2012) are in the high end of reported exposure concentrations compared to other publications.
- The exposure concentrations are derived from personal sampling with and without LEV. In some exposure situations (especially high exposures), workers may be additionally protected by use of PPE, which is not accounted for in the exposure data.
- The exposure concentrations may reflect shorter exposures than 8 hr TWA (sampling time ≥ 1 h).

Moreover, the exposed workforce estimates for thermal cutters and thermal sprayers are conservatively estimated.

Nonetheless, the calculations demonstrate that a number of cancer cases can be related to occupational exposures to Cr(VI) in stainless steel welding, thermal cutting and thermal spraying.

A summary for the burden of disease is provided in the tables below.

Table 3-35: Cr(VI) compounds - Summary of the baseline burden of disease									
Carcinogen	Classification *	Key sectors used	Types of cancer caused	No. of exp. workers	Change exp. level	Change no. of exp. workers	Period for estimation	Current disease burden - no. of cancer cases, 40 years	Future disease burden - no. of cancer cases dynamic, 40 years
Cr(VI) compounds in fumes from welding, plasma cutting and similar processes	Carc. 1A or Carc. 1B	**Welding, thermal cutting and thermal spraying**	Lung cancer	51,100 stainless steel workers (31,000 welders, 5,100 thermal cutters, 15,000 thermal sprayers)	Past: -1% Future: -1%	Past: 0% Future: 0%	40 years	5,274	4,444
* Classification for Cr(VI) compounds, see Table 3-7.									

Table 3-36: Cr(VI) compounds - Summary of the baseline burden of disease, cont.					
CBD no. of other adverse health effects over 60 years	FDB - no. of cases over 60 years	Exp. no. of deaths FDB cancer, 60 years	Exp. no. of deaths FDB other adverse health effects, 60 years	Monetary value FDB, 60 years*, EUR millions	Monetary value FDB other adverse health effects, 60 years, EUR millions
No other effects	7,619	5,587	No other effects	6,200	No other effects
CDB - Current disease burden; FDB - Future Disease Burden * Method 1					

4 Benefits of the measures under consideration

4.1 Introduction

This section comprises the following subsections:

- Section 4.2: Summary of the assessment framework
- Section 4.3: Avoided cases of ill health
- Section 4.4: Benefits to workers & families
- Section 4.5: Benefits to employers
- Section 4.6: Benefits to the public sector
- Section 4.7: Aggregated benefits & sensitivity analysis

4.2 Summary of the assessment framework

4.2.1 Summary of the key features of the model

The benefits of the potential measures to reduce worker exposure equal the costs of avoided cases of ill health. The model developed to estimate these costs takes into account the cost categories set out in the table below.

Table 4-1: The benefits framework

Category	Cost	Notes
Direct	Healthcare	Cost of medical treatment, including hospitalisation, surgery, consultations, radiation therapy, chemotherapy/immunotherapy, etc.
	Informal care[21]	Opportunity cost of unpaid care (*i.e.* the monetary value of the working and/or leisure time that relatives or friends provide to those with cancer)
	Cost for employers (*e.g.* liability insurance)	Cost to employers due to insurance payments and absence from work
Indirect	Mortality – productivity loss	The economic loss to society due to premature death
	Morbidity – lost working days	Loss of earnings and output due to absence from work due to illness or treatment
Intangible	Approach 1 WTP: Mortality	A monetary value of the impact on quality of life of affected workers
	Approach 1 WTP: Morbidity	
	Approach 2 DALY: Mortality	
	Approach 2 DALY: Morbidity	
Note: WTP - Willingness to pay , DALY - Disability adjusted life years		

[21] A decision has been taken to include informal care costs in this analysis even though some elements of these costs may also have been included in individuals' willingness to pay values to avoid a future case of ill health. This decision may result in an overestimate of the benefits as generated by this study.

The total avoided cost of ill health is calculated using the following two methods:

Method 1: Ctotal= Ch+Ci+Cp+Cvsl+Cvsm

Method 2: Ctotal= Ch+Ci+Cp+Cl+Cdaly

The abbreviations are explained below.

Table 4-2: Overview of cost categories

Category	Code	Cost
Direct	*Ch*	Healthcare
	Ci	Informal care
	Ce	Total cost to an employer
Indirect	*Cp*	Productivity loss due to mortality
	Cl	Lost earnings due to morbidity
Intangible	*Cvsl*	Value of statistical life
	Cvsm	Value of cancer morbidity/value of statistical morbidity
	Cdaly	Value of DALYs

Ce is not considered in the totals under both Method 1 and 2 to avoid double-counting. *Cl* is not considered under Method 1 since *Cvsl* may already include these costs.

The outputs of the model include:

- The number of new cases for each health endpoint assigned to a specific year in the 60 year assessment period;
- The Present Value (PV) of the direct, indirect, and intangible costs of each case.

The key scenario is modelled for the exposed workforce. This is:

- **ExW-Constant:** workforce remains unchanged over 40 years (the same individuals, no replacement of workers afflicted by ill health), the whole workforce is replaced in year 41 with these individuals remaining in the exposed workforce over the next 40 years. This scenario does not take into account either the natural turnover of workers changing jobs or the turnover due to the ill health caused by exposure to the relevant chemical agents.

A detailed overview of the key features of the model for the estimation of the benefits and the assumptions underpinning it are set out in the methodology report.

4.2.2 Relevant health endpoints for Cr(VI)

For Cr(VI), the benefits (*i.e.* changes in the costs caused by ill health) have been quantified for one health endpoint: lung cancer.

4.2.3 Summary of the key assumptions for Cr(VI)

Onset of the disease

The time of diagnosis of the cases calculated over an average working life is determined taking into account the minimum and maximum time required to develop the condition (MinEx and MaxEx) and the distribution of new cases between these two points in time, combined with the latency period with which the effects are diagnosed.

The MinEx and MaxEx for lung cancer are summarised below.

Table 4-3: Minimum & maximum exposure duration to develop a condition (MinEx & MaxEx)		
Endpoint	**MinEx (years)**	**MaxEx (years)**
Lung cancer	2	40
Notes: *MinEx* *The minimum exposure duration required to develop the endpoint* *MaxEx* *The time required for all workers at risk to develop the endpoint*		

For lung cancer, it is assumed that no risk (*i.e.* not incidence but risk since incidence is delayed due to latency) arises until MinEx has expired. It is assumed that, subsequently, the distribution of risk is linear, *i.e.* 0% of the excess risk arises in year 2 and 100% of the excess risk arises by year 40.

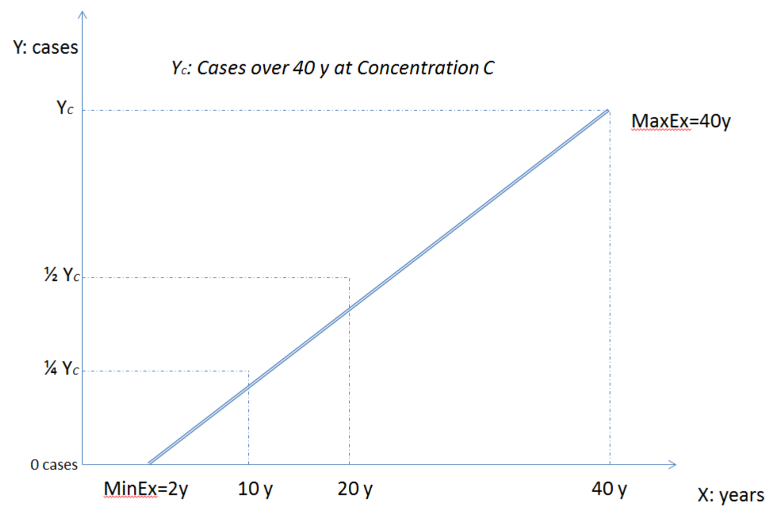

Figure 4-1: Lung cancer risk – distribution over time

For lung cancer, a latency period of 10 years is used in this study. Although longer latency periods are often estimated for lung cancer, a short latency period is used to be protective to workers and ensure that relevant cancer cases are assessed within the 60 year assessment period for this study.

The effects of the disease

The key assumptions used for the modelling of the benefits from reduced exposure to Cr(VI) are summarised below. For a detailed explanation of the model and the assumptions, please refer to the methodology report.

The key inputs and assumptions include:

- treatment periods;
- fatality rates;
- treatment cost;
- values for the Willingness to Pay (WTP) to avoid cases of fatal and
- disability weights for the relevant endpoints.

Treatment period

The treatment periods used in the model are given below. The end of the treatment period signifies either a fatal or illness-free outcome.

Table 4-4: Treatment period	
Endpoint	**Treatment period (years)**
Cancer	5

Mortality rate

The mortality rates used in the model are given below.

Table 4-5: Fatality rates (MoR)	
Endpoint	**MoR (years)**
Cancer - lung	80%

Willingness to Pay (WTP) values

The WTP values for a case of fatal and non-fatal cancer are €4,100,000 and €420,000; this is in line with the approach taken across all the reports produced under this contract, see the methodology report for details.

Disability weights

The disability weights used are summarised below.

Table 4-6: Disability weights collated in European Burden of Disease study (2015)		
Type of cancer	**Stage of disease**	**Disability Weight**
Lung cancer	Disseminated	0.515
Lung cancer	Operable	0.265

Summary

Table 4-7: Unit costs		
Category	**Cost**	**Lung cancer**
Direct	Healthcare	€7,000 /year
	Informal care	€3,000 /year
	Cost for employers	€12,000 /case
Indirect	Mortality – productivity loss	€5,000 /year
	Morbidity – lost working days	€1,000 /year
Intangible	Approach 1 WTP: Mortality	€4,100,000 /case
	Approach 1 WTP: Morbidity	€420,000 /case
	Approach 2 DALY: Morbidity	Value of a DALY: €100,000
* Estimated as proportional to healthcare costs: 3/7 ratio based on cancer healthcare and informal care costs. ** Estimated as proportional to healthcare costs: 1/7 ratio based on the costs of cancer healthcare and lost working days.		

4.3 Avoided cases of ill health (cancer and non-cancer)

This section includes the estimation of the avoided cases of ill health. It includes only one health end-point – lung cancer.

Table 4-8: Cases of lung cancer and for each reference OELV (Source: Modelling by COWI/RPA)

Reference point (inhalable fraction)	Lung cancer cases	
	40 years	60 years
Baseline	4,444	7,619
25 μg/m³	1,296	2,222
5 μg/m³	496	850

These reference points have been used to plot the number of cases as continuous functions.

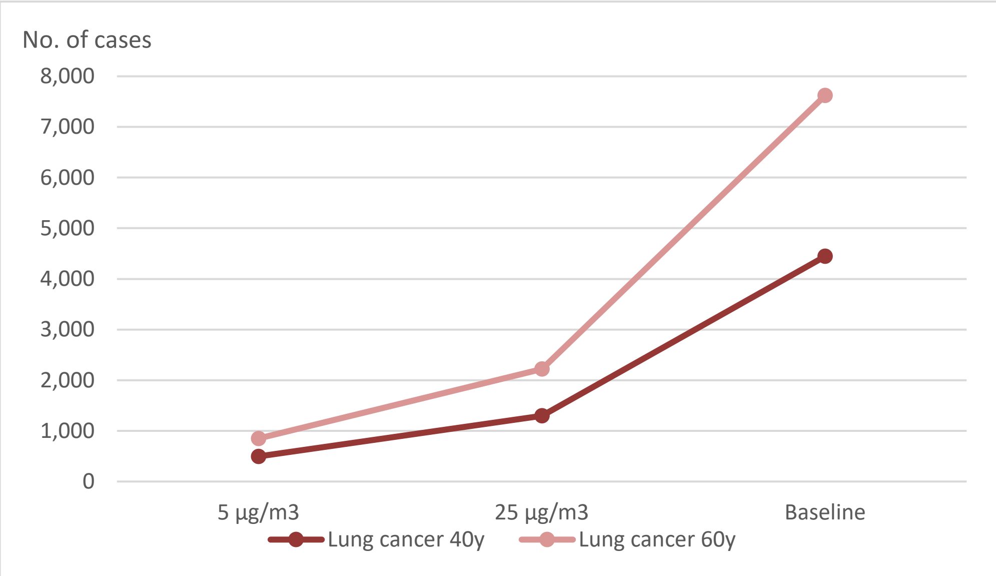

Figure 4-2: Lung cancer cases due to occupational exposure to Cr(VI) relation to different OELV levels

Table 4-9: Cr(VI) compounds - Summary of the baseline burden of disease, cont.

