APPENDICES TO THE ANNEX XV RESTRICTION REPORT

PROPOSAL FOR A RESTRICTION

SUBSTANCE NAME: Certain Cr(VI) substances

EC NUMBERS:	**215-607-8, 231-801-5, 236-881-5, 234-190-3, 231-906-6, 232-143-1, 232-140-5, 231-889-5, 246-356-2, 232-142-6, 234-329-8, 256-418-0, 233-660-5**
CAS NUMBERS:	**1333-82-0, 7738-94-5, 13530-68-2, 10588-01-9, 7778-50-9, 7789-00-5, 7789-00-6, 7775-11-3, 24613-89-6, 7789-06-2, 11103-86-9, 49663-84-5, 10294-40-3**

CONTACT DETAILS OF THE DOSSIER SUBMITTER:

European Chemicals Agency

VERSION NUMBER: 1.0

DATE: 11 April 2025

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Preliminary remarks

This document contains the Appendices to the Annex XV restriction proposal for certain Cr(VI) substances. It is not intended to be a stand-alone document but provides additional information, supplementary analyses and ancillary calculations that should be read in conjunction with the main report. Although the Dossier Submitter has made every effort to ensure that the information is consistent with that reported in the main report, clerical errors cannot be excluded. In such cases, the main report shall prevail.

Appendix A: Manufacture and uses

A.1. Manufacture, import and export

A.1.1. Chromite ore[1]

Chrome iron ore (chromite) was discovered and started to be defined in its mineralogical nature in 1798. A few decades later, oxidative roasting with soda and lime was widely used to manufacture sodium dichromate. Although various minerals contain chromium, only chromium spinel plays a significant role from an economic and production perspective. The formula for the series of isomorphous mixtures of chromium spinel in the geological deposits is the following: $(Fe; Mg)O * (Cr; Al; Fe)_2 O_3$.

Chromite ore enrichment is a key step for its exploitation. Still today, hand picking is the most common way of concentrating chromite and well in use in countries such as Türkiye, Brazil, Iran, and the Philippines. Mining of richer ores, however, continues to decline and therefore the gravity method is now increasingly used to separate the serpentine from the chromite (Borchert 1964).

A.1.2. Sodium dichromate

Sodium dichromate (EC 234-190-3, CAS 10588-01-9), the precursor for most chromium salts (see Figure 1), is commonly manufactured by a three-steps process comprising (i) alkaline roasting of chromite in oxidizing conditions, followed by (ii) leaching, and (iii) conversion of sodium monochromate under acid conditions to sodium dichromate followed by crystallisation as hydrated form ($Na_2Cr_2O_7\ 2\ H_2O$). Continuous vacuum crystallization is increasingly used as a method to obtain sodium dichromate crystals.

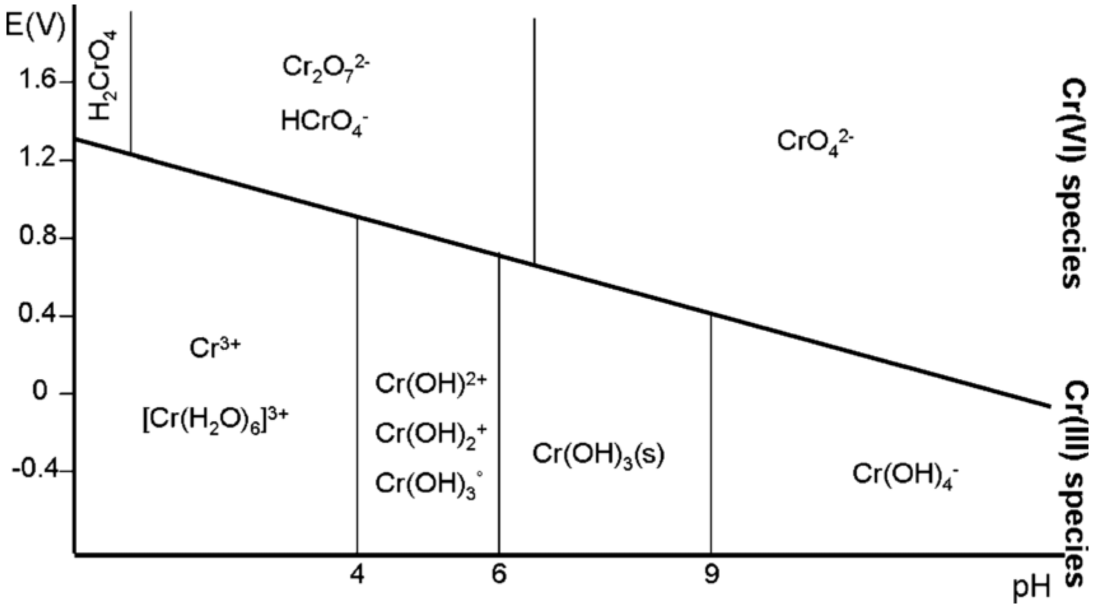

Figure 1. Chemical species of chromium as a function of pH and potential

Source: Unceta, Séby et al. (2010)

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[1] Based on Ullmann's Encyclopaedia of Industrial Chemistry (Chapters 1, 2.1, 2.1).

In acid solution, sodium dichromate is a strong oxidizing agent. It is important to note that sodium dichromate is the most accessible (quantity and pricewise) raw material and therefore, directly or via different manufacturing steps, sodium dichromate is used as the starting material for the production of all chromium compounds and pure chromium metal.

The dihydrate $Na_2Cr_2O_7$ 2 H_2O (EC 616-541-6, CAS 7789-12-0) can be converted into $Na_2Cr_2O_7$—an anhydrous salt that is very hygroscopic and very easily deliquesces in air. Anhydrous sodium dichromate (EC 234-190-3, CAS 10588-01-9) forms light brown to orange-red flakes, which are strongly hygroscopic and decompose above 400°C with the formation of sodium monochromate(VI), chromium(III) oxide, and oxygen. It is obtained by melting down sodium dichromate dihydrate, by crystallizing aqueous dichromate solutions above 86°C, or by drying sodium dichromate solutions in spray driers.

Anhydrous sodium dichromate is used when the water content (dihydrate) has an interfering action. For example, the energy liberated in the oxidation with anhydrous sodium dichromate is greater than that liberated in the case of sodium dichromate dihydrate. Anhydrous sodium dichromate is therefore used in the preparation of chromium(III) oxide by the dry process, in pyrotechnics, and in anhydrous oxidation processes where it replaces the more expensive potassium dichromate. Compared with sodium dichromate dihydrate, anhydrous sodium dichromate has the advantage that it can first absorb two molecules of water instead of deliquescing immediately in presence of moisture.

A.1.3. Chromium trioxide[2]

Chromium trioxide CrO_3 (EC 215-607-8, CAS 1333-82-0), (chromic acid anhydride, chromic acid) is generated by treating sodium dichromate with sulfuric acid: $H_2SO_4 + Na_2Cr_2O_7 \rightarrow 2\ CrO_3 + Na_2SO_4 + H_2O$. This reaction can be produced with solid sodium dichromate or with solutions or suspensions. Chromium trioxide forms dark red crystals which deliquesce in air. The oxide melts at 198°C and starts to decompose, giving off oxygen and brownish red vapours with a pungent smell. Chromium trioxide dissolves in water to form chromic acids. The solubility depends only slightly on temperature. The compound also dissolves in sulfuric acid and nitric acid. Chromium trioxide is a powerful oxidizing agent, particularly in the presence of acids.

A.1.4. Sodium chromate[3]

Sodium Chromate Na_2CrO_4 (EC 231-889-5, CAS 7775-11-3), is hygroscopic and forms several hydrates depending on temperature: decahydrate (EC -, CAS 13517-17-4) below 19.5°C; hexahydrate between 19.5°C and 25.9°C, and tetrahydrate (EC 600-068-7, CAS 10034-82-9) between 25.9°C and 62.8°C which undergoes transformation into anhydrous sodium chromate above 62.8°C.

To prepare the salt, sodium dichromate solution is usually mixed with a stoichiometric amount of sodium hydroxide, and the salt solution is then crystallized or spray dried. The product also contains low quantities of NaCl, Na_2SO_4. On a vast scale, sodium chromate may also be obtained by roasting chromium ores in air in the presence of sodium carbonate: $2Cr_2O_3 + 4\ Na_2CO_3 + 3\ O_2 \rightarrow 4\ Na_2CrO_4 + 4\ CO_2$. This process converts the chromium into a (soluble) water-extractable form, with the separation of iron oxides and silicon and aluminium impurities that remain also in an insoluble form. The industrial route to chromium(III) oxide involves reduction of sodium chromate with sulphur.

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[2] Based on Ullmann's Encyclopaedia of Industrial Chemistry (Chapter 4.3, 6.1).

[3] Based on Ullmann's Encyclopaedia of Industrial Chemistry (Chapter 6.2).

A.1.5. Potassium dichromate[3]

Potassium dichromate $K_2Cr_2O_7$ (EC 231-906-6, CAS 7778-50-9), occurs in two modifications: $K_2Cr_2O_7$, tabular or prismatic, a bright orange-red triclinic (ɑ) crystal (decomposition at 241.6°C) and monoclinic (β) $K_2Cr_2O_7$ (decomposition at 610°C). Today, potassium dichromate is obtained primarily by conversion of sodium dichromate with potassium chloride. Alternatively, it can be obtained from potassium chromate by roasting chromite ore with potassium hydroxide.

Potassium dichromate is soluble in water and in the dissolution process it ionizes:

$$K_2Cr_2O_7 \rightarrow 2\,K^+ + Cr_2O_7^{2-}$$
$$Cr_2O_7^{2-} + H_2O \rightleftharpoons 2\,CrO_4^{2-} + 2\,H^+$$

The substance is not hygroscopic and, above the melting point, decomposes into potassium chromate, chromium oxides, and oxygen. Potassium dichromate has largely been supplanted by the cheaper sodium dichromate but is still used if non-hygroscopic properties are important, e.g., in the firework, film, and photographic industries. Potassium dichromate is also used in the preparation of yellow and green zinc pigments.[4]

A.1.6. Potassium chromate[5]

Potassium Chromate K_2CrO_4 (EC 232-140-5, CAS 7789-00-6), is rarely used. It has been replaced nearly completely by the cheaper sodium chromate and is used only for very specific purposes such as in the photographic industry. It is prepared by treating potassium dichromate with potassium hydroxide: $K_2Cr_2O_7$ (aq)+2KOH → 2 K_2CrO_4 + H_2O, or by the fusion of potassium hydroxide and chromium trioxide: 2KOH + CrO_3 → K_2CrO_4 + H_2O. Potassium chromate can also be produced industrially using potash: $K_2Cr_2O_7$ + K_2CO_3 → 2 K_2CrO_4 + CO_2. The reaction is reversible. In solution, the behaviour of potassium and sodium dichromate are very similar. Potassium chromate occurs as the stable b-modification. The lemon-yellow, non-hygroscopic prisms are isostructural with K_2SO_4. At 666°C they are converted into hexagonal a-potassium chromate. The salt crystallizes from aqueous solution in anhydrous form and is thermally stable.

A.1.7. Ammonium dichromate[3]

Ammonium Dichromate $(NH_4)_2Cr_2O_7$ (EC 232-143-1, CAS 7789-09-5), forms large, bright orange-red crystals. Ammonium dichromate crystallizes in anhydrous form from aqueous solution and is not hygroscopic. Decomposition (not preceded by melting) sets in at temperatures above 180°C; this process becomes self-maintaining at temperatures higher than 225°C. Decomposition proceeds with displays of fire and heat, and large amounts of gas are developed. The products of decomposition are chromium(III) oxide, nitrogen, and water vapor. Ammonium dichromate is prepared by reaction of sodium dichromate with ammonium chloride or, less frequently, ammonium sulphate. The route of synthesis by interaction of ammonia gas and chromic acid in solution also exists bur rarely used. Ammonium dichromate reacts very violently with organic solvents. Because of its self-ignition properties and explosiveness, ammonium dichromate is subject to specific laws (it is subject to IMDG code, class 5.1, UN No. 1439). It is also placed on the market in solution.

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[4] Ullmann’s Pigments, Inorganic, 1. General.

[5] Based on Ullmann's Encyclopaedia of Industrial Chemistry (Chapter 6.2).

A.1.8. Barium chromate[6]

Barium Chromate $BaCrO_4$ (EC 233-660-5, CAS 10294-40-3), crystallizes as light yellow transparent rhombic crystals which are isomorphous with barium sulphate. Barium chromate is only sparingly soluble in water but dissolves readily in acids. It can be synthesized by reacting barium hydroxide or barium chloride with potassium chromate:

$$Ba(OH)_2 + K_2CrO_4 \longrightarrow BaCrO_4\downarrow + 2\,KOH$$

Alternatively, it can be created by the interaction of barium chloride with sodium chromate. The precipitate is then washed, filtered, and dried.

In the presence of excess alkali chromate or dichromate, barium chromate tends to form double salts, among which special mention may be made of potassium barium chromate K_2CrO_4 $BaCrO_4$ (EC -, CAS 13819-19-7), and ammonium barium chromate $(NH_4)_2CrO_4$ $BaCrO_4$ (EC -, CAS 13819-20-0), both of which are light yellow. In weakly acid solutions the precipitation is incomplete. Quantitative precipitation is achieved by adding sodium acetate.

Yellow barium chromate and its double salts can be used to produce chrome pigments for paints; the double salts, in particular, are excellent corrosion protection paints for all metals. They form sparingly soluble metal chromates, which prevent attack by moisture (condensation, seawater) even more readily than zinc chromate.

A.1.9. Strontium chromate[7]

Strontium Chromate $SrCrO_4$ (EC 232-142-6, CAS 7789-06-2), is a yellowish, crystalline, inorganic compound that emits toxic chromium fumes upon heating. Strontium chromate is highly corrosive and is a strong oxidizing agent. Strontium chromate is prepared from strontium chloride and sodium chromate, or from strontium carbonate whereby the latter is reacted under controlled conditions by precipitation in a wet chemical process with the water-soluble chromate solution and a strontium salt or with chromic acid and strontium hydroxide solution. The water dispersion is then dried to form the final strontium chromate powder.

A.1.10. Zinc chromate hydrates

A.1.10.1. Potassium hydroxyoctaoxodizincatedichromate[8,9]

Potassium hydroxyoctaoxodizincatedichromate $Cr_2HO_9Zn_2K$ (EC 234-329-8, CAS 11103-86-9), is a member of the family of potassium zinc chromate hydrates salts. Once precipitated from the solution of zinc salts, potassium (di)chromate and sulfuric acid, potassium hydroxyoctaoxodizincatedichromate is then dehydrated, dried and grinded. These series of zinc chromate hydrates exist having the composition n ZnO m CrO_3 x H_2O and manufactured by the reaction of either a suspension of finely ground zinc white (ZnO) in concentrated sulfuric acid or water-soluble zinc salts ($ZnCl_2$, $ZnSO_4$) with potassium dichromate. The zinc chromates prepared in this manner always incorporate potassium or ammonium ions into their lattice.

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[6] Based on Ullmann's Encyclopaedia of Industrial Chemistry (Chapter 6.3).

[7] Background document_strontium_chromate_en (europa.eu).

[8] Zinc potassium chromate | Cr2HO9Zn2K | CID 25466 - PubChem (nih.gov)

[9] Background document potassium hydroxyoctaoxodizincatedichromate (europa.eu).

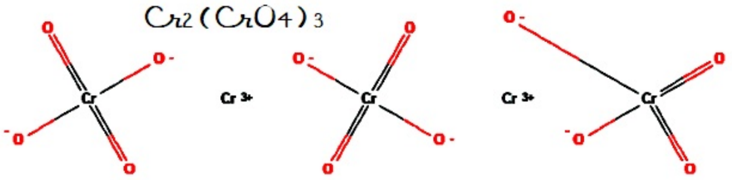
A.1.10.2. Pentazinc chromate octahydroxide[10,11]

Pentazinc chromate octahydroxide $Zn_5(CrO_4)(OH)_8$ (EC 256-418-0, CAS 256-418-0), is a member of the family of zinc chromate hydrates compounds. It is manufactured under controlled conditions by precipitation in a wet chemical process with water-soluble chromate solution and zinc salts. The product is then dehydrated, dried and grinded.

Zinc chromate $ZnCrO_4$ (EC 236-878-9, CAS 13530-65-9, not registered under REACH), is sparingly soluble in water but dissolves readily in acids. Zinc chromate is also known as zinc yellow. Its colour may be controlled by the mode of preparation. It is made by the reaction of either a suspension of finely ground zinc white (ZnO) in concentrated sulfuric acid or water-soluble zinc salts ($ZnCl_2$, $ZnSO_4$) with potassium or ammonium dichromate.

A.1.11. Dichromium tris(chromate)[12]

Chromic chromate, $Cr_2(CrO_4)_3$, or Cr_5O_{12}, also called chromium(III) chromate and dichromium tris(chromate) (EC 246-356-2, CAS 246-356-2), is a strong oxidizer. The synthesis is done by dehydration and decomposition of $CrOHCr_2O_7.2H_2O$ in inert atmosphere. Dehydration occurs at 100-160°C. At 250-350°C the anhydrous $CrOHCr_2O_7$ is dissociated into $Cr_2(CrO_4)_3$ and $Cr_2(Cr_2O_7)_3$.



Cr_5O_{12}

At 400-470°C the substance is reduced to Cr_2O_3 (trivalent Cr) by oxidation of O_2.

A.1.12. Chromic acids generated from CrO_3 and their oligomers[2]

H_2CrO_4 (molecular chromic acid) and $H_2Cr_2O_7$ (dichromic acid) are mixtures made by adding concentrated sulfuric acid to a dichromate, which may contain a variety of compounds, incl. sodium potassium dichromate or solid CrO_3. The resulting mixture consists of infinite chains of CrO_4-tetrahedra that share vertices. Each chromium centre shares two oxygen atoms with its neighbours, while two other oxygen atoms are not shared, giving an overall stoichiometry of 1:3. Chromic acids were widely used as a powerful oxidizing agent for cleaning laboratory glassware of any trace of otherwise insoluble organic residues. They are not known in the free state. Depending on the method of preparation, mono-, di-, tri-, or tetra-chromic acids are formed in aqueous solution. In alkaline or dilute solution, formation of the yellow monochromate ion is favoured, but in acid solution or at high concentrations, the orange-red dichromate ion is formed preferentially. Aqueous solutions of chromic acids are, therefore, yellow or red depending on their concentrations.

Dissociation constants (at 25°C) are as follows:

$H_2CrO_4H^{+}+HCrO_4^{-}$ $K_1 = 1.21$ $HCrO_4^{-}$ $H^{+}+CrO^{2-}$ $K_2 = 3.7E\text{-}7$ $H_2Cr_2O_7$ $H^{+} + HCr_2O_7^{-}$ $K_3 = 1$

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[10] Pentazinc chromate octahydroxide | CrH8O12Zn5 | CID 44144623 - PubChem (nih.gov).

[11] Background document pentazinc chromate octahydroxide (europa.eu).

[12] Background document dichromium tris(chromate) (europa.eu).

$HCr_2O_7^-\ H^+ + Cr_2O^{2-}\ K_4 = 0.85$

$Cr_2O^{2-} + H_2O\ 2\ H^+ + 2\ CrO^{2-}\ K_5 = 3E\text{-}15$

$Cr_2O^{2-} + H_2O\ 2\ HCrO^-\ K_6 = 2.3E\text{-}2$

The standard redox potential for the reaction $Cr_2O^{2-} + 14\ H^+ + 6\ e\ \ 2\ Cr^{3+} + 7\ H_2O$ is 1.36 V. All chromic acid solutions are strong oxidizing agents with a strongly acidic character; they form salts with metals and bases. The monochromates (VI), M_2CrO_4, which are derived from chromic acid, hydrolyse in aqueous solution: $CrO^{2-} + H_2O\ \ HCrO^- + OH^-$. The easiest method of preparing chromic acid solutions is to dissolve chromium(VI) oxide in water.

Chromic acid is often produced from sodium dichromate and sulfuric acid but may also be prepared by anodic oxidation of chromium(III) sulphate solutions; lead-lined cells with a diaphragm and lead electrodes are employed. To keep the concentration of sulfuric acid constant, the chromium(III) sulphate solution is introduced first into the cathode space, where it becomes depleted of sulfuric acid, and then into the anode space. Here, oxidation to chromic acid takes place and the concentration of sulfuric acid is restored to its original value. In practice, several electrolytic cells form a unit. At a current density of 3 A/dm^2 the voltage is 3.5 V. Current efficiency is 80 %. Lost chromium is periodically replenished by adding chromium(III) oxide. The electrolytic preparation of chromic acid can also start from chromium hydroxide hydrate with chromic acid as electrolyte.

A.2. Uses

A.2.1. Mapping of existing AfAs to the use categories

As part of the investigation, the Dossier Submitter defined six use categories (see Section 1.3 of the main report and Appendix E.2.8 for a justification). The Excel spreadsheet "rest_chromium_vi_axreport_afa_mapping_public_en" attached separately maps the Cr(VI) AfAs that ECHA received over the years to these use categories. Note, however, that this mapping is not in all cases unambiguous. For example, some applicants have included pre- and post-treatment steps in the same use as the main surface treatment, while others have applied for these steps as a separate use.

A.3. Other registered Cr(VI) substances

Table 1. Registered Cr(VI) substances not in Annex XIV of REACH

Substance name	EC number	Registration	Additional information
Bis(triphenylsilyl) chromate	216-612-8	Only as intermediate	- 4 active intermediate registrations (2010 - 2012) - 1 inactive intermediate registration (deactivated 2018) - Used as intermediate in production of plastics and in manufacture of other substances - Self classification by registrants: Carc. 1B; Skin Sens. 1; Aquatic Chronic 1; Acute Tox. 3; Carc. 1A; Repr. 2
Barium chromate	233-660-5	10-100 tpa	- 4 active full registrations (2018 - 2023) - Used as catalysts; in detonators; in coatings and sealants for aerospace application; in pyrotechnic articles - Self classification by registrants: Carc. 1A; Muta. 1B; Repr. 2; Acute Tox. 3; Acute Tox. 2; Resp. Sens. 1; Skin Sens. 1; STOT RE 1; Aquatic Acute 1; Aquatic Chronic 1
Pyridinium dichromate	243-478-8	1-10 tpa	- 1 active full registration (2020) - Used as catalyst in laboratory and processing aids - Self classification by registrants: Carc. 1B; Flam. Solid 1; Skin Corr. 1; Eye Damage 1; Skin Sens. 1; Aquatic Acute 1; Aquatic Chronic 1
Reaction mass of barium chromate, copper dichromium tetraoxide and copper oxide	701-287-1	1-10 tpa	- 1 inactive full registration (2019), (deactivated 2025) - Used in pyrotechnic articles - Self classification by registrants: Carc. 1B; Muta. 2; Eye Damage 1; Skin Sens. 1; Aquatic Chronic 1

Source: ECHA CHEM, accessed 20-02-2025.

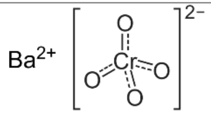
Appendix B: Information on hazard and risk

B.1. Substance identity and physical and chemical properties

B.1.1. Name and other identifiers of the substances

The identity and physicochemical properties of Cr(VI) substances included in Annex XIV of REACH are described in detail in the supporting documents published by ECHA as part of their SVHC identification.[13] The identity and properties of barium chromate, which has been identified as a potential regrettable substitute, are listed in Table 2.

Table 2. Identity and physicochemical properties of barium chromate

Property	**Value**
Substance name	Barium chromate
IUPAC name	barium(2+) dioxochromiumbis(olate)
EC number	233-660-5
CAS number	10294-40-3
Molecular formula	$BaCrO_4$
Structural formula	
Molecular weight/weight range	253.32 g/mol
Relative density	4.498 at 20°C
Physical state at 20°C and 101.3 kPa	Solid, inorganic
Melting / freezing point	1 400°C at 101,325 Pa
Vapour pressure	n/a
Water solubility	0.0026 g/L at 20°C
Partition coefficient n-octanol/water (Log Kow)	n/a, inorganic ionic compound
Partition coefficient organic carbon/water (Log Koc)	n/a

Source: ECHA CHEM, accessed 30-01-2025.

B.1.1.1. Solubility of the substances

In a report by the ETeSS Consortium[14], which was used by RAC to establish the reference dose-response relationships for exposure to Cr(VI) and lung and gastrointestinal cancer, different Cr(VI) substances were grouped to three different solubility categories based on the solubility scheme proposed by OSHA (2006). Because barium chromate was not included in that report, the Dossier Submitter has added that using the same criteria as in the report based on the water solubility reported in Table 2. The solubility categories of all Cr(VI) compounds within the scope of the restriction proposal are presented in Table 3.

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[13] Relevant supporting documents are retrievable from https://echa.europa.eu/candidate-list-table.

[14] See ECHA/2011/01 – SR-11.

Table 3. Solubility categorisation of the Cr(VI) compounds in scope

Highly soluble (water solubility > 500 g/L)	**Sparingly/slightly soluble** (water solubility 0.01-500 g/L)	**Insoluble** (water solubility < 0.01 g/L)
Acids generated from chromium trioxide and their oligomers	Pentazinc chromate octahydroxide	Barium chromate
Ammonium dichromate	Dichromium tris (chromate)	
Chromium trioxide	Potassium hydroxyoctaoxodizincate dichromate(1-)	
Potassium chromate	Strontium chromate	
Potassium dichromate		
Sodium chromate		
Sodium dichromate		

Source: ECHA CHEM, accessed 30-01-2025.

B.1.2. Analytical methods

Due to their toxicity, Cr(VI) compounds have long been regulated not only in the EU but worldwide. As a result, sampling and analytical methods have been developed, consolidated and are available in internationally recognised and validated standards. The fate of Cr(VI) has been studied in virtually all matrices: water, soil, wastes, workplace air, air emissions, cement, packaging, toys, leather, textiles and food/drinking water. In the EU, several legislative frameworks and analytical standards have been established to facilitate the regulation of the presence and use of Cr(VI).

Despite the presence of consolidated analytical methods described by internationally recognised and validated standards, there is a growing interest in developing more advanced and reliable analytical methods that can allow an accurate determination of Cr(VI) in all matrices with minimal species interconversion and maximum recovery in the extraction of Cr(VI) in all the substrates. In the last decades, the development of new technologies has significantly improved the performance of instrumental analytical methods (Bartlett 1991, Gomez and Callao 2006, Séby and Vacchina 2018).

It is important to note that the sampling procedures, conservation, pre-treatments and treatments of samples are of utmost importance to guarantee the quality of the results. This has an increasing role as the levels of the compound to be analysed diminish and is especially true for the determination of Cr(VI) due to its high reactivity. One of the most used analytical techniques in official methods is based on (spectro-) photometry after formation of a complex with diphenyl carbazide. More advanced developments in this field open to the use of on-line hyphenated techniques between liquid chromatography (allowing the separation of species) and ICP-MS (Inductively coupled plasma mass spectrometry) because of its better selectivity and sensitivity. Another advantage of using HPLC (High-performance liquid chromatography)-ICP-MS is the possibility to quantify Cr(VI) with speciated isotope dilution (SID), allowing for the correction of Cr(VI) reduction and/or Cr(III) oxidation that may take place during extraction (Mädler, Todd et al. 2016).

Appropriate extraction procedures play a key role in minimising method-induced oxidation and reduction. Typically, alkaline extraction allows both the extraction of all the Cr(VI) compounds and their stabilization in the extracts while Cr(III) precipitates. Nevertheless, a limited species transformation can still occur with this procedure. In the last years, several studies suggested that speciated isotope dilution (SID) can also be used to allow correction of interconversions between sample species.

Other analytical procedures focus on the separation and quantification of specific Cr(VI) fractions such as water-soluble Cr(VI), soluble Cr(VI) or insoluble Cr(VI), as a mean to differentiate between fractions with a view to better assess the risk associated with the presence of Cr(VI). Extraction may also be carried out using EDTA (Ethylenediamine tetraacetic acid) at high pH to get a good solubilization of Cr(VI). Cr(III) is eliminated from the solid sample by complexation. However, this procedure is still not sufficient to totally extract Cr(III) and the aim of the most advanced technique is to obtain the simultaneous determination of the two Cr species in order to have a complete overview of the presence of chromium forms that will allow obtaining a better knowledge of risk assessment associated with the presence of chromium.

The following sub-sections provide an overview of the sampling methods and suitable analytical methods and techniques that can be used for the determination and quantification of Cr(VI) in the various types of matrices relevant in the context of this restriction proposal, i.e. i) emission's monitoring (industrial air and wastewater emission matrices) and occupational monitoring (workplace air matrix and biological matrices). The analytical methods summarised in this section are i) validated by the International and/or European recognised organisations (e.g., ISO, CEN), or ii) developed by European Member State Agencies (e.g., IFA), or iii) developed by U.S. government agencies (e.g., NIOSH and EPA). Methods developed in research laboratories, following a peer review process, and published by recognised scientific journals are also reported as they play a major role in the context of biomonitoring. Relevant abbreviations are listed in Table 4.

Table 4. Relevant abbreviations

AAS: atomic absorption spectrometric methods	IC: ion chromatography
ASTM: American Society for Testing and Materials	IC, UV-Vis: Ion chromatography and UV-visible spectrophotometry
CFA: Continuous flow analysis	ICP-MS: Inductively coupled plasma mass spectrometry
DPC: 1,5-Diphenylcarbazide complex	ICP-OEP: inductively coupled plasma optical emission spectrometry
dscm: dry standard cubic meter	ISO: International Standard Organisation
EN: European Standard	LC-ICP-MS: Liquid chromatography-inductively coupled plasma-mass spectrometry
EP/TCLP: Extraction Procedure Toxicity Characteristic and Toxicity Characteristic Leaching Procedure) extracts	PTFE: polytetrafluoroethylene
EPA: Environmental Protection Agency (U.S.)	PVC: polyvinyl chloride
ETAAS: Electrothermal atomic absorption spectrometry or Atomic Absorption, Graphite Furnace	UV-Vis : Ultraviolet – visible detectors
FAAS: Flame atomic absorption spectrometry	Vis: Visible wavelengths (400 to 800 nm)
FIA: Flow injection analysis	

B.1.2.1. Monitoring of emissions to the environment

B.1.2.1.1. Water matrix

Table 5 and table 6 report sampling methods and analytical methods validated for water samples that are included by the International and European standards and methods validated from national agencies. The following information regarding sampling methods have been extracted: type of water, type of sampling, sample stability and range of applicability. Information regarding sample preparation, detection analytical techniques, LOD/LOQ are reported as well. Most of those standard methods to measure Cr(VI) are applicable to different types of waters, from very pure water to wastewater. All the official standard methods listed in table 5 and table 6 have been validated (some more than 20 years ago) and updated in the last years. Most of the methods are still in active use.

Water sampling

Before starting any sampling activity, in-depth considerations shall be given to the type of information expected in the study so that appropriate preservation and pretreatment steps can be taken:

- Most appropriate flask material to collect a sample of water
- The maximum acceptable storage time of the sample and
- The presence of relevant interferences

Handling and improper procedures, contamination and wrong equipment can heavily affect the concentration of Cr(VI) in the sample, and consequently the results of analysis. The Standard *ISO 5667-1:2023 Water quality - Sampling* provides guidance on the design of sampling programmes and sampling techniques while *ISO 5667-3:2023 Water quality - Sampling* provides guidance on the preservation and handling of water samples.

Water analyses

Regarding analytical methods and according to ISO standards, suitable analytical methods used for Cr(VI) analysis in wastewater samples are:

- UV-VIS Spectrophotometry (ISO 11083)
- Flow injection analysis and continuous flow analysis/spectrometric detection (ISO 23913, FIA)
- (Spectro) photometric detection using a discrete analysis system (ISO/TS 15923-2); photometric method (ISO 18412)
- LC-ICP-MS after chelating pretreatment (ISO 24384)

It should be noted that the ISO 11083, ISO 18412 and ISO 23913 standards will be replaced by ISO/DIS 18724 in the near future. ISO/DIS 18724 will focus on water quality and determination of dissolved Cr(VI) in water using photometric method.

Other standardised analytical methods are available from the U.S. EPA and ASTM, and some Member States in EU have their own methods:

- Ion chromatography and UV-VIS spectrophotometry (U.S. EPA 218.6 and 7199)
- Ion chromatography and UV-VIS spectrophotometry (ASTM D5257-17) or UV- VIS Spectrophotometry (ASTM D1687-17 Method A)
- UV- VIS Spectrophotometry (U.S. EPA method 7196A)

The US EPA SW-846 Test Method 7195 (1986), SW-846 Test Method 7197 (1986) and SW-846 Test Method 7198 (1986) are applied in the determination of the concentration of Cr(VI) in extraction procedure toxicity characteristic extracts and in ground waters. However, if needed these methods can also be used to analyse hazardous wastes and waste waters providing that no interfering substances are present.[15]

Methods for the determination of total Cr may be used to determine Cr(VI) with a sufficient level of confidence if no other contamination sources of Cr exist in the sampled environment. In this case, the total Cr concentration can be assumed as Cr(VI).

Methods to detect total Cr (expressed as Cr(III)) are reported in table 5 and table 6 as well. According to standards, the suitable analytical techniques used for total Cr analysis in water samples are:

- Flame atomic absorption spectrometry (EN 1233, ASTM D1687-17 method B)
- Electrothermal atomic absorption spectrometry or Atomic Absorption, Graphite Furnace (EN 1233, ISO 15586, ASTM D1687-17 method C)
- Inductively coupled plasma optical emission spectrometry (ISO 1188, ASTM D1976-20)
- Atomic absorption spectrometric methods (ISO 9174)

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[15] See https://www.epa.gov/hw-sw846/sw-846-compendium.

Table 5. Water matrix, sampling methods for Cr(VI) and for Cr(tot) expressed as Cr(III)

Method	Chemical	Type of water	Sampling method	Sample stability
Standards				
ISO 11083:1994 Water quality - Determination of chromium(VI) - Spectrometric method using 1,5-diphenylcarbazide (reviewed in 2021)	Dissolved Cr(VI)	Waters	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ISO 18412:2005 Water quality - Determination of chromium(VI) - Photometric method for weakly contaminated water (reviewed in 2019)	Cr(VI)	Drinking water Weakly polluted ground water Weakly polluted surface water (no interfered reducing agents)	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ISO 23913:2006 Water quality - Determination of chromium(VI) - Method using flow analysis (FIA and CFA) and spectrometric detection (reviewed in 2020)	Cr(VI)	Surface water Leachates Wastewater Drinking water Ground water Seawater	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ISO/TS 15923-2:2017 Water quality - Determination of selected parameters by discrete analysis systems - Part 2: Chromium(VI), fluoride, total alkalinity, total hardness, calcium, magnesium, iron, iron(II), manganese and aluminium with photometric detection (reviewed in 2020)	Cr(VI)	Ground water potable water Surface water Wastewater Eluates, boiler water Marine waters	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ISO 24384:2024 Water quality - Determination of chromium(VI) and chromium(III) in water - Method using liquid chromatography with inductively coupled plasma mass spectrometry (LC-ICP-MS) after chelating pretreatment	Dissolved Cr(VI) Cr(III)	Wastewater Surface water Groundwater Drinking water	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ASTM D5257-17 Standard Test Method for Dissolved Hexavalent Chromium in Water by Ion Chromatography (2017)	Dissolved Cr(VI)	Wastewater Surface water Drinking water	Practice D 1066 Specification D 1192 Practices D 3370	Standard not available to the Dossier Submitter
ASTM D1687-17 Standard Test Methods for Chromium in Water	Dissolved Cr(VI)	Waters	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter

Method	Chemical	Type of water	Sampling method	Sample stability
Method A (2017)				
EN 1233:1996 Water quality - Determination of chromium - Atomic absorption spectrometric methods (reviewed in 2022)	Cr(tot) as Cr(III)	Water	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ISO 11885:2007 Water quality - Determination of selected elements by inductively coupled plasma optical emission spectrometry (ICP-OES) (reviewed in 2021)	Cr(tot) as Cr(III)	Waters	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ISO 15586:2003 Water quality - Determination of trace elements using atomic absorption spectrometry with graphite furnace (reviewed in 2019)	Cr(tot) as Cr(III)	Surface water Ground water Drinking water Wastewater Sediments	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ISO 9174:1988 Water quality - Determination of chromium - Atomic absorption spectrometric methods (reviewed in 2019)	Cr(tot) as Cr(III)	Water	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ASTM D1687-17 Standard Test Methods for Chromium in Water Method B (2017)	Cr(tot) as Cr(III)	Waters	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
ASTM D1976-20 Standard Test Method for Elements in Water by Inductively-Coupled Plasma Atomic Emission Spectroscopy (2020)	Cr(tot) as Cr(III)	Natural waters Wastewaters	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
Validated methods				
U.S. EPA SW-846 Test Method 7196A: Chromium, Hexavalent (Colorimetric) (1992)	Dissolved Cr(VI)	EP/TCLP characteristic extracts Ground waters Certain domestic and Industrial wastes (no interfering substances)	Chapter 9 and 10 of the SW-846 Compendium	24 h (4°C)
U.S. EPA Method 218.6 Determination of Dissolved Hexavalent Chromium in Drinking Water, Groundwater, and Industrial Wastewater Effluents by Ion Chromatography, Rev. 3.3 (1994) and U.S. EPA SW-846 Test Method 7199 (1996)	Dissolved Cr(VI) as CrO_4^{2-}	Drinking Water Groundwater Industrial, wastewater Effluents	Chapter 9 and 10 of the SW-846 Compendium	24 h (4°C)

Table 6. Water matrix, analytical methods for Cr(VI) and for Cr(tot) expressed as Cr(III)

Method	Analyte	Analytical technique	LOD/LOQ and notes
ISO 11083:1994 Water quality - Determination of chromium(VI) - Spectrometric method using 1,5-diphenylcarbazide (reviewed in 2021)	Cr(VI) as Cr-DPC complex	UV-VIS Spectrophotometry	Concentration range: 0,05 g/L to 3 mg/L Sample preparation: Standard not available to the Dossier Submitter
ISO 18412:2005 Water quality - Determination of chromium(VI) - Photometric method for weakly contaminated water (reviewed in 2019)	Cr(VI) as Cr-DPC complex	Photometric methods	Mass concentration range: 2 to 50 µg/L Sample preparation: Standard not available to the Dossier Submitter
ISO 23913:2006 Water quality - Determination of chromium(VI) - Method using flow analysis (FIA and CFA) and spectrometric detection (reviewed in 2020)	Cr(VI) as Cr-DPC complex	FIA and CFA/spectrometric detection	Mass concentration range: FIA: 20 to 200 µg/L and 200 to 2000 µg/L (surface water, leachates, and wastewater) CFA: 2 µg/L to 20 µg/L and 20 to 200 µg/L (drinking water, ground water, surface water, leachates, and wastewater) Sample preparation: Standard not available to the Dossier Submitter
ISO/TS 15923-2:2017 Water quality - Determination of selected parameters by discrete analysis systems - Part 2: Chromium(VI), fluoride, total alkalinity, total hardness, calcium, magnesium, iron, iron(II), manganese and aluminium with photometric detection (reviewed in 2020)	Cr(VI) as Cr-DPC complex	Photometric determination using a discrete analysis system	Standard not available to the Dossier Submitter Sample preparation: Standard not available to the Dossier Submitter
ISO 24384:2024 Water quality - Determination of chromium(VI) and chromium(III) in water - Method using liquid chromatography with inductively coupled plasma mass spectrometry (LC-ICP-MS) after chelating pretreatment (2024)	Cr(VI) as Cr-DPC complex	LC-ICP-MS after chelating pretreatment	Range concentration: 0,20 to 500 µg/L Sample preparation: Standard not available to the Dossier Submitter
ASTM D5257-17 Standard Test Method for Dissolved Hexavalent Chromium in Water by Ion Chromatography (2017)	Cr(VI) as Cr-DPC complex	IC/UV-VIS Spectrophotometry (530nm)	Concentration range: 1 to 1000 µg/L Sample preparation: Standard not available to the Dossier Submitter
ASTM D1687-17 Standard Test Methods for Chromium in Water Method A (2017)	Cr(VI) as Cr-DPC complex	UV-VIS Spectrophotometry	Concentration range: 0.01 to 0.5 mg/L Sample preparation: Standard not available to the Dossier Submitter
U.S. EPA METHOD 7196A Test Method 7196A: Chromium, Hexavalent (Colorimetric) (1992)	Cr(VI) as Cr-DPC complex	UV-VIS spectrophotometry (540 nm) or Filter photometer with a greenish-yellow filter having maximum transmittance near 540	Concentration range: 0.5 to 50 mg Cr(VI)/L

Method	**Analyte**	**Analytical technique**	**LOD/LOQ and notes**
		nm	
U.S. EPA Method 218.6 Determination of Dissolved Hexavalent Chromium in Drinking Water, Groundwater, and Industrial Wastewater Effluents by Ion Chromatography, Rev. 3.3 (1994) and U.S. EPA SW-846 Test Method 7199 (1996)	Cr(VI) as Cr-DPC complex	IC/UV-VIS Spectrophotometry (530nm)	LOD: Reagent water: 0.4 µg/L Drinking/ground water: 0.3 µg/L primary sewage/electroplating wastewater: 0.3 µg/L LOQ: [> 1 µg/L] not validated in the method procedure
EN 1233 Water quality - Determination of chromium - Atomic absorption spectrometric methods (reviewed in 2022)	Cr(tot) as Cr(III)	FAAS ETAAS	Standard not available to the Dossier Submitter
ISO 11885:2007 Water quality - Determination of selected elements by inductively coupled plasma optical emission spectrometry (ICP-OES) (reviewed in 2021)	Cr(tot) as Cr(III)	ICP-OES	Standard not available to the Dossier Submitter
EN ISO 15586:2003 Water quality - Determination of trace elements using atomic absorption spectrometry with graphite furnace (reviewed in 2019)	Cr(tot) as Cr(III)	ETAAS	Standard not available to the Dossier Submitter
ISO 9174:1998 Water quality - Determination of chromium - Atomic absorption spectrometric methods (reviewed 2019)	Cr(tot) as Cr(III)	AAS	Standard not available to the Dossier Submitter
ASTM D1687-17 Standard Test Methods for Chromium in Water Method B (2017)	Cr(tot) as Cr(III)	FAAS	Concentration range: 0.1 to 10 mg/L
ASTM D1687-17 Standard Test Methods for Chromium in Water Method C (2017)	Cr(tot) as Cr(III)	ETAAS	Concentration range: 5 to 100 µg/L Standard not available to the Dossier Submitter
ASTM D1976-20 Standard Test Method for Elements in Water by Inductively-Coupled Plasma Atomic Emission Spectroscopy (2020)	Cr(tot) as Cr(III)	ICP-OES	Standard not available to the Dossier Submitter

B.1.2.1.2. Air matrix

EN 13284-1 is the main reference standard for the measurement of low dust concentration in ducted gaseous streams in the concentrations below 50 mg/m³ at standard conditions. EN 13284-1 was primarily developed and validated for gaseous streams emitted by waste incinerators. However, it can also be applied to gases emitted from other stationary sources, and to higher concentrations.

Table 7 and table 8 report sampling methods and analytical methods available to detect Cr(VI) and Cr in the air (ambient air and stationary emission). The following information regarding sampling methods have been extracted: type of air matrix and sampling, filter, sample stability before the analysis, range of applicability, sample preparation, detection techniques, LOD/LOQ. There are no ISO standards specifically available for Cr(VI).

CEN EN 14385 (standard development is in progress, last revision in 2009) includes Cr into total emission of a metal group from a stationary emission source. Two international standards have been identified as possible references for the detection of Cr(VI) in ambient air i.e., ASTM D7614-20[16] and SOP MLD039[17]. These two standards have been validated and reviewed in 2020 and 2018, respectively.

Air sampling

Before starting any sampling activity, in depth considerations shall be given to the type of information expected in the study so that appropriate preservation and pretreatment steps can be taken:

- Most appropriate equipment to collect a sample of air (e.g., type of filter)
- The flow rate of air and
- The presence of relevant interferences

Handling and improper procedures, contamination and wrong equipment can heavily affect the concentration of Cr(VI) in the sample, and consequently the results of analysis.

According to CEN EN 14385, sampling is performed isokinetically and representatively from a duct or chimney during a certain period of time at a controlled flow rate. The dust in the sampled gas volume is collected on a filter. Thereafter, the gas stream is passed through a series of absorbers containing absorption solutions and the filter passing fractions of the specific elements are collected within these solutions.

Standards ISO EN 16911-1 (that will be replaced by ISO/AWI 16911-1) and ISO EN 16911-2 specify the determination of velocity and flow rate in ducts sampling. Standard CEN EN 13284-1 specifies the reference method for the measurement of low dust concentration in ducted gaseous streams in the concentrations below 50 mg/m³ at standard conditions. The requirements for measurement sections and sites and for the measurement objective, plan and report for stationary source emissions are specified in CEN – EN 15259.

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[16] ASTM D7614-20 - Standard Test Method for Determination of Total Suspended Particulate (TSP) Hexavalent Chromium in Ambient Air Analyzed by Ion Chromatography (IC) and Spectrophotometric Measurements.

[17] See Standard operating procedures of the California Air Resources Board.

Air analysis

Regarding analytical methods and according to ISO standards, suitable analytical methods used for Cr(VI) analysis in air (emission and ambient air) samples are:

- Flame atomic absorption spectrometry (EN 14385) for emissions
- Inductively coupled plasma optical emission spectrometry or inductively coupled plasma-mass spectrometry (EN 14385) for emissions
- Ion chromatography/UV-Vis Spectrophotometry (EPA method 0061 for emissions, ASTM D7614-20, MLD039) for ambient air

Table 7. Air matrix, sampling methods for Cr(VI) and for Cr(tot) expressed as Cr(III)

Method	Chemical	Type of air	Sampling technique	Filter	Sample stability
EN 14385:2024 Stationary source emissions - Determination of the total emission of As, Cd, Cr, Co, Cu, Mn, Ni, Pb, Sb, Tl and V	Cr total	Emissions	Isokinetic sampling	Quartz fibre Glass fibre PTFE	14 days (<6°C)
EPA Test Method 0061: Determination of Hexavalent Chromium Emissions from Stationary Sources (1996)	Cr(VI) Cr total	Emissions (a)	Isokinetic sampling	Glass fibre filter (no organic binder) If SO_2 or SO_3 present, select a filter unreactive to them	14 days
ASTM D7614-20 Standard Test Method for Determination of Total Suspended Particulate (TSP) Hexavalent Chromium in Ambient Air Analysed by Ion Chromatography (IC) and Spectrophotometric Measurements (2020)	Soluble Cr(VI) Insoluble Cr(VI)	Ambient air	Static sampling	Standard not available to the Dossier Submitter	Standard not available to the Dossier Submitter
MLD039 (a) Standard Operating Procedure for Determination of Hexavalent Chromium in Ambient Air by Ion Chromatography (reviewed in 2018)	Cr(VI)	Ambient air	Static sampling (24 h)	cellulose filter (acid wash, impregnated with sodium bicarbonate, ashless)	21 days (< 4°C)

Table notes: (a) hazardous waste incinerators, municipal waste incinerators, municipal waste combustors, sewage sludge incinerators.

Table 8. Air matrix, analytical methods for Cr(VI) and for Cr(tot) expressed as Cr(III)

Method	Analyte	Type of air	Analytical technique	LOD/LOQ and notes
EN 14385:2024 Stationary source emissions - Determination of the total emission of As, Cd, Cr, Co, Cu, Mn, Ni, Pb, Sb, Tl and V	Cr total	Emissions	FAAS ICP-OES ICP-MS	Concentration range: 0.005 to 0.5 mg/m^3 LOD: 1 µg/m^3 for each element LOD: 5 µg/m^3 for the whole sampling train Filter treated with HNO_3 & HF H_3BO_3 addition to form complexes with fluoride (insoluble fluorides dissolved by complexation)
EPA Test Method 0061: Determination of Hexavalent Chromium Emissions from Stationary Sources (1996)	Cr(VI) as Cr-DPC complex	Emissions (a)	IC/UV-Vis Spectrophotometry	LOD: 16 ng/dscm (preconcentration) with a 3 dscm gas sample (0.1 ppb in solution) Post-sampling purge and filtration
ASTM D7614-20 Standard Test Method for Determination of Total Suspended Particulate (TSP) Hexavalent Chromium in Ambient Air Analysed by Ion Chromatography (IC) and Spectrophotometric Measurements (2020)	Cr(VI) as Cr-DPC complex	Ambient air	IC/UV-Vis Spectrophotometry	0.40 to 20.0 ng of Cr(VI)/sample, no dilution 0.019 to 0.926 ng/m^3 assuming a 21.6 m^3 sample volume Sample preparation: Standard not available to the Dossier Submitter
MLD039 (a) Standard Operating Procedure for Determination of Hexavalent Chromium in Ambient Air by Ion Chromatography (reviewed in 2018)	Cr(VI) as Cr-DPC complex	Ambient air	IC/UV-Vis Spectrophotometry, (530 nm)	LOD/LOQ not reported Extraction by sonication

Table notes: (a) hazardous waste incinerators, municipal waste incinerators, municipal waste combustors, sewage sludge incinerators.

B.1.2.2. Workplace air monitoring

The principle of the procedures for measuring Cr(VI) in air involves collecting airborne particles on a suitable filter using a particle sampler (for the inhalable fraction). The trapped Cr(VI) compounds are then extracted using specific solutions, depending on which compounds are of interest, and subsequently analysed using appropriate analytical techniques. The extraction solutions listed in Table 9 are suitable for recovering all Cr(VI) compounds; however, certain methods may also distinguish between soluble and insoluble Cr(VI) species, if required. The limit of quantification (LOQ) is expressed as the mass of chromium.

The methods outlined in Table 9 include validation data demonstrating compliance with the requirements of EN 482, "Workplace exposure — General requirements for the performance of procedures for the measurement of chemical agents." These methods allow for assessing compliance with at least one of the proposed restriction options. Note that according to this standard, a method is considered suitable for testing for compliance if it can be used to measure concentrations, which are 10 % of the limit value (i.e. the LOQ should be at or below 10% of the limit value that is subject to compliance testing).

It is important to note that this table does not provide a comprehensive list of all available methods, nor does it recommend any specific measurement procedure. Its purpose is solely to indicate whether suitable procedures exist to demonstrate compliance with the various restriction options. Furthermore, the information is related to personal measurements, as these are considered more relevant for testing the compliance than static measurements.

Where a particular particulate sampler (and its corresponding flow rate) is specified in a method, sampling time calculations have been based on the maximum flow rate recommended. This does not preclude the possibility of using other samplers at different flow rates, which may help achieve a lower LOQ. Where relevant, such options have been noted as comments.

It is possible to measure sufficiently low concentrations to demonstrate compliance with all the restriction options. For the lowest concentration (0.1 µg/m^3 in RO3), it may be needed to increase sample volumes (by increasing times and/or flow rate) but it should be possible to achieve 10 % of the proposed value (i.e. LOQ of 0.01 µg/m^3). In case of increasing flow rate, suitable sampler should be applied. To check compliance, for even lower concentrations (such as 0.01 µg/m^3) no method using personal sampling that can fulfil the requirements of the EN 482 has been found. If such concentrations would need to be measured probably analytical developments or use of static sampling would be required.

Table 9. Suitable analytical methods to demonstrate compliance with occupational limit values

Method/ fraction	**Filter extraction**	**Analytical technique**	**LOQ and sampling volume and time**	**Comments**
MétroPolChrome VI M-43	QF filter extraction with Na_2CO_3 3 % + NaOH 2 % (for total Cr VI) Other solutions allow to separate soluble and insoluble Cr(VI) compounds	IC with UV/VIS detector	0.08 µg/m^3 for a 960 L sample (8 hours) Flow rate: 2 l/min	A higher flow rate sampler (10l/min) could allow to reduce the LOQ to ≈ **0.02 µg/m^3**
DFG 2024	PTFE-filter Desorption with 10 mL extraction solution (25 mmol ammonium sulphate/l and 150 mmol ammonia/l in water)	IC with post-column derivatization and UV/VIS detection	0.10 µg/m^3 for a 1200 L sample (2 hours) Flow rate: 10 l/min	Longer sampling times (up to 8 hours) are possible allowing a lower LOQ **≈ 0.025 µg/m^3**
DFG 1993	GF filter	UV/VIS-spectrometry after wet-ashing	For personal sampling: 2.5 µg/m^3 for a 450 L sample (less than 1hour hours) Flow rate: 10 L/min	Longer sampling times (up to 8 hours) are possible allowing a lower LOQ **≈ 0.25 µg/m^3**
IFA 6665	QF-filter in a 37 mm cassette filter holder Desorption with 10 mL NaOH/Na_2CO_3, addition of 6 mL H_2SO_4/HNO_3 and 2 mL diphenylcarbazid	UV/VIS-spectrometry	0.27 µg/m^3 for a 1200 L sample (2 hours) Flow rate: 10 L/min	Longer sampling times (up to 8 hours) are possible allowing a lower LOQ **≈ 0.07µg/m^3**
IFA 6664	PTFE filter	IC Analysis with post-column derivatization and UV-VIS-detector	1 µg/m^3 for a 1200 L sample (2 hours) Flow rate: 10 L/min	Longer sampling times (up to 8 hours) are possible allowing a lower LOQ **≈ 0.25 µg/m^3**
ISO 16740	PVC membrane filter Hotplate dissolution with sodium hydroxide/ sodium carbonate solution to extract insoluble chromium	IC Analysis with post-column derivatization and UV-VIS-detector	0.01 µg/m^3 for a 1000 L sample (less than 2 hours) Flow rate: 10 L/min	Longer sampling times (up to 8 hours) are possible allowing a lower LOQ **≈ 0.002 µg/m^3** Calculations for sampled volume and flow rate done with a sample working at 10 L/min
NIOSH 7605	PVC filter Hotplate dissolution with 5 mL 2 % NaOH/ 3 % Na2CO3	IC Analysis with post-column derivatization and UV/VIS detection	0.125 µg/m^3 for a 400 L sample (**≈ 3** hours)	A higher flow rate sampler (10l/min) and sampling time could allow to reduce the LOQ to ≈ **0.01 µg/m^3**

Table notes: IC: Ionic chromatography; UV-VIS: Ultraviolet-visible

B.1.2.3. Costs associated with monitoring Cr(VI)

The information presented in this section was collected using ChatGPT in December 2024.[18]

B.1.2.3.1. Workplace air monitoring

The cost of a monitoring campaign for hexavalent chromium in the European Union can vary widely based on several factors, including the size of the workplace, the complexity of the monitoring required, the frequency of sampling, and the specific methods used.

Cost Components

Initial assessment: conducting a baseline assessment might cost between €1 000 to €5 000, depending on the scope and size of the facility.

Sampling equipment: personal sampling pumps, filters, and other equipment can range from €500 to €2 000. Renting equipment may be an option to reduce costs.

Laboratory analysis: analysing samples typically costs between €50 to €300 per sample, depending on the complexity of the analysis and the laboratory used.

Consultation fees: when hiring an environmental health consultant or occupational safety officer, fees can range from €50 to €150 per hour.

Reporting and record keeping: costs for compiling reports and maintaining records can add to the overall expense, possibly around €200 to €1 000 depending on the depth of reporting required.

Training: worker training sessions may range from €500 to €2 000, depending on the number of employees and the training provider.

Total Estimated Costs

A comprehensive monitoring campaign may cost between approximately €5 000 to €15 000 or more, especially for larger operations with ongoing monitoring needs.

Information sources

The cost estimates for monitoring campaigns are based on general industry practices and insights from occupational health and safety guidelines. While ChatGPT does not have access to specific databases or live data, these figures typically derive from:

- Industry Reports: many environmental health and safety consulting firms publish reports on workplace safety costs and monitoring practices
- Regulatory Guidance: agencies like OSHA and the European Agency for Safety and Health at Work (EU-OSHA) provide resources that outline the costs and methods related to hazardous material monitoring
- Professional Associations: organisations focused on industrial hygiene and occupational safety often offer guidelines and cost estimates based on surveys of their members

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[18] A similar search was conducted using GPT@JRC in March 2025. The information gathered then indicates that the cost estimates given by ChatGPT could be underestimated.

- Consultants and Experts: many companies and consultants specialising in workplace safety can provide quotes based on their services and experiences.

B.1.2.3.2. Monitoring of releases to the environment

Monitoring of releases to air

Cost Components

Initial assessment: baseline assessments specifically for hexavalent chromium might still range from €1 000 to €5 000 but may vary based on site complexity.

Sampling equipment: air sampling equipment specifically for Cr(VI) can range from €1 000 to €5 000. This includes specialized filters and pumps.

Laboratory analysis: analysing samples for hexavalent chromium typically costs between €100 to €300 per sample, as it requires specific analytical methods (e.g., colorimetric analysis or ICP-MS).

Continuous monitoring: setting up continuous monitoring for Cr(VI) in air is less common but can be costly, possibly ranging from €20 000 to €100 000, depending on the technology.

Consultation and reporting: consultation services for interpreting results and compliance reporting could add €50 to €150 per hour.

Total Estimated Costs

Approximately €5 000 to €100 000+, depending on setup and ongoing monitoring needs.

The Dossier Submitter considers unlikely that continuous monitoring would be required for the purpose of the restriction. Therefore, the total estimate costs for monitoring release to air is proposed to be approximately €5 000 to €15 000.

Monitoring of releases to water

Cost Components

Initial assessment: similar to air, initial assessments may cost €1 000 to €5 000.

Sampling equipment: equipment for water sampling specifically for Cr(VI) might cost between €500 to €3 000.

Laboratory analysis: testing water samples for hexavalent chromium can cost between €100 to €400 per sample due to specialized methods required.

Continuous monitoring: continuous monitoring systems for water may be less common for Cr(VI) but could range from €5 000 to €30 000 if available.

Consultation and reporting: similar consultation fees apply as with air monitoring.

Total Estimated Costs

About €5 000 to €50 000+, influenced by sampling frequency and analysis complexity.

The Dossier Submitter considers unlikely that continuous monitoring would be required for the purpose of the restriction. Therefore, the total estimate costs for monitoring release to water is proposed to be approximately €5 000 to €15 000.

Information sources

The cost estimates for monitoring hexavalent chromium are derived from a combination of general industry practices and insights from several reputable sources, including:

- Industry reports: many environmental consulting firms publish detailed reports on the costs associated with environmental monitoring, including specific pollutants like hexavalent chromium
- Regulatory agencies: guidance from organizations such as the European Environment Agency (EEA) and local environmental protection agencies often provide insights into compliance costs and required monitoring practices
- Professional associations: organizations like the American Industrial Hygiene Association (AIHA) and the Institute of Occupational Safety and Health (IOSH) provide resources and guidelines on monitoring hazardous substances, which can include cost data
- Laboratory services: many accredited laboratories that analyse environmental samples publish pricing for various analyses, including those for hexavalent chromium, which helps gauge costs for laboratory services
- Environmental health consultants: expert consultations often provide estimates based on their experiences and the specific needs of clients, which can vary by region and facility
- Market surveys: surveys conducted among companies engaged in environmental monitoring can also yield average cost data for different services related to hazardous materials

B.2. Classification and labelling

See the main report.

B.3. Environmental fate properties

The environmental fate of Cr(VI) is determined by the following properties.

Solubility and Mobility

Cr(VI) is highly soluble in water, which enhances its mobility in aquatic environments. This solubility allows it to easily distribute in surface and groundwater systems. Unlike trivalent chromium (Cr(III)), which tends to form insoluble hydroxides, Cr(VI) remains in solution, facilitating its spread and increasing the risk of contamination.

Speciation and Transformation

In the environment, the fate of Cr(VI) is determined by its ability to transform into other chemical species. Cr(VI) exists primarily as chromate (CrO_4^{2-}) or dichromate ($Cr_2O_7^{2-}$) ions, depending on the pH and concentration. The transformation between these species is reversible and influenced by environmental conditions. Cr(VI) can be reduced to Cr(III) through various chemical and biological processes. This reduction is important because

Cr(III) is less toxic and less mobile than Cr(VI). Reduction can occur abiotically through reactions with organic matter or iron-containing minerals as well as biotically via microbial metabolism.

Adsorption and Desorption

The interaction of Cr(VI) with soil and sediment particles is important for its environmental fate. Cr(VI) has a lower affinity for adsorption compared to Cr(III), but it can still bind to soil constituents like clay minerals, organic matter, and metal oxides. Factors such as pH, redox potential, and the presence of competing ions affect the adsorption-desorption dynamics. In acidic conditions, the adsorption of Cr(VI) to soil particles increases, whereas, in alkaline conditions, desorption is more likely, enhancing mobility.

Environmental Persistence

Under most environmental conditions, Cr(VI) is not persistent in the environment but reduces to Cr(III). The rate of reduction is influenced by several factors, including the presence of reducing agents like ferrous iron, sulfides, and organic matter. The microbial reduction of Cr(VI) is a natural attenuation process, with various bacteria and fungi using Cr(VI) as an electron acceptor in their metabolic processes.

B.4. Human health hazard assessment

B.4.1. Toxicokinetics

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction.

B.4.2. Acute toxicity

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction.

B.4.3. Irritation

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction.

B.4.4. Corrosivity

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction.

B.4.5. Sensitisation

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction.

B.4.6. Repeated dose toxicity

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction.

B.4.7. Mutagenicity

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction.

B.4.8. Carcinogenicity

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction. In addition, some considerations about the carcinogenicity of Cr(VI) substances are warranted. Indeed, although Cr(VI) is a well-established human carcinogen, new studies have been published since the establishment of the reference dose-response relationships for carcinogenicity of Cr(VI) by RAC in 2013. Some of these studies question the low-dose linearity assumption implicit in the reference dose-response relationships for Cr(VI), which was already acknowledged by RAC at the time. Also, more information has been generated since 2013 on the mechanisms causing lung and intestinal cancer. Below is a non-exhaustive summary of the main scientific developments in this area. The focus is on information that do not align with the assumptions made by RAC at the time and may therefore call into question the application of the reference dose-response relationships for the purpose of risk characterisation.

The dose-response relationships derived by RAC is based on epidemiological studies using data from chrome plants in Painesville, OH, and Baltimore, MD. These data have been recently re-analysed. In one study, specifically focusing on the dose-response derivation by RAC, it was proposed that the statistical uncertainty with the data should be taken better into account in setting limit value for occupation exposure to Cr(VI), and it was suggested that there is likely to be less than 4 additional lung cancer cases amongst 1000 workers at the 1 µg Cr(VI)/m^3 exposure level, as concluded by the RAC (Kauermann, Becher et al. 2018). In a study using data from the Baltimore cohort, it was shown that younger chromium production workers have a greater lung cancer risk than older ones (Gibb, Wang et al. 2020). In another study, the original dataset of the Painesville cohort was updated with 714 short-term workers and re-analysed using linear Cox models with unlagged cumulative exposure (Proctor, Suh et al. 2016). In this study, the occupational unit risk of lung cancer mortality, adjusted for smoking and age at hire, was 0.00166 per 45 years of occupation exposure to 1 µg Cr(VI)/m^3, while the environmental unit risk of lung cancer mortality was 8.32E-3 per continuous environmental exposure throughout life to 1 µg Cr(VI)/m^3. These estimates are 20 % and 15 % lower than in the previous analyses for this cohort, and 59 % and 71 % lower compared to the excess lifetime lung cancer mortality risk established by RAC in 2013.

These data sets have also been criticised in a recent review because they are limited to male workers, the exposure periods are relatively short and the exposures very high and lacking information in the low intensity exposure range (Proctor, Bhat et al. 2021). The same source also concluded that the current evidence would support non-mutagenic key events in the mode-of-action, with growing evidence for epigenetic modifiers. In another recent review (Meaza, Williams et al. 2024), it was proposed that the key mechanisms of Cr(VI)-causing carcinogenicity would be the induction of DNA double strand breaks, chromosome instability and neoplastic transformation.

U.S. EPA reviewed the latest toxicological information of Cr(VI) in 2024 (USEPA 2024). This review supported the previous conclusion that there is a causal relationship between inhalation of Cr(VI) and increased incidence of lung cancer in humans. The review also concluded a strong support for the involvement of Cr(VI) in contributing to gastrointestinal cancer by oral exposure. Furthermore, the inhalation unit risk (IUR; risk of incident lung cancer per unit concentration in inhaled air) of 1.1E-2 µg Cr(VI)/m^3 was estimated for the adulthood and of 1.8E-2 µg Cr(VI)/m^3 for the total lifetime. The estimated total excess lifetime risk is slightly lower compared to the RAC's estimated excess lifetime lung cancer mortality risk of 2.9E-2 µg Cr(VI)/m^3 for the general population.

In the U.S. EPA review, the potential confounding factors, such as smoking, were considered strengthening the conclusions on the carcinogenicity of Cr(VI). However, in another recent study, based on the analysis of data on 3 723 Cr(VI) exposed workers no dose-response relationship between cumulative exposure and lung cancer mortality was detected (Lipworth, Panko et al. 2024). It was further concluded that the elevated lung cancer risk in that cohort was primarily smoking-related.

In a recent review on carcinogenic effects of Cr(VI), it was concluded that Cr(VI) can cause lung, nose and nasal sinus cancers and that it is suspected to cause stomach and laryngeal cancer in humans (den Braver-Sewradj, van Benthem et al. 2021). However, the current evidence was considered insufficient to conclude that Cr(VI) could cause small intestine, oral cavity, pancreas, prostate or bladder cancers in humans. Furthermore, it was concluded that there are no convincing indications that Cr(VI) could cause any other types of cancers in humans.

Based on these recent advances in occupational health and safety research, the Dossier Submitter concludes that there is conflicting information concerning the mode-of-action and the dose-response relationships for the carcinogenicity of Cr(VI). Although some of the studies suggest a lower excess lifetime risks than currently used by RAC, given the conflicting information, the Dossier Submitter nevertheless considers the reference dose-response relationships established by RAC fit-for-purpose for the risk characterisation in this restriction proposal, acknowledging that the resulting risks might be overestimated.

B.4.9. Toxicity for reproduction

See Section 1.4.1 of the main report for the harmonised/notified hazard classifications of the Cr(VI) substances in scope of the restriction.

B.4.10. Derivation of DNEL(s)/DMEL(s)

Not relevant.

B.5. Human health hazard assessment of physicochemical properties

B.5.1. Explosivity

Not relevant.

B.5.2. Flammability

Not relevant.

B.5.3. Oxidising potential

Not relevant.

B.6. Environmental hazard assessment

Not within the mandate given to the Dossier Submitter.

B.7. PBT and vPvB assessment

Not relevant.

B.8. Exposure assessment

B.8.1. Humans exposed via environment

B.8.1.1. Release estimation and risk management measures at sites

The risk assessment to evaluate humans exposed via the environment starts with the analysis of the releases to air and water from the sites using Cr(VI) and falling into the scope of the present restriction.

The source of information taken to estimate releases from sites using Cr(VI) are: a) the second submission of upstream Application for Authorisation by CTAC consortium, the so-called CTACSub 2, covering a wide range of uses and sites and b) the information provided by respondents of Call for Evidence launched by ECHA to collect information from companies using Cr(VI), the so called CfE1 (first) and CfE2 (second).

Other possible sources of information have been evaluated but not used as reference here for the risk assessment; if possible, they are rather used to support the outcome of the abovementioned sources (see paragraph B.8.1.1.3). It should be noted that several sites might be included on more than one source of information.

Environmental regulations regulate Cr(VI) and Cr total emissions at national or regional levels, especially for releases to water. A collection and analysis of the current limits for discharging Cr(VI) and Cr total to surface water and public sewage systems is reported in Vaiopoulou and Gikas (2020) and can be summarised as follows: limits for discharging Cr(VI) range from 0.1 to 0.5 mg/l, while the limits for discharges in municipal sewer systems are somewhat higher (0.2-1 mg/l). Limits for emissions of Cr(VI) to air vary between regions and countries; emission limit values range between 0.05 and 0.5 mg/m^3. A list of limit values reported in response to the CfE#1 and CfE#2 is provided in Appendix D.1.2.

B.8.1.1.1. CTACSub2 AfA

In order to compare the data obtained in the CfEs with the data submitted by one of the largest applications for the continued use of CrO_3, the Dossier Submitter had to make some assumptions and edits of the raw data provided by the applicant prior to its analysis. These are succinctly described below.

Emissions to air

- Company and site names were removed from the raw data and replaced by company and site codes
- Yearly operation time: if reported as a range, the mean of the range was used in the analysis; if reported as ">x" or "x<," then x was used in the analysis
- Measured concentrations were harmonised to µg Cr(VI)/m^3. If the concentration was reported as total Cr, it was multiplied by 0.52 to convert to Cr(VI)
- 193 duplicate rows were removed

- 186 data points for which yearly operation time or flow rate was indicated as 0 were removed from the analysis
- 141 measured values reported as 0 were replaced by the P10 value of the non-zero measured value. This was done because neither the limit of quantification (LoQ) nor the limit of detection (LoD) were reported and the lowest measured values seemed unrealistically small and below the LoQ of known analytical methods
- Yearly emissions (g Cr(VI) / year) were calculated using the following equation:

  $$E = C * Q * t * 1E\text{-}6$$

  where E = annual emission [g Cr(VI)/y], C = measured concentration [µg Cr(VI)/m^3], Q = flow rate [m^3/h], t = yearly operation time [h]
- One obvious outlier reporting annual emissions of 9.7 t was removed
- Average yearly emission was calculated for each chimney and year (2021-2023).
- For each site, the sum of average yearly emissions of chimneys at that site were calculated for each year
- Average emissions of each site over the period 2021-2023 were used in the analysis

Emissions to water

- Company and site names were removed from the raw data and replaced by company and site codes
- Sewage volume: if reported as a range, the mean of the range was used in the analysis; if reported as ">x" or "x<," then x was used in the analysis
- Measured concentrations were harmonised to µg Cr(VI)/L. If the concentration was reported as total Cr, it was multiplied by 0.52 to convert to Cr(VI)
- Single measured values were taken forward in the analysis, otherwise, the arithmetic mean measured values of a measurement series were used
- For 427 measurements, the measured value was smaller than the reported LoQ. In that case it was assumed that the measured value was correct
- 76 duplicate rows were removed
- 13 data points for which sewage volume was indicated as 0 were removed from the analysis
- 131 measured values reported as 0 were replaced by the LoQ. If LoQ was not reported, the lowest reported LoQ in the dataset (0.005 µg Cr(VI)/L) was used
- Yearly emissions (g Cr(VI) / year) were calculated using the following equation:

  $$E = C * V * 10^{-3}$$

  where E = annual emission [g Cr(VI)/y], C = measured concentration [µg Cr(VI)/L], V=sewage volume [m^3/y]

- One obvious outlier reporting annual emissions of 9.7 t was removed
- Average yearly emission was calculated for each chimney and year (2021-2023).
- For each site, the sum of average yearly emission of all chimneys at that site were calculated for each year
- Average emissions of each site over the period 2021-2023 were used in the analysis
- One obvious outlier reporting annual emissions of 8 t was removed
- Average yearly emission was calculated for each site and year (2021-2023)
- Average emissions of each site over the period 2021-2023 were used in the analysis

Risk management measures in place

In the raw data provided by the CTACSub2 consortium, there is no indication as to whether there are risk management measures in place to control Cr(VI) emissions. However, in the relevant CSRs[19] (submitted per use applied for) there are generic indications of the RMMs applied at all sites covered by the consortium:

- All sites with potential release to air are equipped with exhaust ventilation systems. The exhaust air is passed through filters or led to one or more wet scrubbers or droplet separators to remove residual particulates. The water of the wet scrubber/ droplet separator is either led to an on-site wastewater treatment plant, redirected to the process cycle, or manually renewed after a given period
- Treatment technology (on-site or off-site) to reduce hexavalent to trivalent chromium (Cr(III)) in wastewater is highly effective and applied widely: it is mostly based on reduction phase followed by neutralisation and precipitation; solid waste containing Cr(VI) is collected and treated as hazardous waste
- It is also assumed that all sites discharge the treated wastewater to the sewage system connected to a municipal sewage treatment plant, where further reduction of Cr(VI) concentration happens.

Main statistics for releases to water and air as reported by the CTACSub2 consortium are described in the main report, see paragraph 1.4.3.2. They are based on ~130 sites that reported releases to water and 300 that reported releases to air. Figure 2 and Figure 3 show the corresponding empirical cumulative frequency distributions (ECDFs) of the release rates to air and water, respectively. Median releases to air are close to 0.1 kg Cr(VI)/year, while P75 and P90 values are 0.8 and 3.6 kg Cr(VI)/year. Emissions to water are clearly lower than the ones estimated for air; they are represented by P50, P75 and P90 values of 0.04, 0.3 and 2 kg Cr(VI)/year.

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[19] See an example CSR related to the formulation process here: https://echa.europa.eu/documents/10162/f25eb39a-76fa-df88-d0a4-da77336e65ce.

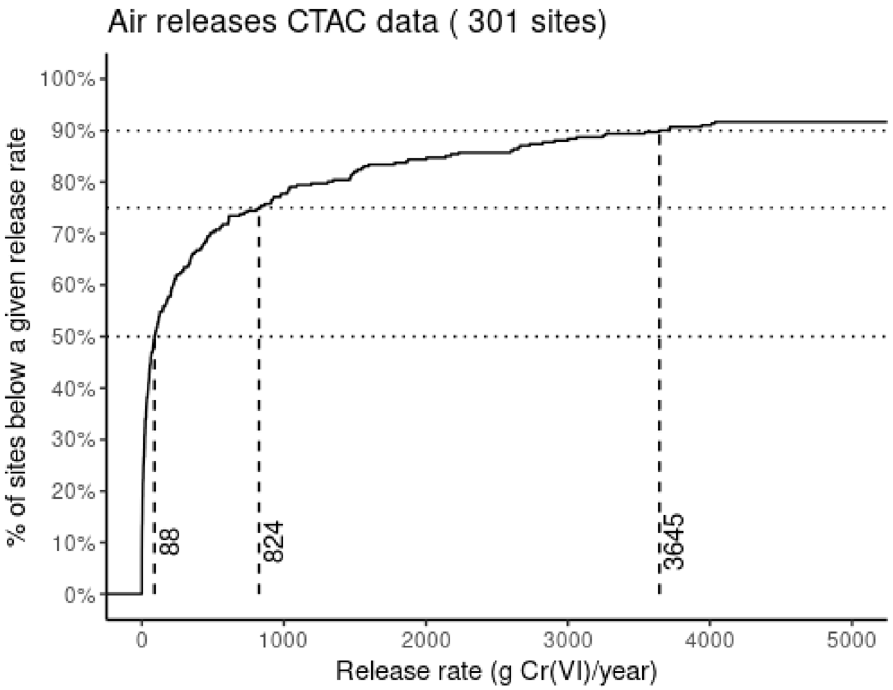

Figure 2. Empirical cumulative distribution function (ECDF) for air releases

Figure notes: Data from the CTACSub2 AfA (all uses); Vertical dashed lines indicate P50, P75, and P90 releases.

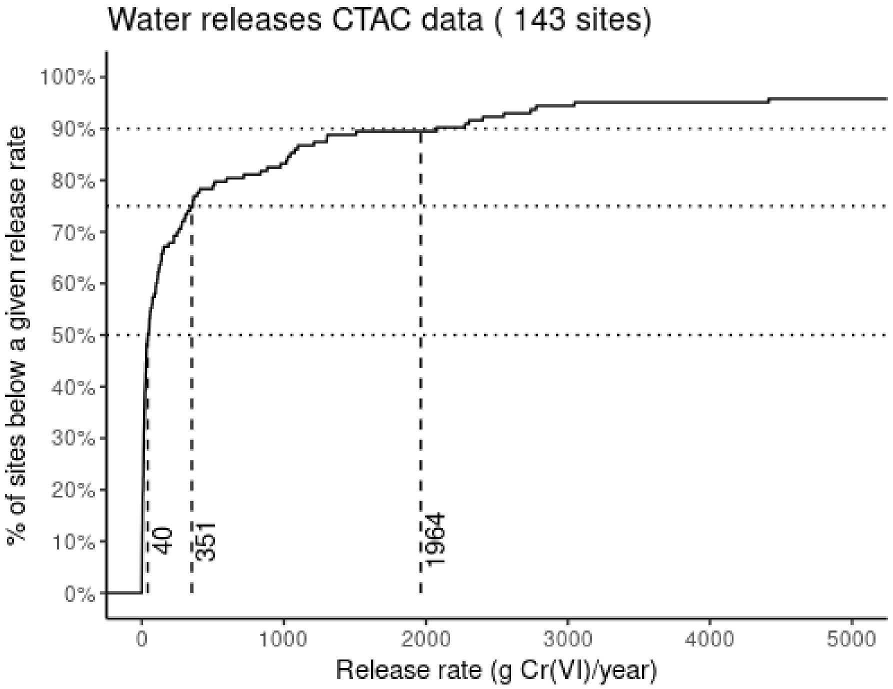

Figure 3. Empirical cumulative distribution function (ECDF) for water releases

Figure notes: Data from the CTACSub2 AfA (all uses); Vertical dashed lines indicate P50, P75 and P90 releases.

B.8.1.1.2. Call for Evidence information

Data received in the CfE#1 and CfE#2 have been merged together and pre-treated to:

- Remove duplication of sites, i.e. to have one emission to air and water per site; this implied merging data when clearly one submission complemented another one for the same site or removing one (in general the first submission) if the emissions were contradicting each other.
- Only for the release estimation, removing submission showing data on tonnages higher than the release estimation (in other terms when the calculated release factor was higher than 100 %).

Table 10 provides a generic overview of responses from CfEs.

Table 10. General statistics on the CfE#1 and CfE#2

	Number	Percentage
Respondents	706	100 %
Tonnage data	585	82.9 %
Air emission data	364	51.6 %
Water emission data	183	25.9 %

Source: CfE#1 and CfE#2.

Not all respondents have reported data on tonnage used (83 %). A significant part has provided data on air emission (about 50 %) while a relatively small fraction of respondents has provided data on water emissions (about 25 %); the possible reason of this is discussed here below.

Air emissions

General statistics related to the risk management measures in place to reduce Cr(VI) from air emissions are reported in Table 11.

Table 11. RMMs for air emission reported in the CfE#1 and CfE#2

	Number	Percentage
Respondents	706	100 %
Reporting RMM to air	444	62.9 %
Droplet separator	254	36.0 %
Scrubber	289	40.9 %
Other RMMs	91	12.9 %

Source: CfE#1 and CfE#2.

A significant part of respondents (63 %) has provided information on risk management (RMMs) in place to reduce air emissions from their sites; typical RMMs in place are air scrubber and droplet separator, often in combination with each other. Other RMMs reducing emissions are also reported (e.g. filters, condensation, evaporation control techniques, etc). The general statistics of air emission provided by about half of the respondents to the CfEs are summarised in the main report (Paragraph 1.4.3.2). Figure 4 shows the ECDF of air release rates as provided in the CfEs.

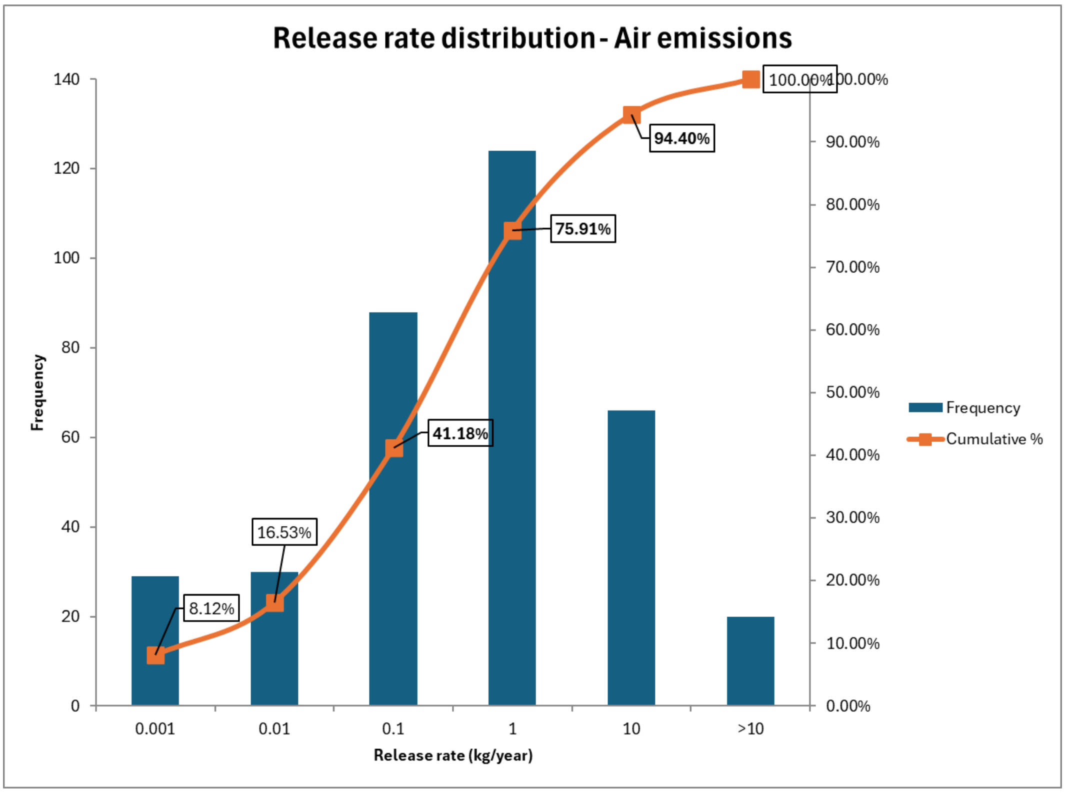

Figure 4. Empirical cumulative distribution function (ECDF) of air release rates

Source: CfE#1 and CfE#2.

The air emissions of Cr(VI) vary between a few grams per year and to more than 100 kg/year; ~25 % of the reporting sites emit more than 1 kg/year, while a small but still significant fraction (about 5 %) of sites emit more than 10 kg/year. In paragraphs B.9.1.1, B.9.1.2 and D.2.1.2.2, it is described how the amount emitted per year can be converted into individual excess lifetime cancer risk, so that this data might be used when elaborating the restriction options for the environment.

Another important element that can be used when looking at the emissions is the estimation of the release factor (i.e. the fraction or percentage of the tonnage of Cr(VI) used released to the environment); this value is relevant either to appreciate the efficiency of the process and the RMM in place to reduce the emission or to estimate releases in cases where only the tonnage is reported for the site. In Figure 5, the ECDF of air release factors is reported.

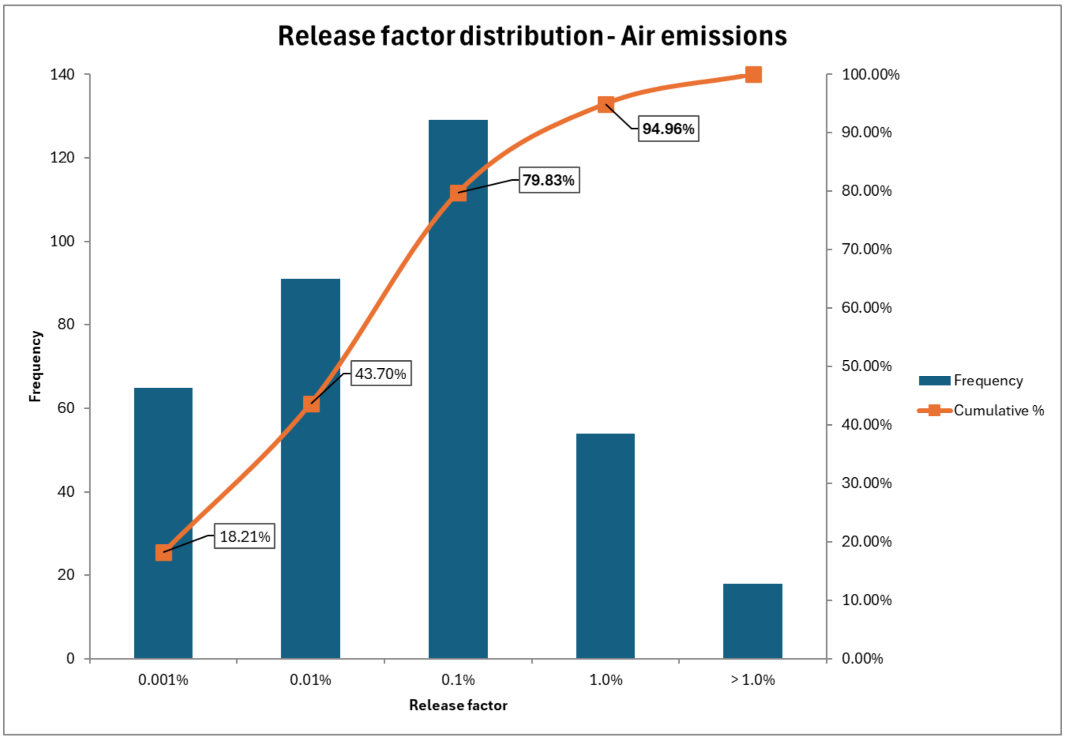

Figure 5. Empirical cumulative distribution function (ECDF) of air release factors

Source: CfE#1 and CfE#2.