CBD no. of other adverse health effects over 60 years	FDB - no. of cases over 60 years	Exp. no. of deaths FDB cancer, 60 years	Exp. no. of deaths FDB other adverse health effects, 60 years	Monetary value FDB, 60 years*, EUR millions	Monetary value FDB other adverse health effects, 60 years, EUR millions
No other effects	7,619	5,587	No other effects	6,200	No other effects
CDB - Current disease burden; FDB - Future Disease Burden * Method 1					

4.4 Benefits to workers & families

The benefits (avoided costs of ill health) for workers and their families are calculated using the two methods summarised below. These equal the cost of ill health under the baseline scenario, less the cost of ill health following the introduction of an OELV.

Table 4-10: Benefits for workers and their families (avoided cost of ill health). Source: Modelling by COWI/RPA		
Stakeholder group	**Costs**	**Method of summation**
Workers/family	Ci, Cl, Cvsl, Cvcm, Cdaly	Method 1: *CtotalWorker&Family=Ci+Cvsl+Cvcm* Method 2: *CtotalWorker&Family=Ci+Cl+Cdaly*

The benefits of each reference OELV are summarised below.

Method 1 relies on WTP values for mortality and morbidity.

Table 4-11: METHOD 1: benefits to WORKERS & FAMILIES (reference OELVs vs baseline), € millions			
Reference point (inhalable)	**5 µg/m³**	**25 µg/m³**	**Baseline**
	Constant workforce		
Lung cancer	€5,439 million	€4,337 million	0
Total	€5,439 million	€4,337 million	0

The benefits calculated on the basis of Method 1 are depicted below.

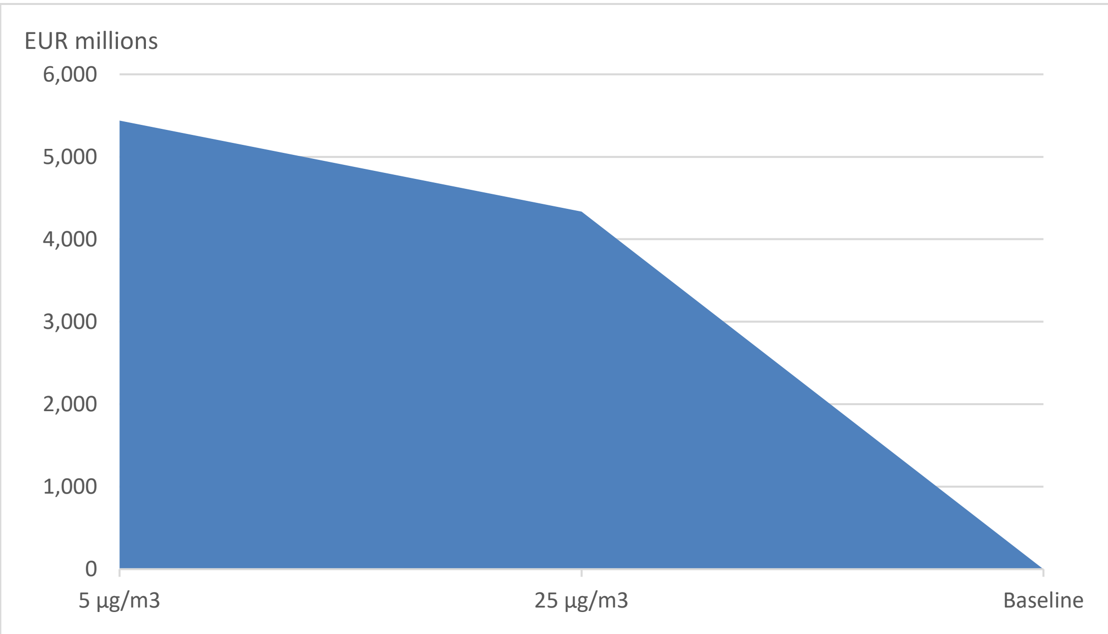

Figure 4-3: METHOD 1: benefits to WORKERS & FAMILIES (reference OELVs vs baseline), € millions

Method 2 relies on monetised DALYs.

Table 4-12: METHOD 2: benefits to WORKERS & FAMILIES (reference OELVs vs baseline), € millions			
Reference point (inhalable)	**5 µg/m³**	**25 µg/m³**	**Baseline**
	Constant workforce		
Lung cancer	€3,546 million	€2,828 million	0
Total	€3,546 million	€2,828 million	0

The benefits calculated on the basis of Method 2 are depicted below.

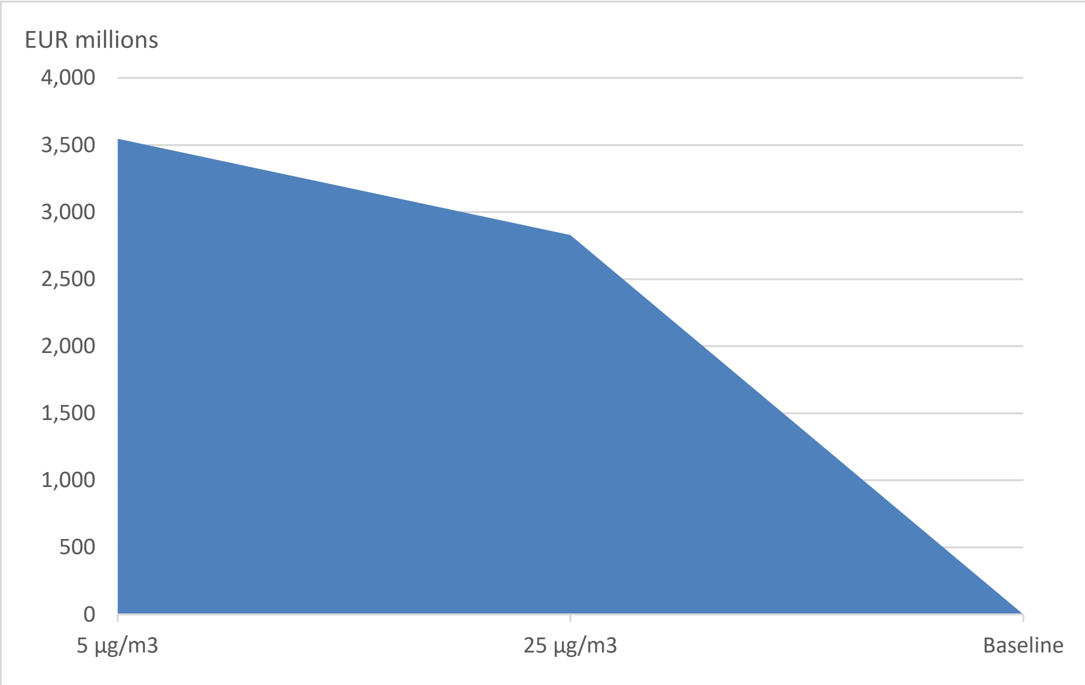

Figure 4-4: METHOD 2: benefits to WORKERS & FAMILIES (reference OELVs vs baseline), € millions

4.5 Benefits to the public sector

The benefits (avoided costs of ill health) for the public sector are calculated using the method summarised below.

Table 4-13: Benefits to the public sector (avoided cost of ill health)		
Stakeholder group	**Costs**	**Method of summation**
Governments	Ch, part of Cp (loss of tax revenue), part of Cl (loss of tax revenue)	*CtotalGov=Ch+0.2(Cp+Cl)*[22]

[22] Assumes 20% tax.

The benefits of each reference OELV are summarised below.

Table 4-14: Benefits to the PUBLIC SECTOR (reference OELVs vs baseline), € millions. Source: Modelling by COWI/RPA			
Reference point (inhalable)	**5 µg/m³**	**25 µg/m³**	**Baseline**
	Constant workforce		
Lung cancer	€63 million	€51 million	0

The benefits to the public sector are also depicted below.

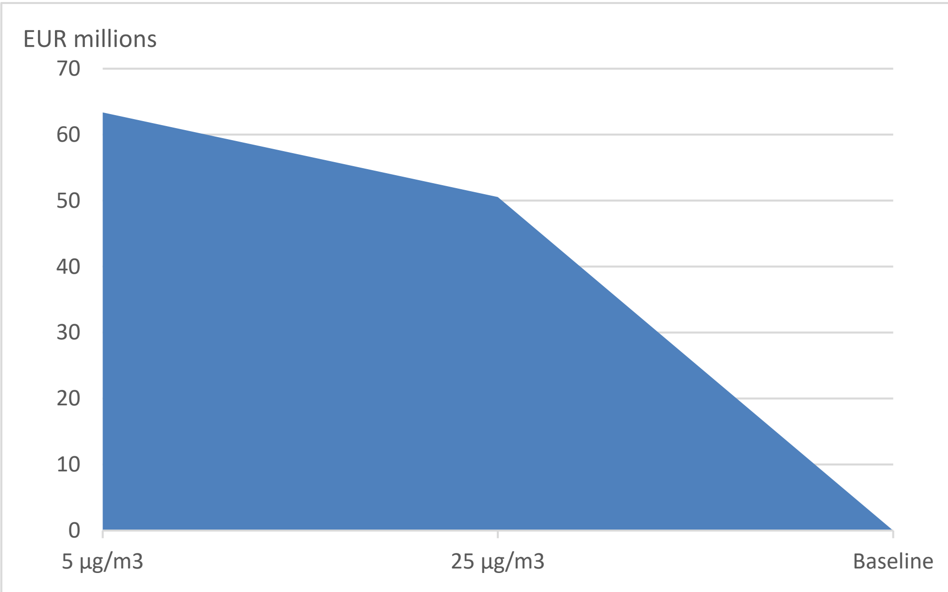

Figure 4-5: Benefits to the PUBLIC SECTOR (reference OELVs vs baseline), € millions

4.6 Benefits to employers

The benefits (avoided costs of ill health) accrued by employers are calculated using the method summarised below.

Table 4-15: Benefits to EMPLOYERS (avoided cost of ill health)		
Stakeholder group	**Costs**	**Method of summation**
Employers	Ce, Cp	*CtotalEmployer=Ce+0.8*Cp*

The benefits of each reference OELV are summarized below.

Table 4-16: Benefits to EMPLOYERS (reference OELVs vs baseline). Source: Modelling by COWI/RPA			
Reference point (inhalable)	**5 µg/m³**	**25 µg/m³**	**Baseline**
	Constant workforce		
Lung cancer	€28 millions	€23 millions	0
Total	€28 millions	€23 millions	0

The benefits to employers are also depicted below.

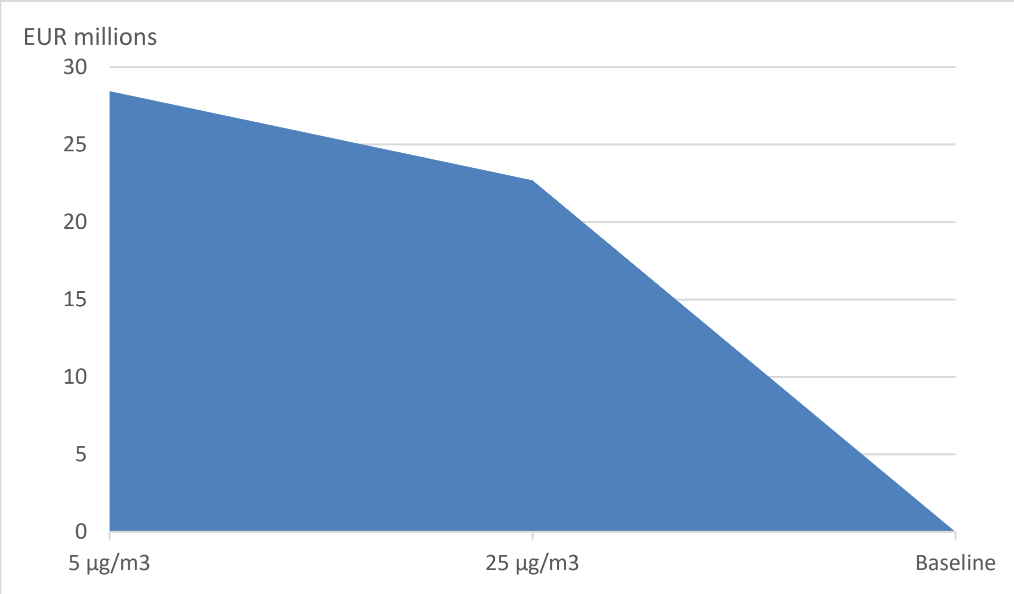

Figure 4-6: Benefits to EMPLOYERS (reference OELVs vs baseline), € millions

4.7 Aggregated benefits & sensitivity analysis

4.7.1 Aggregated benefits

Cost of ill health

The total costs of ill health (over 60 years) are summarised below for the baseline and each of the two reference OELVs.

Method 1 relies on WTP values for mortality and morbidity.