The release factors to air are generally very low, with 80 % of sites releasing less than the 0.1 % of the total Cr(VI) used and only 5 % of sites reporting release factors higher than 1 %. It should be noted that a release factor of 0.1 % is consistent with the high efficiencies of RMM in place (for scrubbers 95-99 % efficiency is typically assumed). Moreover, there are economic incentives to avoid ‘losing’ Cr(VI), e.g. during the plating process.

Water emissions

General statistics related to the risk management in place to reduce the water emissions are reported in Table 12.

Table 12. Type and frequency of RMMs for water emission

	Number	**Percentage**
Respondents	706	100 %
Reporting RMM for water	448	63.5 %
Neutralisation – flocculation	299	42.4 %
Closed systems – recirculation	238	33.7 %
Other RMMs	105	14.9 %

Source: CfE#1 and CfE#2.

About 2/3 of the respondents have reported Risk Management in place to reduce water emissions; the most typical ones are the reduction, neutralisation and removal from the water phase by flocculation (as for CTAC sites) and/or the recirculation/reuse of the (treated) process water (also claimed as closed systems). With respect to water emissions, there are other relevant statistics summarised in Table 13.

Table 13. RMMs for water emission – "No emission" option summary

	Number	Percentage
Respondents	706	100 %
Claiming "no emission to water"	349	49.4 %
- out of it, recirculation	160	45.8 % [a]
- out of it, other justification	24	6.9 % [a]
- out of it, no justification	165	47.3 % [a]

Table notes: a Percentage refers to the part claiming "no emission to water."

Source: CfE#1 and CfE#2.

Almost half of the CfE respondents claimed that there are no emissions to water, with 50 % of them justifying this by closed systems / recirculation of water in place. As mentioned, only a quarter of respondents provided data on water emissions; the distribution of frequency of the yearly release rates (kg/y) to water is reported in Figure 6.

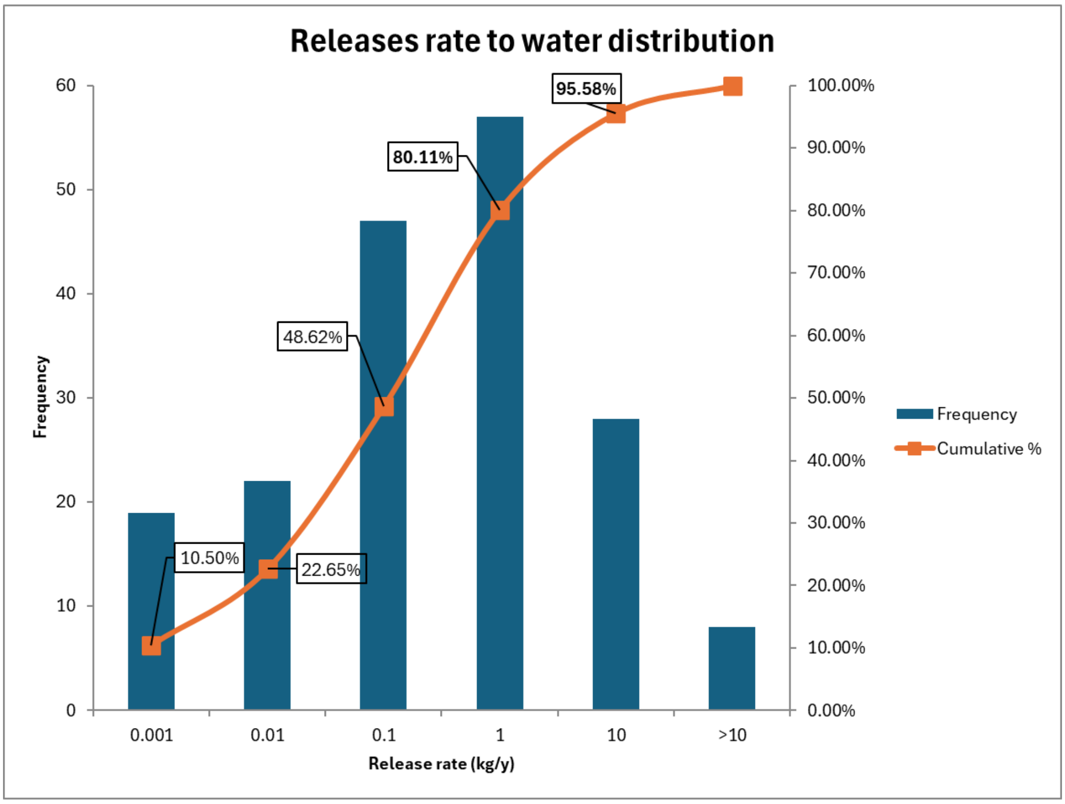

Figure 6. Distribution of frequency for emissions to water

Source: CfE#1 and CfE#2.

The distribution of frequency of emissions to water is not very different than the one of emissions to air, although based on a more limited number of data points; ~20 % of sites report emissions higher than 1 kg/y, while a limited number (less than 5 %) report emissions of 10 kg/y or higher. It should be noticed that these figures represent the releases from the site and, as such, might not reflect the final emissions to the water compartment, since a further reduction takes place at the municipal Sewage Treatment Plant (STP). Moreover, the distribution does not account for the large fraction of CfE respondents claiming no releases to water (i.e. emissions equal to 0). In Figure 7, the distribution of the release factor to water from the sites is reported.

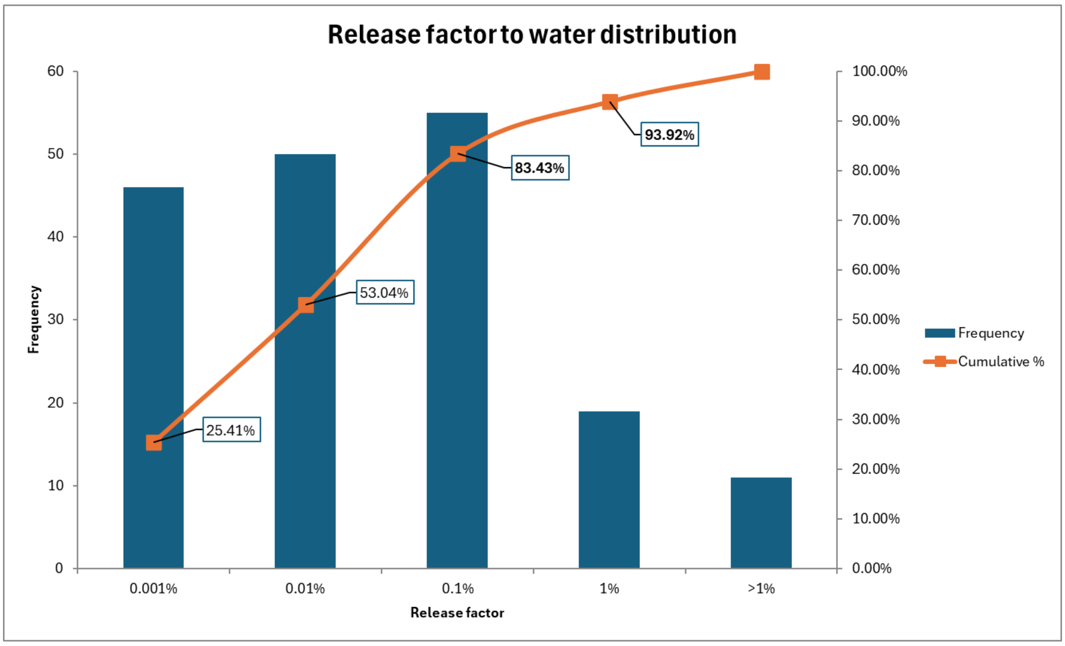

Figure 7. Distribution of release factors to calculate emissions to water

Source: CfE#1 and CfE#2.

The majority of the sites (about 85 %) report release factors lower than 0.1 %; this is in line with the efficiency of the most common RMMs in place (e.g. reduction and flocculation) that shows high efficiencies (>95 %) and the optimisation of the process (e.g. plating).

B.8.1.1.3. Other sources

Other sources of data are the upstream consortium of Application for Authorisation, mainly covering Defence and Aerospace sector, the so called ADCR consortium and the data provided by Downstream covered by upstream application, the so-called Downstream Users notifications. The former, does not include the raw data (CSRs only contain aggregate data), so that it was not possible to process and use the site data to provide statistics and perform an independent risk assessment out of the release estimation. The latter does include raw data from the companies on tonnages and releases (often derived from concentrations at the discharge point and flow rate); in this case, it was possible to establish some comparison between emissions for DUs notification and CfEs; this comparison is summarised here below for air and water emission, respectively.

Table 14. Air emission data

	DU Notification	CfE#1 & CfE#2
Number of sites providing data	502	361
50th percentile (kg/y)	0.18	0.25
80th percentile (kg/y)	1.70	1.50
90th percentile (kg/y)	3.93	4.00
95th percentile (kg/y)	8.79	12.0

Source: CfE#1 and CfE#2 and DU notifications.

Table 15. Water emission data

	DU Notification	CfE#1 & CfE#2
Number of sites providing data	266	183
50th percentile (kg/y)	0.09	0.12
80th percentile (kg/y)	0.90	1.11
90th percentile (kg/y)	4.00	2.22
95th percentile (kg/y)	11.96	8.36

Source: CfE#1 and CfE#2 and DU notifications.

The emissions to air reported in the DUs notification are very similar to the ones provided within the CfEs; as for example, the 90th percentile of the releases to air are equal (about 4 t/y for both) and little differences can be observed for other percentiles; on the contrary, releases to water are different, especially for high percentiles (e.g. for 90th and 95th percentiles), showing higher releases notified by DUs. It should also be noted that the number of sites providing data on emission are significantly higher for the DUs notification, if compared to the CfEs (about 25 % more).

B.8.1.2. Exposure estimation

Releases to air and water are the main input parameters determining the exposure concentrations and doses used for the risk assessment. For water emissions, also the operating days play a role in exposure estimation (for some scenario, see section related to oral exposure). Following the releases, the exposure concentrations (air concentrations at point of inhalation and oral doses) are calculated via the use of the fate and transport model EUSES 2.1.2 as embedded in Chesar 3.7.

B.8.1.2.1. Inhalation exposure

Exposure concentrations estimated by means of EUSES 2.1.2 (Chesar 3.7) are only dependent on the annual releases to air from the site; this is due to the fixed and conservative assumptions made in EUSES 2.1.2[20] on:

- Source of emission: height set to 10 m; heat content of emitted gases set to 0 (no extra plume rise); source area set to 0 m representing an ideal point source
- Environmental conditions for wind, atmospheric stability class, etc.
- Concentration at point of inhalation estimated at 100 m from the source of emissions (representing the worst-case situation)

Therefore, the concentrations at point of inhalation are linearly dependent on the release over the year; for the statistical review of such concentrations, see also Tables 13 and 14 of the main report.

B.8.1.2.2. Oral exposure

Oral exposure via food (fish, crops, meat, dairy products and drinking water) depends in principle on both releases to water (e.g. via sludge application to agricultural soil) and air (e.g. via deposition). However, the most relevant risk from airborne emissions is due to inhalation exposure; air emissions and deposition contribute very little to oral exposure,

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[20] https://echa.europa.eu/documents/10162/17224/information_requirements_r16_en.pdf.

e.g. via drinking water or fish ingestion. In absolute terms, the oral risk due to air emissions is insignificant compared to water emissions (e.g. via drinking water). This implies that the oral exposure and subsequent risk is driven by water emission only. For a further discussion of these aspects see Appendix B.9.1.3.1.

Sources of oral exposure considered by EUSES 2.1.2 are in principle: vegetables (divided in leaf and root crops), fish, meat, dairy products (milk) and drinking water; however, the analysis of the exposure routes in phase of risk assessment showed that:

- Meat and milk ingestion has never been considered as potentially relevant by RAC, and the same line has been taken from a prospective of the present risk assessment

- Ingestion of vegetables (leaf and root) crops are equally disregarded by RAC; however, since few experimental data are reported in literature on the transfer of Cr(VI) from soil to plants (EURAR[21]), an assessment on potential ingestion of Cr(VI) from crops has been performed (see paragraph B.9.1.3.2), confirming the scarce impact of this route to the overall oral exposure

- Ingestion of fish is considered relevant by RAC and has been simulated in the present risk assessment; however, it emerged that the risk due to this route, if compared to the drinking water ingestion, was about 2 orders of magnitude lower, and therefore can be considered negligeable (see paragraph B.9.1.3.2)

Based on these points, one can conclude without making any appreciable underestimation that the only relevant exposure route for oral intake is drinking water ingestion. In EUSES both groundwater and surface freshwater can be considered as a potential source for drinking water; the maximum concentration from the two water resources it put forward for the exposure assessment. Groundwater concentration does depend on the application of municipal sewage treatment plant (STP) sludge to agricultural soil, while the surface water concentration does depend on the emissions (direct or via municipal sewage treatment plant) to surface freshwater compartment. The following key parameters determining the oral exposure via drinking water are selected for the risk assessment:

- When emissions from the site are connected to a municipal STP, 50 % Cr(VI) ends up in the sludge, while 50 % is emitted to surface water (EURAR[22])

- The Cr(VI) in the environment is rapidly reduced to Cr(III); for the sake of risk assessment it can be assumed that only 3 % of Cr(VI) emitted to environment will be available for exposure (EURAR[23]); this is for sure true for emission to soil via STP sludge, where there is enough time for transformation; also in organism such fish, cows, etc, the same rule of 3 % applies. However, when surface water is the drinking water source (scenarios 2 and 3 below), no correction of Cr(VI) to Cr(III) has been considered

- To simulate leaching to soil towards groundwater, the most conservative partition coefficient from soil to water mentioned EURAR[24] has been used for the assessment

In Table 16, the main chemical parameters used for the exposure estimation are reported, together with the source of the information.

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[21] European Union Risk Assessment Report, Paragraph 3.1.5.3.2.

[22] European Union Risk Assessment Report, Paragraph 3.1.1.2.3.

[23] European Union Risk Assessment Report, Paragraph 3.1.1.2.1.

[24] European Union Risk Assessment Report, Paragraph 3.1.1.2.2.

Table 16. Main input parameters used for oral exposure assessment

Parameter	Value	Source
Molecular weight	99.99 g/mol	EURAR table 1.1[1]
Physical state	Solid	EURAR table 1.4[1]
Solubility	1670 mg/l	EURAR table 1.4[1]
Vapour pressure	0.001 Pa	Assumption[2]
Log Kow	0.1 l/kg	Assumption[2]
Biodegradation screening	Not biodegradable	Inorganic substance
Kp soil	2 l/kg	EURAR page 56[3]
Kp susp	100 l/kg	EURAR page 56
Kp sed	200 l/kg	EURAR page 56
Fraction to sludge in STP	50 %	EURAR Paragraph 3.1.1.2.3
BCF	1 l/kg	EURAR page 67

Table notes: [1] refers to CrO_3; [2] very low value for Vp, Kow to allow the tool to work (Kow not impacting on estimation, since Kp are used for the assessment); [3] the minimum value has been taken for the assessment (conservative assumption).

Three release scenarios are possible, triggering different exposure through drinking water:

1. Releases from the site are collected and sent to a municipal Sewage Treatment Plant and the sludge produced is applied to agricultural soil; in such case, the source of drinking water would be the groundwater; this is the most conservative scenario in terms of exposure concentration estimated.

2. Releases from the site are collected and sent to a municipal STP and the sludge is incinerated. In such case only the fraction emitted to surface water would be available for exposure and the source of drinking water would be the receiving surface freshwater.

3. Releases from the site are discharged directly to surface water. In such case, the receiving surface freshwater is the source of the drinking water.

In the CTACSub2 AfA, it is assumed that all releases to water are collected and, after the on-site treatment, are sent to a municipal Sewage Treatment Plant; the resulting STP sludge is applied to agricultural soil, therefore scenario 1 will apply.

In CfE#1 and CfE#2, respondents had to choose which scenario would apply to their case; the answer has been considered in the exposure and risk assessment of the site. In case the management of the STP sludge was unknown, the most conservative Scenario 1 (application to agricultural soil) was applied to the case. No specific statistics on exposure are provided here; general statistics on oral exposure are in Tables 13 and 14 of the main report. The Dossier Submitter emphasises that the assumptions made in the risk assessment for oral exposure, estimated concentrations and doses are directly proportional to the release rate to water.

The Dossier Submitter underlines the conservative nature of the estimations for humans exposed via the environment at the basis of EUSES calculations; on top of the conservative nature of certain parameters reported in the table above (e.g. soil water partition coefficient selected for the assessment), it must be understood that the oral dose estimation assumes that all drinking water ingested comes for the local source "contaminated" directly or indirectly from releases to water.

Environmental risk is outside the scope of the present report; however, it is qualitatively discussed in paragraph B.9.1.3.3.

B.8.1.3. Uncertainty analysis for exposure of humans via the environment

Table 17 summarises the key uncertainties in the environmental exposure assessment.

Table 17. Summary of uncertainties in the environmental exposure assessment

Uncertainty	Influence on exposure and risk	Comment
Data from CfE (release estimation provided by respondents) used for exposure assessment might be biased	Not possible to judge whether exposure estimation is underestimated or overestimated	Comparison with other sources of data (e.g. CTAC sub 2) largely confirms release estimation provided in CfEs.
EUSES assumptions (e.g. air concentrations estimated at 100 m from source) for air concentration form air emissions	Overestimation due to particular and fixed EUSES assumptions is possible	Although EUSES assumptions are recognised as conservative, few measurements in the vicinity of a Cr(VI) source seems to support EUSES calculations for air concentrations
EUSES assumptions on drinking water sources for oral exposure	Oral exposure might be overestimated, for example because it takes the worst case between GW and surface water. Possible share of sources not possible in EUSES	Drinking water is typically a local source (differently than food), therefore not big overestimation for the EUSES setting for the source selection
EUSES assumptions on concentrations calculation for groundwater and surface water (affecting oral route via the drinking water)	Oral exposure is overestimated (e.g. because GW is the topsoil layer water and emissions are diluted to surface water very little)	--
Environmental input parameters used to estimate Groundwater concentration following sludge soil application	Exposure is overestimated due to the selection of the most conservative partition coefficient mentioned in EURAR (alkaline soils)	In absence of data the most conservative soil type had to be selected
Assumption that only 3 % of Cr(VI) emitted is present in the soil as Cr(VI)	Influence unclear	Some measured data support that this assumption is sufficiently conservative, at least for soil
Oral exposure from vegetables, milk and meat not considered	No relevant underestimation	It has been demonstrated from few data that at least for vegetables the impact on oral exposure would be not significant
Dose-response curve might overestimate the risks at low exposure levels.	Overestimate, especially for humans via environment where low doses / concentrations are estimated	--
Environmental hazards not considered.	Probably not significant. Environmental risks are reduced via reduction of releases to protect general population.	It has been shown that the environmental risk for freshwater due to direct releases from the sites is controlled, except for RO1 where the RCR is just above 1

B.8.2. Occupational exposure

Occupational exposure assessment is focusing on the inhalation exposure because the lung cancer risk via the inhalation exposure is considered as the most relevant hazard. The reduction of inhalation exposure is also assumed to decrease the other risks.

The exposure assessment is based on the three different datasets,

1) information provided in the two calls of evidence (CfE)

2) information provided as part of the CTACSub2 AfA (Communication Nr. AFA-C-2114679208-38-01/F) and
3) information collected from DU notifications pursuant Art. 66 of REACH

The same companies and sites can be part of different datasets and therefore all the datasets are analysed separately. The main conclusions are based on the CfE data because this data was collected for the purposes of the restriction proposal and includes data for all use categories. The two other datasets are used mainly to check the plausibility of and to corroborate the CfE data. These datasets have been collected for different purposes and are therefore also constructed differently. Therefore, there are differences in the steps taken to analyse them. The comparison between different data sets is presented in Table 18 and the details of data treatment and analysis are reported below in separate subchapters.

The exposure data from individual AfAs has not been considered in the exposure assessment, because the data, if available, has been reported using different templates containing different kind of information. To collect, clean and analyse such dataset would require amount of time, which would be disproportionate to the added value, because many of companies are already included in the other datasets used in the exposure assessment.

Table 18. Comparison between different exposure data

Reported information	CfE#1 and CfE#2	CTACSub2	DU notification
Use categories covered	1-6	1, 3, 4, 5	1, 3, 4, 5
Use descriptions	Pre-defined use categories.	Pre-defined 12 uses.	Pre-defined use numbers based on authorisation decisions.
Reporting of measurements	Aggregated measurements per task (P90 or maximum)	Individual measurements available	Individual measurements available
Durations of tasks	Yes	Yes	Some reported per task, some per set of tasks
Frequencies of tasks	Yes	Yes	Yes
Sampling method	Sometimes	Yes	Yes
Measurement duration	No	Yes	Yes
Site identification	Companies were asked to report per site	Yes	For majority not available (typically measurements are reported per year, not always possible to know which measurements are from the same site but from different years)
Number of workers	Yes (in CfE#1 per use, in CfE#2 also per task)	No	Yes
Limit of Quantification	Yes, but not for all	No, but indicated if the measured value was below LoQ	Part of the template but often not reported or reported if below LoQ
General ventilation and its effectiveness	Yes	Yes	Yes
RPE and its effectiveness	Yes	Not for each site but aggregated per task	Yes
LEV and its effectiveness	Yes	No	No
Other OCs/RMMs	automation, segregation and containment of each task	No	Use of gloves
General information concerning the data	Data collected specifically for the	Data collected for the purpose of AfAs to	Data collected for the purpose of Art. 66 DU

	purpose of the restriction proposal	create generic exposure scenarios for each use to cover most of the sites	notifications for granted authorisation. Data is reported as submitted files. ECHA has provided an excel template, which can be used for reporting, but also other templates and formats have been used. For the preparation of restriction proposal, the Dossier Submitter has extracted the data, which was submitted using the ECHA template or another most commonly used template.

B.8.2.1. Description of the data

B.8.2.1.1. Call for Evidence data

The following information, which was provided by companies in the CfEs, was used for the occupational exposure assessment:

- Use categories performed at a given site. Use categories were pre-defined to match with the restriction proposal
- Number of directly and indirectly exposed workers onsite
- Maximum of five tasks, which contribute most to the occupational exposure. The task menu included 14 pre-defined tasks and a possibility to add up to five "other tasks". For each of the selected tasks, the duration, frequency, current measured concentration, the highest measured concentration during the last 10 years and the description of the measured concentration was obtained. In CfE#2, companies were additionally asked to provide the number of workers involved in each task and any further comments and information. Moreover, it was specified that the measured concentration should be reported as P90 if six or more measurements were available and as maximum value else. Individual measurements were not asked
- For each selected tasks, the existing operational conditions (automation, segregation, containment, general ventilation, local exhaust ventilation (LEV) and respiratory protection equipment (RPE)) were asked to be reported. For general ventilation, LEV and RPE also their effectiveness
- Binding national occupational exposure limit (OEL) for Cr(VI)

Pre-treatment of the data and the assumptions made

- General data cleaning was conducted prior to the analyses. This included for instance removing text from fields where only numbers should be reported and harmonising the language, e.g. in "yes/no" answers
- For value indications using '>' or '<' the boundary value was taken forward in the analysis

- Concentrations reported as total chromium were converted to Cr(VI) by multiplying the reported value by 0.52 (in all such cases the used substance was CrO_3)

- Because the individual measurements were not provided, it is assumed that the values represent either the P90, in case the reported concentrations were based on six or more measurements, or the maximum measured concentration, in case less than six measurements were conducted, unless mentioned differently

- A column was added to indicate whether the reported measured concentration was reported as 8h-TWA or modelled or based on the static measurement. If the duration of the measurement was reported to be around 8h, the measured value was considered as 8h-TWA. For the analyses only personal measurements were considered. If not stated otherwise, the reported value was assumed to be a personal measurement without any corrections

- For very low concentrations (<0.001 µg Cr(VI)/m^3), it was assumed that the values were either reported as mg Cr(VI)/m^3 instead of µg Cr(VI)/m^3 or where the duration of the task was very short referred to the 8h-TWA concentration

- If task frequencies, durations, measured concentrations and numbers of exposed workers were reported in ranges, the median value was taken forward as a reasonable worst-case assumption

- If the effectiveness of OCs and RMMs in reducing the exposure was reported as a 'greater than' value or as a range, the lowest value was taken forward as a reasonable worst-case assumption

- If the measured value was below the limit of quantification (LoQ), then the LoQ was taken forward in the analysis. If the LoQ for the used method was unknown, 0.1 µg Cr(VI)/m^3 was assumed by default. This value was used as it well reflects the median LoQ of the methods used to measure worker exposure (see B.1.2.2, Table 9)

- If the effectiveness of RPE was reported as assigned protection factor (APF), the effectiveness was calculated as 100 % - (100 % / APF). If only the mask type was reported, the corresponding APF and effectiveness was assumed based on the corresponding standards. In case the mask type was unclear, but it was stated that RPE is used, APF = 4 was used as a worst-case assumption. In case the reported effectiveness was > 99.9 %, 99.9 % (corresponding to APF = 1 000) was used as a worst-case assumption

B.8.2.1.2. CTACSub2 data

The exposure data was provided by the applicant as part of the AfA process. It includes personal and static measurements for occupational exposures from all the companies and sites, which were part of the AfA. Measurements are from three different years (2021-2023). During the opinion development stage, several questions related to the application and data were sent from RAC and SEAC. The answers provided by the applicant were considered in the data analyses. The data contains the following information relevant for the occupational exposure assessment:

- Site ID

- Use(s) performed at the site. Total of 12 different uses were included in the application. The Dossier Submitter assigned the uses to the suitable use categories according to the restriction proposal. CTACSub2 data covers use categories 1, 3, 4 and 5

- All measurements for each site per year with the indication, whether the measurement was static or personal. For static measurements also the location of the measurement was reported for most of the measurements
- Measurement method, date and duration of the measurement and the substance measured (Cr(VI) or total Chromium)
- All the tasks covered by the measurement and the maximal duration and the frequency of each individual task
- Measured value and the indication, whether the concentration was below the LoQ. The LoQ was not reported
- The information about the RPE was not reported as part of the exposure data but was collected from other parts of the application. The same RPE was assumed at all sites for a given task
- Ventilation type (categories based on air changes per hour (ACH))

Pre-treatment of the data and the assumptions made

- For entries with ">" or "<" the value without the symbol was used for the analyses
- Concentrations reported as total chromium were converted to Cr(VI) by multiplying by 0.52
- Concentrations were converted to µg Cr(VI)/m^3
- Measured concentrations of 0 were removed, as these were considered as placeholders by the applicant
- Measured concentrations <0.001 µg Cr(VI)/m^3 were converted to <0.001 µg Cr(VI)/m^3
- Frequencies reported as 0 were converted to 1
- Task durations shorter than 5min were converted to 5min and duration longer than 480min were converted to 480min

B.8.2.1.3. DU notification data

All the downstream users of an authorisation are obliged to notify their uses and submit monitoring data to ECHA. The data have been submitted in different formats and the Dossier Submitter has extracted monitoring data, which has been submitted using two different standard excel templates (template A1 and A2). All the measurements from excel sheets following template A1 were collected in one excel sheet and all the measurements following template A2 in another excel sheets. These two files were then pooled prior to the data cleaning and analyses. The data contains the following information relevant for the occupational exposure assessment:

- Site ID: This information was available only in the template A2

- Use(s) performed at the site and the corresponding authorisation number. The Dossier Submitter assigned the uses to the suitable use categories according to the restriction proposal. The data covers use categories 1, 3, 4 and 5

- All the tasks covered by the measurement. For the data from the template A1 the aggregated duration and frequency of all tasks were reported, while in the template A2 the duration and frequency of all tasks were reported individually

- Measured value and an indication, whether the measurement is static or personal. For static measurements also the location of the measurement is reported for most of the measurements. In the template A1 the LoQ and LoD of the method is reported, while in the template A2 only whether the measurement is below LoQ

- RPE and its assigned protection factor (APF) and the type of general ventilation. In the template A1 also the gloves used during the task is reported

- Sampling method, date and duration of the measurement and for the data from the template A2 also the substance measured (Cr(VI) or total Chromium)

- Ventilation type (categories based on air changes per hour (ACH))

- Number of workers involved in the corresponding task or set of tasks. In template A2 this information was not reported under the exposure data, but as part of the base data for each site, which was extracted separately

Pre-treatment of the data and the assumptions made

- General harmonisation of data, e.g. task names and units for the measured values

- For the data without the site ID, it was assumed that all the data in a single submitted file is for a single site. This might underestimate the number of sites, as single companies might have submitted data for all their sites in a single site. On the other hand, data from a single site, but from different years, may have been submitted in separate files. Therefore, if years are pooled together, the number of sites might be overestimated

- Duplicated values were removed because sometimes the same measurements were part of different files

- Measurements conducted as total Chromium were converted to Cr(VI) by multiplying by 0.52. If the measured substance was not indicated, it was assumed that the measured value was in Cr(VI)

- The measured concentrations <0.001 μg Cr(VI)/m^3 were converted to <0.001 μg Cr(VI)/m^3

- For values reported as ranges, the median value is taken forward for the analysis. For values with ">" or "<" the value without the symbol was used for the analyses

- For the data without the task duration and/or frequency, the median duration/frequency from the same (harmonised) task is used

- If RPE was not reported, then it was assumed that no RPE is worn

B.8.2.2. Exposure assessment for workers

B.8.2.2.1. Description of the approach

The general approach for estimating the exposure is similar for each dataset but there are some differences due to the differences in the available information in different datasets. As a first step, relevant tasks for each UC were selected primarily based on the counts of different tasks reported for a given UC in the CfEs (see Table 19). The decision on the set of tasks was based on the counts from sites, where only a single UC was performed, because in the data it was not stated, which tasks are relevant for which UC.

Table 19. Count of tasks performed as part of a given UC

	Only sites with a single UC							All sites						
Task	**UC 1**	**UC 2**	**UC 3**	**UC 4**	**UC 5 ETP**	**UC 5 Other**	**UC 6**	**UC 1**	**UC 2**	**UC 3**	**UC 4**	**UC 5 ETP**	**UC 5 Other**	**UC 6**
Delivery and storage	**7**	4	88	**6**	**2**	**20**	**2**	10	7	98	8	3	26	3
Weighing, mixing, diluting of liquids	**8**	2	31	**12**	1	**17**	**2**	12	2	43	22	2	32	2
Weighing, mixing, diluting of solids	**8**	4	39	**1**	0	**19**	**5**	10	5	48	7	0	27	6
Loading/unloading of jigs	2	**8**	**143**	2	**1**	**14**	**3**	5	10	161	10	1	25	3
Surface treatment by spraying in spray booth	1	0	7	**31**	0	**3**	0	3	0	19	54	1	23	0
Surface treatment by brushing, rolling or pen stick	2	0	9	**18**	0	**11**	0	3	1	13	31	0	21	0
Surface treatment by dipping/immersion	3	**17**	**277**	4	**2**	**40**	0	11	25	326	26	5	68	0
Concentration adjustment of baths with solids	2	**13**	**150**	2	**0**	**18**	0	5	19	176	15	2	37	0
Concentration adjustment of baths with liquids	1	**6**	**80**	1	**2**	**19**	0	3	8	96	10	3	33	0
Rinsing, drying, (self-)curing of parts	0	0	53	4	1	**18**	0	1	0	66	5	1	22	0
Frequent maintenance activities	**2**	**14**	**177**	**7**	**2**	**26**	**6**	4	17	199	15	2	38	6
Infrequent maintenance activities	3	**12**	**122**	4	1	**21**	**6**	3	14	136	10	1	33	6
Waste/wastewater management	**0**	**11**	**93**	**5**	**1**	**15**	**4**	2	14	103	9	2	22	4
Sampling and transfer to small containers	**6**	**8**	**132**	1	0	**14**	**7**	9	13	148	6	1	21	7
Other1	6	3	47	7	0	8	18	7	6	54	11	0	13	19
Other2	3	1	15	2	0	2	14	4	3	17	2	0	2	15
Other3	0	0	4	0	0	0	9	0	0	4	0	0	0	9
Other4	0	0	2	0	0	0	4	0	0	2	0	0	0	4
Other5	0	0	0	0	0	0	2	0	0	0	0	0	0	2

Source: CfE#1 and CfE#2.

Table notes: Numbers in bold indicate tasks included in the exposure scenario for a given UC.

Table 20. List of additional tasks included in the exposure scenarios

UC 1	UC 2	UC 3	UC 4	UC 5	UC 6
pf conditioning, robotic environment, operations limited to loading/unloading and setting control consoles	Maintenance of porous ceramic pots used to re-oxidize chromium III to chromium VI	Rinsing and storage of work items	Painting by spraying	Painting by spraying	Several tasks for ferrochromium process
CIP cleaning formulating tank	Surface treatment by automatic system	Farfield activities	Spraying airplane in hangar	packaging	Electrolytes solution analysis by operators
Discharge of big bags	General operation of the electroplating system	Sampling for analysis	Surface treatment by pen	production line survey by operators	formulation of pyrotechnic mixtures
The worker works near the system	Concentration adjustment in the oxamate container	chemical analysis	Spraying/painting in Painting booth	Handling of overhead crane to dip articles	Processing of propellant (Type 1) containing barium chromate
laboratory technician: analysis of finished products in small quantities under Sorbonne		operator of another line in the same room	drilled primed parts	Decanting of liquids	Daily activities of production technician
The worker reproduces on a small scale, the formulation and mixing of different raw materials including chromic acid		Manual system	drilling	chemical pretreatment	Filling/topping up cooling system
Washing of empty drums in the drum washing plant		Loading of baths manually	Grinding/Polishing	reactor cleaning	Mixing of the catofin catalyst
		Manual coating system	Spraying and heat treatment in Painting booth and inside closed oven	supervision of Conversion coating process	Loading of the reactor
		Preparing parts for processing	sanding		Cleaning of leakages (solid debris)
		Maintenance of the electrolyte filter			Several tasks of steel melting process
		Surface treatment in big baths with thick walls			Electrolytes solution analysis by laboratory

UC 1	**UC 2**	**UC 3**	**UC 4**	**UC 5**	**UC 6**
		Pretreatment: Taping			Filling hoppers and devices
		Chrome plating task			Filling the delay device with the pyrotechnic formulation
		Preparation of items			Destruction/burning of the propellant
		operating the line - hanging/removing products on/from hangers.			Maintenance
		Manual Plating			Transfer of the spent catalyst
		Laboratory analysis and sampling			Unloading of the spent catofin catalyst from the reactor
		chemical pre-treatment			Dosing of sodium dichromate into closed cooling system
		strainer basket			Several tasks for hot rolling mill process.
		clamping workplaces close to the Automatic Chrome Plating Machines			Verification tour by operator supervisors
		mixed activities: getting out of the bath, stirring, preparing parts and putting into the bath			Scraping the top pf the powder column before closing the delay
		chemical pre-treatment-dipping/immersion-Maintenance of equipment-Re-filling of baths solids			Processing of propellant (Type 2) containing barium chromate
		cleaning of the baths and exhaust hoods			Separation of the catofin catalyst
		Other surface treatment - loading of jigs with concentration adjustment of baths with solids			Reactor maintenance
		Loading/unloading of			Several tasks for cold rolling mill

UC 1	**UC 2**	**UC 3**	**UC 4**	**UC 5**	**UC 6**
		carriers/jigs - hard chrome electroplating line			process
		Filling the dosing system in full protection with actively ventilated face shield			Several tasks for stainless steel maintenance
		cleaning the chromium baths			
		Sampling of the chrome electrolyte from the chrome baths			
		Measurement in the encapsulated area			
		Concentration adjustment (formulator)			
		Chemical analysis			
		Unloading of baths manually			
		mixed activities: getting out of the bath and stirring			
		chemical pre-treatment-dipping/immersion			
		Maintenance of equipment including cleaning of equipment			
		Loading/unloading of carriers/jigs - pilot electroplating line			
		Hard chrome electroplating line			
		Pilot electroplating line			

Source: CfE#1 and CfE#2.

Some adjustments were made to the set of tasks based on information from the CTACSub2 data. For instance, waste management was included in the scenarios even if it was not a common task for a given UC based on the CfE data. Furthermore, several additional tasks were listed under "other tasks" in the CfEs (see Table 20). Such tasks were included in the exposure scenarios if they were listed for sites, where only a single UC is performed.

For the exposure calculations, only personal measurements were considered. The static measurements were analysed separately from the CTACSub2 data as a supplementary analysis (see Figure 8). This analysis showed that the personal measurements were generally resulting in higher estimates than the static measurements, especially at the lower exposure levels. However, at high exposure levels, static measurements resulted in higher exposure estimates than based on personal measurements. The Dossier Submitter notes that there is some uncertainty related to static measurement data, as the sampling location was not always reported or it was unclear how far away from the emission source the sampling location was.

The measured concentrations were converted to an 8h-TWA (time-weighted average) for each task considering the duration of the task (t_{TASK}) as reported (8h-TWA = Conc * t_{TASK} (min) / 480 min). Additionally, frequency-corrected TWAs were calculated considering the reported frequency of a given task, assuming 5 working days a week, 20 working days a month and 240 working days a year. Finally, a RPE and frequency-corrected TWAs were calculated by multiplying the frequency-corrected TWAs by the RPE correction factor. If the effectiveness of RPE was reported as assigned protection factor (APF), the RPE correction factor was calculated as 1 – (1 / APF).

In the creation of combined exposure scenarios (CES), in the CfEs data it was assumed that the tasks, which were reported, were the most relevant ones in terms of the exposure and that a single worker could be involved in all of them, therefore indicating a realistic exposure scenario for given site. For sites with several uses, only the relevant tasks, as indicated in Table 8 of the main report, for a given UC were considered in the CES. For instance, for sites performing both UC3 and UC4, and reporting exposure for dipping and spraying, dipping was only considered for UC3 and spraying only for UC4. In the CTACSub2 and DU data, there were typically several measurements from a single site. The measurements covered often different sets of tasks. In such cases, it was assumed that the measurements were covering realistic sets of tasks for different workers involved in a given UC. Hence, at a single site, there could be several different exposure scenarios hence capturing the diversity of workers' activities.

To calculate combined exposures, the exposures from tasks relevant for a given UC were summed for each site in the CfE data. In CTACSub2 and DU data, the combined exposure was calculated for each set of tasks relevant for a given UC, and a 90th percentiles of the combined exposures were calculated for each site if six or more workers were measured, or the maximum if less than six. Measurements from different years at a given site were pooled. Combined exposures for each site were used to construct empirical cumulative distribution functions (ECDF) for each UC, demonstrating the empirical proportion of sites above/below certain exposure level. The same approach was used to estimate the number of exposed workers above/below a certain limit value. For that, the site-specific exposure value was repeated in the data as many times as there were exposed workers at that site. The calculation of the exposures and ECDFs, and a big part of the data editing, was conducted using the statistical software R.[25] The results are presented in chapter D.1.1.

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[25] R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

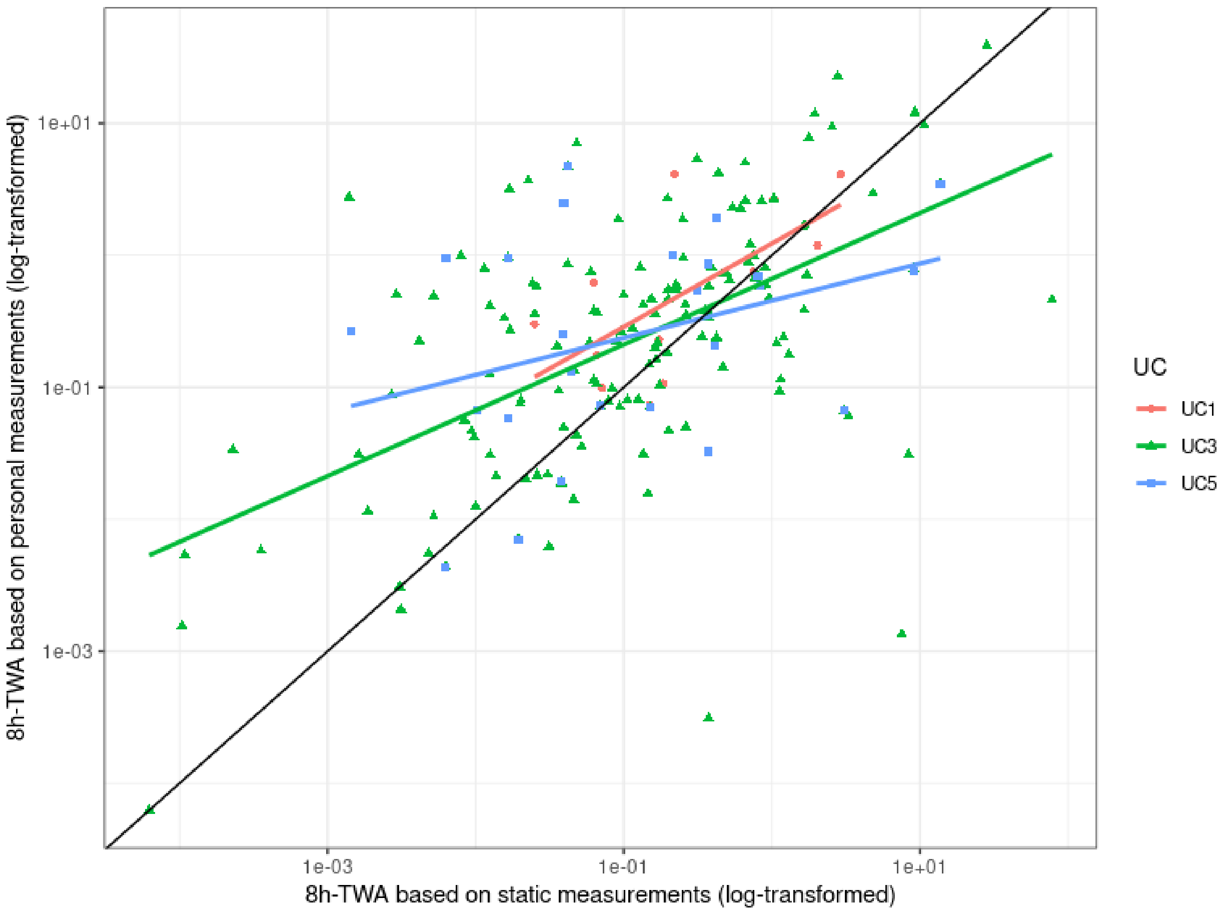

Figure 8. Correlation between personal and static measurements

Figure notes: every point corresponds to the 8h-TWA cumulative exposure calculated for a single site for which both personal and static measurements were available and used in the analysis. Different colours indicate the three different use categories (UCs 1, 3 and 5) for which such data were available. Note that the axes are log-transformed. The diagonal black line is indicating a theoretical perfect correlation between the two different measurements.

B.8.2.2.2. The influence of OCs and RMMs

In the CfEs, companies were asked to report for each relevant task the following information concerning the operational conditions (OCs) and risk management measures (RMMs):

- Automation, segregation and containment of the task
- Presence and effectiveness of general ventilation
- Presence and effectiveness of local exhaust ventilation (LEV)
- Use and effectiveness of respiratory protection equipment (RPE)

In order to estimate the effectiveness of different OCs and RMMs in reducing the exposure the Dossier Submitter conducted an analysis to compare exposures for a given task with and without a given OC/RMM. Comparison was made using the measured concentrations instead of exposure estimates, and for automation, segregation, containment, general ventilation and for LEV. For RPE the comparison is not meaningful, because the concentration is measured outside of the mask. The results are presented in Figure 9-Figure 13.

The presence of different OCs/RMMs had no clear systematic effect on the exposures. This is probably because different sites and plants, even if they are performing same uses, can be very different in terms of factors influencing the exposure. Therefore, sites select the OCs/RMMs based on the actual need to reduce the exposure levels. As a result, different sites might have similar exposure levels with different sets of OCs/RMMs. According to a study based on the ECEL database, the average effectiveness of containment/enclosure, LEV, segregation/compartmentation, automation/robotization and RPE were 79.5 %, 82.8 %, 67 %, 100 % and 92.1 %, respectively (Goede, Ge et al. 2024). And when adjusted by covariates (measurement type, study class, RMM test, study design, data quality and sampling strategy), the estimated effectiveness were 65.1 %, 59.5 %, 57.4 %, 80.2 % and 70.8 %, respectively. However, these results originate from different kinds of uses and are not specific to Cr(VI) substances.

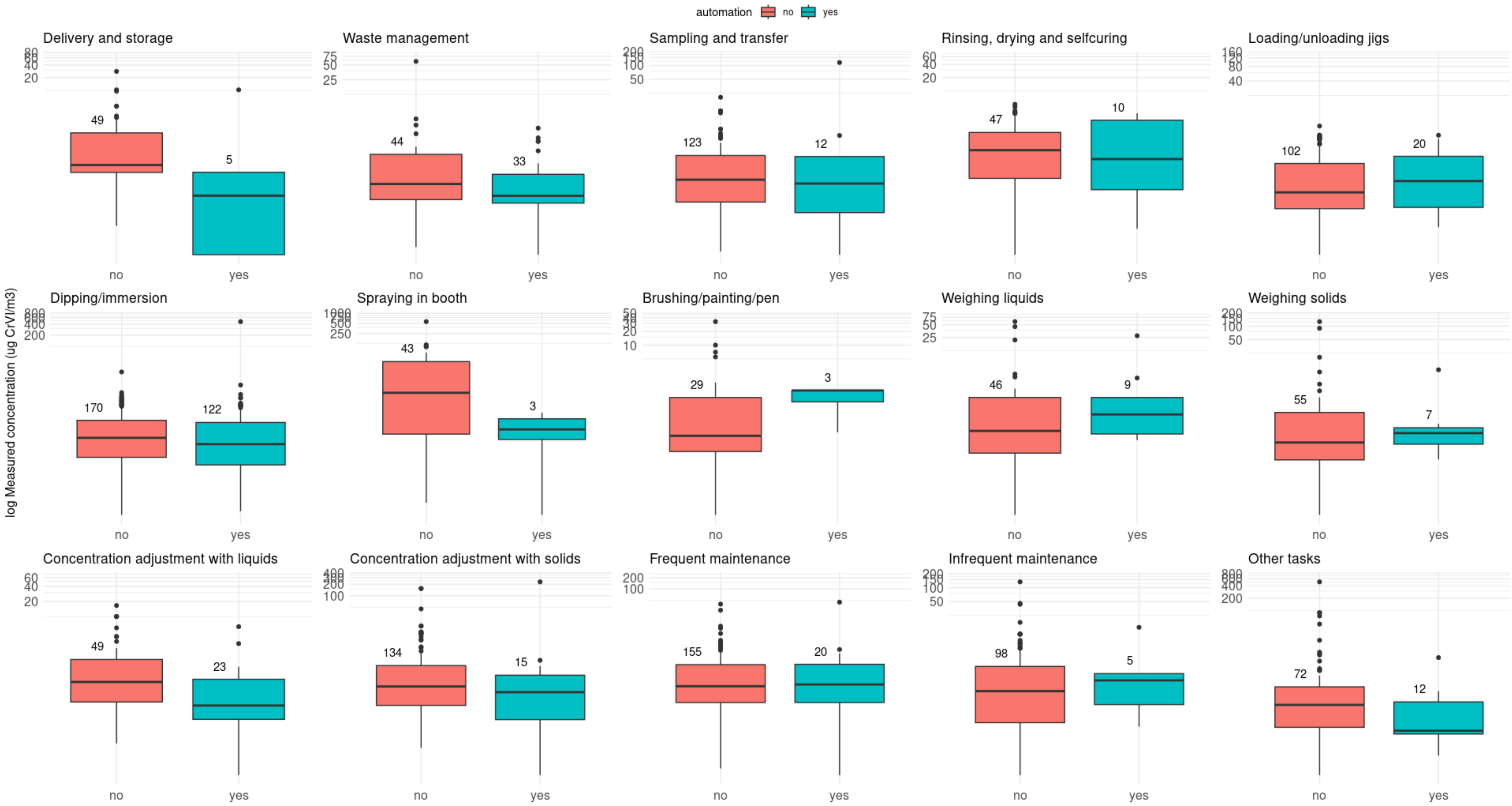

Figure 9. Measured concentrations (log-transformed) in presence/absence of task automation

Source: CfE#1 and CfE#2.

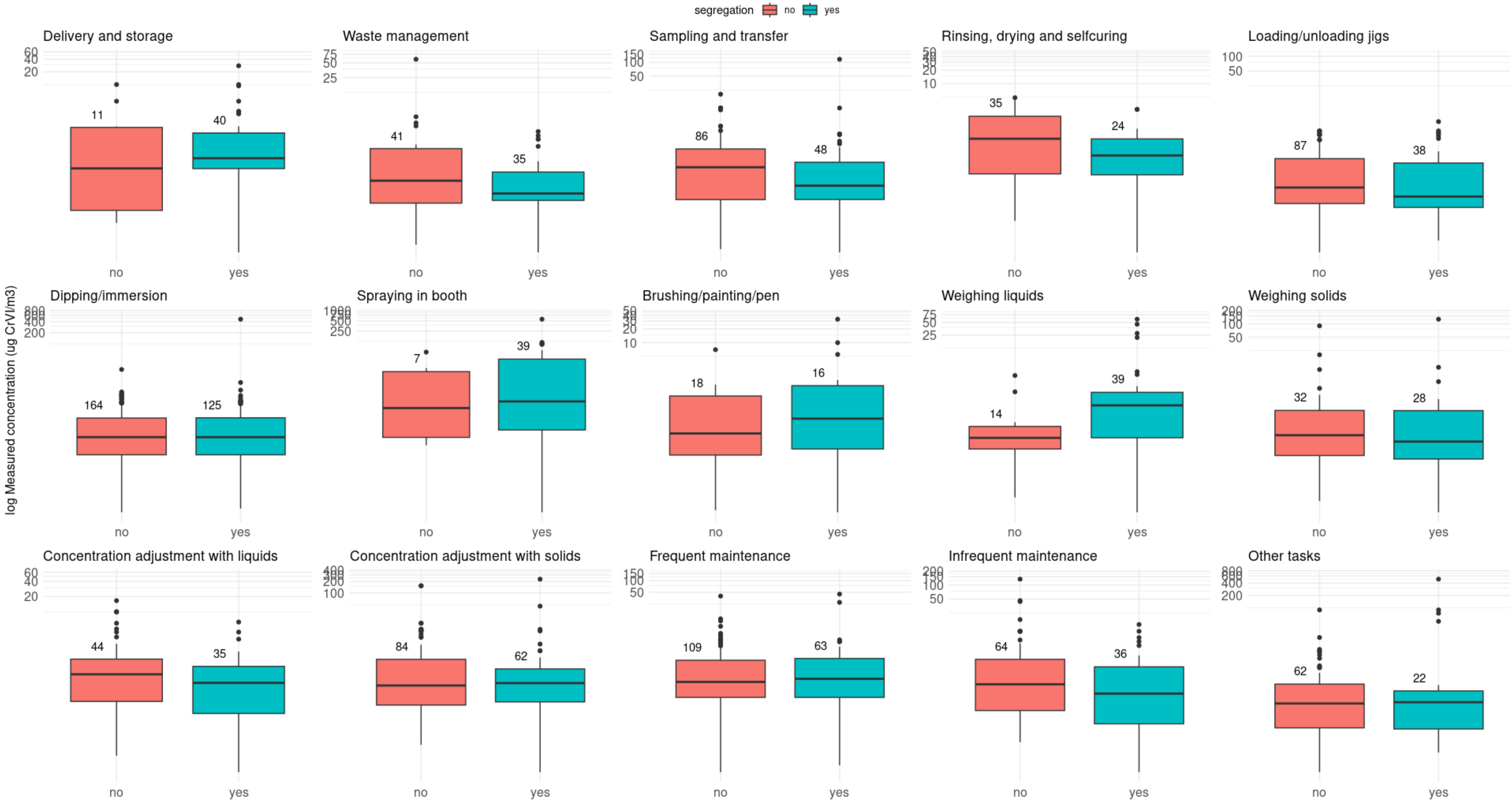

Figure 10. Measured concentrations (log-transformed) in presence/absence of task segregation

Source: CfE#1 and CfE#2.

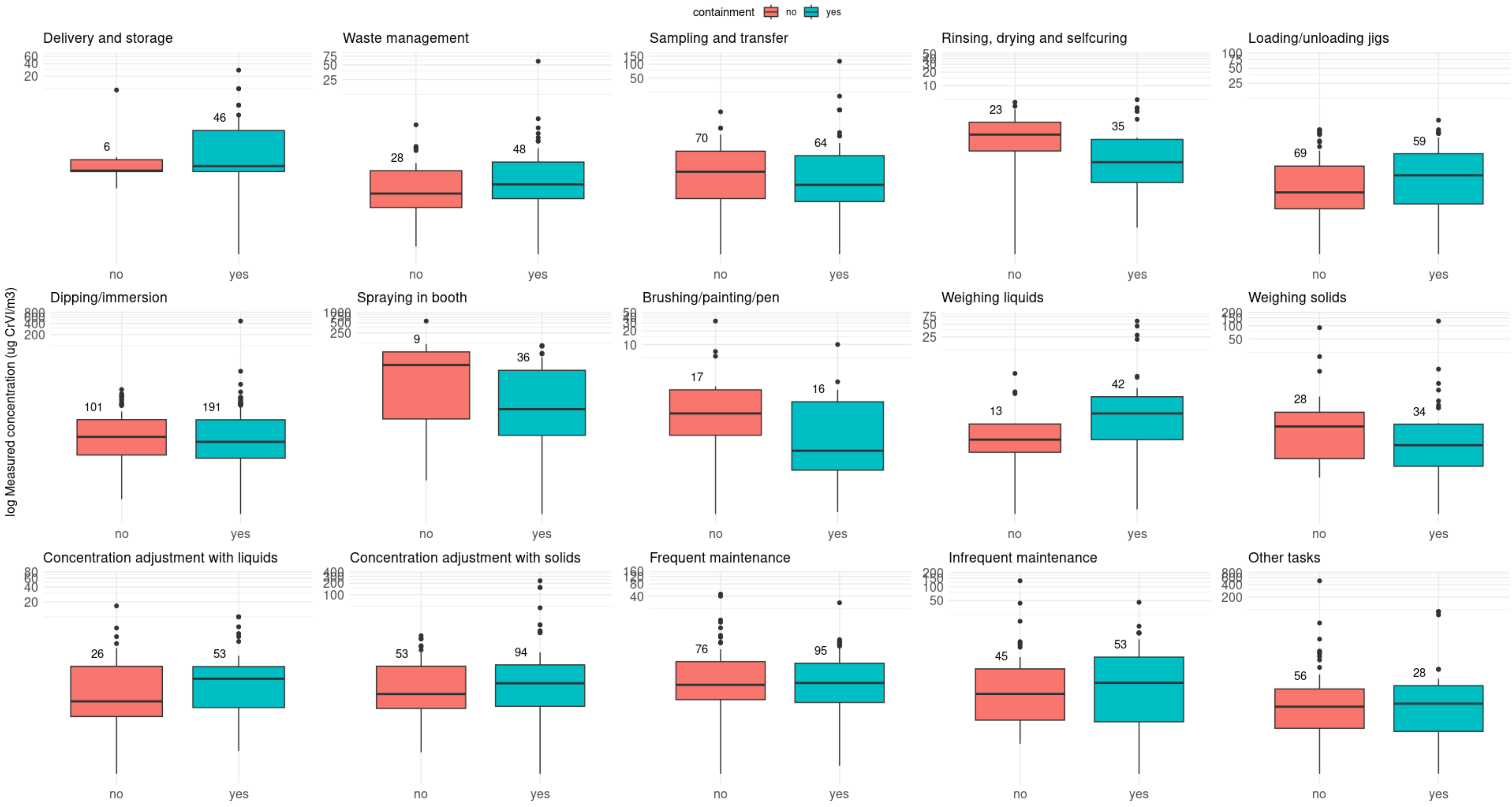

Figure 11. Measured concentrations (log-transformed) in presence/absence of task containment

Source: CfE#1 and CfE#2.

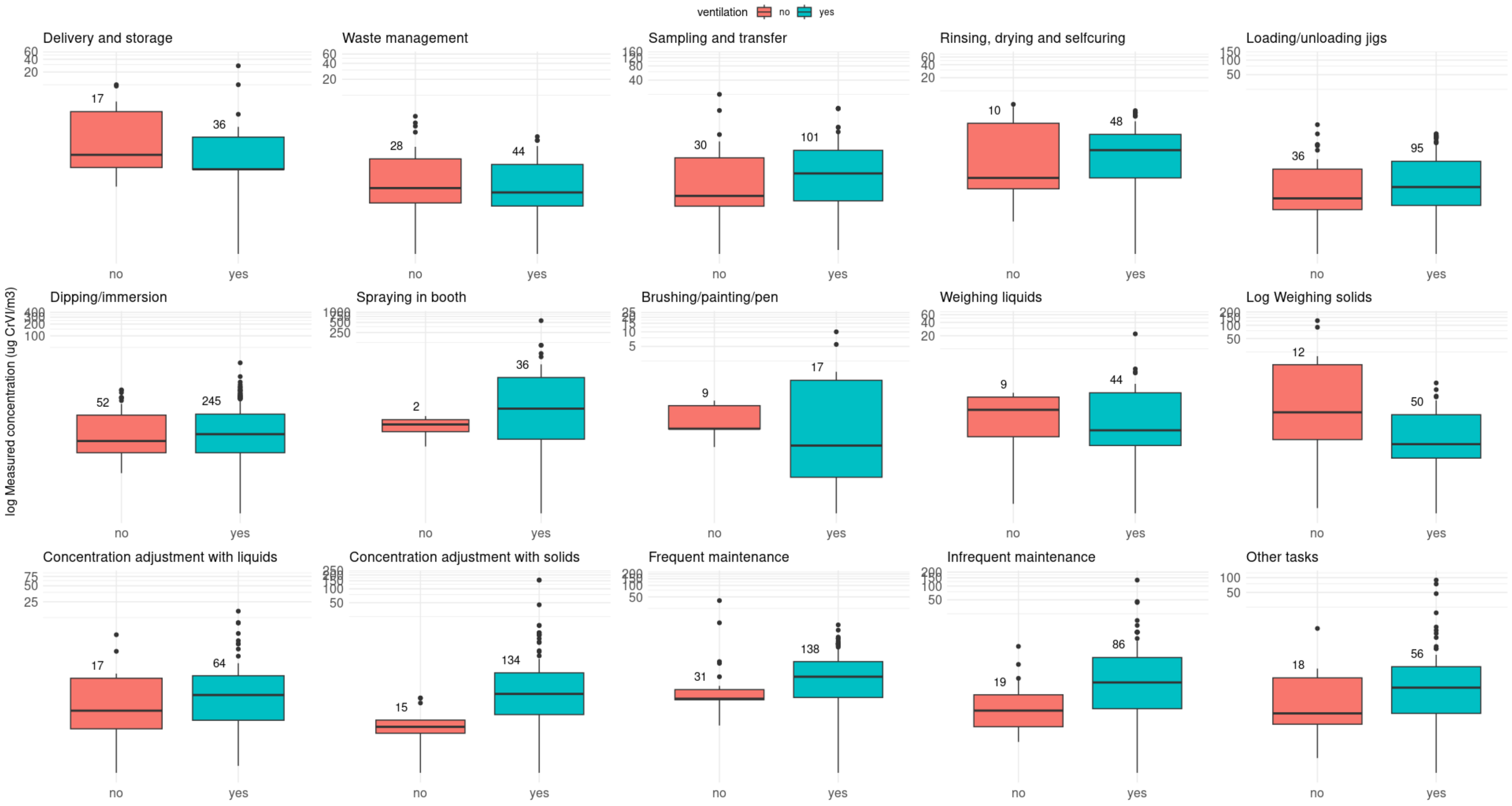

Figure 12. Measured concentrations (log-transformed) in presence/absence of general ventilation

Source: CfE#1 and CfE#2.

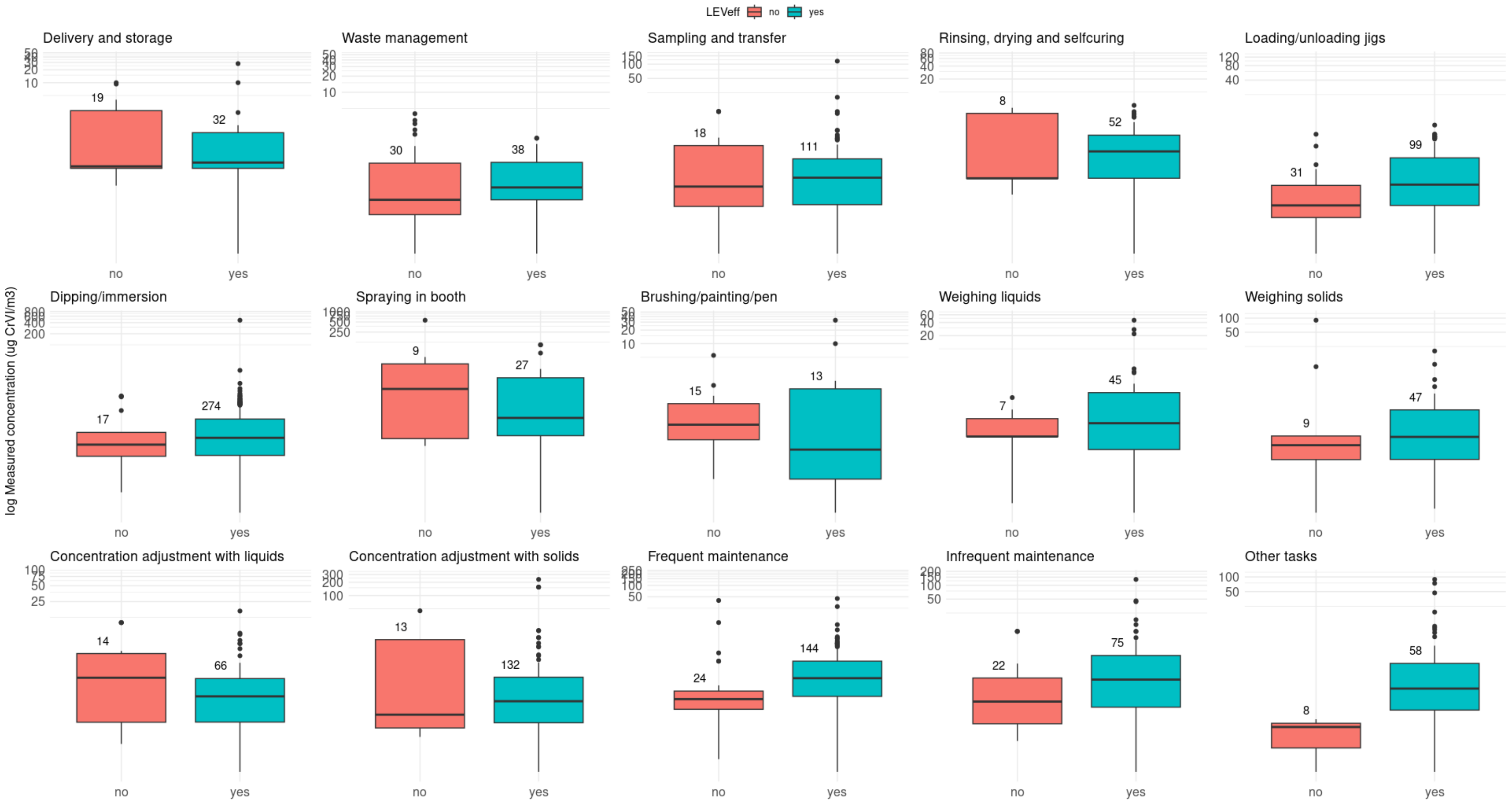

Figure 13. Measured concentrations (log-transformed) in presence/absence of LEV

Source: CfE#1 and CfE#2.

B.8.2.2.3. Summaries for different tasks

Apart from the measured concentrations of Cr(VI), the estimates for the occupation exposure also depend on the frequency and duration of different tasks, included in the combined exposure scenario. To estimate the conservativeness of the worker exposure parameters reported in the CfEs, the Dossier Submitter has compared the frequencies and duration of different tasks between information from the CfEs, the CTACSub2 AfA and the DU notifications. The results are reported in Table 21. Because in the DU notification data sometimes the aggregated duration of a set of tasks is reported, instead of duration of a single task, only entries where the duration and frequency are reported for a single task, have been included in the comparison. Furthermore, the names of the tasks can be different in different datasets but the Dossier Submitter has tried to use the tasks from CTACSub2 and DU notifications that match best the task descriptions used in the CfEs. However, especially for "weighing, mixing, dilution of liquids/solids" and "Frequent/infrequent maintenance activities" the tasks might cover different activities in different datasets, or even within a single dataset. The Dossier Submitter nevertheless considers this comparison indicative for the conservativeness of these parameters.

The frequencies of different tasks are generally smaller in the CfEs compared to CTACSub2 and DU notification data. However, the durations of many tasks are higher in CfEs. The actual exposure time depends on the product of frequency and duration as short tasks conducted frequently could result in the same total exposure as tasks with long duration but conducted less frequently. When considering both parameters together, the longest total exposure times for most of the tasks are in CTACSub2 data, especially for spraying in a spray booth. In the CfEs and in the DU notifications the total exposure times are quite similar, but for instance for brushing/rolling/pen application and for infrequent maintenance activities the total exposure time is generally higher in DU notification data. However, for brushing/rolling/pen application the sample sizes are not very big (41 in CfEs and 31 for DU). And, as mentioned above, infrequent maintenance tasks can cover different kinds of activities, so for this task the comparison may not be very meaningful.

Based on this comparison, the Dossier Submitter concludes that the frequencies and durations of tasks reported in CfEs are generally in line with those reported in DU notifications. In the CTACSub2 AfA, these parameters are in general higher, which could be due to the purpose of the applicant to create a generic exposure scenario to cover all or most of the sites included in the application.

In Table 22 the Dossier Submitter has summarised the assigned protection factors (APF) used during different tasks based on CfE and DU notification data. CTACSub2 is not included as there the same RPE for a given task was assumed for all sites performing this task. In summary, APF of 30 was used for spraying in spray booth, concentration adjustment with solids, frequent and infrequent maintenance activities, transfer of formulation to shipping vessel and machining operations of parts and surfaces in open work areas. For other tasks it was assumed that no RPE is used during the task. In DU notification data the APF are lower for most of the tasks, especially when comparing 90th percentiles. This is partly because the RPE was often not reported and, in such cases, it was conservatively assumed that no RPE is used. In both datasets spraying in spray booth is the task with the highest APF. Biggest difference is for brushing/rolling/pen application with median APF in CfE being 20 whereas in DU notification data 90th percentile APF is 10.

Table 21. Comparison of frequencies and durations of different tasks between different datasets

Task	Frequency (times per month)									Duration (h)					
	CfEs			CTACSub2			DU notification			CfEs		CTACSub2		DU notif.	
	N	P50	P90	N	P50	P90	N	P50	P90	P50	P90	P50	P90	P50	P90
Delivery and storage	59	1	4	191	2	100	242	4	160	0.5	1.7	0.5	7	0.3	2
Weighing, mixing, diluting of liquids	66	4	30	132	20	60	108	8	40	0.5	3	0.2	1	0.5	3
Weighing, mixing, diluting of solids	74	2	11.4	152	4	38.4	50	4	20	0.5	2	0.3	1	0.3	1.1
Loading/unloading jigs	142	22	318	633	80	600	641	200	720	1.8	8	0.5	7.5	0.2	2
Spraying in spray booth	56	20	30	21	40	100	16	20	20	1	5.5	3	4	4	7
Brushing/rolling/pen	41	12	90	28	60	180	31	40	180	0.3	2	0.3	2.7	0.3	2.7
Dipping/immersion	330	20	200	823	100	500	521	100	500	2	8	0.4	8	0.3	4
Concentration adjustment with solids	167	4	12	275	4	20	126	4	20	0.5	1	0.3	1.4	0.3	1.5
Concentration adjustment with liquids	101	3	20	186	6	40	109	4	20	0.5	2	0.3	2	0.3	1.5
Rinsing/drying/self-curing	70	30	202	476	100	600	236	100	720	0.5	4	0.3	3.6	0.2	1
Frequent maintenance activities	195	8	40	417	5	60	253	8	100	0.5	4	1	8	1	8
Infrequent maintenance activities	114	0.3	2	41	2	4	30	2	20	2	8	3	8	1.6	3
Waste management	81	4	30	242	6	38.4	141	20	40	1	5	0.5	7.5	0.5	1.5
Sampling and transfer to small container	144	4	20	65	7.2	17	60	7	20	0.2	1	2	6.6	2	2.7

Table notes: Task names are according to CfEs. In CTACSub2 and DU notifications the task names might have been different. The Dossier Submitter has selected the tasks that correspond best to the description of tasks in the CfEs.

Table 22 Overview of assigned protection factors (APF) for RPE used during different tasks.

Task	CfE			DU notification		
	Min - Max	**P50**	**P90**	**Min - Max**	**P50**	**P90**
Delivery and storage	1 - 1000	7	1000	1 - 2000	1	20
Weighing, mixing, diluting of liquids	1 - 1000	32	1000	1 - 2000	20	40
Weighing, mixing, diluting of solids	1 - 1000	20	1000	1 - 40	20	40
Loading/unloading jigs	1 - 1000	1	39	1 - 200	1	20
Spraying in spray booth	1 - 1000	38	1000	1 - 2000	67	2000
Brushing/rolling/pen	1 - 1000	20	1000	1 - 40	1	10
Dipping/immersion	1 - 1000	5	1000	1 - 2000	10	40
Concentration adjustment with solids	1 - 1000	11	1000	1 - 200	20	40
Concentration adjustment with liquids	1 - 1000	9	1000	1 - 200	10	40
Rinsing/drying/self-curing	1 - 1000	7	110	1 - 40	1	40
Frequent maintenance activities	1 - 1000	20	1000	1 - 2000	10	40
Infrequent maintenance activities	1 - 1000	18	1000	1 - 200	1	20
Waste management	1 - 1000	4	1000	1 - 200	20	20
Sampling and transfer to small container	1 - 1000	17	1000	1 - 40	4	20

Table notes: APF = 1 means that no RPE is worn during the task.

B.8.2.2.4. Representativeness of the exposure data

In order to assess the representativeness of the exposure data, the Dossier Submitter compared the distribution of the sites in the exposure data (CfEs and DU notification) across different countries against the distribution of 1579 sites that have notified ECHA of the Cr(VI) substances use as DUs of a previous upstream authorisation under Art. 66 of REACH using site-specific addresses. Note that exposure data from the DU notifications could be extracted only for relatively small number of sites. For this comparison, only data from 2023 is used. Results are presented in Table 23. DU Site data refers to the data with the site location information from the DU notifications and DU Exposure data to the exposure data from the DU notifications.

Table 23. Distribution of sites across different countries in different data sets.

Member State	DU site data (N = 1 579)	CfEs (N = 684)	DU exposure data (N = 313)
Germany	23.12 %	21.93 %	**19.49 %**
France	21.03 %	**11.70 %**	**12.14 %**
Italy	13.87 %	**24.12 %**	**32.27 %**
Spain	8.80 %	**11.26 %**	**4.47 %**
Czechia	3.67 %	5.41 %	**6.07 %**
Poland	6.84 %	5.41 %	6.71 %
UK	0.70 %	0.15 %	0.00 %
Portugal	1.08 %	0.88 %	0.96 %
Belgium	2.15 %	1.61 %	0.96 %
Sweden	2.91 %	2.78 %	2.24 %

Netherlands	2.66 %	1.17 %	1.60 %
Austria	2.60 %	2.05 %	1.60 %
Croatia	0.19 %	0.00 %	0.32 %
Norway	1.84 %	0.73 %	0.32 %
Denmark	1.20 %	1.46 %	1.28 %
Finland	1.20 %	2.78 %	1.28 %
Slovakia	0.38 %	0.88 %	1.28 %
Greece	0.95 %	1.17 %	3.19 %
Lithuania	0.32 %	0.00 %	0.00 %
Slovenia	0.44 %	0.29 %	0.32 %
Hungary	0.89 %	0.44 %	0.32 %
Romania	1.08 %	1.32 %	1.92 %
Ireland	0.70 %	0.15 %	0.00 %
Bulgaria	1.01 %	0.73 %	1.28 %
Luxembourg	0.25 %	0.15 %	0.00 %
Malta	0.13 %	0.15 %	0.00 %
Latvia	0.00 %	0.00 %	0.00 %
Estonia	0.00 %	0.00 %	0.00 %
Switzerland*	0.00 %	1.17 %	0.00 %

Table notes: Proportions in the CfEs and DU Exposure data that deviate >2 percentage units from the DU Sites data are indicate in ***bold.***

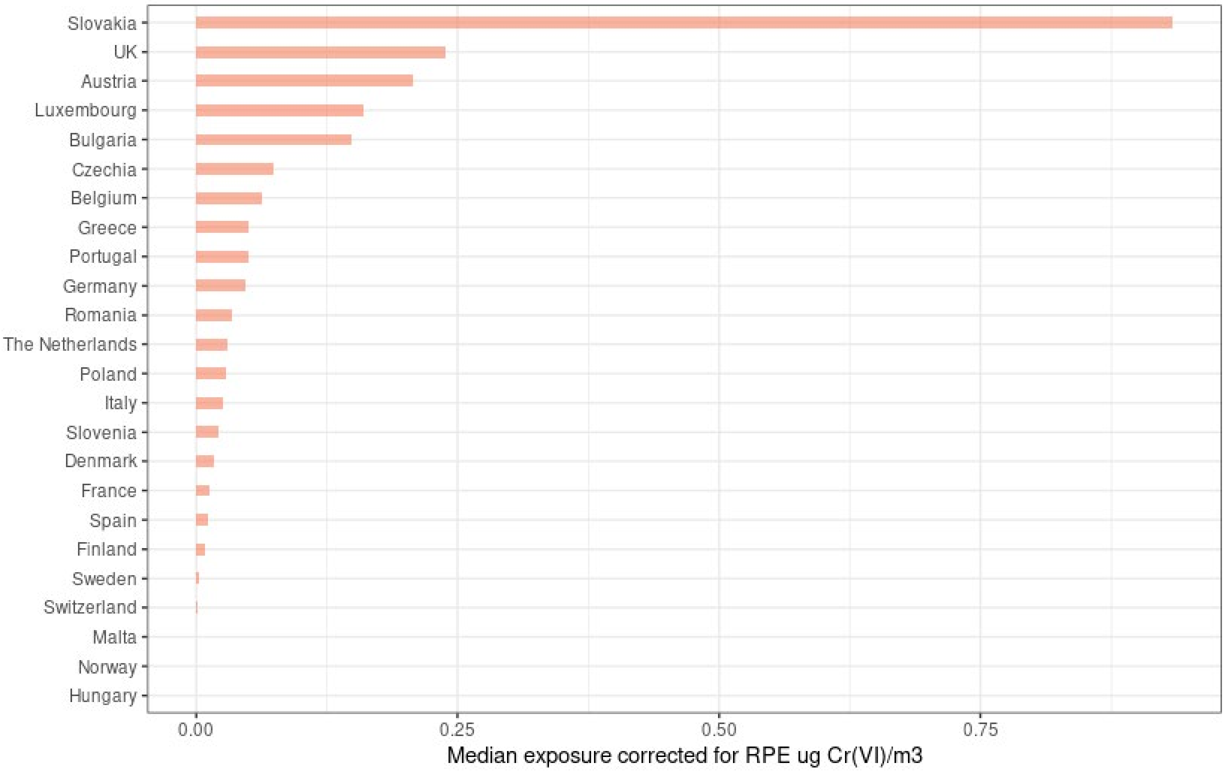

Figure 14. Median occupational exposures in different Member States

Figure notes: combined exposures corrected for frequency and RPE, calculated based on CfE data.

For most of the countries, the proportion of sites in the exposure data is very similar to the proportion in the DU site data. However, in the CfEs data sites in Italy and Spain are overrepresented and sites in France are underrepresented compared to DU site data. In the DU exposure data sites in Italy and Czechia are overrepresented and sites in Germany, France and Spain are underrepresented. Between CfE and DU exposure data the biggest difference is for Spain with 11.26 % of the sites located in Spain in the CfEs data and only 4.47 % in the DU exposure data.

Based on the responses from CfEs, the exposures in Italian and Spanish sites are generally lower than in most of the other countries (see Figure 14). Because Spanish and Italian sites are overrepresented in the CfEs data, it means that the analyses based on the whole dataset might underestimate the exposures at the EEA level. On the other hand, the exposures at the French sites are also generally low. It means that the underrepresentation of French sites in the data results in an overestimation of the exposures at the EEA level. To conclude, the Dossier Submitter considers that the CfE exposure data is geographically representative for the EEA.

B.8.2.2.5. Biomonitoring

Human biomonitoring (HBM) is a useful tool to measure internal exposure of workers resulting from inhalation, dermal or oral uptake of substances occurring at the workplace. HBM also allows to monitor effectiveness of risk management measures and operational conditions. The most frequently used method to monitor Cr(VI) exposure in workers is by measuring total Cr(III) in urine (U-Cr). Other methods determine Cr(VI) in red blood cells or in exhaled breath condensate (Santonen, Porras et al. 2022). In addition, several biomarkers of early biological effects can be measured (Tavares, Aimonen et al. 2022).

Urine

Cr(VI) is rapidly reduced to Cr(III) in all body fluids and tissues, which is eliminated with the urine (O'Flaherty, Kerger et al. 2001). Even if the measurement of U–Cr is currently the most frequently used biomarker for the occupational assessment of exposure to Cr(VI), this method is not specific for Cr(VI) exposure but also reflects exposure to Cr(III) substances.

Lifelong occupational lung cancer risks due to Cr(VI) exposure in welding and chromium-plating activities were estimated on the basis of total U–Cr data (P95, representing realistic worst case) spanning almost 40 years (1980–2016) (Mahiout, Kiilunen et al. 2022).

Within the EU human biomonitoring initiative, HBM4EU, a collaborative human biological monitoring study on occupational exposure to Cr(VI), the ‘chromate study’ was set up (Santonen, Alimonti et al. 2019). The authors concluded that this study was able to demonstrate the added value of the human biomonitoring approach in assessment and management of occupational exposure to Cr(VI) (Santonen, Louro et al. 2023). Results of this study are presented in the publication Viegas et al. (2022). The key insights from these studies can be summarised as follows:

- Both inhalation exposure and dermal exposure can be reflected as enhanced urinary chromium excretion
- A high correlation between pre- and post-shift urinary chromium suggests that this biomarker reflects recent as well as past exposure
- The U–Cr and air-Cr(VI) correlations among chrome platers were different to those among welders due to different Cr(VI) species and thus may be partly task specific

- A high correlation between Cr(VI) in the air and U-Cr in the urine of platers not using RPE (respiratory protective equipment). The relationship between inhalable air Cr(VI) levels (5 µg Cr(VI)/m^3) and urinary Cr levels in platers (of 7 µg/g creatinine) are consistent with earlier reported regression equations published by Chen, Guo et al. (2002)

- The use of RPE in bath plating and painting correlated with lower U-Cr

- Machining workers that did not wear gloves (28.9 %) had higher U-Cr compared to workers wearing gloves; all other workers in the study were already using gloves

- Automation of chromium electroplating dipping resulted in lower U-Cr levels compared to the manual process

- The existence of a dedicated place for storing working clothes might increase the exposure if not combined with clear procedures for washing/disposing of the working clothes/PPE and stringent housekeeping measures

Within the HBM4EU initiative, occupational exposure to Cr(VI) was also characterised by measuring biomarkers of genotoxicity and oxidative stress, including micronucleus analysis in lymphocytes and reticulocytes, the comet assay in whole blood, and malondialdehyde and 8-oxo-2'-deoxyguanosine in urine (Tavares, Aimonen et al. 2022).

Blood

In several publications the measurement of Cr(VI) in red blood cells is reported. For example, Devoy, Géhin et al. (2016) noted that this measurement is specific to Cr(VI) exposure. Within the HBM4EU chromates also study the measurement of Cr(VI) in red blood cells was performed. Based on the study results the authors concluded that Cr-blood-based biomarkers can provide information on how workplace exposure translates into systemic availability of Cr(III) extracellular in plasma and Cr(VI) intracellular in red blood cells. However, further studies are needed to fully appreciate their use in an occupational health and safety context (Ndaw, Leso et al. 2022).

Exhaled breath condensate

The practicability of exhaled breath condensate (EBC) as a biological matrix was also investigated within the HBM4EU chromates study to detect and measure Cr(VI) and Cr(III) in workers occupationally exposed to Cr(VI). EBC has the potential to be a valid, non-invasive biological matrix to assess occupational exposure to Cr(VI) and Cr(III) for biological monitoring assessment, with the ability to detect low level inhalation exposures (Leese, Jones et al. 2023).

Relevance of biomonitoring data in the context of the restriction proposal

As highlighted above, biomonitoring is a useful method to assess workers' exposure to Cr(VI). However, the Dossier Submitter has decided to base the exposure assessment on the inhalation measurements instead of biomonitoring data due to the following reasons:

- Data availability for personal inhalation measurements is better than for biomonitoring data. Indeed, in AfAs biomonitoring data is typically submitted and used only as a supportive data. Furthermore, Dossier Submitter is not aware of any large, harmonised datasets with biomonitoring data for Cr(VI) or Cr(III) for uses relevant for the restriction proposal. Some biomonitoring data has been submitted as part of DU notifications. However, data has been submitted using different formats and is often lacking information needed for meaningful analysis, such as tasks performed, duration of exposure and whether PPE/RPE are used.

- The existing regulations and monitoring campaigns are mainly focused on personal inhalation measurements. Because the current restriction proposal is also based on inhalation measurements, for industry and enforcement authorities it might be easier to understand and to compare with the existing procedures.

- The driving hazard of the restriction proposal is the lung cancer risk due to the inhalation exposure. Biomonitoring might also capture exposures via other routes, such as dermal exposure, which would not be relevant for the lung cancer.

- Because workers are often conducting several tasks during the day, with the biomonitoring it is difficult to detect the contribution of different tasks to total exposure, which could be important for improving the operating conditions.

B.8.2.3. Uncertainty analysis for occupational exposure

The uncertainties related to the occupational exposure assessment and their influence on the exposure and risk estimates are listed in table 24. Some of the uncertainties might overestimate and some underestimate the exposures and risks, but it is not possible to quantify the possible over- or underestimation of the exposure assessment. Considering all the uncertainties together, the Dossier Submitter concludes that the exposures and risks are more likely to be overestimated than underestimated.

Table 24. Uncertainties related to occupational exposure assessment

Uncertainty	**Influence on exposure and risk**	**Comment**
Solubility of compounds not considered.	Exposure overestimated as in reality not all particles would be bioavailable.	
Particle size not considered.	Exposure overestimated as in reality bigger particles would not be respirable and therefore not contributing to inhalation exposure.	Non-respirable particles could nevertheless contribute to oral exposure and to gastrointestinal cancer.
Not all relevant tasks are necessarily included in the exposure scenario in CfE data.	Exposure could be underestimated.	Because companies were asked to report the most relevant tasks, the influence of not including all the tasks is probably small.
Indirect exposure for bystanders is not considered in the exposure scenarios.	Exposure underestimated.	Combined exposure scenarios include several tasks, which are assumed to be most relevant for the exposure. This approach also intends to describe the exposure for a worker, who is working most of the time directly with Cr(VI) compounds. Therefore, the indirect exposure is not assumed to have a strong impact on the overall exposure. However, in the analysis including the number of workers per site, this approach might overestimate exposures for sites where there is variation in direct exposure durations among the workers.
Correctness of the exposure parameters reported in CfEs.	Because it is not possible to check the correctness of the data submitted in the CfEs, the exposure estimates could be over- or underestimated.	Comparison of the durations and frequencies of different tasks in different datasets demonstrated that these parameters were similar in CfE and in DU data, and generally higher in CTACSub2 (see B.8.2.2.3). Also, the comparison of the empirical cumulative distributions of the exposures were similar between CfE and DU data (see D.1.1). The exposures based on CTACSub2 data were generally higher for most of the UCs especially when corrected for RPE. The higher exposures based on CTACSub2 are likely to be due to the purpose of the data collection to create a generic exposure scenario covering most of the sites. As the results are similar based on CfE and DU notification, the Dossier Submitter considers that the data reported in CfE is plausible and realistic.
Dose-response curve might overestimate the risks at low exposure levels.	Overestimate	Based on the review of scientific evidence (see B.4.8.) there is conflicting evidence for the correctness of the used dose-response curve. Dossier Submitter concludes that the risks might be overestimated but it is uncertain how much (if at all).
Representativeness of the exposure data	The data could be biased, so that sites with high or low exposures could be overrepresented.	As stated above, the CfE and DU notification data results in similar exposure estimates, indicating that the companies who replied in CfE are similarly presented in the DU notifications. Furthermore, as demonstrated in 0, CfE exposure data is considered geographically representative.
In CfE data RPEs are used also for long-lasting tasks. It might therefore not be realistic to assume that RPEs are really used the whole time.	RPE-corrected exposure values might be underestimated because RPE may not be used during the whole duration.	Because the use of RPE can be very variable between tasks and sites, it is not possible to set any correction factor for a "realistic" use of RPE.

B.9. Risk characterisation

B.9.1. Indirect exposure of humans via the environment

B.9.1.1. Inhalation

Under the assumptions made (see paragraph B.8.1.2) for exposure estimation and considering the dose-response curve for inhalation (See the main report, paragraph 1.4.2.2), it is possible to establish a direct correlation between annual releases to air and risk due to exposure by inhalation (ELR): **1 kg of Cr(VI) emitted to air** per year does correspond to an **ELR of about 2.2E-5**. Using such correlation is then possible to build the distribution of frequency of the risk for all sites for which CTACSub2 AfA and CfE data is available.

B.9.1.1.1. CTACSub2

In Figure 15, the distribution of frequency of ELR associated with inhalation exposure is depicted; ~40 % of the sites have a ELR < 1E-6, 70 % have a ELR < 1E-5, while 8 % have a ELR > 1E-4.

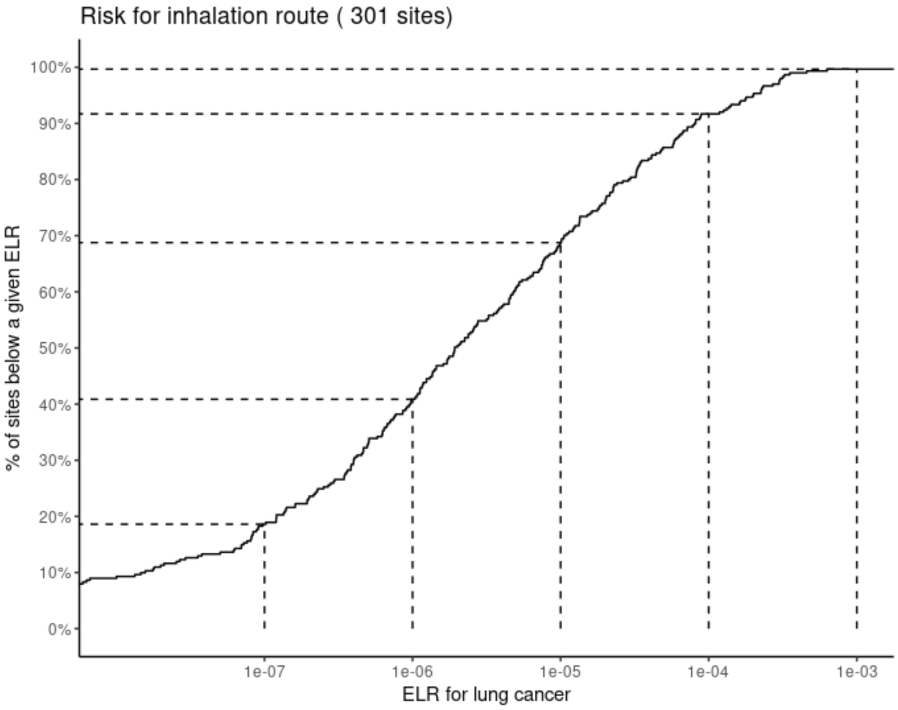

Figure 15. Cumulative distribution of sites based on lung cancer ELR

Figure notes: based on CTACSub2 data.

B.9.1.1.2. CfE#1 and CfE#2

Figure 16 shows the distribution of frequency of risk for all sites for which respondents to the CfEs have provided data on air emission. Table 25 disaggregates the distribution of frequency for the individual use categories, as defined in the main report, paragraph 1.4.4.

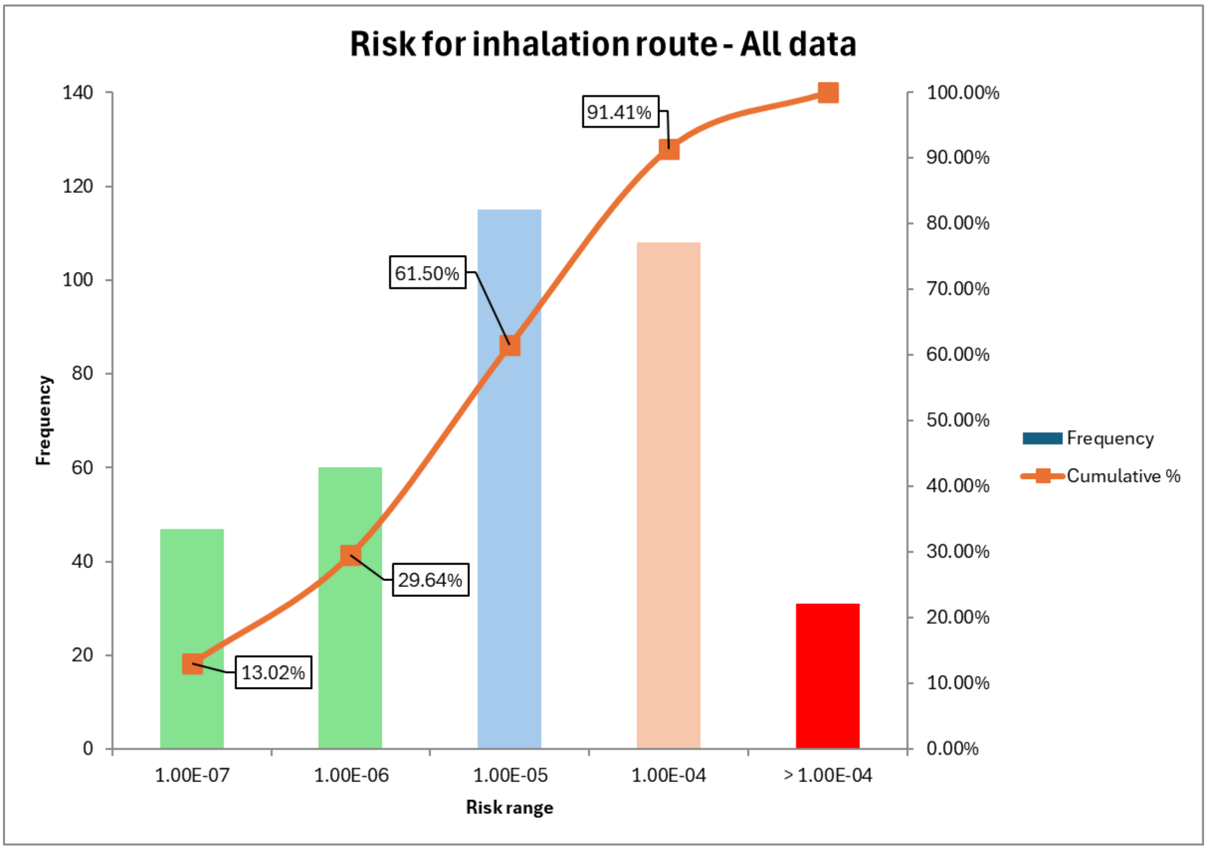

Figure 16. Cumulative distribution of ELR across all sites, inhalation route

Source: CfE#1 and CfE#2.

Table 25. Distribution of inhalation risk per use category

Use category	**% of sites, ELR < 1E-6**	**% of sites, ELR > 1E-6**	**% of sites, ELR > 1E-5**	**% of sites, ELR > 1E-4**
UC 1 – Formulation*	-	-	-	-
UC 2 - Electroplating on plastic	25.0 %	75.0 %	41.7 %	4.2 %
UC 3 - Electroplating on metal	26.1 %	73.9 %	41.4 %	9.3 %
UC 4 – Use of primers and other slurries/spraying	42.4 %	57.6 %	24.2 %	3.0 %
UC 5 – Other surface treatments	37.5 %	62.5 %	30.4 %	5.4 %
UC 6 – Functional additive*	-	-	-	-
All Uses	29.6 %	70.4 %	39.5 %	8.6 %

*Table notes: * Number of sites not sufficient to build a reliable ECDF.*

The following risk threshold are used as reference for the analysis:

- ELR = 1E-6: it is widely agreed that below this level risk for the general population can be considered not significant; this level is also used by RAC as a condition for AfA review periods longer than 12 years

- ELR = 1E-4: it is commonly agreed that above this level risk for the general population cannot be accepted and must be reduced

- ELR = 1E-5: this presents an intermediate level

From Table 25, it emerges that:

- Only 30 % of the sites show a risk level lower than ELR = 1E-6, while about 9 % of the sites show a risk level higher than 1E-4.
- UC 2 and UC 3 (electroplating on plastic and metal substrates) are the uses that exhibits higher level of risk, with more 40 % of sites showing a risk higher than 1E-5 and about 10 % (UC 3) of sites a risk higher than 1E-4

B.9.1.2. Oral

As for inhalation route, there is also a direct correlation between annual releases to water and risk for oral intake, considering the dose-response curve for oral exposure (See the main report, paragraph 1.4.2.2). However, 2 elements need to be considered when establishing such correlation:

- The release scenario, i.e. whether the releases are directed or not to a municipal sewage treatment plant (STP) and, in such case, whether the sludge is applied to agricultural soil or it is incinerated; therefore, 3 different scenarios can be established:
    - Releases to STP and application of sludge to agricultural soil (Scenario 1)
    - Direct releases to surface water from the site (Scenario 2)
    - Releases to STP and sludge incineration (Scenario 3)
- For the scenario of application of sludge to agricultural soil, also number of emission days over the year plays a role in defining the exposure and therefore the risk level.

For the CTACSub2 AfA, the Scenario 1 will apply (from information contained in the CSRs), while, in absence of data, a default value of 200 emission days per year is assumed for the estimation. For the CfE data, information is available on both the scenario that will apply and the number of emission days per year; again, in absence of such information the following default will apply:

- Scenario 1, which is the most conservative and
- 200 emission days per year

In relation to the abovementioned correlation between releases to water and level of risk for oral exposure, the following figures can be deducted:

- For the Scenario 1 (STP sludge application to agricultural soil): **1 kg of annual emission to water** does correspond to an oral **ELR of about 6.2E-6**.
- For the Scenario 2 (direct release to surface water): **1 kg of annual emission to water** does correspond to an oral **ELR of about 3.1E-6**.
- For the Scenario 3 (STP sludge to incineration): **1 kg of annual emission to water** does correspond to an oral **ELR of about 1.5E-6**.

B.9.1.2.1. CTACSub2

Figure 17 presents the distribution of frequency of risk associated with the oral route.

About 70 % of the sites show a ELR < 1E-6, 90 % show a ELR < 1E-5, and 1-2 % show a ELR > 1E-4.

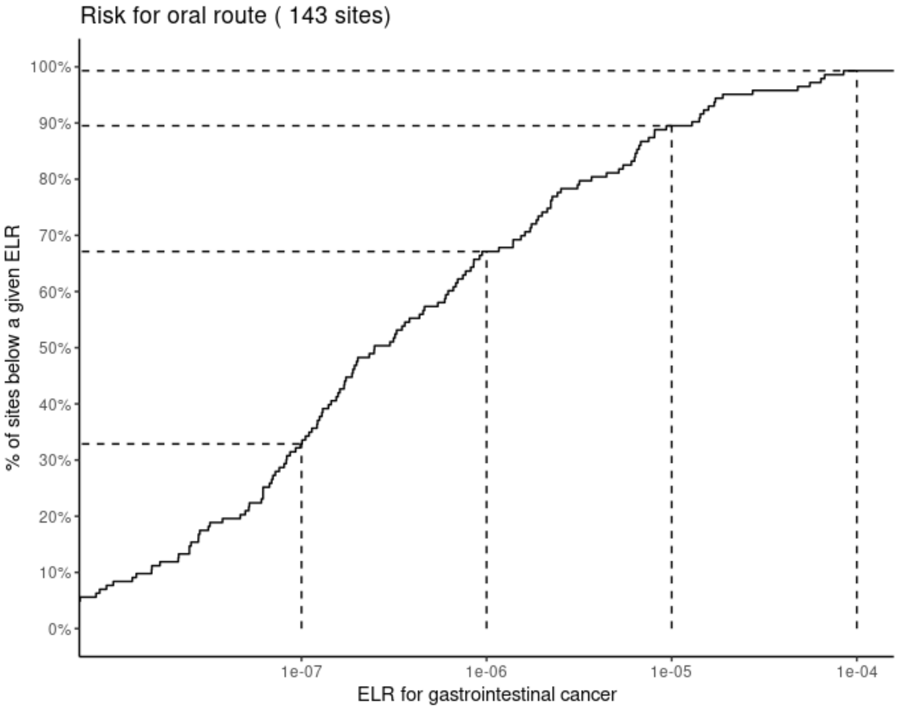

Figure 17. Cumulative distribution of sites based on intestinal cancer ELR

Figure notes: based on CTACSub2 data.

B.9.1.2.2. CfE#1 and CfE#2

In Figure 18 and Table 26, the distribution of frequency of oral risk for the sites divided by scenario and uses is reported. It should be emphasised that the statistics include only sites reporting releases to water (on which the oral risk is linearly dependent): they do not consider that a significant part of the CfE respondents have claimed no emissions to water (i.e. no significant contribution to the oral risk).

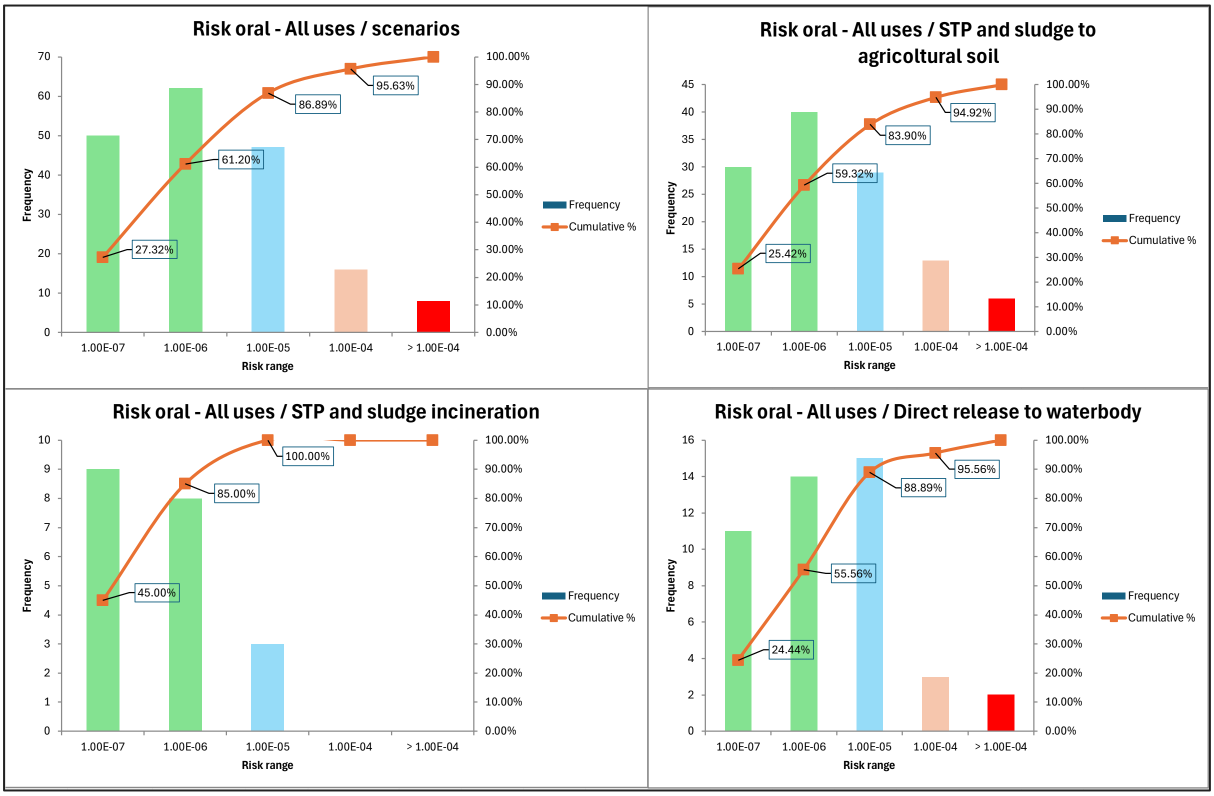

Figure 18. Oral exposure – Frequency distribution for all sites (per scenario)

Figure notes: based on CfE data.

From the distribution above it emerges that:

- Almost 60 % if the sites show an ELR lower than 1E-6, while only a small fraction of about 4 % have an ELR higher than 1E-4.
- For the scenarios implying sludge application and direct releases to surface water, the risks due to oral exposure are higher than for the scenario with sludge incineration, where about 85 % of the sites show an ELR lower than 1E-6.

Table 26. Distribution of oral risk per use category

Use	% of sites < ELR 1E-6	% of sites > ELR 1E-6	% of sites > ELR 1E-5	% of sites > ELR 1E-4
UC 1 – Formulation*	-	-	-	-
UC 2 - Electroplating on plastic	37.0 %	73.0 %	14.8 %	0.0 %
UC 3 - Electroplating on metal	63.4 %	36.6 %	13.8 %	5.7 %
UC 4 – Use of primers and other slurries / spraying	72.7 %	27.3 %	13.6 %	0.0 %
UC 5 – Special surface treatments	51.2 %	48.8 %	14.6 %	2.4 %
UC 6 – Functional additive*	-	-	-	-
All Uses	61.2 %	38.8 %	13.1 %	4.4 %

*Table notes: * Number of sites not sufficient to build a reliable distribution of frequency*

Different from the inhalation route, there is not a clear "leading" use responsible for oral risk. However, one sees that, at least for the medium- and high-risk levels, UC 3 (electroplating on metal substrate), UC 5 (special surface treatment) and UC 2 (electroplating on plastic) show levels higher than the average.

B.9.1.3. Other routes of exposure

In this section the impact on exposure from other routes or compartment is discussed and considered as being not significant or relevant for the present risk assessment. The conclusions are often based on specific estimations made with Chesar 3.7.

B.9.1.3.1. Impact of air deposition on oral risk

As mentioned in the previous paragraph (B.8.1.2.2) the Dossier Submitter considers the contribution to the oral risk due to deposition from air emission as negligible compared to the risk due to the water emission, either directly or indirectly (STP sludge application). To better substantiate this, the Dossier Submitter has simulated a scenario where 1 kg/year of Cr(VI) is emitted to water and, separately, one scenario where 1 kg/year of Cr(VI) is emitted to air; then, the oral dose due to ingestion of drinking water and fish is compared for these 2 scenarios. The results of this assessment are reported in Table 27.

Table 27. Relative contribution of air and water emissions to oral exposure

Scenario	1 kg Cr(VI) / year to WATER Oral dose (µg/kg/d)	1 kg Cr(VI) / year to AIR Oral dose (µg/kg/d)
Releases to STP and sludge application to agricultural soil	7.75E-3*	2.40E-6*
Direct releases to surface water	3.90E-3	2.40E-6*
Release to STP and sludge incineration	1.95E-3	2.40E-6*

*Table notes: * Drinking water is the groundwater, therefore only 3 % of the Cr tot available is considered in the form of Cr(VI) (see also paragraph B.8.1.2.2)*

The contribution of air emissions to oral risk is at least 3 orders of magnitude lower than the one from water emissions, assuming the same amount released to the environment. Of course, it is also true that the most relevant route in terms of risk for air emission is the inhalation; in fact, while 1 kg/year emitted to air "generates" an ELR of 2.18E-5 by inhalation, the same amount determines an estimated ELR of about 2E-9 for by oral route.

B.9.1.3.2. Other food intake routes

The dominant route for oral exposure is the drinking water ingestion for all the scenarios considered; other routes are either not relevant or significant (meat and milk, root and leave crops) or, although estimated, are order of magnitudes lower than the drinking water (fish consumption). As mentioned, fish consumption has been estimated in the initial analysis; in Table 28, doses from 1 kg Cr(VI) /year of emissions to water are reported for all scenarios; then, Cr(VI) intake via fish consumption and drinking water are compared.

The contribution of fish ingestion is 3 orders of magnitude lower than the drinking water route; moreover, even without applying the rule of 3 % to biota, the contribution of drinking water to oral dose will be still 20-100 times higher than the fish ingestion.

Table 28. Oral exposure (dose) via drinking water and fish consumption

Scenario	**1 kg Cr(VI) / year WATER Drinking water µg/kg bw/d**	**1 kg Cr(VI) / year WATER Fish µg/kg bw/d**
Releases to STP - sludge application to agricultural soil	7.75E-3*	3.60E-6**
Direct releases to surface water	3.90E-3	7.20E-6**
Release to STP and sludge incineration	1.95E-3	3.60E-6**

*Table notes: * Drinking water is the groundwater, therefore only 3 % of the Cr tot available is considered in the form of Cr(VI) (see also paragraph B.8.1.2.2); ** For biota like fish the same rule of 3 % of the Cr tot available as Cr(VI) will apply (see also paragraph B.8.1.2.2)*

The rest of the of exposure routes (milk and meat, leaf and root crops) are considered as irrelevant by RAC; however, based on the data reported in EURAR on concentration in soil and crops[26], it was possible to derive a bio-transfer factor from soil to crops (leaves and roots), and apply them to the risk assessment. The outcome of such assessment (considering 1 kg/year emitted to water via STP and sludge application to agricultural soil – Scenario 1) is reported in the next table and compared to the oral exposure via drinking water. As it can be seen from Table 29, the doses from crops intake are at least 2 order of magnitude (leaf crops) lower than the one from drinking water ingestion, further supporting the scarce relevance of these specific routes in the overall risk assessment.

Table 29. Oral exposure via leaf and root crops consumption

Scenario	**Leaf crops**	**Root crops**
Bio-transfer factor (P90)	0.01	0.001
Estimated crop concentration	6.0E-3 mg/kg	6.1E-4 mg/kg
Estimated doses from crops ingestion	1.2E-4 mg/kg/d	3.9E-6 mg/kg/d
Comparison to Drinking Water dose	7.75E-3 mg/kg/d	7.75E-3 mg/kg/d

B.9.1.3.3. Environmental risk

The environmental risk is not part of the present risk assessment, which focuses on humans exposed via the environment. Nevertheless, the Dossier Submitter made a screening analysis limited to the surface water compartment, on whether there is any environmental risk associated to water emissions. For that, the following assumptions were made:

- The PNEC freshwater used for the assessment is the one derived in EURAR[27], which is 3.4 µg/l.
- The scenario 2 (direct releases to surface water) is applied since the most conservative in relation to the environmental risk for the water compartment.

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[26] European Union Risk Assessment Report, Table 3.47, p. 100 https://www.echa.europa.eu/documents/10162/3be377f2-cb05-455f-b620-af3cbe2d570b

[27] European Union Risk Assessment Report, Paragraph 3.2.1.7.1, p. 124 https://www.echa.europa.eu/documents/10162/3be377f2-cb05-455f-b620-af3cbe2d570b

- The release rate used for the assessment is equal to the 90th percentile of annual emission rates to water from CfE data, which is 2.22 kg/year (See the main report, Table 12).

- Other EUSES default values are used for the assessment.

The outcome of the exposure estimation is a PEC (Predicted Environmental Concentration) in freshwater equal to 0.55 µg/l, which results in a Risk Characterisation Ratio for freshwater well below 1.

Moreover, restriction options (RO1, RO2, and RO3) as defined in the main report, table 20 will be also protective for the environment, except the most lenient RO1, which determines an expected concentration in water (PEC) slightly above the PNEC (RCR just above 1) when wastewater form the site is directly discharged to surface waterbodies.

B.9.1.4. Comparison with measured data

It is not easy to compare the exposure estimation from EUSES calculation to the real environmental data collected for Cr(VI) and available in literature; this is mainly due to the conservative nature of EUSES estimations and to the fact that concentrations are estimated in the vicinity to the source (site emissions).

However, some indication or indirect support to calculations can be retrieved; the following considerations are derived from the screening programme from the Swedish competent authority, which measured Cr(VI) and total Cr in different locations and compartments:

- Air concentrations of Cr(VI) have been measured in rural, urban areas and in the vicinity of Cr(VI) industrial source (electroplating industry); measured concentrations of Cr(VI) in the vicinity of the source ranged between 0.64 to 2.6 ng/m^3; these values, order of magnitude higher than in rural or urban areas, are also well in line with the concentrations estimated via the EUSES model, which are 0.2 ng/m^3 (P50) and 3 ng/m^3 (P90), see table 13 in main report.

- Samples collected in soil compartment shows that Cr(VI) constitutes the 0.01 % to 1.5 % of the Cr(tot) measurements, with values in the low range in the vicinity of the Cr(VI) industrial source; this supports further the assumption made for soil compartment (and groundwater) that only 3 % of the Cr (VI) emitted will be available as Cr VI in soil.

No other specific environmental concentrations can be compared directly with EUSES calculations since there are neither groundwater concentration mentioned in the report nor surface water concentration measured in the vicinity of the industrial source.

Appendix C: Justification for action on a Union-wide basis

See the main report.

Appendix D: Baseline

D.1. Worker exposure

D.1.1. Current exposure levels for workers

The results of the exposure assessment, conducted as described in chapter B.8.2, are presented in Figure 19 for UC 1-3 and in Figure 20 for UC 4-6. The figures present empirical cumulative distribution functions (ECDF) of combined exposure for workers for different UCs based on data from CfEs, CTACSub2 and DU notifications. ECDFs are presented for 8h-TWA exposures without any corrections (grey curve), 8h-TWA exposures with frequency-correction (green curve) and 8h-TWA exposures with frequency- and RPE-correction (blue curve). Additionally, a scenario including the number of workers is also presented based on CfE and DU notification data (black curve). These curves represent the proportion of sites (or workers for black curve) with the exposures below a given level. Hence, the higher the curve the lower the exposure.

In general, it can be concluded that in CTACSub2 data the exposures, especially RPE-corrected exposures, are higher compared to CfE and DU notification data. This is because in CTACSub2 the RPEs are not site specific, and the same, conservative, RPE for the same task is assumed for all sites. Furthermore, because the CTACSub2 data was collected for the purpose of creating a generic realistic worst-case scenario to cover most of the sites, the assumptions for other parameters, such as durations and frequencies of the tasks, might also be conservative as demonstrated by the comparison between datasets (see B.8.2.2.3). Furthermore, compared to CfE and DU notification data, the shape of the distributions for CTACSub2 data is slightly different, with less sites having very low exposures. This is apparent especially for UC2 and UC5. In the CfEs and DU notification data the distributions are very similar with and without considering the number of workers (black and blue curves, respectively). This demonstrates that there is no bias in exposures related to the size of the site.

D.1.1.1. Use category specific occupational exposure

Concerning the UC1 (formulation), all three datasets give quite similar results, especially between CfE and DU notification data. Basically, at all the sites the frequency corrected combined exposures are below 5 µg Cr(VI)/m^3 and at 76-84 % of the sites below 0.5 µg Cr(VI)/m^3, depending on the dataset. When RPE is considered, even 94 % of the sites have exposures below 0.5 µg Cr(VI)/m^3 based on CfE and DU notification data.

For UC2 (plating on plastic), exposure data is only available from CfEs. Over 80 % of the sites have frequency corrected combined exposures below 0.5 µg Cr(VI)/m^3 and around 60 % below 0.1 µg Cr(VI)/m^3. With RPE-correction the percentages are 100 % and 76 %, respectively. Although the exposures are in general lower than for UC3 (plating on metal), due to a relatively small sample size of 17 for UC2, compared to 275 for UC3, no firm conclusions concerning the exposures between UC2 and UC3 can be made. Indeed, based on the information from AfAs, all else being equal, no clear differences in exposures can be expected between UC2 and UC3. As in UC2 an additional pre-treatment (etching), which typically requires Cr(VI), is often mandatory prior to the actual plating, the overall exposure time to Cr(VI) in UC2 might be longer than for UC3.

For UC3 the distributions between CfE and DU notification data are again very similar, although in CfE the exposures are slightly lower (~5 percentage points). This could be because in CfE data combined exposures consist of up to five tasks, whereas in DU notification data the number of tasks included in the combined exposure scenarios could be higher, thus resulting in slightly higher exposures. The curves for with and without frequency correction (green and grey, respectively) are very close to each other indicating that the tasks contributing most to the exposure are conducted daily. As already stated above, the exposures based on CTACSub2 data are generally higher, presumably due to the use of more conservative assumptions for the purpose of generating a realistic worst-case scenario. Regarding UC3, the difference is especially clear for the RPE-corrected exposures (blue curve) because in CTACSub2 no RPE is assumed during dipping task, which is indicated by very similar curves for exposures with and without RPE correction (blue and green curves). For CfE and DU notification data, in turn, the blue curves are above green curves indicating the use of RPE during tasks with high exposure potential resulting in a lower combined exposure.

For UC4 (spraying and painting) the exposures are generally higher in CfE data than in two other datasets. Based on frequency corrected exposures at almost 20 % of the sites the exposures are above 5 µg Cr(VI)/m^3 and even with RPE-correction, 7 % of the sites. This is because the second CfE was focused on aerospace sector, where Cr(VI) substances are often used in spraying applications with high exposures. There the high reliance on RPE is also apparent, because often the use cannot be automatised or contained (e.g. spraying of the whole airplane). When the number of workers is also considered, then the proportion of workers (black curve) exposed below a given limit is higher than the proportion of sites (blue curve). Based on the closer inspection of the data, this seems to be because bigger sites are implementing more efficient RPE, which results in lower exposures. Furthermore, at sites with several UCs, the number of workers sometimes refers to the exposed worker at the whole site and is not specific to a given UC, therefore overestimating the number of exposed workers due to a given UC. As the CTACSub2 data only contains five sites performing UC4, the exposure distribution is not reliable.

The exposure distributions for UC5 look very similar to those for UC3, except the exposures being generally slightly lower in UC5. The similarity with the UC3 might be due to the fact, that the uses covered by UC5 also often include the task "dipping/immersion", which is also included in UC3. Although there could be a difference in the actual dipping/immersion task between UC3 and UC5 (in UC3 typically with current and in UC5 with no or low current), the reported exposure values might be same for both UCs, especially for sites where different UCs take place.

Exposure information for UC6 is only available in CfE data. UC6 covers wide range of different kinds of uses and the sample size is low (N = 12). Therefore, it is not possible to draw any firm general conclusions concerning the exposure.

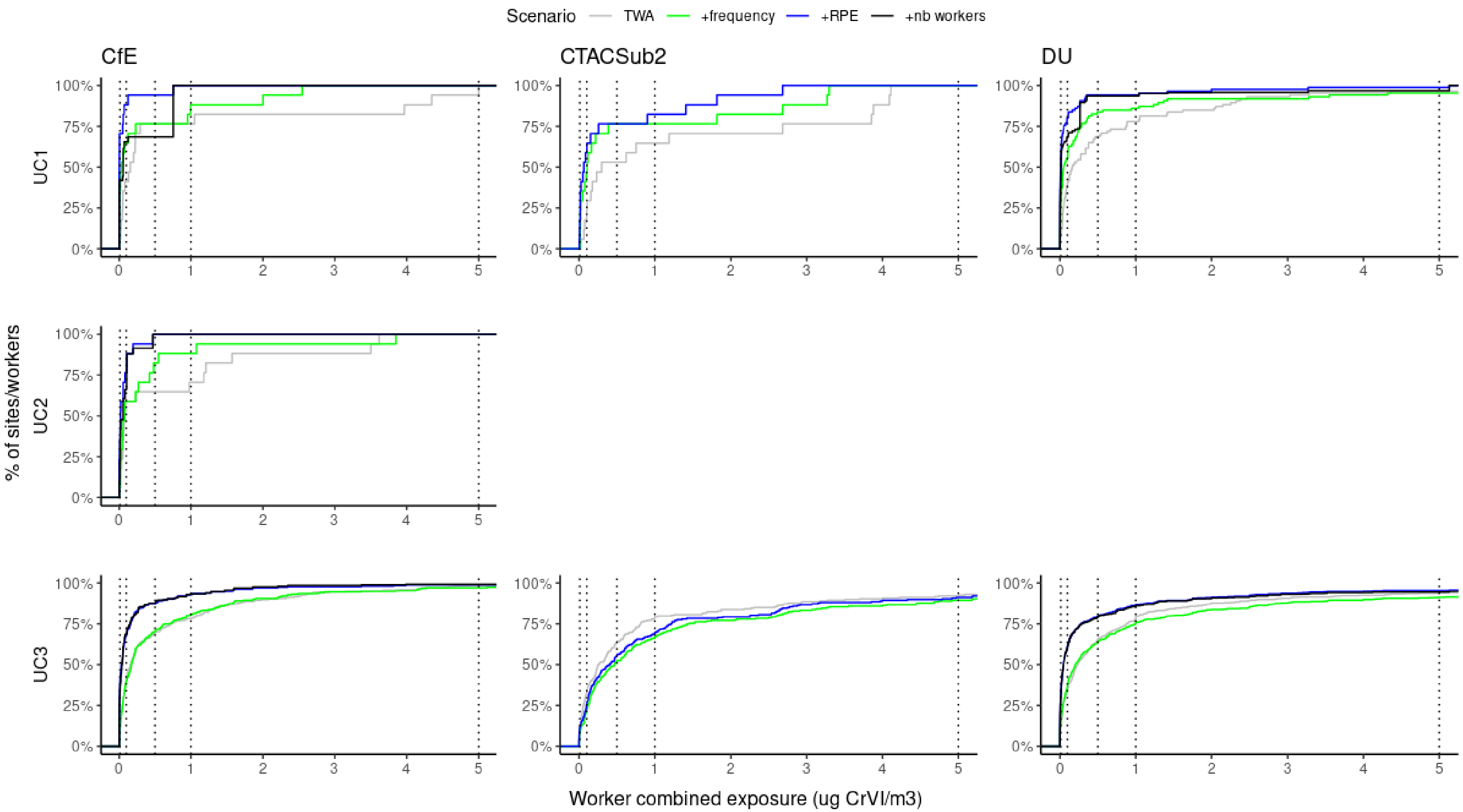

Figure 19. Empirical cumulative distribution functions of combined worker exposure for UCs 1-3

Figure notes: Three different datasets were compared for each of the use categories (UCs). The grey curve is an 8h-TWA combined exposure without any corrections; the green curve is the frequency-corrected 8h-TWA combined exposure; the blue curve is the frequency- and RPE corrected 8h-TWA combined exposure; the black curve is the frequency- and RPE corrected 8h-TWA combined exposure considering the number of workers at a given site.

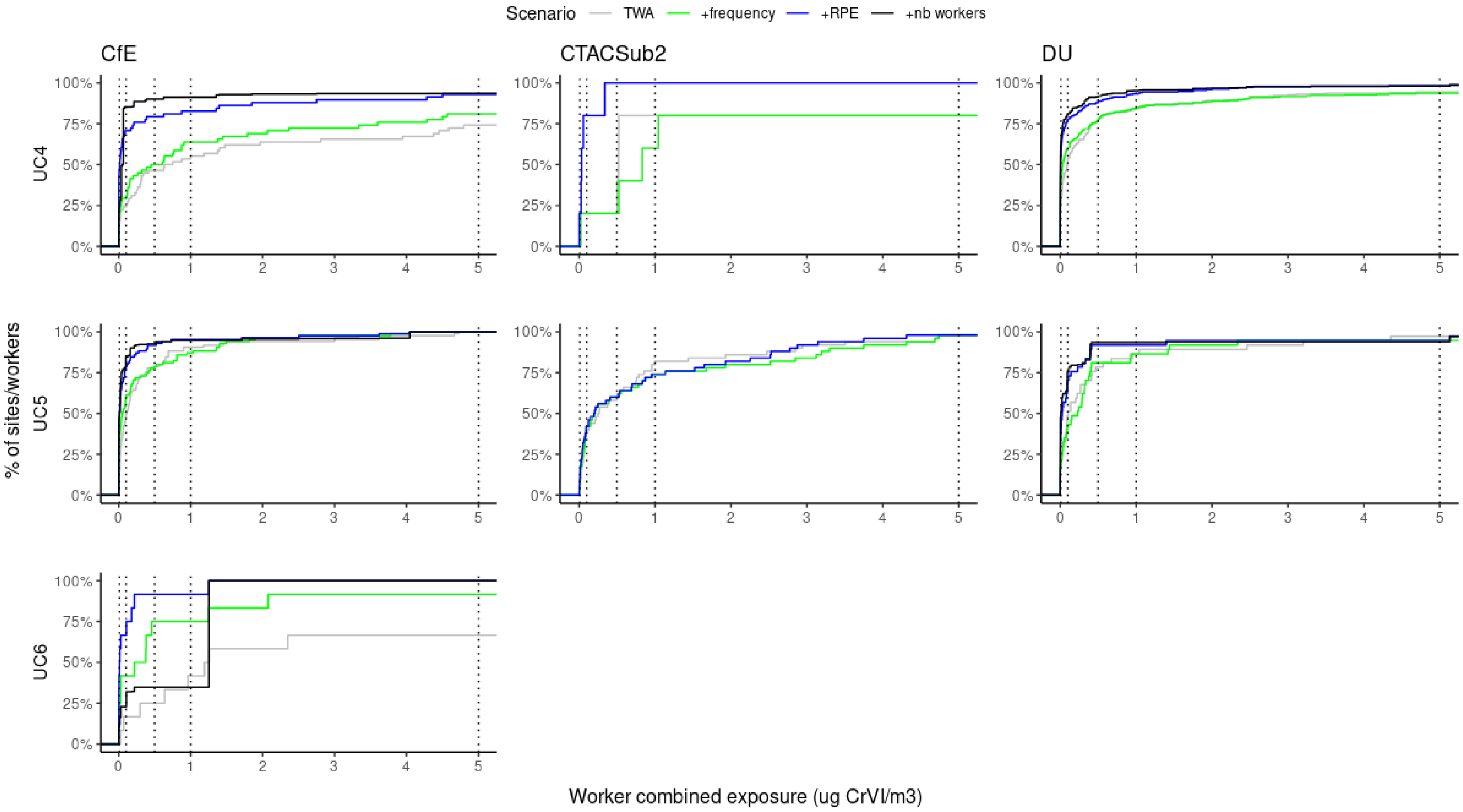

Figure 20. Empirical cumulative distribution functions of combined worker exposure for UCs 4-6

Figure notes: Three different datasets were compared for each of the use categories (UCs). The grey curve is an 8h-TWA combined exposure without any corrections; the green curve is the frequency-corrected 8h-TWA combined exposure; the blue curve is the frequency- and RPE corrected 8h-TWA combined exposure; the black curve is the frequency- and RPE corrected 8h-TWA combined exposure considering the number of workers at a given site.

D.1.1.2. Occupational exposure from machining, sanding and blasting

Machining, sanding and blasting of Cr(VI)-containing coatings are work tasks conducted primarily in the A&D sector to prepare surfaces for (re-)painting. In the logic of this dossier, they therefore belong to UC5. In the CfEs, information for such tasks was not explicitly asked for and therefore the information about the exposures from such activities is scarce. Also, in the past AfAs such scenarios are often not included in the occupational exposure assessment or the exposure assessment is based on modelling. To assess the exposure from machining, sanding and blasting, the Dossier Submitter has used the data provided in the applications from the ADCR Consortium submitted for UK REACH. In total 6 of these applications contain information concerning machining, sanding and blasting. Applications and relevant worker contributing scenario (WCS) are summarised below in Table 30. The same WCSs and exposure values are used in all six applications.

<u>Description of activities</u>

The following descriptions are based on the public CSRs from the UK REACH AfAs by the ADCR Consortium. Links to the applications, including CSRs, are provided as footnotes of Table 30.

Machining involves numerous activities related to mechanical treatment of metallic parts. Different types of machining might be necessary: sawing, drilling, bolting, countersinking, riveting, deburring, grinding, fettling, sanding, etc. All machining activities are conducted in areas, which are separated from the site’s other processes and is access controlled (either physically (barrier/signage) or through strict procedures. Machining can take place either in an extraction bench/room/booth, in large work areas, and less frequently in very small work areas. Typical activities with possible direct Cr(VI) exposure performed by these operators are machining on metallic parts previously treated with primers containing strontium chromate (StC), pentazinc chromate octahydroxide (PCO), and/or potassium hydroxyoctaoxodizincate dichromate (PHD). In the CSRs, machining activities are divided into six different tasks, three of them (WCS 1-3 in Table 30) being for machining on surfaces and three of them (WCS 4-6) for machining on parts. **Machining on parts** refers to a process where a part can be pierced, milled, cut, etc. i.e., machining operations affecting the deeper metallic layers of the part (without Cr(VI)). During these processes, release of shaving/chips and little (or no) dust containing potentially low Cr(VI) concentration may occur. **Machining on surfaces** includes removal/activation of the part surface only (abrasion, sanding, etc.) i.e. machining operations affecting exclusively the surface layer of the part that may have been previously treated with Cr(VI) primer products. This kind of machining processes generate high emissions of dust particles containing higher Cr(VI) concentration.

Sanding (WCS 7) of large parts or complete aircrafts is performed in dedicated hangars (equipped like dedicated spray hangars) under local exhaust ventilation. Sanding on aircrafts is necessary (a) to remove (remains of) coatings during overhaul prior to the application of new primer(s), or (b) as surface activation of primer(s) prior to the application of topcoat(s). During the sanding process, sanders are inside the dedicated hangar equipped with exhaust ventilation (down-flow or cross-flow) and move around the aircraft on fixed scaffolds or movable platforms. The workers use sanding tools (e.g., grinders, orbital/rotary sanders) with e.g., on-tool extraction, wetting/lubrication at release point or connected to vacuum cleaner(s). Small areas e.g., prior to brushing/rolling application or around a window are sanded by sanders either using a scotch brite, sandpaper or sanding tools without on-tool extraction.

Two different scenarios for **blasting** are presented in the CSRs, media blasting in closed system (WCS 8) and media blasting in a room/hall. **Media blasting in closed system** is typically performed on small to medium sized parts (e.g., components of landing gear, vane), in order to remove the surface layer for rework (e.g., nonconformity), for quality testing or before refurbishment (strip off paint including Cr(VI) primers). Typically, plastic beads, plastic granules, or nut shells are used as blasting medium. Media blasting is performed in a glovebox or blasting cabinet (closed system), the worker stands outside, in front of the equipment and operates by placing his hands in dedicated gloves to allow him to manipulate the part, and the blasting gun. Part of the box is usually transparent to allow the operator to see what is being manipulated. No or low exposure is expected during the media blasting process itself. At the beginning of the process, the worker opens the blasting machine, introduces the part and closes the system. Then, they put their hands into the gloves to maintain the part with one hand and to move the blasting gun with the other one. Some sites are equipped with automatic blast cabinets allowing workers to operate the blasting process remotely, from a computer. At the end of the blasting process or for exchanging parts, the worker opens the machine. During this operation, they may be exposed to dust deposits present inside the cabinet, on the blasted part, as well as on remaining beads or granules. At a few sites, the workers carry out media blasting in a semi-closed system. This is a system that is not completely closed, as it has narrow openings at the front sealed by brush strips, through which the worker inserts the arms to manoeuvre the blasting gun and the component. The system is equipped with LEV and the worker wears respiratory protection during this activity (at least a half-mask with P3 filter).

Media blasting in a room/hall is typically performed on medium-sized to large parts (i.e., parts which do not fit into a media-blasting cabinet; e.g., components of aircrafts) or whole aircrafts in order to remove the surface layer of a part or aircraft (including the layer with Cr(VI) primers). Typically, plastic beads are used as blasting medium. The working hall where media-blasting is performed is equipped with roof to floor extraction. Shafts are embedded in the floor where the off-blasted surface material and blasting medium are collected and through which the exhaust air is extracted. Also, designated areas of the hall (e.g., in a corner) may be equipped with additional roof to wall extraction to allow more efficient exhaust air extraction. In these designated areas preferably medium-sized parts are media blasted, e.g., on a table. Also, a mobile LEV system may be used where required to enhance air extraction. For media-blasting of a whole aircraft typically scaffoldings are installed in the hall to allow workers to access all parts of the aircraft. For blasting a whole aircraft typically three to four workers perform media blasting simultaneously. They stand on the floor or on the scaffold and blast the aircraft using blasting guns. After the aircraft is blasted, the workers typically move it to a washing area (close to the blasting hall), where they wash the airplane with water (using a hose) to remove the blasting particles and dust from the surface.

Table 30. Overview of uses and WCSs relevant to machining, sanding and blasting from the public CSRs of ADCR Consortium

Use	**Reference**	**Relevant Worker contributing scenarios***
Use of wash primers containing potassium hydroxyoctaoxodizincate dichromate in aerospace and defence industry and its supply chains.	AFA058-01[28]	WCS 1: Machining on surfaces on an extraction bench/room/booth, including cleaning WCS 2: Machining on surfaces in large work areas (e.g., workshop, hall, room), including cleaning WCS 3: Machining on surfaces in very small work areas (confined space, e.g., wing area/tank), including cleaning WCS 4: Machining on parts on an extraction bench/room/booth, including cleaning WCS 5: Machining on parts in large work areas (e.g., workshop, hall, room), including cleaning WCS 6: Machining on parts in very small work areas (confined space, e.g., wing area/tank), including cleaning WCS 7: Sanding of large surfaces containing Cr(VI) in a dedicated hangar, including cleaning WCS 8: Media blasting in closed system, including cleaning and waste removal WCS 9: Media blasting in a room/hall
Use of wash primers containing pentazinc chromate octahydroxide or potassium hydroxyoctaoxodizincate dichromate in aerospace and defence industry and its supply chains.	AFA059-01[29]	
Use of bonding primers containing strontium chromate in aerospace and defence industry and its supply chains	AFA060-01[30]	
Use of bonding primers containing strontium chromate in aerospace and defence industry and its supply chains	AFA061-01[31]	
Use of primer products other than wash or bonding primers containing strontium chromate and/or potassium hydroxyoctaoxodizincate dichromate in aerospace and defence industry and its supply chains	AFA062-01[32]	
Use of primer products other than wash or bonding primers containing strontium chromate and/or pentazinc chromate octahydroxide and/or potassium hydroxyoctaoxodizincate dichromate in aerospace and defence industry and its supply chains	AFA063-01[33]	

*Table notes: * The Dossier Submitter has re-numbered WCS for the purpose of restriction proposal.*

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[28] REACH - Applications for authorisation AFA058-01 Potassium hydroxyoctaoxodizincate dichromate (PHD) - Health and Safety Executive - Citizen Space.

[29] REACH - Applications for authorisation AFA059-01 Multiple Cr(VI) - Health and Safety Executive - Citizen Space.

[30] REACH - Applications for authorisation AFA060-01 Strontium chromate (StC) - Health and Safety Executive - Citizen Space.

[31] REACH - Applications for authorisation AFA061-01 Strontium chromate (StC) - Health and Safety Executive - Citizen Space.

[32] REACH - Applications for authorisation AFA062-01 Multiple Cr(VI) - Health and Safety Executive - Citizen Space.

[33] REACH - Applications for authorisation AFA063-01 Multiple Cr(VI) - Health and Safety Executive - Citizen Space.

Conditions of use

Conditions of use for different WCSs based on the applications from ADCR Consortium are summarised in Table 31. The durations and frequencies of the tasks are very variable between sites and most of the uses take place in places without mechanical general ventilation. LEV is usually implemented during the tasks and the access to area, where the task takes place is typically restricted.

Inhalation exposure measurements

The public CSRs for uses of ADCR Consortium contain inhalation exposure measurements collected 2020-2023 for all WCS, except for "WCS 9: Media blasting in a room/hall", for which the exposure assessment is based on the measurements for "WCS 7: Sanding of large surfaces containing Cr(VI) in a dedicated hangar, including cleaning", which cover only the sanding activities (for WCS 7, also measurements covering other activities is considered). Because the CSRs were submitted in the UK, the exposure data is also primarily from sites located in the UK. However, due to the low sample size, for WCS 7 and 8, also measurements from sites located in the EEA have been included. The data includes long- and short-term personal measurements as well as long- and short-term static measurements. Because the raw measurement data is not available in the CSR, the Dossier Submitter has not assessed the quality and representativeness of the data and the values presented in Table 32 are as reported in the CSRs.

For machining, exposures for different WCSs (1-6) are presented but the exposure and risk assessment for "machinist" is based on the long-term personal measurements for machining on surfaces (WCS 1-3 combined), for which the 90th percentile is 0.91 µg Cr(VI)/m^3. For machining on parts (WCS 4-6, but long-term personal measurements only available for WCS 5), the exposure is lower (90th percentile = 0.09 µg Cr(VI)/m^3). The highest exposure for machining activities is for WCS 1 alone (machining surfaces on an extraction bench/room/booth only), with a mean exposure of 1.63 µg Cr(VI)/m^3 and maximum exposure of 4.60 µg Cr(VI)/m^3. However, only 8 long-term personal measurements are available for this WCS.

For sanding (WCS 7), the 90th percentile exposure from long-term personal measurements was 91.8 µg Cr(VI)/m^3 when all measurements were included. This value was used for the risk assessment for WCS 7 in the CSR and is also similar to the 90th percentile of long-term personal measurements for UC4 based on the responses from CfE (93.5 µg Cr(VI)/m^3; see Chapter 1.4.3.1 of the restriction proposal). However, some of the measurements also covered other tasks apart from sanding, such as decanting/mixing, brush application of primers and cleaning of equipment. When only measurements, which cover exclusively sanding, were included (~28 % of measurements), the 90th percentile was 232 µg Cr(VI)/m^3. This value was used as a proxy in risk assessment for WCS 9.

For blasting in closed system (WCS 8), the 90th percentile exposure from long-term personal measurements was 0.307 µg Cr(VI)/m^3, which was used for the risk assessment in the CSR. As mentioned above, for blasting in a room/hall, no measurements were available, and therefore, the measurements for sanding were used in risk assessment for WCS 9.

Table 31. Conditions of use for different WCSs based on applications from ADCR Consortium

Task	**Task duration (min/shift)**	**Task frequency (days/year)**	**LEV**	**General ventilation**	**Other RMM**
WCS 1: Machining on surfaces on an extraction bench/room/booth, including cleaning	5 - 480	<1 - 240	LEV system installed in extraction bench/room/booth	Natural ventilation	Restriction of access by means of signage or physical segregation or through strict procedure
WCS 2: Machining on surfaces in large work areas (e.g., workshop, hall, room), including cleaning	5 - 420	<1 - 240	On-tool extraction system or mobile extraction (including vacuum cleaner)	Natural ventilation	Restriction of access by means of signage or physical segregation or through strict procedure. If not technically possible to implement a LEV, workers operate under wet conditions.
WCS 3: Machining on surfaces in very small work areas (confined space, e.g., wing area/tank), including cleaning	5 - 360	<1 - 240	On-tool extraction system or mobile extraction (including vacuum cleaner)	Mechanical ventilation unless use of mechanical ventilation would introduce risks (e.g. local spark risk) or would otherwise not be technically and practically possible. ACH not reported.	Restriction of access by means of signage or physical segregation or through strict procedure. If not technically possible to implement a LEV, workers operate under wet conditions.
WCS 4: Machining on parts on an extraction bench/room/booth, including cleaning	5 - 420	<1 - 240	LEV system installed in extraction bench/room/booth	Natural ventilation	Restriction of access by means of signage or physical segregation or through strict procedure
WCS 5: Machining on parts in large work areas (e.g., workshop, hall, room), including cleaning	5 - 480	<1 - 240	On-tool extraction system or mobile extraction (including vacuum cleaner)	Natural ventilation	Restriction of access by means of signage or physical segregation or through strict procedure. If not technically possible to implement a LEV, workers operate under wet conditions.
WCS 6: Machining on parts in very small work areas (confined space, e.g., wing area/tank), including cleaning	5 - 360	<1 - 240	On-tool extraction system or mobile extraction (including vacuum cleaner)	Mechanical ventilation unless use of mechanical ventilation would introduce risks (e.g. local spark risk) or would otherwise not be technically and practically possible. ACH not reported.	Restriction of access by means of signage or physical segregation or through strict procedure. If not technically possible to implement a LEV, workers operate under wet conditions.
WCS 7: Sanding of large surfaces containing Cr(VI) in a dedicated hangar,	5 - 240	<1 - 96	Hangar - laminar down-flow or cross-flow (≥3 ACH)	n.a.	Restriction of access by means of signage or physical segregation or through strict procedure. Depending on the site and its

Task	**Task duration (min/shift)**	**Task frequency (days/year)**	**LEV**	**General ventilation**	**Other RMM**
including cleaning					organisation, either on-tool extraction or a vacuum cleaner or wetting/lubrication at the point of release is used during sanding in a hangar to minimise Cr(VI) exposure. Sanding of small areas (e.g., around windows or prior to brushing application) with sandpaper or sanding tools in a hangar with LEV requires no on-tool extraction.
WCS 8: Media blasting in closed system, including cleaning and waste removal	5 - 270	<1 - 240	No (cleaning and waste removal)	Natural ventilation	Restriction of access by means of signage or physical segregation or through strict procedure
WCS 9: Media blasting in a room/hall	5 - 480	1 - 240	Blasting hall - laminar down-flow or cross-flow (≥ 3 ACH)	n.a.	Mobile LEV for medium-sized parts Restriction of access by means of signage or physical segregation or through strict procedure. During media-blasting, only persons involved in the blasting process are allowed in the working hall.

Table 32. Inhalation exposure measurements from the CSRs of ADCR Consortium

Long term personal (µg Cr(VI)/m^3)	**N**	**Mean**	**SD**	**P50**	**P90**
Machining all (WCS 1-6)	239	0.165	0.485	0.023	0.34
Machining on surfaces only (WCS 1-3)	56	0.321	0.822	0.03	**0.914**
Machining on parts only (WCS 4-6)	80	0.0561	0.15	0.012	0.0896
Machining on surfaces on an extraction bench/room/booth only (WCS 1)	8	1.63	n.a.	n.a.	4.60*
Machining on surfaces in large work areas only (WCS 2)	30	0.0929	0.319	0.017	0.102
Machining on surfaces in very small work areas only (WCS 3)	18	0.121	0.186	0.056	0.3
Machining on parts in large work areas only (WCS 5)	80	0.0561	0.15	0.012	0.0896
Sanding all (WCS 7)	79	39.1	69.4	17	**91.8**
Sanding exclusively (WCS 7; used as proxy for WCS 9)	22	81	115	10.7	**232**
Blasting in closed system (WCS 8)	13	0.115	0.13	0.0449	**0.307**
Short term personal (µg Cr(VI)/m^3)	**N**	**Mean**	**SD**	**P50**	**P90**
Machining all (WCS 1-6)	30	14	23.7	1.82	43
Machining on surfaces only (WCS 1-3)	23	17.2	26.2	1	48.4
Machining on parts only (WCS 4-6)	3	1.46	n.a.	n.a.	4.3*
Machining on surfaces on an extraction bench/room/booth only (WCS 1)	19	20.8	27.6	7.9	50.9
Machining on surfaces in large work areas only (WCS 2)	4	0.0933	n.a.	n.a.	0.182*
Machining on parts in large work areas only (WCS 5)	3	1.46	n.a.	n.a.	4.3*
Sanding all (WCS 7)	98	74.6	127	9	245
Sanding exclusively (WCS 7; used as proxy for WCS 9)	73	97.6	140	26	274
Blasting in closed system (WCS 8)	8	0.611	n.a.	n.a.	2.00*
Long term static (µg Cr(VI)/m^3)	**N**	**Mean**	**SD**	**P50**	**P90**
Machining all (WCS 1-6)	24	0.0253	0.0294	0.0158	0.0445
Machining on surfaces only (WCS 1-3)	6	0.045	n.a.	n.a.	0.130*
Machining on parts only (WCS 4-6)	6	0.0118	n.a.	n.a.	0.046*
Machining on surfaces on an extraction bench/room/booth only (WCS 1)	4	0.0325	n.a.	n.a.	0.09*
Machining on surfaces in large work areas only (WCS 2)	2	n.a.	n.a.	n.a.	0.130*
Machining on parts in large work areas only (WCS 5)	6	0.0118	n.a.	n.a.	0.046*
Sanding all (WCS 7)	15	0.766	1.54	0.05	2.39
Sanding exclusively (WCS 7)	4	0.0481	n.a.	n.a.	0.12*
Blasting in closed system (WCS 8)	13	0.0652	0.0516	0.05	0.134
Short term static (µg Cr(VI)/m^3)	**N**	**Mean**	**SD**	**P50**	**P90**
Machining all (WCS 1-6)	4	0.0148	n.a.	n.a.	0.029*
Machining on surfaces only (WCS 1-3)	3	0.01	n.a.	n.a.	0.01*
Machining on parts only (WCS 4-6)	1	n.a.	n.a.	n.a.	0.029*
Machining on surfaces on an extraction bench/room/booth only (WCS 1)	3	0.01	n.a.	n.a.	0.01*
Machining on parts in large work areas only (WCS 5)	1	n.a.	n.a.	n.a.	0.029*
Sanding all (WCS 7)	9	0.731	n.a.	n.a.	1.84*
Sanding exclusively (WCS 7)	6	0.882	n.a.	n.a.	1.84*
Blasting in closed system (WCS 8)	2	n.a.	n.a.	n.a.	0.14*

*Table notes: * maximum value instead of 90th percentile reported due to low sample size; the values in **bold** were used in the exposure assessment in the corresponding CSR.*

Exposure assessment

The exposure assessment in CSR was based on the long-term personal inhalation measurements described above. The exposures were corrected for RPE and overall time of a working day spent with Cr(VI) relevant activities. Furthermore, in the CSR the exposures were corrected for market share to account for the exposure specifically from the present use. These factors were 0.01 for wash primers, 0.21 for bonding primers and 0.78 for primers other than wash of bonding primers. In order to present the data in a manner that would be more comparable with the exposure assessment in the restriction proposal, the Dossier Submitter has not considered this "marker share correction factor" in the Table 33, which summarises the long-term exposure estimates for different WCS. Considering the RPE and time correction factor, the long-term exposures vary between 0.09 µg Cr(VI)/m^3 for WCS 1-6 and 0.93 µg Cr(VI)/m^3 for WCS 9. These values are within the range of 8h-TWA values corrected for frequency and RPE for different UCs based on the CfE responses, except for UC4 for which the exposure is 3.21 µg Cr(VI)/m^3 (see Chapter 1.4.3.1 of the restriction proposal). However, these values are not fully comparable as they have been calculated differently, for example, no combined exposure from different tasks was calculated in the CSRs of ADCR Consortium, because it was claimed that the measurements typically already covered several tasks. Furthermore, no frequency correction was considered in CSRs.

Table 33. Long-term exposure values from the CSRs of ADCR Consortium

WCS	N	Exposure value µg Cr(VI)/m^3	APF for RPE	Exposure value corrected for RPE	Time correction factor for Cr(VI) tasks	Long term exposure
WCS 1-6: Machinist	56	0.91	10	0.09	1	0.09
WCS 7: Sanders in dedicated hangar	79	91.8	250	0.37	0.4	0.15
WCS 8: Workers performing media blasting in closed system	13	0.31	1	0.31	0.6	0.18
WCS 9: Workers performing media blasting in a room/hall	22	232	250	0.93	1	0.93

Table notes: Time correction factor is used to account for working time spent on tasks with Cr(VI) of workers conducting a given WCS.

D.1.2. Existing exposure limits for workers

Companies operating in the EU and working with the Cr(VI) compounds need to ensure that the workers are not exposed to Cr(VI) levels higher than the occupational exposure limit (OEL). Since 17 January 2025, the binding occupational exposure limit value (BOELV) in the EU is 0.005 mg Cr(VI)/m^3. All the EEA countries need to implement national OELVs, which are at least as stringent as EU-BOELV. The Dossier Submitter is aware of some countries that have implemented more stringent OELVs at the national level. These countries and corresponding OELVs are listed below in the Table 34. The information is mainly from the GESTIS database[34] but additional information has been searched for from national websites. Because the new EU-BOELV came into force only four months before the submission of the restriction proposal, it is possible that the databases and websites have not yet been updated.

In both calls-for-evidence (CfE), the companies were asked to report national binding occupational exposure limits. The results are reported in Table 35. Because the CfEs were conducted before the implementation of the EU-BOELV, some companies were reporting the OELs higher than EU-BOELV. Some reported values seem quite high and might refer

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[34] See the GESTIS Substance Database.

to some other limit values, such as short-term exposure limit (STEL) or to some specific use, such as welding. However, most of the replies are in agreement with the old EU-BOELV of 0.01 mg Cr(VI)/m^3 (until 17.1.2025), the new EU-BOELV of 0.005 mg Cr(VI)/m^3 (from 17.1.2025) or the more stringent national limits of 0.001 mg Cr(VI)/m^3 or 0.00025 mg Cr(VI)/m^3, which are also reported in Table 34.

Table 34. National occupational exposure limits (OEL) in the EU

Member State	Compound	OEL in µg Cr(VI)/m^3, 8h-TWA	Remarks	Reference
EU-BOELV	Cr(VI) compounds	5	valid from 17.1.2025	
Denmark	Chromium acid and chromates and Cr(VI) compounds, expressed as Cr, excluding strontium chromate	0.25		https://at.dk/regler/bekendtgoerelser/graensevaerdier-stoffer-materialer-1619/bilag-2-graensevaerdier-luftforureninger/afsnit-a
France	Cr(VI) compounds	1	Restrictive statutory limit value	Gestis 2025
Germany	Cr(VI) compounds	1	Assessment scale, risk based. Inhalable fraction	Gestis 2025
The Netherlands	Cr(VI) compounds	1	Applies for soluble compounds	Gestis 2025

Table notes: Only countries, with the OELs below EU-BOELV are mentioned. Other countries are assumed to have adopted EU-BOELV at the national level.

Table 35. National occupational exposure limits according to CfE responses

Country	8h-OEL in µg Cr(VI)/m^3	Count	Country	8h-OEL in µg Cr(VI)/m^3	Count
Austria	5	2	**Hungary**	10	3
Austria	10	3	**Italy**	5	10
Austria	20	4	**Italy**	10	129
Belgium	10	10	**Italy**	20	1
Bulgaria	1	2	**Italy**	50	2
Bulgaria	10	2	**Italy**	100	4
Czechia	1	1	**Luxembourg**[1]	1	1
Czechia	1.5	1	**Malta**	25	1
Czechia	5	13	**Norway**	1	4
Czechia	10	11	**Poland**	1	1
Czechia	100	1	**Poland**	5	4
Czechia	1500	1	**Poland**	10	21
Denmark	0.25	3	**Portugal**	10	5
Denmark	1	5	**Romania**	2	1
Finland	5	15	**Romania**	5	1
Finland	10	1	**Romania**	10	5
Finland	25	1	**Romania**	50	1
France	1	57	**Slovakia**	10	5
France	2	1	**Slovenia**	10	1
France	3	1	**Slovenia**	100	1
France	5	2	**Spain**	0.2	1
France	10	3	**Spain**	1	1
France	50	1	**Spain**	5	2
France	100	3	**Spain**	10	52
Germany	0.2	2	**Spain**	25	1
Germany	1	98	**Spain**	30	1
Germany	5	6	**Sweden**	5	16
Germany	10	1	**Sweden**	10	1
Germany	12.5	1	**Switzerland**	1	7
Germany	25	2	**Switzerland**	5	1
Germany	50	5	**The Netherlands**	1	7
Greece	0.142	1	**UK**	10	1

Source: compilation based on the CfEs.

Table notes: [1]no binding national occupational exposure limit (OEL) for Cr(VI) applicable to Luxembourg, however this company applies the French OEL of 1 µg Cr(VI)/m^3.

D.1.3. Compliance with the proposed limit values

In both CfEs, companies using Cr(VI) substances in the EU were asked to report the exposures of up to five tasks that contribute most to the worker exposure. Furthermore, they were asked to report whether they would already comply with different limit values proposed in the restriction proposal. The compliance with the limit values is typically based on EN 689 standard, in which the exposure data is treated differently than in the exposure assessment presented in the current restriction proposal. The Dossier Submitter has compared the calculated combined exposures with the reported compliance in order to assess the conservativeness of the exposure assessment.

Figure 21 presents this comparison. It shows that where companies claimed to comply with a given limit value (indicated as "below"), the calculated exposure was in most cases below this limit. However, where companies claimed not to comply with a certain limit value (indicated as "above"), the calculated exposure was still often below the limit. This inconsistency might be due to different assumptions in the calculation of combined exposure in the context of compliance check and exposure assessment. Indeed, the Dossier Submitter used the P90 value of measurements as a realistic worst-case if >5 samples were available. However, for assessing compliance with EN 689, companies should use different statistics depending on the sample size and distribution of data. For cases with >5 samples, the norm recommends using the 70 % upper confidence limit (UCL) of the P95 value of measurements for compliance checks. This approach results in higher exposures than the realistic worst-case approach taken by the Dossier Submitter.

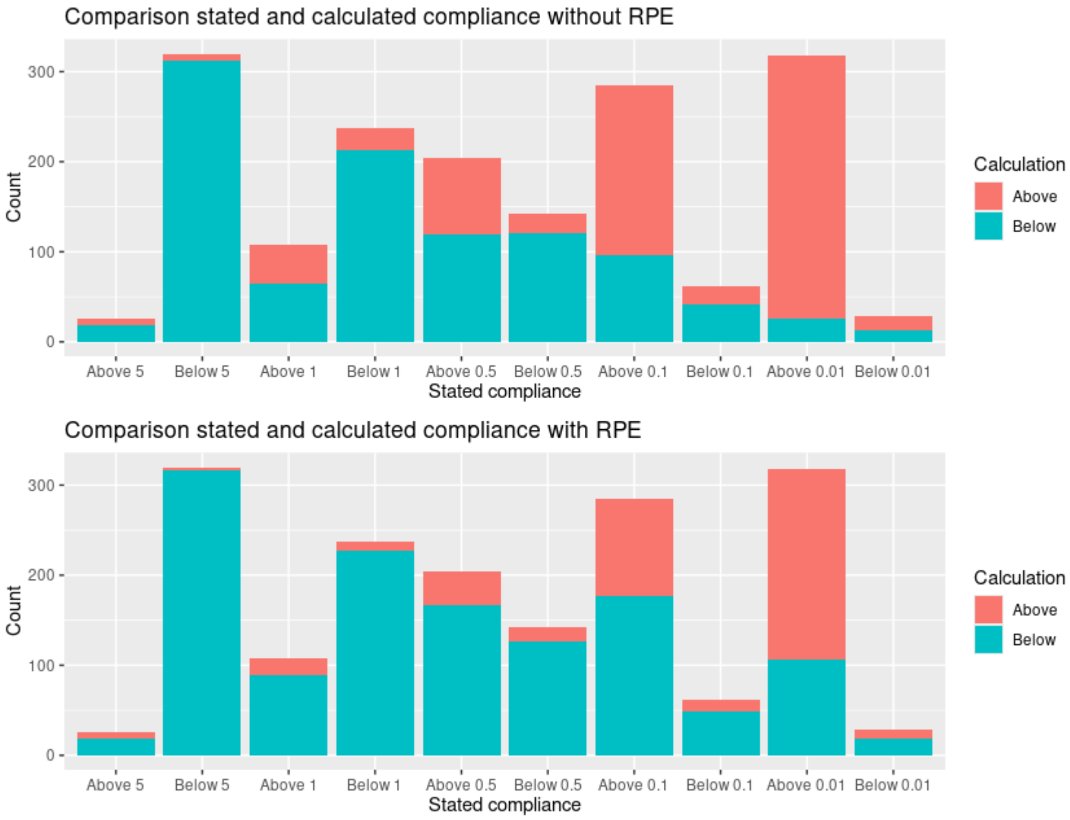

Figure 21. Comparison of stated and calculated compliance with different LVs

Source: based on the responses from the CfEs.

Figure notes: all values in (µg Cr(VI)/m^3); in the upper panel, exposure is calculated without considering RPE; in the lower panel exposure is corrected for use of RPE.

For the impact assessment presented in Section 3 of the main report, the implications of using the reported rather than calculated compliance rates are minor. Figure 21 shows that the proportion of companies reporting compliance but that would not comply according to the calculations (i.e. the red proportion in the 'Below' bins) is much lower than the proportion of companies that report non-compliance but would actually comply according to the calculations (i.e. the green proportion in the 'Above' bins). Thus, using reported compliance will result in a higher estimate of the benefits in the impact assessment compared with use of calculated compliance.

D.2. General population exposure

D.2.1.1. Background

Chromium compounds have historically been an important pollutant in the EU whose emissions need to be reported under the Industrial Emissions Portal Regulation (EU) 2024/1244 if the reporting thresholds for air (100 kg/y) and water (50 kg/y) emissions are exceeded. Because of these reporting provisions, chromium compounds have been monitored in the EU since 2007 and data for *total* chromium emissions to air and water from sites exceeding the relevant thresholds is available from the European Industrial Emissions Portal.[35] The IEPR data suggest that chromium emissions to air more than halved between 2007 and 2022. Over the same period, recorded chromium emissions to water decreased by more than 70 %. Of specific interest in the context of the Annex XV restriction proposal on certain Cr(VI) substances is the metals sector (IEPR main activity '2(f) – Production and processing of metals'). In this sector, which includes the electroplating with Cr(VI) substances, air and water emissions went down by 70 % and almost 80 %, respectively.

D.2.1.2. Data analysis

While the IEPR data indicate a significant reduction in total chromium emissions across the EU, this does not allow any firm conclusions to be drawn on the current risk to the general population living in the vicinity of Cr(VI)-emitting sites. As it cannot be ruled out that individuals be exposed to emissions from several sites, the Dossier Submitter undertook a spatially explicit analysis of sites that notified Cr(VI) substance uses under existing upstream authorisations in accordance with Art. 66 of REACH. However, the information provided in the DU notifications is scattered and not easy to analyse. In order to analyse the information, the Dossier Submitter had to make several assumptions.

D.2.1.2.1. Emissions

At the individual site, the Dossier Submitter assumed that:

- emissions to air and water are measured in kg Cr(VI) emitted per year
- emissions to air can be converted into inhalation exposure using EUSES standard assumptions and from that into individual ELR of lung cancer using the RAC DRF
- emissions to water can go:
  - directly to the surface water, in which case EUSES standard assumptions are applied to convert emissions to the daily exposure dose via drinking water

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[35] See https://industry.eea.europa.eu.

  - to a local STP, in which case it is assumed that 50 % of the Cr(VI) is discharged to surface water and the other 50 % go to sludge, if the sludge is:
    - incinerated, no Cr(VI) emission potential remains
    - applied to agricultural land, EUSES standard assumptions are applied to model Cr(VI) leaching into groundwater and convert groundwater pollution to the daily exposure dose via drinking water
  - based on the information from the CfEs, the split between the above scenarios is: 25 % no discharge to water (closed system), 19 % direct discharge to surface water, 8 % discharge to STP with sludge incineration, and 48 % discharge to STP with sludge fertilisation
  - moreover, from Eurostat data it is known that the split of sludge handling after STP is: 20 % incineration, 30 % landfill, and 50 % use as fertiliser
- using the observed fractions as weights, the individual ELR of intestinal cancer is estimated by applying the RAC DRF to the average daily exposure dose

D.2.1.2.2. Risk calculations

Using EUSES standard assumptions and the RAC DRF for inhalation and oral exposure of the general population (assuming 70y of exposure), the following standard conversion factors can be derived:

- for a person 100 m away from the stack of an emitting site, 1 kg/y of Cr(VI) emitted to air corresponds to a ELR of lung cancer of **2.18E-5**
- for a person living close to an emitting site, 1 kg/y of Cr(VI) directly discharged to surface water corresponds to a ELR of intestinal cancer of **3.12E-6**
- for a person living close to an emitting site, 1 kg/y of Cr(VI) discharged to wastewater and treated in the local STP where sludge is incinerated corresponds to a ELR of intestinal cancer of **1.5E-6**
- for a person living close to an emitting site, 1 kg/y of Cr(VI) discharged to wastewater and treated in the local STP where sludge is used as fertiliser corresponds to a ELR of intestinal cancer of **6.20E-6**
- for a person living close to an emitting site, 1 kg/y of Cr(VI) discharged with unknown fate corresponds to an expected ELR of intestinal cancer of **3.69E-6**[36]

D.2.1.2.3. Geospatial analysis

The Dossier Submitter geolocated 1 578 individual sites in the EU that have notified ECHA of their Cr(VI) substance use as DUs of a previous upstream authorisation under Art. 66 of REACH using site-specific addresses. In a next step, these geolocations were merged with a 1x1 km^2 grid downloaded from GISCO for which population statistics are available.[37] For reasons of confidentiality, the resulting map of DU locations is reproduced on a 20x20 km^2 grid map. However, Figure 22 gives a good idea of the locations of Cr(VI)-using and

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[36] 0.25*0+0.19*3.12E-6+0.08*1.5E-6+0.48*6.2E-6 = 3.69E-6.

[37] The Geographical information system of the Commission (GISCO) is hosted by Eurostat and can be accessed under: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Geographical_information_system_of_the_Commission_(GISCO).

emitting sites in the EU. (If there is an overlap of sites in the same grid cell, they appear in bold.) The confidential DU data and R code to reproduce the analysis will be made available to the rapporteurs of ECHA's Scientific Committees.

The Dossier Submitter relied on the geospatial analysis to produce summary statistics on the geographical clustering of sites that emit Cr(VI). In fact, the analysis found that there are 1 578 notifying sites located in 1 486 different 1x1 km^2 grid cells; out of these 'host cells', 1 404 cells (94.5 %) contained one site, 77 cells (5.2 %) contained two sites, and 5 cells (0.3 %) contained more than two sites; the median, mean and P90 population in the host cells amounts to 430, 1 573 and 3 980 individuals. For a subset of the notifying sites, data is available on measured or modelled emissions to air and water. Applying the assumptions made in Section B.8.1, these data were used to establish distributions of geographically explicit ELR estimates as reported in the main report.

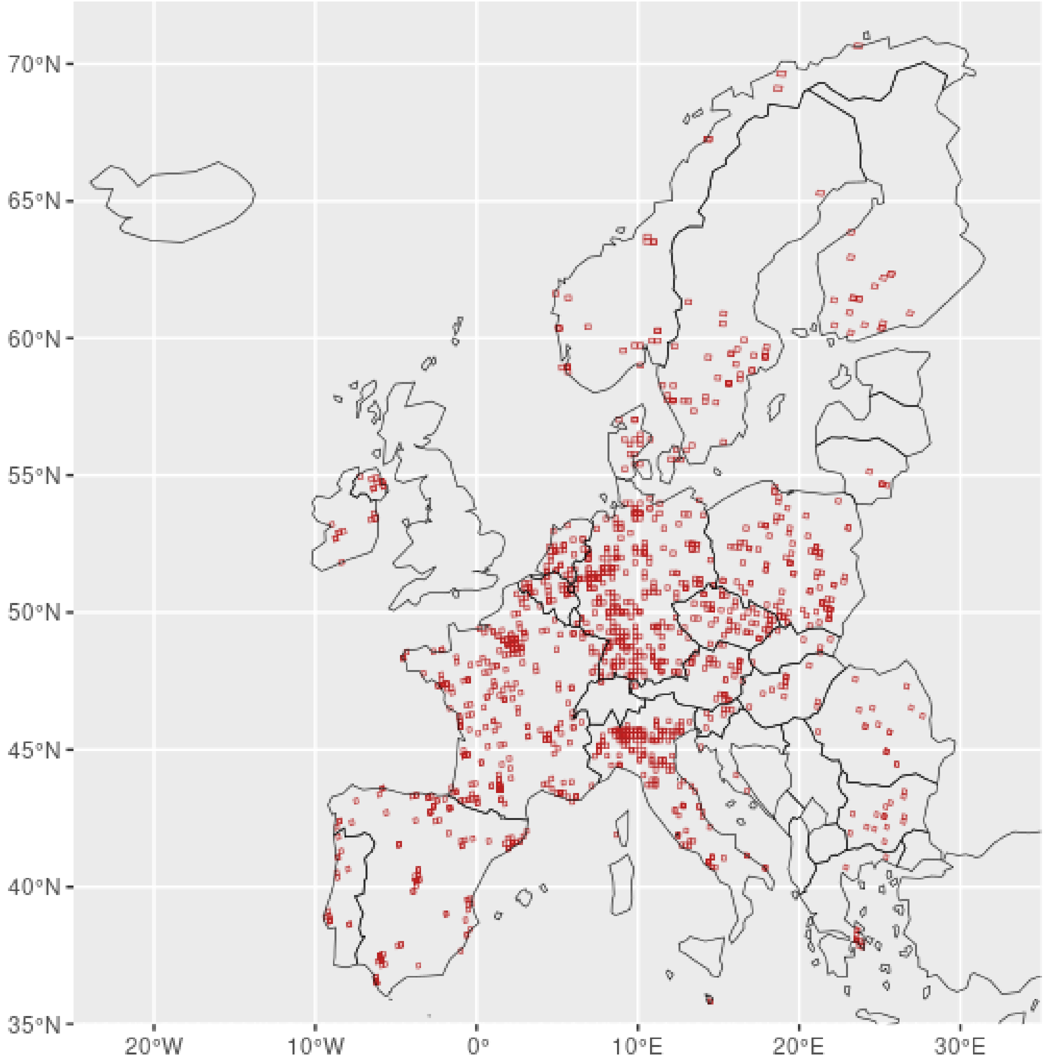

Figure 22. Map of notified Cr(VI) substance uses in the EU

Figure note: The map uses a 20x20 km^2 resolution due to confidentiality reasons.

D.2.1.2.4. Current emission limits

In both CfEs, companies were asked to report binding environmental emission limit values for Cr(VI) at their site, both for air and water. Because these limit values can be region- or site-specific, or related to a specific use, there can be many different values in a single country. Summaries of the CfE responses are presented in Table 36 for air and in Table 37 for water. Although the responses indicate a high variability in limit values (1-5 000 µg Cr(VI)/m^3 for air and 1-1 000 000 µg Cr(VI)/L for water), the most common limit values were 50 and 100 µg Cr(VI)/m^3 for air and 100 and 200 µg Cr(VI)/L for water.

The Dossier Submitter has also received information about the emission limits at the national level from some EU member states. This information is summarised in table 38 for air and in table 39 for water.

Although only a few countries are covered, it can be concluded, similar to the information received in CfEs, that there are differences between countries. For instance, concerning the air emissions, Sweden does not have any threshold value for chromium in outdoor air whereas in Belgium (Flemish region) for Cr(VI) substances there is a general emission limit of 0.1 mg/Nm^3 and in Italy 1 mg/Nm^3. At the EU level, directive 2010/75/EU sets an emission limit of 0.5 mg Cr/Nm^3 for waste incineration plants. Concerning the emission limits for water, the variation is even higher and countries have several limits for different kinds of uses. At the EU level directive 2010/75/EU sets an emission limit of 500 µg Cr/L for discharges in wastewater.