Table 4-17: METHOD 1: total cost over 60 years of ill health (baseline and reference OELVs), € millions. Source: Modelling by COWI/RPA

Reference point (inhalable)	5 µg/m³	25 µg/m3	Baseline
	Constant workforce		
Lung cancer	€692 millions	€1,808 millions	€6,199 millions
Notes: All benefits are relative to the baseline (PV over 60 years)			

The total costs calculated on the basis of Method 1 are depicted below.

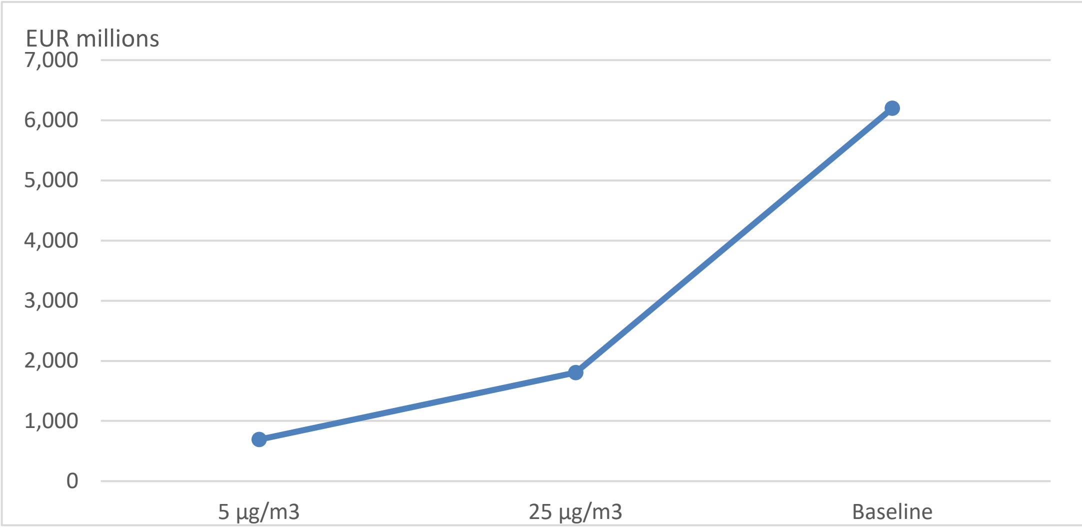

Figure 4-7: METHOD 1: total cost of ill health (baseline and reference OELVs), € millions

Method 2 relies on monetised DALYs.

Table 4-18: METHOD 2: total cost over 60 years of ill health (baseline and reference OELVs) , € millions

Reference point (inhalable)	5 µg/m3	25 µg/m3	Baseline
	Constant workforce		
Lung cancer	€454 millions	€1,187 millions	€4,069 millions
Notes: All benefits are relative to the baseline (PV over 60 years)			

The total costs calculated on the basis of Method 2 are depicted below.

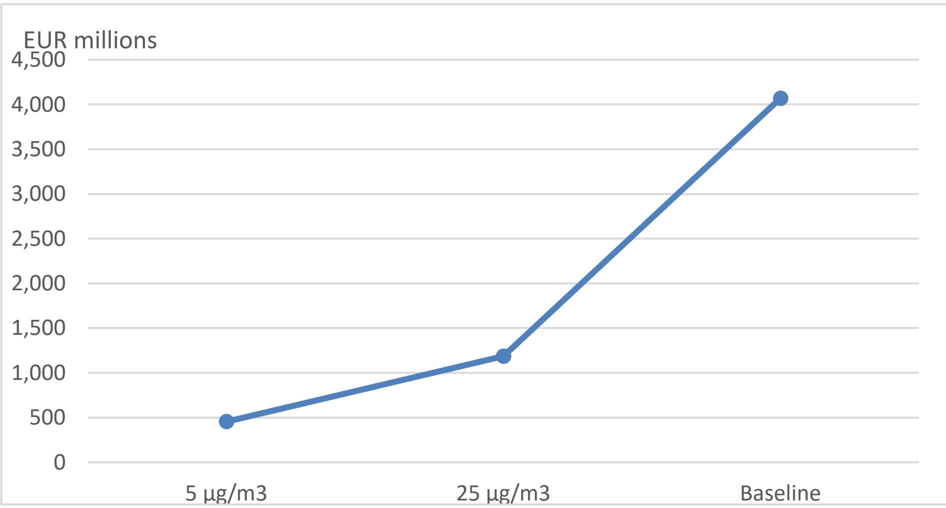

Figure 4-8: METHOD 2: total cost of ill health (baseline and reference OELVs), € millions

Benefits – avoided ill health vis-à-vis the baseline

The benefits of each reference OELV are summarised below. These equal the cost of ill health under the baseline scenario, less the cost of ill health following the introduction of an OELV.

Method 1 relies on WTP values for mortality and morbidity.

Table 4-19: METHOD 1: total cost over 60 years of ill health (reference OELVs vs baseline), EUR millions			
Reference point (inhalable)	5 µg/m^3	25 µg/m^3	Baseline
Constant workforce			
Lung cancer	€5,507 millions	€4,391 millions	€0
Total	€5,507 millions	€4,391 millions	€0

The benefits calculated on the basis of Method 1 are depicted below.

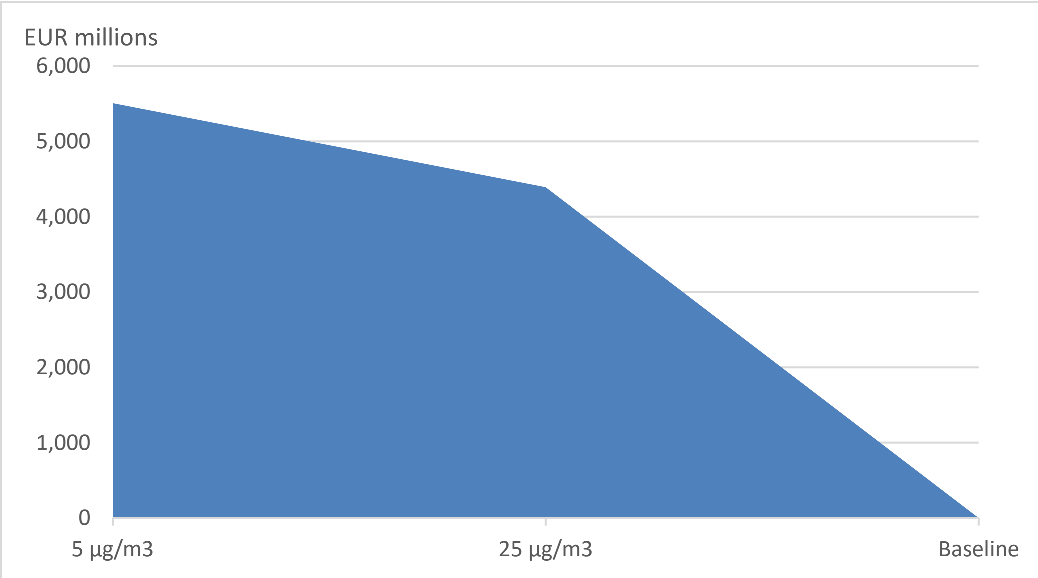

Figure 4-9: METHOD 1: benefits from avoided ill health (reference OELVs vs baseline), € millions

Method 2 relies on monetised DALYs.

Table 4-20: METHOD 2: benefits from avoided ill health (reference OELVs vs baseline), € millions			
Reference point (inhalable)	5 µg/m^3	25 µg/m^3	Baseline
Constant workforce			
Lung cancer	€3,615 millions	€2,882 millions	0
Total	€3,615 millions	€2,882 millions	0

The total benefits calculated on the basis of Method 2 are depicted below.

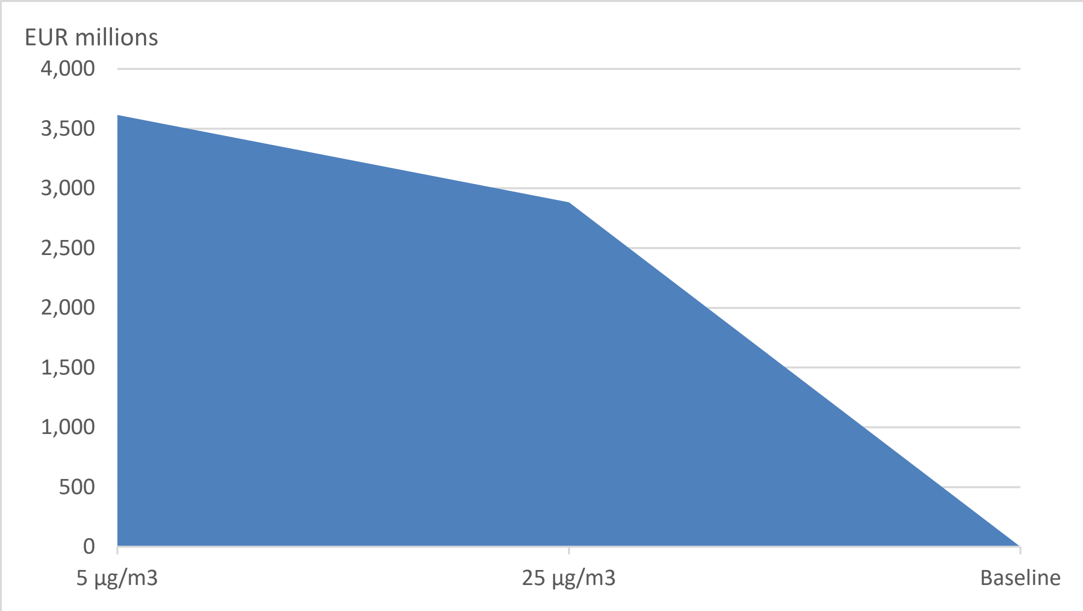

Figure 4-10: METHOD 2: benefits from avoided ill health (reference OELVs vs baseline), € millions

4.7.2 Sensitivity analysis

Some of the uncertainties related to the input data from the baseline scenario used for the benefit calculation have been described in sections 3.4.2, 3.5 and 3.15.5 and are briefly mentioned here.

The exposure concentrations used for the calculations originate from measurements in working environments with anticipated high/measurable exposures (reported by Pesch *et al*., 2015, and IFA, 2012) and are in the high end of reported exposure concentrations compared to other publications. In some exposure situations (especially high exposures), workers may be additionally protected by use of PPE, which is not accounted for in the exposure data and in the calculation of the cost estimate. Furthermore, the reported exposure concentrations were typically based on sampling for 2 hr and may thus not be fully suitable for comparison to OEL(V)s based on 8 hr TWA concentrations. Furthermore, the estimated disease burden for the highest exposure concentration interval may be too high as there are presumably more workers exposed in the lower area of the interval, while the benefits model calculates with an average of the range. This opens for the possibility that the benefit estimate could be overestimated.

The exposed workforce estimates for thermal cutters and thermal sprayers are conservatively estimated, likewise favouring an overestimation of the benefit estimates.

It is assumed that the **trend in exposure concentrations** is -1% p.a. in the past and in the future. According to communication with the industry, the trend is set cautiously, as allegedly use of LEV and PPE has become significantly more widespread during the last decades. However, the data from the MEGA database do not support the declining trend considering data over a 16 year period (1994 - 2009). A bias is possible due to the sampling strategy for the Cr(VI) data in the MEGA database. Possibly, the declining trend is underestimated. This could mean an overestimation of the benefits.

Distribution of workers into exposure concentrations ranges. For every process, the number of workers exposed to a given concentration has been estimated using a lognormal distribution fitted to the median and the percentiles (P75, P90, and P90) data from the MEGA dataset. For the calculation of the number of cancer cases, the workers have been distributed into eight exposure concentration bands based on the fitted distributions. The uncertainty introduced by assigning the number of workers to concentrations bands based on the fitted distribution is considered to be low.

Considerable uncertainties are related to the **calculation of cancer cases based on the ERR** (see section 2.4 Exposure-Risk-Relationship). The ERR was developed based on exposure to Cr(VI) via inhalable particles. Therefore, the calculated number of cancer cases is subject to the hypothesis that the Cr(VI) content in fumes from welding or plasma cutting processes and similar work processes (respirable fraction) is decisive for lung cancer with equal potency as is Cr(VI) exposure, *e.g.*, from chrome plating (inhalable fraction). The number of cancer cases was calculated adequately with exposure concentrations of Cr(VI) from inhalable particles (consisting almost entirely of respirable particles in welding). Given the carcinogenic potency of the respirable particle fraction is higher than of the inhalable particle fraction, the number of cancer cases may be underestimated, leading to a potential underestimation of the benefits estimate. However, co-exposure to further chemical agents within respective fumes may influence carcinogenic potency of the Cr(VI) fraction with – currently – no unambiguous scientific understanding of the type of combination effects (increasing, reducing potency or with no mutual influence).