Table 36. Environmental limit values for air emissions based on CfE responses

Country	Air emission limit	Unit	N
Austria	5	µg Cr(VI)/m^3	1
Austria	10	µg Cr(VI)/m^3	3
Austria	15	µg Cr(VI)/m^3	1
Austria	50	µg Cr(VI)/m^3	2
Belgium	1	µg Cr(VI)/m^3	1
Belgium	50	µg Cr(VI)/m^3	2
Belgium	100	µg Cr(VI)/m^3	3
Belgium	5 000	µg Cr(VI)/m^3	2
Bulgaria	1	µg Cr(VI)/m^3	1
Czechia	1	µg Cr(VI)/m^3	1
Czechia	2	µg Cr(VI)/m^3	2
Czechia	10	µg Cr(VI)/m^3	4
Czechia	50	µg Cr(VI)/m^3	2
Czechia	500	µg Cr(VI)/m^3	1
Czechia	1 000	µg Cr(VI)/m^3	3
Czechia	2 000	µg Cr(VI)/m^3	3
Denmark	140	µg Cr(VI)/m^3	1
Denmark	250	µg Cr(VI)/m^3	2
Denmark	5 000	µg Cr(VI)/m^3	1
France	10	µg Cr(VI)/m^3	3
France	50	µg Cr(VI)/m^3	5
France	100	µg Cr(VI)/m^3	30
France	100	µg total Cr/m^3	2
France	180	µg Cr(VI)/m^3	1
France	1 000	µg Cr(VI)/m^3	2
France	5 000	µg total Cr/m^3	1
Germany	1	µg Cr(VI)/m^3	14
Germany	5	µg Cr(VI)/m^3	1
Germany	7	µg Cr(VI)/m^3	1
Germany	10	µg Cr(VI)/m^3	5
Germany	22	µg Cr(VI)/m^3	1
Germany	50	µg Cr(VI)/m^3	81
Malta	250	µg Cr(VI)/m^3	1
Norway	1	µg Cr(VI)/m^3	1
Poland	1	µg Cr(VI)/m^3	1
Poland	5	µg Cr(VI)/m^3	1
Poland	20	µg Cr(VI)/m^3	1
Poland	25	µg Cr(VI)/m^3	1
Poland	129	µg Cr(VI)/m^3	1
Poland	220	µg Cr(VI)/m^3	1
Poland	375	µg Cr(VI)/m^3	2
Poland	400	µg Cr(VI)/m^3	1
Poland	500	µg Cr(VI)/m^3	1
Portugal	5	µg Cr(VI)/m^3	1
Portugal	100	µg Cr(VI)/m^3	1
Portugal	5 000	µg Cr(VI)/m^3	1
Romania	10	µg Cr(VI)/m^3	1
Romania	200	µg Cr(VI)/m^3	5
Slovakia	50	µg Cr(VI)/m^3	6
Slovenia	50	µg Cr(VI)/m^3	1
Slovenia	1 000	µg Cr(VI)/m^3	1
Spain	1	µg Cr(VI)/m^3	1
Spain	10	µg Cr(VI)/m^3	3
Spain	100	µg Cr(VI)/m^3	5
Spain	200	µg Cr(VI)/m^3	9
Spain	200	µg total Cr/m^3	1
Spain	500	µg Cr(VI)/m^3	1
Spain	1 000	µg Cr(VI)/m^3	4
Sweden	10	µg Cr(VI)/m^3	1
Sweden	100	µg Cr(VI)/m^3	1
Switzerland	1	µg Cr(VI)/m^3	1
Switzerland	5	µg Cr(VI)/m^3	1
Switzerland	1 000	µg Cr(VI)/m^3	4
The Netherlands	50	µg Cr(VI)/m^3	4

Country	**Air emission limit**	**Unit**	**N**
Germany	100	µg Cr(VI)/m^3	1
Germany	1 000	µg Cr(VI)/m^3	1
Germany	5 000	µg Cr(VI)/m^3	1
Hungary	1 000	µg Cr(VI)/m^3	2
Italy	1	µg Cr(VI)/m^3	1
Italy	3	µg Cr(VI)/m^3	1
Italy	4	µg Cr(VI)/m^3	1
Italy	5	µg Cr(VI)/m^3	1
Italy	10	µg Cr(VI)/m^3	3
Italy	30	µg Cr(VI)/m^3	1
Italy	50	µg Cr(VI)/m^3	1
Italy	52	µg Cr(VI)/m^3	1
Italy	100	µg Cr(VI)/m^3	55
Italy	200	µg Cr(VI)/m^3	1
Italy	250	µg Cr(VI)/m^3	1
Italy	300	µg Cr(VI)/m^3	5
Italy	500	µg Cr(VI)/m^3	16
Italy	1 000	µg Cr(VI)/m^3	24
The Netherlands	100	µg Cr(VI)/m^3	3

Table 37. Environmental limit values for water emissions based on CfE responses

Country	**Water concentration limit**	**Unit**	**N**
Austria	100	µg Cr(VI)/L	5
Austria	500	µg Cr(VI)/L	1
Austria	1000	µg Cr(VI)/L	1
Belgium	1	µg Cr(VI)/L	1
Belgium	5	µg Cr(VI)/L	1
Belgium	10	µg Cr(VI)/L	1
Belgium	150	µg total Cr/L	1
Belgium	200	µg Cr(VI)/L	1
Bulgaria	1	µg Cr(VI)/L	2
Bulgaria	100	µg Cr(VI)/L	1
Bulgaria	500	µg Cr(VI)/L	1
Czechia	7	µg Cr(VI)/L	1
Czechia	18	µg Cr(VI)/L	1
Czechia	20	µg Cr(VI)/L	1
Czechia	50	µg Cr(VI)/L	2
Czechia	100	µg Cr(VI)/L	9
Czechia	200	µg Cr(VI)/L	3
Czechia	1000	µg Cr(VI)/L	2
Czechia	1200	µg Cr(VI)/L	1
Denmark	100	µg Cr(VI)/L	1
Denmark	300	µg Cr(VI)/L	2
Denmark	300	µg total Cr/L	4
Finland	20	µg Cr(VI)/L	1
Finland	100	µg Cr(VI)/L	8
Finland	500	µg Cr(VI)/L	1
Finland	500	µg total Cr/L	1
France	20	µg Cr(VI)/L	1
France	50	µg Cr(VI)/L	2
France	100	µg Cr(VI)/L	19
France	100	µg total Cr/L	1
France	1000000	µg Cr(VI)/L	1
Germany	1	µg Cr(VI)/L	4
Germany	20	µg Cr(VI)/L	2
Germany	50	µg Cr(VI)/L	9
Germany	100	µg Cr(VI)/L	72
Germany	200	µg Cr(VI)/L	5
Germany	500	µg Cr(VI)/L	6
Italy	5	µg Cr(VI)/L	1
Italy	7	µg total Cr/L	1
Italy	10	µg Cr(VI)/L	1
Italy	20	µg Cr(VI)/L	2
Italy	50	µg Cr(VI)/L	3
Italy	100	µg Cr(VI)/L	1
Italy	150	µg Cr(VI)/L	1
Italy	200	µg Cr(VI)/L	56
Italy	1000	µg Cr(VI)/L	3
Italy	2000	µg Cr(VI)/L	1
Italy	200000	µg Cr(VI)/L	1
Luxembourg	100	µg Cr(VI)/L	1
Malta	5000	µg Cr(VI)/L	1
Norway	1	µg Cr(VI)/L	1
Poland	100	µg Cr(VI)/L	4
Poland	200	µg Cr(VI)/L	7
Poland	250	µg Cr(VI)/L	1
Portugal	2	µg Cr(VI)/L	1
Portugal	100	µg Cr(VI)/L	3
Romania	140	µg Cr(VI)/L	1
Romania	200	µg Cr(VI)/L	4
Slovakia	50	µg Cr(VI)/L	1
Slovakia	100	µg Cr(VI)/L	3
Slovenia	100	µg Cr(VI)/L	1
Spain	1	µg Cr(VI)/L	1
Spain	50	µg Cr(VI)/L	1
Spain	200	µg Cr(VI)/L	4
Spain	200	µg total Cr/L	1
Spain	300	µg Cr(VI)/L	4
Spain	500	µg Cr(VI)/L	13
Spain	500	µg total Cr/L	1
Spain	600	µg Cr(VI)/L	1
Spain	1000	µg Cr(VI)/L	3
Sweden	1	µg Cr(VI)/L	2
Sweden	2	µg Cr(VI)/L	1
Sweden	100	µg Cr(VI)/L	4
Sweden	500	µg Cr(VI)/L	1

Country	**Water concentration limit**	**Unit**	**N**
Hungary	1000	µg Cr(VI)/L	1
Ireland	500	µg total Cr/L	1
Switzerland	100	µg Cr(VI)/L	3
The Netherlands	20	µg Cr(VI)/L	1
The Netherlands	100	µg Cr(VI)/L	3
The Netherlands	1000	µg Cr(VI)/L	1

Table 38. Air emission value for chromium compounds based on the information received from EU Member States

Country	Compound	Air emission value (mg/Nm^3)	Notes
European Union	Chromium and its compounds	0.5[1]	- As Cr - Waste incineration plants
Belgium (Flemish region)	Cr(VI) substances	0.1[2] (expressed as Cr, if the mass flow is 0,5 g/h or more)	- General emission limit
	Cr(VI) substances	3.5[3] (dust, if the emission of Cr(VI) is above 0,05 mg/Nm^3)	- Following the BAT-conclusions (best available technique) for the ferrous metals processing industry, in the specific case of electric arc furnaces
Italy	Cr(VI) and its compounds	1[4]	- As Cr - Relevance threshold, expressed as mass Flow: 5g/h - Emission value
Luxembourg	Chromium and chromium compounds	0.5[1]	- Waste incineration plants
		0.05[5]	
Slovak Republic	Cr(VI) substances	0.05[6] mg/m^3 (prescribed mass concentration; c) 0.15[6] g/h (prescribed mass flow; HT)	- Air pollution (emission from plants) - General emission limit for industrial activities where such emissions occur. - Limits applied either as HT or as c
Spain	Chromium and chromium compounds	0.5[7]	
Sweden	Chromium and chromium compounds	-	- No threshold value for chromium in outdoor air

Table notes: BAT: best available techniques.

Sources: [1] Directive 2010/75/EU; [2] VLAREM II: Order of the Flemish Government of 1 June 1995 concerning General and Sectoral provisions relating to Environmental Safety (in annex 4.4.2, 6° of VLAREM II) and in [3] VLAREM III, art.10.8.2.3; [4] D. LGS. n. 152, 3 Aprile 2006, Parte Quinta, Allegato I; [5] Arrêté 1/17/0568 (2020); [6] Regulation of the Ministry of the Interior of the Slovak Republic No. 248/2023 Coll. (Annex 3, Part I.); [7] The Royal Decrees 815/201

Table 39. Water emission values (µg/l) for Chromium compounds based on the information received from EU member states

Member State	Compound	Water emission value (µg/l)	Type of water and source of emission	Notes
EU	Cr and Cr compounds	500[1]	Discharges in wastewater From the cleaning of waste gases	As Cr
Belgium (Flemish region)	Total Cr	50[2]	Wastewater	There is no general concentration limit for Cr(VI) (IGS; indelingscriterium gevaarlijke stiffen), only a LOQ (limit of quantification) of 10 µg/l above which an emission limit value is expected in the permit; There is a reference to CAS-number 7440-47-3, for metallic chromium, the Dossier Submitter infers that total Cr includes Cr(III) and Cr(VI) emissions

Belgium (Flemish region)	Cr(VI)	10[2)]	Discharges in surface waters Sector of industry (15°): Glass, manufacture, and use of hollow glass	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	500[2)]	Discharges in surface waters and in public sewage system Sector of industry (23°): Tanneries and tawers, furriers and fur works	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	200[2)]	Discharges in surface waters and in public sewage system Sector of industry (27): Non-ferrous	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	50[2)]	Discharges in surface waters Sector of industry (33°): Petroleum refineries	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	50[2)]	Discharges in surface waters Sector of industry (36°): Internal cleaning of recipients	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	50[2)]	Discharges in surface waters and in public sewage system Sector of industry (44°): Textiles a) textile finishing	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	300[2)]	Discharges in public sewage system Sector of industry (53°): Liquid products storage of liquid hazardous substances	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	200[2)]	Discharges in surface waters Sector of industry (53°): Liquid products storage of liquid hazardous substances	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	50[2)]	Discharges in surface waters and in public sewage system Sector of industry (55°): Construction of mechanical tools, cold working and surface treatment of metals	It is possible that in some cases a more stringent emission limit is set out in the environmental permit
Belgium (Flemish region)	Cr(VI)	50[3)]	Wastewater Non-ferrous metals industries (BAT-conclusions EU/2016/1032)	
Belgium (Flemish region)	Cr(VI)	50[3)]	Wastewater surface treatment using organic solvents including preservation of wood and wood products with chemicals (BAT-conclusions EU/2020/2009)	
Belgium (Flemish region)	Cr(VI)	50[3)]	Wastewater Ferrous Metals Processing Industry (BAT-conclusions EU/2022/2110)	
Italy	Cr(VI)	200[4)]	Discharges in surface	

			water and sewerage	
Italy	Total Cr	4000	Discharges in sewerage	
Italy	Total Cr	2000	Discharges in surface water	
Luxembourg	Cr(VI)	100 5), 6)	Discharges in wastewater From the purification of gaseous effluents	Industrial wastewater must be treated in the wastewater treatment plant. The effluent from the treatment plant into the receiving watercourse must not exceed the limit values
Luxembourg	Tot Cr	500 1), 5), 6), 7))	Discharges in wastewater From the purification of gaseous effluents	
Slovak Republic	Tot Cr	200 8)	Surface water intended for irrigation	Na
Slovak Republic	Cr(VI)	9 8)	n/a	Immission limit values - general indicators
Slovak Republic	Total Cr	50 8)	n/a	Immission limit values - non-synthetic specific substances relevant for Slovakia (Annex 5) The background concentration values of heavy metals derived for each water body must be added to the values given. The values refer to filtered samples.
Slovak Republic	Total Cr	800 8)	Industrial waste waters and special waters discharged into surface waters Metallurgical industry: Metallurgy of non-ferrous metals	Immission limit values
Slovak Republic	Cr(VI)	100 8)	Industrial waste waters and special waters discharged into surface waters Metallurgical industry: Metallurgy of non-ferrous metals	Immission limit values
Slovak Republic	Total Cr	500 8)	Industrial waste waters and special waters discharged into surface waters	Immission limit values
Slovak Republic	Cr(VI)	100 8)	Industrial waste waters and special waters discharged into surface waters Mechanical and electrical engineering industry: i) Surface treatment of metals and plastics ii) Heat treatments iii) Enamelling iv) Varnishing v) Electronic production, production of galvanic cells	Immission limit values
Slovak Republic	Total Cr	1000 8)	Industrial waste waters and special waters discharged into surface waters Consumer industry: Leather Industry	Immission limit values
Slovak Republic	Cr(VI)	100 8)	Industrial waste waters and special waters	Immission limit values

			discharged into surface waters Consumer industry: Leather Industry	
Slovak Republic	Total Cr	500[8]	Wastewater Incineration and co-incineration plants From flue gas cleaning and are expressed as the mass concentration of unfiltered samples	Immission limit value Incineration and co-incineration plants limit values 95 %/ 30 mg/l, 100 %/45 mg/l The limit values for the pollutant indicators apply to discharges of wastewater from flue gas cleaning and are expressed as the mass concentration of unfiltered samples
Slovak Republic	Total Cr	500[8]	Landfill sites (leachate)	Immission limit values
Spain	Cr and Cr compounds	500[9]	Wastewater From exhaust gas depuration	Unfiltered sample
Spain	Cr(VI)	5[10]	Inland surface water and other surface water	
Spain	Total Cr	50[10]	Inland surface water	
Sweden	Total Cr	3.4[11]	threshold value for "good status" surface water, annual average value for all types of water; inland surface & coastal waters and waters in the transition zone	
Sweden	Total Cr	25[11]	Drinking water Limit value	
Sweden	Total Cr	25[11]	Ground water Threshold value	

Table notes: BAT stands for 'best available techniques.'

Sources: [1] Directive 2010/75/EU on industrial emission; [2] VLAREM II: Order of the Flemish Government of 1 June 1995 concerning General and Sectoral provisions relating to Environmental Safety; [3] VLAREM III: Order of the Flemish Government of 16 May 2014 concerning supplementary General and Sectoral environmental provisions for IED-installations; [4] D. LGS. n. 152, 3 aprile 2006, Allegati alla Parte Terza, Allegato V; [5] Arrêté 1/17/0568 (2020); [6] Arrêté 3/20/0176 (2021); [7] Arrêté 1/23/0620 (2024); [8] Regulation of the Government of the Slovak Republic No. 269/2010 Coll; [9] Royal Decrees 815/2013; [10] Royale Decree 60/2011; [11] Havs- och vattenmyndighetens föreskrifter om klassificering och miljökvalitetsnormer avseende ytvatten natural sources: Krom (sgu.se)

Appendix E: Impact Assessment

E.1. Restriction Options

E.1.1. Modular approach to assessing restriction options

The modular design of the impact assessment allows the decision maker to modify the ROs in order to accommodate various policy views. In particular, the Dossier Submitter designed the analysis so that the LVs and ELVs imposed on different UCs can be 'mixed and matched' to construct permutations of the ROs assessed in the main report. For example, the decision maker may wish to combine the LVs assessed under RO2 with the ELVs assessed under RO1. The result of combining these ROs would be a new option with net impacts between those of RO1 and RO2.[38]

More generally, the impacts can be summarised in a matrix of use categories and LVs or ELVs. Table 40 and Table 41 present these matrices, which can subsequently be used to consider restriction options that have not been assessed in the main report.

Notably, Table 40 does not display impacts for a LV of 5 µg/m^3 because compliance with this LV is already prescribed by the EU BOEL for Cr(VI) and therefore any impact of this LV could not be attributed to this restriction proposal. In addition to impacts expected under the various LVs, the Dossier Submitter also provides an assessment of a full ban on use. This assessment is however tentative because it only comprises direct impacts in the primary markets affected. It must be repeated that knock-on consequences on secondary markets that rely on parts manufactured with the use of Cr(VI) substances will be more than one order of magnitude higher than the primary impacts listed in Table 40.

A total ban on use would mean that companies would no longer emit Cr(VI) to air and water. The emission abatement costs would therefore be eliminated. However, these cost savings would be more than offset by the loss in producer surplus. This goes to show that Table 40 and Table 41 have to be considered together.

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[38] As there are five different LVs and three different ELVs that could be imposed for any of the six UCs, there is a total of 5^6*3 = 46 875 possible combinations. In any of these potential ROs, the decision maker could either allow for or exclude the use of RPE to achieve the LV, making the number of combinations even higher.

Table 40. Impacts per use category assessed for the different occupational limit values and the ban on use

Use category	**1 $\mu g/m^3$**	**0.5 $\mu g/m^3$**	**0.1 $\mu g/m^3$**	**0.01 $\mu g/m^3$**	**Ban on use**
UC 1	Health benefit: €21m Abatement cost: €2m Producer surplus loss: €66m Other welfare costs: €11m	Health benefit: €28m Abatement cost: €15m Producer surplus loss: €249m Other welfare costs: €23m	Health benefit: €33m Abatement cost: €36m Producer surplus loss: €872m Other welfare costs: €79m	Health benefit: €34m Abatement cost: €30m Producer surplus loss: €1.2bn Other welfare costs: €108m	Health benefit: €34m Abatement cost: none Producer surplus loss: €1.8bn Other welfare costs: €164m
UC 2	Health benefit: €21m Abatement cost: €3m Producer surplus loss: €19m Other welfare costs: €6m	Health benefit: €28m Abatement cost: €23m Producer surplus loss: €38m Other welfare costs: €11m	Health benefit: €38m Abatement cost: €70m Producer surplus loss: €469m Other welfare costs: €77m	Health benefit: €40m Abatement cost: €40m Producer surplus loss: €905m Other welfare costs: €149m	Health benefit: €40m Abatement cost: none Other welfare costs: €210m Producer surplus loss: €1.3bn
UC 3	Health benefit: €388m Abatement cost: €86m Producer surplus loss: €831m Other welfare costs: €192m	Health benefit: €516m Abatement cost: €525m Producer surplus loss: €4.7bn Other welfare costs: €567m	Health benefit: €604m Abatement cost: €1.6bn Producer surplus loss: €10.0bn Other welfare costs: €1.2bn	Health benefit: €620m Abatement cost: €882m Producer surplus loss: €18.2bn Other welfare costs: €2.2bn	Health benefit: €621m Abatement cost: none Producer surplus loss: €24.8bn Other welfare costs: €2.9bn
UC 4 (w/ RPE)	Health benefit: €49m Abatement cost: €2m Other welfare costs: €43m Producer surplus loss: €297m	Health benefit: €55m Abatement cost: €6m Other welfare costs: €43m Producer surplus loss: €297m	Health benefit: €63m Abatement cost: €17m Other welfare costs: €64m Producer surplus loss: €755m	Health benefit: €42m Abatement cost: €16m Other welfare costs: €171m Producer surplus loss: €2.01bn	Health benefit: €155m Abatement cost: none Producer surplus loss: €5.0bn Other welfare costs: €428m
UC 4 (w/o RPE)	Health benefit: €110m Abatement cost: €56m Other welfare costs: €92m Producer surplus loss: €638m	Health benefit: €130m Abatement cost: €120m Other welfare costs: €175m Producer surplus loss: €1.2bn	Health benefit: €154m Abatement cost: €187m Other welfare costs: €276m Producer surplus loss: 3.25bn	Health benefit: €155m Abatement cost: €139m Other welfare costs: €340m Producer surplus loss: €4.01bn	Health benefit: €155m Abatement cost: none Producer surplus loss: €5.0bn Other welfare costs: €428m
UC 5	Health benefit: €112m Abatement cost: €6m Producer surplus loss: €361m Other welfare costs: €83m	Health benefit: €133m Abatement cost: €18m Other welfare costs: €158m Producer surplus loss: €685m	Health benefit: €163m Abatement cost: €56m Other welfare costs: €287m Producer surplus loss: €2.14bn	Health benefit: €167m Abatement cost: €54m Other welfare costs: €401m Producer surplus loss: €2.98bn	Health benefit: €167m Abatement cost: none Producer surplus loss: €5.0bn Other welfare costs: €674m
UC 6	Health benefit: €13m Abatement cost: €210k Producer surplus loss: €152m Other welfare costs: €14m	Health benefit: €21m Abatement cost: €1m Producer surplus loss: €203m Other welfare costs: €18m	Health benefit: €21m Abatement cost: €7m Producer surplus loss: €531m Other welfare costs: €23m	Health benefit: €22m Abatement cost: €5m Producer surplus loss: €1.2bn Other welfare costs: €50m	Health benefit: €22m Abatement cost: none Producer surplus loss: €2.3bn Other welfare costs: €114m

Table notes: the quantification of impacts followed the approach outlined in Section 3 of the main report and assumes a 20y impact assessment period.

Table 41. Impacts per use category assessed for the different environmental limit values and the ban on use

Use category	2.5 kg/y to air 15 kg/y to water	0.25 kg/y to air 1.5 kg/y to water	0.025 kg/y to air 0.15 kg/y to water	Ban on use
All UCs	Health benefit: €296m Abatement cost: €127m	Health benefit: €360m Abatement cost: €520m	Health benefit: €380m Abatement cost: €1.37bn	Health benefit: €385m Abatement cost: none

Table notes: the quantification of impacts followed the approach outlined in Section 3 of the main report and assumes a 20y impact assessment period.

E.1.2. Alternative option 1 – Harmonised limit values

To demonstrate how this approach can be applied in practice, the Dossier Submitter has assessed a combination of RO1 and RO2 where the LV is harmonised at 1 µg Cr(VI)/m^3 across all UCs, thus mimicking a generic OEL. The ELVs are set at 2.5 kg Cr(VI)/y for emissions to air and 15 kg Cr(VI)/y for emissions to water. In line with principles of the hierarchy of control, according to which RPE should only be used as last resort, the Dossier Submitter did not account for the possible use of RPE to meet the LV in any of the UCs in the assessment of this alternative option (AO1). Analogous to the impact assessment in the main report, Table 42 summarises the expected impacts of AO1.

Table 42. Response to AO1 with a harmonised LV of 1 µg Cr(VI)/m^3

Use category	Relevant LVs and ELVs	Already compliant			Invest in RMMs	Close/ relocate	Substitute
		Worker	Air	Water			
UC 1	LV: 1 µg Cr(VI)/m^3 ELV$_{air}$: 2.5 kg Cr(VI)/y ELV$_{water}$: 15 kg Cr(VI)/y	72 %			21 %	5 %	2 %
UC 2	LV: 1 µg Cr(VI)/m^3 ELV$_{air}$: 2.5 kg Cr(VI)/y ELV$_{water}$: 15 kg Cr(VI)/y	79 %			18 %	2 %	1 %
UC 3	LV: 1 µg Cr(VI)/m^3 ELV$_{air}$: 2.5 kg Cr(VI)/y ELV$_{water}$: 15 kg Cr(VI)/y	70 %			24 %	6 %	1 %
UC 4	LV: 1 µg Cr(VI)/m^3 ELV$_{air}$: 2.5 kg Cr(VI)/y ELV$_{water}$: 15 kg Cr(VI)/y	55 %			24 %	14 %	8 %
UC 5	LV: 1 µg Cr(VI)/m^3 ELV$_{air}$: 2.5 kg Cr(VI)/y ELV$_{water}$: 15 kg Cr(VI)/y	69 %			18 %	9 %	4 %
UC 6	LV: 1 µg Cr(VI)/m^3 ELV$_{air}$: 2.5 kg Cr(VI)/y ELV$_{water}$: 15 kg Cr(VI)/y	80 %			8 %	8 %	4 %
Total		**68 %**	**87 %**	**96 %**	**22 %**	**7 %**	**2 %**

Source: based on information submitted in response to the CfEs.

Benefits

Across all UCs, health benefits are expected to accrue to directly exposed workers from implementing AO1. As reported in Table 42, the compliance rates with the harmonised LV of 1 µg Cr(VI)/m^3 range from 55 % to 80 %, depending on the use category. The main compliance strategy of companies under this option is to invest in improved RMMs. The reduction in worker exposure in companies that invest in RMMs is expected to equal the difference between baseline exposure and the proposed harmonised LV. Applying the marginal benefit per exposed worker as reported in the main report to non-compliant companies and their directly exposed workers results in a total benefit to workers of ~€472m over the 20-year assessment period.

Directly exposed workers of companies that stop using Cr(VI) substances in response to AO1 will also benefit from a reduction of Cr(VI)-induced cancer risk.[39] AO1 will result in a substantial proportion of companies closing down, relocating or substituting. Worker exposure to Cr(VI) at these sites will be reduced to zero. However, as explained in the main report, if in each use category a significant proportion of the market continues to operate in the EU, then this reduction in exposed workers is expected to be at least partially offset by staff growth at the compliant sites. Therefore, a conservative assumption

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[39] These benefits may be partially or fully offset by health risks related to the workers' new tasks.

is that the reduction in exposure across the EU corresponds again to the difference between the baseline levels and the proposed harmonised LV. Combining this assumption with the numbers of workers at the sites that indicate to cease the use of Cr(VI) substances in response to this option results in a total benefit to workers of €192m over the 20-year assessment period.

The benefits to the general population of AO1 can be monetised by applying the marginal benefit estimate for a 1 kg reduction in Cr(VI) emissions to air/water reported in the main report. The average reduction in releases to air/water due to the ELVs imposed by this option is estimated to be 16 kg/123 kg per year. These reductions occur at 14 %/4 % of the 2 000 Cr(VI)-emitting sites in the EU. As explained in the main report, the average population of the 1x1 km^2 grid cells hosting sites that have notified Cr(VI) uses according to Art. 66 of REACH is 1 600 people. Combining these assumptions suggests that the total benefit of RO1 for the general population amounts to €252m (reduction in releases to air)/€64m (reduction in releases to water) over the 20-year assessment period. However, it might be argued that not everyone living in a 1x1 km^2 grid cell around a site is exposed to Cr(VI) air emissions. Assuming a relevant exposure radius of 500m around the stack, the local population at risk is scaled down by a factor of π/4, decreasing the expected benefit of reducing Cr(VI) releases to air to ~€198m.

Costs

Investment in additional RMMs is the most common response to the harmonised LV proposed under AO1. Scaled to the EU level, this means that ~440 companies across the different use categories would need to invest in order to comply with this option. The marginal abatement cost curves derived in the main report are used to estimate the compliance costs for those companies that intend to invest in RMMs. The total cost to comply with the proposed harmonised LV ranges from €1 800 for UC 6 to €12 800 for UC 3 per directly exposed worker. However, data on the abatement cost for UC 4 not considering the use of RPE to meet the LV is sparse.

A few responses to the CfEs suggest that the abatement cost might be at least one order of magnitude higher if other measures, such as automation, are required to meet the LV. This is line with estimates from a recent AfA[40] of the industrial use of slurry mixtures containing CrO_3 where the cost of automatising a spraying booth was estimated to in the ballpark of €100k per directly exposed worker. For an indicative cost assessment, the Dossier Submitter thus assumed that the abatement cost would be €44k per directly exposed worker—one order of magnitude higher than in the main report (where the use of RPE to comply with the LVs was considered). When multiplied by the expected number of directly exposed workers affected by the investment in further RMMs across all UCs, the compliance costs over the 20-year assessment period amount to €3m (UC 1), €3m (UC 2), €86m (UC 3), €56m (UC 4), €6m (UC 5) and €200 000 (UC 6). The total compliance cost of AO1 is estimated at €151m.

The non-use costs are weighted according to the reported rates of closure/relocation and substitution, and include the expected loss of producer surplus, the expected cost of unemployment and the expected cost of substitution (see the main report). The Dossier Submitter notes that the cost of non-use is at least one order of magnitude higher than the technical compliance cost for all use categories, even if only direct costs incurred by the companies are considered and the social cost of unemployment is ignored.

At the use category level, the reported non-use rates for this option range from 3 % and 6 % for electroplating (UC 2 and UC 3) to almost 30 % for UC 4, which includes spraying,

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[40] See https://echa.europa.eu/applications-for-authorisation-previous-consultations/-/substance-rev/74148/del/200/col/synonymDynamicField_1512/type/asc/pre/3/view.

painting, primers and slurry coating uses. Since the cost of non-use is so much higher than the cost of abatement for the harmonised LV proposed under AO1, the optimal response of companies should be to invest in more effective RMMs whenever technically/financially feasible. Based on the reported non-use rates, the welfare cost of AO1 amounts to ~€2.5bn over the 20-year assessment period. By use category, the non-use costs are highest for UC 4 (€730 million) and UC 3 (€1bn).

Concerning general population exposure, this option proposes ELVs for releases to air and water of 2.5 kg/y and 15 kg/y, respectively. As explained in the main report, around 13 % of all companies using Cr(VI) substances need to invest in more efficient abatement technologies for releases to air and 4 % of companies need to invest in more efficient abatement technologies for releases to water. At the EU level, this corresponds to ~260 companies that would need to reduce their releases to air, and around 90 companies that would need to reduce their releases to water. The corresponding total compliance costs over the 20-year assessment period are ~€86m for air releases and ~€41m for water releases.

Other impacts

Section 3.5 of the main report discusses other impacts that are not assessed quantitatively. Similar to the quantitatively assessed impacts, the qualitatively assessed impacts of AO1 are between those of RO1 and RO2. The closure/relocation rate of companies under this option would be around 7 %, down by 3 % compared to that of RO2. One of the main differences is the higher non-use rate in UC 4. If (as assumed for this option) the use of RPE is not considered for meeting the harmonised LV this non-use rate is >20 %. If, on the other hand, the use of RPE was considered, the non-use rate would drop to ~10 %. UC 4 comprises critical uses that are needed for the maintenance of aircraft, e.g. the slurry coating of engine parts and landing gear parts. Therefore, the proposed option could put pressure on critical aircraft maintenance operations in the EU, which would have negative impacts on the resilience, sovereignty, and strategic autonomy. Table 43 summarises the other impacts expected under AO1 and compares them to those expected under RO1 and RO2.

Table 43. Comparison of qualitatively assessed impacts of AO1, RO1 and RO2

Impact category [1]	**RO1**	**RO2**	**Option**
Climate	o	-	-
Working conditions, job standards and quality	+	++	++
Public health & safety and health system	+	++	+
Conduct of business	o	-	-
Position of SMEs	o	-	o
Sectoral competitiveness, trade, and investment flows	o	-	-
Functioning of the internal market and competition	o	-	-
Employment	o	-	-
Consumers and households	o	o	o
Innovation (productivity and resource efficiency), research (academic and industrial)	o	o	o
Resilience, technological sovereignty, open strategic autonomy, security of supply	o	-	-

Table notes: [1] '--' significant negative impact, '-' mild negative impact, 'o' no or marginal impact, '+' mild positive impact, '++' significant positive impact.

Source: adapted from Chapter 3 of the Better Regulation Toolbox; scoring applies to the 'key questions' listed in Section 4 of Chapter 3.

Proportionality

The health benefits resulting for directly exposed workers are estimated at ~€664m, equivalent to approximately 110 statistical cancer cases avoided. The corresponding compliance cost, i.e. the cost of installing more efficient RMMs, is estimated at ~€152m. However, based on the responses to the CfEs, 9 % of all companies would close down their Cr(VI)-related operations, if they had to comply with the LVs imposed under this option and 22 % of the latter would try to substitute. Considering substitution intentions, the total cost of non-use would be ~€2.45bn. This highlights that non-use is a costly and economically undesirable outcome of restricting the use of Cr(VI) substances. While the non-use rate is smaller compared to RO2, the non-use share of UC 4 is much higher. This is because the use of RPE is not considered to reach the 8h TWA exposure level of the LV.

There is reason to believe that the costs of non-use may be somewhat exaggerated. Based on the responses to the CfEs, the abatement costs are at least two orders of magnitude lower than the costs associated with closure or relocation. In addition, if a non-negligible fraction of competitors have to exit the market that creates opportunities for the companies that can comply with the conditions imposed under this option. Consequently, there is a strong incentive for companies to meet the harmonised LV by implementing additional RMMs if they can.

The health benefit of about €664m under this option may be compared to the restriction-induced job loss by applying the non-use rates reported in the CfEs. Doing so leads to an estimate of ~3 200 jobs lost and an aggregate cost of unemployment of ~€400m. However, the Dossier Submitter expects that some of the affected jobs would move to EU companies that can comply with the conditions of option and thus stay in the market. The net impact on employment is therefore likely to be smaller.

Notwithstanding the worker benefits, many companies would have to close down or make substantial investments to find alternatives that are safer. The estimated producer surplus loss resulting from AO1 is ~€2.05bn. Although this figure may be somewhat exaggerated due to a possible selection bias in the CfEs, it is likely that, based on standard cost-benefit reasoning, this option is not proportionate. This is because the aggregate net benefits to workers are not going to offset the costs incurred by the companies using the Cr(VI) substances. Ultimately, the question of proportionality boils down to distributional preferences—if impacts on workers are given more weight in the decision than impacts on businesses, then this option could still be considered proportionate.

AO1 also proposes ELVs that would be imposed for all use categories. The health benefit associated with these ELVs would be ~€296m, while the cost of more efficient release control for the companies concerned is estimated at ~€127m. From these figures it can be concluded that compliance with the harmonised LV and ELVs proposed under AO1 is proportionate for those companies for which it is technically possible to reduce Cr(VI) exposure of workers and Cr(VI) emissions to air and water.

The quantified impacts of AO1 are summarised in Table 44. Taking all aspects into consideration, and paying due attention to worker safety, the Dossier Submitter notes that this option may be a proportionate restriction option, if the decision maker places more weight on the health and safety of workers compared to the detrimental impacts on employment and the economy. The main difference is between AO1 and RO2 is that for all but UC 4, it is easier to comply with AO1. For UC 4, it is more difficult to comply with AO1 than with RO2 despite the lower LV imposed by the latter. This is because RPE correction was not applied under AO1 to calculate the 8h TWA exposure. Due to relatively high non-use cost for operators in UC 4, the aggregate cost of AO1 is not much lower than that of RO2. Another difference to RO2 results from the less strict ELVs imposed under AO1. This has a positive economic impact on the NPV of AO1.

Table 44. Proportionality of AO1 and comparison to RO1 and RO2

Impact category	**RO1**	**RO2**	**AO1**
Workers (LV compliance), monetised health benefit	€24m	€532m	€472m
Workers (redundant), monetised health benefit	€11m	€179m	€192m
Population at the vicinity of sites, health benefit	€296m	€360m	€296m
Total monetised benefits over 20y-assessment period	*€331m*	*€1.07bn*	*€0.96bn*
Workers (redundant), monetised cost of unemployment	€21m	€433m	€397m
Companies, abatement cost, workers	€3m	€171m	€152m
Companies, abatement cost, releases	€127m	€520m	€127m
Companies, costs of non-use	€170m	€2.12bn	€2.05bn
Total monetised costs over 20y-assessment period	*€314m*	*€3.23bn*	*€2.73bn*
Net benefit	***€10m (= €331m-€314)***	***-€2.17bn (= €1.07bn-€3.23bn)***	***€-1.77bn (= €0.96bn-€2.73bn)***
Summary of key impacts assessed qualitatively	RO1 is a step towards better standards for occupational and environmental health and safety but has no significant negative impacts that deserve mentioning.	RO2 entails both positive and negative impacts; on the benefit side, there are positive impacts for health (workers and general public); mild negative impacts are expected in terms of climate, SMEs, business profitability & competitiveness. In terms of worker protection, the health benefits are expected to be larger than the estimated cost of regulation-induced unemployment.	AO1 entails both positive and negative impacts; on the benefit side, there are positive impacts for health (workers and general public); mild negative impacts are expected in terms of climate, SMEs, business profitability & competitiveness. There could be some issues related to UC 4, and the strategic autonomy of some important maintenance work of aircraft. In terms of worker protection, the health benefits are expected to be larger than the estimated cost of regulation-induced unemployment.
Dossier Submitter's conclusion	**Proportionate**	**May be proportionate**	**May be proportionate**

E.1.3. Alternative option 2 – Broad ban on use

The Dossier Submitter observes that the lowest LV of 0.01 µg Cr(VI)/m^3 assessed under E.1.1, which corresponds to the lower ELR level of 4E-5 proposed by the Advisory Committee on Safety and Health at Work, would result in non-use rates ranging from 44 % (in UC 6, where many uses are fully enclosed) to around 80 % for UC 4 (assuming that the use of RPE to meet the LV is accounted for). For electroplating (UCs 2 and 3), about 75 % of sites would have to close their Cr(VI)-based operations. The remaining 25 % of sites indicated in the CfEs that they would try to comply through automation and enclosure of activities that entail exposure.

While a non-negligible fraction of the users indicated they could comply with a LV of 0.01 µg Cr(VI)/m^3, it is not meaningful to assess an even lower LV because this would inevitably result in monitorability and enforceability issues as the current limit of detection of Cr(VI) in air is close to 0.01 µg Cr(VI)/m^3. Instead, the Dossier Submitter assessed the impacts that would result from a *ban* on all uses of the Cr(VI) substances in the scope of this Annex XV restriction proposal.

For analytical reasons it is not relevant how exactly such a ban would be implemented. Therefore, the Dossier Submitter treats the ban as an abstract concept and does not elucidate through which mechanisms it would be imposed. However, it should be noted that the design of an actual ban raises several practical questions that would have to be considered. Abstracting from these complications, one can still generically assess the consequences of entirely ceasing the use of Cr(VI) substances covered by this restriction proposal. In the following, the Dossier Submitter will refer to this scenario as alternative option 2 (AO2).

AO2 would eliminate the exposure of workers and the general population to Cr(VI). Accordingly, there would be health benefits for both workers and the general population living in the vicinity of the sites where Cr(VI) substances are currently used. The methodology for estimating the health benefits is explained in Section 3.1.4 of the main report. Applying this methodology, one finds health benefits for workers in the order of €1.04 billion over the 20-y impact assessment period. Compared to the most stringent restriction option assessed in the main report (RO3), the health benefits for workers and the general population are ~€120m and ~€5m larger, respectively.

As for the costs of AO2, the direct consequences are relatively straightforward to estimate. As Cr(VI) substances could not be used anymore, there would be no compliance costs for companies. All of the ~2 000 companies in the EU would have to cease using the substances. The cost of non-use can be estimated using the same methodology as explained in Section 3.1.2 of the main report. The costs of non-use are pegged at ~€45bn over the 20-y impact assessment period. This cost is €33 billion larger than that of RO3, and €42bn larger than that of RO2.

These figures only account for direct impacts. The Dossier Submitter analysed other impacts of restriction proposals in a qualitative manner in Section 3.5 of the main report. In that regard, AO2 would entail a positive impact on working conditions, job standards and quality, and public health and safety (at least inside the EU). As assessed above, the incremental benefits beyond those provided by RO3 are limited. In all other categories, the impacts would be highly negative. A large proportion of companies using Cr(VI) substances in the EU are SMEs and the vast majority of them would have to close down their business if they could no longer use Cr(VI) substances. In terms of unemployment, the Dossier Submitter estimates that ~37 000 workers directly handling Cr(VI) substances would be made redundant. However, the Dossier Submitter expects that knock-on impacts throughout complex and integrated supply chains would be even more severe.

Eventually, consumers would be adversely affected by both a deterioration in the quality and the price/availability of certain products on the EU market. Under AO2, the production of such goods would move outside the EU (with little hope that users of alternative technologies in the EU could size capture sizeable market shares because existing alternatives entail higher production costs as discussed in Section 3.1.2 in the main report). This would have a detrimental impact on the strategic autonomy of the Union. In terms of resilience, sovereignty, open strategic autonomy and security of supply, the most critical UCs are 3, 4 and 5. Most importantly, under AO2, the maintenance of aircraft and other means of transportation would no longer be possible and the availability of spare parts for critical industries could become dependent on imports.

Table 45 summarises both the quantitative and qualitative impacts for the purpose of assessing the proportionality of AO2. As the benefits to workers and the general population are only slightly greater than under RO3, but AO2 entails almost four times the costs of RO3 and would have drastic impacts on the resilience, sovereignty and autonomy of the EU, the Dossier Submitter discarded AO2 as a non-viable restriction option.

Table 45. Proportionality of AO2 and comparison to RO1 and RO2

Impact category	**RO2 (for comparison)**	**RO3 (for comparison)**	**AO2**
Workers (LV compliance), monetised health benefit	€532m	€571m	-
Workers (redundant), monetised health benefit	€179m	€346m	€1.04bn
Population at the vicinity of sites, health benefit	€360m	€380m	€385m
Total monetised benefits over 20y-assessment period	*€1.07bn*	*€1.30bn*	*€1.43bn*
Workers (redundant), monetised cost of unemployment	€433m	€1.04bn	€4.6bn
Companies, abatement cost, workers	€171m	€872m	-
Companies, abatement cost, releases	€520m	€1.37bn	-
Companies, costs of non-use	€2.12bn	€8.85bn	€40bn
Total monetised costs over 20y-assessment period	*€3.23bn*	*€12.05bn*	*€44.6bn*
Net benefit	***-€2.17bn (= €1.07bn-€3.24bn)***	***-€10.83bn (= €1.30bn-€12.13bn)***	***-€43.17bn (= €1.43bn–€44.60bn)***
Summary of key impacts assessed qualitatively	RO2 entails both positive and negative impacts; on the benefit side, there are positive impacts for health (workers and general public); mild negative impacts are expected in terms of climate, SMEs, business profitability & competitiveness. In terms of worker protection, the health benefits are expected to be larger than the estimated cost of regulation-induced unemployment.	RO3 entails more significant negative impacts outweighing the positive impacts; while health benefits for workers and the general public are notable, they are to be balanced against significant negative impacts for the EU economy (SMEs, competitiveness, unemployment, knock-on impacts), climate (increase in GHG) and resilience and sovereignty.	AO2 entails significant negative impacts that outweigh the positive impacts; while it offers slightly larger health benefits for workers and the general public slightly, they must be balanced against severely negative impacts for the EU economy (SMEs, competitiveness, unemployment, knock-on impacts), the climate (increase in GHG), and EU resilience and sovereignty.
Dossier Submitter's conclusion	**May be proportionate**	**Not proportionate**	**Not proportionate**

E.1.4. Alternative option 3 – Ban on functional uses of Cr(VI) substances with decorative character

In the main report, the Dossier Submitter explained its approach to categorising the uses of the Cr(VI) substances in scope. However, during the investigation it became clear that the decision maker might need additional information on so-called "functional uses of Cr(VI) substances with decorative character." In an attempt to accommodate this need, the Dossier Submitter included a tentative assessment of the impact of banning "functional uses of Cr(VI) substances with decorative character." As will become clear from the discussion, the results of this assessment have to be interpreted with caution.

To start, the Dossier Submitter observes that all applicants seeking authorisation for such uses have indicated that the decorative character is complementary to the functional properties achieved by the substance use. It would therefore be challenging to define the boundaries of a use category solely based on decorative features, which vary widely across the tens of thousands of parts that are electroplated. The Dossier Submitter considers that setting such boundaries is not a scientific task, but a policy choice. In the absence of a legal definition of "decorative character" or of detailed instructions as to what may be the inclusion criteria of such a category, the Dossier Submitter assesses a ban on "functional uses of Cr(VI) substances with decorative character" based on the self-reported decorative character in the use descriptions of certain AfAs.[41]

In concrete terms, this scenario – to which the Dossier Submitter will refer as alternative option 3 (AO3) – entails a ban on all uses that belong to use category 2 (based on the available information electroplating on plastic substrate always has an aesthetic aspect[42]) and on the activities of those companies that electroplate metal substrate to achieve, among others, a decorative function. In other words, the Dossier Submitter considers that "functional uses with a decorative character" only occur in electroplating and therefore belong, i.e. they belong to the use categories 2 and 3 defined in the main report.

A key challenge in the assessment of AO3 is then to approximate the proportion of companies operating in use category 3 that would be affected by a ban on "functional uses of Cr(VI) substances with decorative character." As no such information was collected during the CfEs, the Dossier Submitter turned to the confidential version of the substitution plan of the Hapoc AfA (AFA-C-2114328834-45-01/F), which seeks to cover 124 named companies that use Cr(VI) substances for various surface treatments. Out of the 124 companies, 117 companies indicated that they used Cr(VI) substances for either purely functional electroplating or functional in electroplating with decorative character, or both. Table 46 summarises the proportions of companies engaged in functional plating and/or functional plating with decorative character.

Table 46. Indicative proportions of companies that do functional electroplating and/or functional electroplating with decorative character

	Functional *and* functional with decorative character	**Only functional**	**Only functional with decorative character**
All electroplating	117 (100 % of the sample)		
- **Functional**	93 (80 % of the sample)	78 (67 % of the sample)	--
- **Functional with decorative character**	38 (33 % of the sample)	--	23 (20 % of the sample)

Source: Computation based on the confidential version of the substitution plan of the Hapoc AfA (AFA-C-2114328834-45-01/F).

In the absence of better information, the Dossier Submitter employs these proportions for the indicative assessment of the impacts of AO3 on companies in UCs 2 and 3. Based on this sample of electroplaters, the following assessment of the impact of a ban on Cr(VI)

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[41] As explained in Section 1.3.2 of the main report, the Dossier Submitter took a different approach to categorise uses. Accordingly, the CfE were designed differently and do not contain information regarding aesthetics, haptics or any other criterion necessitating value judgments.

[42] All applicants for electroplating on plastic substrate have indicated that, in addition to providing functional properties to the parts plated, the use has a decorative character (see also Section 1.3.2 of the main report).

substance used for "functional electroplating with decorative character" can be made.

- Overall, there are ~1 200 plating shops in the EU that use Cr(VI) substances, out of which ~100 plating shops (i.e. 8 %) plate plastic substrate
- Based on Table 46, ~240 plating shops (i.e. 20 %) do only functional electroplating with decorative character on both metal and plastic substrates
- Assuming that electroplating on plastics always has a decorative character (in addition to other functions provided by the coating), there are ~140 plating shops (i.e. 12 %) that do functional electroplating with decorative character on metal substrates only
- Based on Table 46, ~160 plating shops (i.e. 13 %) do functional electroplating with and without decorative character on metal substrates
- The remaining 800 plating shops (i.e. 75 %) do functional electroplating on metal substrates without decorative character

Consequences on companies in UC 2

For the 100 plating shops that make up the companies covered by UC 2, the expected impact of AO3 is the same as for AO2. In fact, the Dossier Submitter assumed 4 years of profit loss for the proportion of companies that indicated in the CfEs that they would not be able to substitute (77 % of companies in UC 2). The resulting loss in producer surplus is due to the premature retirement of productive capital. It should be noted though that this implies that about 80 % of this capital will be reinvested in similarly productive means. Whether this happens inside or outside the EU cannot be predicted.

For companies that intend to substitute (23 % of companies in UC 2), an investment cost of around €0.5m will be incurred. These assumptions are based on the actual costs incurred by a few companies that have already substituted Cr(VI) substances in electroplating on plastic substrate and reported the associated investment in the CfEs (see Appendix E.3.2). The same companies also reported an increment in operative costs of ~10-20 %, which casts doubt on the economic viability of such substitution intentions.

Ignoring this increase in the operative costs, the Dossier Submitter estimates a total producer surplus loss of €1.12bn. In addition, at least 1 600 workers occupied in companies belonging to UC 2 would lose their job, resulting in welfare costs of ~€210m. These can be compared against the expected health benefits to workers that are no longer exposed to Cr(VI), which amount to ~€40m.

Consequences on companies in UC 3

The impact of AO3 on the ~300 plating shops that do functional electroplating with decorative character on metal substrates depends on whether they also do functional plating without decorative character. For the ~140 companies that do only functional electroplating with decorative character, it can be expected based on the responses in the CfEs that only 10 % will seek to substitute, while the other 90 % will close. To gauge the impact on the former, the Dossier Submitter followed the same logic as above and assumed 4 years of profit losses. As for the companies that seek to substitute, the Dossier Submitter notes that only two metal platers indicated in the CfEs that they had successfully substituted Cr(VI) substances in their electroplating operations. On average, their substitution cost was close to €4.4m, which will be used here to assess the impact of a ban on companies that find economically viable alternatives. For the ~160 companies that do functional electroplating with and without decorative character on metal substrates, the Dossier Submitter assumes that they continue their functional plating business but lose

20 % of their turnover (and profit) over two years.

Taking all these factors into account, the total producer surplus loss of AO3 for companies in UC 3 amounts to €5.30bn. In addition, at least 6 300 workers occupied in companies belonging to UC 2 would lose their job, resulting in welfare costs of ~€780m. These can be compared against the expected health benefits to workers that are no longer exposed to Cr(VI), which amount to ~€162m. Table 47 summarises both the quantitative and qualitative impacts for the purpose of assessing the proportionality of AO3. On the basis of this tentative impact assessment, and notwithstanding the enforceability issues that a ban on functional electroplating with decorative character would bring about, the Dossier Submitter discarded AO3 as a non-viable restriction option.

Table 47. Proportionality of AO3

Use category	**# of companies**	**Benefits to workers**	**Costs**
UC 2	~100	€40m	Producer surplus loss: €1.12bn Other welfare costs: €210m
UC 3	~140 (only decorative) ~160 (both decorative and functional)	€162m	Producer surplus: €5.30bn Other welfare costs: €780m
Total	~400	€214m	€7.42bn
Dossier Submitter's conclusion	**Not proportionate**		

E.2. Analysis of Alternatives

The information presented in this section gives an overview of alternatives to various uses of Cr(VI) substances that the Dossier Submitter identified from different sources. In particular, the overview includes those alternatives that were identified as most promising or shortlisted in the analysis of alternative submitted as part of the Cr(VI) AfAs received and processed by ECHA. Where review reports have been submitted by authorisation holders, the most recent information was used. This sometimes meant discarding potential alternatives that had been identified in the original application but dismissed as not feasible in the review report. Where relevant, the information has been complemented with information from other sources such as:

- Data submitted to ECHA during both the CfE and in bilateral discussions with stakeholders
- Data submitted as part of the reporting by downstream users covered by granted authorisations [43]
- Information from general literature and reports

Below, information on the hazard classification of the substances identified in these information sources is reported in form of summary tables at the end of each section. This information was extracted from the ECHA database by the Dossier Submitter. In these summary tables, the name of the substance may differ from the name used in the AfAs as the Dossier Submitter used the name retrieved from the ECHA database. Substances that are not registered under REACH, have harmonised classifications as CMR 1, 2, Resp. Sens. 1, STOT RE 1, have been identified as SVHCs or contain a critical raw material as per the

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[43] See Downstream uses covered by granted authorisations - ECHA.

5th list of critical raw materials for the EU[44] are flagged in the summary tables.

E.2.1. Alternatives to the formulation of chromium acids and speciality mixtures made from various Cr(VI) substances

At the formulation stage, the Cr(VI) substance itself does not exert any specific function. For this reason, an analysis of alternative is not meaningful. No alternatives have therefore been identified for this use type.

E.2.2. Alternatives to Cr(VI) electroplating

Electroplating with Cr(VI) substances is the most common utilisation (in terms of users) in the scope of this restriction proposal. Electroplating can be done on both metal and plastic substrate. Although the plating process as such is the same regardless of the substrate, there are a number of important differences between electroplating of plastic parts and of metal parts.

1) Conductivity: Metal substrates are conductive, which makes them inherently suitable for electroplating since they can carry the electrical current needed for the process. Plastic substrates are non-conductive, so they require additional steps to make the surface conductive before it can be electroplated. This often involves applying a conductive coating or sublayer to the plastic.

2) Preparation of surfaces: Metal surfaces usually undergo cleaning, degreasing, and sometimes pickling to remove oxides and contaminants and to ensure good adhesion of the electroplated layer. The preparation of plastic substrates is more complex. It typically involves etching the surface of the plastic part to create micro-roughness for better adhesion, followed by sensitisation and activation steps to deposit a thin conductive layer before the actual chrome plating is performed.

3) Adhesion: Achieving strong adhesion is generally easier on metal substrates since the electrochemical bonding of the chrome layer happens directly on the metal substrate. Ensuring good adhesion on plastics is more challenging due to the inherently different nature of the substrate and the need to create a compatible interface between the plastic part and the chrome layer.

4) Function: Electroplating on metals is commonly applied for functional purposes such as corrosion resistance, wear resistance, and electrical conductivity, as well as for decorative finishes. Electroplating on plastics is used in applications where weight reduction is relevant (e.g. in automotive parts, sanitary applications, consumer electronics, and household fixtures), while a metallic finish is desired. Plastic plating typically has a decorative aspect, whereas the same cannot be said for metal plating.

From the above, it is clear that while the end goal of achieving a metallic finish is similar, the processes and challenges involved in the electroplating of metal substrates versus plastic substrates are significantly different due to the inherent properties of the substrates and the wide range of uses of the plated parts. In addition, as is explained in the description of potential alternatives to Cr(VI) electroplating, the range of such alternatives is limited for plastic plating. Of the eleven potential alternatives technologies identified, only four are applicable to plastic substrates. This difference indicates that progress towards substitution is more advanced for plastic substrates than for metal substrates.

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[44] See Critical raw materials - European Commission.

As the differences are decisive for the socio-economic impact of a restriction under REACH, the Dossier Submitter assessed the impact of the restriction options on two separate use categories – use category 2 comprises Cr(VI)-based electroplating on plastic substrate, while use category 3 comprises Cr(VI)-based electroplating on metal substrate. This categorisation is further supported by the difference in substitution intentions in response to a ban. As reported in Appendix E.1.3, twice as many plastic platers (23 %) as metal platers (11 %) are expected to substitute in response to a ban on use.

However, as the technical plating process is similar regardless of the substrate and as there is an overlap in the potential alternatives applicable, it appears more meaningful to assess the alternatives to Cr(VI)-based electroplating without considering the final use of the plated parts, while acknowledging the technological differences between the two substrates, where relevant. Whether or not a specific alternative may be suitable for substituting the use of a Cr(VI) substance will depend on multiple factors, including technical, economic and safety aspects. Based on the companies' best responses to the proposed limit values documented in Appendix E.3, it is however foreseeable that substituting Cr(VI) in the electroplating of plastic parts is more often feasible than in the electroplating of metal parts.

E.2.2.1. Cr(III)-based electroplating (with/without nickel undercoating)

Technology

This alternative has been identified for both metal and plastic substrates. The technology relies on an electroplating process and is therefore conceptually similar to Cr(VI)-based electroplating. It uses trivalent chromium electrolytes instead of hexavalent chromium to deposit a layer of metallic chromium on the workpiece. There is virtually no difference between the two options (with or without nickel undercoating) except from the introduction of a nickel undercoating in the former. This underlayer can be used to overcome the issues related to macro cracking and achieve higher corrosion protection or, for plating on plastics, to ensure that a conductive sublayer is deposited before the chromium layer can be deposited. The deposition rate is slower with Cr(III) than with Cr(VI).

Although the basic technology is very similar to Cr(VI)-based electroplating, the transition requires modifications to the process line/equipment used. For instance:

- Additional (or different type of) pre-treatment step (pickling/etching) seems to be required in some cases

- Anodes: mixed metal oxide or graphite anodes must be used instead of lead anodes

- Electrolyte solution: due to a more complex composition and a lower concentration of chromium, the electrolyte is more sensitive to impurities; additional analytical efforts, additional rinses (pre and post treatment) and ion exchanger are required. At least part of the impurities can come from the substrate of the workpiece, making e.g. brass a difficult substrate to plate with Cr(III)-based solutions

- Electrical current: modifications required to the rectifiers used – pulse-reverse

- Modification required to the wastewater treatment plant due to the different chemistry used in the electrolyte

- In some applications, an additional heat treatment is required to achieve comparable hardness

Risk reduction potential

Substituting Cr(VI) substances by Cr(III) substances represents a shift away from a non-threshold carcinogen. However, the substances commonly used in Cr(III)-based electroplating including chromium chloride, basic (EC 256-852-0) and dichromium tris(sulphate) (EC 233-253-2) are potent skin sensitisers. In addition, data is currently generated to assess their potential for reproductive toxicity and endocrine disruption. See ECHA's recent assessment of regulatory needs for 'Simple chromium compounds.'[45]

In case of plating on plastic, it should be noted that Cr(VI) is also used in the etching step during the pre-treatment of the plastic substrate (discussed under other surface treatments). Therefore, substitution of the substance during this step is also necessary to ensure the full transition to a Cr(VI)-free process.

Cr(III)-based electroplating often requires the use of boric acid (EC 233-139-2) as a buffer in the solution, which is an identified SVHC. In addition, if a nickel underlayer is used to improve corrosion protection of the coated part, this implies the use of another carcinogen.

Technical feasibility

Some companies have reported to have successfully switched to a Cr(III)-based plating process, at least for a part of their products. However, depending on the source consulted, the technical readiness level reported for this alternative varies between TRL 3 and TRL 5 and many companies explain that they encounter difficulties in the implementation of the alternative and need more time to continue/complete testing or validation activities or to address issues related to loss of performance compared to Cr(VI).

The specific performance loss depends on the type of product plated. Some examples include poor adhesion of the plated layer on the workpiece, insufficient hardness, corrosion protection or abrasion protection, issue with throwing power of the solution[46] resulting in areas of the workpiece poorly or not plated at all.

For applications where the decorative character of the plated parts plays an important role, users have reported that it is difficult to ensure consistency in the optical properties and colouring achieved with Cr(III)-based plating. This is a major issue from the perspective of customer acceptance.

Development of 'second generation' electrolytes (boric acid free) has been reported by applicants for authorisation but still requires work. Estimates are difficult but for the A&D sector the information received indicates technical readiness by 2036 at the earliest. Once the different issues are solved, time will also be needed for the transition itself. Moreover, sufficient market availability is questioned by many users of Cr(VI).

Suppliers of Cr(III) plating electrolytes claim that solutions with a nickel underlayer (i) provide comparable or better technical performance for certain applications, (ii) have been accepted and validated by multiple OEMs (including automotive), and (iii) have been used for many years already. These suppliers also argue that the continued availability of Cr(VI) solutions (supported by authorisations granted for continued use) hinders substitution.

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[45] https://echa.europa.eu/documents/10162/1f5bd7fc-977b-923f-3b2c-85ce20216553, PACT - Public Activities Coordination Tool - ECHA.

[46] Measure of an electroplating solution's ability to plate to a uniform thickness over an irregularly shaped cathode (Throwing Power).

Economic viability

In addition to the costs incurred by the necessary modifications to the process, these changes in line/equipment may be possible for some users in the same plant but in other cases, building a new facility may be required.

E.2.2.2. Electroless Nickel plating[47]

Technology

This alternative has been identified for both metal and plastic substrates. This technology relies on an electroplating process and is therefore conceptually similar to Cr(VI)-based electroplating (Loto 2016). Instead of chromium, it deposits nickel alloy (either phosphorus or boron) on the surface of the part to be coated. The reduction of the metal cations in solution to metallic is achieved by purely chemical means, through an autocatalytic reaction promoted by heat (the bath is typically heated to a temperature of about 85-95°C). This creates an even layer of metal regardless of the geometry of the surface. The source of nickel is typically nickel chloride (EC 231-743-0) or nickel sulphate (EC 232-104-9). The nickel deposit usually consists of nickel-phosphor (Ni-P) or nickel-boron (Ni-B) alloys. Co-deposition of composite materials in the alloy is also possible to improve the properties of the coating.

Because the metal deposition in electroless plating is driven by chemical reactions rather than by means of an electrical current implies that in addition to the source of nickel, the bath solutions contain additives (e.g. reducing agents, chelating agents, stabilisers, etc.) to promote the deposition and to regulate the solution. Boric acid (EC 233-139-2) is commonly used as a buffer agent to control pH. The impact of this more complex chemistry is that the bath is generally more difficult to handle/maintain than a Cr(VI)-based electroplating bath. The wastewater treatment must also be designed to handle the different additives. Additional post-treatments may be used, e.g. passivation to further improve the corrosion resistance or heat treatment to improve the hardness.

Risk reduction potential

This potential alternative uses nickel compounds that are classified as carcinogenic. In addition, boric acid (commonly used as a buffer in the solution) is an identified SVHC.

Technical feasibility

Some companies have reported that while electroless nickel is a well-established process used within many industries, it is not a solution that can be used for all components in all applications. Major issues seem to arise with parts that require a combination of corrosion resistance, hardness and wear resistance. Although hardness, can be improved with an additional heat treatment, this has been reported to reduce the corrosion resistance of the coating.

Other technical issues reported include insufficient adhesion to the substrate due to the low elasticity of the coating or, for applications on gun barrels, a too low melting point of the nickel-phosphorous alloy (1 000°C) to withstand extremely high temperatures generated during firing and an insufficient chemical resistance against nitrogen oxides formed during firing.

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[47] Electroless nickel plating – everything you need to know (surfacetechnology.co.uk), Electroless nickel-phosphorus plating - Wikipedia.

For applications where the decorative character of the plating plays an important role, users have reported that the slightly yellow appearance of the coating is an issue for customers that expect the bright silvery-bluish appearance achieved with Cr(VI) electroplating.

Economic viability

Electroless nickel plating is a mature, well-established and commercially recognised process, with a number of companies supplying the coating solutions and equipment required for the process. The operative costs are reported to be higher than that of Cr(VI) plating, even without the use of electricity.

E.2.2.3. Nickel (alloy) electroplating (with or without co-deposited particles)

Technology

This alternative has been identified for metal substrates only. The technology relies on an electroplating process and is therefore conceptually similar to Cr(VI)-based electroplating. In nickel electroplating, the source of nickel comes from soluble nickel salts contained in the electrolyte and from the anodes themselves. There are different types of electrolytes available with variations in chemistry depending on the type of application. The Watts electrolyte, which combines nickel sulphate, nickel chloride and boric acid, is particularly used in decorative but also in functional electroplating. Additives are used to change the properties or appearance of the coating (e.g. to produce bright or semi-bright nickel coatings). Nickel sulphamate solutions are mostly used for the deposition of functional coatings and for electroforming. Other types of solutions exist for specific applications, but their use is relatively limited.[48]

In terms of nickel alloy electroplating, Ni-P electroplating is extensively used employed in engineering is and usually carried out in an aqueous electrolytic bath that contains Ni2+ ions as a source of nickel and a phosphorus oxyacid (or its salt) as a source of phosphorus (Lelevic and Walsh 2019). Ni-P coatings generally have mechanical and tribological properties which confer protection against corrosion and wear. Hardness of the coating can be improved by heat treatment. Co-deposited particles can also improve the wear resistance of the deposited coating.

Risk reduction potential

This potential alternative uses nickel compounds that are classified as carcinogenic. In addition, boric acid (EC 233-139-2) used as a buffer in the solution is an identified SVHC.

Technical feasibility

Although nickel (alloy) electroplating is a well-established and commercially available process, companies have reported that it is not suitable as a general alternative for functional chrome plating. Contamination with metal impurities also seems to be an issue for nickel-plating solutions.

Companies have reported issues related to insufficient hardness, abrasion resistance or antiadhesion properties, especially with plain nickel electroplating. Companies also reported having difficulties to establish a reliable process to achieve a good layer of reproducible quality (thickness, hardness, etc). Generally, it was concluded that additional

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[48] Nickel plating handbook, Nickel Institute.

R&D and time for qualification is needed for most applications that are currently done with Cr(VI) plating.

Economic viability

In addition to changes required in the installation, companies have reported that nickel/nickel alloy plating has higher operative costs than Cr(VI) electroplating.

E.2.2.4. Nanocrystalline Cobalt-Phosphorous alloy coating

Technology

This alternative has been identified for metal substrates only. The technology relies on an electroplating process and is therefore conceptually similar to Cr(VI)-based electroplating. Nanocrystalline cobalt phosphorous alloy (nCoP) coatings are electrodeposited in an aqueous bath process using pulse plating technology. Controlled deposition of nano-grains is enabled through the pulse technology, resulting in an ultra-fine grain structure throughout the entire coating from the substrate surface.[49]

Risk reduction potential

This potential alternative uses cobalt (II) dichloride (EC 231-589-4) is identified as a SVHC for carcinogenic and toxic for the reproduction.

Technical feasibility

Although presented in some sources as a technology performing better than Cr(VI) electroplating[49], companies have reported issues with insufficient hardness and non-stick property. Heat treatment might be an option to improve the hardness, but not when heat sensitive substrates are used (e.g. aluminium, high strength steel).

Economic viability

Issues of commercial and intellectual property have been reported to prevent further development of this technology.

E.2.2.5. Case hardening

Technology

This alternative has been identified for metal substrates only. Case hardening is a metallurgical technique that enhances the surface hardness of metal parts, creating a hard, wear-resistant layer while preserving a softer, more flexible core. The process generally combines the introduction of an element/substance into the surface layer of the substrate with heat treatment (quenching). The choice of element/substance is done according to its ability of creating interstitial hardening in the crystal lattice of the substrate.

Different types of case hardening exist e.g. carburising, nitriding, nitrocarburizing, boriding, etc. and different types of application techniques have been developed (gas, salt-

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[49] Electrodeposition of Nanocrystalline Cobalt-Phosphorus Coatings as a Hard Chromium Alternative for Use in DoD Acquisition Programs | Products Finishing.

bath, plasma, vacuum etc.).[50] Process temperatures vary (~500 to ~1 000°C) and quenching may occur before or after the saturation step, depending on the process used.

Risk reduction potential

This alternative seems to constitute a shift to less hazardous substances. However, depending on the type of process, the use of hazardous substances has been reported (e.g. sodium or potassium cyanate).

Technical feasibility

One company has reported to have moved to a nitriding process for part of their products (hydraulic cylinders) but that this was not possible for their whole product range. Generally, the literature reports that although the technology has evolved over the last twenty years, issues of stresses and strains after hardening have not been solved fully and will require additional work (Wołowiec-Korecka 2023).

Suppliers of liquid nitrocarburizing + oxidizing technology indicate that the process can be operated on all ferrous materials, from cast iron to high alloyed steels, including Ni-based materials. They explain that these processes bring similar or better characteristics to the parts treated provide increased durability and usable lifetime to the plated components.

Economic viability

The equipment needed is completely different from what is used in Cr(VI) plating. Therefore, suppliers of liquid nitrocarburizing explain that a full refurbishment of the existing equipment or a new line of surface treatment is required but that the process is available through different business models, (jobbing, technology transfer).

E.2.2.6. Physical vapour deposition

Technology

This alternative has been identified for both metal and plastic substrates. Physical Vapor Deposition (PVD) is a process in which matter is vaporized from a solid or liquid source, transported as vapor through vacuum or low-pressure gaseous environment and condensed on a substrate.[51] PVD can be divided into different categories:

- Vacuum evaporation/deposition: a PVD process in which the atoms or molecules from a thermal vaporization source reach the substrate without collisions with residual gas molecules in the deposition chamber (Mattox 2010)
- Sputter deposition: this method deposits a thin film by ejecting material from a target or source, which deposits on a substrate. Sputter-deposited layers exhibit better adhesion than layers deposited by other methods but because of the energetic particles involved, they may cause lattice disorder[52]
- Ion plating: this process is applied in evaporation or sputtering to improve the film adhesion or influence the morphology. It provides a high energy flux (ion beam) to

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[50] Nitrocarburizing and Carbonitriding ThermalProcessing-201707-CaseHardening.pdf, Hardening Options for Steel: Through Hardening vs. Nitriding vs. Carburizing vs. Induction (sullivansteel.com), Nitrocarburising - Case hardening without subsequent hardening operation (bodycote.com).

[51] Physical Vapor Deposition - an overview | ScienceDirect Topics.

[52] Sputter Deposition - an overview | ScienceDirect Topics.

the surface, increasing its temperature which enhances the surface diffusion and the possible chemical reactions. However, due to the ion energies, it can also increase the defect concentration, at the interface and on the surface[53]

For applications where the decorative character of the coating plays an important role, PVD is generally used in combination with one or more lacquer coatings.

Risk reduction potential

The coating is prepared in a closed system, so it is not expected that there is any exposure during its application. However, the materials reported to be used include at least one substance with a harmonised classification for carcinogenicity (silicon carbide).

Technical feasibility

The basic PVD process as such is technically mature (TRL9) and is reported to have replaced chromium coating in certain niche areas (e.g. fretting wear[54] or for small rotationally symmetrical tools). PVD was also identified as an alternative to chrome plating of printing plates, enabling the deposition of very durable and thin Cr / CrN layers to harden the surface of the printing plate of some printing machines.

However, many companies have reported issues with complex geometries as well as limitations related to the size of the parts the be treated. Other issues related to insufficient thickness, failure in wear and corrosion resistance, residual stress and tendency to chipping have been reported.

For applications where the decorative character of the coating plays an important role, users have reported issues with colour consistency. Moreover, PVD coating technique is generally limited to smaller parts (depending on the size of the vacuum chamber) and limited geometries (inner diameters may be problematic as well as non-flat geometries).

For internal surfaces of cylindrical components (such as gun barrels), EPVD® is an electro-magnetically enhanced PVD technology that has been specifically engineered to produce coatings tailored for gun barrel applications and is patented by a non-EU based technology developer. Some companies are currently testing this potential alternative.

Economic viability

The PVD process differs fundamentally from functional chrome plating, which means high investment costs for the implementation. In addition, it has been reported that the coating time is usually significantly higher, resulting in increased costs per part and reduced competitiveness compared to Cr(VI) based electroplating. On the other hand, companies have reported that the process requires no wastewater treatment.

E.2.2.7. Diamond like carbon

Technology

This alternative has been identified for metal substrates only. Diamond Like Coating (also known as DLC coating) is a nanocomposite consisting of a mixture of graphite and diamond bonds in an amorphous structure that displays some of the typical properties of diamond (hardness, wear resistance, and slickness). DLC can be deposited using vacuum processes

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[53] Ion Plating - an overview | ScienceDirect Topics.

[54] Fretting Wear – About Tribology.

such as PVD or CVD. Fine-tuning of the deposition parameters is essential to achieve the desired coating properties.[55]

Risk reduction potential

No specific issue reported.

Technical feasibility

As DLC relies on other processes for deposition (CVD, PVD) the limitations flagged for these processes also apply. For example, companies have reported issues with adhesion, insufficient thermal resistance, limitation of substrates than can be coated.

One company operating in the weapon manufacture sector reported running a testing project with a technology provider but flagged that as the project is still in early stages (prototype testing and pilot coating) there are still considerable uncertainties related to substitution timelines. In addition, the company flagged that DLC is one of the two alternatives they consider.

For applications where the decorative character of the plating plays an important role, users have reported that the dark grey to anthracite finish appearance of the coating can be an issue for customers expecting the bright silvery-bluish appearance achieved with Cr(VI) electroplating.

Economic viability

The processes used to deposit DLC (CVD, PVD) differ fundamentally from functional chrome plating, which means high investment costs for the implementation.

E.2.2.8. Chemical vapour deposition

Technology

This alternative has been identified for metal substrates only. Chemical vapour deposition (CVD) is a deposition process of solid materials (from a volatile precursor) at high temperature as a result of a chemical reaction directly on the substrate. CVD is typically conducted under vacuum at temperatures around 1 000°C. It enables the deposition of a wide type of materials such as metals, nitrides, carbides, oxides, polymers, and other non-metallic elements.[56] Different categories of CVD exist, for example:

- Atmospheric CVD
- Low pressure CVD
- Plasma enhanced CVD

Risk reduction potential

Some literature sources report the risk of using toxic, corrosive, flammable, and/or

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[55] Complete Guide To DLC Coating (Diamond Like Coating) (dekmake.com), Diamond-like carbon - Wikipedia, Diamond-Like Carbon Coating - an overview | ScienceDirect Topics.

[56] Chemical Vapor Deposition - an overview | ScienceDirect Topics, What is Thermal Spraying? - TWI.

explosive precursor gases.

Technical feasibility

The CVD process as such is technically mature that is reported to already be used by some companies for part of their portfolio. However, when considering it as an alternative to remaining uses of Cr(VI), companies have reported issues with insufficient thickness of the coating, high process temperature excluding substrates such as aluminium alloys, high strength steels or plastics and limitation with regard to the size of the part to be coated.

Economic viability

PVD process differs fundamentally from functional chrome plating, which means high investment costs for the implementation.

E.2.2.9. Thermal spraying

Technology

This alternative has been identified for metal substrates only. Thermal spraying techniques are coating processes in which a feedstock (coating precursor) is heated by electrical (plasma or arc) or chemical means (combustion flame) in a combustion chamber and sprayed onto a surface using a spray gun. Almost any material can be deposited so long as it melts or becomes plastic during the spraying operation. At the substrate surface, the particles form 'splats' or 'platelets' that interlock and build up to give the coating that interlock and build up to give the coating.

The bond between a thermally sprayed coating and the substrate is primarily mechanical, and not metallurgical or fused. This is a significant feature of thermal spraying compared to many other coating processes. There are different types of thermal spraying techniques, including plasma spraying, flame spraying, High velocity oxy-fuel coating spraying (HVOF), High velocity air fuel (HVAF). In high velocity processes, the feedstock is accelerated to sub-sonic speed.

Risk reduction potential

In addition to noise issues, the materials reported to be used include cobalt, a substance with a harmonised classification for CMR hazards.

Technical feasibility

Thermal spraying is deemed a feasible alternative for parts of the products electroplated with Cr(VI) substances. The technology is known and has been used for specific applications and some companies have reported that the coating produced with this type of technology performs in comparable way to coatings produced with Cr(VI) electroplating.

However, issues with the thickness of the coating, the typically rough resulting surface requiring additional machining to achieve desired smoothness as well as limitations in the substrate materials and for parts with complex geometry have been reported.

Some companies also explained that the type of bonding between the substrate and the coating (mechanical instead of metallurgical) may impact the bond strength and the impact resistance of the coating, and that this must be considered, especially when such coatings are considered for use in critical industrial applications.

Economic viability

The thermal spraying processes differ fundamentally from functional chrome plating, which means high investment costs for the implementation. Production capacity has also been reported as a limiting factor.

E.2.2.10. Laser cladding

Technology

This alternative has been identified for metal substrates only. Laser cladding is a directed energy deposition (DED) process in which metallic powder or wire feedstock is melted on metallic surfaces using a high-power laser to repair damaged surfaces or to enhance surface properties (Vilar 1999). The laser beam melts a thin surface layer of the substrate, and the overlay material is then metallurgically bonded to the surface. Only enough of the surface melts to form the bond with the overlay material. The process is also called “hard facing.”[57]

There are different variants of laser cladding technology. One of them Extreme High-Speed Laser Application (EHLA, developed relatively recently by Fraunhofer Institute for Laser Technology) can be applied to small and large components at higher speeds and in a way that reduces the thermal impact of the laser on the substrate compared to conventional laser cladding (Schopphoven, Gasser et al. 2017).[58]

Laser cladding has traditionally been a ‘line of sight’ technology, but recent research programmes indicate that EHLA is also being developed for coating of internal bores, e.g. for the oil and gas industry.[59]

Risk reduction potential

Dependent on the material coated (e.g. metal matrix composite MMC including carbides (WC tungsten carbide (EC 235-123-0), TiC titanium carbide (EC 235-120-4), CBN boron nitride (cubic) (EC 701-307-9)).

Technical feasibility

Companies have reported to be engaged in testing laser cladding and especially EHLA technologies. However, issues related to complex post-processing (grinding), insufficient hardness, heat impact leading to deformation of the workpiece or limitation for non-rotationally symmetrical parts have been reported. In addition, difficulties with the consistency of the blends of materials deposited have led to rejection from customers.

Despite these shortcomings, EHLA seems to be a promising technology for specific applications but has been flagged as an interesting addition, not a full alternative to chrome plating.

Economic viability

The laser cladding processes differ fundamentally from functional chrome plating, which

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[57] Laser Cladding - an overview | ScienceDirect Topics, What is Laser Cladding Technology? - TWI (twi-global.com).

[58] What is Extreme High Speed Laser Application (EHLA)? - TWI (twi-global.com).

[59] Internal Bore Coatings for Applications in Corrosion and Hydrogen Environment - TWI.

means high investment costs for the implementation.

E.2.2.11. Powder coating, wet lacquering/colour painting

Technology

This alternative has been identified for both metal and plastic substrates. These technologies have been identified as potential alternatives for applications where the decorative character of the plating plays an important role. Powder coating is a dry coating process where the coating powder is typically applied to the substrate electrostatically (via electrostatic spray deposition) and then cured under heat or with ultraviolet light. Powder coatings has originally been used on metal substrates but can also be applied to non-metallic substrates such as plastics and medium density fibreboard (MDF).[60]

Wet lacquering/colour painting are liquid coating processes that can be applied via spraying or dipping. After the application, the part is either dried or cured.

Risk reduction potential

Use of organic solvents in liquid coatings and potentially critical paint ingredients.

Technical feasibility

Some companies already use dry or wet coatings for part of their product portfolio. However, from the perspective of using these coatings as alternatives to Cr(VI) plating, issues related to insufficient electrical conductivity, hardness, corrosion and chemical resistance as well as low reflectivity have been reported. It was also mentioned that the aesthetic appearance of the powder coated parts is neither comparable nor competitive to the bright silvery-bluish appearance of chrome coated parts.

Economic viability

These coating processes have been reported to be somewhat less expensive, however, as they differ fundamentally from functional chrome plating, implementation would mean high investment costs.

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[60] What is Powder Coating? - Powder Coating Institute.

Table 48. Information on substances identified as potential alternatives to Cr(VI) electroplating

Shortlisted Alternative	Substance - material	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
Cr(III) chloride-based electroplating	Chromium trichloride	233-038-3	10025-73-7	-	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Sens. 1, H317 Aquatic Chronic 2, H411	Applicable to plastic and metal plating
Cr(III) chloride-based electroplating	Ammonium chloride	235-186-4	12125-02-9	-	Acute Tox. 4, H302 Eye Irrit. 2, H319	Applicable to plastic and metal plating
Cr(III) chloride-based electroplating	Chromium chloride, basic	256-852-0	50925-66-1	-	Skin Corr. 1, H314 Eye Damage 1, H318 Skin Sens. 1, H317 Aquatic Acute 1, H400 Aquatic Chronic 3, H412	Applicable to plastic and metal plating
Cr(III) sulphate-based electroplating	Dichromium tris(sulphate)	233-253-2	10101-53-8	-	Acute Tox. 4, H302 Skin Corr. 1, H314 Eye Damage 1, H318 Skin Sens. 1, H317 Aquatic Chronic 2, H411	Applicable to plastic and metal plating
Cr(III) electroplating with nickel sublayer	Nickel chloride (NiCl2), hexahydrate	616-576-7	7791-20-0	-	-	Applicable to metal plating only Not REACH registered Nickel (battery grade) is identified as critical raw material
Cr(III)-based electroplating	Ammonium formate	208-753-9	540-69-2	-	Eye Irrit. 2A, H319 STOT SE 3, H335 Skin Irrit. 2 H315	Applicable to metal plating only
Cr(III)-based electroplating	Sodium hydroxide	215-185-5	1310-73-2	Skin Corr. 1A, H314 Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1, H290 Skin Corr. 1A, H314 Eye Damage 1, H318	Applicable to metal plating only
Cr(III)-based electroplating	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315	Acute Tox. 3, H331 Skin Corr. 1A, H314	Applicable to metal plating only
Cr(III)-based electroplating	Potassium bromide	231-830-3	7758-02-3	-	Eye Irrit. 2, H319	Applicable to metal plating only
Cr(III)-based electroplating	Chromium oxide	234-361-2	11118-57-3	-	Pyr. Solid 1, H250	Applicable to plastic and metal plating
Cr(III)-based electroplating	Chromium hydroxide sulphate	235-595-8	12336-95-7	-	Skin Irrit. 2, H315 Eye Irrit. 2, H319	Applicable to metal plating only

Shortlisted Alternative	**Substance - material**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
					Skin Sens. 1, H3177 Aquatic Chronic 3, H412	
Cr(III)-based electroplating	Chromium trichloride hexahydrate	629-714-6	10060-12-5	-	-	Applicable to metal plating only Not REACH registered
Electroless Nickel Plating and Nickel/nickel alloy plating	Nickel dichloride	231-743-0	7718-54-9	Acute Tox. 3, H301 Skin Irrit. 2, H315 Repr. 1B, H360D STOT RE 1, H372 STOT RE 2, H373 Muta. 2, H341 Carc. 1A, H350i Acute Tox. 3, H331 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334 Skin Sens. 1, H317	Skin Irrit. 2, H315 Carc. 1A, H350 Repr. 1B, H360 Skin Sens. 1, H317 STOT RE 1b, H372 Carc. 1A, H350i Muta. 2, H341 Repr. 1B, H360D Acute Tox. 3, H301 Acute Tox. 3, H331 Skin Irrit. 2, H315 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Applicable to metal plating only CLH for Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Resp. Sens. 1 Nickel (battery grage) is identified as critical raw material
Electroless Nickel Plating and Nickel/nickel alloy plating	Nickel sulphate	232-104-9	7786-81-4	Acute Tox. 4, H302 Skin Irrit. 2, H315 Skin Sens. 1, H317 Repr. 1B, H360D STOT RE 1, H372 Muta. 2, H341 Carc. 1A, H350i Acute Tox. 4, H332 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334 Skin Sens. 1, H317 Skin Irrit. 2, H315 STOT RE 1, H372 STOT RE 2, H373	Skin Irrit. 2, H315 Skin Sens. 1 H317 STOT RE 1a ,H372 Repr. 1B, H360 Carc. 1A, H350i Carc. 1A, H350 Muta. 2, H341 Repr. 1B, H360D Acute Tox. 4, H302 Acute Tox. 4, H332 Skin Irrit. 2, H315 Eye Irrit. 2, H319 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Applicable to metal plating only CLH for Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Resp. Sens. 1 Nickel (battery grage) is identified as critical raw material
Electrolytic Nickel	Nickel	231-111-4	7440-02-0	STOT RE 1, H372 Carc. 2, H351 Skin Sens. 1, H317	Carc. 1A, H350i Carc. 1B, H350 Carc. 2, H351	Applicable to metal plating only

Shortlisted Alternative	Substance - material	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
					Muta. 2, H341 Repr. 1B, H360F Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Acute 2, H401 Aquatic Chronic 3, H412 Aquatic Chronic 2, H411	CLH for STOT RE 1, Carc. 2 Classification in registration for Carc. 1A, Carc. 1B, Carc. 2, Muta. 2, Repr. 1B, Resp. Sens. 1 Nickel (battery grage) is identified as critical raw material
Laser cladding	Titanium carbide	235-120-4	12070-08-5	-	Carc. 2 H351	Applicable to metal plating only Classification in registration for Carc. 2 Titanium metal is identified as critical raw material
Laser cladding	Tungsten carbide	235-123-0	12070-12-1	-	-	Applicable to metal plating only Tungsten is identified as critical raw material
Laser cladding	Boron nitride (cubic)	701-307-9	-	-	-	Applicable to metal plating only Boron is identified as critical raw material
Nanocrystalline Cobalt-Phosphorous alloy coating	Cobalt dichloride	231-589-4	7646-79-9	Acute Tox. 4, H302 Repr. 1B, H360F Muta. 2, H341 Carc. 1B, H350i Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334 Skin Sens. 1, H317	Carc. 1A, H350i Carc. 1B, H350i Muta. 2 H341 Repr. 1B, H360Fd Repr. 1B, H360FD Acute Tox. 4, H302 Eye Damage 1, H318 Resp. Sens. 1B, H334 Skin Sens. 1, H317 Skin Sens. 1A, H317 STOT RE 2b, H373 Aquatic Acute 1, H400 Aquatic Chronic 2, H411 Aquatic Chronic 1, H410	Applicable to metal plating only CLH for Carc. 1B, Muta. 2, Repr. 1B, Resp. Sens. 1 Identified SVHC for Carcinogenic (Article 57a) and Toxic for reproduction (Article 57c) Cobalt is identified as critical raw material
Nanocrystalline Cobalt-Phosphorous alloy coating	Orthophosphoric acid	231-633-2	7664-38-2	Eye Irrit. 2, H319 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Corr. 1B, H314 Eye Damage 1, H318	Applicable to metal plating only Phosphorus is identified as critical raw material

Shortlisted Alternative	**Substance - material**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
Nickel electroplating	Nickel bis(sulphamidate)	237-396-1	13770-89-3	-	Carc. 1A, H350i Muta. 2, H341 Repr. 1B, H360D Acute Tox. 4, H302 Acute Tox. 4, H332 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Applicable to metal plating only Classification in registrations for Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Resp. Sens. 1 Nickel (battery grade) is identified as critical raw material
Physical vapour deposition (PVD)	Titanium aluminium nitride (TiAlN)	-	-	-	-	Applicable to metal plating only Titanium is identified as critical raw material
Physical vapour deposition (PVD)	Silicon carbide	206-991-8	-	Carc. 1B, H350i	-	Applicable to metal plating only CLH for Carc. 1B
Physical vapour deposition (PVD)	Titanium Carbide	235-120-4	12070-08-5	-	Carc. 2, H351	Applicable to metal plating only Titanium is identified as critical raw material
Physical vapour deposition (PVD)	Chromium nitride	246-016-3	24094-93-7	-	-	Applicable to metal plating only Not REACH registered
Physical vapour deposition (PVD)	Titanium nitride	247-117-5	25583-20-4	-	Carc. 2, H351 Flam. Solid 2, H228	Applicable to metal plating only Titanium is identified as critical raw material
Physical vapour deposition (PVD)	Zirconium nitride	247-166-2	25658-42-8	-	-	Applicable to metal plating only Not REACH registered
Physical vapour deposition (PVD)-based processes, PVD metal , Lacquer + PVD (+ lacquer)	Titanium carbonitride	603-147-4	12654-86-3	-	-	Applicable to plastic and metal plating Not REACH registered Titanium is identified as critical raw material
Plasma spraying	Tribaloy 400	-	-	-	-	Applicable to metal plating only Some applicants flag this alternative as potentially regrettable due to the

Shortlisted Alternative	**Substance - material**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
						presence of Co and Ni in the alloy Cobalt and Nickel are identified as critical raw materials
Plasma spraying	Tribaloy 800	-	-	-	-	Applicable to metal plating only Some applicants flag this alternative as potentially regrettable due to the presence of Co and Ni in the alloy Cobalt and Nickel are identified as critical raw materials
Thermal spray coatings	Tungsten	231-143-9	7440-33-7	-	Flam. Sol. 1, H228 Flam. Sol. 2, H228 Self-heat. 2, H252	Applicable to metal plating only Tungsten is identified as critical raw material
Thermal spray coatings	Carbon	231-153-3	7440-44-0	-	Eye Irrit. 2, H319 STOT SE 3, H335	Applicable to metal plating only
Thermal spray coatings	Chromium	231-157-5	7440-47-3	-	-	Applicable to metal plating only
Thermal spray coatings	Cobalt	231-158-0	7440-48-4	Repr. 1B, H360F Muta. 2, H341 Carc. 1B, H350 Aquatic Chronic 4, H413 Resp. Sens. 1, H334 Skin Sens. 1, H317	Carc. 1B, H350 Muta. 2, H341 Repr. 1B, H360Fd Acute Tox. 4, H302 Acute Tox. 1, H330 Eye Irrit. 2, H319 Resp. Sens. 1B, H334 Skin Sens. 1, H317 STOT RE 2, H373 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Aquatic Chronic 4, H413 Aquatic Chronic 3, H412 Aquatic Chronic 2, H411	Applicable to metal plating only CLH for Carc. 1B, Muta. 2, Repr. 1B, Resp. Sens. 1 Cobalt is identified as critical raw material
Tin-Cobalt (cobalt-based alloy electroplating)	Tin sulphate	231-302-2	7488-55-3	-	Acute Tox. 4, H332 Skin Irrit. 2, H315 Eye Damage 1, H318 Skin Sens. 1, H317	Applicable to metal plating only Classification in registration for STOT RE 1

Shortlisted Alternative	Substance - material	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
					STOT RE 1, H372 Aquatic Chronic 3, H412	
Tin-Cobalt (cobalt-based alloy electroplating)	Cobalt sulphate	233-334-2	10124-43-3	Acute Tox. 4, H302 Repr. 1B, H360F Muta. 2, H341 Carc. 1B, H350i Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334 Skin Sens. 1, H317	Carc. 1B, H350i Carc. 1A, H350i Muta. 2, H341 Repr. 1B, H360FD Acute Tox. 4, H302 Eye Irrit. 2, H319 Resp. Sens. 1B, H334 Skin Sens. 1, H317 Skin Sens. 1A, H317 STOT RE 2, H373 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Aquatic Chronic 2, H411	Applicable to metal plating only CLH for Carc. 1B, Muta. 2, Repr. 1B, Resp. Sens. 1 Identified SVHC for Carcinogenic (Article 57a) and Toxic for reproduction (Article 57c) Cobalt is identified as critical raw material
Trivalent chrome electroplating with nickel sublayer	Nickel bis(sulphamidate)	237-396-1	13770-89-3	-	Carc. 1A, H350i Muta. 2, H341 Repr. 1B, H360D Acute Tox. 4, H302 Acute Tox. 4, H332 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Applicable to metal plating only Classification in registrations for Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Resp. Sens. 1 Nickel (battery grade) is identified as critical raw material

Source: based on information provided as part of Cr(VI) AfAs.