Further uncertainties with the establishment of a reliable ERR for Cr(VI) from welding, thermal cutting and thermal spraying are related to:

- the high variability in exposure between and within the same processes
- the influence of the solubility of the Cr(VI) compounds on the toxicokinetics
- the variable particle size distribution
- completeness of endpoints.

The uncertainties related to ERR, which in summary tend to underestimate the total number of cases of disease and therefore also the benefits estimate, are further elaborated in the Box below.

Sensitivity analysis of toxicological parameters (ERR, DRR)

Benefits of alternative OELs for inorganic Cr(VI) compounds depend on the toxicological parameters (ERR, DRR), as derived in Section 2.4 in this report. However, those parameters include some uncertainties, because of the completeness of endpoints (Are all relevant tumour locations addressed? Are all relevant non-cancer endpoints covered?), and because of the respective selected slope of the ERR or DRR (effects and severity in higher doses compared to lower doses).
The risk analyses for lung cancer is based on the key studies reported in Section 2.4.2, where all resulted in risk estimates within a narrow range of 2-6 x 10^{-3} at workplace concentrations of 1 µg/m3. There are reasons to consider a sublinear dose response and a linear extrapolation applied may be regarded as a conservative approach. However, all occupational risk assessments are based on linear extrapolation, as it is also suggested by SCOEL (2017). However, some assessments find it too uncertain to apply linear extrapolation to low concentrations < 1 µg/m³ (*e.g.*, AGS, 2014, who limit the risk quantification to concentrations ≥ 1 µg/m³).
Besides the lung system with the strongest evidence as target organ at occupational exposure to Cr(VI) there are weaker and less consistent data on nasal and sinonasal carcinogenicity and tumours of the gastrointestinal tract (IARC, 2012). A total of ten cohort studies report 25 cases of nasal or sinonasal cancer, a rare tumour type. From four of them, a Standard Mortality Ratio (SMR) could be stated and the pooled analysis revealed a SMR of 8.0 based on 12 cases, but several studies failed to detect or did not mention any cases (publication and reporting bias). IARC (2012) concluded that the aggregate epidemiological evidence is suggestive, but inconclusive for an effect

of Cr(VI), and 12 case reports without cumulative exposure information are even more difficult to assess for relevance. There is little evidence of an association between stomach cancer and exposure to Cr(VI): there is an equal number of SMR point estimates above and below 1.0 in the 12 studies available, and only 2 of them reported significantly increased SMR of about 2.0 (IARC, 2012). Few publications report increased risk also for pancreas, prostate and bladder. With regard to the latter endpoints, IARC stated that "the number of reports of excess risk is unremarkable in the context of the numbers of studies that have been conducted" and these endpoints were not considered further (IARC, 2012). Thus, quantitative data from single studies provide a higher or lower relative risk (standard mortality ratio or odds ratio) compared to lung cancer. Therefore no conclusions in the shift of the slope for the ERR (all cancer sites vs. most significant cancer site) can be provided in this sensitivity analysis. Moreover, there exists no adequate methodology to discriminate the occurrence of multiple cancers in identical persons or the additive occurrence of cancers in different persons (hence, additional cancer cases, if more cancer sites are considered). Therefore a quantitative sensitivity analysis is not feasible, but it may be concluded that the reference to only lung cancers tends to underestimate total number of cancer cases to be expected after occupational exposure to Cr(VI). Specific uncertainties to apply the cancer risk estimate for exposure to Cr(VI) in fumes from welding, plasma cutting and similar processes have been discussed in Section 2.4.2.

Beyond carcinogenicity, Cr(VI) exerts relevant non-cancer effects:

- Skin sensitisation and corrosion from dermal exposure
- Respiratory effects including effects in the upper and lower respiratory tract from inhalation exposure,
- Reproductive effects at elevated exposure levels or from oral exposure (which may not be relevant for occupational exposure).

It is currently not possible to link non-cancer effects from welding or plasma cutting processes and similar work processes that generate fume to Cr(VI) exposure in a quantitative way. Similar effects may also occur from other components within the welding/thermal cutting or spraying process and an additivity assumption (providing an attributable fraction of the effects to the single components of such fumes) appears not to be justified. This is specifically true for non-cancer respiratory effects. Neither for skin-sensitisation are sufficient potency assessments available. Because non-cancer endpoints have not been selected for this assessment (the studies often do not provide a dose response relationship validated for the occupational exposure scenario fumes from welding and similar processes) and because those studies are not equally analysed for reliability, a quantitative sensitivity analysis is not feasible. However, it may be concluded that the reference to only cancer effects tends to underestimate total number of cases of disease to be expected after occupational exposure to Cr(VI) in fumes from welding and similar processes.

The short **latency period of 10 years** for lung cancer is a protective chosen parameter potentially overestimating the benefit estimates.

Cases after the 60-years period - Due to the applied latency time of 10 years, approximately 1/6 of the cancer cases will occur after the 60-years assessment period. This systematically underestimates the long-term benefits of introduction of the OELV as a significant part of the cancer cases induced by the exposure during the 60 years period does not contribute to estimated costs of cancers (in case the OELV is not introduced).

The **monetary valuation** of the health end point is also subject to uncertainty. The specific values applied, for example the value of a statistic life, is drawn the literature and are best practice estimates. The methodology report includes more details. The use of two alternative methods, one using willingness to pay estimates of the value of statistical life and one using DALY, is not per se a reflection of uncertainty, but it reflects of the challenges of monetary valuation. In this case the two methods give results which vary in the order of 50%. This might be considered as indication of the uncertainty of the monetary valuation itself.

5 Costs of expiration of the transition period

5.1 Introduction

This section comprises the following subsections:

- Section 5.2: The costs framework
- Section 5.2: OELVs – compliance costs for companies
- Section 5.3: OELVs - indirect costs for companies
- Section 5.4: OELVs - costs for public authorities
- Section 5.5: Aggregated costs & sensitivity analysis

5.2 The costs framework

5.2.1 Summary of the cost assessment framework

The first step in estimating the economic impacts of introducing a new OELVs for Cr(VI) was the development of a cost framework describing the different cost components (direct, indirect and intangible; one-off versus recurring) and the determination of the assessment period.

In line with the more general impact assessment requirements of BR Tool #19, this first involved determining which of the potentially relevant impacts are expected to be significant and should thus be subject to a detailed cost assessment.

Taking into account the direct and indirect behavioural changes as well as potential ultimate impacts, the most relevant impacts were selected on the basis of the following factors:

- The relevance of the impact within the intervention logic;
- The absolute magnitude of the expected impacts;
- The relative size of expected impacts for specific stakeholders (such as impacts which may be small in absolute terms but may be particularly significant to specific types of companies, regions, sectors, etc.); and
- The importance of the impacts for Commission horizontal objectives and policies.

The table below summarises the impact categories that could be significant and that are thus assessed in this report, together with the relevant questions considered in this section (costs for companies and public authorities) and the next section (impacts on competitiveness, etc.).

Table 5-1: Assessment of the most significant economic impact categories

Impact category	Key impacts
Operating costs and conduct of business	• Will it impose additional adjustment, compliance or transaction costs on businesses? • Does it impact on the investment cycle? • Will it entail the withdrawal of certain products from the market? • Will it lead to new or the closing down of businesses? • Are some products or businesses treated differently from others in a comparable situation?
Administrative burdens on businesses	• Does it affect the nature of information obligations placed on businesses?

Table 5-1: Assessment of the most significant economic impact categories	
Impact category	**Key impacts**
Trade and investment flows	• How will the option affect exports and imports out of and into the EU? Will imported products be treated differently to domestic goods? • How will investment flows be affected and the trade in services? • Will the option affect regulatory convergence with third countries? • Have international standards and common regulatory approaches been considered?
Public authorities	• Does the option have budgetary consequences for public authorities at different levels of government (EU own resources, national, regional, local), both immediately and in the long run? • Does it bring additional governmental administrative burden? • Does the option require the creation of new or restructuring of existing public authorities?
Consumers and households	• Does the option affect the prices consumers pay for goods and services? • Does it have an impact on the quality or safety of the goods/services consumers receive? • Does it affect consumer choice, trust or protection? • Does it have an impact on the availability or sustainability of consumer goods and services?
Specific regions or sectors	• Does the option have significant effects on certain sectors? • Will it have a specific impact on certain regions, for instance in terms of jobs created or lost? • Is there a single Member State, region or sector which is disproportionately affected (so-called "outlier" impact)?
Source: BR Tool #19	

The costs assessed in this section, together with an indication of which stakeholders are likely to be affected, are presented below.

Table 5-2: Cost impacts on different stakeholders						
Type of cost		**Citizens**	**Consumers**	**Workers**	**Enterprises**	**Public authorities**
Direct	Compliance costs				✓	✓
Indirect	Product choice/price				(✓)	
Enforcement	Measurements & inspections				✓	✓

These costs are assessed below qualitatively and, whenever possible, quantitatively.

A continuous cost function has been developed by means of estimating the costs for the reference OELVs and other significant tipping points, and subsequently connecting these estimated to estimate the costs for the intervening OELV values.

5.3 OELVs – compliance costs for companies

5.3.1 Introduction

Compliance costs are defined as the additional costs of complying with an OELV, *i.e.* the costs incurred by companies in bringing down their exposure to levels below the OELV. The total compliance cost of the introduction of an OELV depends on the number of companies above the OELV and the cost for each company of reducing the exposure concentration to a level below the OELV. The costs for each company depend on the relevant processes, number of workers and the gap between the actual exposure and the OELV, as well as the type of RMM needed to bridge the gap.

The method used to estimate the compliance costs for companies is based on the same cost model, which has been applied in the substance report for Cd, but with specific input data for Cr(VI) as described below.

5.3.2 Current exposure levels

The key input parameters for the cost and benefit estimation models developed for this study is the distribution of the exposure levels across companies or facilities and workers. Whilst the distribution function for the benefit model focuses on the distribution of the workforce over different exposure concentrations, the key parameter for the cost function is the distribution of companies across different exposure levels.

The relevant reference points have been assigned to the different size bands on the basis of the numbers of exposed workers and information about company sizes from the stakeholder consultation.

Table 5-3: Cost model inputs – size bands

Size band	Number of companies
Large (average 63 exposed workers)	8
Medium (average 37 exposed workers)	657
Small (average 7 exposed workers)	3397

The distribution of the companies over exposure concentrations is summarised in the figure below.

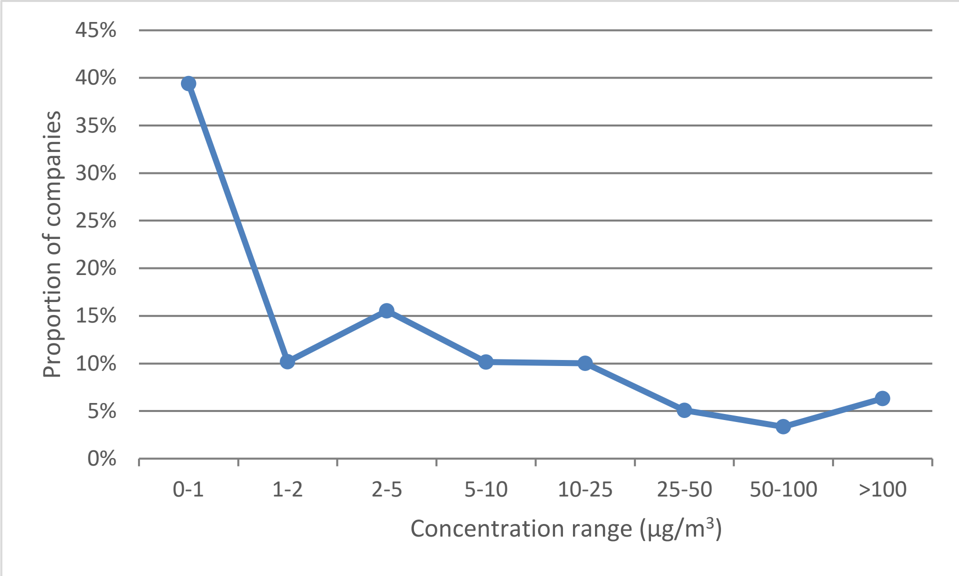

Figure 5-1: Proportion of companies in the modelling input data distributed over exposure concentration ranges. Please note that the concentration ranges are not equally large.

Figure 5-1 indicates that based on the exposure concentrations reported from the MEGA database (see section 3.5) 65% of the companies can be anticipated to already comply with an OELV of 5 µg/m³, while 85% can be anticipated to comply with the current OELV of 25 µg/m³.