E.2.3. Alternatives to primers and other slurries with CrO_3

E.2.3.1. Cr(III)-based surface treatments

Technology

Cr(III) processes are generally based on the same principle as Cr(VI) processes. However, depending on the kind of surface treatment, there are major differences in the distinct chemical composition of the solutions and required additives, as well as the operating parameters and ancillary equipment, such as ion exchangers. Different solutions are used, mostly sulphate- and chloride-based but other formulations are also available.

Risk reduction potential

Substituting Cr(VI) by Cr(III) represents a shift away from a non-threshold carcinogen. In the absence of a more detailed information on the composition of the formulations, it is difficult to evaluate the hazard/risk reduction capacity of these alternatives more precisely.

It is worth repeating that chromium chloride, basic (EC 256-852-0) and dichromium tris(sulphate) (EC 233-253-2) are skin sensitisers. In addition, data is being generated to assess their potential for reproductive toxicity and endocrine disruption (see ECHA's recent assessment of regulatory needs for 'Simple chromium compounds')[45].

Technical feasibility

According to information provided in AfAs, the alternative is already applied for certain applications in the industry. However, for the most part the alternative seems to still be in early stages of R&D. Issues with insufficient corrosion resistance for some alloys have been reported.

Economic viability

According to information provided in AfAs, although companies have reported economic risk related to switching to a Cr(III)-based alternative as long as it does not perform as well as the Cr(VI)-based coating, there is no indication that this alternative would be economically infeasible.

E.2.3.2. Electrophoretic paint deposition (Anaphoresis)

Technology

Electrophoretic painting or coating is a form of electrodeposition based on electrophoretic motion of charged particles suspended in an electrolyte towards an electrode under an applied electrical field. Depending on the setup, electrophoretic coating can be divided into anodic and cathodic processes. In anaphoretic coating (anodic electrocoating), the workpiece acts as an anode, and the electrical field drives negatively charged particles in the electrolyte towards the workpiece and deposit on the surface.

After deposition, the workpiece is normally rinsed to remove the undeposited bath and baked or cured. Typically, the composition of a primer (paint) used in the electrophoretic paint deposition process is 20 % paint solids to 80 % water, containing no more than 5 % organic solvents. [61]

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[61] Electrophoretic Coating - an overview | ScienceDirect Topics.

Risk reduction potential

Substituting Cr(VI) by electrophoretic painting seems to represent a shift away from a non-threshold carcinogen. However, in the absence of a more detailed information on the composition of the primer, it is difficult to evaluate the hazard/risk reduction capacity of this alternative more precisely.

Technical feasibility

Information reported in AfAs indicate that the technology is commercially available. However, issues with the lack of active corrosion inhibition[62], the fact that to achieve sufficient corrosion protection on specific substrates require the application of a second layer, the variability in coating thickness requiring sometimes grinding post treatment have been reported. In addition, one of the major drawbacks of the process is its inapplicability for processes undertaken on assembled aircraft.

Economic viability

According to information provided in AfAs, there is no indication that this alternative would be economically infeasible.

E.2.3.3. Cadmium plating

Technology

Surface treatment using cadmium salts forms a thin layer of cadmium compounds on the substrate’s surface (e.g., steel, aluminium). This layer protects the substrate from corrosion and allows adhesion of subsequent coatings (e.g., a paint). Cadmium plating is used in the aerospace sector for sacrificial coatings, meaning that it corrodes and falls apart before the underlying substrate, adding a layer of protection to the plated substrate.

Risk reduction potential

Cadmium (EC 231-152-8) is classified as carcinogenic (Carc. 1B), Acute Tox. 2, Repr. 2, and Muta. 2. Thus, the transition from chromium trioxide – which is a non-threshold carcinogen – to cadmium-based coatings would not constitute a significant shift to less hazardous substance.

Technical feasibility

Cadmium plating can be applied in an ultra-thin, lightweight layer, while still providing adhesives with an exceptional bonding surface. However, the company that shortlisted this alternative clearly stated that it is not yet technically feasible, mainly due to insufficient corrosion resistance of the coating and insufficient active corrosion inhibition, as compared to Cr(VI)-based coating.

Economic viability

The company reported that the use of cadmium plating would require high investment costs, dismantling costs for the old equipment and much higher process costs.

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[62] Active corrosion protection directly influences a corrosive reaction by either using resistant materials, a galvanic separation or cathodic protection. Passive corrosion protection stops or slows down corrosion by separating metal from a corrosive agent, see Corrosion Protection - Hilti GB, Classification of corrosion protection methods – Transport Information Service.

E.2.3.4. Chromium-free aluminium-based coatings

Technology

Aluminium-based coatings is a category of coatings using aluminium particles as the primary source of corrosion resistance to metallic substrates. The formulations comprise aluminium-based particles in Cr(VI) free inorganic binders (usually metal phosphate salts).

There are two types of applications i. sacrificial coatings where corrosion resistance is achieved after curing of the aluminium/inorganic binder ceramic coating via the sacrificial mechanism, imparted by the incorporated aluminium particles and ii. high temperature (diffusion) coatings where the metallic component of the coating diffuses or reacts with the substrate to form a corrosion resistant layer. In most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings.

Risk reduction potential

Substituting Cr(VI) by chromium-free aluminium-based coatings seems to represent a shift away from the use of non-threshold carcinogen. However, in the absence of a more detailed information on the composition of the different formulations, it is difficult to evaluate the hazard/risk reduction capacity of these alternatives more precisely.

Technical feasibility

The fact that this alternative includes many different formulations makes it difficult to come to a clear conclusion. For sacrificial coatings, issues with corrosion resistance have been reported for some of the formulations tested (some not passing basic corrosion resistance tests while others do). Differences in adhesion promotion were also reported.

High temperature (diffusion) coatings seem to perform better in laboratory tests, but the technical readiness levels are still low. Also, for high temperature diffusion coatings there are differences in the spraying, curing and storage requirements. This means that changes in the manufacturing lines will be required.

Economic viability

Information reported in AfAs indicate that a transfer to the technology will lead to an increase in operative costs, mostly due to higher raw material costs.

E.2.4. Alternatives to primers and other slurries with other Cr(VI) substances [63]

E.2.4.1. Bonding primers (strontium chromate)

Adhesive bonding involves the joining together of two or more metal or non-metal components and is typically performed when the joints being formed are essential to the structural integrity of the final product or component.

Bonding primers maintain adhesion between the substrate and adhesive material. Prior to application of the bonding primer, bonding surfaces are typically roughened mechanically

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[63] The information was extracted from AfAs not yet published by ECHA. However, equivalent documents were submitted by the ADCR Consortium as part of the UK REACH process and are publicly available at UK REACH: List of UK REACH authorisations – granted and applications in progress, (AFA058 to AFA064).

or etched chemically to provide increased surface areas for the bonding and then treated chemically to provide further adhesion between the substrate and primer, either through mechanical interlocking or chemical interaction. The surfaces are then thinly coated with the adhesive bonding primer before application of the adhesive. The components are joined together and cured at ambient temperatures, in an oven, or in an autoclave to provide a permanent bond.

Unlike protective and wash primers, bonding primers are not applied during outdoor repair activities, and so their application is limited to environmentally controlled indoor spaces.

E.2.4.1.1. Proprietary mixtures of Cr(VI)-free corrosion inhibitors

Technology

This is a broad category of coatings. Due to confidential business information, the composition of the formulations is not known.

Risk reduction potential

As the composition of the formulation is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives.

Technical feasibility

According to information provided in AfAs for this category of alternatives, the results from testing indicate issues with corrosion resistance, adhesion promotion and handling performance. The issues described are sometimes dependent on the substrate coated.

Economic viability

In most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings however, it seems that the material price would likely increase.

E.2.4.1.2. pH-buffering additives

Technology

The additives contain substances such as magnesium oxide, magnesium hydroxide, calcium carbonate, and calcium hydroxide that neutralize acidic conditions.

Risk reduction potential

As the composition of the formulation is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives.

Technical feasibility

One company reported that a test candidate has reached TRL 6 for aluminium and its alloys. Further testing is ongoing (corrosion inhibition, adhesion promotion) to determine tis suitability. This indicates that pH-buffering additives may be used to replace Cr(VI)-based bonding primers in some applications in the future.

Economic viability

The company reported that the material price would likely increase and that an additional process step would be needed.

E.2.4.1.3. Phosphate-based corrosion inhibitors

Technology

Phosphate produces a surface layer on the applied substrate which provides a degree of corrosion protection. Different phosphate-based corrosion inhibitors are available.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, one phosphate-based corrosion inhibitor has been reported to present endocrine disrupting properties.

Technical feasibility

According to information provided in AfAs for this category of alternatives, issues with adhesion promotion and handling properties were observed during testing of one candidate. As most of the testing activities are still at an early stage no conclusion of the modes of failure can yet be drawn.

Economic viability

In most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings. However, companies reported that the material cost would likely increase.

E.2.4.1.4. Silane-based coatings

Technology

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Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, according to information provided in AfAs the hazard profile of one specific silane-based coating seems to be of less concern than that of strontium chromate.

Technical feasibility

Different and sometime contradicting performance results have been reported by companies, indicating that silane-based coatings may rather be considered as an adhesion-promoting preparatory step than a bonding primer.

Economic viability

In most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings. However, companies reported that the material cost would likely increase.

E.2.4.2. Protective primers

Protective primers (with strontium chromate, potassium hydroxyoctaoxodizincate dichromate, pentazinc chromate octahydroxide) are corrosion inhibiting coatings applied as a thin layer which subsequently converts to a solid, adherent and tough film.

Their main function is to provide corrosion resistance and active corrosion inhibition. They may also provide protection from the environment, functional fluid resistance and adhesion properties. Protective primers must also provide adhesion to the substrate(s) and to any previous (e.g. wash or bonding primers) or subsequent layers (e.g. topcoats or sealants).

Spraying is the most common and cost-effective technique to cover large surfaces with a uniform layer of protective primer, however dipping application may also occur. For small repair work or on surfaces which are not suitable for spraying, brush or pen application may also be used. After application, the protective primer is cured at room temperature, in an oven, or using another heat source.

Cr(VI)-based protective primers are generally provided as three component kits: 1. a base (epoxy, alkyd or polyurethane resin) in which the chromate is dispersed, 2. a catalyst which controls the rate of curing of the base, and 3. a thinner (organic solvent, water, or a combination) controlling the viscosity of the dispersion.

E.2.4.2.1. Magnesium-based corrosion inhibitors

Technology

Magnesium-based corrosion inhibitors are also known as magnesium rich primers. An aspect of the mode of action of Cr(VI)-free magnesium rich primer is to corrode sacrificially thereby protecting the substrate. As a result, magnesium corrosion products are formed.

Risk reduction potential

Magnesium powder is self-heating in contact with moisture and oxygen and in some cases can spontaneously ignite. However, when present within a mixture with organic solvents and binders, the risk of spontaneous combustion is largely mitigated.

Technical feasibility

Magnesium-based primers require electrical contact with the base metal and are therefore sensitive to the pre-treatment used. Compatibility with the topcoat also needs to be ensured. In some cases, they are reliant on the qualification of Cr(VI)-free bonding primers before the test candidate can be introduced at the system level.

Magnesium-based corrosion inhibitors are at a mature state of technical readiness for use in specific applications. However, companies testing this category of alternatives have reported issues with unacceptable corrosion resistance, excessive generation of corrosion reaction products affecting surface appearance and interference with future inspection/ maintenance procedures.

Companies also noted that magnesium-based corrosion inhibitors are typically thicker than the Cr(VI) primers, which adds weight to the final product (e.g. aircraft).

Economic viability

In most cases, these alternatives can be applied using the same equipment as used for

Cr(VI)-based coatings. However, companies reported that the material cost would likely increase.

E.2.4.2.2. Silane-based processes including sol-gel coatings

Technology

Sol-gel coatings are a group of processes in which a solvent is evaporated leading to the formation of a transparent gel film.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. To provide a qualitative element of comparison, the hazard profiles of methyl trimethoxysilane (EC 214-685-0) and vinyl trimethoxysilane (EC 220-449-8) are referred to. Both represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

Progression for silane-based corrosion inhibitors for this use is reported to be variable. Some companies testing this category of alternatives have reported issues with corrosion resistance, adhesion, and application for more complex geometries. However, using a proprietary mixture of silane-based process with zinc-based corrosion inhibitor, performance requirements reaching a maturity of TRL 9 were reported for a narrow range of aluminium alloys. Further testing is still required on other relevant substrates of the component design before industrialisation.

Economic viability

These alternatives use the same equipment as Cr(VI)-based coatings.

E.2.4.2.3. Electrocoat primers

Technology

For the basic technology description, see Electrophoretic paint deposition (E.2.3.2).

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, according to information provided in AfAs the hazard profile of one specific electrocoat primer is reported to be of less concern than that of strontium chromate.

Technical feasibility

Testing of the performance of electrocoat primers have shown variable results. Adhesion, in basic primer applications is reported to be deficient in some instances when followed with certain subsequent layers and sealants. In other cases, testing is reported as mature and ranges up to and including TRL 5. However, challenges remain concerning compatibility with sealants and topcoats where further development work is required.

Economic viability

The application processes differ fundamentally from the application of Cr(VI)-based protective binders. This means high investment costs associated with the significant changes needed in the facilities for implementation.

E.2.4.2.4. Calcium-based corrosion inhibitors

Technology

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Risk reduction potential

Examples of calcium-based inhibitors used in proprietary formulations contain calcium silicate (EC 233-250-6) or calcium sulphate (gypsum, EC 603-783-2). Both substances represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

Testing activities so far indicate that calcium-based corrosion inhibitors are usually used in combination with other corrosion inhibitors (e.g. Cr(VI)-based bonding primer) as they otherwise do not provide the required corrosion resistance.

Economic viability

Economic viability of this category of alternatives is not a barrier to use.

E.2.4.2.5. Organic and organometallic corrosion inhibitors

Technology

This category of alternatives typically includes derivatives of benzotriazole (BZT, EC 202-394-1) such as 5-methyl-1H-benzotriazol (5-BZT, EC 205-265-8) and triazol thiol.

Risk reduction potential

According to the classification provided by companies to ECHA in REACH registrations benzothiazole itself is toxic if swallowed, is toxic in contact with skin, causes serious eye irritation, is harmful if inhaled and may cause damage to organs through prolonged or repeated exposure. It should be noted that Germany concluded an assessment of regulatory needs for benzotriazole in 2023 and concluded that the substance is PMT, vPvM, ED ENV and reprotoxic. Based on its analysis, Germany proposed harmonised classification followed by SVHC identification.[64]

Technical feasibility

Companies have reported varied results of testing activities with benzothiazole-containing proprietary mixtures, which also contain inorganic corrosion inhibitors (for example, metal phosphates) showing performance levels up to TRL 4 for a limited number of substrates. However, issues with decrease in shear strength as well as loss in adhesion were observed.

Economic viability

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[64] For the assessment of regulatory needs for benzotriazole, see https://echa.europa.eu/documents/10162/1b7d62d9-053b-ae54-1f30-2005ecdce123.

In most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings. However, companies reported that the material cost would likely increase.

E.2.4.2.6. pH-buffering additives

Technology

These additives contain substances such as magnesium oxide (EC 215-171-9), magnesium hydroxide (EC 215-170-3), calcium carbonate (EC 207-439-9) and calcium hydroxide (EC 215-137-3). Information reported in AfAs indicates that these additives supplement the mode of action of the other components of binders by neutralizing the acidic conditions that otherwise support corrosive attack. Evaluating their potential as alternative in isolation would be meaningless. For this reason, their evaluation is conducted in combination with other components of binders and is not further discussed here.

E.2.4.2.7. Phosphate-based corrosion inhibitors

Technology

Proprietary corrosion inhibitors formulations usually mix different individual corrosion inhibitors. An example of this is a proprietary formulation combining zinc-based and phosphate-based inhibitors.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, information presented in AfAs indicates that phosphate-based corrosion inhibitors represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

Companies conducting testing activities have reported issues with insufficient corrosion and chemical resistance, loss of adhesion. Generally, the progression of testing is still at early-stage; phosphate-based corrosion inhibitors have attained TRL 3 and working towards TRL 4 in most cases.

Economic viability

In most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings. However, companies reported that the material cost would likely increase.

E.2.4.2.8. Rare-earth-based corrosion inhibitors

Technology

Rare-earth-based corrosion inhibitors formulations typically comprise praseodymium or cerium compounds (such as praseodymium hydroxide or cerium nitrate) in combination with other additives.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, information presented in AfAs indicates that rare-earth-based corrosion inhibitors represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

One company has indicated that they have used a commercially available proprietary formulation containing rare-earth-based corrosion inhibitor for years in a limited part of their applications. Other companies conducting testing activities have reported that the performance of rare-earth-based corrosion inhibitors is closely dependent on the substrate they are applied to. Progression to TRL 6 has been achieved in some cases while in others, testing activities have stopped at TRL 3.

Economic viability

In most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings. However, companies reported that the material cost would likely increase.

E.2.4.2.9. Sacrificial metal-based corrosion inhibitors

Technology

Sacrificial metal-based corrosion inhibitors contain magnesium, aluminium, or zinc alloy particles of specific shapes, sizes, surface conditions, and alloy compositions, and can also be modified to control their reactivity. However, the exact composition is not known as they are proprietary formulations and was reported to be confidential business information.[65] A more detailed description of magnesium- and zinc-based corrosion inhibitors is presented in specific chapters therefore this category is not further discussed.

E.2.4.2.10. Zinc-based corrosion inhibitors (including zinc molybdates)

Technology

Zinc-based test candidates are reported to be used in a range of proprietary formulations. Examples of zinc-based corrosion inhibitors reported as used in proprietary formulations include, zinc powder (EC 231-175-3), trizinc bis(orthophosphate) (EC 231-944-3), and zinc oxide (EC 215-225-5). An aspect of the mode of action of zinc-based corrosion inhibitors is to corrode sacrificially thereby protecting the substrate.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, information presented in AfAs indicates that zinc-based corrosion inhibitors represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

According to information provided in AfA, the performance of zinc-based corrosion inhibitors is dependent on the substrate they are applied to. To help resolve some of the

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[65] Sacrificial corrosion coating mechanism means that upon contact with corrosive environments such as oxygen, moisture and electrolytes, the specific substance (inhibitor) within the coating corrodes, thereby protecting the under layer / substrate from corrosion.

technical issues identified (e.g. adhesion failure), zinc-based corrosion inhibitors may be combined with other corrosion inhibitors working in synergy with one another.

One proprietary formulation containing zinc-based corrosion inhibitor is reported to be used specifically tor touch-up applications, but it does not offer longer-term corrosion protection. Progression to expand the scope of this touch-up application to additional designs has reached a mature TRL 8.

Economic viability

It is expected that in most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings. Companies reported that the material cost would likely increase but that could be counterbalanced by lower quantity required. Increased operative costs have also been reported due to a longer curing time compared to chromated primers.

E.2.4.2.11. Lithium-based corrosion inhibitors

Technology

Lithium-based corrosion inhibitors are available in proprietary mixtures that usually contain other corrosion inhibitors such as zinc-based and organic corrosion inhibitors.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, information presented in AfAs indicates that lithium-based corrosion inhibitors represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

Progression in testing activities is reported to have reached a wide range of maturity (from TRL 1-2 to TRL 4-5). However, one company also reported progression to MRL 10 for a lithium-based corrosion inhibitor applied to exterior decorative applications that can be easily inspected.

Variable performance in terms of corrosion resistance has been reported and it seems that the use of Cr(VI)-free chemical conversion coating reduces the corrosion resistance of lithium-based corrosion inhibitor in some cases.

Incompatibility with sealants applied on the primer surface has been observed in specific applications and associated with specific environmental conditions. On the other hand, favourable results are reported for adhesion promotion in limited situations where sealant compatibility is not a requirement. Chemical resistance, layer thickness, mechanical properties and surface appearance used for basic primer and fuel tank primer applications are reported to be acceptable.

Economic viability

Costs attributed to the use of lithium-based corrosion inhibitors is reported to be represent an increase compared to Cr(VI)-based primers.

E.2.4.2.12. Cr(VI)-free test candidate corrosion inhibitors

Technology

This category of alternatives contains proprietary mixtures of the corrosion inhibitors or technologies described previously. Corrosion inhibitors are combined to achieve greater functional performance than with the individual corrosion inhibitors/ technologies alone. The composition of proprietary mixtures is confidential business information.

Risk reduction potential

Generally speaking, as the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives.

Technical feasibility

Depending on the application and the mixture used, variable results have been reported for corrosion resistance, compatibility with substrates sealants and other coatings, and mechanical properties. Some proprietary mixtures cases are reported to meet all required technical feasibility criteria for some limited programmes while others show deficiencies. Where issues have been identified, reformulation of mixtures is ongoing to try resolving the issues observed. Applications on non-aluminium substrates are reported to be at a more advanced maturity (up to TRL 6) whereas TRL 3 has not yet been achieved for aluminium alloy substrates.

Economic viability

Increased operative costs have been reported due to a longer curing time compared to chromated primers.

E.2.4.3. Wash primers

Wash primers, sometimes referred to as etch primers, are a ‘pre-treatment’ coating containing potassium hydroxyoctaoxodizincate dichromate or pentazinc chromate octa-hydroxide. They contain at least 0.5 % acids (by weight) and are applied directly to metal surfaces to passivate the surface by neutralising metal (hydr)oxides and/or etching the surface. They help to establish corrosion resistance and promote adhesion between the substrate and subsequent coating for a component.

Wash primers can be applied to untreated or abraded metal because they have the ability to react with the surface to replace native oxides with a reaction layer that adheres the primer to the substrate. As most wash primers are not resistant to hydraulic fluids typically used in commercial aircraft, they must be overcoated with a hydraulic fluid resistant primer.

E.2.4.3.1. Magnesium-rich primers

Technology

This category of potential alternatives refers to powdered magnesium metal within an organic binder system to provide corrosion resistance to the substrate through a sacrificial mechanism. Upon contact with corrosive environments such as oxygen, moisture and electrolytes, the magnesium within the coating corrodes, thereby protecting the base alloy from corrosion.

Risk reduction potential

Magnesium powder is self-heating in contact with moisture and oxygen and in some cases can spontaneously ignite. However, when present within a mixture with organic solvents and binders, the risk of spontaneous combustion is largely mitigated.

Technical feasibility

One of the mixtures was reported to perform well against all performance requirements however, it contains certain per- or polyfluorinated solvents. This specific candidate was not further pursued. Testing of other magnesium-rich primers have shown issues with corrosion resistance, adhesion promotion and layer thickness were reported.

Economic viability

Due to limitations in technical feasibility, it is not possible yet to estimate the economic impacts of substitution with magnesium-rich primers.

E.2.4.3.2. Phosphate-based corrosion inhibitors

Technology

Phosphate produces a surface layer on the applied substrate which provides a degree of corrosion protection.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, information presented in AfAs indicates that phosphate-based corrosion inhibitors represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

Though phosphate-based corrosion inhibitors have seen additional and ongoing R&D activities since ~2015, very limited progression of these test candidates has been reported since. The limitations identified in their initial technical performance indicates that these test candidates will not likely be considered a viable alternative for the wider A&D sector.

Economic viability

Due to the limited technical feasibility of phosphate-based corrosion inhibitors, no detailed economic feasibility assessments have taken place.

E.2.4.3.3. Zinc-based corrosion inhibitors

Technology

Zinc-based inhibitors refer to corrosion inhibitors which are either powdered zinc metal, or various zinc salts such as zinc silicate.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, information presented in

AfAs indicates that zinc-based corrosion inhibitors represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

According to information reported in AfAs, test candidates of this category have all been eliminated at very early stages of R&D due to clear limitations in corrosion resistance, adhesion and compatibility with substrates.

Economic viability

Due to the limited technical feasibility of zinc-based corrosion inhibitors, no detailed economic feasibility assessments have taken place.

E.2.4.3.4. Silane-based coatings

Technology

Silane-based coatings typically refer to sol-gel systems which are typically used to promote adhesion between the substrate and subsequent coating layers.

Risk reduction potential

As these test candidates have not shown sufficient technical performance to replace Cr(VI)-based wash primers in the A&D sector, no detailed health and safety assessments have been reported. However, vinyl trimethoxysilane (EC 220-449-8) that has a harmonised classification for Skin Sens. 1B is reported to be used in such coatings

Technical feasibility

Companies have reported that all tested candidates have failed to progress beyond TRL 2. Issues with insufficient corrosion resistance, unacceptable mechanical properties have been identified.

Economic viability

Due to clear limitations in the technical feasibility of current silane-based coatings, no detailed assessment of the economic feasibility has been conducted.

E.2.4.3.5. Zirconate-based corrosion inhibitors (Organometallics)

Technology

Organometallics are mainly investigated as a replacement to chromate chemical conversion coatings and as part of sol-gel formulations, but not as a direct wash primer alternative.

Risk reduction potential

As zirconate-based corrosion inhibitors have not shown sufficient technical performance to replace Cr(VI)-based wash primers in the A&D sector, no detailed health and safety assessments have been reported.

Technical feasibility

One company reported R&D activities on the use of a zirconate-based corrosion inhibitor. They noted that although zirconate-based corrosion inhibitors generally perform well with regards to adhesion to substrate, layer thickness, chemical resistance and mechanical properties, progression to TRL 3 has been limited by continuously poor performance in corrosion inhibition.

Economic viability

Due to their limitation in technical feasibility, no detailed assessment of the economic feasibility of zirconate-based corrosion inhibitors has been conducted. However, no information was obtained during consultation that would suggest that they would not be economically feasible.

E.2.4.3.6. Cr(VI)-free test candidate corrosion inhibitors

Technology

This category of alternatives contains proprietary mixtures of the corrosion inhibitors or technologies described previously. Corrosion inhibitors are combined to achieve greater functional performance than with the individual corrosion inhibitors alone. The composition of the of the proprietary mixtures is confidential business information.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives.

Technical feasibility

Depending on the application and the mixture used, variable test results have been reported. Corrosion resistance and adhesion promotion are the key reasons for failure of this category in wash primers. In addition, issues with chemical compatibility and thermal resistance have been reported. Candidates under this category are typically at TRL 3, however it has been reported that some test candidates have surpassed TRL 5 for less challenging substitutions (non-aluminium substrates).

Economic viability

In most cases, these alternatives can be applied using the same equipment as used for Cr(VI)-based coatings.

Table 49. Information on substances identified as potential alternative to primers and other slurries with Cr(VI) substances

Shortlisted Alternative	Substance / material	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
Cadmium plating	Cadmium	231-152-8	7440-43-9	Repr. 2; H361fd STOT RE 1; H372 Muta. 2; H341 Carc. 1B; H350 Acute Tox. 2; H330 Aquatic Acute 1; H400 Aquatic Chronic 1; H410	Carc. 1B H350, Muta. 2 H341 Repr. 2 H361 Pyr. Solid 1 H250 Acute Tox. 2 H330 STOT RE 1 H372 Aquatic Acute 1 H400 Aquatic Chronic 1 H410	CLH for Repr. 2, STOT RE 1, Muta. 2, Carc. 1B
Chromium-free aluminium -based coatings	Trizinc bis(orthophosphate)	231-944-3	7779-90-0	Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Phosphorus is identified as critical raw material
Chromium-free aluminium -based coatings	Aluminium tris (dihydrogen phosphate)	236-875-2	13530-50-2	-	Eye Damage 1, H318	Phosphorus is identified as critical raw material
Cr(III)-based surface treatments	Chromium (III) oxide	215-160-9	1308-38-9	-	Carc. 1A, H350 Muta. 1B, H340 Repr. 2, H361 Acute Tox. 4, H302 Acute Tox. 3, H311 Acute Tox. 4, H332 Acute Tox. 2, H330 Skin Irrit. 2, H315 Skin Corr. 1A, H314 Eye Damage 1, H318 Eye Irrit. 2, H319 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 STOT RE 2, H373 STOT SE 3, H335 Aquatic Chronic 2, H411 Aquatic Chronic 3, H412	Classification in registration for Carc. 1A, Muta. 1B, Repr. 2, Resp. Sens. 1, STOT RE 1
Cr(III)-based surface treatments	Chromium trifluoride	232-137-9	7788-97-8	-	Acute Tox. 3, H301 Skin Corr. 1, H314 Eye Damage 1, H318 Skin Sens. 1, H317	-

Shortlisted Alternative	**Substance / material**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
					Aquatic Acute 1, H400 Aquatic Chronic 2, H411	
Cr(III)-based surface treatments	Chromium trichloride	233-038-3	10025-73-7	-	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Sens. 1, H317 Aquatic Chronic 2, H411	-
Cr(III)-based surface treatments	Chromium hydroxide sulphate	235-595-8	12336-95-7	-	Skin Irrit. 2, H315 Eye Irrit. 2, H319 Skin Sens. 1, H317 Aquatic Chronic 3, H412	-
Manganese-based processes	Potassium permanganate	231-760-3	7722-64-7	Acute Tox. 4, H302 Ox. Sol. 2, H272 Repr. 2, H361d Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Repr. 2, H361 Oxid. Solid 2, H272 Acute Tox. 4, H302 Skin Corr. 1C, H314 Eye Damage 1, H318 STOT RE 2, H373 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Aquatic Chronic 1, H410 Aquatic Acute 1, H400	CLH for Repr. 2 Manganese is identified as critical raw material
Protective primers, Calcium-based corrosion inhibitors	Calcium silicate	233-250-6	10101-39-0			Not REACH registered
Protective primers, Calcium-based corrosion inhibitors	Gypsum	603-783-2	13397-24-5	-	-	Not REACH registered
Protective primers, Lithium-based corrosion inhibitors	Trilithium orthophosphate	233-823-0	10377-52-3	-	Acute Tox. 4 H302 Skin Corr. 1B H314 Eye Damage 1 H318 Eye Irrit. 2A H319	Lithium is identified as critical raw material Phosphorus is identified as critical raw material
Protective primers, Organic and organometallic corrosion inhibitors	Benzotriazole	202-394-1	95-14-7	-	Acute Tox. 4 H302 Eye Irrit. 2 H319 Aquatic Chronic 2 H411 Eye Irrit. 2A H319 Skin Irrit. 2 H315	-
Protective primers, Organic and organometallic corrosion inhibitors	6-methylbenzotriazole	205-265-8	136-85-6	-	Skin Corr. 1B, H314 Eye Damage 1, H318	-

Shortlisted Alternative	Substance / material	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
Protective primers, pH-buffering additives	Calcium carbonate	207-439-9	471-34-1	-	Skin Irrit. 2 H315 Eye Damage 1 H318 STOT SE 3 H335	-
Protective primers, pH-buffering additives	Calcium dihydroxide	215-137-3	1305-62-0	-	Skin Irrit. 2 H315 Eye Damage 1 H318 STOT SE 3 H335 Resp. Sens. 1A H334 Aquatic Acute 3 H401 Eye Irrit. 2A H318	Classification in registration for Resp. Sens. 1A
Protective primers, pH-buffering additives	Magnesium hydroxide	215-170-3	1309-42-8	-	Carc. 1A H350 (impurities) STOT RE 2 H373 (impurities)	Classification in registration for Carc. 1A (impurities) Magnesium is identified as critical raw material
Protective primers, pH-buffering additives	Magnesium oxide	215-171-9	1309-48-4	-	-	Not REACH registered Magnesium is identified as critical raw material
Protective primers, Phosphate-based corrosion inhibitors	Dipraseodymium trioxide	234-845-3	12036-32-7	-	-	Praseodymium is identified as critical raw material
Protective primers, Phosphate-based corrosion inhibitors	Aluminium dihydrogen triphosphate	237-714-9	13939-25-8	-	-	Phosphorus is identified as critical raw material
Protective primers, Sacrificial metal-based corrosion inhibitors	Magnesium	231-104-6	7439-95-4	Pyr. Sol. 1; H250 Water-react. 1; H260	Flam. Solid 1 H228 Pyr. Solid 1 H250 Self Heat. 2 H252 Water React. Flam. Gas 2 H261 Water React. Flam. Gas 1 H260	Magnesium is identified as critical raw material
Protective primers, Silane-based processes including sol-gel coatings	Trimethoxy(methyl)silane	214-685-0	1185-55-3	-	Flam. Liquid 2 H225	-
Protective primers, Silane-based processes including sol-gel coatings	Trimethoxyvinylsilane	220-449-8	2768-02-7	Skin Sens. 1B; H317	Flam. Liquid 3 H226 Acute Tox. 4 H332 Skin Sens. 1B H317	-
Protective primers, Zinc-based corrosion	Zinc oxide	215-222-5	1314-13-2	-	-	Classification in registration for Repr. 1A

Shortlisted Alternative	Substance / material	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
inhibitors (including zinc molybdates)						
Protective primers, Zinc-based corrosion inhibitors (including zinc molybdates)	Zinc	231-175-3	7440-66-6	-	Aquatic Acute 1 H400 Aquatic Chronic 1 H410 Aquatic Chronic 2 H411	-
Protective primers, Zinc-based corrosion inhibitors (including zinc molybdates)	Trizinc bis(orthophosphate)	231-944-3	7779-90-0	-	Eye Irrit. 2 H319,	Phosphorus is identified as critical raw material
Wash primers, Silane-based coatings	Trimethoxyvinylsilane	220-449-8	2768-02-7	Skin Sens. 1B; H317	Flam. Liquid 3 H226 Acute Tox. 4 H332 Skin Sens. 1B H317	-

Source: based on information provided as part of Cr(VI) AfAs.

E.2.5. Alternatives to Cr(VI) in passivation of tin-plated steel (ETP)

The overview of alternatives for ETP also include potential alternatives for electrolytic chromium coated steel (ECCS) although from a technical perspective, ECCS is an electroplating process and would therefore better fit under UC 3. However, ETP and ECCS are closely linked to each other as the steel thus manufactured is used by the metal packaging industry in the manufacturing of steel cans (tin-plated steel for the body and electrolytic chromium coated steel mostly for the two ends of the can). For this reason, the Dossier Submitter considers appropriate to present the overview of alternatives for these two uses together.

As the development of alternatives for ETP and ECCS are well advanced, only the most promising alternatives are described here.

E.2.5.1.1. Chrome Free Passivation Alternative

Technology

The Chromium Free Passivation Alternative (CFPA) uses a Titanium/Zirconium (Ti/Zr) oxide film which replace the passivation by using hexavalent chromium. In addition to preventing further oxidation of the tin layer, one of the main performance criteria of the passivation is the adhesion of the organic coating (lacquer or laminate) on the metal packaging material. CFPA is being developed as alternative to ETP. It consists of a liquid solution system applied by spraying and drying.

Risk reduction potential

As the composition of the formulations is not known, it is not possible to judge the hazard/risk reduction capacity of these alternatives. However, information presented in AfAs indicates that although using some substances with hazardous classifications, there would be an overall reduction in the risk from the CFPA process. The main ingredients of CFPA are dihydrogen hexafluorotitanate(2-) (EC 241-460-4), Dihydrogen hexafluorozirconate(2-) (EC 234-666-0) and zirconium dioxide (EC 215-227-2).

Technical feasibility

Information gathered via the calls for evidence, AfAs and DU notifications indicate that this alternative is being developed by the European producers of steel for packaging commonly. The variety of organic coatings use has been reported as a challenge in the development of the alternative. However, CFPA is expected to become the European production standard around 2028.

It should also be noted that information provided by Metal Packaging Europe (MPE) indicates that the timelines announced in AfAs for transition to an alternative may not hold. MPE states that during testing of the alternatives, "…*significant issues of varying severity (e.g. corrosion, delamination, rust, mottling, perforation, surface staining, loss of adhesion, limited chemical resistance at filling) continue to be identified by MPE members on approx. 20 % of the total packaging tests carried out…*" and that "…*there is no guarantee that the chrome-free alternatives will lead to similar performance as tinplate and ECCS when applied to the same coating and product, jeopardizing the functionality of steel cans and the position of the can manufacturers on the market.…*" [66]

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[66] The full communication from MPE is available in Appendix G: Stakeholder information.

Economic viability

The transition to the alternative requires modifications to existing passivation lines but is expected to be possible. Some restrictions due to space limitation may be encountered. However, stakeholders from the European producers of steel for packaging sector have flagged that allowing continued imports of Cr(VI) passivated steel from outside the EU would skew the market and delay investments in CFPA technology.

E.2.5.1.2. Low Tin Steel (LTS)

Technology

This alternative represents a change in the substrate used to a non-reflowed low tin steel[67] (LTS) combined with a surface treatment based on hexafluoro titanic / zirconic acids. Together with Trivalent Chromium Coating Technology (TCCT), Low Tin Steel (LTS) is being developed as an alternative to electrolytic chromium coated steel (ECCS).

Risk reduction potential

According to information from the AfA, there are no substances of very high concern contained within the formulation. This seems to indicate that LTS represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

The LTS alternative and the CFPA alternative are based on the same chemistry, which means that issues identified for one will also be applicable to the other. During development of this alternative two challenges were encountered that could affect the viability of this alternative, which makes it currently not yet technically feasible. Note that the information provided by Metal Packaging Europe (MPE) and described in E.2.5.1.1 is also applicable to LTS.

Economic viability

Expected cost of LTS alternative is equivalent to the raw material cost of the current raw materials used in the ECCS process. However, adaptation of the lines will require considerable engineering works and financial resources, and some lacquers may require re-formulation or development. This would mean additional qualification rounds by other actors in the supply chain (to ensure safety of use in terms of food contact) and may have significant economic impact on the downstream supply chains.

E.2.5.1.3. Trivalent Chromium Coating Technology (TCCT)

Technology

This alternative represents a change in the coating process. It is an electro-deposition process based on Cr(III) coating on black plate that was developed as a proprietary technology. Together with Low Tin Steel (LTS), Trivalent Chromium Coating Technology (TCCT) is being developed as an alternative to electrolytic chromium coated steel (ECCS).

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[67] Reflowed tin is a process that results in improved solderability as opposed to standard electroplated tin. After a part has been electroplated with tin, the part is reheated above the melting point of the tin plating (greater than 450°F), then cooled. Tin reflowing reduces the internal stresses that arise during the electroplating process that have been proven to contribute to tin whisker formation. From Technical - Associated Plating Associated Plating.

Risk reduction potential

According to information from the AfA, the TCCT technology does not require the use of additional substances that are currently classed as SVHCs. This seems to indicate that TCCT represent a reduction in hazard profile compared to Cr(VI) substances.

Technical feasibility

The TCCT alternative is overall promising, but tests have shown that it still fails to meet required performance standards and requires further research and development. This development (and subsequent implementation) will result in significant financial costs with no offsetting benefits. Note that the information provided by Metal Packaging Europe (MPE) and described in E.2.5.1.1 is also applicable to TCCT.

Economic viability

The raw material costs, energy, human resource and other ancillary costs would be equivalent. However, adaptation of the lines would require considerable engineering works and financial resources.

Table 50. Information on substances identified as potential alternative to ETP and/or ECCS

Shortlisted Alternative	Substance name	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
ETP, Chrome Free Passivation Alternative (CFPA)	Zirconium dioxide	215-227-2	1314-23-4	-	-	-
ETP, Chrome Free Passivation Alternative (CFPA)	Dihydrogen hexafluorozirconate(2-)	234-666-0	12021-95-3	-	Met. Corr. 1, H290 Acute Tox. 3, H301 Acute Tox. 3, H311 Acute Tox. 3, H331 Skin Corr. 1B, H314 Eye Dam. 1, H318	-
ETP, Chrome Free Passivation Alternative (CFPA)	Dihydrogen hexafluorotitanate(2-)	241-460-4	17439-11-1	-	Met. Corr. 1, H290 Acute Tox. 3, H301 Acute Tox. 3, H311 Acute Tox. 3, H331 Skin Corr. 1, H314	-
Low Tin Steel (LTS)	Zirconium dioxide	215-227-2	1314-23-4	-	-	-
Low Tin Steel (LTS)	Dihydrogen hexafluorozirconate(2-)	234-666-0	12021-95-3	-	Met. Corr. 1, H290 Acute Tox. 3, H301 Acute Tox. 3, H311 Acute Tox. 3, H331 Skin Corr. 1B, H314 Eye Dam. 1, H318	-
Low Tin Steel (LTS)	Dihydrogen hexafluorotitanate(2-)	241-460-4	17439-11-1	-	Met. Corr. 1, H290 Acute Tox. 3, H301 Acute Tox. 3, H311 Acute Tox. 3, H331 Skin Corr. 1, H314	-

Source: based on information provided as part of Cr(VI) AfAs.

E.2.6. Alternatives to Cr(VI) in other surface treatments

E.2.6.1. Etching of plastics

E.2.6.1.1. Manganese-based etching solutions

Technology

Etching is performed to "roughen" the surface of a substrate and improve adhesion of the coating. When etching plastic polymers e.g. ABS, the elastomer phase of the polymer is removed, and a sub microscopic pore system is generated in the surface of the workpiece. When a metal coating is then deposited, the unevenness of the etched surface allows to create a strongly anchored layer (Burkhardt, Hüsgen et al. 2000). Manganese-based etching solutions (including permanganate and more specifically potassium permanganate) have been identified in several AfAs as the most promising alternative for etching on plastics.

Risk reduction potential

The substances identified in some AfAs seem to indicate a reduction in hazard profile compared to Cr(VI). Sodium permanganate (EC 233-251-1), Manganese (EC 231-105-1), Manganese sulphate (EC 232-089-9).

Technical feasibility

Manganese-based etching solutions have been identified in several AfAs as the most promising alternative for etching on plastics. However, depending on the formulation and the substrate tested, companies have reported issues with adhesion. Companies also reported that these etching solutions need strict analytical control of the process chemistry and have limited processing window compared to the Cr(VI)-based etching. One company reported that they are conducting trials in a pilot plant.

Economic viability

Companies have indicated that investment for the adaptation of the production facility and of the wastewater treatment system will be needed. Increase in costs of the final product has also been mentioned.

E.2.6.2. Alternative surface treatments (pre-treatments) used in sectors other than the A&D sector

Pre-treatment is required in many sectors (e.g. building, automotive, metal manufacturing & finishing, general engineering) to prepare the surface of the substrate for subsequent process steps. Such pre-treatments include e.g. functional cleaning, pickling, stripping or deoxidizing.[68]

E.2.6.2.1. Cr(III)-based pre-treatments

Technology

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[68] Information extracted from AfA 0364-12: https://echa.europa.eu/applications-for-authorisation-previous-consultations/-/substance-rev/76824/term.

Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

The companies indicated that this alternative is (potentially) technically feasible. It is also commercially available and (potentially) suitable. However, additional time required for implementation and transition.

Economic viability

Most companies indicated that this alternative is economically feasible and does not bear significant impact on costs or prices.

E.2.6.2.2. Pickling/etching of copper

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

The companies indicated that although commercially available, this alternative does not fulfil customer specific requirements and is therefore not yet technically feasible.

Economic viability

Most companies indicated that this alternative is economically feasible and does not bear significant impact on costs or prices.

E.2.6.2.3. Acidic surface pre-treatment

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative does not constitute a shift to a less hazardous process.

Technical feasibility

Some of the companies indicated that although commercially available, there are issues with inadequate removal of oxides and debris and lack of selective attack of substrate material. Therefore, this alternative is not yet technically feasible.

Economic viability

Some companies indicated that using this alternative will increase costs and sale prices.

E.2.6.2.4. No surface pre-treatment

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative does not constitute a shift to a less hazardous process.

Technical feasibility

The companies indicated that this alternative is (potentially) technically feasible. It is also commercially available but not considered suitable due to technical/economic limitations and/or safety issues.

Economic viability

The companies indicated that using this alternative will require additional investments, increase recurring costs as well as sale's price.

E.2.6.3. Other surface treatments (main treatments), (except ETP) for other sectors than the A&D sector

The main surface treatments comprised in this category include chemical conversion coating (CCC), chromic acid anodizing (CAA) and slurry coating. [68]

E.2.6.3.1. Organometallics

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative does not constitute a shift to a less hazardous process.

Technical feasibility

Some companies indicated that this alternative is (potentially) technically feasible while others reported issues with insufficient adhesion promotion (adhesion to subsequent coatings/paint) and therefore do not see it yet as technically feasible. The alternative is commercially available however, where it is deemed suitable, additional time is required for implementation and transition.

Economic viability

Some companies indicated that using this alternative will require additional investments, increase recurring costs, dismantling costs as well as sale's price.

E.2.6.3.2. Cr(III)-based surface treatments

Technology

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Risk reduction potential

Companies expressed different views with some indicating that this alternative constitutes a shift to a less hazardous process while others considered that it does not.

Technical feasibility

Some companies indicated that this alternative is (potentially) technically feasible while others reported issues with insufficient corrosion resistance (active corrosion inhibition), abrasive resistance and insulation coating resistance. In addition, the low coefficient of thermal expansion is expected to introduce tension between the coating and the steel matrix. For these reasons, these other companies do not see it yet as technically feasible. In most cases, the alternative is reported to be commercially available however, where it is deemed suitable, additional time is required for implementation and transition.

Economic viability

Some companies indicated that using this alternative will require additional investments, increase recurring costs, dismantling costs as well as sale’s price.

E.2.6.3.3. Acidic surface treatments

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

Some companies indicated that this alternative is (potentially) technically feasible while others reported issues with layer thickness, roughness, and adhesion promotion. In most cases, the alternative is reported to be commercially available however, where it is deemed suitable, additional time is required for implementation and transition.

Economic viability

Some companies indicated that using this alternative will increase sales prices.

E.2.6.3.4. Silane/siloxane and sol-gel coatings

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

The alternative is reported to be commercially available however, due to issues with insufficient adhesion promotion, it is not considered technically feasible yet.

Economic viability

Most companies indicated that this alternative is economically feasible and does not bear significant impact on costs or prices.

E.2.6.3.5. Physical vapour deposition (PVD) in colouring application

Technology

Chromium trioxide is used in chemical passivation reaction to produce decorative colours, e.g. for stainless steel plates. The colouring is followed by a cathodic hardening treatment where the substance is also used. In addition to colouring, the process stimulates the natural passivation of the material.

Risk reduction potential

The coating is prepared in a closed system, so it is not expected that there is any exposure during its application.

Technical feasibility

The basic PVD process as such is technically mature (TRL9). It has been identified as the most promising alternative for this specific application but there are still technical issues to be addressed before full transition to this alternative is possible. For example, PVD requires an additional pre-treatment step to activate the steel surface, it is more limited in terms of range of colours that can be produced and the colours produced are less homogeneous. These require additional development work and engineering to close the technical gaps.

Economic viability

PVD process differs fundamentally from chromium trioxide-based passivation, which means high investment costs for the implementation. In addition, the cost of raw materials is reported to be higher than that of chromium trioxide.

E.2.6.4. Other surface treatments (post-treatments), (except ETP) for sectors other than the A&D sector

Post-treatments are required to confer additional beneficial properties to the treated component. Such post-treatments include e.g. sealing (after anodizing or plating), passivation. [68]

E.2.6.4.1. Cr(III)-based post-treatments

Technology

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Risk reduction potential

Companies expressed different views with some indicating that this alternative constitutes a shift to a less hazardous process while others considered that it does not.

Technical feasibility

The alternative is reported to be commercially available however some companies reported issues with anti-reflectivity. In such cases, it is not considered to be technically feasible yet. When such technical issues are not observed, additional time is anyway required for implementation and transition.

Economic viability

Some companies indicated that using this alternative will require additional investments, increase recurring costs, dismantling costs as well as sale’s price.

E.2.6.4.2. Mn-based post-treatments

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

Companies have indicated that this alternative is (potentially) technically feasible, however it is only available on lab-scale/not for commercial scale production.

Economic viability

Companies indicated that this alternative is economically feasible and does not bear significant impact on costs or prices.

E.2.6.4.3. Pickling/etching of copper

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

Companies have indicated that this alternative is (potentially) technically feasible and commercially available. However, additional time is required for implementation and transition.

Economic viability

Companies indicated that this alternative is economically feasible and does not bear significant impact on costs or prices.

E.2.6.4.4. PVD post-treatments

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

The companies indicated issues with corrosion resistance, microcracked surface texture, hardness. In addition, the alternative is only available on lab-scale/not for commercial scale production. For these reasons it is considered not yet technically feasible.

Economic viability

Companies indicated that using this alternative will require additional investments, increase recurring costs, dismantling costs as well as sale’s price.

E.2.6.4.5. Zn coating post-treatments

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

Companies have indicated that this alternative is (potentially) technically feasible and commercially available. However, additional time is required for implementation and transition.

Economic viability

Companies indicated that this alternative is economically feasible and does not bear significant impact on costs or prices.

E.2.6.4.6. No surface treatment

Technology

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Risk reduction potential

The companies indicated that based on substances used, this alternative constitutes a shift to a less hazardous process.

Technical feasibility

Although this alternative is commercially available, companies indicated issues with corrosion resistance, coefficient of friction, aesthetics. For these reasons it is considered not yet technically feasible.

Economic viability

Companies indicated that using this alternative will require additional investments, increase, dismantling costs as well as sale’s price.

E.2.6.5. Pre-treatments used in the A&D sector

Pre-treatment is required to prepare the surface of the substrate for subsequent process steps. Such pre-treatments include e.g. deoxidising, pickling, etching and/or desmutting, and inorganic finish stripping.

E.2.6.5.1. Sulfonitroferric acid

Technology

Potential alternative for pickling/etching, deoxidising and inorganic finish stripping using a mixture of sulphuric acid, nitric acid, and ferric ions, “sulfonitroferric acid.”

Risk reduction potential

According to the information presented in the AfA, this alternative constitutes a shift to less hazardous substances.

Technical feasibility

Sulfonitroferric acid is reported to be commercially available, technically feasible and implemented as pre-treatment (pickling/etching and deoxidising) to e.g. anodising and chemical conversion coating for a number of substrates in aerospace and defence applications.

However, additional development work is ongoing to refine operational process parameters of use for substrate/design configurations where the performance requirements are more demanding. This is the case for fatigue sensitive parts which are less tolerant to more aggressive treatments resulting in increased etch rate. Issues with insufficient adhesion when using sulfonitroferric etching prior to bonding have also been reported. Similarly, when used as pre-treatment before Cr(III)-based conversion coating of some aluminium alloys, sulfonitroferric acid results in decreased corrosion resistance that still require assessment and approval by the A&D sector.

For inorganic finish stripping, the alternative is available commercially and has been tested and it has reached a TRL 5 for a specific coating and remained TRL 2 for others. It is expected to be at TRL 6 by 2030 for all relevant sealed anodic layers. This candidate alternative is not generally available as it lacks the qualification for use on A&D components as well as the qualification across the supply chain.

Economic viability

In addition to some changes required in the installation, the operative costs are expected to increase due to longer process times, higher raw material prices and potentially increase in volumes of wastes to be disposed of.

E.2.6.5.2. Nitric/sulphuric acid mixture

Technology

Potential alternative for pickling/etching and deoxidising.

Risk reduction potential

According to the information presented in the AfA, this alternative constitutes a shift to less hazardous substances.

Technical feasibility

The alternative is commercially available and technically feasible as pre-treatments (deoxidising, and pickling/etching) processes on copper and some selected aluminium substrates. Maturity of substitution varies. TRL 4 to 5 for pickling/etching prior to anodising aluminium alloy, and TRL 9 for deoxidising prior to anodising. Although technical feasibility for the purposes of deoxidising substrates such as copper and some aluminium alloys is fulfilled, further work is required to ensure that the material removal from the substrate remains within acceptable limits (e.g. with fatigue sensitive components) and to certify this test candidate for use with some alloys. This is estimated to be completed in 2028.

Economic viability

The cost of this alternative is reported to be higher than the Cr(VI) solution, however, no further quantification was provided.

E.2.6.5.3. Phosphoric acid-based solutions

Technology

This category includes solutions of phosphoric acid with either fluoride or sulphuric acid as potential alternative for pickling and deoxidising. A solution of phosphoric acid and sodium molybdate is identified as potential alternative for inorganic finish stripping of anodic layers on aluminium alloys.

Risk reduction potential

According to the information presented in the AfA, this alternative constitutes a shift to less hazardous substances.

Technical feasibility

Phosphoric acid/sulphuric acid mixture is identified as achieving good results for specific pickling uses, including electropolishing, for steel and stainless steels. Trials have been successful on many grades of stainless steel, however issues with insufficient surface decontamination have been reported for certain grades. Further development for the electropolishing use is on-going and qualification could be achieved in 2028.

Phosphoric acid/fluoride mixture has been identified as a technically feasible for the pre-treatment (deoxidiser) of titanium to enhance adhesion promotion. On other substrates the development is at early stages (TRL 1-3).

For inorganic finish stripping from aluminium alloys, a solution of phosphoric acid and sodium molybdate has progressed to TRL 6 and shows some etching for some alloys. Further research regarding the optimisation of process conditions is needed. This candidate alternative is not generally available as it lacks the qualification for use on A&D components as well as the qualification of the supply chain.

Economic viability

The economic feasibility of the solution of phosphoric acid and sodium molybdate depends on the stability of the bath, which is under study, if the solution needs to be replaced regularly it would mean significant additional costs. Otherwise, no significant economic feasibility barriers are reported.

E.2.6.5.4. Sulphuric acid (including electrolytic sulphuric acid) pickling

Technology

Potential alternative for pickling/etching and deoxidising.

Risk reduction potential

According to the information presented in the AfA, this alternative constitutes a shift to less hazardous substances.

Technical feasibility

Companies reported the use of sulphuric acid for specific application such as the reactivation of metallic coatings (e.g. cadmium, following plating onto steel substrates) to ensure compatibility with further treatments. However, these applications are not certified for use with a wide array of substrates, components and main treatments, and testing is still ongoing.

Economic viability

No significant economic feasibility barriers are reported.

E.2.6.5.5. Sodium hydroxide containing additives

Technology

Potential alternative for pickling/etching.

Risk reduction potential

According to the information presented in the AfA, this alternative constitutes a shift to less hazardous substances.

Technical feasibility

Sodium hydroxide is used as a pre-treatment etchant for non-destructive inspection to check for defects including pits, corrosion products, discolouration, uneven etching, increased surface roughness etc., that could impact subsequent treatment processes. Its use typically produces a smut residue that may require removal with a suitable desmutting process. This limits the extent of use of this alternative.

Economic viability

No significant economic feasibility barriers are reported.

E.2.6.5.6. Cr(III) for anodic pickling

Technology

Potential alternative for pickling/etching and deoxidising. Anodic pickling is the electrolytic process of removing oxide layers or other contaminants from the surface of a substrate prior to electroplating. For example, Cr(VI) electroplating baths can be used for the dual purpose of anodic pickling and electroplating. Pickling is achieved by inverting the polarity of the treatment bath, i.e. the component to be treated becomes the anode.

Risk reduction potential

According to the information presented in the AfA, this alternative constitutes a shift to less hazardous substances.

Technical feasibility

The substitution of Cr(VI) by Cr(III) in main treatments (electroplating) has led to studies on the possibility to use Cr(III) for anodic pickling in the same was as has been done with Cr(VI), i.e. using the same electrolyte. Anodic pickling of ferrous metals introduces iron into the electrolyte solution. While Cr(VI) electrolyte is relatively tolerant to this contamination, Cr(III) electrolyte is not. Increased filtration is possible but reportedly not sufficient to resolve the issue. Skipping the pickling step could be possible for simple designs but this is not valid for more complex designs. Therefore, it is concluded that for most applications, Cr(III) anodic pickling is not technically feasible

Economic viability

In addition to changes required in the installation, the operative costs are expected to increase due to longer process times, higher raw material prices and potentially increase in volumes of wastes to be disposed of.

E.2.6.5.7. Mechanical cleaning/abrasive blast

Technology

Potential alternative for pickling/etching and deoxidising. Abrasive blast uses the physical effect of a fine particulate abrasive medium such as sand/silica, metallic grit, pumice (EC 603-719-3), and aluminium oxide (EC 215-691-6) to remove surface contaminants. The choice of the material depends on the substrate to be cleaned, and the treatment itself is typically done by forcing solid particles through a nozzle and across the surface at high speed.

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances. It has been reported that some of the materials used may pose serious health impacts, e.g. silica (silicon dioxide, EC 231-545-4).

Technical feasibility

Abrasive blast is reported to be limited to deoxidising or removal of light deposits of scale and hint-tint. Due to its typically line-of-sight application method, it usually cannot be used for complex geometries. In addition, the process may be too aggressive for components made of thin materials vulnerable to impact deformation. Use of manual abrasive pads is generally limited to smaller scale applications such as pre-treatment of parts prior to touch-up processes.

Economic viability

Mechanical cleaning/abrasive blast processes differ fundamentally from pre-treatments using Cr(VI) that are usually carried out by immersion of the part in an aqueous solution containing dissolved chromates. This means that changes to the facilities will be required. The associated costs will depend on the type of operations and size of the dedicated installation.

E.2.6.5.8. Ammonia-based solutions

Technology

Potential alternative for inorganic finish stripping for the removal of copper plating from steel alloys. The process is based on an aerated bath of ammonia used to solubilise copper ions from the substrate surface.

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

This potential alternative is commercially available and has progressed to TRL 3 with good results although there is a reduction in process efficiency. However, it lacks the qualification for use on A&D components as well as the qualification across the supply chain.

Economic viability

This alternative requires a modification to the process line (e.g. equipment for chemical regeneration). No quantitative assessment is presented, only qualitative assessment, which shows an increase in the costs due to new equipment, higher costs of raw material and higher waste disposal costs.

E.2.6.5.9. Cyanide-based solutions

Technology

Potential alternative for inorganic finish stripping for the removal of copper plating from steel. The process uses a ‘reversed’ copper plating process (the components used as anodes and the steel as the cathode) in a sodium cyanide solution.

Risk reduction potential

Although representing a shift away from the use of a non-threshold carcinogen, this alternative involves the use of sodium cyanide (EC 205-599-4) classified for acute toxicity and could lead to the generation of hydrogen cyanide.

Technical feasibility

This potential alternative uses chemicals commercially available, has progressed to TRL 3 with good results, although there is a reduction in process efficiency. In addition, its applicability to other substrates than steel alloys or other coatings than copper is unknown. This candidate lacks the qualification for use on A&D components as well as the qualification across the supply chain.

Economic viability

This alternative would require substantial changes to the process line, including for the treatment of cyanide containing wastewater. In addition, longer process times have been reported.

E.2.6.5.10. Sodium nitrite-based solutions

Technology

Potential alternative for inorganic finish stripping for the removal of copper plating from steel.

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances. However, the company testing this alternative reported the formation of a nitrite vapour when preparing the bath.

Technical feasibility

This potential alternative has shown good results so far, being at TRL 4. It is commercially available but with limited availability in Europe. This candidate lacks the qualification for use on A&D components as well as the qualification across the supply chain.

Economic viability

Some increase in costs is expected due to the new substances. As the process is otherwise similar to the existing one, costs related to adaptation of equipment are expected to be limited.

E.2.6.5.11. Sodium chlorite-based solutions

Technology

Potential alternative for inorganic finish stripping for the removal of copper plating from steel. Two different formulations have been developed and are considered as candidates for the replacement of Cr(VI).

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances. However, sodium chlorite (EC 231-836-6) is classified for acute toxicity and is a strong oxidiser that may cause fire or explosion.

Technical feasibility

Currently both formulations are considered available. They have reached TRL 3-4 and are expected to reach TRL 6 by 2024. Industrialisation could start by 2028. These candidates lack the qualification for use on A&D components as well as the qualification of the supply chain.

Economic viability

The costs are similar to the existing process, but some additional costs are expected for safety reasons (risk of fire or explosion of sodium chlorite) and for waste disposal.

E.2.6.6. Main treatments used in the A&D sector

The main surface treatments comprised in this category include chemical conversion coating (CCC), passivation of stainless steel, chromic acid anodizing (CAA). The potential alternatives identified are reported per main treatment category.

E.2.6.6.1. Boric-sulphuric acid anodising (BSA)

Technology

Potential alternative for chromic acid anodising (CAA).

Risk reduction potential

The potential alternative relies on the use of boric acid (EC 233-139-2) which is classified as reproductive toxicant category 1B.

Technical feasibility

BSA is comparable to CAA in terms of ease of control of operational parameters to avoid potential damage to the substrate. BSA is already industrialised for some components of the A&D sector. In other applications, for example where excellent fatigue strength properties are required, further testing is required. In these cases, the TRL varies from TRL 3 to TRL 7-8, with an expectation for some companies to achieve TRL 9, as early as 2025. Also, use with magnesium and magnesium alloys is at very early stages of evaluation within TRL 1. Transition to a Cr(VI) free alternative may also require the parallel development and approval of a Cr(VI) free anodise sealing process (post-treatment).

Economic viability

Equipment costs for the implementation of BSA are generally expected to be minimal. However, the operative costs are expected to increase due to higher energy costs or higher waste disposal costs.

E.2.6.6.2. Sulphuric acid anodising (SAA)

Technology

Potential alternative for chromic acid anodising (CAA).

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

This potential alternative is commercially available and qualified at certain companies for corrosion protection of both painted and unpainted aluminium alloys, but not for fatigue sensitive components and components of low manufacturing tolerances. The layer thickness of SAA is significantly higher than for CAA. This will in general enhance corrosion protection, at the expense of fatigue strength. It has been reported that SAA surface treatment can reduce the component's fatigue strength by half or more compared to CAA treatment. Issues with the potential for electrolyte residues to be entrapped in the layer deposited have also been reported; these can cause corrosion of the treated component. Transition to a Cr(VI) free alternative may also require the parallel development and approval of a Cr(VI) free anodise sealing process (post-treatment).

Economic viability

Equipment costs for the implementation of SAA are generally expected to be minimal, however the process typically requires more frequent monitoring to ensure process parameters remain within the appropriate ranges. This monitoring may result in increased costs. On the other hand, waste disposal costs are expected to be lower than those of Cr(VI) containing wastes.

E.2.6.6.3. Thin-film sulphuric acid anodising (TFSAA)

Technology

Potential alternative for chromic acid anodising (CAA). Thin Film Sulphuric Acid Anodising is a modification to the standard sulphuric acid anodising process. TFSAA seeks to control the thickness of the anodic layer and reduce impact on fatigue strength.

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

Companies confirmed that the TFSAA process is already approved and implemented by some OEMs, although not universally across the sector. It has been identified as the most promising candidate by many companies. Where not yet introduced/ approved, TFSA has reached TRL 4 – 7 and additional testing needs to be conducted to assess fatigue strength loss. Transition to a Cr(VI) free alternative may also require the parallel development and approval of a Cr(VI) free anodise sealing process (post-treatment).

Economic viability

Research and development to achieve the reduction in layer thickness has led to novel solutions some of which have been published in patents within the EU. However, intellectual property (IP) patents, block some companies from using the technology in the patented form if a commercial arrangement cannot be obtained. Raw material costs for the anodising step are reported to be comparable or lower than CAA and waste disposal costs are expected to be lower than those of Cr(VI) containing wastes.

E.2.6.6.4. Tartaric-sulphuric acid anodising (TSAA)

Technology

Potential alternative for chromic acid anodising (CAA). This category includes tartaric-sulphuric acid anodising long-cycle (TSAA-LC), a variant of TSAA developed with the aim of increasing the scope of applications of TSAA.

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances. However, TSAA would require the introduction of a biocidal agent to prevent fungal growth some of the equipment.

Technical feasibility

TSAA has successfully replaced CAA for providing adequate corrosion resistance in anodising of certain aluminium alloys for certain applications where compatible sealing options (post-treatment) are available.

For some applications on certain alloys comparable results have been reported for corrosion resistance, chemical resistance, and adhesion requirements for bonding processes. However, in some application corrosion resistance provided by TSAA is not sufficient and needs to be supplemented with the use of a subsequent coating with adequate adhesion depending upon the criticality of this function.

Companies have reported that the stability of TSAA solution is more difficult to maintain than that of CAA solution. Transition to a Cr(VI) free alternative may also require the parallel development and approval of a Cr(VI) free anodise sealing process (post-treatment).

Economic viability

Raw materials for TSAA are reported to be more expensive than for CAA (up to twice the cost). In addition, maintenance of the solution requires more frequent analysis than the Cr(VI) process. Changes to the equipment may be necessary (e.g. additional tanks and pipework) as well as microbial control measure (use of a biocidal agent) to prevent fungal growth in immersion tanks or pipework.

E.2.6.6.5. Phosphoric acid-based anodising (PSA/PAA)

Technology

Potential alternative for chromic acid anodising (CAA). This category includes phosphoric-sulphuric anodising (PSA) and phosphoric acid anodising (PAA).

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

Both phosphoric and sulphuric acids are commercially available. The processes are reported as delivering good adhesion performance but insufficient intrinsic corrosion resistance as they are not readily sealed. Therefore, they are only suitable where either sealing is not a requirement or a subsequent coating such as a bonding primer/protective primer is permitted/feasible. For example, PSA has been certified as a replacement for CAA when used prior to specific bonding primer applications.

Economic viability

Raw materials for phosphoric acid-based anodising are reported to be more expensive than for CAA (up to twice the cost). In addition, maintenance of the solution requires more frequent analysis than the Cr(VI) process. Changes to the equipment may also be necessary (e.g. additional tanks and pipework).

E.2.6.6.6. Electrophoretic paint deposition (Anaphoresis)

Technology

Potential alternative for chromic acid anodising (CAA) and chemical conversion coating (CCC). A general description of the technology is given in E.2.3.2. After the deposition process is complete, the part is cured in an oven (110-120°C).

Risk reduction potential

The company that selected this alternative indicated they consider it to constitute a shift to a less hazardous process.

Technical feasibility

According to information reported, a single coating step is necessary with this process. This leads to cycle time reductions and increased production capability. Also, automation makes the process very efficient and excess paint can be recycled. However, issues with insufficient corrosion resistance for military applications have been reported and, for some substrates, additional coating may be needed to improve the corrosion resistance. It is also reported that electrophoretic paint deposition does not provide active corrosion inhibition. The main drawback reported is the fact that the process cannot be applied on assembled aircraft, only on parts that can be disassembled from aircrafts.

Economic viability

According to information provided in AfA, the process does not appear to require sophisticated appliances or expensive chemicals

E.2.6.6.7. Rare earth metals-based alternatives

Technology

Potential alternative for chromic acid anodising (CAA). A conversion coating process is applied to deposit oxides or hydroxides of rare earth elements on the surface of the part to prevent corrosion.

Risk reduction potential

The company that selected this alternative indicated they consider it does not constitute a shift to less hazardous process.

Technical feasibility

The company that selected this alternative indicated they consider it technically feasible. However, recent research also indicates that although rare-earth metals-based surface treatment can provide good corrosion protection to Mg alloys, suitable pre- and post-treatments need to be selected.

Economic viability

The company that selected this alternative indicated they consider it economically feasible.

E.2.6.6.8. Cr(III)-based surface treatments

Technology

Potential alternative for chromic acid anodising (CAA). Cr(III) processes are generally based on the same principle as Cr(VI) processes. There are two main types of solutions: sulphate- and chloride-based.

Risk reduction potential

The company that selected this alternative indicated they consider it does not constitute a shift to less hazardous process.

Technical feasibility

The company that selected this alternative indicated they consider it technically feasible. However, it is also reported that although there are Cr(III)-based surface treatments that might fulfil requirement for some applications, the coating performance is dependent on the optimal combination of product and alloy used. Therefore, the process is not robust enough to meet the requirements for all alloys.

Economic viability

The company that selected this alternative indicated they consider it economically feasible.

E.2.6.6.9. Acidic surface treatments

Technology

Potential alternative for passivation of stainless steel. This category of alternatives includes surface treatments using nitric acid (EC 231-714-2), nitric & hydrofluoric acid mixture and citric acid (EC 201-069-1).

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

The raw materials used in the reported alternatives are expected to be available on the EU market. For those stainless-steel alloys not yet using an alternative to Cr(VI), the majority of substitution has advanced to TRL5 to TRL 9 for nitric acid, with industrialisation expected within 2-4 years. Phased transition across different production lines is reported as a means of managing the implementation of nitric acid. For alloys more sensitive to corrosion, operational parameters have to be adjusted to reduce contact time during processing.

In one example, refining processing conditions (e.g. temperature and concentration) has failed to reproduce the performance achieved with Cr(VI) in combination with post-treatments, such as a bonding primer. Consequently, the whole passivation and bonding system needs to be replaced in unison. To date, even in combination with a Cr(VI) bonding primer, performance of the non-Cr(VI) acid surface treatment is inferior to that delivered with Cr(VI). Further steps are required prior to industrialisation of nitric acid, including the modification of design drawings, incorporating the use of nitric acid across additional designs, and industrial qualification of suppliers in accordance with new process instructions.

The mixture of nitric and hydrofluoric acid (HF) is an option permitted in some OEM specifications. Process conditions need to be monitored as HF at specific concentration can etch stainless steel alloys which may be detrimental to the part design.

Citric acid has achieved TRL 3 to 5, and the qualification process is ongoing. A potential issue to overcome with the use of citric acid is microbial growth in processing equipment; pipework and tanks, as well as on the treated components themselves that may require the use of a biocide as a preventive measure. This outcome could render the test candidate unsuitable if technical feasibility criteria or performance attributes were negatively affected either from the presence of biofilm fragments in the treatment solution, or as an indirect consequence of the use of a biocide. Further work is required to assess any potential risk and impact of biocides. The introduction of another non-certified substance into the production process would also influence the timeline for overall substitution. Steps required prior to industrialisation of citric acid include modification and linkage of the substance to design drawings, qualification of suppliers in accordance with new process instructions, identification and qualification of the biocide (if deemed necessary) for maintenance of processing equipment.

Development and testing work on these alternatives are still ongoing and therefore at present, there are no alternatives which have met the strict regulatory requirements within the A&D industry for all components onto which stainless steel passivation containing Cr(VI) are currently applied.

Economic viability

Limited information is presented regarding economic feasibility in the AfA. However, it is stated that the economic feasibility of the alternative may be a problem for some companies who will meet higher operative costs (caused by e.g. higher raw material prices, higher energy costs because of a higher process temperature needed, infrastructure costs like additional tanks). No estimates of expected cost increases are given.

E.2.6.6.10. Cr(III)-based surface treatments (TCP, Trivalent Chromium Process)

Technology

Potential alternative for chemical conversion coating (CCC).

Risk reduction potential

According to the information presented in the AfAs, this alternative seems to constitute a shift to less hazardous substances. However, the use of hydrogen peroxide (EC 231-765-0) in one of the processes as post-treatment is reported as a reason for concern.

Technical feasibility

Cr(III)-based alternatives are reported to be the most promising and by far the most investigated candidate to replace Cr(VI) in conversion coating. A range of Cr(III)-based proprietary formulations are available on the market and are being investigated by companies in the A&D sector. The different formulations perform differently to each other, even when tested on the same alloy.

The main issues reported is insufficient corrosion protection and the variation of corrosion protection performance on different alloys. Screening tests indicate that better corrosion resistance is achieved on selected aluminium alloys (in 5000 and 6000 series) but this is attributable to the higher inherent corrosion resistance of these alloys.

Adhesion promotion is reported to be sufficient in some cases but insufficient in others. This seems to be linked to the difference in crystalline structure formed by different Cr(III) formulations.

Unlike Cr(VI) coatings, Cr(III) coatings are not clearly coloured and therefore not easily visible on the substrate. This is reported as an issue that prevented the use of Cr(III) for some customers as it can result in difficulties detecting the Cr(III) coating and damages to the coating during quality control inspection.

Cr(VI)-based conversion coatings can accommodate inconsistent/incomplete cleaning and surface activation on a wide variety of aluminium alloys and still produce reliable coatings with acceptable performance. This is not the case with Cr(III)-based alternatives with which performance of the treatment (corrosion resistance) is very sensitive to the type of pre-treatment. Therefore, the corrosion protection package of pre-treatment in conjunction with main treatment need to be considered in parallel.

Altogether, TRLs for Cr(III)-based conversion coatings today range from TRL 3 to TRL 9, depending on the alloy treated, the type of application and the type of components and their use environment.

Economic viability

Due to the sensitivity of Cr(III) to process parameters, it has been reported that additional analytical equipment may be required for maintaining tight control of the chemistry of the treatment bath.

In some cases, additional post-treatment steps are required to achieve the required performance; this means modifications to existing process lines. On a more general level, it was reported that some of the Cr(III)-based alternatives would lead to increased sales prices of components.

E.2.6.6.11. Acidic anodising + organic coating

Technology

Potential alternative for chemical conversion coating (CCC). This category of alternatives includes surface treatments using either sulphuric, tartaric-sulphuric, boric-sulphuric acid or phosphoric acid, in addition to an organic coating/ sealant.

Risk reduction potential

According to the information presented in the AfA, except for the boric-sulphuric acid candidate (boric acid (EC 233-139-2) is classified as reproductive toxicant category 1B), this category of alternatives seems to constitute a shift to less hazardous substances.

Technical feasibility

All anodising variants are commercially available. They can create a hard surface, but the surface will no longer be electrically conductive. This limits the scope of the substitution potential of this category.

Cr(VI)-free acidic anodising can replace Cr(VI) conversion coating prior to paint application in some cases, however it cannot replace all applications of Cr(VI) conversion coating.

Issues with layer thickness (reducing the component's fatigue strength), lack of electrical conductivity, and the difficulty in performing as a localized repair have been reported. In cases where individual companies can achieve acceptable performance testing results for specific components and substrates, validation and certification steps still need to be carried out. Development is reported to be highly application dependent and TRL are between levels 3-9.

Economic viability

Anodising is reported to be potentially more expensive than CCC as it is an electrolytic process requiring electrical current during the application process. This would also mean additional equipment.

E.2.6.6.12. Silane/Siloxane and Sol-gel coating

Technology

Potential alternative for chemical conversion coating (CCC).

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

In general silane/siloxane and sol-gel coatings do not provide adequate corrosion resistance and a subsequent primer/paint coating needs to be applied. This limits the scope of application of this potential alternative. Development varies widely, with TRL 7-9 reported in 2021-22 by a small minority of companies on certain aluminium alloys and parts, in some cases with measures to increase visibility of the coating. In other projects, issues including poor corrosion resistance and surface conductivity have been reported and the developments are at TRL 2-3.

Economic viability

No detailed analysis of economic feasibility has been reported but in general this alternative is not thought to be significantly different from Cr(VI).

E.2.6.7. Post-treatments used in the A&D sector

Post-treatments are required to confer additional beneficial properties to the treated component. Such post-treatments include anodise sealing, passivation, chromate rinsing after phosphating.

E.2.6.7.1. 2-step Cr(III)/Zr-based treatment including hot water sealing

Technology

Potential alternative for anodise sealing.

To deliver the required corrosion resistance and chemical resistance for certain aerospace components porous anodised coatings need to be sealed. Cr(III) sealing alone has been reported to leave a level of porosity that impaired corrosion resistance. This potential alternative includes zirconium that enables the deposition of chromium in the pores by acting as a reaction partner as well as a second sealing step to close remaining pores.

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

The use of Cr(III)/Zr-based treatments with hot water seal relies on commercially available formulations. The process has been demonstrated to be technically feasible as a sealing for some anodising processes. For sealing of tartaric sulphuric-acid anodising (TSA) companies have reported progresses to TRL 5, however there are issues with process optimisation and stability that result in insufficient corrosion resistance. One company has already certified the process for use following TSA LC and is currently working to qualify the process as a sealing for sulphuric acid anodising (SAA). Issues with lack of repeatability and robustness of the sealing have been reported for SAA.

Economic viability

Companies have reported that although using standard equipment, changes to the existing lines are needed (at least one additional tank). In addition, a two-step process will increase processing times and impact the production rates. Potential increases in the volume of wastes have also been reported.

E.2.6.7.2. 2-step Cr(III)/Zr-based treatment including rare-earth elements

Technology

Potential alternative for anodise sealing. Similarly to the alternative process involving hot water sealing, this potential alternative includes a second sealing step to close remaining pores. The bath required for the second step contains hydrogen peroxide.

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

Most of the companies testing this and the alternative process involving hot water sealing in parallel have reported this to be the more promising technology.

2-step Cr(III)/Zr-based treatment including rare-earth element represents a technically feasible test candidate for all anodising processes after which it has been tested, however it still needs to be certified on all relevant components. For some other anodising processes, reproducibility and bath stability still need to be demonstrated on an industrial level.

Economic viability

Companies have reported that changes to the existing lines are needed (at least one additional tank). In addition, a two-step process will increase processing times and impact the production rates. The process requires cooling and ventilation as well as more raw materials (the hydrogen peroxide containing bath degrades over time and regular replenishment is required to maintain performance); therefore, the associated energy and raw material costs will increase. Potential increases in the volume of wastes have also been reported.

E.2.6.7.3. Cr(III)-based surface treatments

Technology

Potential alternative for passivation of non-aluminium metallic coatings.

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

This alternative uses Cr(III) as the passivation agent to be applied to the non-aluminium coating. There are multiple types of formulations (with different additives) that can be suitable for some components or type of non-aluminium coating.

Companies have included different formulations in their testing programmes, progressing in the development of a valid test candidate. Their variety is reflected in the status of development, as it ranges between TRL 3 and TRL 9 (depending on the company, and type of application/component). Unlike Cr(VI) coatings, Cr(III) coatings are not clearly coloured and therefore not easily visible on the substrate. This is reported as an issue that prevented the use of Cr(III) for some customers as it can result in difficulties detecting the Cr(III) coating and damages to the coating during quality control inspection.

In general, the alternative is potentially technically feasible, except for the friction/torque characteristic, which is important for some components. Further testing for this requirement is therefore ongoing. The alternative is commercially available although qualification of the supply chain is needed.

Economic viability

The alternative is considered economically feasible, without any significant impact on costs.

E.2.6.7.4. Zinc-nickel electroplating (passivated by Cr(III))

Technology

Potential alternative for passivation of non-aluminium metallic coatings. This alternative has been developed to replace non-aluminium metallic coating (cadmium coating) with a zinc-nickel coating, which is passivated using Cr(III).

Risk reduction potential

The consensus of companies is that the use of zinc nickel electroplating passivated with Cr(III) will result in an overall risk reduction compared to Cr(VI) and cadmium. However, it should be noted that the reported nickel components of the plating solution (nickel sulphate (EC 232-104-9), nickel dichloride (EC 231-743-0)) have harmonised classifications for CMR properties.

Technical feasibility

There are multiple types of Cr(III)-based proprietary formulations, incorporating a range of different additives, are available on the market. Companies have included different formulations to be used with zinc-nickel electroplating in their testing programmes and report development ranging between TRL 4 and TRL 9 (depending on the company, and type of application/component). This alternative is considered a very promising test candidate to replace cadmium-plated surfaces which have been passivated by Cr(VI) or Cr(III). It is technically feasible and, in some cases, considered a drop-in alternative. However, issues have been reported for example in its application to fasteners and connectors and additional testing is required. The alternative is commercially available although qualification of the supply chain is needed.

Economic viability

Production costs are generally expected to increase. Additional sand blasting may be required before the plating. With some of the Cr(III)-based formulations additional temperature controls (heating/cooling) is required and generally speaking, the plating process requires more time. The chemistry of the plating solution is also reported to be more complex to maintain, requiring specialist analytical equipment.

E.2.6.7.5. Acidic Surface Treatments

Technology

Potential alternative for passivation of non-aluminium metallic coatings on steel. This category of potential alternatives includes nitric passivation, an inorganic acid solution and a phosphating acid solution.

Risk reduction potential

All three selected treatments were considered as less hazardous than the current Cr(VI) process.

Technical feasibility

For the passivation of steels, nitric acid can be used and has already been implemented for decades, although it may not be applicable to all kinds of stainless steels and metallic coatings. Nitric acid passivation is qualified for certain applications, but this does not cover the full range of corrosion requirements of the aeronautics and aerospace sector. A post-treatment process is necessary for some stainless steels, e.g., high carbon stainless steels at 440°C, and this is usually performed with chromium trioxide. Information regarding the other two acid-based passivation alternatives was not provided. All three reported acidic treatments were considered (potentially) technically feasible. All three acidic treatments were considered to be generally available but would need more time for implementation.

Economic viability

Two of the three treatments are considered to be economically feasible. For the third one, inacceptable higher running costs and a higher sales price of the final components were expected.

E.2.6.7.6. Hot water sealing (possibly including inhibitors)

Technology

Potential alternative for chromate rinsing after phosphating. Phosphating is a chemical treatment applied to steel parts that creates a thin adhering layer of iron, zinc, or manganese phosphates to improve corrosion resistance or lubrication or as a foundation for subsequent coatings or painting. It naturally generates a certain porosity which negatively affects the corrosion resistance of the coated surface if no post-treatment is used. Hot water sealing can be used as a rinsing post-treatment after phosphate to remove residues from the previous process and increase the corrosion resistance by passivating the surface. This category of alternatives includes hot water sealing and hot water sealing with inhibitors (such as such as hexafluorozirconic acid (EC 234-666-0)).

Risk reduction potential

According to the information presented in the AfA, this alternative seems to constitute a shift to less hazardous substances.