The distribution in the figure above, together with information on current RMMs collected through consultation (see, for example, Section 3.6), has been used to estimate the distribution of current RMMs by company.

Table 5-4: Percentage breakdown of RMMs currently used by enterprises

Type of RMM	% of small enterprises currently with this type of RMM	% of medium enterprises currently with this type of RMM	% of large enterprises currently with this type of RMM
Full enclosure LEV1	5%	15%	20%
Partial enclosure LEV2	5%	5%	5%
Open hood LEV3	50%	40%	40%
Pressurised or sealed cabin WE2	0%	0%	0%
Simple enclosed cab WE1	10%	10%	10%
Powered helmets or full face mask RPE3	5%	5%	5%
Mask with a HEPA filter RPE2	0%	0%	0%
Simple mask RPE1	0%	0%	0%
Organisational measures OH1	5%	5%	5%
General dilution ventilation GDV1	10%	15%	15%
Nothing	10%	5%	0%

5.3.3 Sector/use-specific cost curves

Estimation using the cost model developed for this study

Model inputs

In the table below, the exposure to fumes from welding, thermal cutting and thermal spraying is roughly characterised according to duration, gas/particle exposure and spreading. These values were built into the cost model.

Table 5-5: Cr(VI) – Duration of exposure, form of exposure and extent of spread of Cr(VI) in fumes from welding, thermal cutting and thermal spraying. (Source: Study team estimates based on stakeholder consultation)

Sector	<1h	>1h	Dust	Gas	Local	Diffuse	Peripheral
Stainless steel welding, thermal cutting and thermal spraying	10%	90%	95%	5%	90%	10%	0%
Note: Dust = dust and fibres, Gas = vapour, gas, mist							

Model output

The total compliance costs over 60 years (CAPEX and OPEX) are shown below as estimated by the cost model.

Table 5-6: Additional compliance costs for the reference OELVs (PV CAPEX and OPEX over 60 years) excluding measurement costs, € millions. Source: Modelling by COWI/RPA

Sector	5 µg/m^3	25 µg/m^3	*Baseline*
Stainless steel welding, thermal cutting and thermal spraying	€8,971 million	€3,491million	0
Notes: All values expressed as inhalable fraction.			

5.3.4 Measurement costs

It is expected that all companies that would have to reduce exposure would need to re-measure to demonstrate compliance with the new OELV. The table below estimates the numbers of companies that would have to pay for air sampling and analysis.

Table 5-7: Estimated number of companies that would have to remeasure Cr(VI) in fumes from welding, thermal cutting and thermal spraying.

Reference OELV	Number of companies
25 µg/m3	598
5 µg/m3	1,417
Note: Exposure concentrations expressed as inhalable fraction.	

Estimates of costs of monitoring air concentrations of the six substances subject to this contract (As, Be, Cd, Cr(VI), CH_2O, and MOCA) have been developed for a number of EU Member States; see the methodology report for detailed and itemised estimates. The resulting costs for Cr(VI) are summarised below.

Table 5-8: Estimated cost of a monitoring campaign	
Member State	**Cost per company**
Denmark	€12,000
Greece	€6,000
Lithuania	€4,000
Poland	€5,000
Slovenia	€6,000
UK	€10,000
Average of DK, EL, PL, UK	€8,000

These estimates are somewhat lower than previously estimated in RPA (2017[23]).[24] However, it is expected that only some workers would be monitored in each company and the two sets of cost estimates are seen as broadly consistent.

The cost of carrying out additional measurements is estimated below.

Table 5-9: Cost of air sampling and analysis		
Reference OELV	**Number of companies**	**Cost**
25 µg/m3	598	€ 4,784,000
5 µg/m3	1417	€ 11,336,000
Note: Exposure concentrations expressed as inhalable fraction.		

5.3.5 Sum of all compliance costs

The total compliance costs are shown below as estimated by the cost model.

Table 5-10: Sum of all costs for the reference OELVs (PV CAPEX and OPEX over 60 years)			
Cost	**5 µg/m³**	**25 µg/m³**	**Baseline**
Total across all sectors /companies /stakeholders	€8,983 million	€3,496 million	0
Notes: All values expressed as inhalable fraction.			

23 RPA (2017): Second study to collect updated information for a limited number of chemical agents with a view to analyse the health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC

24 The cost of monitoring can be in the range of €1,000-€3,000 per worker which includes the cost of equipment, monitoring by an occupational technician (one of which is required to monitor 3-5 people at a cost of €800-1,200 per day) and sample analysis (the cost of analysis per sample has been estimated to range between €50-€100). The frequency of sampling depends on the requirements of specific national authorities but, in general, repeat monitoring may not be necessary if the production process does not change.

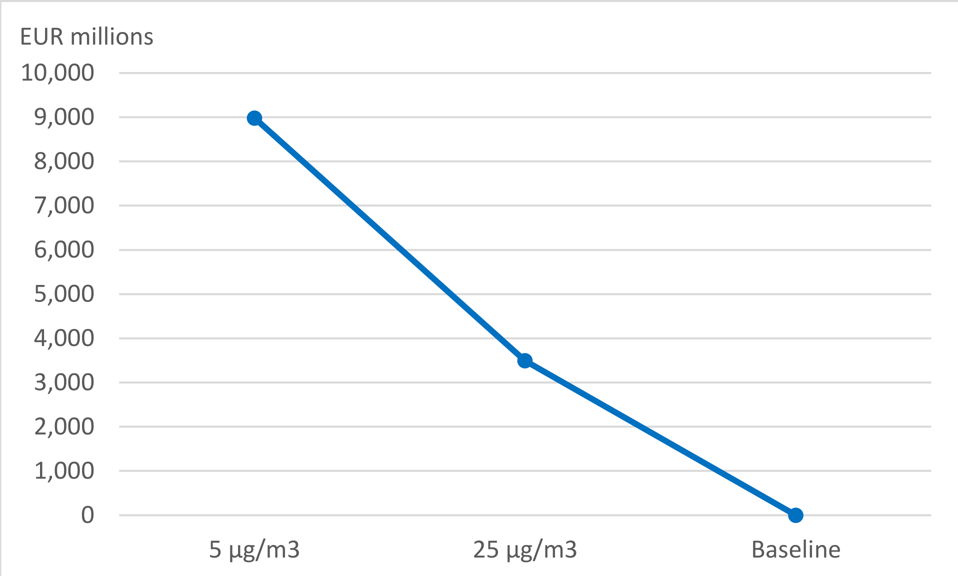

Figure 5-2: Sum of all costs for the reference OELVs (PV CAPEX and OPEX over 60 years), € millions
Note: Exposure concentrations expressed as inhalable fraction.

5.4 OELVs – indirect costs for companies

Indirect costs could include possible ripple effects through value chain and the potential for costs to be passed on to users further down the value chain or consumers.[25]

Examples of indirect costs that could be incurred by economic actors as a result of achieving compliance with new limits include:

- Availability of products; and
- Choice of products.

The effects on the downstream supply chain or consumers depends on whether affected companies in the stainless steel industry will cease to continue their operation, change their products or pass on the compliance costs.

In section 6 on Market Effects, these issues are further explored. Overall, the estimated compliance costs are not insignificant. However, for SMEs, it could be challenging to finance the up-front investments needed for compliance. On the other hand, stainless steel products are generally high value products; for example to the food industry. Hence, in many cases the affected companies could pass on the costs.

5.5 OELVs – costs for public authorities

The impacts on public authorities, mainly at the national level but in some Member States also at the regional level, are expected to relate to:

[25] Impacts on consumers are considered in Section 6 (Market effects).

- the cost of adapting national legislation and procedures to the new OELV (where the Member State is above the OELV); and
- the enforcement of the new OEL.

It is not expected that there will be a significant cost to national authorities in the Member States which already have an OEL for Cr(VI).[26] Member States where this is not the case may incur a one-off cost for changing their legislation and a recurring cost of increased enforcement. Thus, although the specific OELV level will determine whether a Member State needs to revise legislation, the transposition and implementation costs are unlikely to depend on the specific values so there will only be a cost difference between the baseline scenario and scenarios where a new OEL is introduced in a Member State.

In addition, the cost of legislative change will only be incurred once, regardless of whether one or several chemical agents are covered, and whether an OELV or also a STEL and/or skin notation is introduced.

5.5.1 Cost of transposition

Of the 28 EU Member States, research carried out for this study has confirmed that 23 have an OEL(s) for Cr(VI). There is no information with regard to a Cr(VI) OEL for the following Member States and this study thus assumes that they do not have an OEL for Cr(VI): Cyprus, Italy, Luxembourg, Malta and Portugal. It is thus assumed that these five Member States would incur costs for transposing an OELV introduced under the CMD.

Specific data on the costs of transposition of EU legislation by Member States and their relevant departments/ministries are not readily available. As noted in RPA (2012)[27], one UK impact assessment states that *"the costs of amending current regulations to implement a Directive are thought to be around £700,000"* (around €900,000 in €2017). Although no details are given on the basis for this calculation, it is expected that these costs relate to a rather substantial legislative change and would include those costs of making (*e.g.* preparing an impact assessment, drafting a substantial bill and presenting the legislation before parliament), printing and publishing the legislation. This estimate is significantly higher than the cost estimated in UK Department for Transport (2011) which notes that *"a combination of legal and technical resources as well as policy advisors are usually required to implement such a change, costing approximately £15,687 per amendment"* (approximately €20,000 in €2017).

Considering that all Member States have transposed the CMD which already contains a number of OELVs, it appears more likely that the cost of transposing an additional OELV would be closer to the low-end estimate. However, it is also appears that there has been a general trend towards increased impact assessment in the Member States (see, for example, RPA 2015[28]), which suggests that the costs would likely be higher than €20,000. This study thus takes €50,000 per Member State as an approximation of the general order of magnitude of the applicable transposition costs.

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[26] Some Member States may carry out Impact Assessments on the transposition of EU legislation but this cost is not considered here.

[27] RPA (2012): Ex-Post Evaluation and Impact Assessment Study on Enhancing the Implementation of the Internal Market Legislation Relating to Motor Vehicles, http://www.rpaltd.co.uk/documents/J746_MotorVehicleLegislation_FinalReport_publ.pdf

[28] RPA (2015): Study on the potential of impact assessments to support environmental goals in the context of the European Semester, available at http://ec.europa.eu/environment/integration/green_semester/pdf/J856.pdf

Table 5-11: Transposition costs. Source: COWI/RPA		
Member States with no OEL	**Transposition cost per Member State**	**Total cost across the EU**
5 Member States: Cyprus, Italy, Luxembourg, Malta and Portugal	€50,000	€250,000

It is assumed that for Member States that already have an OEL for Cr(VI), the change to a different value (in case the OEL were to be higher than the OELV) would entail no significant costs.

5.5.2 Enforcement costs

The enforcement costs depend on the number of companies that will be covered by the OELV. In principle, national authorities are supposed to inspect companies already as they have the general obligation to protect workers. However, there could be an additional cost due to the need to ensure compliance with the new rules. Such enforcement costs depend on the inspection regime in each country and they are not estimated in this study.

5.6 Aggregated costs & sensitivity analysis

5.6.1 Aggregated costs

The total compliance costs over 60 years are set out below for welding, thermal cutting and thermal spraying. Although the impact of the fact that no deduction could be made for the baseline CAPEX was, to some extent, offset by means of incurring only a single CAPEX over 60 years, it is possible that the data in the table below may still be overestimates. In addition, these costs do not model the possibility of complying with an OELV by means of PPE.

Cost data estimated by the model developed for this study

The total compliance costs are shown below as estimated by the cost model.