Technical feasibility

Hot water used by itself as a rinse after phosphating may help dry components and prevent instantaneous corrosion but otherwise provides no other functionality. Therefore, the formulations tested contain inhibitor additives. Some of the test candidates are in use by some companies for some components on some alloys, however significant technical challenges remain before any of these test candidates can be used in all situations.

One company is treating a particular class of components with a modified phosphating process, and for this they are using a proprietary Cr(VI)-free zirconium-based rinse. However, the inferior corrosion protection provided by the process limits its use and it is necessary to undertake feasibility studies on other classes of components. Another company is using another proprietary Cr(VI)-free zirconium-based rinse (based on hexafluorozirconic acid). Performance was not significantly different from the incumbent Cr(VI) rinsing process. In this specific case, the change did not impact the qualification of components as this type of alternative was already included in the specifications.

Economic viability

In general, companies reported they did not expect any significant impact on the economic feasibility when using hot water sealing with inhibitor additives for rinsing after phosphating, compared to the Cr(VI)-based rinsing process. Companies have reported that some limited modifications to the existing process lines would be necessary but no there are no significant differences in the equipment required.

Table 51. Information on substances identified as potential alternative in other surface treatments using Cr(VI) substances

Shortlisted Alternative	Substance name	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
2-step Cr(III)/Zr-based treatment including hot water sealing	Ammonium nitrate	229-347-8	6484-52-2	-	Oxid. Solid 3, H272 Eye Irrit. 2, H319	-
2-step Cr(III)/Zr-based treatment including hot water sealing	Dichromium tris(sulphate)	233-253-2	10101-53-8	-	Acute Tox. 4, H302 Skin Corr. 1, H314 Eye Damage 1, H318 Skin Sens. 1, H317 Aquatic Chronic 2, H411	-
2-step Cr(III)/Zr-based treatment including hot water sealing	Ammonium hexafluorozirconate	240-970-4	16919-31-6	-	Acute Tox. 3, H301 Skin Irrit. 2, H315 Eye Damage 1, H318 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Chronic 3, H412	Classification in registration for STOT RE 1
2-step Zr-based treatment including rare earth elements	Hydrogen peroxide	231-765-0	7722-84-1	Eye Dam. 1, H318 Eye Irrit. 2, H319 Ox. Liq. 1, H271 Ox. Liq. 2, H272 Skin Corr. 1A, H314 Skin Corr. 1B, H314 Skin Irrit. 2, H315 STOT SE 3, H335 Acute Tox. 4, H302 Ox. Liq. 1, H271 Acute Tox. 4, H332	Skin Corr. 1A, H314 Oxid. Liquid 1, H271 Acute Tox. 4, H302 Acute Tox. 4, H332 Eye Damage 1, H318 STOT SE 3, H335 Aquatic Chronic 3, H412	-
2-step Zr-based treatment including rare earth elements	Dipotassium hexfluorozirconate	240-985-6	16923-95-8	-	Acute Tox. 3, H301 Eye Damage 1, H318	-
2-step Zr-based treatment including rare earth elements	Lanthanum nitrate hexahydrate	600-351-5	10277-43-7	-	-	Not REACH registered Lanthanum is identified as critical raw material
Acidic anodising + organic coating	(+)-tartaric acid	201-766-0	87-69-4	-	Eye Damage 1, H318	-
Acidic anodising + organic coating	(±)-tartaric acid	205-105-7	133-37-9	-	Eye Damage 1, H318	-

Shortlisted Alternative	Substance name	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
Acidic anodising + organic coating	Orthophosphoric acid	231-633-2	7664-38-2	Irrit. 2, H319 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Corr. 1B, H314 Eye Damage 1, H318	Phosphorus is identified as critical raw material
Acidic anodising + organic coating	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315	Acute Tox. 3, H331 Skin Corr. 1A, H314	-
Acidic anodising + organic coating	Boric acid	233-139-2	10043-35-3	Repr. 1B, H360FD	Repr. 1B, H360	CLH for Repr. 1B Identified SVHC for Toxic for reproduction (Article 57c) Boron is identified as critical raw material
Acidic surface treatments	Citric acid	201-069-1	77-92-9	Eye Irrit. 2, H319 STOT SE 3, H335	Eye Irrit. 2, H319 STOT SE 3, H335	-
Acidic surface treatments	Hydrogen fluoride	231-634-8	7664-39-3	Acute Tox. 2, H300 Acute Tox. 1, H310 Skin Corr. 1A, H314 Acute Tox. 2, H330	Acute Tox. 2, H300 Acute Tox. 1, H310 Acute Tox. 2, H330 Skin Corr. 1A, H314	-
Acidic surface treatments	Nitric acid	231-714-2	7697-37-2	Skin Corr. 1A, H314 Ox. Liq. 2, H272 Acute Tox. 1, H330 Ox. Liq. 2, H272 Ox. Liq. 3, H272	Oxid. Liquid 3, H272 Oxid. Liquid 2, H272 Met. Corr. 1, H290 Acute Tox. 3, H331 Acute Tox. 1, H330 Skin Corr. 1A, H314 Eye Damage 1, H318	-
Ammonia-based solutions	Ammonia, anhydrous	231-635-3	7664-41-7	Skin Corr. 1B, H314 Press. Gas Flam. Gas 2, H221 Acute Tox. 3, H331 Aquatic Acute 1, H400	Flam. Gas 2 H221 Liquefied gas H280 Acute Tox. 4 H332 Acute Tox. 3 H331 Skin Corr. 1B H314 STOT SE 3 H335 Aquatic Acute 1, H400 Aquatic Chronic 2, H411	-
Benzotriazoles-based processes	6-methylbenzotriazole	205-265-8	136-85-6	-	Skin Corr. 1B, H314 Eye Damage 1, H318	-
Boric Sulphuric acid anodising	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315 Skin Corr. 1A, H314	Acute Tox. 3, H331 Skin Corr. 1A, H314	-

Shortlisted Alternative	Substance name	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
Boric Sulphuric acid anodising	Boric acid	233-139-2	10043-35-3	Repr. 1B, H360FD	Repr. 1B, H360	CLH for Repr. 1B Identified SVHC for Toxic for reproduction (Article 57c) Boron is identified as critical raw material
Cr(III) for anodic pickling	Nickel chloride (NiCl2), hexahydrate	616-576-7	7791-20-0	-	-	Not REACH registered Nickel (battery grade) is identified as critical raw material
Cr(III) process	Dichromium tris(sulphate)	233-253-2	10101-53-8	-	Acute Tox. 4, H302 Skin Corr. 1, H314 Eye Damage 1, H318 Skin Sens. 1, H317 Aquatic Chronic 2, H411	-
Cr(III)-based alternatives	Cobalt dinitrate	233-402-1	10141-05-6	Repr. 1B, H360D STOT RE 1, H372 Muta. 2, H341 Carc. 1A, H350i Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 2, H373	Carc. 1A, H350i Carc. 1B, H350i Muta. 2, H341 Repr. 1B, H360FD Oxid. Solid 2, H272 Acute Tox. 4 H302, Eye Damage 1, H318 Resp. Sens. 1B, H334 Skin Sens. 1, H317 Skin Sens. 1A, H317 STOT RE 2, H373 Aquatic Acute 1, H400 Aquatic Chronic 2, H411 Aquatic Chronic 1, H410	CLH for Carc. 1B, Muta. 2, Repr. 1B, Resp. Sens. 1 Identified SVHC for Carcinogenic (Article 57a) and Toxic for reproduction (Article 57c) Cobalt is identified as critical raw material
Cr(III)-based surface treatments	Chromium(III) oxide	215-160-9	1308-38-9	-	Carc. 1A, H350 Muta. 1B, H340 Repr. 2, H361 Acute Tox. 4, H302 Acute Tox. 3, H311 Acute Tox. 3, H331 Acute Tox. 4, H332 Acute Tox. 2, H330 Skin Irrit. 2, H315 Skin Corr. 1A, H314 Eye Damage 1, H318 Eye Irrit. 2, H319	Classification in registration for Carc. 1A, Muta. 1B, Repr. 2, Resp. Sens. 1, STOT RE 1

Shortlisted Alternative	Substance name	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
					Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 STOT RE 2, H373 STOT SE 3, H335 Aquatic Chronic 2, H411 Aquatic Chronic 3, H412	
Cr(III)-based surface treatments	Hydrogen fluoride	231-634-8	7664-39-3	Acute Tox. 2, H300 Acute Tox. 1, H310 Skin Corr. 1A, H314 Acute Tox. 2, H330	Acute Tox. 2, H300 Acute Tox. 1, H310 Acute Tox. 2, H330 Skin Corr. 1A, H314	-
Cr(III)-based surface treatments	Nickel dichloride	231-743-0	7718-54-9	Skin Irrit. 2, H315 Skin Sens. 1, H317 STOT RE 1, H372 STOT RE 2, H373 Acute Tox. 3, H301 Repr. 1B, H360D Muta. 2, H341 Carc. 1A, H350i Acute Tox. 3, H331 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334	Skin Irrit. 2, H315 Carc. 1A, H350 Repr. 1B, H360 Skin Sens. 1, H317 STOT RE 1, H372 Carc. 1A, H350i Muta. 2, H341 Repr. 1B, H360D Acute Tox. 3, H301 Acute Tox. 3, H331 Skin Irrit. 2, H315 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	CLH for Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Resp. Sens. 1 Nickel (battery grage) is identified as critical raw material
Cr(III)-based surface treatments	Hydrogen peroxide	231-765-0	7722-84-1	Eye Dam. 1, H318 Eye Irrit. 2, H319 Ox. Liq. 1, H271 Ox. Liq. 2, H272 Skin Corr. 1A, H314 Skin Corr. 1B, H314 Skin Irrit. 2, H315 STOT SE 3, H335 Acute Tox. 4, H302 Ox. Liq. 1, H271 Acute Tox. 4, H332	Skin Corr. 1A, H314 Oxid. Liquid 1, H271 Acute Tox. 4, H302 Acute Tox. 4, H332 Eye Damage 1, H318 STOT SE 3, H335 Aquatic Chronic 3, H412	-
Cr(III)-based surface treatments	Zinc sulphate	231-793-3	7733-02-0	Acute Tox. 4, H302 Eye Dam. 1, H318	Acute Tox. 4, H302 Eye Damage 1, H318	-

Shortlisted Alternative	Substance name	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
				Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Aquatic Acute 1, H400 Aquatic Chronic 1, H410	
Cr(III)-based surface treatments	Nickel sulphate	232-104-9	7786-81-4	Acute Tox. 4, H302 Skin Irrit. 2, H315 Repr. 1B, H360D STOT RE 1, H372 Muta. 2, H341 Carc. 1A, H350i Acute Tox. 4, H332 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 STOT RE 2, H373	Skin Irrit. 2, H315 Skin Sens. 1, H317 STOT RE 1, H372 Repr. 1B, H360 Carc. 1A, H350i Carc. 1A, H350 Muta. 2, H341 Repr. 1B, H360D Acute Tox. 4, H302 Acute Tox. 4, H332 Skin Irrit. 2, H315 Eye Irrit. 2, H319 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	CLH for Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Resp. Sens. 1 Nickel (battery grade) is identified as critical raw material
Cr(III)-based surface treatments	Chromium trifluoride	232-137-9	7788-97-8	-	Acute Tox. 3, H301 Skin Corr. 1, H314 Eye Damage 1, H318 Skin Sens. 1, H317 Aquatic Acute 1, H400 Aquatic Chronic 2, H411	-
Cr(III)-based surface treatments	Cobalt dinitrate	233-402-1	10141-05-6	Carc. 1B, H350i Muta. 2, H341 Repr. 1B, H360F Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334 Skin Sens. 1, H317	Oxid. Solid 2, H272 Acute Tox. 4, H302 Eye Damage 1, H318 Resp. Sens. 1B, H334 Skin Sens. 1, H317 Skin Sens. 1A, H317 STOT RE 2 H373 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Aquatic Chronic 2, H411 Carc. 1A, H350 Carc. 1B, H350 Muta. 2, H341 Repr. 1B, H360	CLH for Carc. 1B, Muta. 2, Repr. 1B, Resp. Sens. 1 Identified SVHC for Carcinogenic (Article 57a) and Toxic for reproduction (Article 57c) Cobalt is identified as critical raw material
Cr(III)-based surface treatments	Chromium hydroxide sulphate	235-595-8	12336-95-7	-	Skin Irrit. 2, H315 Eye Irrit. 2, H319	-

Shortlisted Alternative	**Substance name**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
					Skin Sens. 1, H317 Aquatic Chronic 3, H412	
Cr(III)-based surface treatments	Chromium trinitrate	236-921-1	13548-38-4	-	Oxid. Solid 3, H272 Acute Tox. 4, H332 Skin Corr. 1B, H314 Eye Damage 1, H318 Skin Sens. 1A, H317 Aquatic Chronic 2, H411	-
Cr(III)-based surface treatments	Ammonium hexafluorosilicate	240-968-3	16919-19-0	Acute Tox. 3, H301 Acute Tox. 3, H311 Acute Tox. 3, H331	Eye Irrit. 2, H319 Aquatic Chronic 3, H412 Acute Tox. 3, H301 Acute Tox. 3, H311 Acute Tox. 3, H331 Eye Damage 1, H318	-
Cr(III)-based surface treatments	Ammonium hexafluorozirconate	240-970-4	16919-31-6	-	Acute Tox. 3, H301 Skin Irrit. 2, H315 Eye Damage 1, H318 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Chronic 3, H412	Classification in registration for STOT RE 1
Cr(III)-based surface treatments	Dipotassium hexafluorozirconate	240-985-6	16923-95-8	-	Acute Tox. 3, H301 Eye Damage 1, H318	-
Cr(III)-based surface treatments	Zinc sulfate heptahydrate	616-097-3	7446-20-0	Acute Tox. 4, H302 Eye Dam. 1, H318 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	-	Not REACH registered
Cyanide-based solutions	Sodium cyanide	205-599-4	143-33-9	-	Aquatic Acute 1, H400 Met. Corr. 1, H290 Acute Tox. 1, H300 Acute Tox. 1, H310 Acute Tox. 1, H330 Skin Corr. 1B, H314 Skin Irrit. 2, H315 Eye Irrit. 2, H319 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Classification in registration for STOT RE 1
Cyanide-based solutions	Sodium hydroxide	215-185-5	1310-73-2	Skin Corr. 1A, H314 Eye Irrit. 2, H319 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1, H290 Skin Corr. 1A, H314 Eye Damage 1, H318	-

Shortlisted Alternative	Substance name	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
Hot water-based sealing with inhibitors	Dihydrogen hexafluorozirconate(2-)	234-666-0	12021-95-3	-	Met. Corr. 1, H290 Acute Tox. 3, H301 Acute Tox. 3, H311 Acute Tox. 3, H331 Skin Corr. 1B, H314 Eye Dam. 1, H318	-
Manganese-based etching	Manganese	231-105-1	7439-96-5	-	Aquatic Chronic 3, H412 Aquatic Chronic 2, H411	Manganese is identified as critical raw material
Manganese-based etching	Manganese sulphate	232-089-9	7785-87-7	STOT RE 2, H373 Aquatic Chronic 2, H411	Eye Damage 1, H318 STOT RE 2, H373 Aquatic Chronic 2, H411	Manganese is identified as critical raw material
Manganese-based etching	Sodium permanganate	233-251-1	10101-50-5	-	Oxid. Liquid 2, H272 Skin Corr. 1A, H314 Eye Damage 1, H318 STOT RE 2, H373	Manganese is identified as critical raw material
Mechanical cleaning/Abrasive blast	Aluminium oxide	215-691-6	1344-28-1	-	Carc. 2, H351 Carc. 1A, H350 Acute Tox. 4, H302 Acute Tox. 4, H332 Eye Irrit. 2, H319 Skin Sens. 1, H317 STOT RE 2, H373	Classification in registration for Carc. 1A, Carc. 2
Mechanical cleaning/Abrasive blast	Iron	231-096-4	7439-89-6	-	Flam. Solid 1, H228 Self Heat. 1, H251	-
Mechanical cleaning/Abrasive blast	Silicon dioxide	231-545-4	7631-86-9	-	STOT RE 2, H373	-
Mechanical cleaning/Abrasive blast	Pumice	603-719-3	1332-09-8	-	-	Not REACH registered
Mechanical cleaning/Abrasive blast	Glass	920-837-3	308066-74-2	-	-	Not REACH registered
Nitric/sulphuric acid mixture	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315	Acute Tox. 3, H331 Skin Corr. 1A, H314	-
Nitric/sulphuric acid mixture	Nitric acid	231-714-2	7697-37-2	Skin Corr. 1A, H314 Ox. Liq. 2, H272 Acute Tox. 1, H330	Oxid. Liquid 3, H272 Oxid. Liquid 2, H272 Met. Corr. 1, H290 Acute Tox. 3, H331	-

Shortlisted Alternative	Substance name	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
				Ox. Liq. 2, H272 Ox. Liq. 3, H272	Acute Tox. 1, H330 Skin Corr. 1A, H314 Eye Damage 1, H318	
Organometallics (zirconium and titanium-based products)	Zirconium dioxide	215-227-2	1314-23-4	-	-	-
Organometallics (zirconium and titanium-based products)	Dihydrogen hexafluorotitanate(2-)	241-460-4	17439-11-1	-	Met. Corr. 1, H290 Acute Tox. 3, H301 Acute Tox. 3, H311 Acute Tox. 3, H331 Skin Corr. 1, H314	-
Phosphoric acid/sodium molybdate	Nitric acid	231-714-2	7697-37-2	Skin Corr. 1A, H314 Ox. Liq. 2, H272 Acute Tox. 1, H330 Ox. Liq. 2, H272 Ox. Liq. 3, H272	Oxid. Liquid 3, H272 Oxid. Liquid 2, H272 Met. Corr. 1, H290 Acute Tox. 3, H331 Acute Tox. 1, H330 Skin Corr. 1A, H314 Eye Damage 1, H318	-
Phosphoric acid/sodium molybdate stripping	Disodium molybdate	231-551-7	7631-95-0	-	-	-
Phosphoric acid/sodium molybdate stripping	Orthophosphoric acid	231-633-2	7664-38-2	Eye Irrit. 2, H319 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Corr. 1B, H314 Eye Damage 1, H318	Phosphorus is identified as critical raw material
Phosphoric acid-based anodising	Orthophosphoric acid	231-633-2	7664-38-2	Eye Irrit. 2, H319 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Corr. 1B, H314 Eye Damage 1, H318	Phosphorus is identified as critical raw material
Phosphoric acid-based anodising	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315 Skin Corr. 1A, H314	Acute Tox. 3, H331 Skin Corr. 1A, H314	-
Phosphoric acid-based anodising solutions	Sodium hydrogendifluoride	215-608-3	1333-83-1	Eye Irrit. 2, H319 Skin Corr. 1B, H314 Skin Irrit. 2, H315 Acute Tox. 3, H301	Acute Tox. 3, H301 Skin Corr. 1B, H314	-

Shortlisted Alternative	**Substance name**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
Phosphoric acid-based anodising solutions	Orthophosphoric acid	231-633-2	7664-38-2	Eye Irrit. 2, H319 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Corr. 1B, H314 Eye Damage 1, H318	Phosphorus is identified as critical raw material
Phosphoric acid-based anodising solutions	Hydrogen fluoride	231-634-8	7664-39-3	Acute Tox. 2, H300 Acute Tox. 1, H310 Skin Corr. 1A, H314 Acute Tox. 2, H330	Acute Tox. 2, H300 Acute Tox. 1, H310 Acute Tox. 2, H330 Skin Corr. 1A, H314	-
Phosphoric acid-based anodising solutions	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315	Acute Tox. 3, H331 Skin Corr. 1A, H314	-
Phosphoric acid-based anodising solutions	Potassium hydrogendifluoride	232-156-2	7789-29-9	Eye Irrit. 2, H319x Skin Corr. 1B, H314 Skin Irrit. 2, H315 Acute Tox. 3, H301	Acute Tox. 3, H301 Skin Corr. 1B, H314	-
Phosphoric acid-based stripping and pre-treatment solutions	Orthophosphoric acid	231-633-2	7664-38-2	Skin Corr. 1B, H314 Eye Irrit. 2, H319 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1,H290 Acute Tox. 4, H302 Skin Corr. 1B, H314 Eye Damage 1, H318	Phosphorus is identified as critical raw material
Physical vapour deposition (PVD)	Graphene	801-282-5	1034343-98-0	-	Aquatic Chronic 3, H412	-
Phytic acid	Fytic acid	201-506-6	83-86-3	-	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Corr. 1, H314 Eye Damage 1, H318	-
Sodium chlorite-based solutions	Ammonium hydrogencarbonate	213-911-5	1066-33-7	-	Acute Tox. 4, H302	-
Sodium chlorite-based solutions	3,6,9-triazaundecamethylene diamine tetraethylenepentamine	203-986-2	112-57-2	Acute Tox. 4, H302 Acute Tox. 4, H312 Skin Corr. 1B, H314 Aquatic Chronic 2, H411 Skin Sens. 1, H317	-	Not REACH registered
Sodium chlorite-based solutions	Sodium carbonate	207-838-8	497-19-8	Eye Irrit. 2, H319	Eye Irrit. 2, H319	-
Sodium chlorite-based solutions	Ammonia, aqueous solution	215-647-6	1336-21-6	STOT SE 3, H335 Skin Corr. 1B, H314 Aquatic Acute 1, H400	Skin Corr. 1A, H314 STOT SE 3, H335 Aquatic Acute 1, H400	-
Sodium chlorite-based solutions	Sodium chlorite	231-836-6	7758-19-2	-	Oxid. Solid 1, H271 Acute Tox. 3, H301 Acute Tox. 2, H310	-

Shortlisted Alternative	**Substance name**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
					Skin Corr. 1B, H314 STOT RE 2, H373 Aquatic Acute 1, H400 Aquatic Chronic 3, H412	
Sodium chlorite-based solutions	Ammonium carbonate	233-786-0	10361-29-2	-	Acute Tox. 4, H302	-
Sodium hydroxide containing additives	Sodium hydroxide	215-185-5	1310-73-2	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Corr. 1B, H314 Skin Irrit. 2, H315	Met. Corr. 1, H290 Skin Corr. 1A, H314 Eye Damage 1, H318	-
Sodium nitrite-based solutions	Sodium acetate	204-823-8	127-09-3	-	-	-
Sodium nitrite-based solutions	Sodium nitrite	231-555-9	7632-00-0	Acute Tox. 3, H301 Ox. Sol. 3, H272 Aquatic Acute 1, H400	Oxid. Solid 3, H272 Eye Irrit. 2, H320 Oxid. Solid 2, H272 Acute Tox. 3, H301 Eye Irrit. 2A, H319 Aquatic Acute 1, H400	-
Sulfonitroferric acid (and derived proprietary formulations)	Hydrogen fluoride	231-634-8	7664-39-3	Acute Tox. 2, H300 Acute Tox. 1, H310 Skin Corr. 1A, H314 Acute Tox. 2, H330	Acute Tox. 2, H300 Acute Tox. 1, H310 Acute Tox. 2, H330 Skin Corr. 1A, H314	-
Sulfonitroferric acid (and derived proprietary formulations)	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315	Acute Tox. 3, H331 Skin Corr. 1A, H314	-
Sulfonitroferric acid (and derived proprietary formulations)	Nitric acid	231-714-2	7697-37-2	Skin Corr. 1A, H314 Ox. Liq. 2, H272 Acute Tox. 1, H330 Ox. Liq. 2, H272 Ox. Liq. 3, H272	Oxid. Liquid 3, H272 Oxid. Liquid 2, H272 Met. Corr. 1, H290 Acute Tox. 3, H331 Acute Tox. 1, H330 Skin Corr. 1A, H314 Eye Damage 1, H318	-
Sulfonitroferric acid (and derived proprietary formulations)	Potassium nitrate	231-818-8	7757-79-1	-	Oxid. Solid 3, H272	-
Sulfonitroferric acid (and derived proprietary formulations)	Diiron tris(sulphate)	233-072-9	10028-22-5	-	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Irrit. 2, H315	-

Shortlisted Alternative	**Substance name**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
					Eye Damage 1, H318 Skin Sens. 1, H317	
Sulphuric acid (anodising/ including electrolytic sulphuric acid pickling)	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315	Acute Tox. 3, H331 Skin Corr. 1A, H314	-
Tartaric sulphuric acid anodising	(+)-tartaric acid	201-766-0	87-69-4	-	Eye Damage 1, H318	-
Tartaric sulphuric acid anodising	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315 Skin Corr. 1A, H314	Acute Tox. 3, H331 Skin Corr. 1A, H314	-
Thin-film sulphuric acid anodizing	Sulphuric acid	231-639-5	7664-93-9	Eye Irrit. 2, H319 Skin Corr. 1A, H314 Skin Irrit. 2, H315 Skin Corr. 1A, H314	Acute Tox. 3, H331 Skin Corr. 1A, H314	-
Zinc-nickel electroplating (passivated by Cr(III))	Zinc oxide	215-222-5	1314-13-2	Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Repr. 1A, H360 Acute Tox. 4, H302 Acute Tox. 4, H332 STOT RE 2, H373 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Classification in registration for Repr. 1A
Zinc-nickel electroplating (passivated by Cr(III))	Nickel sulphate	232-104-9	7786-81-4	Acute Tox. 4, H302 Skin Irrit. 2, H315 Repr. 1B, H360D STOT RE 1, H372 Muta. 2, H341 Carc. 1A, H350i Acute Tox. 4, H332 Aquatic Acute 1, H400 Aquatic Chronic 1, H410 Resp. Sens. 1, H334 Skin Sens. 1, H317 Skin Irrit. 2, H315 Skin Sens. 1, H317 STOT RE 1, H372 STOT RE 2, H373	Skin Irrit. 2, H315 Skin Sens. 1, H317 STOT RE 1, H372 Repr. 1B, H360 Carc. 1A, H350i Carc. 1A, H350 Muta. 2, H341 Repr. 1B, H360D Acute Tox. 4, H302 Acute Tox. 4, H332 Skin Irrit. 2, H315 Eye Irrit. 2, H319 Resp. Sens. 1, H334 Skin Sens. 1, H317 STOT RE 1, H372 Aquatic Acute 1, H400 Aquatic Chronic 1, H410	CLH for Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Resp. Sens. 1 Nickel (battery grade) is identified as critical raw material

Shortlisted Alternative	**Substance name**	**EC / List no**	**CAS**	**Harmonised classification**	**Classifications in registrations**	**Remarks**
Zinc-nickel electroplating (passivated by Cr(III))	Disodium tetrahydroxy zincate	235-342-1	12179-14-5	-	-	Not REACH registered

Source: based on information provided as part of Cr(VI) AfAs.

E.2.7. Alternatives to Cr(VI) in uses as functional additive or process aid

Different uses applied for are grouped under this use category. The uses and public information on potential alternatives gathered from the applications for authorisation received by ECHA[69] are briefly summarised below.

E.2.7.1. Alkali metal dispenser

Potassium chromate, Sodium chromate are used as alkali metal dispenser in the production of photocathodes. Vanadate, tungstate, silicate or other salts are identified as potential alternatives but have been rejected due to technical feasibility and availability issues. Digital detectors, thermal or IR imaging technologies were also considered but rejected for technical feasibility reasons.

1 AfA submitted for 2 uses. The authorisations delivered are valid until March 2026. The authorisation holder has submitted a review report to ECHA. Reference IDs 0115-01 - 0115-04 on Adopted opinions and previous consultations on applications for authorisation - ECHA.

E.2.7.2. Anticorrosion in cooling systems

Sodium chromate and especially sodium dichromate are used to prevent corrosion and scaling in cooling systems (generally in closed systems) for various applications (gas absorption heat pumps, production of freeze-dried food products, dewaxing and deoiling process of petroleum raffinate, etc.).

Although chemicals alternatives have been considered (molybdate compounds, Sodium nitrite, Zinc containing corrosion inhibitors etc.) for some of the applications, change of (parts of) the cooling system has also been mentioned. In most cases the potential alternatives have been rejected for technical feasibility reasons.

8 AfAs submitted for 8 uses in total. The authorisations delivered are valid until max. August 2034. Reference IDs 0030-01, 0042-01, 0074-01, 0075-01, 0104-01, 0124-01, 0136-01 and 0236-01 on Adopted opinions and previous consultations on applications for authorisation - ECHA.

E.2.7.3. Catalyst, processing aid

Chromium trioxide and especially sodium dichromate are used as catalysts or processing aids in the electrolytic manufacture of different chemicals or ore processing applications.

In many applications, Chromium(III) chloride, Sodium molybdate, Molybdenum-based cathode coatings and Two-compartment electrolytic systems have been rejected, mostly for technical or economic feasibility reasons.

10 AfAs submitted for 11 uses in total. One authorisation delivered has expired, the other ones are valid until max. August 2032. Reference IDs 0031-01, 0035-01, 0036-01, 0037-01, 0038-01, 0039-01, 0040-01, 0041-01, 0041-02, 0102-01 and 0137-01 on Adopted opinions and previous consultations on applications for authorisation - ECHA.

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[69] Cases that are in the ECHA opinion or Commission decision making process or that have a valid authorisation. Cases for which the authorisation decision expired, have been refused or are discontinued and for which no review report have been submitted are excluded as these specific uses are no longer legally authorised in the EU.

E.2.7.4. Photochemical

Ammonium dichromate is used as a photosensitizer in UV lithography process to manufacture micro-structured components (filters, sieves, grids, etc.). Photosensitizer based on other chemistry (iron-arene complex SYN936 with sodium chlorate or with cumol hydroperoxide; Diazo-based polymers with formaldehyde; chromium-free photosensitive lacquer) have been explored but rejected for technical feasibility reasons. Alternative structuring technologies (laser direct ablation) have been explored in some of the applications but rejected for technical, economic feasibility and availability reasons.

2 AfAs submitted for 2 uses in total. One authorisation delivered has expired, the other one is valid until September 2029. Reference IDs 0049-01 and 0073-01 on Adopted opinions and previous consultations on applications for authorisation - ECHA.

E.2.7.5. Colour indicator

Potassium dichromate is used as a colour indicator in single-use chemical breathalysers. The chemical breathalyser contains silica crystals on which potassium dichromate and sulphuric acid are adsorbed. When used and in in the presence of a certain level of alcohol, the orange-coloured dichromate ions are reduced by ethanol to green Cr3+ ions. One alternative has been identified as very promising but there are still technical issues to be addressed before full transition to this alternative is possible.

1 AfA submitted for 1 use, RAC/SEAC opinion finalised in July 2024 (review period recommended until 29 May 2027), authorisation not granted yet at the time of writing. Reference ID 0351-01 on Adopted opinions and previous consultations on applications for authorisation - ECHA.

Table 52. Information on substances identified as potential alternative to Cr(VI) substances used as functional additive

Shortlisted Alternative	Substance / material	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
Cr(III) chloride	Chromium trichloride	233-038-3	10025-73-7	-	Met. Corr. 1, H290 Acute Tox. 4, H302 Skin Sens. 1, H317 Aquatic Chronic 2, H411	-
Dextrin	Dextrin	232-675-4	9004-53-9	-	-	Not REACH registered
Molybdate	Ammonium molybdate(VI)	236-031-3	13106-76-8	-	Acute Tox. 4 H302	-
Phosphates and phosphonate compounds	Trisodium orthophosphate	231-509-8	7601-54-9	-	Skin Irrit. 2 H315, Eye Irrit. 2 H319, STOT SE 3 H335, , affected organs: Respiratory tract	Phosphorus is identified as critical raw material
Rare Earth Metal Salts (REMSs)	Cerium trinitrate	233-297-2	10108-73-3	-	Oxid. Solid 3 H272 Eye Damage 1 H318 Aquatic Acute 1 H400 Aquatic Chronic 1 H410	Cerium is identified as critical raw material
Silicates and water glass	Calcium silicate	233-250-6	10101-39-0	-	-	Not REACH registered
Silicates and water glass	Calcium borate silicate	686-605-6	59794-15-9	-	-	Not REACH registered
Sodium molybdate as processing aid	Disodium molybdate	231-551-7	7631-95-0	-	-	-
Sodium nitrite	Sodium nitrite	231-555-9	7632-00-0	7632-00-0	Acute Tox. 3, H301 Ox. Sol. 3, H272 Aquatic Acute 1, H400	Oxid. Solid 3, H272 Eye Irrit. 2, H320 Oxid. Solid 2, H272 Acute Tox. 3, H301 Eye Irrit. 2A, H319 Aquatic Acute 1, H400
Strong alkaline solutions	Potassium hydroxide	215-181-3	131E-58-3	Acute Tox. 4; H302 Skin Corr. 1A; H314 Eye Irrit. 2; H319 Skin Irrit. 2; H315	Skin Corr. 1A H314 Met. Corr. 1 H290 Acute Tox. 4 H302 Skin Corr. 1A H314 Eye Damage 1 H318 STOT SE 3 H335	-
Zinc containing corrosion inhibitors	Zinc	231-175-3	7440-66-6	-	Aquatic Acute 1 H400 Aquatic Chronic 1 H410 Aquatic Chronic 2 H411	-
Zinc containing corrosion inhibitors	Trizinc bis(orthophosphate)	231-944-3	7779-90-0	Aquatic Acute 1, H400	Aquatic Acute 1, H400 Aquatic Chronic 1, H410	Phosphorus is identified as critical raw material

Shortlisted Alternative	Substance / material	EC / List no	CAS	Harmonised classification	Classifications in registrations	Remarks
				Aquatic Chronic 1, H410		

Source: based on information provided as part of Cr(VI) AfAs.

E.2.8. Conclusion on alternatives to Cr(VI) substances

On the basis of the analysis of alternatives presented in Sections E.2.1 to E.2.7, and considering the information on substitution intentions and on the associated costs obtained in the CfEs (see Sections E.3.2 and E.3.3), the Dossier Submitter decided to group the various uses of Cr(VI) substances into the following six use categories:

1) Formulation of chromic acids and other speciality mixtures made from the Cr(VI) substances in scope, which are subsequently used in other use categories

2) Electroplating on plastic substrate, e.g. for the automotive and sanitary sectors, providing both functional and aesthetic characteristics to the plated parts

3) Electroplating on metal substrate, e.g. to achieve corrosion resistance, hardness, and durability of machine parts, providing primarily functional and secondarily aesthetic characteristics to the plated parts

4) Use of primers and other slurries (incl. applications by painting, spraying, brushing, or pen), primarily done in the aerospace and defence (A&D) sector

5) Other surface treatments, incl. passivation (anodizing, conversion coating), etching, cleansing and sealing, which typically require no or low current

6) Speciality uses of Cr(VI) substances as functional additive or process aid

Subsequently, the Dossier Submitter used this categorisation in its impact assessment. Although broader than the use descriptions in existing AfAs, this categorisation allows the impact of a restriction to be assessed across all market actors operating in a given sector. It therefore also allows making meaningful assumptions to be made about shifts in producer surplus from companies that cannot comply to companies that can comply with a given limit value or operate outside the EU. A further differentiation of use categories according to product segments, as is done in certain AfAs, is not meaningful in the context of so-called job platers. These companies are service providers similar to toll manufacturers, i.e. they are supplied with the raw parts and the specifications for their treatment but have no influence on the technology used to achieve the specified functionalities. This particular business model of the job plater has been discussed in previous AfAs and the relevant SEAC opinions recognise the challenges that toll manufacturing poses for the substitution of SVHCs.

E.3. Economic impacts

E.3.1. Derivation of abatement costs

General remarks

Abatement cost estimates were obtained using the data from the CfE#1 and CfE#2 in the following way:

- Data cleaning and conversion into €: all data provided by respondents were converted to € amounts and transformed into proper integers (removal of breaks and interpunctuation, conversion of non-numeric figures, etc.)

- Costing over the 20y-impact assessment period: investment cost plus operative cost (total discounted operative cost over the 20-year impact assessment period calculated with a 3 % discount rate)

- Comparison: To allow comparing the consequences for small, medium and large companies, the cost estimates were divided by the number of workers directly exposed to Cr(VI); i.e., abatement costs are no longer measured in € but in € per exposed worker

- Marginalization: abatement costs per worker were further divided by the reduction in exposure to Cr(VI) resulting from ever tighter limit values. For example, moving from 5 µg Cr(VI)/m^3 to 1 µg Cr(VI)/m^3 will result in an exposure reduction of 4 µg Cr(VI)/m^3, whereas moving from 1 µg Cr(VI)/m^3 to 0.5 µg Cr(VI)/m^3 will result in an exposure reduction of 0.5 µg Cr(VI)/m^3, etc. This marginalization implies that abatement costs are no longer absolute (i.e., in € per worker) but relative (i.e., in € per worker and per µg Cr(VI)/m^3)

- Handling gaps and jumps: if respondents indicated that their investment would let them meet not only the next stricter limit value (i.e., if they invest, they reduce exposure from, say, 5 µg Cr(VI)/m^3 to 0.5 µg Cr(VI)/m^3), then the MAC for complying with 1 µg Cr(VI)/m^3 was set equal to the MAC for complying with 0.5 µg Cr(VI)/m^3. This results in a conservative cost estimate in the spirit of the Turnbull (1976) estimator. If a respondent did not indicate any cost for a specific limit value, this was coded in the data as a missing observation

- Estimation of a pseudo-panel regression: the analysis of the resulting dataset can be done in different ways. However, it is important to note that the abatement cost indicated by a given firm for reaching a specific limit value is not independent from the other abatement cost indications of that firm. The Dossier Submitter decided to exploit this pseudo-panel nature of the dataset by estimating OLS models with individual fixed effects[70]

- Specification of the cost curve: since the descriptive statistics (and common sense) suggest marginally increasing abatement costs, the Dossier Submitter estimated a model specification of the form: $\log y = \alpha + \beta x + \varepsilon$. This specification is known as log-level regression. It is straightforward to see that this specification can be re-written as $y = \exp(\alpha + \beta x) = \exp(\alpha) * \exp(\beta x) = \tilde{\alpha} \exp(\beta x)$. Therefore, the Dossier Submitter implicitly estimated the coefficients of an exponential cost model

- Regression results for conducting this MAC analysis in form of an individual MAC curve for each of the six use categories as well as a pooled cost curve across use categories. (Since most observations were made for electroplating (UC 3), the pooled MAC curve is close to the MAC curve of this category.) To construct the curves, the Dossier Submitter evaluated the weighted mean of fixed effects and the use category specific cost coefficient at hypothetical limit values. The raw coefficient estimates for each of the seven models are reported below

Estimation of marginal and total abatement costs

To estimate the MAC curves displayed in Figure 9 of the main report, the Dossier Submitter undertook a log-level regression where costs are explained by a non-linear function of the form exp(Intercept α + abatement factor β * LV). Following the considerations above, the responses by each use category are treated as a panel with *n* companies, *T* cost indications and *N* total observations.

---

[70] Usually, panel data contain information on individual actors for multiple time periods. In our case, the dataset contains information on individual actors for multiple limit values. However, as the limit values are perfectly correlated with the reductions in exposure, it is not possible to estimate a limit value fixed effect (analogous to a time fixed effect).

Raw coefficient estimates, i.e. $\hat{\alpha}$ and $\hat{\beta}$, of this panel regression analysis are reported below for each of the use categories. Based on the coefficient estimates, it is possible to calculate for any LV the total abatement costs per use category by integrating the corresponding marginal abatement cost curve from the target *LV* up to the status quo (*SQ*) exposure. Thus, the total abatement cost (*AC*) for company *j* operating in use category *i* to comply with limit value *k* is given by:

$$AC_{ijk} = \int_{LV_k}^{SQ_j} \exp\left(\hat{\alpha}_i + \hat{\beta}_i x\right) \mathrm{d}x = \frac{\exp\left(\hat{\alpha}_i + \hat{\beta}_i SQ_j\right) - \exp\left(\hat{\alpha} + \hat{\beta}_i LV_k\right)}{\hat{\beta}_i}$$

Below, the Dossier Submitter reports the definite integrals for any LV up to a SQ of 5 µg Cr(VI)/m^3. Note that this is done for reporting convenience since on that basis, one can easily calculate the total cost for any *SQ* and any target *LV*. For example, if one was interested in finding the TC for a company that currently complies with 1 µg Cr(VI)/m^3 and would need to comply with 0.5 µg Cr(VI)/m^3, one finds that:

$$AC_i = \int_{0.5}^{1} \exp\left(\hat{\alpha}_i + \hat{\beta}_i x\right) \mathrm{d}x = \int_{0.5}^{5} \exp\left(\hat{\alpha}_i + \hat{\beta}_i x\right) \mathrm{d}x - \int_{1}^{5} \exp\left(\hat{\alpha}_i + \hat{\beta}_i x\right) \mathrm{d}x$$

Raw regression output for UC1

```
Unbalanced Panel: n = 29, T = 2-4, N = 81

Residuals:
Min.          1st Qu.       Median        3rd Qu.       Max.
-8.35394      -1.34806      0.44949       1.34806       4.04819

Coefficients:
              Estimate      Std. Error    t-value       Pr(>|t|)
Intercept     12.55222      0.78168       16.058        < 2.2e-16 ***
Abatement     -2.69611      0.23463       -11.491       < 2.2e-16 ***
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares: 2062.1
Residual Sum of Squares: 316.67
R-Squared: 0.84643
Adj. R-Squared: 0.84449
F-statistic: 132.037 on 1 and 79 DF, p-value: < 2.22e-16
```

Marginal and total abatement costs for complying with different LVs under UC1

$\exp(12.55222\ - 2.69611 * 5) \approx 0$

$\exp(12.55222\ - 2.69611 * 1) \approx 19\,100 \rightarrow \int_{1}^{5} 12.55222 * \exp(\ - 2.69611 * x)\,\mathrm{d}x \approx 7\,100$

$\exp(12.55222\ - 2.69611 * 0.5) \approx 73\,400 \rightarrow \int_{0.5}^{5} \exp(12.55222\ - 2.69611 * x)\,\mathrm{d}x = 27\,200$

$\exp(12.55222\ - 2.69611 * 0.1) \approx 215\,900 \rightarrow \int_{0.1}^{5} \exp(12.55222\ - 2.69611 * x)\,\mathrm{d}x = 80\,100$

$\exp(12.55222\ - 2.69611 * 0.01) \approx 275\,200 \rightarrow \int_{0.01}^{5} \exp(12.55222\ - 2.69611 * x)\,\mathrm{d}x = 102\,100$

Raw regression output for UC2

```
Unbalanced Panel: n = 38, T = 2-5, N = 112

Residuals:
Min.          1st Qu.       Median        3rd Qu.       Max.
-9.45942      -1.32935      0.36596       1.26361       4.92850
```

```
Coefficients:
              Estimate      Std. Error    t-value       Pr(>|t|)
Intercept      12.44161     0.47771       26.044        < 2.2e-16 ***
Abatement     -2.65870       0.15032      -17.688       < 2.2e-16 ***
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares: 2950.1
Residual Sum of Squares: 386.5
R-Squared: 0.86898
Adj. R-Squared: 0.86779
F-statistic: 312.846 on 1 and 110 DF, p-value: < 2.22e-16
```

Marginal and total abatement costs for complying with different LVs under UC2

$\exp(12.44161 - 2.65870 * 5) \approx 0$

$\exp(12.44161 - 2.65870 * 1) \approx 17\ 700 \rightarrow \int_{1}^{5} \exp(12.44161 - 2.65870 * x)\,\mathrm{d}x \approx 6\ 700$

$\exp(12.44161 - 2.65870 * 0.5) \approx 67\ 000 \rightarrow \int_{0.5}^{5} \exp(12.44161 - 2.65870 * x)\,\mathrm{d}x = 25\ 200$

$\exp(12.44161 - 2.65870 * 0.1) \approx 194\ 000 \rightarrow \int_{0.1}^{5} \exp(12.44161 - 2.65870 * x)\,\mathrm{d}x = 73\ 000$

$\exp(12.44161 - 2.65870 * 0.01) \approx 246\ 500 \rightarrow \int_{0.01}^{5} \exp(12.44161 - 2.65870 * x)\,\mathrm{d}x = 92\ 700$

Raw regression output for UC3

```
Unbalanced Panel: n = 449, T = 2-5, N = 1330

Residuals:
Min.          1st Qu.       Median        3rd Qu.       Max.
-11.57873     -1.37115      0.11745       1.37115       7.56366

Coefficients:
              Estimate      Std. Error     t-value      Pr(>|t|)
Intercept     13.210024      0.167702     78.771         < 2.2e-16 ***
Abatement      -2.742304    0.052843      -51.895       < 2.2e-16 ***
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares: 37633
Residual Sum of Squares: 4871.7
R-Squared: 0.87055
Adj. R-Squared: 0.87045
F-statistic: 2693.13 on 1 and 1328 DF, p-value: < 2.22e-16
```

Marginal and total abatement costs for complying with different LVs under UC3

$\exp(13.21002 - 2.74304 * 5) \approx 0$

$\exp(13.21002 - 2.74304 * 1) \approx 35\ 100 \rightarrow \int_{1}^{5} \exp(13.21002 - 2.74304 * x)\,\mathrm{d}x \approx 12\ 800$

$\exp(13.21002 - 2.74304 * 0.5) \approx 138\ 500 \rightarrow \int_{0.5}^{5} \exp(13.21002 - 2.74304 * x)\,\mathrm{d}x = 50\ 500$

$\exp(13.21002 - 2.74304 * 0.1) \approx 414\ 900 \rightarrow \int_{0.1}^{5} \exp(13.21002 - 2.74304 * x)\,\mathrm{d}x = 151\ 300$

$\exp(13.21002 - 2.74304 * 0.01) \approx 531\ 000 \rightarrow \int_{0.01}^{5} \exp(13.21002 - 2.74304 * x)\,\mathrm{d}x = 193\ 600$

Raw regression output for UC4

```
Unbalanced Panel: n = 93, T = 2-5, N = 240

Residuals:
```

```
Min.          1st Qu.       Median        3rd Qu.       Max.
-13.6468      -0.9650       -0.3528       0.9650        12.8677

Coefficients:
              Estimate      Std. Error    t-value       Pr(>|t|)
Intercept     10.98847      1.20481       9.1205        < 2.2e-16 ***
Abatement     -1.93000      0.33629       -5.7391       2.884E-8 ***
---
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Total Sum of Squares: 3986.1
Residual Sum of Squares: 1822.4
R-Squared: 0.54281
Adj. R-Squared: 0.54089
F-statistic: 32.9367 on 1 and 238 DF, p-value: 2.8837E-8
```

Marginal and total abatement costs for complying with different LVs under UC4

$$\exp(10.98847 - 1.930 * 5) \approx 0$$

$$\exp(10.98847 - 1.930 * 1) \approx 8\,600 \rightarrow \int_{1}^{5} \exp(10.98847 - 1.930 * x)\,\mathrm{d}x \approx 4\,400$$

$$\exp(10.98847 - 1.930 * 0.5) \approx 22\,600 \rightarrow \int_{0.5}^{5} \exp(10.98847 - 1.930 * x)\,\mathrm{d}x = 11\,700$$

$$\exp(10.98847 - 1.930 * 0.1) \approx 48\,800 \rightarrow \int_{0.1}^{5} \exp(10.98847 - 1.930 * x)\,\mathrm{d}x = 25\,300$$

$$\exp(10.98847 - 1.930 * 0.01) \approx 58\,100 \rightarrow \int_{0.01}^{5} \exp(10.98847 - 1.930 * x)\,\mathrm{d}x = 30\,100$$

Raw regression output for UC5

```
Unbalanced Panel: n = 134, T = 2-5, N = 379

Residuals:
Min.          1st Qu.       Median        3rd Qu.       Max.
-8.233334     -1.128461     -0.012776     1.128461      10.842545

Coefficients:
              Estimate      Std. Error    t-value       Pr(>|t|)
Intercept     11.31010      0.56444       20.038        < 2.2e-16 ***
Abatement     -2.25692      0.17153       -13.157        < 2.2e-16 ***
---
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Total Sum of Squares: 8312.3
Residual Sum of Squares: 2418.9
R-Squared: 0.709
Adj. R-Squared: 0.70823
F-statistic: 173.116 on 1 and 377 DF, p-value: < 2.22e-16
```

Marginal and total abatement costs for complying with different LVs under UC5

$$\exp(11.31010 - 2.25692 * 5) \approx 0$$

$$\exp(11.31010 - 2.25692 * 1) \approx 8\,500 \rightarrow \int_{1}^{5} \exp(11.31010 - 2.25692 * x)\,\mathrm{d}x \approx 3\,800$$

$$\exp(11.31010 - 2.25692 * 0.5) \approx 26\,400 \rightarrow \int_{0.5}^{5} \exp(11.31010 - 2.25692 * x)\,\mathrm{d}x = 11\,700$$

$$\exp(11.31010 - 2.25692 * 0.1) \approx 65\,100 \rightarrow \int_{0.1}^{5} \exp(11.31010 - 2.25692 * x)\,\mathrm{d}x = 28\,900$$

$$\exp(11.31010 - 2.25692 * 0.01) \approx 79\,800 \rightarrow \int_{0.01}^{5} \exp(11.31010 - 2.25692 * x)\,\mathrm{d}x = 35\,400$$

Raw regression output for UC6

```
Unbalanced Panel: n = 25, T = 2-5, N = 71
```

```
Residuals:
Min.          1st Qu.       Median        3rd Qu.       Max.
-8.828603     -1.075507     0.060659      1.075507      5.255803

Coefficients:
              Estimate      Std. Error    t-value       Pr(>|t|)
Intercept     10.40997      0.93775       11.1010       < 2.2e-16 ***
Abatement     -2.15101      0.28732       -7.4865       1.734e-10 ***
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares: 1385.6
Residual Sum of Squares: 470.59
R-Squared: 0.66036
Adj. R-Squared: 0.65544
F-statistic: 56.0482 on 1 and 69 DF, p-value: 1.7341e-10
```

Marginal and total abatement costs for complying with different LVs under UC6

$$\exp(10.40997 - 2.15101 * 5) \approx 0$$

$$\exp(10.40997 - 2.15101 * 1) \approx 3\,800 \rightarrow \int_{1}^{5} \exp(10.40997 - 2.15101 * x)\,\mathrm{d}x \approx 1\,800$$

$$\exp(10.40997 - 2.15101 * 0.5) \approx 11\,300 \rightarrow \int_{0.5}^{5} \exp(10.40997 - 2.15101 * x)\,\mathrm{d}x = 5\,300$$

$$\exp(10.40997 - 2.15101 * 0.1) \approx 26\,800 \rightarrow \int_{0.1}^{5} \exp(10.40997 - 2.15101 * x)\,\mathrm{d}x = 12\,400$$

$$\exp(10.40997 - 2.15101 * 0.01) \approx 32\,500 \rightarrow \int_{0.01}^{5} \exp(10.40997 - 2.15101 * x)\,\mathrm{d}x = 15\,100$$

E.3.2. Information on substitution costs

Substitution of Cr(VI) substances in the uses subsumed under the six use categories defined in this Annex XV restriction proposal was the main objective of their inclusion in Annex XIV. However, the assessment of hundreds of AfAs of such uses suggests that only a fraction of these uses may be substitutable in the short and medium term. Even where substitution is feasible in principle there might be economic reasons not to do so. E.g. the investment (or fixed costs) and operative costs (or variable costs) may be prohibitively high, the resulting quality may not meet the demand of every customer, or the customers are not ready to accept any change in specifications.

In order to learn more about the costs of substituting Cr(VI) substances in various uses, the Dossier Submitter dedicated a part of the CfE#2 to collect information related to substitution and substitutability. Below, the Dossier Submitter provides a concise summary of the results of this information gathering.

General information

The purpose of the alternatives part of CfE#2 was to gather specific information on alternatives to Cr(VI) substances, including their technical feasibility and economic viability. A dedicated survey was designed and targeted at alternative providers and companies that have already replaced or are in the process of replacing the use of a Cr(VI) substance with another substance/technology.[71]

The CfE survey asked respondents to provide information on the type of alternative, the use(s) which the alternative is intended to replace, the type of equipment required to implement the alternative, and the typical investment and operative costs associated with

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[71] A copy of the questionnaire is available in Appendix G.2.

using the alternative. Respondents were asked to complete one survey per alternative used or supplied. A total of 99 responses were received. Four responses were discarded because (i) they did not contain relevant information, (ii) they were duplicates of other responses, or (iii) the respondent clearly indicated that their response was intended to replace a previous response. Just over half of respondents (52 out of 95 valid responses or 55 %) indicated that their response contained confidential information. For this reason, the responses are not reported in full but have been aggregated and summarised.

It should also be noted that not all responses were unambiguous and sometimes the option chosen by a respondent to a particular question was not consistent with the remaining submission from the same respondent. Wherever possible, the Dossier Submitter used information from other respondents, public information gathered from the respondent's website and common sense to better understand and interpret the response.

Suppliers of alternatives

The Dossier Submitter received six responses submitted by suppliers of alternatives that provide information on alternatives for the following use categories:

- UC 2 – Electroplating on plastic substrate
- UC 3 – Electroplating on metal substrate
- UC 5 – other surface treatments including anodizing, "blackening" and conversion coating

The respondents provided details on the composition of the alternatives, their performance compared to Cr(VI) as well as on the type of equipment and investments required to implement the alternative. While the alternatives identified in the CfE#2 were already known from other data sources, the Dossier Submitter used certain details in the overall description of the relevant alternatives presented in Appendix E.2.

Companies already using an alternative to Cr(VI) substances

Out of 26 responses submitted by companies that already use alternatives to the Cr(VI) substances, one respondent indicated that it only used CrO_3 and another respondent encouraged the Dossier Submitter to refer to the information provided in the AfAs by the ADCR consortium covering use categories 3, 4 and 5. The remaining 24 responses provided information on alternatives for the following uses:

- UC 2 – Electroplating on plastic substrate including pretreatment (n=4)
- UC 3 – Electroplating on metal substrate (n=7)
- UC 4 – Painting, spraying, brushing and slurry coating (n=1)
- UC 5 – Passivation of tin-plated steel (ETP) and electrolytic chromium coating of steel (ECCS) (n=2); and other surface treatments including anodizing, "blackening" and conversion coating (n=11)

It should be highlighted that as part of the 26 responses submitted, many respondents indicated difficulties in the implementation of the alternatives. The following elements were mentioned:

- alternative is still in the testing or validation phase

- issues with loss of performance compared to Cr(VI)
- alternative is suitable for only a part of the products manufactured or treated

One company provided information on an alternative that seemed to be different from alternatives identified from other data sources: *deoxidation of aluminium before Anodizing and Chemical Conversion Coating*. However, the composition reported corresponds to the use of sulfonitroferric acid identified for pre-treatments in use category 5. As for other submissions pointing to alternatives that were already known from other data sources, the details were integrated in the description of the relevant alternatives in Appendix E.2.

Other respondents

The remaining 66 responses were submitted by stakeholders that identified themselves either as users of Cr(VI) substances (n=59) or sector associations (n=4). The uses mentioned by the former respondents all fall into the use categories 3, 5 and 6.

Users of Cr(VI) substances

One respondent indicated that it only uses Cr(VI) and that there is no alternative technology to chrome plating for its activity. Three responses provided new information regarding the use of Barium Chromate as oxidiser in pyrotechnical articles (such as delay devices) for the defence sector (falling under UC6). The general message of those submissions was that barium chromate allows to achieve a wide range of precisely controlled and reproducible burning rates that other potential oxidisers do not achieve. For that use, the companies are looking at developing different pyrotechnic compositions for different ranges of burning rates. The companies underline in a qualitative manner that development and especially qualification of the new compositions require time.

Ten responses indicated that for some applications falling under use categories 3 and 5 companies have already transitioned to an alternative or are in the process of doing so. The alternatives mentioned in these responses were already known from other data sources therefore the details provided have been integrated into the overall description of the relevant alternatives.

Six responses provided information on potential alternatives falling under use categories 3, 5 and 6 that had not been identified from other data sources. In all cases, the respondents indicated difficulties in the development/implementation of the alternative. As barriers, they mentioned that the alternative is still in the testing or validation phase and/or issues with loss of performance compared to Cr(VI). Since all of these respondents indicated that their responses include confidential business information, the potential alternatives are not further discussed here.

The remaining 39 responses provided information on potential alternatives that were already known from other data sources. In all cases, the respondents indicated difficulties in the development of or transition to the alternative. The following barriers were mentioned:

- alternative is still in the testing, validation or qualification phase
- unacceptable loss of performance compared to Cr(VI)
- alternative being suitable for only part of the products manufactured or treated
- the use of the Cr(VI) substance is given by the customer requirements

- the alternative is not (yet) certified by customers
- potential for regrettable substitution
- issues with the availability of the alternative
- issues of economic feasibility, especially when the alternative is a different technology that requires a completely different setting/equipment

Sector associations

One of the responses contained information related to an alternative already known from other data sources, the details provided have been integrated into the overall description of that alternative. The other three responses encourage the Dossier Submitter to refer to the information provided in specific AfAs, underline the importance of the use of Cr(VI) to respect authenticity in e.g. the restauration of historic vehicles or in specific industry sectors such as the Aerospace, Security and Defence Industries or the process industry.

Substitution costs

The Dossier Submitter also inquired about variable and fixed costs associated with the alternatives mentioned by respondents. Most of the respondents (90 out of 95) gave an indicative cost estimate for the investment needed to implement an alternative.

The mean and median investment cost per line was ~€4.4m and ~€3.5m, respectively. However, responses varied a lot with the cost estimate being dependent on the alternative itself and the changes to the industrial processes needed to implement it. The 10th, 30th, 70th and 90th percentiles of the investment cost distributions correspond to €35k, €750k, €7.5m and €10m.

High investment cost estimates are for example expected by platers that would have to extensively modify an existing plating line (indicative cost estimates for that range from €0.5m to €2m) or build a new facility in order to incorporate new line(s) (indicative cost estimates for that range from €5m to €10m). On the lower end of the cost range are users that switch from a spray paint containing Cr(VI) to another one that does not contain Cr(VI). For this type of substitution, the cost estimates are significantly lower than €100k.

Respondents were also asked to estimate the operative costs relative to the use of a Cr(VI)-based technology. The mean and median estimates indicated 200 % and 175 % higher operative costs for the alternatives, indicating that on average respondents considered that their variable production costs could double when switching to an alternative.

How reliable these estimates are can of course be questioned. As there are different respondents, there are also different incentives at play. Also, one has to bear in mind that many of the respondents have not yet implemented or struggle to implement an alternative, and therefore it seems probable that they provided worst-case cost estimates that may exaggerate the actual costs somewhat. Nevertheless, the CfE#2 collected relevant information, e.g. from seven plating shops that had substituted and whose investment cost estimates range from €350k up to €10m. These companies indicated that they had invested in Cr(III) technology as alternative and estimated that their operative costs increased on average by 15 % compared to their previous use of CrO_3 plating.

In Section 3.1.3 of the main report, it is explained how this data was used in the impact assessment. Due to the uncertainties in the data, all central estimates were subject to a quantitative uncertainty analysis reported in Section 5 of the main report.

E.3.3. Breakdown of company reactions per use category

Figure 11 in the main report shows the responses of users of Cr(VI) substances reported in the CfEs. In Table 53, these responses are further broken down by use category to identify differences in terms of substitutability, risk control potential and market pressure.

Table 53. Breakdown of company reactions per use category for different LVs

Use category	1 µg/m^3	0.5 µg/m^3	0.1 µg/m^3	0.01 µg/m^3	Ban on use [1]
UC 1	Complies: 72 % Invest: 21 % Close: 5 % Substitute: 1 %	Complies:48 % Invest: 38 % Close: 11 % Substitute: 3 %	Complies: 21 % Invest: 31 % Close: 38 % Substitute: 10 %	Complies: 14 % Invest: 21 % Close: 52 % Substitute: 14 %	Close: 79 % Substitute: 21 %
UC 2	Complies: 79 % Invest: 18 % Close: 2 % Substitute: 0 %	Complies: 45 % Invest: 50 % Close: 4 % Substitute: 1 %	Complies: 11 % Invest: 52 % Close: 28 % Substitute: 9 %	Complies: 5 % Invest: 24 % Close: 55 % Substitute: 16 %	Close: 77 % Substitute: 23 %
UC 3	Complies: 69 % Invest: 25 % Close: 6 % Substitute: 1 %	Complies: 37 % Invest: 44 % Close: 17 % Substitute: 2 %	Complies: 16 % Invest: 44 % Close: 36 % Substitute: 4 %	Complies: 7 % Invest: 20 % Close: 65 % Substitute: 4 %	Close: 89 % Substitute: 11 %
UC 4 (w/o RPE)	Complies: 54 % Invest: 38 % Close: 14 % Substitute: 8 %	Complies: 38 % Invest: 22 % Close: 27 % Substitute: 14 %	Complies: 19 % Invest: 16 % Close: 42 % Substitute: 23 %	Complies: 10 % Invest: 11 % Close: 52 % Substitute: 28 %	Close: 65 % Substitute: 35 %
UC 4 (w/ RPE)	Complies: 90 % Invest: 5 % Close: 3 % Substitute: 2 %	Complies: 80 % Invest: 10 % Close: 7 % Substitute: 3 %	Complies: 70 % Invest: 15 % Close: 10 % Substitute: 5 %	Complies: 40 % Invest: 30 % Close: 20 % Substitute: 10 %	Close: 65 % Substitute: 35 %
UC 5	Complies: 69 % Invest: 18 % Close: 9 % Substitute: 4 %	Complies: 54 % Invest: 22 % Close: 16 % Substitute: 7 %	Complies: 27 % Invest: 30 % Close: 30 % Substitute: 13 %	Complies: 15 % Invest: 26 % Close: 41 % Substitute: 18 %	Close: 69 % Substitute: 31 %
UC 6	Complies: 80 % Invest: 12 % Close: 8 % Substitute: 4 %	Complies: 64 % Invest: 20 % Close: 10 % Substitute:6 %	Complies: 32 % Invest: 48 % Close: 13 % Substitute: 7 %	Complies: 24 % Invest: 32 % Close: 28 % Substitute: 16 %	Close: 64 % Substitute: 36 %

Table notes: [1] the closure and substitution rates were calculated based on the responses to a LV of 0.01 µg/m^3; e.g. for UC 3, 65 % of the respondents indicated closure as their best response, while 4 % indicated they would substitute. Applying this ratio proportionally results in (65 %/(65 % + 4 %))=89 % and (4 %/(65 % + 4 %))=11 %, respectively.

E.3.4. Bayesian truth-telling mechanism

More than any other group of SVHC, the chromates have generated a debate about the suitability of substitutes. Specifically, it has been suggested that some uses can be substituted by alternative substances or technologies. While such alternatives are used by certain companies in the EU, e.g. for the coating of plastic parts, switching to a new production technology necessitates significant investments and oftentimes entails higher operative costs, e.g. Cr(III)-coating processes require more energy than Cr(VI)-coating processes. Nevertheless, multiple applicants for authorisation have announced in their substitution plans that they intend to switch to alternatives within the next decade. In contradiction to that, only very few respondents to the CfE#1 suggested that they might substitute in response to a restriction of their Cr(VI) substance uses. This raises the question as to whether there are incentives to deliberately understate the substitution potential of known alternatives.

In order to reduce strategic incentives and to reward honest responses to the questions asked in the CfE#2, the Dossier Submitter opted to implement a so-called 'Bayesian truth serum' (BTS) mechanism. The specific BTS mechanism employed is known as 'choice matching.' It rewards truthful answers and punishes exaggerations (in any direction) by giving more weight to the former and less to the latter type of responses. When applied to the numerical assumptions made in the evaluation of various restriction options, these weights will tilt the calculations in favour of honest respondents thus creating an incentive for companies to respond truthfully (i.e. to the best of their knowledge).

While the technical assumptions are explained in Cvitanić, Prelec et al. (2019), the main idea of choice matching is straightforward. Choice matching as implemented in the CfE#2 links statements about substitutability to an auxiliary task, which implicitly reveals the 'type' of the respondent. In this auxiliary task, the respondent is asked to predict the market share of competitors that indicate they can substitute, i.e. they are asked to predict how everyone else answers the question of interest. Respondents are informed that on the basis of their responses the Dossier Submitter is going to assign them a weight – the honesty score – which corresponds to a weighted sum of a prediction accuracy score and the average prediction accuracy score of all other companies that responded in the same way. As demonstrated by Cvitanić et al. (2019), in this setting it is each respondent's best strategy to truthfully report about their possibility to substitute.

To calculate the honesty scores, the Dossier Submitter followed closely the theoretical results of Cvitanić et al. (2019). Adopting their notation, the CfE#2 elicited two vectors. The first vector $x^r = (x_1^r, x_2^r, x_3^r)$ collects respondent r's best response to the lowest LV of 0.01 µg Cr(VI)/m^3 where $x_k^r = 1$ if the respondent indicates that answer k is their best response and $x_k^r = 0$ if it is not. Specifically, the survey provided three possible responses $k \in (1,2,3)$: investment into risk control, shutdown or relocation, and substitution. The second vector $y^r = (y_1^r, y_2^r, y_3^r)$ collects estimates of predictions where y_k^r is respondent r's prediction of the frequency of other actors choosing the response k. Each respondent is then scored using a proper scoring rule via the function $S(\bar{x}^{-r}, y^r)$ where $\bar{x}^{-r}$ stands for the distribution of the reported choice frequencies (excluding the own choice). The last piece for constructing honesty scores is the function $\bar{S}^{-r}$ which denotes the average prediction score of all respondents different from r that provide the same response. Based on this similarity score, the honesty scores are defined as $H = \lambda S + (1-\lambda)\bar{S}^{-r}$, where $\lambda \in (0,1)$ is an arbitrary weight distinguishing between prediction score S and similarity score $\bar{S}^{-r}$.

In practice, the Dossier Submitter calculated the honesty scores employing the quadratic scoring rule $S^r = -\sum_k (y_k^r - \bar{x}^{-r})^2$ and assuming $\lambda = 0.5$, i.e. equal attention is given to the respondent's prediction accuracy score and the average prediction accuracy score of all other companies that responded in the same way. A dedicated spreadsheet to implement the choice matching is available and will be provided together with this Annex XV restriction proposal. The main upshot of analysing the responses are discussed in Sections 3.2.2 and 5 of the main report. In a nutshell, applying the weights will raise the closure/relocation rate in CfE2 from 61 % (unweighted responses) to 68 % (weighted responses) at the expense of the substitution rate, which drops from 17 % (unweighted responses) to 10 % (weighted responses).

E.4. Health impacts

Section E.3.1 presents use-category specific marginal abatement costs for complying with a limit value. These costs may be directly compared to the marginal benefit of reducing exposure to Cr(VI). To this end, the Dossier Submitter considers that the dose-response relationships for Cr(VI) established by RAC relates excess lifetime cancer mortality risk (ELR) to exposure to Cr(VI). Therefore, it is straightforward to convert a marginal risk reduction into a marginal benefit (MB) estimate. (For worker exposure, this MB estimate is also plotted into Figure 9 of the main report.)

To do so, consider that the ELR over a 40y work life corresponds to 4E-3 per µg Cr(VI)/m^3 (TWA), and the ELR over a 70y life in the vicinity of a plant corresponds to 2.9E-2 per µg Cr(VI)/m^3. Accordingly, the annual excess risk contributions corresponds to 1E-4 per µg Cr(VI)/m^3 and 4.14E-4 per µg Cr(VI)/m^3 for workers and members of the general population, respectively; analogously, the excess risks over a 20y analytical horizon (ER20) correspond to 2E-3 per µg Cr(VI)/m^3 and 8.29E-3 per µg Cr(VI)/m^3 for workers and members of the general population, respectively.

As ER20 expresses the excess mortality risk associated with exposure to 1 µg Cr(VI)/m^3, and as the dose-response relationship is assumed to be linear, one can multiply the ER20 with the value per statistical life (VSL) to monetize the marginal benefit of a reduction in mortality risk. However, even though survival prospects for lung cancer (the primary endpoint of concern here) are limited, approximately one in five lung cancer diseases are survived.[72] This suggests that for every statistical case of *fatal* lung cancer, one expects 0.2 statistical cases of *nonfatal* lung cancer. Therefore, the marginal benefit of reducing exposure to Cr(VI) by 1 µg Cr(VI)/m^3 over the analytical horizon equals the discounted value of the monetised risk reduction achieved.

Formally, this means:

$$MB_{worker} = \sum_{t=1}^{20y} (1+r)^{-t}\left(\frac{ELR_{worker}}{40y}\right)\left(VSL+\left(\frac{1}{5}\right)VCM\right)$$

and

$$MB_{population} = \sum_{t=1}^{20y} (1+r)^{-t}\left(\frac{ELR_{population}}{70y}\right)\left(VSL+\left(\frac{1}{5}\right)VCM\right)$$

where VCM stands for the value of a statistical case of cancer morbidity and r denotes the social discount rate of 3 % recommended by the Better Regulation Guidelines.

E.5. Other impacts

E.5.1. SME test

According to Chapter 3 of the BRG, a 'SME test' should be performed to assess whether an EU-wide regulatory proposal has disproportional impact on SMEs. Specifically, this test seeks to identify affected businesses, consult SME stakeholders, assess and consider ways of minimising the impact on them. Below, the Dossier Submitter discusses how it addressed each of these steps in the context of this Annex XV restriction proposal on certain Cr(VI) substances.

Identification of affected businesses

As the Cr(VI) substances in scope have been on Annex XIV of REACH for more than a decade, ECHA has a good understanding of which businesses will be directly affected by a restriction. Indeed, the Dossier Submitter has identified as users of these substances companies that either have applied on their own or in a group of applicants for an authorisation or are covered by an authorisation granted to an actor one step up in their supply chain.

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[72] See https://ecis.jrc.ec.europa.eu.

Consultation of SME stakeholders

These companies as well as the registrants of any of the substances in scope and several industry-sector associations were contacted via email and invited to participate in two dedicated Calls for Evidence in order to provide relevant information for this Annex XV restriction report. More information about companies that participated in the CfEs is provided in Appendix G.

Assessment of the impact on SMEs

As can be seen from Figure 26 (in Appendix G), a significant portion of companies that are using Cr(VI) substances in the EU are micro or small enterprises. These companies are less likely to already comply with the proposed LVs and more financially challenged to invest in either RMMs or the development of substitutes. However, the Dossier Submitter did not find large differences in the CfEs responses of SMEs with regard to the best response to comply. That means the breakdown of responses per use category presented in Section E.4.3 holds for small and large companies alike.

Depending on the restriction option, SMEs may be more severely affected by the imposed conditions. For example, if a specific LV can only be achieved through full automatization of a specific worker-contributing task, then this may be prohibitively expensive for a SME, while it may be affordable for a large company. However, this discrepancy does neither stem from the SMEs' position in the value chain nor is it a consequence of subcontracting.

Comparing the competitiveness of micro companies with that of small and medium-sized companies does not suggest large differences in the intended response to the proposed LVs. However, the aforementioned economies of size effects are even more pronounced for micro companies most of which have turnovers well below €2m per year.

Given the fact that SMEs intend to react in similar ways to the proposed restriction options as large companies, no specific measures to mitigate negative impacts on SMEs have been foreseen in the Annex XV restriction proposal.

E.5.2. Distributional impacts

See Section 5 of the main report for a discussion of distributional effects.

E.6. Practicality and monitorability

E.6.1. Compliance with the limit values for occupational exposure

To test the compliance with the scientific limit values (LV) set by this restriction, the EN 689:2019 standard could be followed, using analytical methods described in Appendix B.1.2.2. This standard is already used in the OSH practices (e.g. compliance with the occupation exposure limits, OEL) and the companies and the national enforcement authorities are therefore expected to be familiar with it. It provides guidance for instance concerning the sampling strategy, performing the exposure measurements and how to compare the results with the limit values.

EN 689:2019 does not consider the use and effectiveness of respiratory protective equipment (RPE) in testing compliance with the limit value. However, where risks cannot be adequately controlled by engineering controls and other means, adequate PPE must be provided and properly maintained (Directive *98/24/EC and Directive 89/656/EEC).* Standards such as EN 529 and ISO/TS 16975-1 offer guidance for selecting adequate and suitable RPE.

E.6.2. Compliance with the environmental limit values

The existing sampling and analytical methods for monitoring emissions to the environment are presented in Appendix B.1.2.1.

According to Annex VI, part 6, point 1.2 of the Directive 2010/75/EC on industrial and livestock rearing emissions (integrated pollution prevention and control)[73], sampling and analysis of all polluting substances as well as the quality assurance of automated measuring systems and the reference measurement methods to calibrate them shall be carried out according to CEN-standards. If CEN standards are not available, ISO, national or other international standards which ensure the provision of data of an equivalent scientific quality shall apply.

The Dossier Submitter acknowledges that Annex VI of the Directive relates to waste incineration plants and waste co-incineration plants and so is not directly applicable to the scope of the activities covered in the restriction proposal. However, the Dossier Submitter considers this a strong indication of the type of approach to be followed generally when monitoring emissions to the environment.

The emission limit values proposed by the Dossier Submitter are expressed in release rate, i.e. a specified mass of pollutant (kg) per unit of time (year). The release rate can be calculated by combining the concentration measured from the released air or water stream with the air or water flowrate. The actual formula to be used will depend on the release pattern from the site (batch versus continuous) as well as on the number of sampling points and monitoring campaigns performed over the year. In any case, the following basic principle will remain:

$$Release\ rate\ (kg\ per\ year) = \frac{VF \times MC \times ET}{0.000001}$$

where *VF*: air or water volume flow at the sampling point in m^3/hour, *MC*: measured value in mg Cr(VI)/m^3 prior to any correction, *ET*: emitting time from the sampling point in hours per year.

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[73] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02010L0075-20240804.

Appendix F: Assumptions, uncertainties and sensitivities

In Section 5 of the main report, the Dossier Submitter undertook a dedicated sensitivity analysis to assess how uncertainties, pertaining to the key assumptions of the impact assessment presented in Section 3 of the main report affect the estimation of the benefits and costs of the proposed restriction options. Specifically, the Dossier Submitter conducted a Monte Carlo analysis to quantitatively explore the drivers of and their relevance for uncertainty in the impact assessment presented. Monte Carlo analysis is a probabilistic method commonly used for (i) assessing the robustness of results and (ii) quantifying the drivers various uncertainties (Cullen and Frey 1999). It does so by simulating a wide range of possible outcomes based on the variation of key input variables. The identification of key input parameters for the quantitative uncertainty analysis, and the summary of the assumed distributions for these key input parameters and a summary of the reasoning behind these assumptions are presented in Table 35 of the main report. Here, additional considerations are provided on how these distributions were derived.

F.1. Abatement cost, worker exposure

Abatement costs for reducing worker exposure were derived as described in Appendix E.3.1. To derive a meaningful distribution to be used in the Monte Carlo simulation, the estimated coefficients (intercept, abatement) and their standard errors were used to calculate 95 % confidence intervals (corresponding to the 90.25 % joint confidence for the two parameters) for the total costs. Table 54 summarises for all UCs, the central estimates, derived confidence interval, and distributional assumptions made in the Monte Carlo simulation.

Table 54. Distributions of abatement costs per exposed worker

UC	LV in µg/m^3	Total Cost (TC) € – central estimate	Confidence Interval (CI)	RiskLognorm(µ, σ)
1	5	0	Constant	Constant
1	1	7 081	[1 426, 35 166]	RiskLognorm(7081, 4000)
1	0.5	27 300	[5 795, 127 948]	RiskLognorm(27300, 14389)
1	0.1	79 895	[17 197, 370 759]	RiskLognorm(79895, 40923)
1	0.01	101 911	[19 774, 476 546]	RiskLognorm(101911, 51956)
2	5	0	Constant	Constant
2	1	6 688	[2 492, 17 907]	RiskLognorm(6688, 4000)
2	0.5	25 127	[9 669, 65 279]	RiskLognorm(25127, 14389)
2	0.1	73 000	[28 568, 186 697]	RiskLognorm(73000, 40923)
2	0.01	92 737	[36 374, 236 223]	RiskLognorm(92737, 51956)
3	5	0	Constant	Constant
3	1	12 763	[9 011, 18 290]	RiskLognorm(12763, 2369)
3	0.5	50 108	[35 792, 70 180]	RiskLognorm(50108, 8798)
3	0.1	150 722	[108 424, 209 532]	RiskLognorm(150722, 25973)
3	0.01	192 260	[138,413, 266,914]	RiskLognorm(192260, 33106)
4	5	0	Constant	Constant
4	1	2 470	[367, 53 373]	RiskLognorm(2470, 13536)
4	0.5	9 760	[1 066, 127 963]	RiskLognorm(9760, 32489)
4	0.1	23 507	[2 419, 268 390]	RiskLognorm(23507, 68198)
4	0.01	28 268	[2 876, 317 892]	RiskLognorm(28268, 81025)
5	5	0	Constant	Constant
5	1	3 334	[1 189, 11 999]	RiskLognorm(3334, 2769)
5	0.5	11 262	[3 783, 36 197]	RiskLognorm(11262, 8270)
5	0.1	28 318	[9 489, 87 086]	RiskLognorm(28318, 19766)
5	0.01	34 895	[11 672, 106 947]	RiskLognorm(34895, 24265)
6	5	0	Constant	Constant
6	1	1 470	[255, 12 391]	RiskLognorm(1470, 3097)
6	0.5	4 936	[811, 33 801]	RiskLognorm(4936, 8369)
6	0.1	12 112	[1 976, 78 086]	RiskLognorm(12112, 19573)
6	0.01	14 771	[2 405, 94 796]	RiskLognorm(14771, 23760)

F.2. Abatement cost, environmental emissions

Abatement costs for reducing emissions to air and water to different required efficiencies were assumed to range between 50 % and 150 % of the estimate assumed in the main analysis (central estimate). A uniform distribution is typically assumed when there is no information on the most likely value, but reasonable minimum and maximum values are available, see Table 55.

Table 55. Distributions of abatement costs per site

Abatement efficiency	Central estimate in €	Range	RiskUniform
<90 %	248 770	[124 385, 373 155]	RiskUniform(124385, 373155)
90-99 %	683 503	[341 752, 1 025 255]	RiskUniform(341752, 1025255)
99-99.9 %	1 118 235	[559 118, 1 677 353]	RiskUniform(559118, 1677353)
99.9-99.99 %	1 552 968	[776 484, 2 329 452]	RiskUniform(776484, 2329452)
>99.99 %	1 987 700	[993 850, 2 981 550]	RiskUniform(993850, 2981550)

F.3. Turnover at stake

One important input to the impact assessment are the percentages of turnover/profit lost for companies in the different use categories due to non-use of the substance. These percentages were derived based on information in the CTACSub2 AfA. The estimates reflect the consequences of closure or relocation of operations or businesses, with outcomes ranging from complete closure/relocation (100 % loss) to partial closure/relocation to outsourcing (partial loss) to little or no impact. Central estimates and uncertainty ranges were developed using a combination of AfA data, expert judgment, and statistical modelling for integration in a Monte Carlo simulation done in @Risk.

- Input data from the CTACSub2 AfA: Closure/relocation shares for 12 broad uses, which were mapped to the UCs 1-6, provided probabilities of complete (100 % loss) and partial outcomes (e.g., UC 3 averaged 51 % complete loss and 42 % partial loss across six uses).

- Expert Judgment: For UC 1 (formulation, 60 %), UC 2 (plating on plastics, 60 %), and UC 6 (functional additive/process aid, 30 %), estimates were based on industry characteristics due to limited data. For UC 3 (plating on metal, 60 %), UC 4 (use of primers and other slurries, 60 %), and UC 5 (specialty surface treatments, 30 %), estimates leveraged data coverage, adjusted for partial closure impacts (where the exact share of turnover lost is uncertain itself).

Table 56 provides a summary of the aggregated turnover loss in percentage that was obtained based on the approach described above.

Table 56. Aggregate turnover loss per UC

UC	Central estimate (% Turnover Lost)	Complete Loss (100 %)	Partial Loss (50 % or adjusted)	No Loss (0 %)
1	60 %	60 %	20 %	20 %
2	60 %	52 %	48 %	0 %
3	60 %	51 %	42 %	7 %
4	60 %	60 %	40 %	0 %
5	30 %	11.75 %	63.75 %	24.5 %
6	30 %	30 %	50 %	20 %

Where data was sparse or absent (UCs 1, 4, and 6), conservative assumptions were made. Lower bound assumes 0 % profit loss for partial closure, and higher bound 100 %. Asymmetric triangle distribution was selected to have more probability mass on the lower end of the range. The distributions are presented in Table 57.

Table 57. Distributions used to model turnover at stake per UC

UC	Distribution	Mean
1	RiskTriang(0, 0.8, 1)	0.6
2	RiskTriang(0, 0.8, 1)	0.6
3	RiskTriang(0, 0.8, 1)	0.6
4	RiskTriang(0, 0.8, 1)	0.6
5	RiskTriang(0, 0.1, 1)	0.3667
6	RiskTriang(0, 0.1, 1)	0.3667

F.4. Turnover loss per UC

Turnover of the companies was used to calculate the producer surplus loss of companies under different ROs. Companies were asked to report their turnover in the CfEs. A Beta-PERT distribution, combined with expert judgment, was chosen to represent the sample statistics. The data from CfEs were used to derive minimum, maximum, mean and most likely values. The simulations with the Beta-PERT distribution were pruned by excluding outliers and by adjusting for a possible sample bias towards larger companies with a higher participation rate in the CfEs. Table 58 summarises the distributions used to model expected turnover loss.

Table 58. Distributions used to model expected turnover loss per UC

UC	Distribution
1	RiskPert(53 571, 3 707 592, 10 000 000)
2	RiskPert(200 000, 1 897 352, 10 000 000)
3	RiskPert(20 000, 2 888 647, 15 000 000)
4	RiskPert(21 740, 3 712 539, 18 000 000)
5	RiskPert(53 571, 4 519 718, 30 000 000)
6	RiskPert(214 286, 13 804 136, 45 000 000)

F.5. Closure/substitution rate

An analysis was done to the truthfulness of the substitution rates, based on the Bayesian truth-telling mechanism discussed in Appendix E.3.4. In a nutshell, applying the weights derived from that mechanism to the use categories 2 and 3 would raise the closure/relocation rate found in the CfEs by 7 % (from 61 % based on unweighted responses to 68 % based on weighted responses) at the expense of the substitution rate, which would drop by 7 % (from 17 % based on unweighted responses to 10 % based on weighted responses). This drop in the substitution rate is modelled for UCs 2 and 3 in the following way.

UC 2 – Substitution Rate

Description: Represents a substitution rate believed to be the upper bound (0.2307692) for UC 2, with downward uncertainty to less probable lower values.

Distribution: RiskTriang(0.13846152, 0.2207692, 0.2307692)

Parameters: Minimum = 0.13846152 (60 % of 0.2307692), Mode = 0.2207692 (closer to upper bound), Maximum = 0.2307692 (upper bound).

Characteristics: Mean ≈ 0.1967, 5th percentile ≈ 0.1385, 95th percentile ≈ 0.2308. Lower tail (0.13846152 to 0.2207692) has lower probability mass, reflecting less probable lower values.

Purpose: Models uncertainty in UC 2's substitution dynamics, favouring higher rates but allowing rare lower outcomes.

UC 3 – Substitution Rate

Description: Represents a substitution rate believed to be the upper bound (0.1052632) for UC 3, with downward uncertainty to less probable lower values.

Distribution: RiskTriang(0.06315792, 0.1002632, 0.1052632)

Parameters: Minimum = 0.06315792 (60 % of 0.1052632), Mode = 0.1002632 (closer to upper bound), Maximum = 0.1052632 (upper bound).

Characteristics: Mean ≈ 0.0896, 5th percentile ≈ 0.0632, 95th percentile ≈ 0.1053. Lower tail (0.06315792 to 0.1002632) has lower probability mass, reflecting less probable lower values.

Purpose: Models uncertainty in UC 3's substitution dynamics, favouring higher rates but allowing rare lower outcomes.