Table 5-12: Sum of all costs for the reference OELVs (PV CAPEX and OPEX over 60 years). Source: Modelling by COWI/RPA			
Cost	**5 µg/m³**	**25 µg/m³**	**Baseline**
Total across all sectors /companies /stakeholders	€8,983 millions	€3,496 millions	€0
Notes: All costs are relative to the baseline (PV over 60 years)			

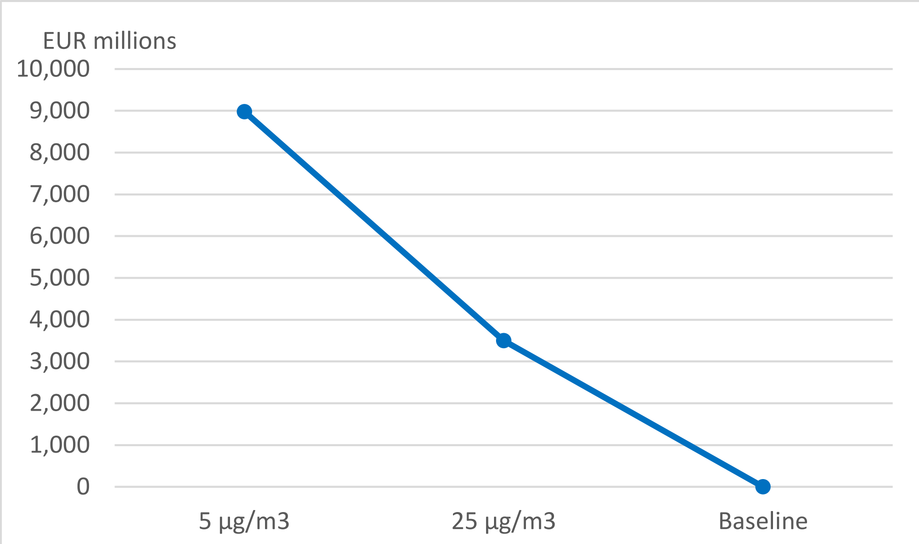

Figure 5-3: Sum of all costs for the reference OELVs (PV CAPEX and OPEX over 60 years), € millions
Note: Exposure concentrations expressed as inhalable fraction.

5.6.2 Sensitivity analysis

The estimate is sensitive to the assumption that monitoring of the workplace concentration will be required in all MS. In some MS, the enforcement may be limited to requiring compliance with national OEL of fume particle concentrations. On the other hand, it cannot be excluded that in some MS the authorities may use the OELV of 5 µg/m³ as a driver for reducing exposure to hazardous substances from welding and related processes and require that the workplace air concentration is measured regularly. In this case the total costs over the next 60 years would be higher.

The uncertainties related to the input data from the baseline scenario used for the cost calculation have been described in sections 3.4.2, 3.5 and 3.15.5 and are briefly mentioned here.

The exposure concentrations used for the calculations originate from measurements in working environment with anticipated high/measurable exposures (reported by Pesch *et al.*, 2015, and IFA, 2012) and are in the high end of reported exposure concentrations compared to other publications. In some exposure situations (especially high exposures), workers may be additionally protected by use of PPE, which is not accounted for in the exposure data and in the calculation of the cost estimate. This causes the cost estimate to be overestimated.

The number of companies was derived from the number of exposed workforce. The exposed workforce estimates for thermal cutters and thermal sprayers are conservatively estimated, favouring an overestimation of the cost estimate.

The distribution of companies on sizes and the number of companies are based on expert judgements and extrapolations, which may have no, an over- or underestimating effect on the cost estimate.

The estimated costs are based on a cost model that applied generic assumptions about what measures would be needed to insure compliance. There is some uncertainty about the whether there could individual companies facing either larger or lower costs. Overall, the uncertainty of the costs assessment might be in the order of 50%.

6 Market effects

This section comprises the following subsections:

- Section 6.1: Overall impacts (comparing compliance costs and turnover)
- Section 6.2: Impact on research and innovation
- Section 6.3: Impact on the single market
- Section 6.4: Impact on competitiveness
- Section 6.5: Impact on employment

6.1 Overall impact

The impacts of compliance costs can be compared to industry turnover to provide an indication of the significance of the estimated costs.

The exposed workers and companies belong to several types of industries. An average manufacturing turnover of €240,000 per employee can be used to give an indication of the cost implications. How the individual companies will be affected depends on how many of their employees are exposed workers. While there will be employees not exposed even the smallest companies a range could be applied assuming that the share is between 25% and 100%.

The results of this assessment are presented in Table 6-1. For the OELV of 5 µg/m³, the costs compared to turnover range from 0.8% to 3.2%. This level means that compliance costs are not insignificant and there could be cases where they would affect the operation of the company. The largest share of costs are investment costs, but not all of which are to be invested in the first year.

Table 6-1: Compliance costs compared to company turnover (PV over 60 tear assessment period)

	5 µg/m³	25 µg/m³
Compliance costs per worker in €	€0.18 million	€0.07 million
Turnover per worker over 60 years €	€5.4 million	
Compliance costs in % of turnover per exposed worker	3.2%	1.3%
Compliance costs in % of turnover assuming exposure of 25% of employees in the affected companies	0.8%	0.3%

How much estimated level of compliance costs would impact on the affected companies depend on their ability to pass on the costs their customers. Given that much of the stainless steel products are high value specialised equipment, it is not unlikely that they could pass on part of the costs.

6.2 Research and innovation

The magnitude of the estimate compliance costs suggests that there could be an impact on research and innovation in the effected industries. It is not possible to quantify the impacts.

6.3 Single market

6.3.1 Competition

A positively effect would be that the introduction of the common OELV for all EU producers will lead to more even competition across the affected industries. A negative effect would come if there are

SMEs closing their activities due the increased costs. This could potentially reduce the level of competition across the affected industries leading to higher prices for the customers.

6.3.2 Consumers

The affected industries mainly supply to other industries. Though there could be some impacts on the directly affected industries, and some might be able to pass on costs their direct customers, only very limited impacts could be expected for consumers in the form of marginally higher prices.

6.3.3 Internal market

There are two types of impacts. One is that a common EU OELV would lead to a more level playing field for companies in the affected industries. The other impacts, which is negative, would arise if the additional compliance costs would lead to companies closing down. Given that there are many SMEs, some of those could decide to close. This would decrease the level of competition leading to higher prices. It has not been assessed which effect is the more dominant. Overall, it is not expected that there will any major impacts.

6.4 Competitiveness of EU businesses

6.4.1 Cost competitiveness

Potentially, the production costs could be increased by 1-4% leading to a weaker competitiveness of the affected companies.

6.4.2 Capacity to innovate

As above, there could be a negative impact on the capacity to innovate. It has not been quantified.

6.4.3 International competitiveness

The increased production costs would weaken the international competitiveness of the affected industries. Many affected companies supply high value specialised equipment or repair such equipment. It is expected that they face less international competition and therefore it is assessed that there will be no major impacts.

6.5 Employment

It is not expected that there will be any overall reduction in the employment in the affected industries. There could be local effects if some companies would be faced to close down.

7 Environmental impacts

This section comprises the following subsections:

- Section 7.1: PBT screening
- Section 7.2: Current environmental levels in relation to hazard data
- Section 7.3: Current environmental exposure – sources and impact
- Section 7.4: Humans via the environment
- Section 7.5: Conclusion

7.1 PBT screening

Cr(VI) compounds as a group are very toxic to environmental organisms (H400, H410). The PNECsaqua in the REACH registrations dossiers of sodium chromate, potassium chromate and potassium dichromate are reported to 0 µg/L (assessment factor 10). Thus correctness, relevance and background of these values are unclear. The structurally related compounds chromium trioxide and sodium dichromate (formally not included in this analysis) have PNECs of 3 µg/L and 5 µg/L, respectively (assessment factor 10). These values are close to the PNEC of 3.4 µg/L derived by ECB (2005). The PNECssoil for all mentioned compounds are 35 µg/kg dry weight (assessment factor 10), with the exception of chromium trioxide with 31 µg/kg. A PNECssoil of 35 µg/kg dry weight was also derived by ECB (2005). A PBT assessment is not available for all compounds. If performed, it was “not PBT”: toxic, but not persistent and not bioaccumulative (ECHA Dissemination, 2017, as of November 2017).

7.2 Current environmental levels in relation to hazard data

Releases of Cr (VI) from any sources are expected to be reduced to Cr (III) in most situations in the environment. Therefore relevant increases in Cr(VI) are usually limited to the area around the source (ECB, 2005).

As most environmental concentrations were measured as total chromium, the data cannot be used for an assessment of a possible impact of Cr(VI) on organisms in the environment.

From the rare data for Cr(VI) given for regional concentrations in rivers and lakes in the USA, environmental concentrations in surface water usually are well below 1 µg/l. Reported PNECs (aquatic compartment) for Cr(VI) are in the range of 3 µg/l (ECB, 2005). Therefore it is expected that environmental concentrations of Cr(VI) are of no ubiquitous concern.

7.3 Current environmental exposure – sources and impact

Human exposure to chromium occurs from both natural and anthropogenic sources. The chromium release into the environment as a result of human activities accounts for 60-70% of the total emissions of atmospheric chromium (ATSDR, 2012).

The arithmetic mean concentrations of total chromium in the ambient air in USA, urban, suburban, and rural areas monitored during 1977–1984 ranged from 5 to 525 ng/m3, but were mostly below 100 ng/m3 (ATSDR, 2012). WHO (2003) report similar values: at most measuring stations in USA, the concentration was <300 ng/m3 and median levels were <20 ng/m3.

Chromium in the aquatic phase occurs either in a soluble state or as suspended solids adsorbed onto clayish materials, organics, or iron oxides. The majority of chromium in surface waters is deposited in sediments, the small remainder consists of soluble Cr (VI) or Cr (III) complexes. Though soluble Cr (VI) may persist, the majority is expected to be reduced to Cr (III) in the presence of organic matter or other reducing agents in water. Under rare oxidative conditions, Cr (III) may also be converted into Cr (VI). In the United States, total chromium concentrations were up to 84 µg/L in surface water and 0.2-1 µg/L in rainwater. The mean chromium concentration in ocean water was 0.3 µg/L. In the United States, groundwater concentrations are generally low (range of 2-10 µg/L) (ATSDR, 2012; WHO, 2003). Comparable low values have also been reported in Germany. Elevated drinking water concentrations were attributed to leakage from *e.g.* kitchen and bathroom fittings (Grohmann *et al*., 2003).

Disposal of chromium-containing commercial products may be the largest contributor to chromium in soil, accounting for approximately 51% of the total chromium released to soil, followed by the disposal of coal fly ash and bottom fly ash from electric utilities and other industries (33.1%), agricultural and food wastes (5.3%), animal wastes (3.9%) and atmospheric fallout (2.4%) (SCOEL, 2017). Therefore the air emissions may be estimated as negligible with respect to soil contamination.

Chromium in soils is predominantly in the oxidation state III, except under oxidative conditions. Cr (III) in soil is mostly present as insoluble carbonate and oxide, which will not be mobile in soil. The solubility of Cr (III) in soil and its mobility may increase due to the formation of soluble complexes with organic matter in soil, with a lower soil pH potentially facilitating complexation. Chromium has a low mobility for translocation from roots to the aboveground parts of plants. Total chromium concentrations in soils in USA were 37 mg/kg as geometric mean, with a range of 1-2000 mg/kg (ATSDR, 2012; IARC, 2012).

Currently there are no EU wide thresholds for chromium in fertilizers. In Germany, a limit concentration of 2 mg Cr(VI)/kg fertilizer dry weight is in place (BMJV, 2012/2017).

A possible increase of Cr (VI) emissions due to lower occupational limit values (more effective exhaust systems) will possibly impact environmental emissions to ambient air. The chromium release data provided in the European Pollutant Release and Transfer Register (E-PRTR) for the EU-28 states and also other emission data (*e.g.* ATSDR, 2012; ECB, 2005) are not helpful, because they are not linked to emissions of welding or plasma cutting processes and similar work processes that generate fume.

According to TA Luft for Germany (BMU, 2002), the emission of Cr (VI) compounds, except barium and lead chromate, is restricted to 0.15 g Cr/h or 0.05 mg Cr/m^3.

7.4 Humans via the environment

The EFSA Panel on Contaminants in the Food Chain (CONTAM) concluded that it can be considered 'that all the chromium ingested via food is in the trivalent form, in contrast to drinking water where chromium may easily be present in the hexavalent state', primarily due to the use of strong oxidants in drinking water purification. Therefore in may not be excluded that chromium in drinking water contributes to health effects (EFSA, 2014).

7.5 Conclusion

Considering

- the T properties of Cr(VI),

- the environmental exposure/PNEC ratio of (probably) significantly below 1,
- the low contribution of Cr(VI) industrial air emissions to the total emission and
- a moderate human exposure via the environment (possibly from drinking water),
- environmental impact of Cr(VI) is regarded as "moderate".

As conclusion derived in a preceding project, SHEcan (IOM, 2011), the authors state that "controls in place to control environmental emissions are sufficient to control the potential risk to the environment …" even in view of potentially increased emissions due to OEL related measures.

This characterisation is independent from an additional potential environmental impact from changes of the OEL. However, quantitative calculation of an environmental impact due to OEL changes is not feasible (see methodology report). Qualitatively, it is expected that this impact is minor and does not modify the overall assessment result for Cr(VI) fumes form welding or plasma cutting processes and similar work processes that generate fume.

8 Distribution of the impacts

The OELVs of 0.025 mg/m³, which is a derogation for welding, and 0.005 mg/m³, which will enter into force 5 years after the transition date, are already defined through the compromise reached by Council and the European Parliament on the Commission proposal COM(2016)248 final.

Therefore the assessment of the distributional effects of the new OELV is kept at a general, qualitative level.

This section comprises the following subsections:

- Section 8.1: Businesses
- Section 8.2: SMEs
- Section 8.3: Workers
- Section 8.4: Consumers
- Section 8.5: Taxpayers/public authorities
- Section 8.6: Specific Member States/regions
- Section 8.7: Different timeframes for costs and benefits

8.1 Businesses

The costs and benefits for businesses are summarised below for the reference OELVs. The benefits are mainly the reduced production loss when the number of workers being absent from work is reduced.

Table 8-1: Comparison of the costs and benefits to EMPLOYERS (PV over 60 years, reference OELVs vs baseline)

Reference point (inhalable)	*5 µg/m3*	*25 µg/m3*	Baseline
Benefits – constant workforce	€28 millions	€23 millions	€0
Costs	€8,983 million	€3,496 million	€0

8.2 SMEs

The large majority (anticipated 99% according to stakeholder consultation) of the companies are small or medium size companies.

As noted in Tool #22 The SME test in the Better Regulation toolbox, SMEs generally tend to *"find it more difficult to access capital and their cost of capital is often higher than for larger businesses."*

Many of the RMMs required to meet the OELVs require significant capital expenditure, putting SMEs at a disadvantage due to the likely higher cost of finance, if they can secure it. However, since stainless steel SMEs work with high-value products, they are likely to be able pass on at least some of the costs resulting from compliance.

8.3 Workers

The costs and benefits for workers and their families are summarised below for the reference OELVs. The benefits to workers and their families are the avoided cases of ill health and therefore the main benefits of the assessed OELVs.

Table 8-2: Comparison of the costs and benefits to WORKERS & THEIR FAMILIES (PV over 60 years, reference OELVs vs baseline)			
Reference point (inhalable)	***5 µg/m3***	***25 µg/m3***	**Baseline**
Method 1 (VSL, VSM)			
M1 Benefits – constant workforce	€5,439 million	€4,337 million	€0
Method 2 (Monetised DALYs)			
M2 Benefits – constant workforce	€3,546 million	€2,828 million	€0
Costs			
Costs	€0	€0	€0

8.4 Consumers

No significant impacts on consumers have been identified. Possibly, consumers will have to pay slightly increased prices for products which are produced using stainless steel components or for stainless steel consumer product.

8.5 Taxpayers/public authorities

The costs and benefits for the public sector are summarised below for the reference OELVs.

Table 8-3: Comparison of the costs and benefits to the PUBLIC SECTOR (PV over 60 years, reference OELVs vs. baseline)			
Reference point (inhalable)	***5 µg/m3***	***25 µg/m3***	**Baseline**
Benefits – constant workforce	€63 million	€51 million	€0
Costs	€250,000	€250,000	€0

8.6 Specific Member States/regions

MS national limits

OELs already exist in most MS but these differ from MS to MS. Table 3-1 in Section 3.2 of this report sets out the OELs in force in the MS[29] and it can be seen that a number of MS already have equivalent or lower OELs in place than those being proposed. Table 8-4 below summarises the information on national OELs for Cr(VI) and lists the MS at the adopted OELV of 5 µg/m³, and at and above the current OELV of 25 µg/m³.

Table 8-4: MS with OELs for Cr(VI) higher than proposed levels		
OEL (mg/m³)	**Member States**	**Notes regarding national limits**
≤ 0.005	DK, FI, FR, DE, LT, NL, SE	DE: Excess cancer risk: 4 x 10^{-3} (0.001 µg/m³;"tolerable risk") NL: Excess cancer risk: 4 x 10^{-3} (0.001 µg/m³;"tolerable risk") SE: 0.005 mg/m³ (T)
> 0.005 – 0.025	BE, EE, HU, IE, LV, ES	BE: 0.01 mg/m³ for water insoluble compounds. EE: 0.02 mg/m³ for chromic acid and chromates. HU: 0.01 mg/m³ for slightly soluble compounds IE: 0.01 mg/m³ for water insoluble compounds. LV: 0.01 mg/m³ for chromium trioxide, dichromium tris(chromate), Me_2CrO_4 or $Me_2Cr_2O_7$.

[29] Where these are known. The study team has been unable to identify values for CY, IT, LU, MT and PT.

Table 8-4: MS with OELs for Cr(VI) higher than proposed levels		
OEL (mg/m³)	**Member States**	**Notes regarding national limits**
		ES: 0.01 mg/m³ for water insoluble compounds
> 0.025	AT, BE, BU, HR, CZ, EL, HU, IE, PL, RO, SI, SK, ES, GB	AT: 0.1 mg/m³ (I) for manual arc welding, 0.05 mg/m³ for other uses. BE: 0.05 mg/m³ for water soluble compounds. HU: 0.05 mg/m³ for sodium chromate, potassium chromate and other soluble Cr VI compounds. IE: 0.05 mg/m³ for water soluble compounds. SK: 0.1 mg/m³ (I) for manual welding, production of water soluble Cr(VI) compounds, 0.05 mg/m³ for others SI: 0.1 mg/m³ (I) for manual arc welding, soluble compounds, 0.05 mg/m³ for others ES: 0.05 mg/m³ for water soluble compounds
(I) = inhalable, (T) = total dust		

Numbers of companies affected in different MS

Main industries using stainless steel for are located in Germany, followed by Italy, France, UK, Spain, Netherlands, Portugal, Poland, Sweden, Finland and Romania (sequence only roughly indicative and not exhaustive, based on qualitative experts' judgements). Germany, France, the Netherlands, Sweden as well as the remaining MS with an OEL ≤ 0.005 mg/m³ are estimated to contribute with 34% of the workforce in the EU28.

That means that the calculated costs related to the compliance of the adopted OELV would mainly have to be distributed among companies in the remaining 21 MS (presenting 66% of the EU28 workforce), primarily in Italy, UK, Spain, Portugal, Poland and Romania.

8.7 Different timeframes for costs and benefits

Typically, the benefits only occur with some time lag. Presumably, there is no large difference in the timeframes for costs and benefits related to the introduction of an OELV. The cost-benefit assessment presented in next section takes the differences in time frames into account and presents comparable benefits and costs.

9 Conclusions & sensitivity analysis

This section comprises the following subsections:

- Section 9.1: Cost-benefit assessment (CBA)
- Section 9.2: Multi-criteria analysis (MCA); and
- Section 9.3: Sensitivity analysis.

9.1 Cost-benefit assessment (CBA)

9.1.1 Overview of the costs and benefits of the reference OELVs

The costs and benefits are presented for the assessment of the two reference OELVs, OELV A: 5 µg/m³ and OELV B: 25 µg/m³.

Reference OELV A: 5 µg/m³

The benefits and costs estimated in this report for reference OELV A: 5 µg/m³ are summarised in Table 9-1 and Table 9-2, respectively.

Table 9-1: Overview of the benefits (reference OELV A: 5 µg/m³)		
Description	**Amount for 60 year with a constant discount rate**	**Comments**
	Direct benefits	
Reduced number of cancer cases	€112 million	Benefits to workers and their families, public sector and employers
	Indirect benefits	
Reduced number of cancer cases	€7 million	Benefits to employers and public sector
	Intangible benefits	
Reduced number of cancer cases	€5,412 million*	Benefits to workers and their families
Note: Benefits presented in Section 4 assumes a constant discount rate. * Intangible-WTP VSL (method 1)		

Table 9-2: Overview of the costs (reference OELV A: 5 µg/m³)							
		Citizens/consumers		**Businesses**		**Administrations**	
		One-off	**Recurrent**	**One-off**	**Recurrent****	**One-off**	**Recur-rent**
Action (a)	Direct costs	0	0	€8,909 million	€74.1 million	€0.25 million	≈0
	Indirect costs	≈0	≈0	*	*	≈0	≈0
*Possible indirect costs to industry have been monetised **OPEX and measurement cost							

Reference OELV B: 25 μg/m³

The benefits and costs estimated in this report for reference OELV B: 25 μg/m³ are summarised in Table 9-3 and Table 9-4, respectively.

Table 9-3: Overview of the benefits (reference OELV B: 25 μg/m³)		
Description	**Amount for 60 year with a constant discount rate**	**Comments**
	Direct benefits	
Reduced number of cancer cases	€89 million	Benefits to workers and their families, public sector and employers
	Indirect benefits	
Reduced number of cancer cases	€5 million	Benefits to employers and public sector
	Intangible benefits	
Reduced number of cancer cases	€4,316 million*	Benefits to workers and their families
Note: Benefits presented in Section 4 assumes a constant discount rate. *Intangible-WTP VSL (method 1)		

Table 9-4: Overview of the costs (reference OELV B: 25 μg/m³)							
		Citizens/consumers		**Businesses**		**Administrations**	
		One-off	**Recurrent**	**One-off**	**Recurrent****	**One-off**	**Recurrent**
Action (a)	Direct costs	0	0	€3,474 million	€21.7 million	€0.25 million	≈0
	Indirect costs	≈0	≈0	*	*	≈0	≈0
*Possible indirect costs to industry have been monetised **OPEX and measurement cost							

9.1.2 CBA for the reference OELVs

The overall costs and benefits of establishing an OELV at the two different reference levels are shown in Table 9-5 and Figure 9-1.

Table 9-5: Cr(VI) in fumes from welding, plasma cutting and similar processes. Summary of monetised costs and benefits		
Reference OELV	**PV benefits over 60 years (€2017)***	**PV costs over 60 years (€2017)**
A: 5 μg/m³	€5,507 million	€8,983 million
B: 25 μg/m³	€4,391 million	€3,496 million
Monetised costs and benefits	*Avoided lung cancer vis-à-vis the baseline*	*RMMs* *Measurements*
Significant non-monetised costs and benefits	*None*	*None*
*Method 1		

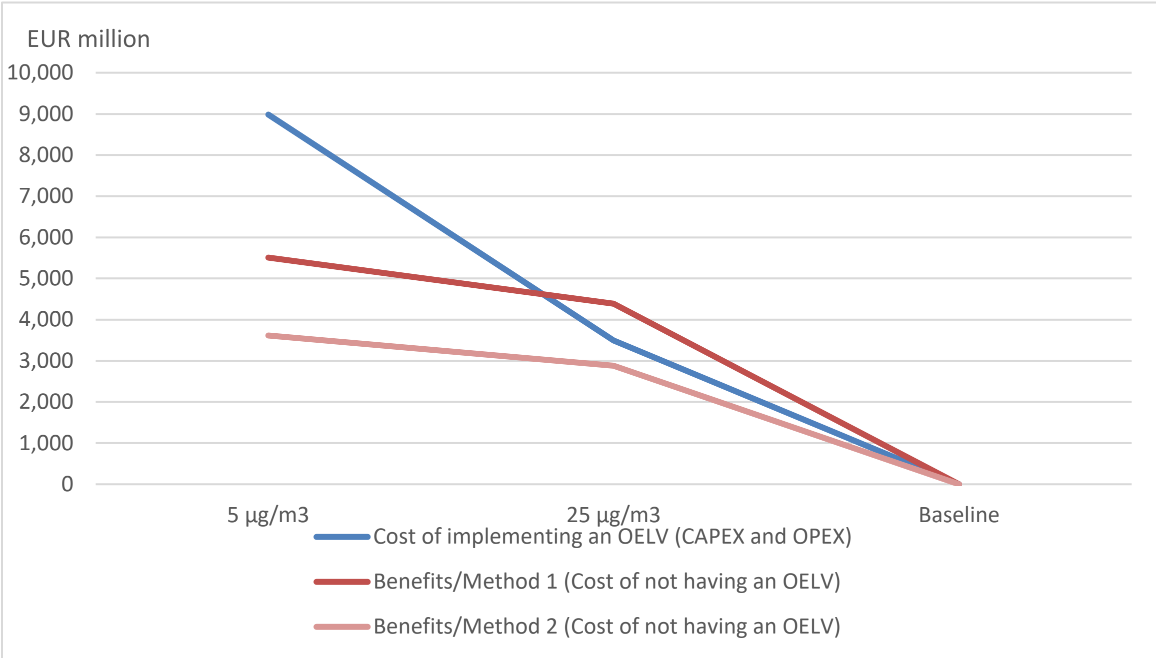

Figure 9-1: Costs/benefits of establishing an OELV for Cr(VI) in fumes from welding, plasma cutting and similar processes in the EU. Estimated costs (CAPEX AND OPEX) for 60 year and benefits (costs of not having an OELV) for a static baseline with a declining discount rate.