F.6. Substitution cost per line

As part of the CfE#2 data was obtained from 89 respondents on the cost of substitution (see Appendix E.3.2). The cost range that respondents could choose from went from €5k to €10m per substituted use, with a mean of ~€4.4m and a median of ~€3.5m. The distribution is highly skewed, with a standard deviation of close to €4m. Another notable feature of the cost data is the frequent occurrence of the highest cost (€10m selected by 22 respondents), while the lowest cost was less common (€5k selected by 4 respondents). This explains the right-skew of the distribution. To model this, a lognormal distribution (RiskLognorm(4 430 500, 3 600 000)) provided the best model fit. This distribution captures the skewed nature of the data, avoids unrealistic values, and reflects the presence of both very high costs and rare low costs. Given the variability across sectors, this approach seems suitable for assess uncertainty in substitution costs.

F.7. Substitution-related induced change in operative costs

As reported in Appendix E.3.2., companies expected significant increments in their operative costs due to substituting to an alternative. However, this data is not very structured. While there are almost 90 responses, most of them are from companies that have not yet substituted. There are only 22 responses from companies that have already substituted and the Dossier Submitter considers that these companies may have more accurate information on the expected change in the operative costs. While even these companies have reported increases in their operative costs, there is some variation in the responses. Interestingly, both the sign and magnitude of the change in operative costs depend on the implemented alternative. Where companies switched to Cr(III)-based technologies, the operative costs have typically gone up by 10 %. Some paints for spray painting can be even cheaper than the Cr(VI)-based paints previously used. And some technologies (e.g. laser cladding) raise operative costs by more than double.

In the uncertainty analysis, the Dossier Submitter assumed that because of higher operative costs some producers would incur profit losses also in case of successful substitution. The upper bound for such loses was set to 50 % of current profits, whereas a lower bound of 0 % was assumed. A triangle distribution was used to ensure a higher probability of values close to 0.

F.8. Willingness-to-pay values

Traditionally, VSL values used in U.S. government impact analysis have been slightly higher compared to EU VSL values. The U.S. EPA published in 2006 a guidance on how the VSL should be applied in the context of regulatory cost-benefit analysis. At the time, the recommended value was $7.4m, with guidance on how to adjust it for inflation. After adjusting for current prices, this value would be close to $10m. Further adjustments for purchasing power parity can be made to convert this U.S. VSL into €8.5m. In addition, the Dossier Submitter ignored any cancer-related health care costs to keep the analysis in the main report simple. However, it is noted that such costs account for only a small fraction of the value per statistical case (VSC) of cancer avoided. In some AfAs these costs were accounted for and applicants found that the health care costs per case of cancer were less than 1 % of the VSC. In the uncertainty section, the Dossier Submitter used the U.S. VSL value as an upper bound estimate of the VSC and added 2 % health care costs. In the Monte Carlo simulations, the VSC thus varied from €4.85m (EU VSL + 1 % health care costs) to €8.67 (U.S. VSL + 2 % health care costs). The expected value of the assumed triangular distribution was set to the midpoint of EU values (€5.82m = (€4.8m + €6.7m)/2), which was further adjusted for health care costs (€5.87m). Values are right-skewed, favouring the lower EU VSL value over the higher U.S. VSL value.

F.9. General population living in the vicinity of Cr(VI) emitting sites

The Dossier Submitter undertook a spatially explicit analysis of the DU notifications for existing authorisations of Cr(VI) substance uses. This exercise is explained in Section 2.2.1.2 of the main report, with details provided in Appendix D.1.2. In addition, the Dossier Submitter simulated the population living in the vicinity of Cr(VI) emitting sites draws from the observed population density distribution, where the probabilities at 30th , 50th, 70th and 90th percentiles are estimated based on the density of the population count between different percentiles. The following distribution was then used: RiskDiscrete({100, 428, 1557, 3987},{0.3, 0.2, 0.2, 0.3}).

F.10. Compliance, investment and non-use rates for different UCs

For all of the LVs proposed in the restriction options, the compliance, investment and non-use rates per UC sum up to 100 % because companies had to select their best response to these LVs. The data collected in the CfEs represent ~40 % of all Cr(VI) substance users. The theoretical minimum thus equals 40 % of reported non-use rates. Triangle distributions were employed to ensure a higher probability mass for lower non-use rates, which reflects the possibility of a selection bias as discussed in Section 3 of the main report. The compliance rates are as follows:

Table 59. Compliance rates per LV and UC

UC	LV of 5 µg/m^3	LV of 1 µg/m^3	LV of 0.5 µg/m^3	LV of 0.1 µg/m^3	LV of 0.01 µg/m^3
1	100 %	72.41 %	48.28 %	20.69 %	13.79 %
2	100 %	78.95 %	44.74 %	10.53 %	5.26 %
3a	100 %	68.53 %	37.72 %	16.29 %	7.14 %
3b	100 %	80.00 %	32.00 %	12.00 %	4.00 %
4 (w/	100 %	90.00 %	80.00 %	70.00 %	40.00 %

RPE)					
5a	100 %	57.14 %	42.86 %	14.29 %	14.29 %
5b	100 %	69.77 %	55.04 %	27.91 %	14.73 %
6	100 %	80.00 %	64.00 %	32.00 %	24.00 %

The following non-use rates were applied in the uncertainty analysis:

Table 60. Distribution of non-use rates per LV and UC

UC	LV of 5 µg/m³	LV of 1 µg/m³	LV of 0.5 µg/m³	LV of 0.1 µg/m³	LV of 0.01 µg/m³
1	RiskTriang(0,0,0)	RiskTriang(0.028,0.069,0.104)	RiskTriang(0.055, 0.138,0.207)	RiskTriang(0.193,0.483,0.724)	RiskTriang(0.262,0.655,0.862)
2	RiskTriang(0,0,0)	RiskTriang(0.011,0.026,0.039)	RiskTriang(0.0210, 0.053,0.079)	RiskTriang(0.147, 0.368,0.553)	RiskTriang(0.284, 0.711,0.947)
3a	RiskTriang(0.003,0.007,0.010)	RiskTriang(0.0269, 0.067,0.100)	RiskTriang(0.078, 0.194,0.291)	RiskTriang(0.163, 0.408,0.613)	RiskTriang(0.296, 0.741,0.929)
3b	RiskTriang(0,0,0)	RiskTriang(0,0,0)	RiskTriang(0.032, 0.08,0.12)	RiskTriang(0.112, 0.28, 0.42)	RiskTriang(0.224,0.56, 0.84)
4 (w/ RPE)	RiskTriang(0,0,0)	RiskTriang(0.02, 0.05,0.075)	RiskTriang(0.04,0.1,0.15)	RiskTriang(0.06, 0.15, 0.225)	RiskTriang(0.12,0.3,0.45)
5a	RiskTriang(0,0,0)	RiskTriang(0.114,0.286,0.429)	RiskTriang(0.114, 0.286,0.429)	RiskTriang(0.171,0.429,0.643)	RiskTriang(0.229,0.571,0.857)
5b	RiskTriang(0.028,0.070,0.105)	RiskTriang(0.047,0.116,0.174)	RiskTriang(0.093, 0.232,0.349)	RiskTriang(0.171, 0.426,0.640)	RiskTriang(0.239, 0.597,0.853)
6	RiskTriang(0.016,0.04,0.06)	RiskTriang(0.048,0.12,0.18)	RiskTriang(0.064, 0.16,0.24)	RiskTriang(0.08, 0.2, 0.3)	RiskTriang(0.176, 0.44, 0.66)

Appendix G: Stakeholder information

G.1. Calls for Evidence

In the preparation of this Annex XV restriction report two Calls for Evidence (CfE) were held to gather information on aspects relevant to the preparation of the proposal. Specifically, CfE#1[74] ran from 13/12/2023 to 27/02/2024 and focused on gathering information about the costs and effectiveness of RMMs to limit exposure to and emissions of Cr(VI) and any additional information deemed relevant by stakeholders for the preparation of the Annex XV restriction proposal; CfE#2[75] ran from 05/06/2024 to 15/08/2024 and targeted users of Cr(VI) substances that had not participated in the CfE#1 (in CfE#2a) as well as providers (manufacturers, formulators, suppliers, importers, distributors) of alternatives to Cr(VI) substances and companies that have substituted Cr(VI) substances or are just completing such substitution (in CfE#2b).

ECHA announced both CfE on its website. All registrants, authorisation applicants and DU notifiers of Cr(VI) substance uses were informed of the information gathering via email and REACH-IT. In addition, a list of ~120 stakeholder organisations were made aware of the CfEs. Figures 23-27 provide an overview of the respondents and their representativity for the sectors affected by this restriction proposal.

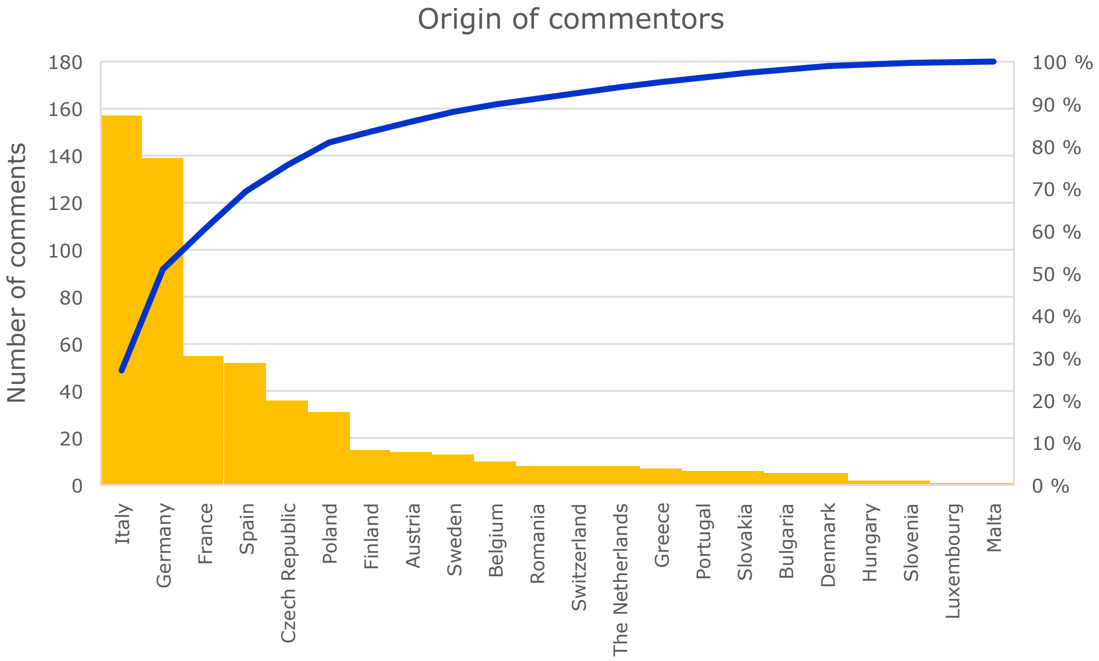

Figure 23. Origin of respondents to the Calls for Evidence

Source: CfE#1 and CfE#2.

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[74] For details, see https://echa.europa.eu/previous-calls-for-comments-and-evidence/-/substance-rev/75309/term.

[75] For details, see https://echa.europa.eu/previous-calls-for-comments-and-evidence/-/substance-rev/77101/term.

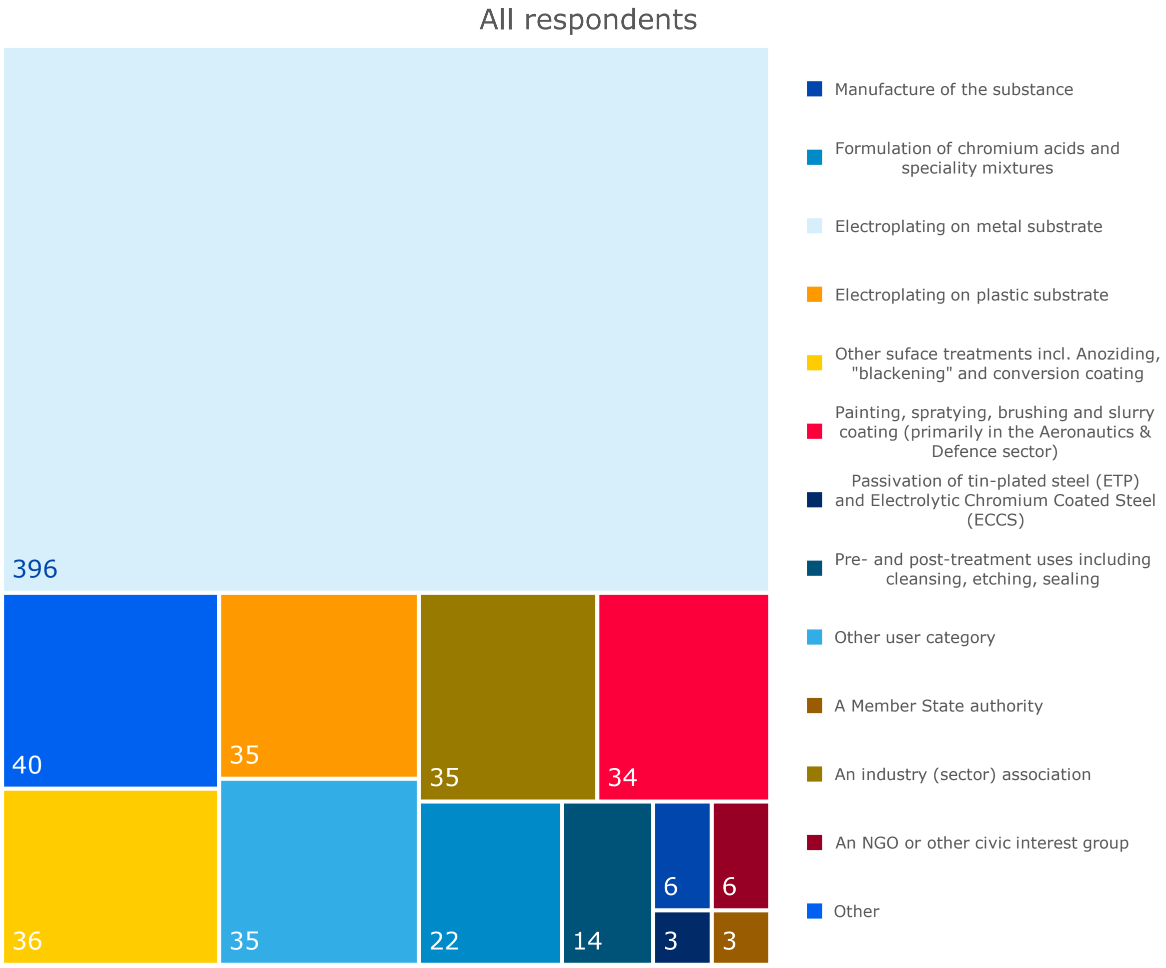


Figure 24. Number and type of respondents to the Calls for Evidence

Source: CfE#1 and CfE#2.

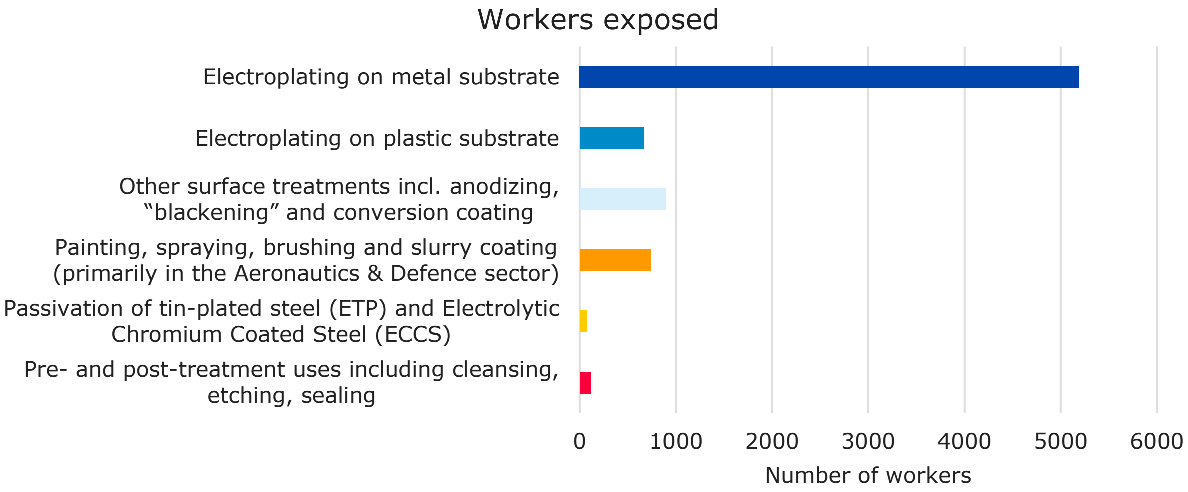


Figure 25. Number of workers per use category

Source: CfE#1 and CfE#2.

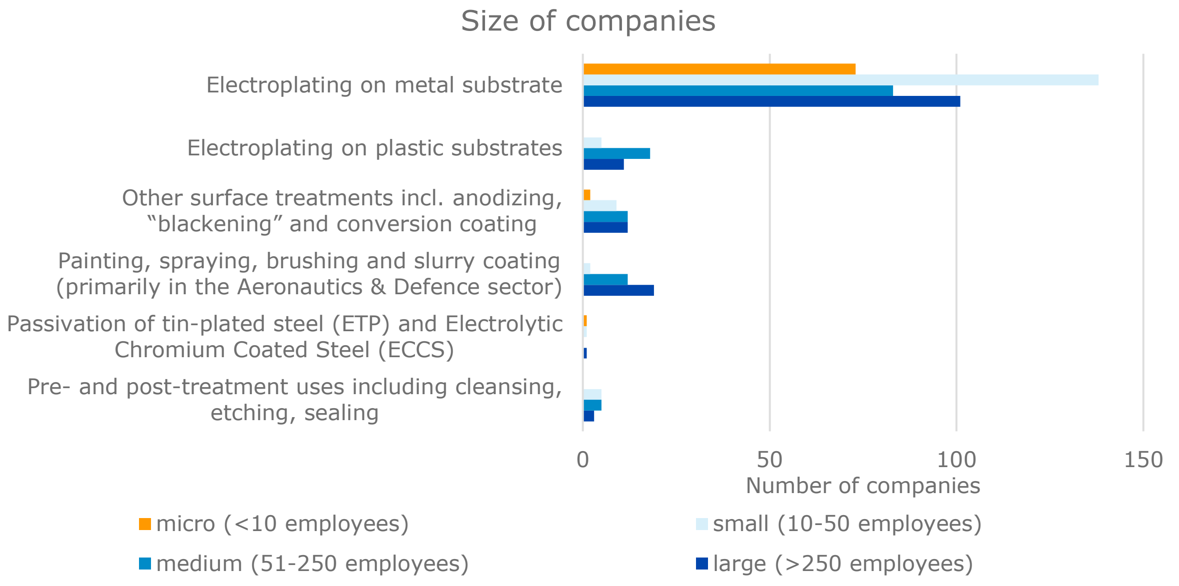


Figure 26. Size of companies using Cr(VI) substances in different UCs

Source: CfE#1 and CfE#2.

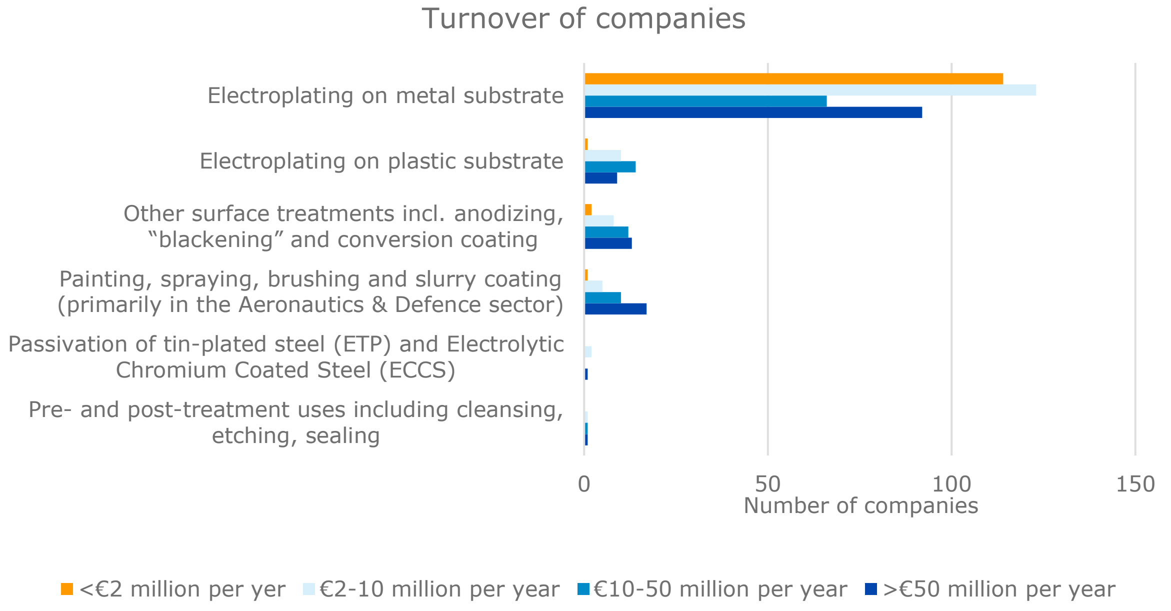


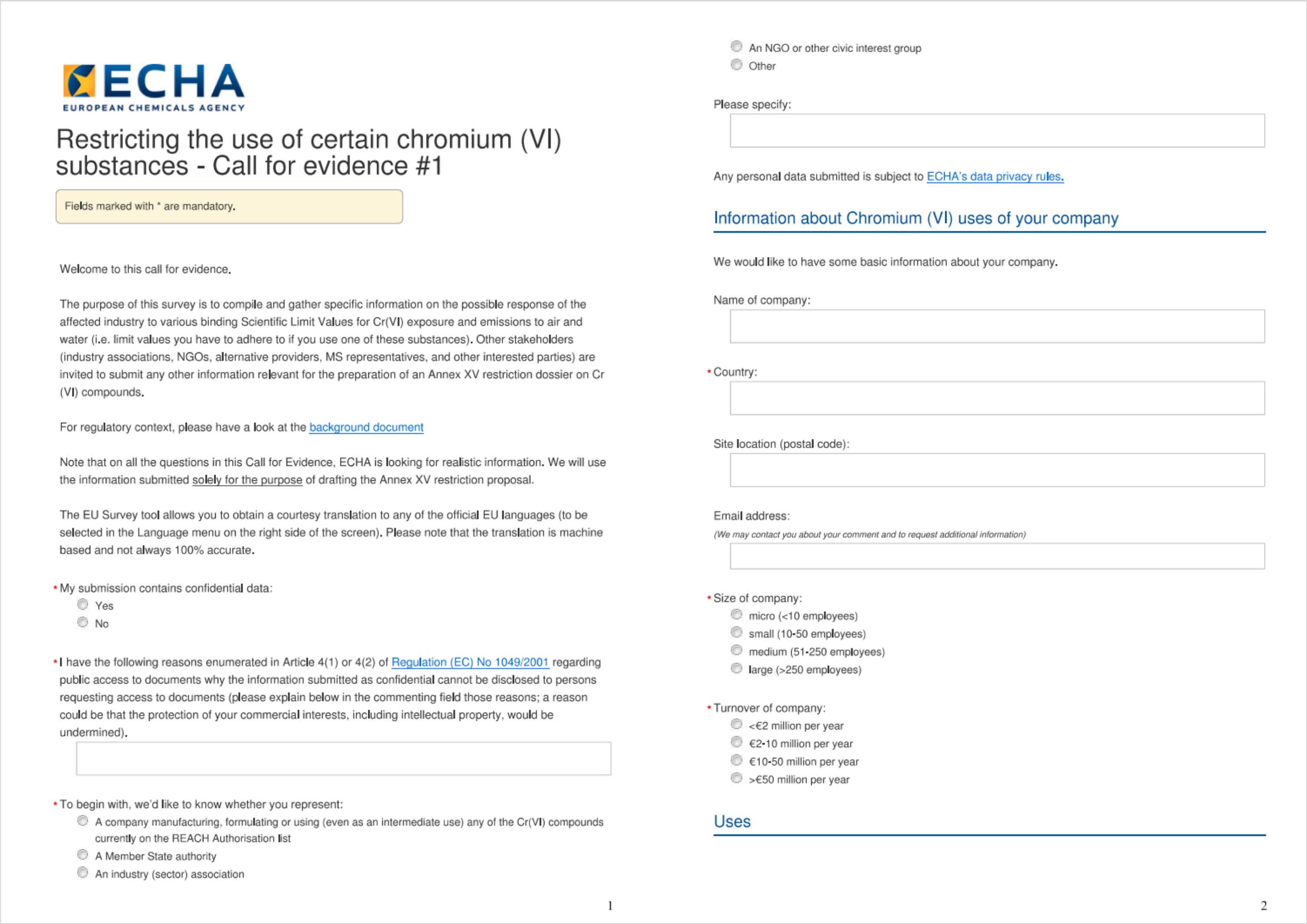
Figure 27. Turnover of companies using Cr(VI) substances in different UCs

Source: CfE#1 and CfE#2.

G.2. Copies of the CfE surveys

Below, the Dossier Submitter reproduces the questionnaires that were used in the CfEs to collect the information.

G.2.1. CfE#1 questionnaire



Restricting the use of certain chromium (VI) substances - Call for evidence #1

Fields marked with * are mandatory.

Welcome to this call for evidence.

The purpose of this survey is to compile and gather specific information on the possible response of the affected industry to various binding Scientific Limit Values for Cr(VI) exposure and emissions to air and water (i.e. limit values you have to adhere to if you use one of these substances). Other stakeholders (industry associations, NGOs, alternative providers, MS representatives, and other interested parties) are invited to submit any other information relevant for the preparation of an Annex XV restriction dossier on Cr (VI) compounds.

For regulatory context, please have a look at the background document

Note that on all the questions in this Call for Evidence, ECHA is looking for realistic information. We will use the information submitted solely for the purpose of drafting the Annex XV restriction proposal.

The EU Survey tool allows you to obtain a courtesy translation to any of the official EU languages (to be selected in the Language menu on the right side of the screen). Please note that the translation is machine based and not always 100% accurate.

* My submission contains confidential data:
- ○ Yes
- ○ No

* I have the following reasons enumerated in Article 4(1) or 4(2) of Regulation (EC) No 1049/2001 regarding public access to documents why the information submitted as confidential cannot be disclosed to persons requesting access to documents (please explain below in the commenting field those reasons; a reason could be that the protection of your commercial interests, including intellectual property, would be undermined).

* To begin with, we'd like to know whether you represent:
- ○ A company manufacturing, formulating or using (even as an intermediate use) any of the Cr(VI) compounds currently on the REACH Authorisation list
- ○ A Member State authority
- ○ An industry (sector) association
- ○ An NGO or other civic interest group
- ○ Other

Please specify:

Any personal data submitted is subject to ECHA's data privacy rules.

Information about Chromium (VI) uses of your company

We would like to have some basic information about your company.

Name of company:

* Country:

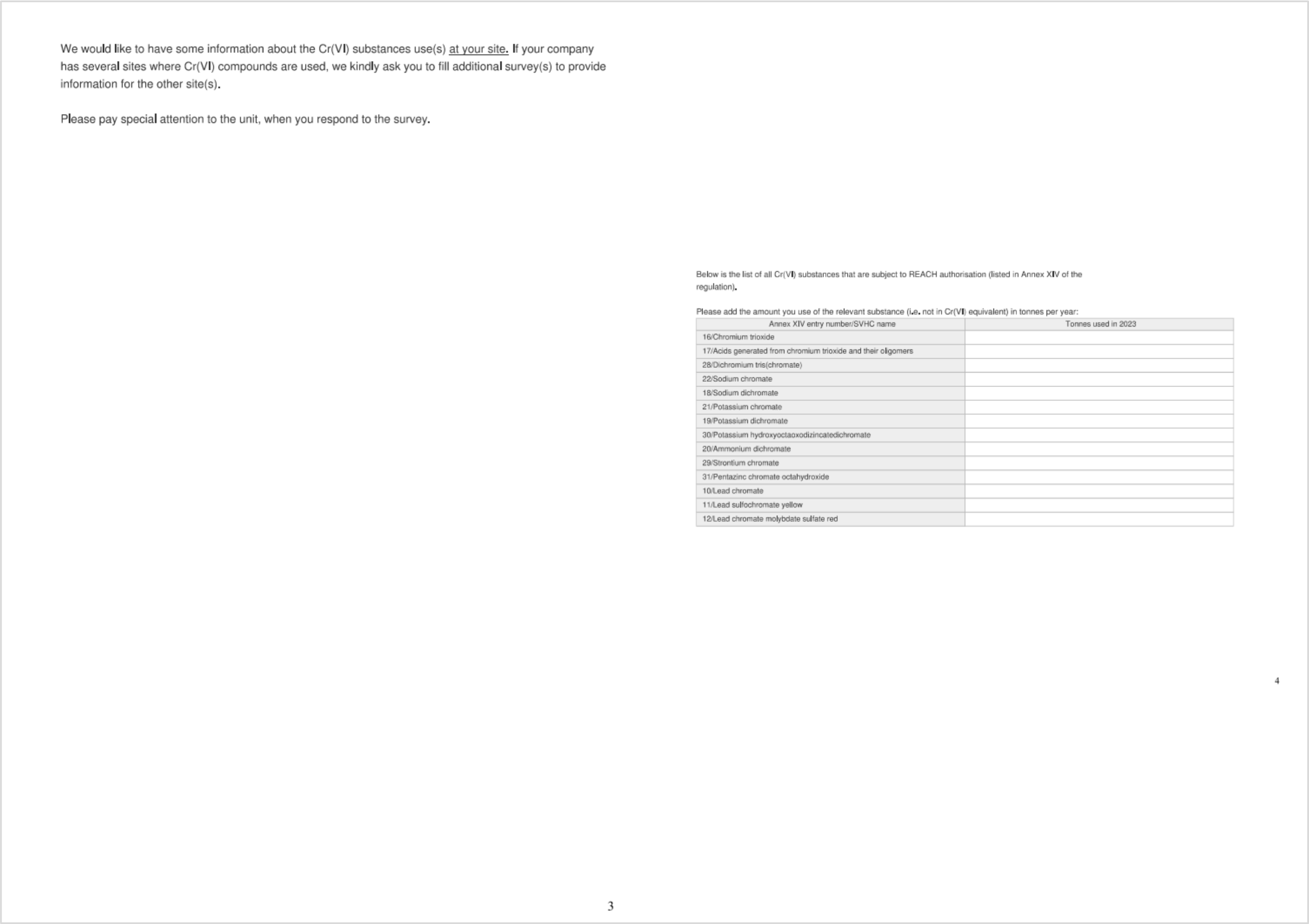
Site location (postal code):

Email address:
(We may contact you about your comment and to request additional information)

* Size of company:
- ○ micro (<10 employees)
- ○ small (10-50 employees)
- ○ medium (51-250 employees)
- ○ large (>250 employees)

* Turnover of company:
- ○ <€2 million per year
- ○ €2-10 million per year
- ○ €10-50 million per year
- ○ >€50 million per year

Uses



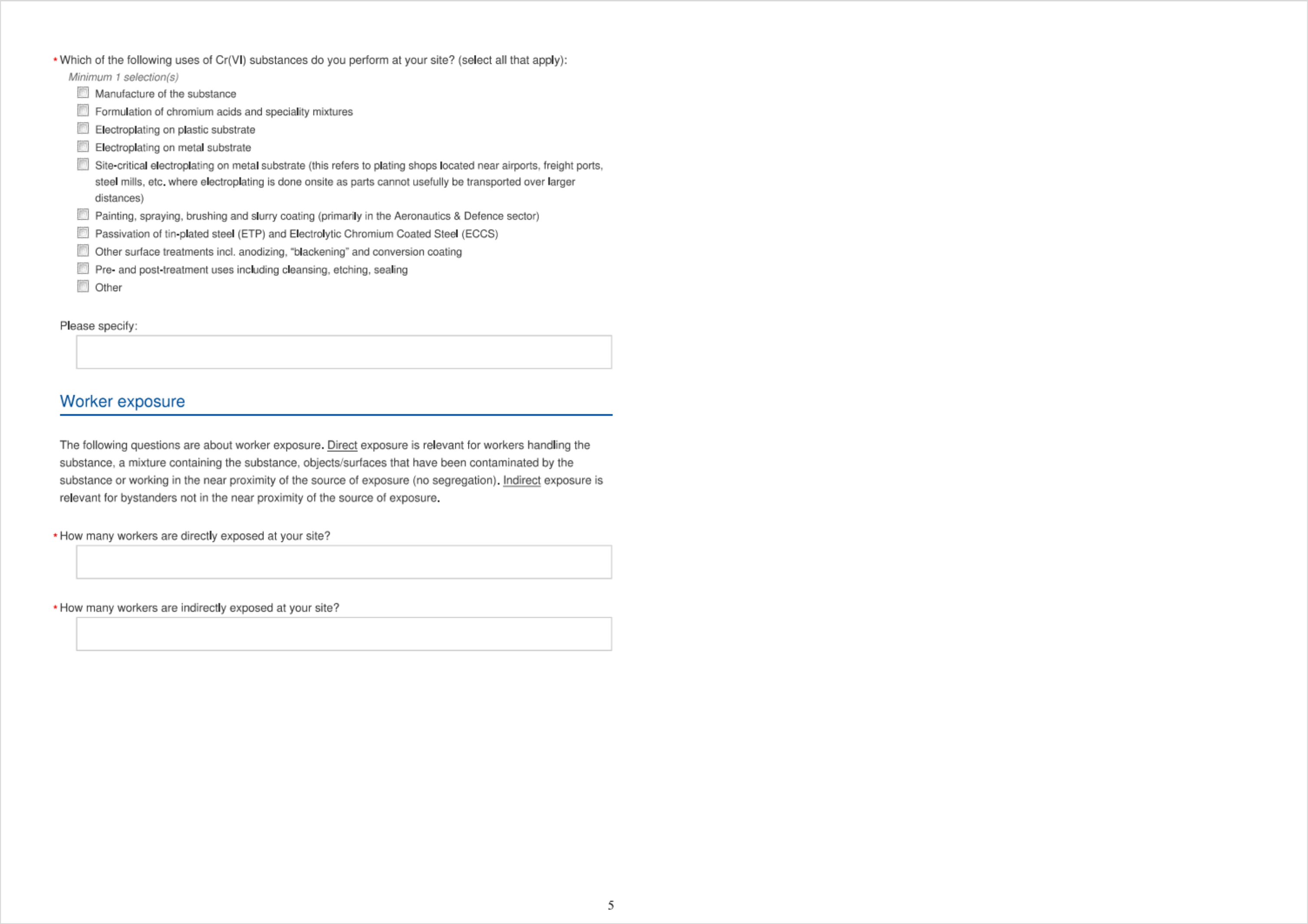
We would like to have some information about the Cr(VI) substances use(s) at your site. If your company has several sites where Cr(VI) compounds are used, we kindly ask you to fill additional survey(s) to provide information for the other site(s).

Please pay special attention to the unit, when you respond to the survey.

Below is the list of all Cr(VI) substances that are subject to REACH authorisation (listed in Annex XIV of the regulation).

Please add the amount you use of the relevant substance (i.e. not in Cr(VI) equivalent) in tonnes per year:

Annex XIV entry number/SVHC name	Tonnes used in 2023
16/Chromium trioxide	
17/Acids generated from chromium trioxide and their oligomers	
28/Dichromium tris(chromate)	
22/Sodium chromate	
18/Sodium dichromate	
21/Potassium chromate	
19/Potassium dichromate	
30/Potassium hydroxyoctaoxodizincatedichromate	
20/Ammonium dichromate	
29/Strontium chromate	
31/Pentazinc chromate octahydroxide	
10/Lead chromate	
11/Lead sulfochromate yellow	
12/Lead chromate molybdate sulfate red	



* Which of the following uses of Cr(VI) substances do you perform at your site? (select all that apply):

Minimum 1 selection(s)

- ☐ Manufacture of the substance
- ☐ Formulation of chromium acids and speciality mixtures
- ☐ Electroplating on plastic substrate
- ☐ Electroplating on metal substrate
- ☐ Site-critical electroplating on metal substrate (this refers to plating shops located near airports, freight ports, steel mills, etc. where electroplating is done onsite as parts cannot usefully be transported over larger distances)
- ☐ Painting, spraying, brushing and slurry coating (primarily in the Aeronautics & Defence sector)
- ☐ Passivation of tin-plated steel (ETP) and Electrolytic Chromium Coated Steel (ECCS)
- ☐ Other surface treatments incl. anodizing, “blackening” and conversion coating
- ☐ Pre- and post-treatment uses including cleansing, etching, sealing
- ☐ Other

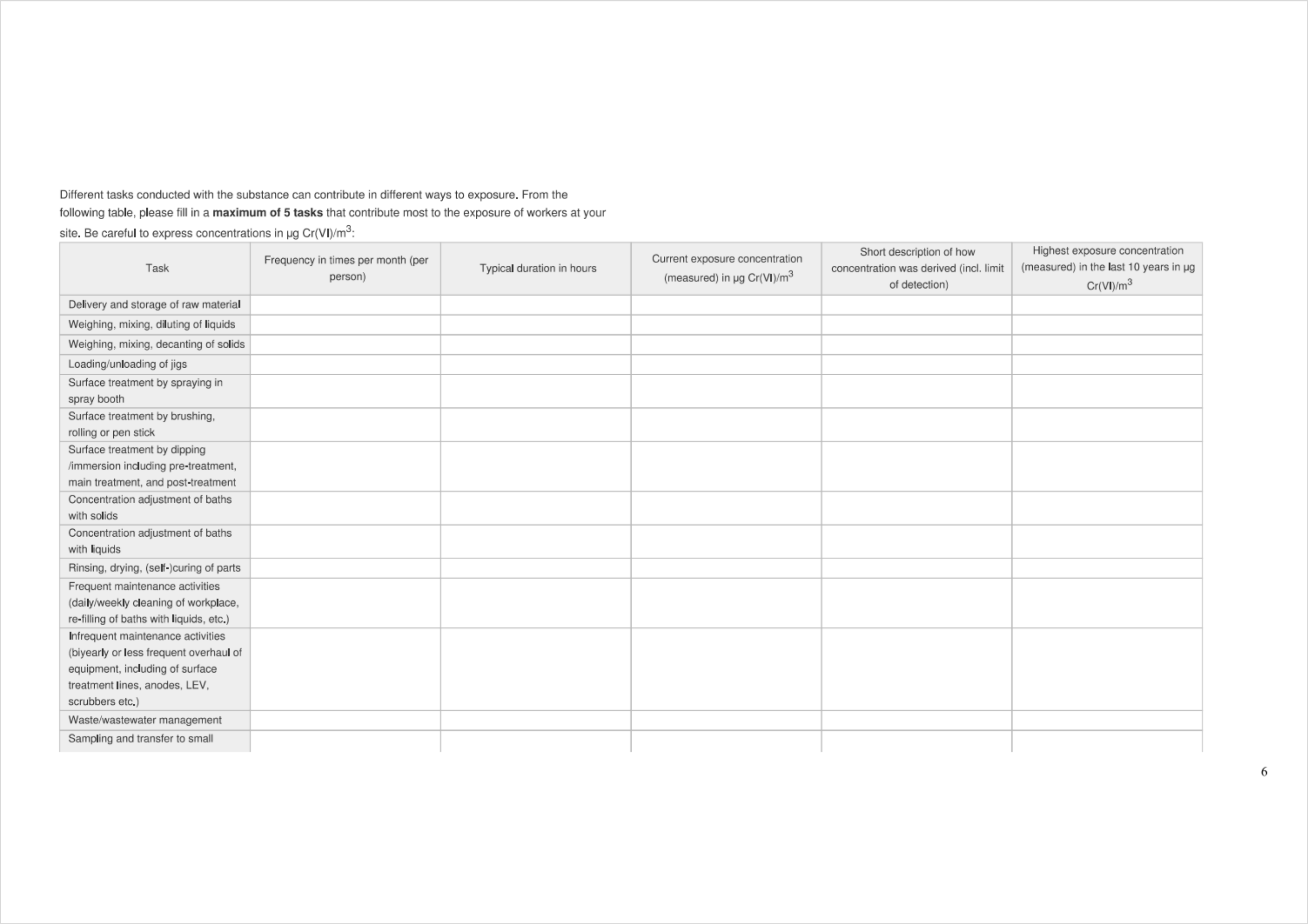
Please specify:

Worker exposure

The following questions are about worker exposure. Direct exposure is relevant for workers handling the substance, a mixture containing the substance, objects/surfaces that have been contaminated by the substance or working in the near proximity of the source of exposure (no segregation). Indirect exposure is relevant for bystanders not in the near proximity of the source of exposure.

* How many workers are directly exposed at your site?

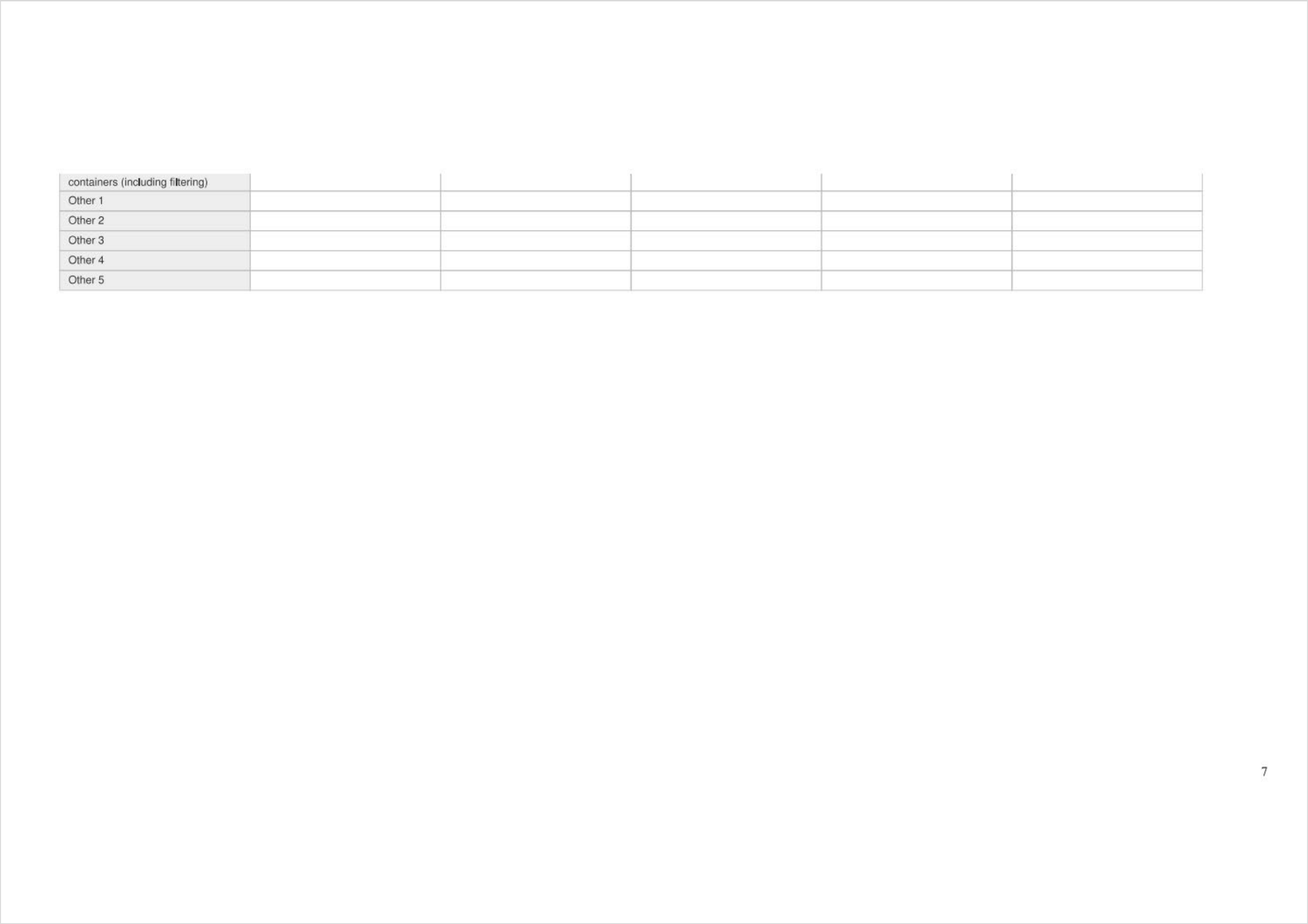
* How many workers are indirectly exposed at your site?



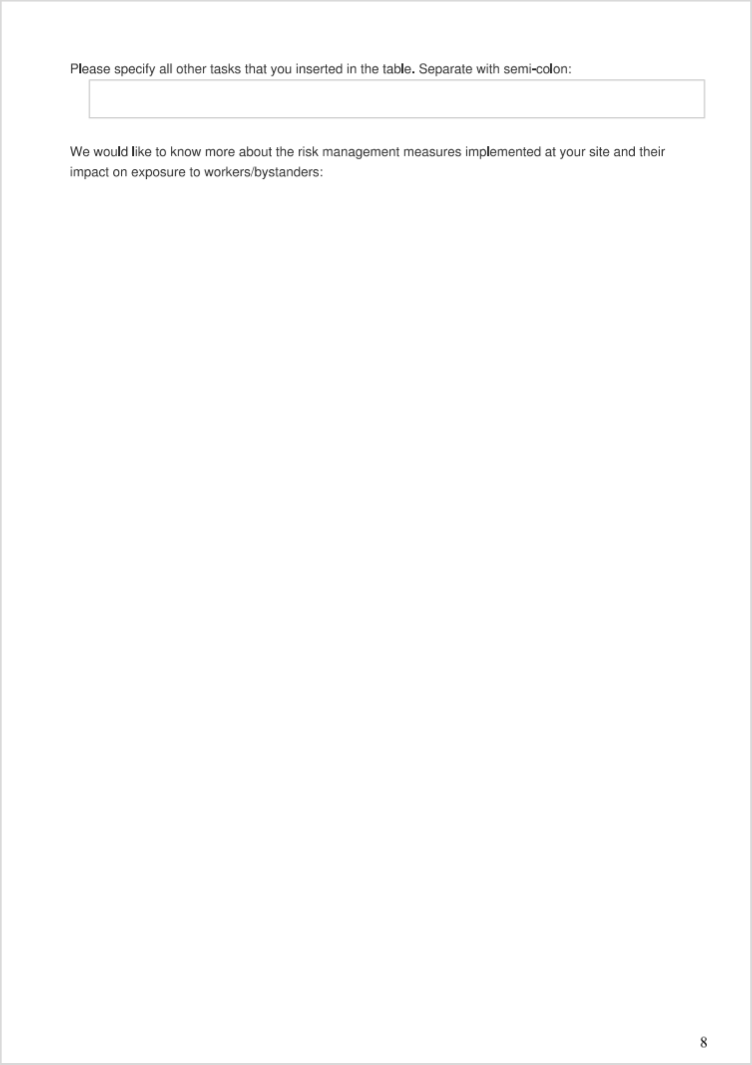
Different tasks conducted with the substance can contribute in different ways to exposure. From the following table, please fill in a **maximum of 5 tasks** that contribute most to the exposure of workers at your site. Be careful to express concentrations in µg Cr(VI)/m^3:

Task	Frequency in times per month (per person)	Typical duration in hours	Current exposure concentration (measured) in µg Cr(VI)/m^3	Short description of how concentration was derived (incl. limit of detection)	Highest exposure concentration (measured) in the last 10 years in µg Cr(VI)/m^3
Delivery and storage of raw material					
Weighing, mixing, diluting of liquids					
Weighing, mixing, decanting of solids					
Loading/unloading of jigs					
Surface treatment by spraying in spray booth					
Surface treatment by brushing, rolling or pen stick					
Surface treatment by dipping /immersion including pre-treatment, main treatment, and post-treatment					
Concentration adjustment of baths with solids					
Concentration adjustment of baths with liquids					
Rinsing, drying, (self-)curing of parts					
Frequent maintenance activities (daily/weekly cleaning of workplace, re-filling of baths with liquids, etc.)					
Infrequent maintenance activities (biyearly or less frequent overhaul of equipment, including of surface treatment lines, anodes, LEV, scrubbers etc.)					
Waste/wastewater management					
Sampling and transfer to small					

6



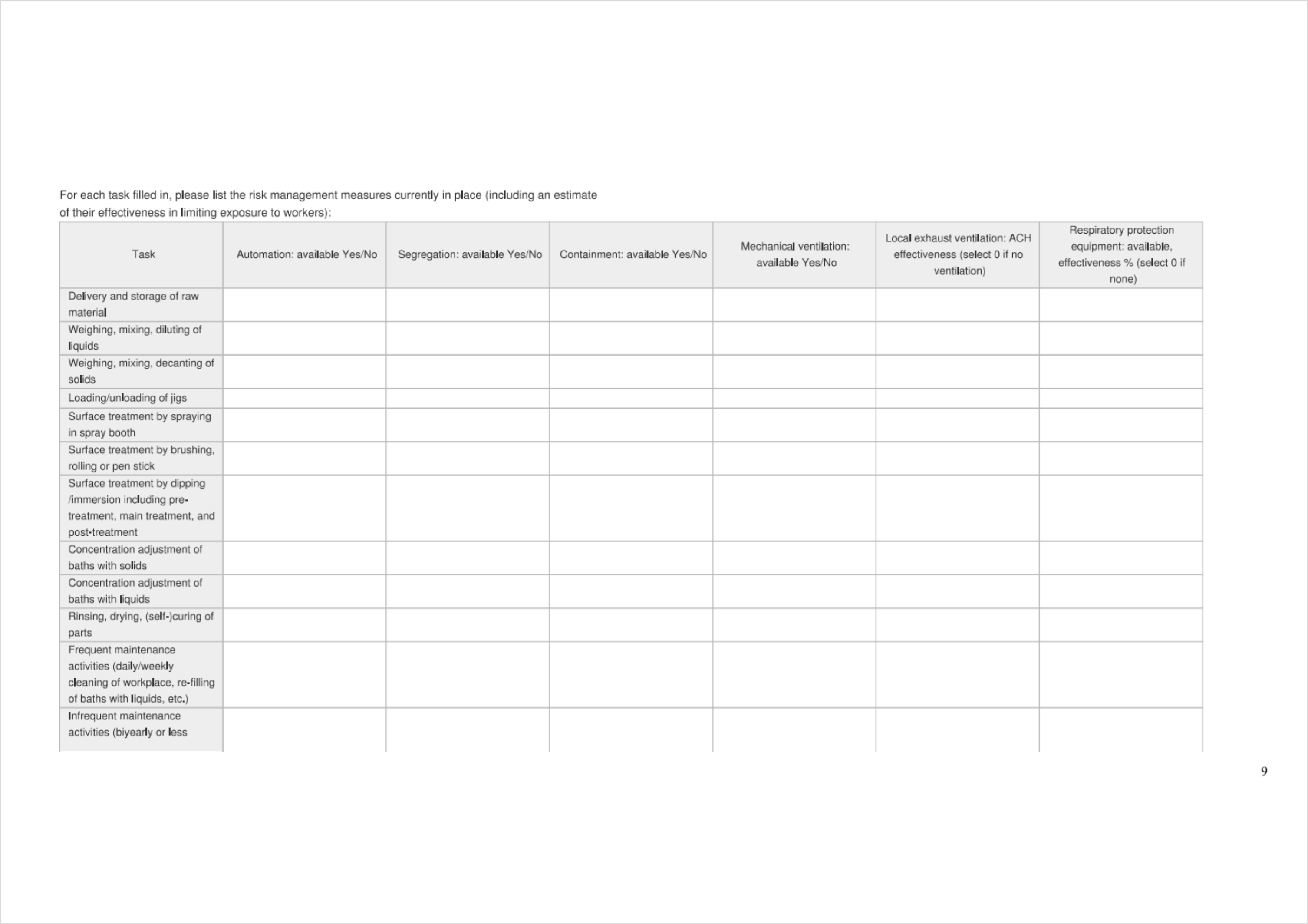
containers (including filtering)					
Other 1					
Other 2					
Other 3					
Other 4					
Other 5					



Please specify all other tasks that you inserted in the table. Separate with semi-colon:

We would like to know more about the risk management measures implemented at your site and their impact on exposure to workers/bystanders:

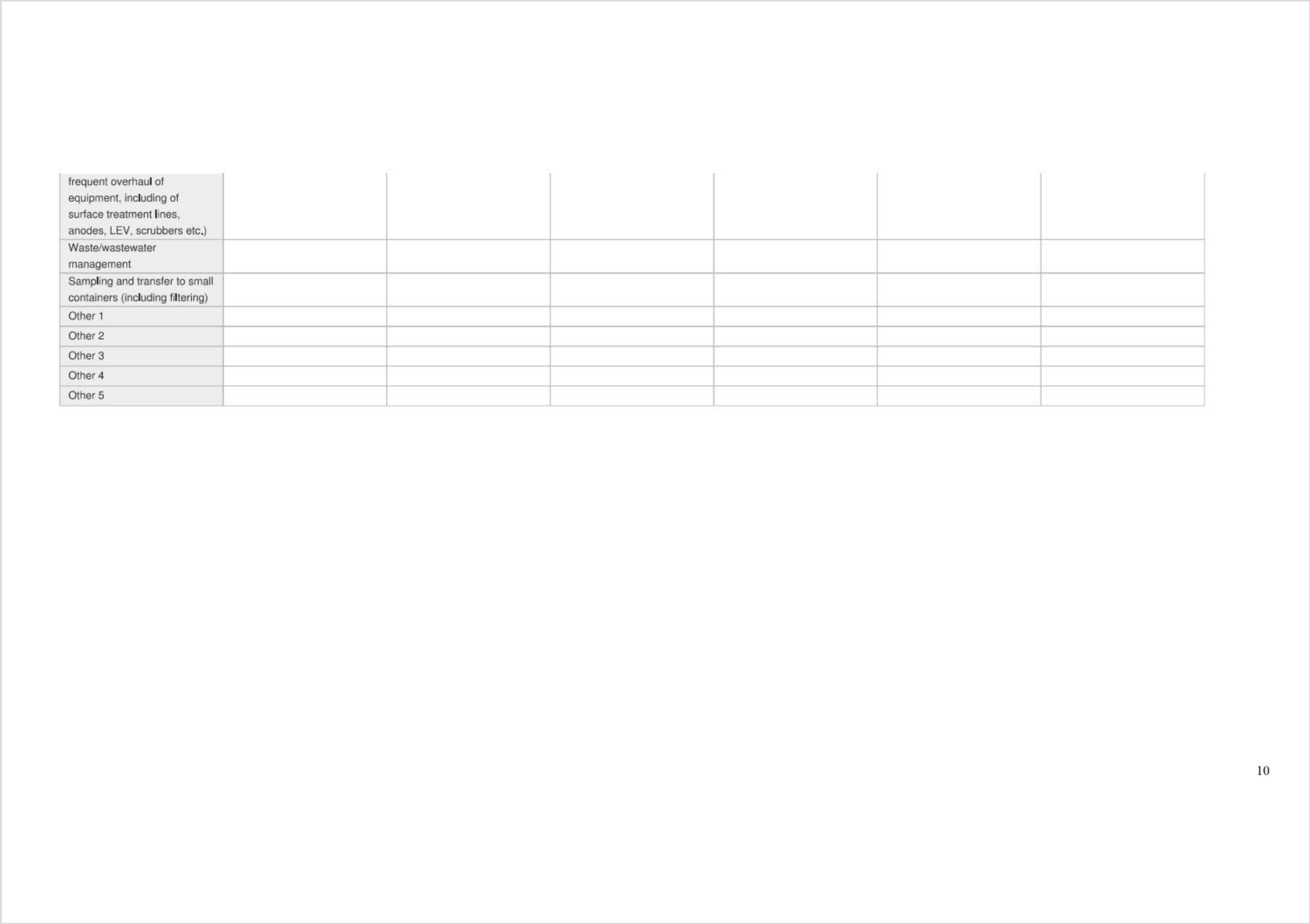
8



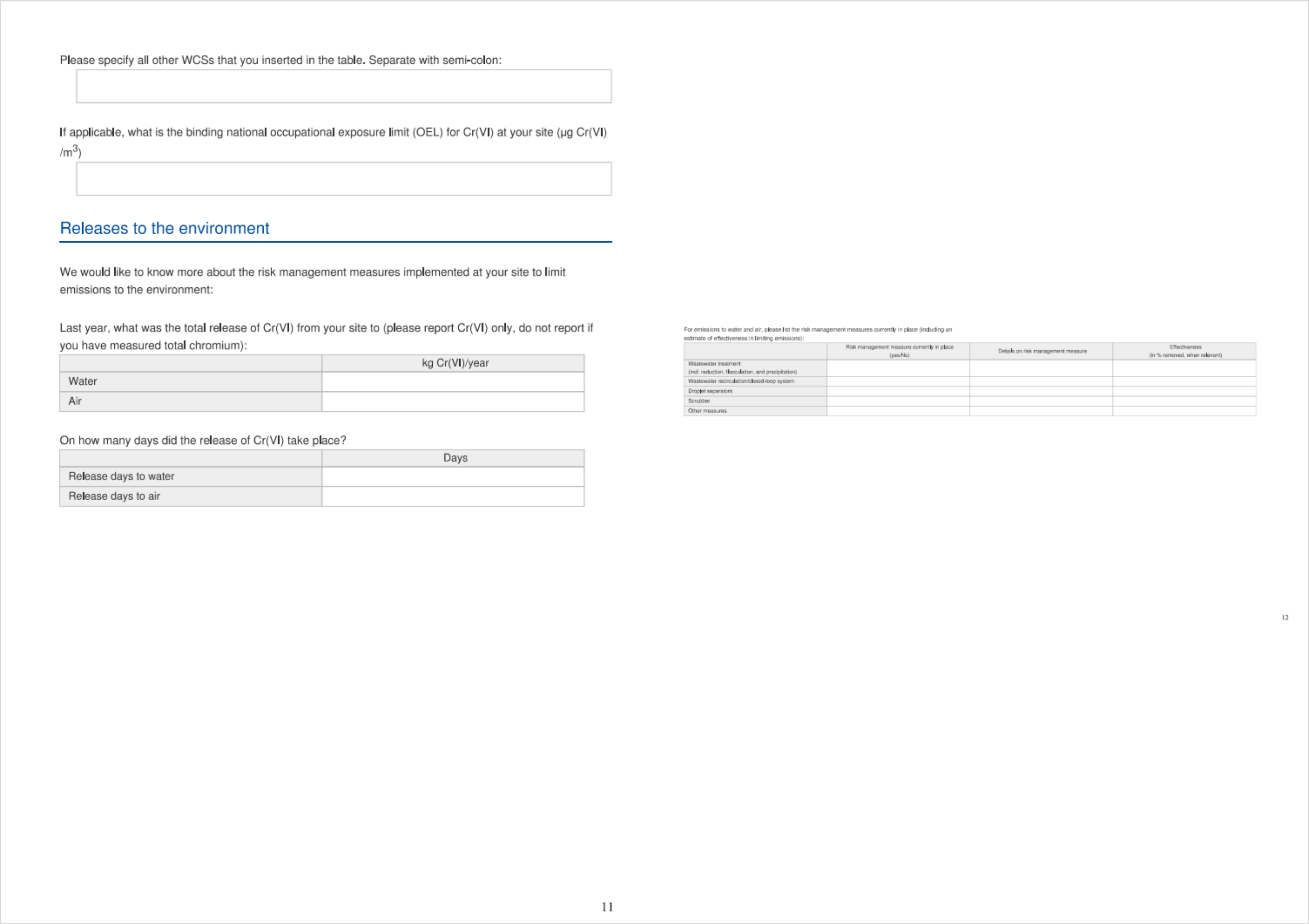
For each task filled in, please list the risk management measures currently in place (including an estimate of their effectiveness in limiting exposure to workers):

Task	Automation: available Yes/No	Segregation: available Yes/No	Containment: available Yes/No	Mechanical ventilation: available Yes/No	Local exhaust ventilation: ACH effectiveness (select 0 if no ventilation)	Respiratory protection equipment: available, effectiveness % (select 0 if none)
Delivery and storage of raw material						
Weighing, mixing, diluting of liquids						
Weighing, mixing, decanting of solids						
Loading/unloading of jigs						
Surface treatment by spraying in spray booth						
Surface treatment by brushing, rolling or pen stick						
Surface treatment by dipping /immersion including pre-treatment, main treatment, and post-treatment						
Concentration adjustment of baths with solids						
Concentration adjustment of baths with liquids						
Rinsing, drying, (self-)curing of parts						
Frequent maintenance activities (daily/weekly cleaning of workplace, re-filling of baths with liquids, etc.)						
Infrequent maintenance activities (biyearly or less						

9



frequent overhaul of equipment, including of surface treatment lines, anodes, LEV, scrubbers etc.)						
Waste/wastewater management						
Sampling and transfer to small containers (including filtering)						
Other 1						
Other 2						
Other 3						
Other 4						
Other 5						



Please specify all other WCSs that you inserted in the table. Separate with semi-colon:

If applicable, what is the binding national occupational exposure limit (OEL) for Cr(VI) at your site (µg Cr(VI) /m^3)

Releases to the environment

We would like to know more about the risk management measures implemented at your site to limit emissions to the environment:

Last year, what was the total release of Cr(VI) from your site to (please report Cr(VI) only, do not report if you have measured total chromium):

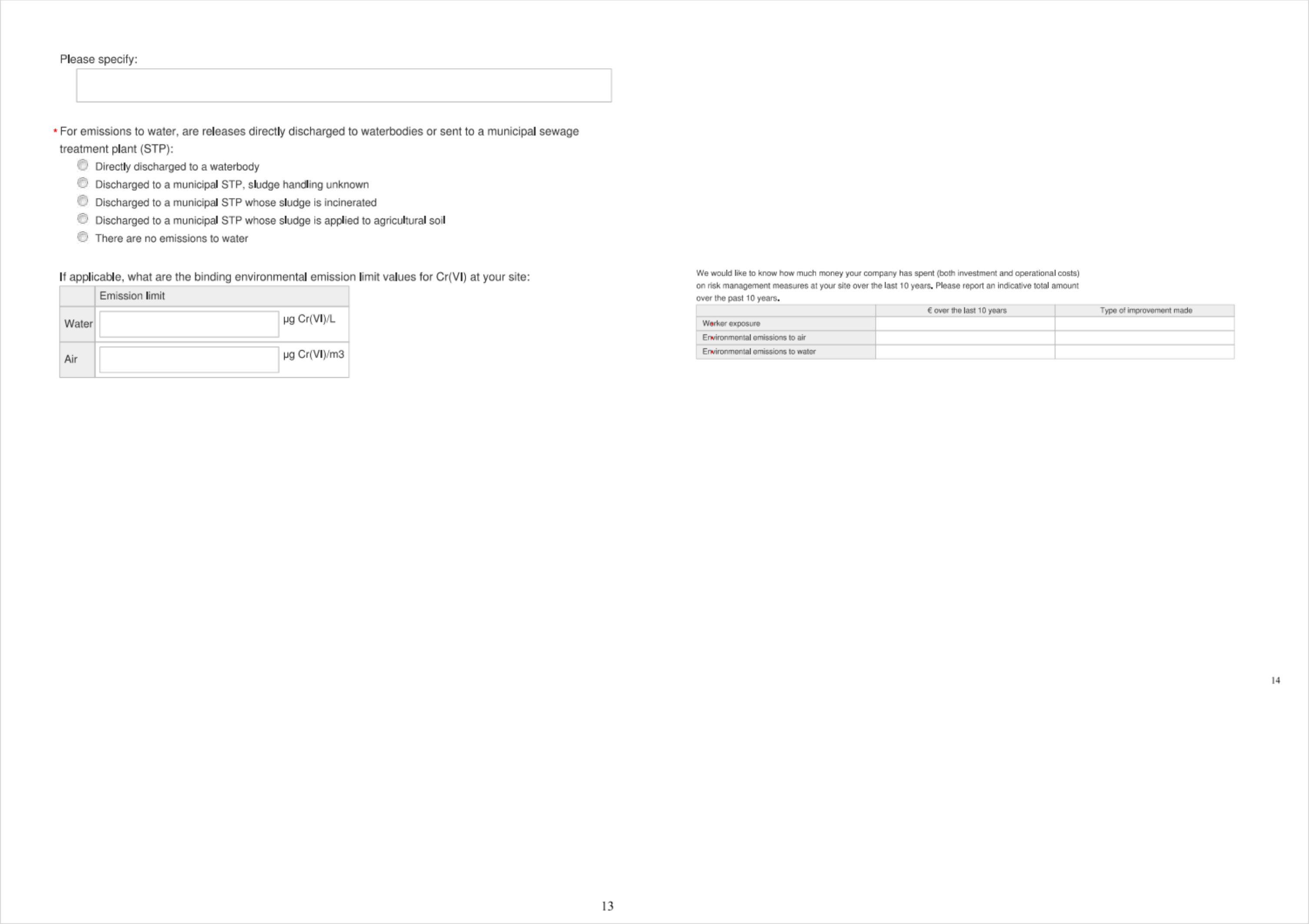
	kg Cr(VI)/year
Water	
Air	

On how many days did the release of Cr(VI) take place?

	Days
Release days to water	
Release days to air	

For emissions to water and air, please list the risk management measures currently in place (including an estimate of effectiveness in limiting emissions):

	Risk management measure currently in place (yes/No)	Details on risk management measure	Effectiveness (in % removed, when relevant)
Wastewater treatment (incl. reduction, flocculation, and precipitation)			
Wastewater recirculation/closed-loop system			
Droplet separators			
Scrubber			
Other measures			



Please specify:

* For emissions to water, are releases directly discharged to waterbodies or sent to a municipal sewage treatment plant (STP):

- ○ Directly discharged to a waterbody
- ○ Discharged to a municipal STP, sludge handling unknown
- ○ Discharged to a municipal STP whose sludge is incinerated
- ○ Discharged to a municipal STP whose sludge is applied to agricultural soil
- ○ There are no emissions to water

If applicable, what are the binding environmental emission limit values for Cr(VI) at your site:

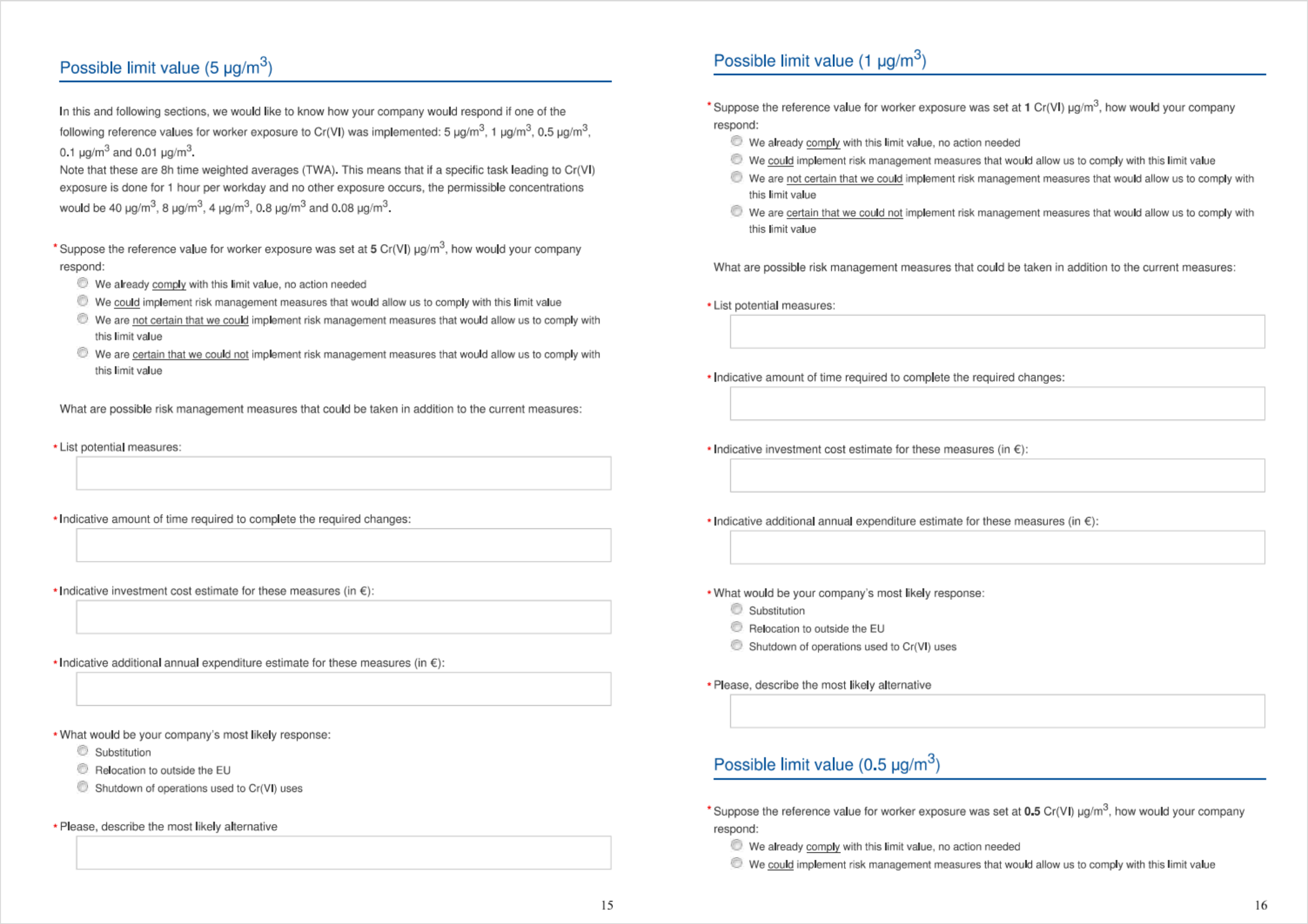
	Emission limit
Water	µg Cr(VI)/L
Air	µg Cr(VI)/m3

We would like to know how much money your company has spent (both investment and operational costs) on risk management measures at your site over the last 10 years. Please report an indicative total amount over the past 10 years.

	€ over the last 10 years	Type of improvement made
Worker exposure		
Environmental emissions to air		
Environmental emissions to water		

14

13



Possible limit value (5 µg/m^3)

In this and following sections, we would like to know how your company would respond if one of the following reference values for worker exposure to Cr(VI) was implemented: 5 µg/m^3, 1 µg/m^3, 0.5 µg/m^3, 0.1 µg/m^3 and 0.01 µg/m^3.
Note that these are 8h time weighted averages (TWA). This means that if a specific task leading to Cr(VI) exposure is done for 1 hour per workday and no other exposure occurs, the permissible concentrations would be 40 µg/m^3, 8 µg/m^3, 4 µg/m^3, 0.8 µg/m^3 and 0.08 µg/m^3.

* Suppose the reference value for worker exposure was set at **5** Cr(VI) µg/m^3, how would your company respond:

- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

What are possible risk management measures that could be taken in addition to the current measures:

* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):

* Indicative additional annual expenditure estimate for these measures (in €):

* What would be your company's most likely response:

- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

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Possible limit value (1 µg/m^3)

* Suppose the reference value for worker exposure was set at **1** Cr(VI) µg/m^3, how would your company respond:

- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

What are possible risk management measures that could be taken in addition to the current measures:

* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):

* Indicative additional annual expenditure estimate for these measures (in €):

* What would be your company's most likely response:

- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Possible limit value (0.5 µg/m^3)

* Suppose the reference value for worker exposure was set at **0.5** Cr(VI) µg/m^3, how would your company respond:

- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value

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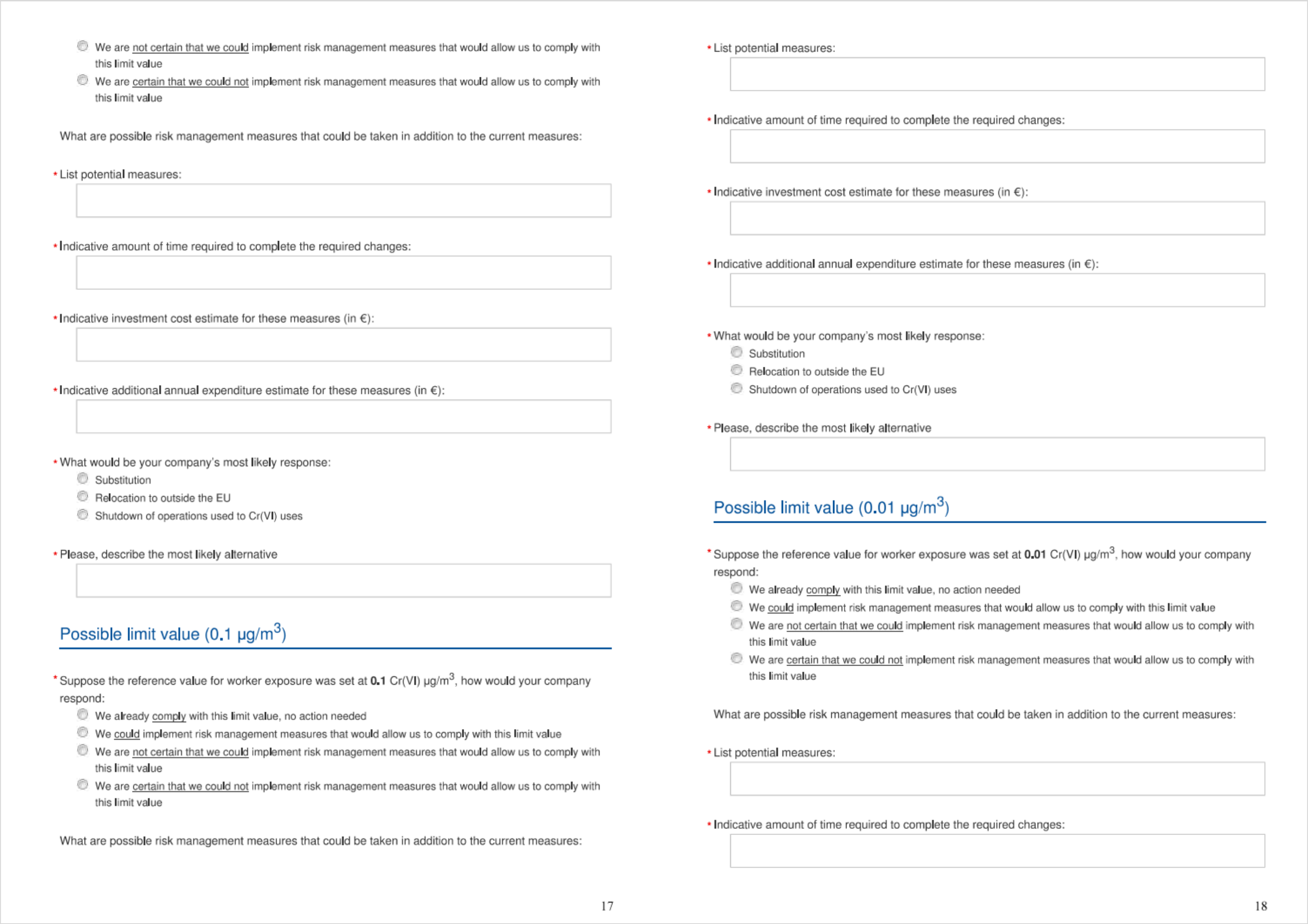

- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

What are possible risk management measures that could be taken in addition to the current measures:

* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):

* Indicative additional annual expenditure estimate for these measures (in €):

* What would be your company's most likely response:

- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Possible limit value (0.1 $\mu g/m^3$)

* Suppose the reference value for worker exposure was set at **0.1** Cr(VI) $\mu g/m^3$, how would your company respond:

- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

What are possible risk management measures that could be taken in addition to the current measures:

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* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):

* Indicative additional annual expenditure estimate for these measures (in €):

* What would be your company's most likely response:

- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Possible limit value (0.01 $\mu g/m^3$)

* Suppose the reference value for worker exposure was set at **0.01** Cr(VI) $\mu g/m^3$, how would your company respond:

- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

What are possible risk management measures that could be taken in addition to the current measures:

* List potential measures:

* Indicative amount of time required to complete the required changes:

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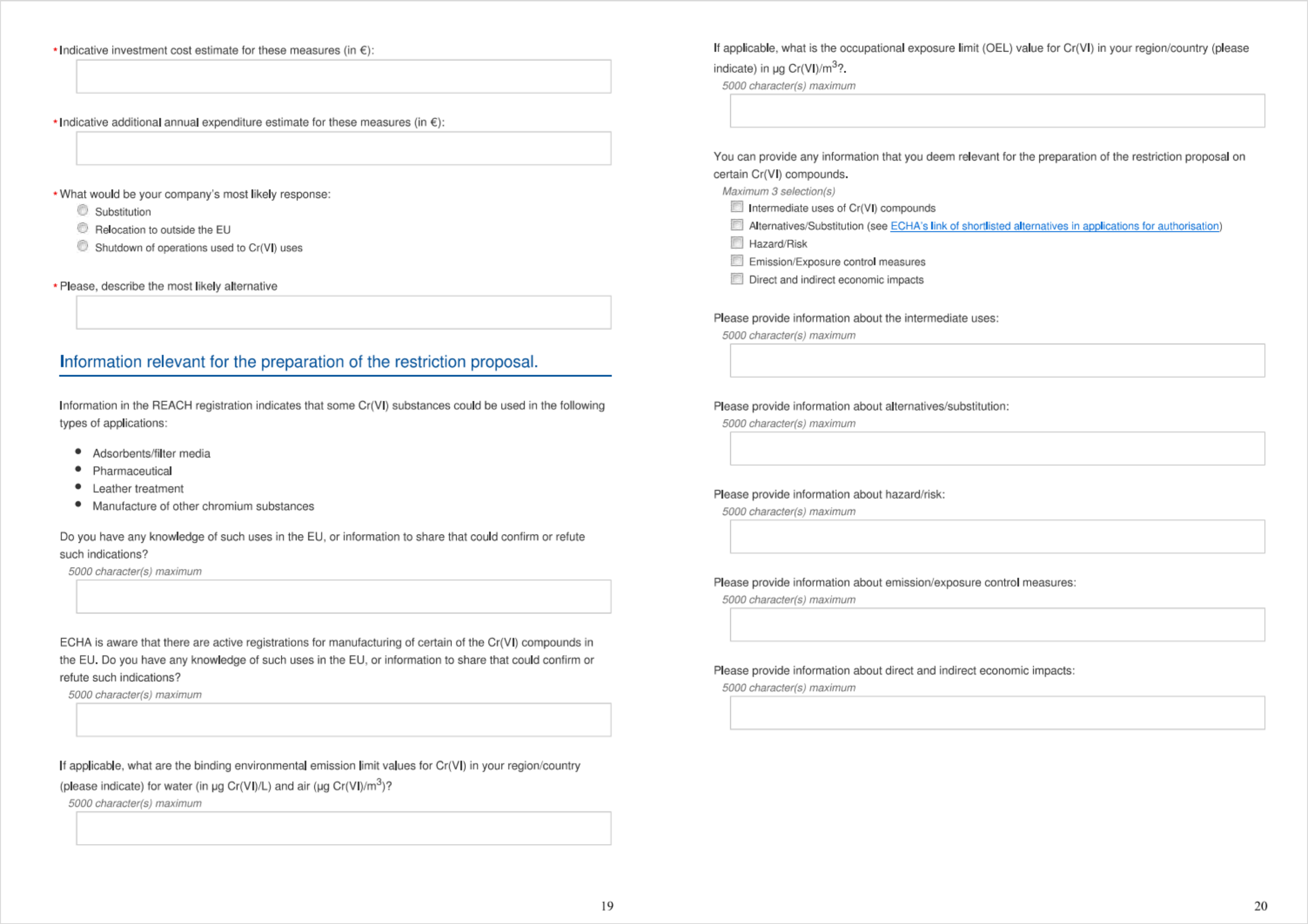

* Indicative investment cost estimate for these measures (in €):

* Indicative additional annual expenditure estimate for these measures (in €):

* What would be your company's most likely response:
○ Substitution
○ Relocation to outside the EU
○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Information relevant for the preparation of the restriction proposal.

Information in the REACH registration indicates that some Cr(VI) substances could be used in the following types of applications:

- Adsorbents/filter media
- Pharmaceutical
- Leather treatment
- Manufacture of other chromium substances

Do you have any knowledge of such uses in the EU, or information to share that could confirm or refute such indications?
5000 character(s) maximum

ECHA is aware that there are active registrations for manufacturing of certain of the Cr(VI) compounds in the EU. Do you have any knowledge of such uses in the EU, or information to share that could confirm or refute such indications?
5000 character(s) maximum

If applicable, what are the binding environmental emission limit values for Cr(VI) in your region/country (please indicate) for water (in µg Cr(VI)/L) and air (µg Cr(VI)/m^3)?
5000 character(s) maximum

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If applicable, what is the occupational exposure limit (OEL) value for Cr(VI) in your region/country (please indicate) in µg Cr(VI)/m^3?.
5000 character(s) maximum

You can provide any information that you deem relevant for the preparation of the restriction proposal on certain Cr(VI) compounds.
Maximum 3 selection(s)
☐ Intermediate uses of Cr(VI) compounds
☐ Alternatives/Substitution (see ECHA's link of shortlisted alternatives in applications for authorisation)
☐ Hazard/Risk
☐ Emission/Exposure control measures
☐ Direct and indirect economic impacts

Please provide information about the intermediate uses:
5000 character(s) maximum

Please provide information about alternatives/substitution:
5000 character(s) maximum

Please provide information about hazard/risk:
5000 character(s) maximum

Please provide information about emission/exposure control measures:
5000 character(s) maximum

Please provide information about direct and indirect economic impacts:
5000 character(s) maximum

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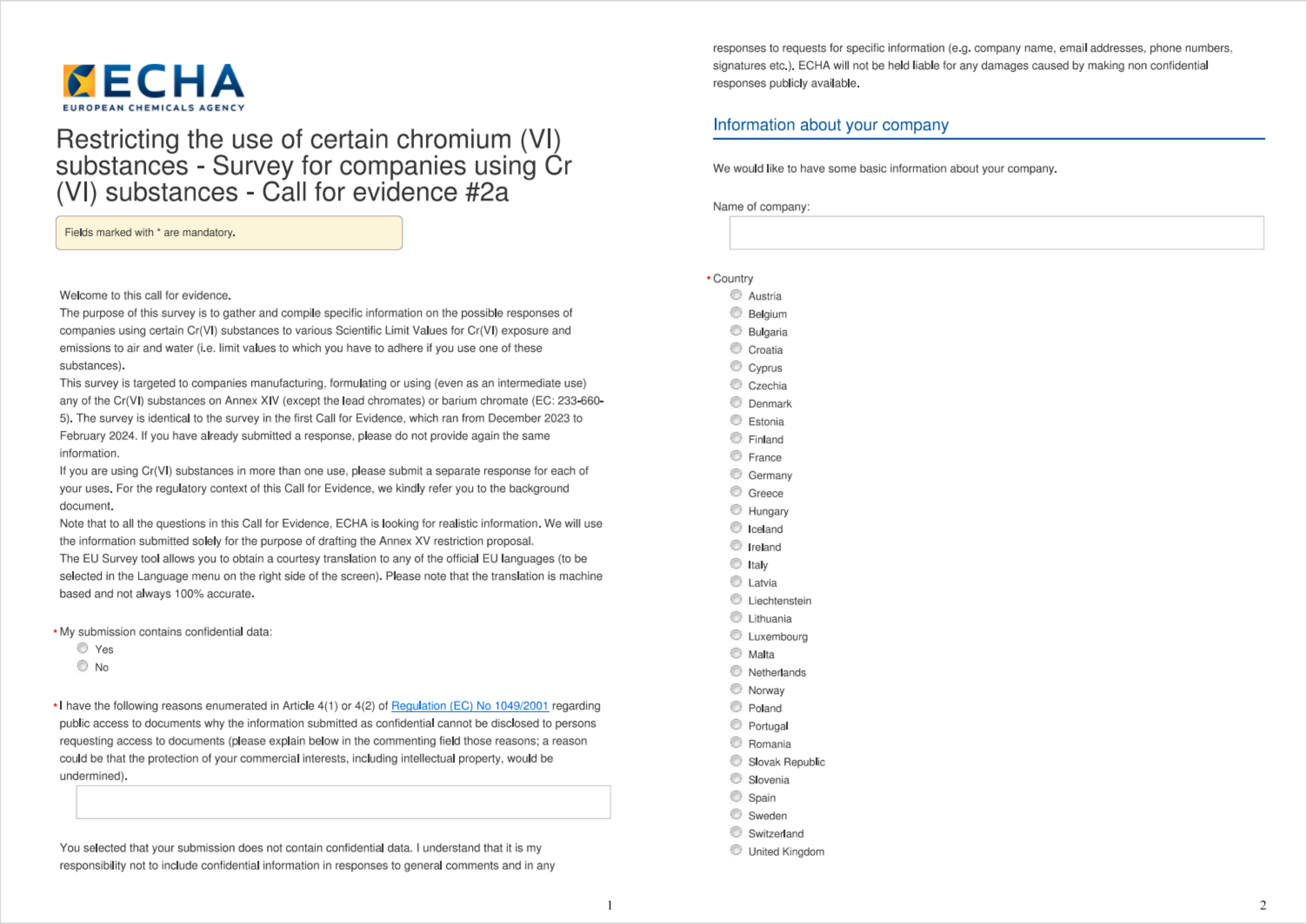
G.2.2. CfE#2a questionnaire



ECHA
EUROPEAN CHEMICALS AGENCY

Restricting the use of certain chromium (VI) substances - Survey for companies using Cr (VI) substances - Call for evidence #2a

Fields marked with * are mandatory.