9.2 Multi-criteria analysis (MCA)

The overall assessment illustrates that benefits and costs are in the same order of magnitude considering the uncertainties. For the reference OELV B, the assessment points to benefits being higher than the estimated compliance costs, while for the OELV A, compliance costs seem to outweigh benefits. The uncertainty on both the benefits and costs could be at least in the order of 50% and therefore, benefit and costs could be considered as being of the same order of magnitude also the reference value A.

There are compliance costs of a not insignificant magnitude. Comparing the compliance costs and company turnover indicates that compliance costs could be up to 1-3% depending on how many workers are exposed in each affected company. Assuming that only 25% of the employees in the affected companies are exposed, the compliance costs would be less than 1% of turnover. Many of the affected companies supply high quality equipment or repair high quality equipment, and they might be able to pass on the additional costs. Overall, limited market effects are expected.

Table 9-6: Cr(VI) in fumes from welding, plasma cutting and similar processes. Multi-criteria analysis, €. Source: Modelling by COWI/RPA

Impact	Stakeholders affected	Reference OELV A: 5 µg/m³	Reference OELV B: 25 µg/m³
Economic impacts			
Compliance and administrative costs	Companies exposing their workers	€ 8,983 million	€ 3,496 million
Increased business	RMM suppliers	Increased business for RMM supplies – reduced business across all other industries	
Enforcement costs	Public sector	€0.25 million	€0.25 million

Table 9-6: Cr(VI) in fumes from welding, plasma cutting and similar processes. Multi-criteria analysis, €. Source: Modelling by COWI/RPA			
Impact	**Stakeholders affected**	**Reference OELV A: 5 μg/m³**	**Reference OELV B: 25 μg/m³**
Benefits from reduced ill health	Employers	€28 million	€23 million
	Public sector	€63 million	€51 million
Single-market: competition	Business	Some negative impacts	Some negative impacts
Single-market: consumers	Consumers	Limited impacts	Limited impacts
Single-market: internal market	Business	All companies will face same OELVs	All companies will face same OELVs
International competitiveness	Business	Some negative impacts	Some negative impacts
SMEs	Business	Some negative impacts	Some negative impacts
Specific MS/regions	Business	21 Member States have OELs > 5 μg/m3	14 Member States have OELs >25 μg/m3
Social impacts			
Ill-health avoided	Workers & families	€5,439 million	€4,337 million
Employment	Workers	Limited impacts	Limited impacts
Environmental impacts			
Environmental releases		No impact	No impact
Recycling – loss of business	Recycling companies	No impact	No impact
Recycling – durability of consumer goods, etc.		No impact	No impact
Notes: All costs/benefits are relative to the baseline (PV over 60 years).			

The benefits are avoided ill health cases and they are overall estimated at an order comparable to the costs. The reduced number of ill health cases are avoided lung cancer cases. There are no other significant benefits.

10 Sensitivity analysis

As mentioned above, the estimated benefits and costs are in the same order of magnitude. Below, key factors that could influence the estimated benefit and costs are described.

The exposure concentrations used for the calculations originate from measurements in working environments with anticipated high/measurable exposures (reported by Pesch *et al.*, 2015, and IFA, 2012) and are in the high end of reported exposure concentrations compared to other publications. In some exposure situations (especially high exposures), workers may be additionally protected by use of PPE, which is not accounted for in the exposure data and in the calculation of the cost estimate. Furthermore, the reported exposure concentrations were typically based on sampling for 2 hr and may thus not be fully suitable for comparison to OEL(V)s based on 8 hr TWA concentrations. Furthermore, the estimated disease burden for the highest exposure concentration interval may be too high as there are presumably more workers exposed in the lower area of the interval. This opens for the possibility that the benefit estimate could be overestimated.

The exposed workforce estimates for thermal cutters and thermal sprayers are conservatively estimated, likewise favouring an overestimation of the benefit estimates.

Considerable uncertainties are related to the **calculation of cancer cases based on the ERR** (see section 2.4 Exposure-Risk-Relationship). The ERR was developed based on exposure to Cr(VI) via inhalable particles. Therefore, the calculated number of cancer cases is subject to the hypothesis that the Cr(VI) content in fumes from welding or plasma cutting processes and similar work processes (respirable fraction) is decisive for lung cancer with equal potency as is Cr(VI) exposure, *e.g.*, from chrome plating (inhalable fraction). The number of cancer cases was calculated adequately with exposure concentrations of Cr(VI) from inhalable particles (consisting almost entirely of respirable particles in welding). Given the carcinogenic potency of the respirable particle fraction is higher than of the inhalable particle fraction, the number of cancer cases may be underestimated, leading to a potential underestimation of the benefits estimate. However, co-exposure to further chemical agents within respective fumes may influence carcinogenic potency of the Cr(VI) fraction with – currently – no unambiguous scientific understanding of the type of combination effects (increasing, reducing potency or with no mutual influence).

Further uncertainties with the establishment of a reliable ERR for Cr(VI) from welding, thermal cutting and thermal spraying are related to:

- the high variability in exposure between and within the same processes
- the influence of the solubility of the Cr(VI) compounds on the toxicokinetics
- the variable particle size distribution

The **monetary valuation** of the health end point is also subject to uncertainty. The specific values applied, for example the value of a statistic life, is drawn the literature and are best practice estimates. The methodology report includes more details. The use of two alternative methods one using willingness to pay estimates of the value of statistical life and one using DALY is not per se a reflection of uncertainty, but it reflects of the challenges of monetary valuation. In this case the two methods give results which vary in the order of 50%. This might be considered as indication of the uncertainty of the monetary valuation itself.

The **costs estimates** are sensitive to the assumption that monitoring of the workplace concentration will be required in all MS. In some MS, the enforcement may be limited to requiring compliance with national OEL of fume particle concentrations. On the other hand, it cannot be excluded that in some

MS the authorities may use the OELV of 5 µg/m³ as a driver for reducing exposure to hazardous substances from welding and related processes and require that the workplace air concentration is measured regularly. In this case the total costs over the next 60 years would be higher.

The **exposure concentrations** used for the calculations originate from measurements in working environment with anticipated high/measurable exposures (reported by Pesch *et al*., 2015, and IFA, 2012) and are in the high end of reported exposure concentrations compared to other publications. In some exposure situations (especially high exposures), workers may be additionally protected by use of PPE, which is not accounted for in the exposure data and in the calculation of the cost estimate. This causes the cost estimate to be overestimated.

The **number of companies** was derived from the number of exposed workforce. The exposed workforce estimates for thermal cutters and thermal sprayers are conservatively estimated, favouring an overestimation of the cost estimate.

The estimated costs are based on a **cost model** that applied generic assumptions about what measures would be needed to insure compliance. There are some uncertainty about the whether there could individual companies facing either larger or lower costs. Overall, the uncertainty of the costs assessment might be in the order of 50%.

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Annex 1 Summary of consultation responses

Responses to consultation relevant to Cr(VI)

Table A11-1: Number of responses relevant to Cr(VI)	
Questionnaire responses	18
Interviews	12
Site visits	5
Total	**35**

There were a relatively larger number of questionnaire responses, interviews and site visits for Cr(VI) due to its widespread occurrence welding, cutting and spraying processes.

Besides the general stakeholder consultation addressing a large number of stakeholders with a request for information across the six substances/substance groups, a number of organisations and companies were addressed directly by identifying the relevant contact person by phone or mail prior to sending an information request specifically about Cr(VI) emission from welding, thermal cutting and similar processes.

The organisations were asked to forward the questionnaire to member organisations and member companies, about the knowledge on relevant processes and companies with Cr(VI) emissions, number of workers and companies, Cr(VI) exposure concentrations, risk management measures etc. In most cases, the consultation process and data acquisition comprised several phone calls, emails, and in a few instances, also face-to-face meetings.

In order to kick-off the direct stakeholder consultation and get into contact with a wide range of relevant stakeholders, a member of the project team (Marlies Warming) participated at the quadrennial, international fair trade "Joining, Cutting and Surfacing" in Düsseldorf in September 2017, where technology manufactures, consumable producers, the ventilation companies, trade associations and occupational health and safety organisations met. During the fair trade, the direct contact to 10 ventilation manufacturers and suppliers was established, furthermore several trade organisations, German organisations concerned with HSE, and welding consumable producers were interviewed.

In the direct stakeholder consultation, the following European organisations have been consulted:

- EWA - European Welding Association
- EWF - European Welding Federation
- TWI Ltd - The Welding Institute
- CEEMET - European Tech & Industry Employers

Notably, the EWA and TWI contributed in the study with information on exposed workforce, technology knowledge, risk management measures and contacts to industry and knowledge persons.

Furthermore, the following national organisations have been consulted:

- BFA-I, Danish Industry community for working environment in industry
- BGHM - German Employers' Liability Insurance Association for the wood and metal sector (Berufsgenossenschaft Holz und Metall)

- DGUV - German Employers' Liability Insurance Association (Deutsche Gesetzliche Unfallversicherung)
- DVS - German Welding Institute (Deutscher Verband für Schweissen)
- FORCE technology, Danish Knowledge Center for Welding and Thermal Spraying
- FVEM – Spanish trade organisation of metal works companies
- GTS - German association for thermal spraying (Gemeinschaft Thermisches Spritzen)
- Schneidforum Consulting GmbH & Co.KG, German Thermal Cutting Consulting company
- Schweisselektrodenvereiningung, German Welding consumables Association
- The Welding Greek Institute
- TNO - The Netherlands Organisation for Applied Scientific Research
- TSSEA - UK Thermal Spraying and Surface Engineering Association

Especially the mentioned Danish and German organisations were able to provide a lot of information and/or studies on relevant processes, exposed workforce, exposure data, best practice, risk management measures (RMM), and trends in use of processes, RMM and research for exposure reduction.

Annex 2 Distribution of workers across exposure concentrations – method of fit

The distribution of exposed workers according to concentrations in the different processes is based on Cr(VI) exposure data from the MEGA database. Due to the relatively low median concentrations and the comparatively high percentiles, log-normal distribution is considered appropriate for estimating the number of exposed workers at the respective concentrations.

For every process, the number of workers exposed to a given concentration is estimated using a lognormal distribution fitted to the median and the percentiles (P75, P90, and P90) data from the MEGA dataset, and using the number of exposed workers according to section 3.4.2. For thermal cutting and thermal spraying, the number of workers was distributed on the concentrations from the datasets of personal and stationary measurements in order to approach actual exposure situations (see section 3.5.3 and 3.5.4, respectively).

The number of exposed workers per process, concentrations per percentile, the corresponding percentiles from the fitted lognormal function and the indicators of fit are shown in the table below. The closer the value of the indicator of fit is to zero, the better the fit of the distribution to the actual reported exposure concentrations. The fitting used steps of 0.1 as resolution of the concentration values.

The distributions were fitted by approaching the values of the indicator of fit to zero by adjusting the mean and the standard deviation.

Table A2-1: Overview of parameters used for distribution fitting and indicators for fit					
Process	Exposed Workforce (No.)	Concentra-tion (µg/m³)	Percentile reported	Percentile from fitted distribution	Indicator for fit
GMAW	13,000	3.6	0.50	0.500	0.000
		9.9	0.75	0.749	0.001
		23.9	0.90	0.898	0.002
		43.7	0.95	0.953	-0.003
FCAW	4,000	5.7	0.50	0.5000	0.000
		41.6	0.75	0.7583	-0.008
		57.2	0.90	0.7920	0.108
		62.4	0.95	0.8007	0.149
TIG	5,000	0.2	0.50	0.5079	-0.008
		-	0.75	#N/A	#N/A
		5.2	0.90	0.8982	0.002
		6.8	0.95	0.9145	0.036
MMA	8,000	6.8	0.50	0.5000	0.000
		38.0	0.75	0.7519	-0.002
		145.6	0.90	0.8861	0.014
		348.4	0.95	0.9390	0.011
Thermal cutting, personal	2,550	-	0.50	#N/A	#N/A
		2.8	0.75	0.746	0.004
		27.6	0.90	0.928	-0.028
		45.2	0.95	0.949	0.001
Thermal cutting, stationary	2,550	0	0.50	#N/A	#N/A
		1.3	0.75	0.580	0.170
		1.8	0.90	0.636	0.264
		3.8	0.95	0.781	0.169
Thermal spraying, personal	1,500	37.0	0.50	0.517	-0.017
		161.0	0.75	0.604	0.146
		832.0	0.90	0.695	0.205
		1027.0	0.95	0.704	0.246
Thermal spraying, stationary	13,500	0.8	0.50	0.500	0.000
		5.0	0.75	0.756	-0.006
		24.0	0.90	0.901	-0.001
		45.0	0.95	0.937	0.013

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