Welcome to this call for evidence.
The purpose of this survey is to gather and compile specific information on the possible responses of companies using certain Cr(VI) substances to various Scientific Limit Values for Cr(VI) exposure and emissions to air and water (i.e. limit values to which you have to adhere if you use one of these substances).
This survey is targeted to companies manufacturing, formulating or using (even as an intermediate use) any of the Cr(VI) substances on Annex XIV (except the lead chromates) or barium chromate (EC: 233-660-5). The survey is identical to the survey in the first Call for Evidence, which ran from December 2023 to February 2024. If you have already submitted a response, please do not provide again the same information.
If you are using Cr(VI) substances in more than one use, please submit a separate response for each of your uses. For the regulatory context of this Call for Evidence, we kindly refer you to the background document.
Note that to all the questions in this Call for Evidence, ECHA is looking for realistic information. We will use the information submitted solely for the purpose of drafting the Annex XV restriction proposal.
The EU Survey tool allows you to obtain a courtesy translation to any of the official EU languages (to be selected in the Language menu on the right side of the screen). Please note that the translation is machine based and not always 100% accurate.

* My submission contains confidential data:
○ Yes
○ No

* I have the following reasons enumerated in Article 4(1) or 4(2) of Regulation (EC) No 1049/2001 regarding public access to documents why the information submitted as confidential cannot be disclosed to persons requesting access to documents (please explain below in the commenting field those reasons; a reason could be that the protection of your commercial interests, including intellectual property, would be undermined).

☐

You selected that your submission does not contain confidential data. I understand that it is my responsibility not to include confidential information in responses to general comments and in any responses to requests for specific information (e.g. company name, email addresses, phone numbers, signatures etc.). ECHA will not be held liable for any damages caused by making non confidential responses publicly available.

Information about your company

We would like to have some basic information about your company.

Name of company:

☐

* Country
○ Austria
○ Belgium
○ Bulgaria
○ Croatia
○ Cyprus
○ Czechia
○ Denmark
○ Estonia
○ Finland
○ France
○ Germany
○ Greece
○ Hungary
○ Iceland
○ Ireland
○ Italy
○ Latvia
○ Liechtenstein
○ Lithuania
○ Luxembourg
○ Malta
○ Netherlands
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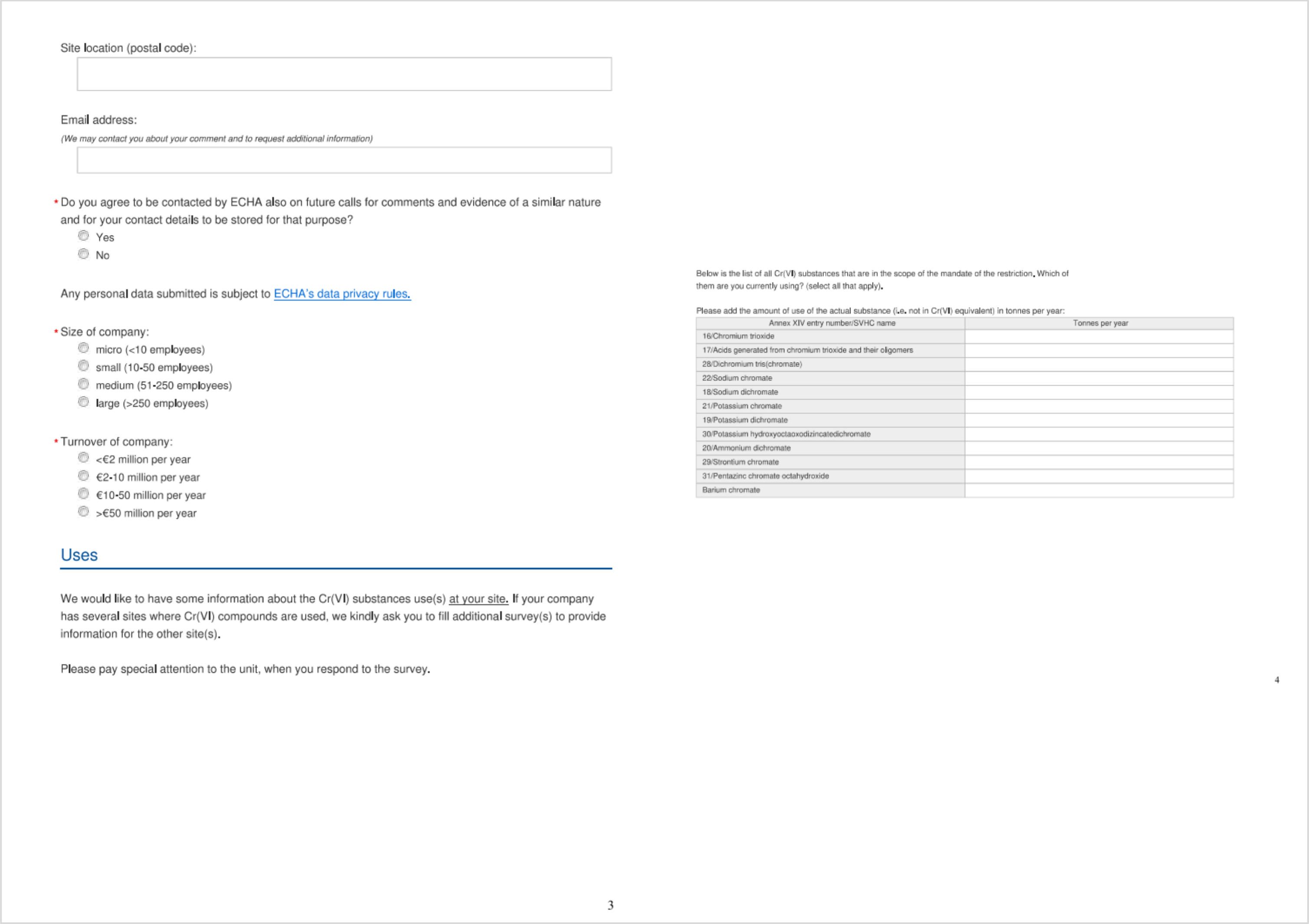
○ Poland
○ Portugal
○ Romania
○ Slovak Republic
○ Slovenia
○ Spain
○ Sweden
○ Switzerland
○ United Kingdom



Site location (postal code):

Email address:

(We may contact you about your comment and to request additional information)

* Do you agree to be contacted by ECHA also on future calls for comments and evidence of a similar nature and for your contact details to be stored for that purpose?

○ Yes
○ No

Any personal data submitted is subject to ECHA's data privacy rules.

* Size of company:

○ micro (<10 employees)
○ small (10-50 employees)
○ medium (51-250 employees)
○ large (>250 employees)

* Turnover of company:

○ <€2 million per year
○ €2-10 million per year
○ €10-50 million per year
○ >€50 million per year

Uses

We would like to have some information about the Cr(VI) substances use(s) at your site. If your company has several sites where Cr(VI) compounds are used, we kindly ask you to fill additional survey(s) to provide information for the other site(s).

Please pay special attention to the unit, when you respond to the survey.

3

Below is the list of all Cr(VI) substances that are in the scope of the mandate of the restriction. Which of them are you currently using? (select all that apply).

Please add the amount of use of the actual substance (i.e. not in Cr(VI) equivalent) in tonnes per year:

Annex XIV entry number/SVHC name	Tonnes per year
16/Chromium trioxide	
17/Acids generated from chromium trioxide and their oligomers	
28/Dichromium tris(chromate)	
22/Sodium chromate	
18/Sodium dichromate	
21/Potassium chromate	
19/Potassium dichromate	
30/Potassium hydroxyoctaoxodizincatedichromate	
20/Ammonium dichromate	
29/Strontium chromate	
31/Pentazinc chromate octahydroxide	
Barium chromate	

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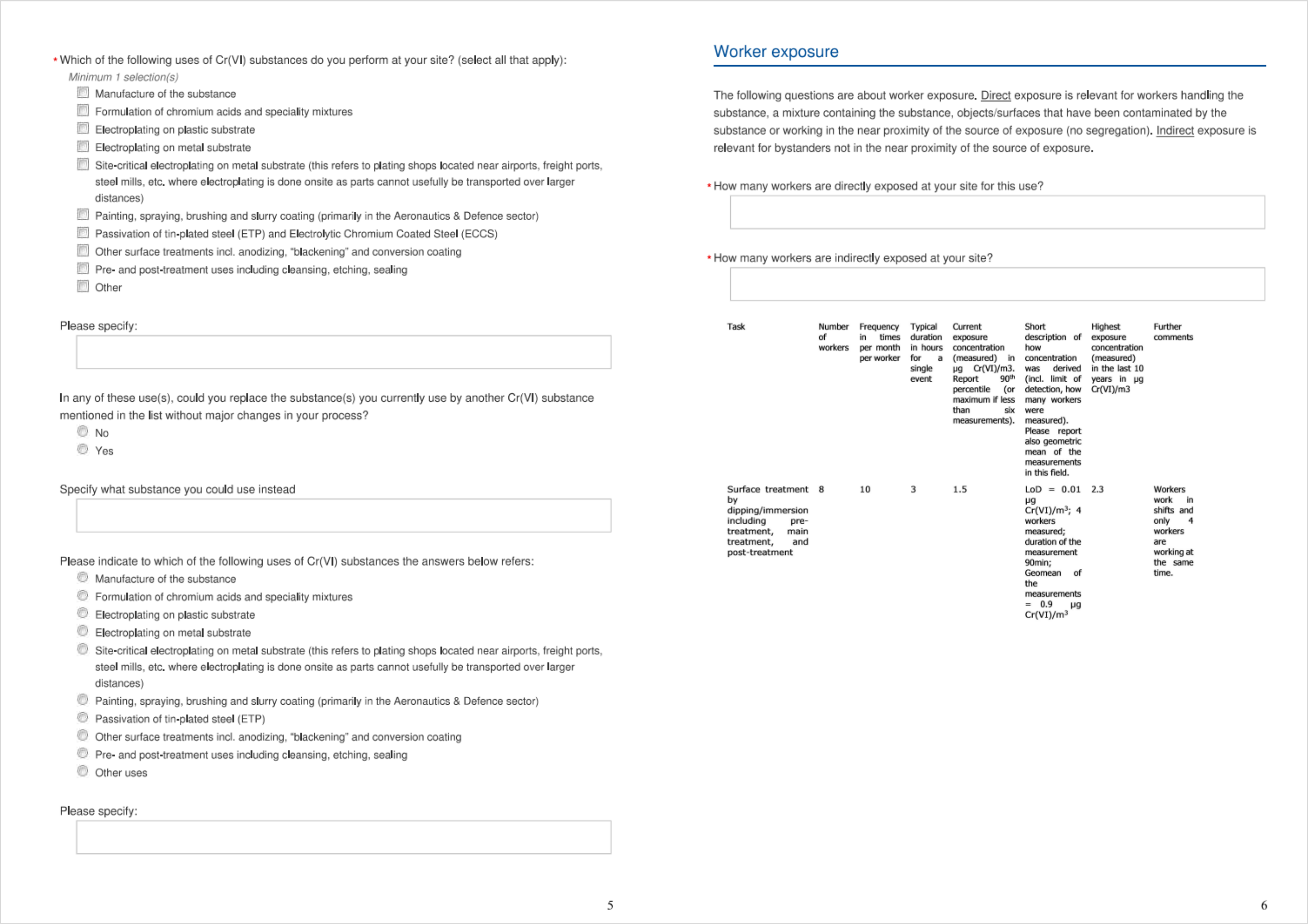

* Which of the following uses of Cr(VI) substances do you perform at your site? (select all that apply):

Minimum 1 selection(s)

- ☐ Manufacture of the substance
- ☐ Formulation of chromium acids and speciality mixtures
- ☐ Electroplating on plastic substrate
- ☐ Electroplating on metal substrate
- ☐ Site-critical electroplating on metal substrate (this refers to plating shops located near airports, freight ports, steel mills, etc. where electroplating is done onsite as parts cannot usefully be transported over larger distances)
- ☐ Painting, spraying, brushing and slurry coating (primarily in the Aeronautics & Defence sector)
- ☐ Passivation of tin-plated steel (ETP) and Electrolytic Chromium Coated Steel (ECCS)
- ☐ Other surface treatments incl. anodizing, "blackening" and conversion coating
- ☐ Pre- and post-treatment uses including cleansing, etching, sealing
- ☐ Other

Please specify:

In any of these use(s), could you replace the substance(s) you currently use by another Cr(VI) substance mentioned in the list without major changes in your process?

- ○ No
- ○ Yes

Specify what substance you could use instead

Please indicate to which of the following uses of Cr(VI) substances the answers below refers:

- ○ Manufacture of the substance
- ○ Formulation of chromium acids and speciality mixtures
- ○ Electroplating on plastic substrate
- ○ Electroplating on metal substrate
- ○ Site-critical electroplating on metal substrate (this refers to plating shops located near airports, freight ports, steel mills, etc. where electroplating is done onsite as parts cannot usefully be transported over larger distances)
- ○ Painting, spraying, brushing and slurry coating (primarily in the Aeronautics & Defence sector)
- ○ Passivation of tin-plated steel (ETP)
- ○ Other surface treatments incl. anodizing, "blackening" and conversion coating
- ○ Pre- and post-treatment uses including cleansing, etching, sealing
- ○ Other uses

Please specify:

5

Worker exposure

The following questions are about worker exposure. Direct exposure is relevant for workers handling the substance, a mixture containing the substance, objects/surfaces that have been contaminated by the substance or working in the near proximity of the source of exposure (no segregation). Indirect exposure is relevant for bystanders not in the near proximity of the source of exposure.

* How many workers are directly exposed at your site for this use?

* How many workers are indirectly exposed at your site?

Task	Number of workers	Frequency in times per month per worker	Typical duration in hours for a single event	Current exposure concentration (measured) in µg Cr(VI)/m3. Report 90th percentile (or maximum if less than six measurements).	Short description of how concentration was derived (incl. limit of detection, how many workers were measured). Please report also geometric mean of the measurements in this field.	Highest exposure concentration (measured) in the last 10 years in µg Cr(VI)/m3	Further comments
Surface treatment by dipping/immersion including pre-treatment, main treatment, and post-treatment	8	10	3	1.5	LoD = 0.01 µg Cr(VI)/m^3; 4 workers measured; duration of the measurement 90min; Geomean of the measurements = 0.9 µg Cr(VI)/m^3	2.3	Workers work in shifts and only 4 workers are working at the same time.

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Different tasks conducted with the substance can contribute in different ways to exposure. From the following table, please fill in a **maximum of 5 tasks** that contribute most to the exposure of workers at your site. Please see the example above. Be careful to express concentrations in µg Cr(VI)/m^3

Task	Number of workers	Frequency in times per month per worker	Typical duration in hours for a single event	Current exposure concentration (measured) in µg Cr (VI)/m3. Report 90th percentile (or maximum if less than six measurements)	Short description of how concentration was derived (incl. limit of detection, how many workers were measured). Please report also geometric mean of the measurements in this field.	Highest exposure concentration (measured) in the last 10 years in µg Cr (VI)/m^3	Further comments
Delivery and storage of raw material	☐	☐	☐	☐	☐	☐	☐
Weighing, mixing, diluting of liquids	☐	☐	☐	☐	☐	☐	☐
Weighing, mixing, decanting of solids	☐	☐	☐	☐	☐	☐	☐
Loading/unloading of jigs	☐	☐	☐	☐	☐	☐	☐
Surface treatment by spraying in spray booth	☐	☐	☐	☐	☐	☐	☐
Surface treatment by brushing, rolling or pen stick	☐	☐	☐	☐	☐	☐	☐
Surface treatment by dipping/immersion including pre-treatment, main treatment, and post-treatment	☐	☐	☐	☐	☐	☐	☐
Concentration adjustment of baths with solids	☐	☐	☐	☐	☐	☐	☐

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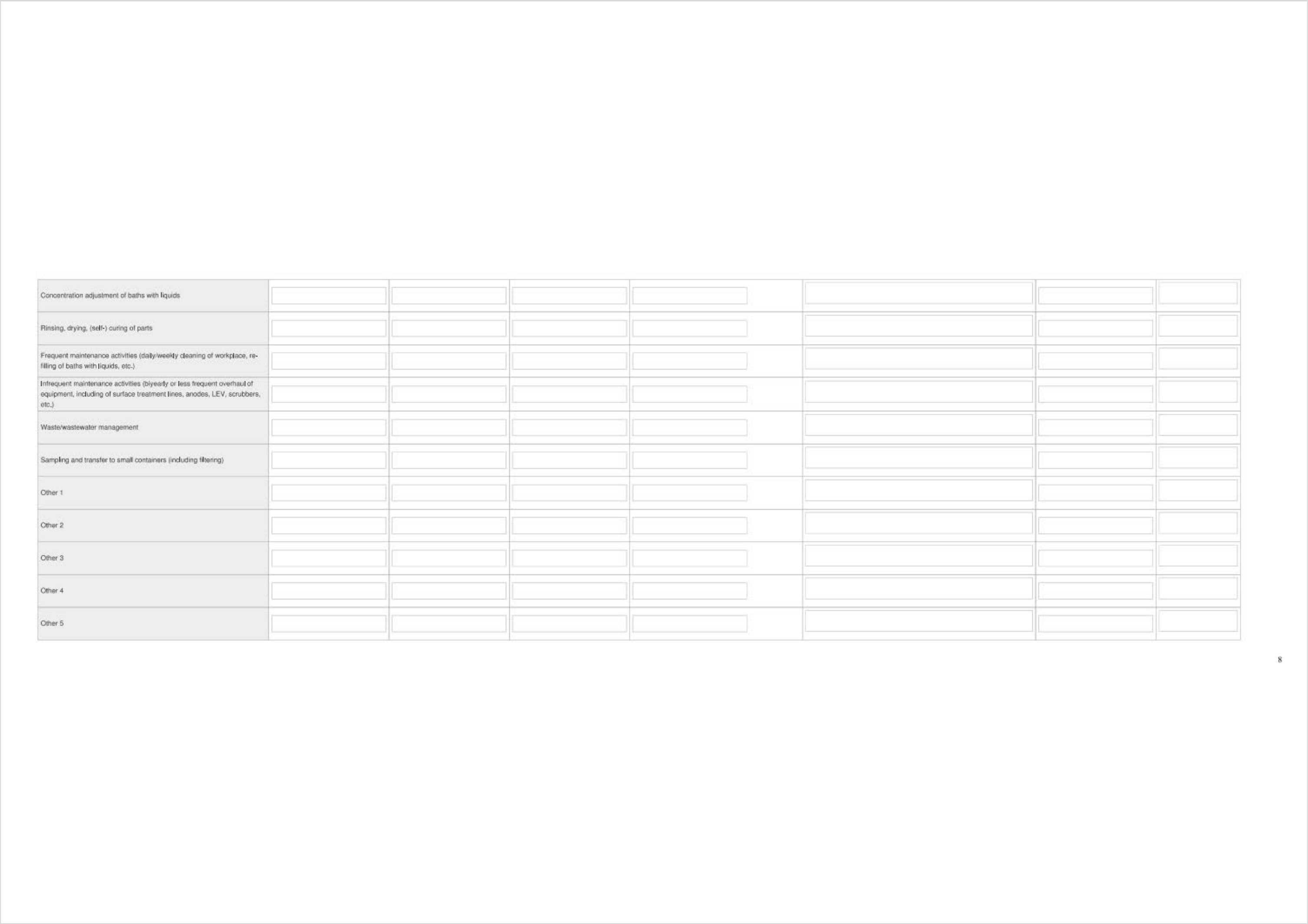

Concentration adjustment of baths with liquids							
Rinsing, drying, (self-) curing of parts							
Frequent maintenance activities (daily/weekly cleaning of workplace, re-filling of baths with liquids, etc.)							
Infrequent maintenance activities (biyearly or less frequent overhaul of equipment, including of surface treatment lines, anodes, LEV, scrubbers, etc.)							
Waste/wastewater management							
Sampling and transfer to small containers (including filtering)							
Other 1							
Other 2							
Other 3							
Other 4							
Other 5							

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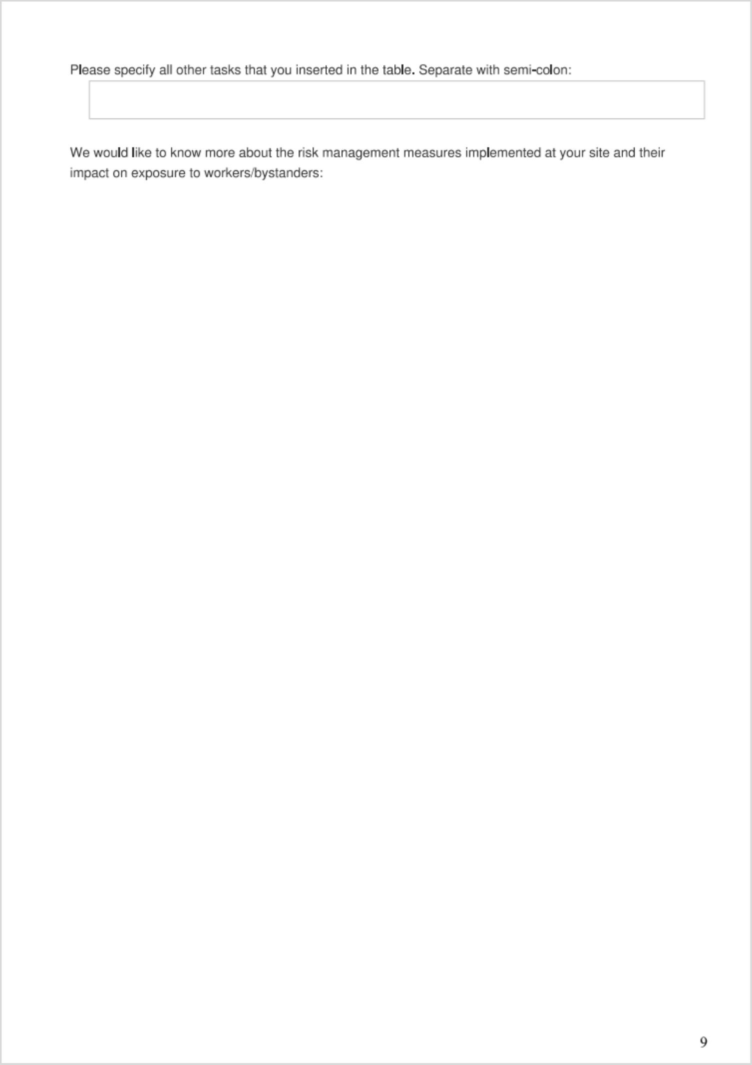

Please specify all other tasks that you inserted in the table. Separate with semi-colon:

We would like to know more about the risk management measures implemented at your site and their impact on exposure to workers/bystanders:

For each task filled in, please list the risk management measures currently in place (including an estimate of their effectiveness in limiting exposure to workers when asked. When asked for a “Yes/No” -answer, please only write “Yes” or “No”):

Task	Automation: available Yes /No	Segregation: available Yes/No	Containment: available Yes/No	General ventilation: Effectiveness of mechanical ventilation in air changes per hour (ACH). Select 0 if no mechanical ventilation	Local exhaust ventilation (LEV): effectiveness % (select 0 if no LEV)	Respiratory protection equipment: available, effectiveness % (select 0 if none)
Delivery and storage of raw material	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Weighing, mixing, diluting of liquids	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Weighing, mixing, decanting of solids	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Loading/unloading of jigs	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Surface treatment by spraying in spray booth	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Surface treatment by brushing, rolling or pen stick	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Surface treatment by dipping/immersion including pre-treatment, main treatment, and post-treatment	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Concentration adjustment of baths with solids	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Concentration adjustment of baths with liquids	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Rinsing, drying, (self-) curing of parts	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			

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Frequent maintenance activities (daily/weekly cleaning of workplace, re- filling of baths with liquids, etc.)	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Infrequent maintenance activities (biyearly or less frequent overhaul of equipment, including of surface treatment lines, anodes, LEV, scrubbers, etc.)	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Waste/wastewater management	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Sampling and transfer to small containers (including filtering)	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Other 1	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Other 2	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Other 3	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Other 4	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			
Other 5	○ Yes ○ No	○ Yes ○ No	○ Yes ○ No			

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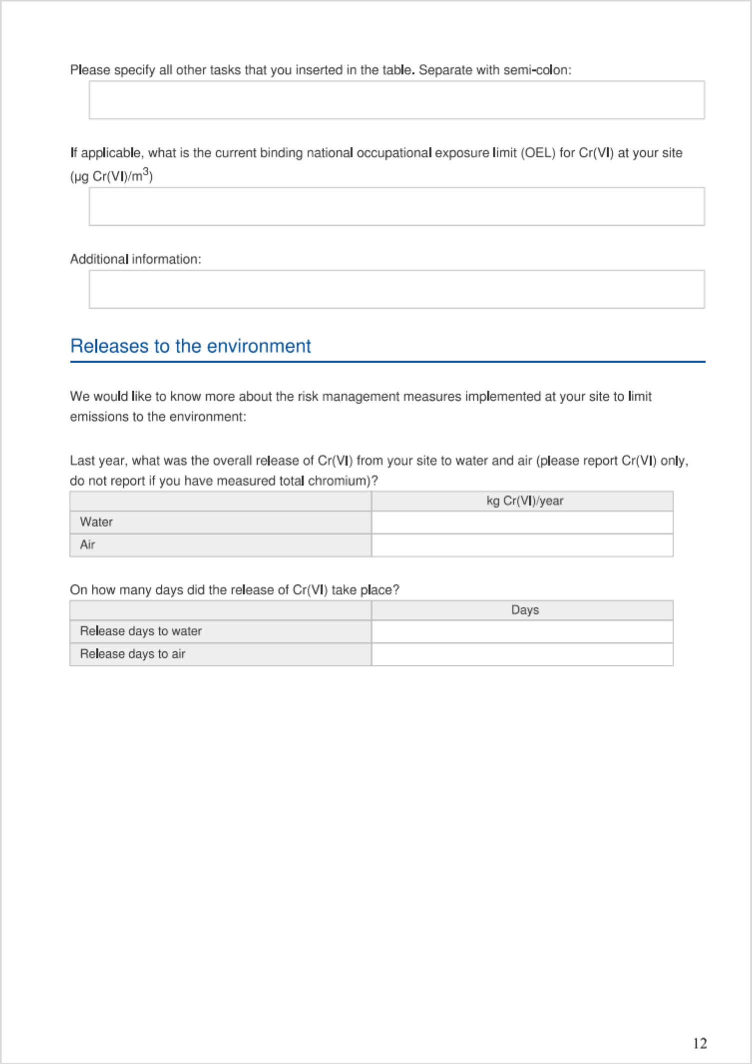

Please specify all other tasks that you inserted in the table. Separate with semi-colon:

If applicable, what is the current binding national occupational exposure limit (OEL) for Cr(VI) at your site (µg Cr(VI)/m^3)

Additional information:

Releases to the environment

We would like to know more about the risk management measures implemented at your site to limit emissions to the environment:

Last year, what was the overall release of Cr(VI) from your site to water and air (please report Cr(VI) only, do not report if you have measured total chromium)?

	kg Cr(VI)/year
Water	
Air	

On how many days did the release of Cr(VI) take place?

	Days
Release days to water	
Release days to air	

12

For emissions to water and air, please list the risk management measures currently in place (including an estimate of effectiveness in limiting emissions):

	Risk management measure currently in place (yes/No)	Details on risk management measure	Effectiveness (in % removed, when relevant)
Wastewater treatment (incl. reduction, flocculation, and precipitation)			
Wastewater recirculation/closed-loop system			
Droplet separators			
Scrubber			
Other measures			

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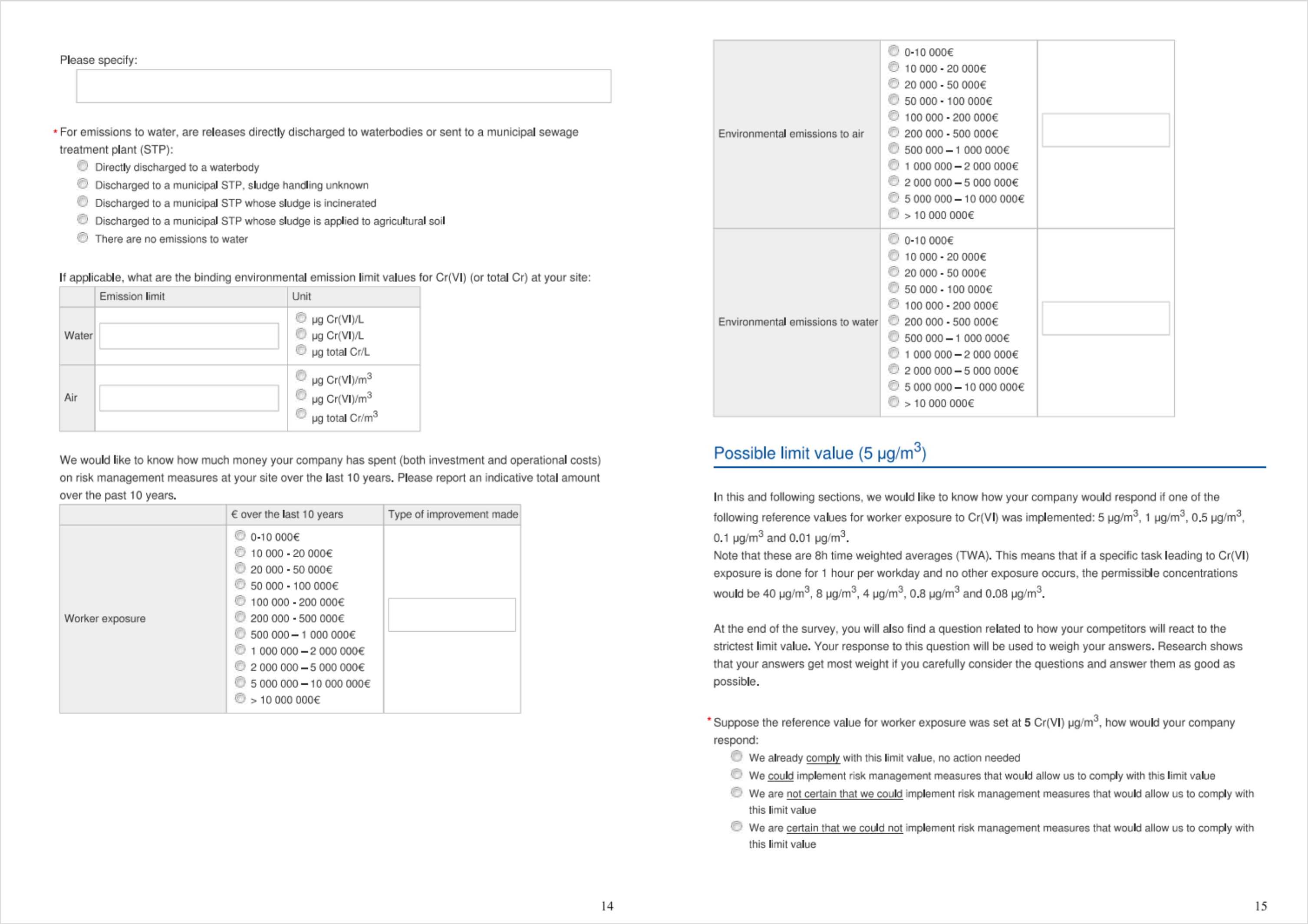

Please specify:

* For emissions to water, are releases directly discharged to waterbodies or sent to a municipal sewage treatment plant (STP):

- ○ Directly discharged to a waterbody
- ○ Discharged to a municipal STP, sludge handling unknown
- ○ Discharged to a municipal STP whose sludge is incinerated
- ○ Discharged to a municipal STP whose sludge is applied to agricultural soil
- ○ There are no emissions to water

If applicable, what are the binding environmental emission limit values for Cr(VI) (or total Cr) at your site:

	Emission limit	Unit
Water		○ µg Cr(VI)/L ○ µg Cr(VI)/L ○ µg total Cr/L
Air		○ µg Cr(VI)/m^3 ○ µg Cr(VI)/m^3 ○ µg total Cr/m^3

We would like to know how much money your company has spent (both investment and operational costs) on risk management measures at your site over the last 10 years. Please report an indicative total amount over the past 10 years.

	€ over the last 10 years	Type of improvement made
Worker exposure	○ 0-10 000€ ○ 10 000 - 20 000€ ○ 20 000 - 50 000€ ○ 50 000 - 100 000€ ○ 100 000 - 200 000€ ○ 200 000 - 500 000€ ○ 500 000 – 1 000 000€ ○ 1 000 000 – 2 000 000€ ○ 2 000 000 – 5 000 000€ ○ 5 000 000 – 10 000 000€ ○ > 10 000 000€	
Environmental emissions to air	○ 0-10 000€ ○ 10 000 - 20 000€ ○ 20 000 - 50 000€ ○ 50 000 - 100 000€ ○ 100 000 - 200 000€ ○ 200 000 - 500 000€ ○ 500 000 – 1 000 000€ ○ 1 000 000 – 2 000 000€ ○ 2 000 000 – 5 000 000€ ○ 5 000 000 – 10 000 000€ ○ > 10 000 000€	
Environmental emissions to water	○ 0-10 000€ ○ 10 000 - 20 000€ ○ 20 000 - 50 000€ ○ 50 000 - 100 000€ ○ 100 000 - 200 000€ ○ 200 000 - 500 000€ ○ 500 000 – 1 000 000€ ○ 1 000 000 – 2 000 000€ ○ 2 000 000 – 5 000 000€ ○ 5 000 000 – 10 000 000€ ○ > 10 000 000€	

14

Possible limit value (5 µg/m^3)

In this and following sections, we would like to know how your company would respond if one of the following reference values for worker exposure to Cr(VI) was implemented: 5 µg/m^3, 1 µg/m^3, 0.5 µg/m^3, 0.1 µg/m^3 and 0.01 µg/m^3.
Note that these are 8h time weighted averages (TWA). This means that if a specific task leading to Cr(VI) exposure is done for 1 hour per workday and no other exposure occurs, the permissible concentrations would be 40 µg/m^3, 8 µg/m^3, 4 µg/m^3, 0.8 µg/m^3 and 0.08 µg/m^3.

At the end of the survey, you will also find a question related to how your competitors will react to the strictest limit value. Your response to this question will be used to weigh your answers. Research shows that your answers get most weight if you carefully consider the questions and answer them as good as possible.

* Suppose the reference value for worker exposure was set at **5** Cr(VI) µg/m^3, how would your company respond:

- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

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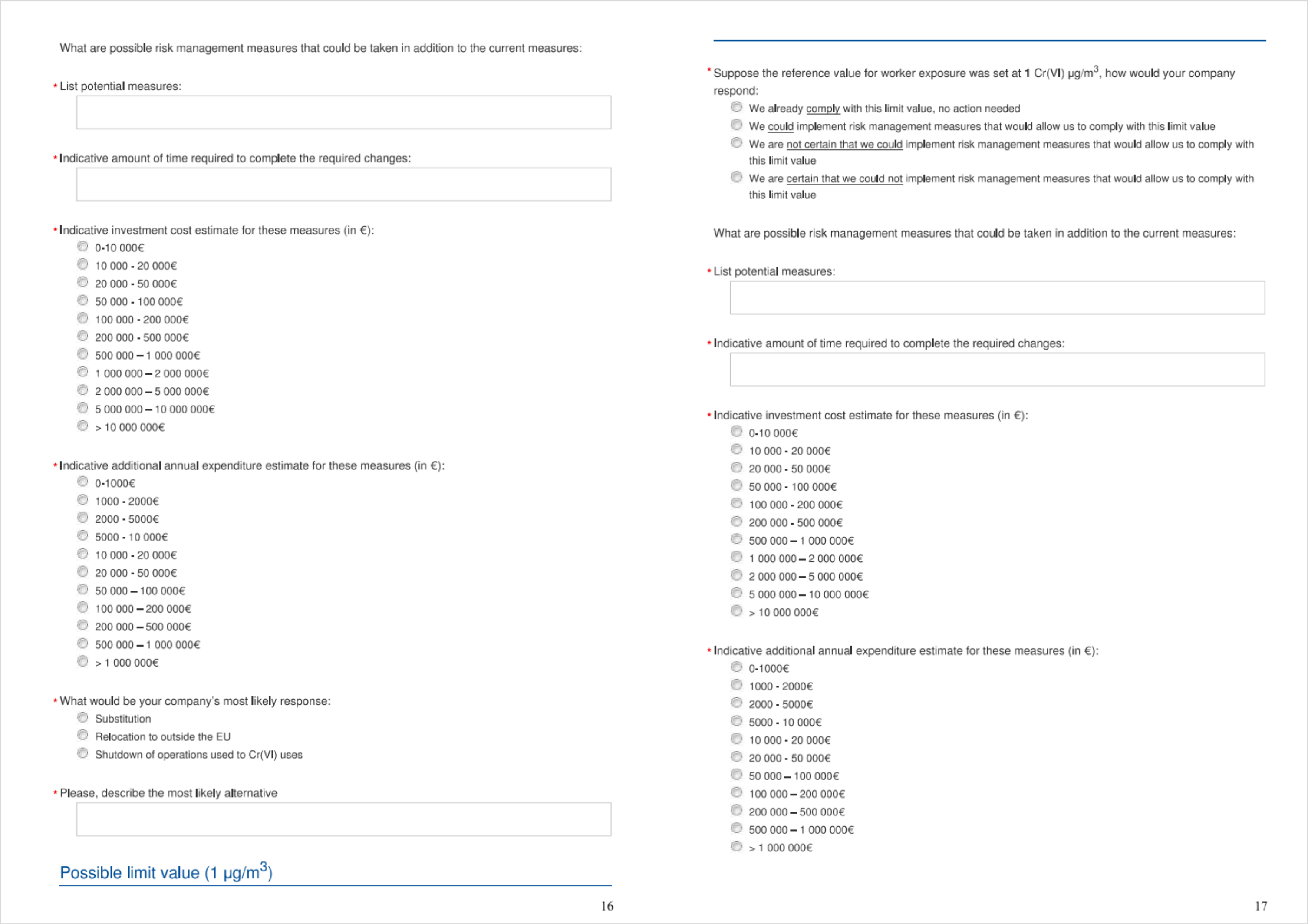


What are possible risk management measures that could be taken in addition to the current measures:

* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):
- ○ 0-10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 - 100 000€
- ○ 100 000 - 200 000€
- ○ 200 000 - 500 000€
- ○ 500 000 – 1 000 000€
- ○ 1 000 000 – 2 000 000€
- ○ 2 000 000 – 5 000 000€
- ○ 5 000 000 – 10 000 000€
- ○ > 10 000 000€

* Indicative additional annual expenditure estimate for these measures (in €):
- ○ 0-1000€
- ○ 1000 - 2000€
- ○ 2000 - 5000€
- ○ 5000 - 10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 – 100 000€
- ○ 100 000 – 200 000€
- ○ 200 000 – 500 000€
- ○ 500 000 – 1 000 000€
- ○ > 1 000 000€

* What would be your company's most likely response:
- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Possible limit value (1 µg/m^3)

16

* Suppose the reference value for worker exposure was set at **1** Cr(VI) µg/m^3, how would your company respond:
- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

What are possible risk management measures that could be taken in addition to the current measures:

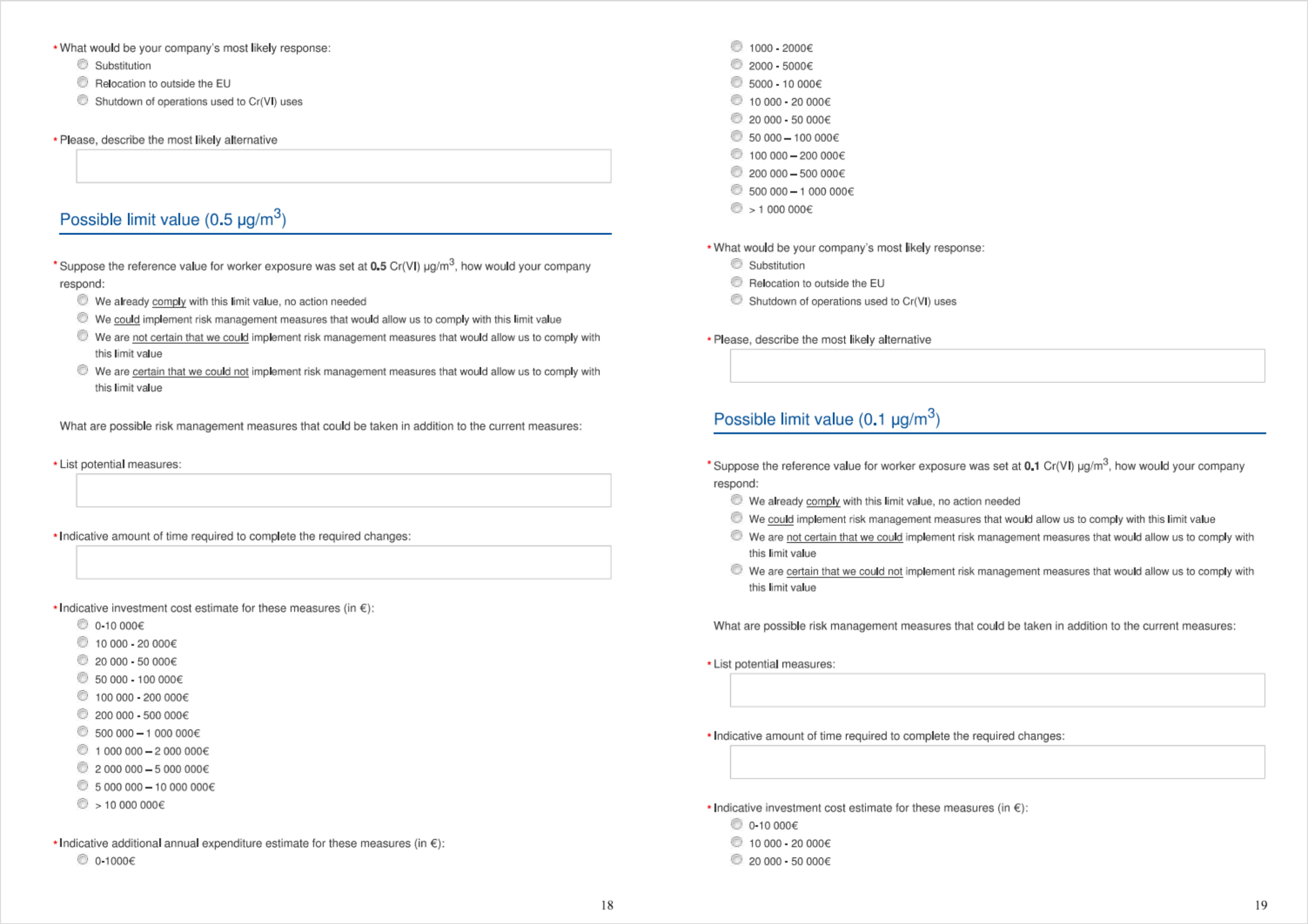
* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):
- ○ 0-10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 - 100 000€
- ○ 100 000 - 200 000€
- ○ 200 000 - 500 000€
- ○ 500 000 – 1 000 000€
- ○ 1 000 000 – 2 000 000€
- ○ 2 000 000 – 5 000 000€
- ○ 5 000 000 – 10 000 000€
- ○ > 10 000 000€

* Indicative additional annual expenditure estimate for these measures (in €):
- ○ 0-1000€
- ○ 1000 - 2000€
- ○ 2000 - 5000€
- ○ 5000 - 10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 – 100 000€
- ○ 100 000 – 200 000€
- ○ 200 000 – 500 000€
- ○ 500 000 – 1 000 000€
- ○ > 1 000 000€

17



* What would be your company's most likely response:
- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Possible limit value (0.5 μg/m^3)

* Suppose the reference value for worker exposure was set at **0.5** Cr(VI) μg/m^3, how would your company respond:
- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

What are possible risk management measures that could be taken in addition to the current measures:

* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):
- ○ 0-10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 - 100 000€
- ○ 100 000 - 200 000€
- ○ 200 000 - 500 000€
- ○ 500 000 – 1 000 000€
- ○ 1 000 000 – 2 000 000€
- ○ 2 000 000 – 5 000 000€
- ○ 5 000 000 – 10 000 000€
- ○ > 10 000 000€

* Indicative additional annual expenditure estimate for these measures (in €):
- ○ 0-1000€

18

- ○ 1000 - 2000€
- ○ 2000 - 5000€
- ○ 5000 - 10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 – 100 000€
- ○ 100 000 – 200 000€
- ○ 200 000 – 500 000€
- ○ 500 000 – 1 000 000€
- ○ > 1 000 000€

* What would be your company's most likely response:
- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Possible limit value (0.1 μg/m^3)

* Suppose the reference value for worker exposure was set at **0.1** Cr(VI) μg/m^3, how would your company respond:
- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

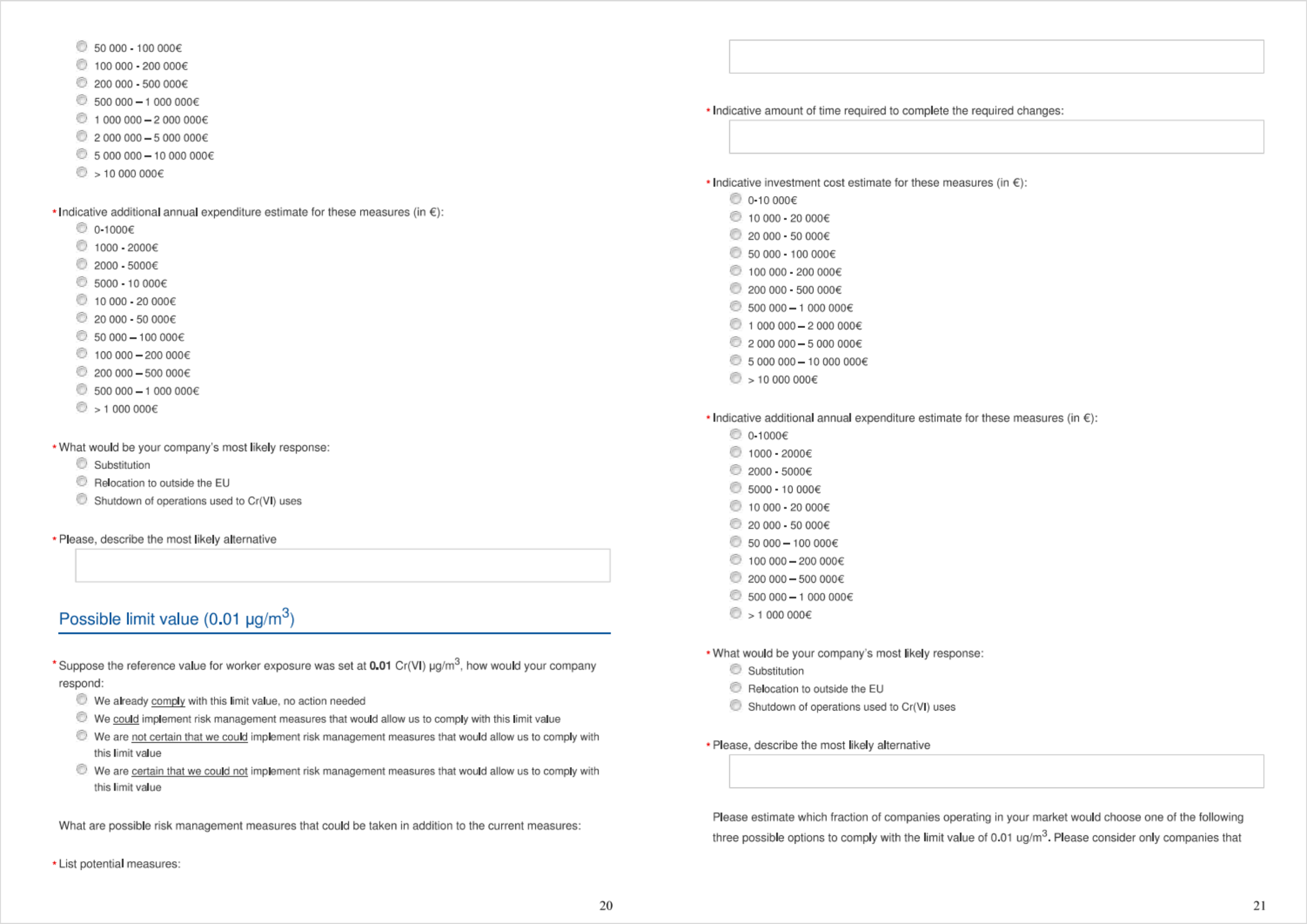
What are possible risk management measures that could be taken in addition to the current measures:

* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):
- ○ 0-10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€

19



- ○ 50 000 - 100 000€
- ○ 100 000 - 200 000€
- ○ 200 000 - 500 000€
- ○ 500 000 – 1 000 000€
- ○ 1 000 000 – 2 000 000€
- ○ 2 000 000 – 5 000 000€
- ○ 5 000 000 – 10 000 000€
- ○ > 10 000 000€

* Indicative additional annual expenditure estimate for these measures (in €):

- ○ 0-1000€
- ○ 1000 - 2000€
- ○ 2000 - 5000€
- ○ 5000 - 10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 – 100 000€
- ○ 100 000 – 200 000€
- ○ 200 000 – 500 000€
- ○ 500 000 – 1 000 000€
- ○ > 1 000 000€

* What would be your company's most likely response:

- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Possible limit value (0.01 $\mu g/m^3$)

* Suppose the reference value for worker exposure was set at **0.01** Cr(VI) $\mu g/m^3$, how would your company respond:

- ○ We already comply with this limit value, no action needed
- ○ We could implement risk management measures that would allow us to comply with this limit value
- ○ We are not certain that we could implement risk management measures that would allow us to comply with this limit value
- ○ We are certain that we could not implement risk management measures that would allow us to comply with this limit value

What are possible risk management measures that could be taken in addition to the current measures:

* List potential measures:

* Indicative amount of time required to complete the required changes:

* Indicative investment cost estimate for these measures (in €):

- ○ 0-10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 - 100 000€
- ○ 100 000 - 200 000€
- ○ 200 000 - 500 000€
- ○ 500 000 – 1 000 000€
- ○ 1 000 000 – 2 000 000€
- ○ 2 000 000 – 5 000 000€
- ○ 5 000 000 – 10 000 000€
- ○ > 10 000 000€

* Indicative additional annual expenditure estimate for these measures (in €):

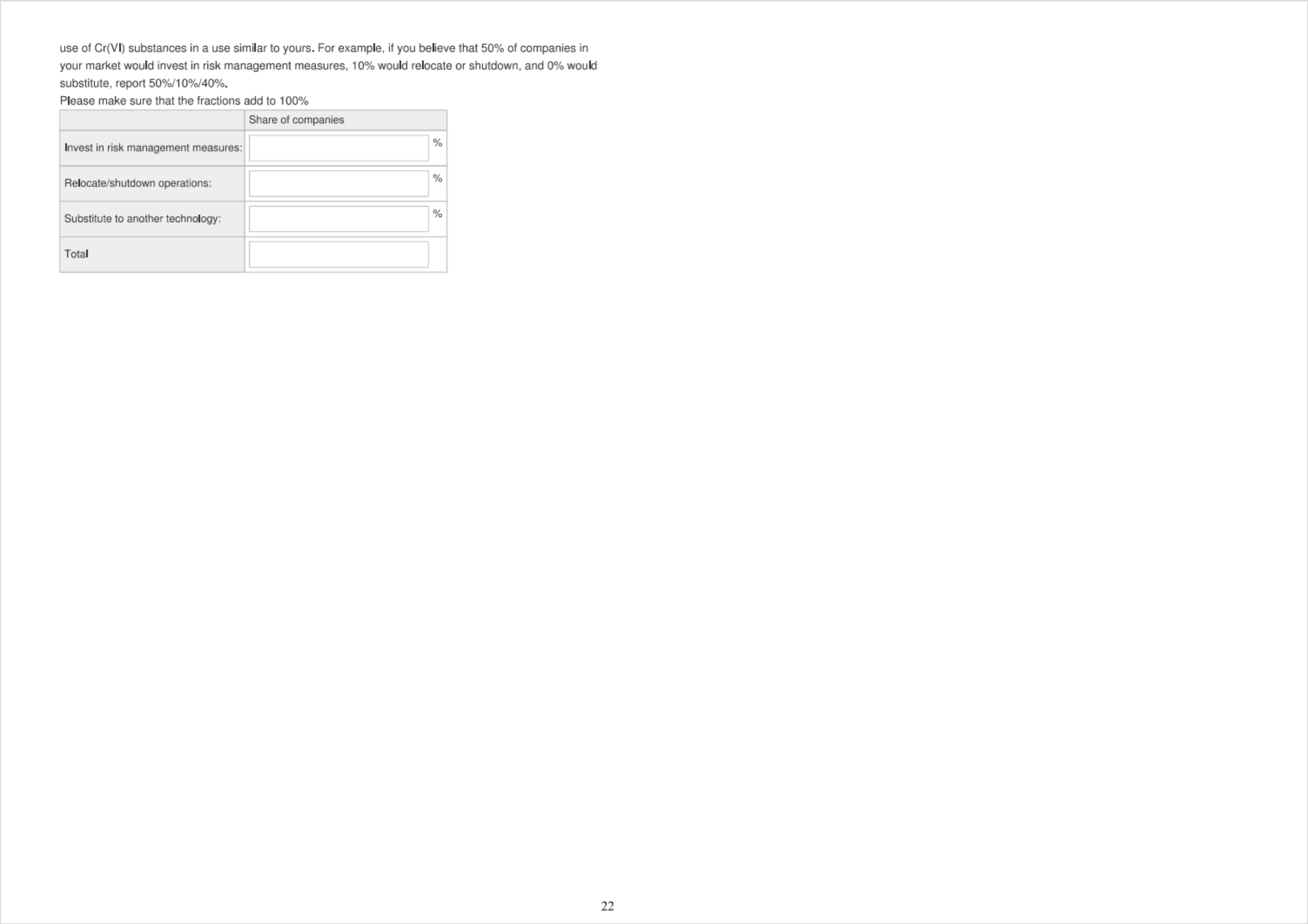
- ○ 0-1000€
- ○ 1000 - 2000€
- ○ 2000 - 5000€
- ○ 5000 - 10 000€
- ○ 10 000 - 20 000€
- ○ 20 000 - 50 000€
- ○ 50 000 – 100 000€
- ○ 100 000 – 200 000€
- ○ 200 000 – 500 000€
- ○ 500 000 – 1 000 000€
- ○ > 1 000 000€

* What would be your company's most likely response:

- ○ Substitution
- ○ Relocation to outside the EU
- ○ Shutdown of operations used to Cr(VI) uses

* Please, describe the most likely alternative

Please estimate which fraction of companies operating in your market would choose one of the following three possible options to comply with the limit value of 0.01 ug/m^3. Please consider only companies that

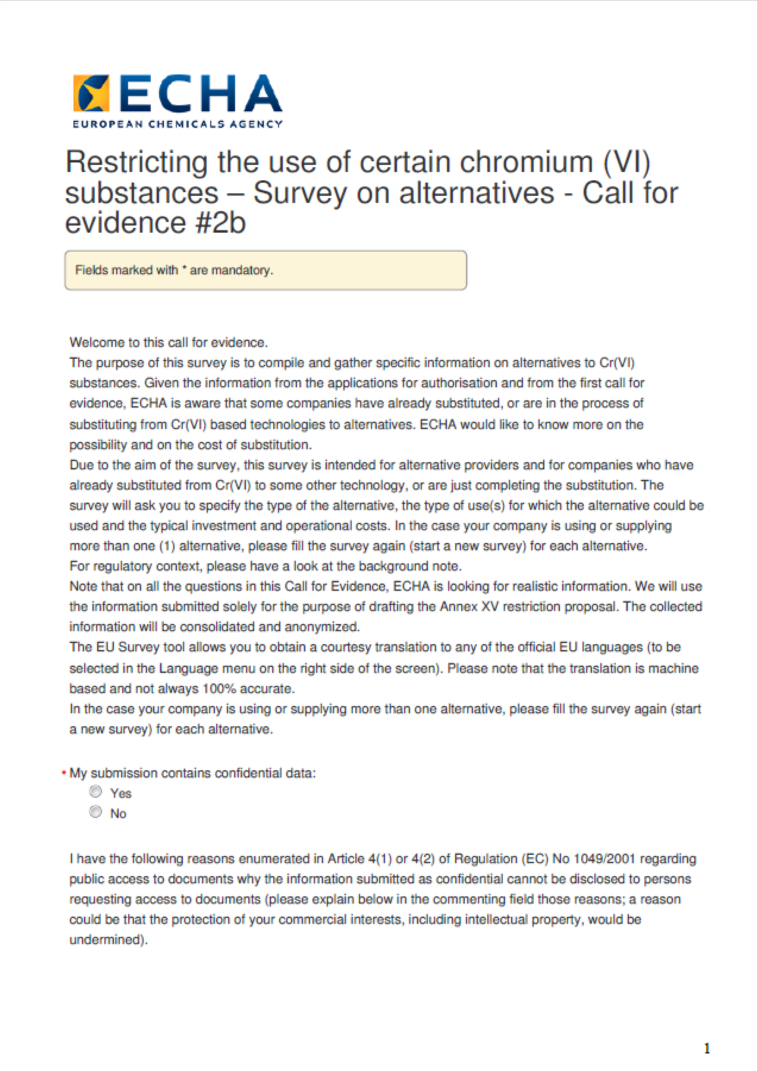


use of Cr(VI) substances in a use similar to yours. For example, if you believe that 50% of companies in your market would invest in risk management measures, 10% would relocate or shutdown, and 0% would substitute, report 50%/10%/40%.

Please make sure that the fractions add to 100%

	Share of companies	
Invest in risk management measures:		%
Relocate/shutdown operations:		%
Substitute to another technology:		%
Total		

G.2.3. CfE#2b questionnaire



ECHA
EUROPEAN CHEMICALS AGENCY

Restricting the use of certain chromium (VI) substances – Survey on alternatives - Call for evidence #2b

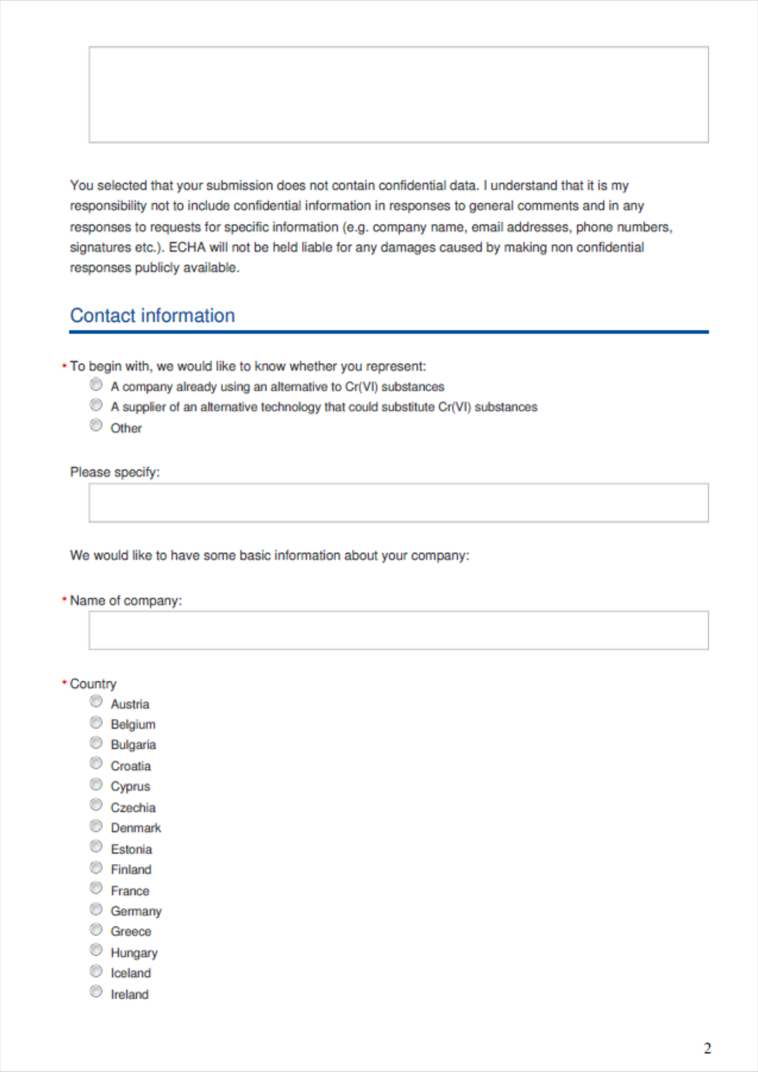
Fields marked with * are mandatory.

Welcome to this call for evidence.
The purpose of this survey is to compile and gather specific information on alternatives to Cr(VI) substances. Given the information from the applications for authorisation and from the first call for evidence, ECHA is aware that some companies have already substituted, or are in the process of substituting from Cr(VI) based technologies to alternatives. ECHA would like to know more on the possibility and on the cost of substitution.
Due to the aim of the survey, this survey is intended for alternative providers and for companies who have already substituted from Cr(VI) to some other technology, or are just completing the substitution. The survey will ask you to specify the type of the alternative, the type of use(s) for which the alternative could be used and the typical investment and operational costs. In the case your company is using or supplying more than one (1) alternative, please fill the survey again (start a new survey) for each alternative.
For regulatory context, please have a look at the background note.
Note that on all the questions in this Call for Evidence, ECHA is looking for realistic information. We will use the information submitted solely for the purpose of drafting the Annex XV restriction proposal. The collected information will be consolidated and anonymized.
The EU Survey tool allows you to obtain a courtesy translation to any of the official EU languages (to be selected in the Language menu on the right side of the screen). Please note that the translation is machine based and not always 100% accurate.
In the case your company is using or supplying more than one alternative, please fill the survey again (start a new survey) for each alternative.

* My submission contains confidential data:
○ Yes
○ No

I have the following reasons enumerated in Article 4(1) or 4(2) of Regulation (EC) No 1049/2001 regarding public access to documents why the information submitted as confidential cannot be disclosed to persons requesting access to documents (please explain below in the commenting field those reasons; a reason could be that the protection of your commercial interests, including intellectual property, would be undermined).

1



You selected that your submission does not contain confidential data. I understand that it is my responsibility not to include confidential information in responses to general comments and in any responses to requests for specific information (e.g. company name, email addresses, phone numbers, signatures etc.). ECHA will not be held liable for any damages caused by making non confidential responses publicly available.

Contact information

* To begin with, we would like to know whether you represent:
○ A company already using an alternative to Cr(VI) substances
○ A supplier of an alternative technology that could substitute Cr(VI) substances
○ Other

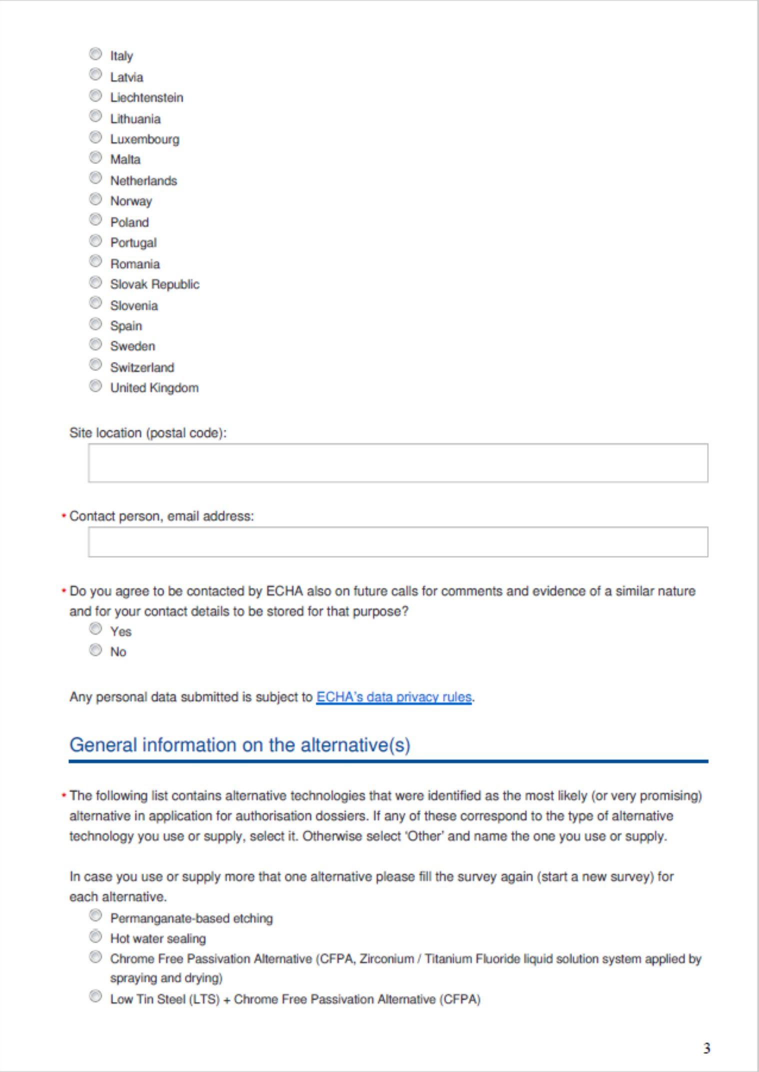
Please specify:

We would like to have some basic information about your company:

* Name of company:

* Country
○ Austria
○ Belgium
○ Bulgaria
○ Croatia
○ Cyprus
○ Czechia
○ Denmark
○ Estonia
○ Finland
○ France
○ Germany
○ Greece
○ Hungary
○ Iceland
○ Ireland

2



○ Italy
○ Latvia
○ Liechtenstein
○ Lithuania
○ Luxembourg
○ Malta
○ Netherlands
○ Norway
○ Poland
○ Portugal
○ Romania
○ Slovak Republic
○ Slovenia
○ Spain
○ Sweden
○ Switzerland
○ United Kingdom

Site location (postal code):

* Contact person, email address:

* Do you agree to be contacted by ECHA also on future calls for comments and evidence of a similar nature and for your contact details to be stored for that purpose?
○ Yes
○ No

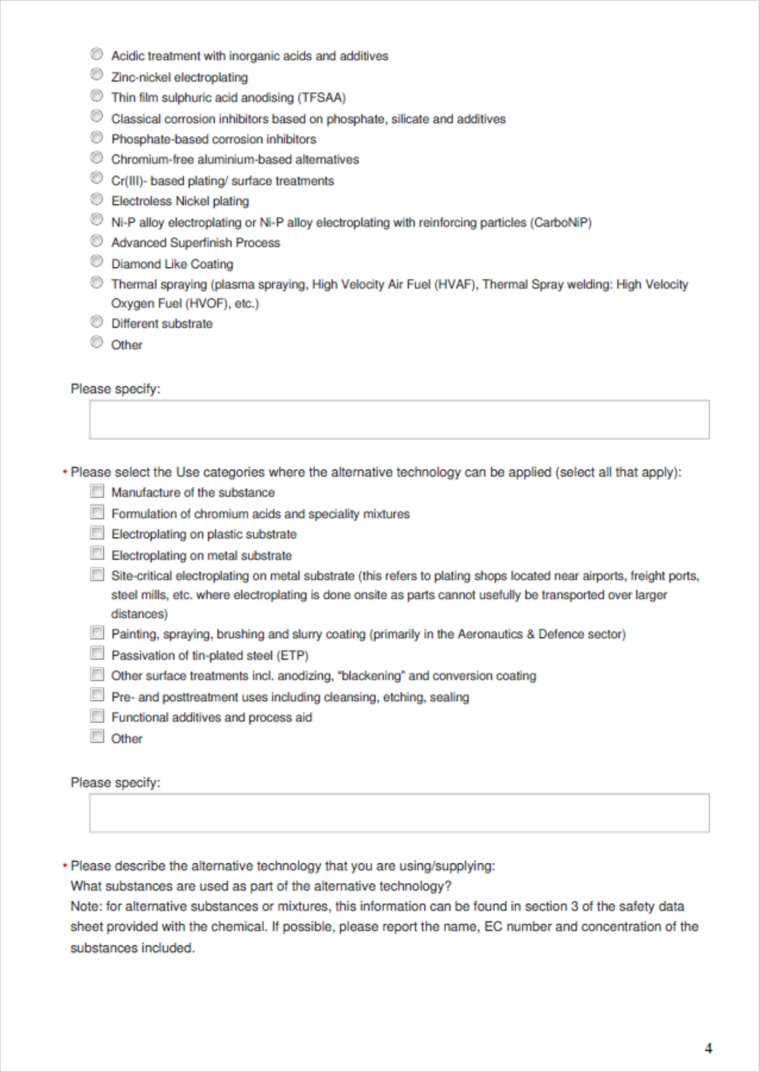
Any personal data submitted is subject to ECHA's data privacy rules.

General information on the alternative(s)

* The following list contains alternative technologies that were identified as the most likely (or very promising) alternative in application for authorisation dossiers. If any of these correspond to the type of alternative technology you use or supply, select it. Otherwise select 'Other' and name the one you use or supply.

In case you use or supply more that one alternative please fill the survey again (start a new survey) for each alternative.
○ Permanganate-based etching
○ Hot water sealing
○ Chrome Free Passivation Alternative (CFPA, Zirconium / Titanium Fluoride liquid solution system applied by spraying and drying)
○ Low Tin Steel (LTS) + Chrome Free Passivation Alternative (CFPA)

3



○ Acidic treatment with inorganic acids and additives
○ Zinc-nickel electroplating
○ Thin film sulphuric acid anodising (TFSAA)
○ Classical corrosion inhibitors based on phosphate, silicate and additives
○ Phosphate-based corrosion inhibitors
○ Chromium-free aluminium-based alternatives
○ Cr(III)- based plating/ surface treatments
○ Electroless Nickel plating
○ Ni-P alloy electroplating or Ni-P alloy electroplating with reinforcing particles (CarboNiP)
○ Advanced Superfinish Process
○ Diamond Like Coating
○ Thermal spraying (plasma spraying, High Velocity Air Fuel (HVAF), Thermal Spray welding: High Velocity Oxygen Fuel (HVOF), etc.)
○ Different substrate
○ Other

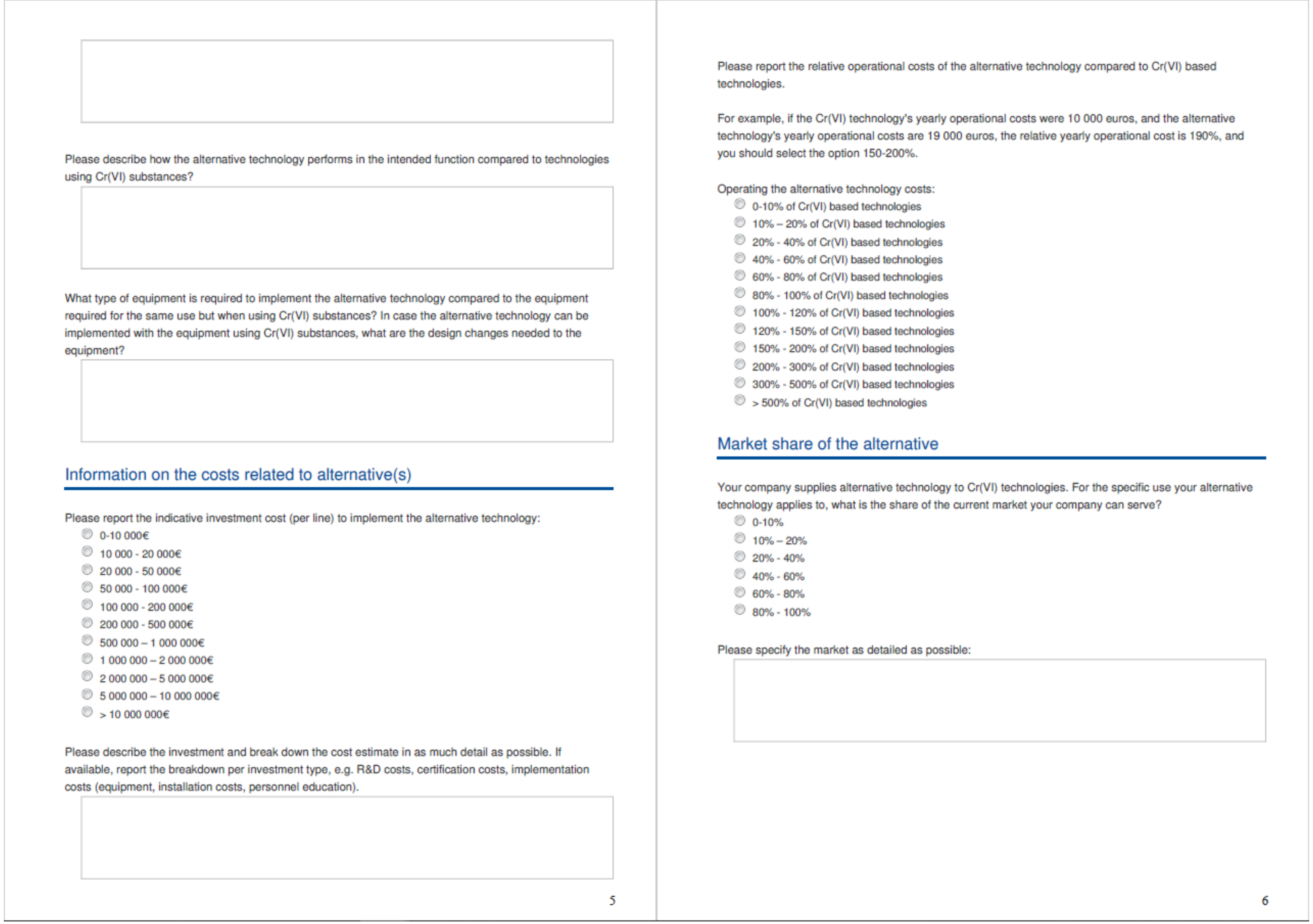
Please specify:

* Please select the Use categories where the alternative technology can be applied (select all that apply):
☐ Manufacture of the substance
☐ Formulation of chromium acids and speciality mixtures
☐ Electroplating on plastic substrate
☐ Electroplating on metal substrate
☐ Site-critical electroplating on metal substrate (this refers to plating shops located near airports, freight ports, steel mills, etc. where electroplating is done onsite as parts cannot usefully be transported over larger distances)
☐ Painting, spraying, brushing and slurry coating (primarily in the Aeronautics & Defence sector)
☐ Passivation of tin-plated steel (ETP)
☐ Other surface treatments incl. anodizing, "blackening" and conversion coating
☐ Pre- and posttreatment uses including cleansing, etching, sealing
☐ Functional additives and process aid
☐ Other

Please specify:

* Please describe the alternative technology that you are using/supplying:
What substances are used as part of the alternative technology?
Note: for alternative substances or mixtures, this information can be found in section 3 of the safety data sheet provided with the chemical. If possible, please report the name, EC number and concentration of the substances included.

4



Please describe how the alternative technology performs in the intended function compared to technologies using Cr(VI) substances?

What type of equipment is required to implement the alternative technology compared to the equipment required for the same use but when using Cr(VI) substances? In case the alternative technology can be implemented with the equipment using Cr(VI) substances, what are the design changes needed to the equipment?

Information on the costs related to alternative(s)

Please report the indicative investment cost (per line) to implement the alternative technology:

○ 0-10 000€
○ 10 000 - 20 000€
○ 20 000 - 50 000€
○ 50 000 - 100 000€
○ 100 000 - 200 000€
○ 200 000 - 500 000€
○ 500 000 – 1 000 000€
○ 1 000 000 – 2 000 000€
○ 2 000 000 – 5 000 000€
○ 5 000 000 – 10 000 000€
○ > 10 000 000€

Please describe the investment and break down the cost estimate in as much detail as possible. If available, report the breakdown per investment type, e.g. R&D costs, certification costs, implementation costs (equipment, installation costs, personnel education).

5

Please report the relative operational costs of the alternative technology compared to Cr(VI) based technologies.

For example, if the Cr(VI) technology's yearly operational costs were 10 000 euros, and the alternative technology's yearly operational costs are 19 000 euros, the relative yearly operational cost is 190%, and you should select the option 150-200%.

Operating the alternative technology costs:

○ 0-10% of Cr(VI) based technologies
○ 10% – 20% of Cr(VI) based technologies
○ 20% - 40% of Cr(VI) based technologies
○ 40% - 60% of Cr(VI) based technologies
○ 60% - 80% of Cr(VI) based technologies
○ 80% - 100% of Cr(VI) based technologies
○ 100% - 120% of Cr(VI) based technologies
○ 120% - 150% of Cr(VI) based technologies
○ 150% - 200% of Cr(VI) based technologies
○ 200% - 300% of Cr(VI) based technologies
○ 300% - 500% of Cr(VI) based technologies
○ > 500% of Cr(VI) based technologies

Market share of the alternative

Your company supplies alternative technology to Cr(VI) technologies. For the specific use your alternative technology applies to, what is the share of the current market your company can serve?

○ 0-10%
○ 10% – 20%
○ 20% - 40%
○ 40% - 60%
○ 60% - 80%
○ 80% - 100%

Please specify the market as detailed as possible:

6

G.3. Bilateral discussions with stakeholders and experts

Various ad-hoc meetings and calls were held between October 2023 and April 2024 to collect additional information from stakeholders. In particular, the Dossier Submitter was in exchange with the following stakeholders and experts:

- Aerospace, Security and Defence Industries Association of Europe (ASD)
- Airbus SE
- Apeiron Consultancy
- Association Européenne des Métaux (Eurometaux)
- Association for Safeguarding the Application and Use of Chromium Trioxide and Other Chemicals in Surface Technology (VECCO)
- emlyon business school, Prof. Aurelien Baillon
- European Agency for Safety and Health at Work (EU-OSHA)
- European Automobile Manufacturers' Association (ACEA)
- European Committee for Surface Treatment (CETS)
- Fachverband galvanisierte Kunststoffe (FGK)
- International Institute for Applied Systems Analysis (IIASA), Dr. Peter Rafaj
- Joint Research Centre of the European Commission (JRC)
- Metal Packaging Europe (MPE)
- Ramboll Consultancy
- Steel for Packaging Europe (APEAL)

G.4. Additional information submitted by stakeholders

During the preparation of this Annex XV restriction report the Dossier Submitter was in exchange with several stakeholders (as listed in Appendix G.3). Some of these stakeholders provided additional information outside the CfEs, which is reproduced below.

G.4.1. Metal Packaging Europe (MPE)

Metal Packaging Europe state of play on the application of chrome-free alternatives

ABOUT METAL PACKAGING EUROPE (MPE)

Metal Packaging Europe is the united voice of Europe's rigid metal packaging industry (steel and aluminium), bringing together manufacturers, suppliers, and national associations. Our members produce over 140 billion cans annually, supporting 66,000 direct jobs in Europe across 350 sites. Metal packaging actively contributes to the Circular Economy and supports numerous value chains and applications, like beverages, food, fish, chemicals, paints, aerosol and others.

ABOUT STEEL PACKAGING

Steel packaging (see picture) is produced as a 3-piece can or a 2-piece can. A typical 3-piece steel can is composed of a body and two ends (top and bottom), whereas a typical 2-piece steel can is composed of a body and one top end.

The body is made of tinplate whereas the ends are mostly made of ECCS (Electrolytic Chromium Coated Steel) or tinplate in some cases.

Following the ban of Cr-VI compounds used for the passivation of steel for packaging, the following chrome-free alternatives have been developed by the EU steel industry:

- CFPA (Chrome Free Passivation Alternative) to replace tinplate,
- LTS (Low Tin Steel) and TCCT (Trivalent Chromium-Coating Technology) to replace ECCS.

The introduction of the chrome-free alternatives is a fundamental change to the steel packaging supply chain, consequently an enormous effort has been underway at all levels of the value chain to ensure that the new materials work well together (a can is made of one body and 1 or 2 ends) and meet the high level of safety that is currently expected for steel for packaging.

STATUS OF THE APPLICATION OF CHROME-FREE ALTERNATIVES FOR THE MANUFACTURING OF STEEL PACKAGING

Since 2019, the can makers - members of Metal Packaging Europe (MPE), have been extensively testing the chrome-free alternatives in thousands of packaging tests for products such as meat, fish, vegetables, milk infant formulas, paints, deodorants, etc. packed in cans, aerosols and other packaging (e.g. steel closures for glass bottles and jars).

Based on these results, it has been possible to obtain an overview of the behaviour of chrome-free alternatives across the steel packaging portfolio which shows that, although many packaging tests are successful, some challenges still exist.

In fact, significant issues of varying severity (e.g. corrosion, delamination, rust, mottling, perforation, surface staining, loss of adhesion, limited chemical resistance at filling) continue to be identified by MPE members on approx. 20% of the total packaging tests carried out. **It must be noted that the percentage of failed packaging tests does not reflect the production volume of the tested cans, hence the impact on the market is expected to be much higher.**

Packaging tests are performed following defined standards before placing new products on the market, and their success is a pre-condition for effective launch. Every time a filled can fails the packaging test, it means that the specifications used for that product-packaging-coating combination don't work, the product cannot be placed on the market and new specifications must be tried out. Filled cans are tested for as long as the shelf life of the tested products (up to 5 years for food cans), given that accelerated packaging tests cannot be used as they don't provide reliable information. Therefore, every time a filled can fails the packaging test, a new test with new combination of product-packaging-coating must start again from the beginning.

The failures are, to a larger extent, due to the complexity of the specifications of the product-packaging-coating combinations and, to a smaller extent, to the variability of chrome-free alternatives across steel suppliers in the transition to an industrial scaled-up production.

As a matter of fact, some European steel producers have stopped the production of one of the chrome-free alternatives for ECCS due to technical issues, and it is unknown when the new material will be delivered. This implies two negative consequences: not only the can makers and the coating suppliers will have less

time before the end of the authorisation period to develop the right specifications for that substrate, but they will also lose the entire experience gained so far because the new substrate will perform differently and will require to start new packaging tests from scratch.

The development of specific coatings for chrome-free alternatives is key to solve the current issues, however the process to develop alternative coatings lasts many years and the current ban of specific chemicals (e.g. BPA, PFAS) adds a layer of complexity.

At the moment, there is no guarantee that the chrome-free alternatives will lead to similar performance as tinplate and ECCS when applied to the same coating and product, jeopardizing the functionality of steel cans and the position of the can manufacturers on the market.

POTENTIAL IMPLICATIONS TO THE EUROPEAN MARKET

The lack of performance of chrome-free alternatives will have direct consequences on the entire steel packaging supply chain and on the European consumers.

- Coating failures must be prevented as these could spoil the food and compromise consumer safety.
- Can manufacturers, brand owners and fillers may be forced to withdraw their products from the market in case where the chrome-free alternatives show defects, with serious economic and reputation damages to the entire industry.
- Can manufacturers may not be able to guarantee a long and stable shelf life of the cans when using the chrome-free alternatives, which could lead to an increase of product waste (e.g. food).
- Import of canned food or can components from outside Europe, where the ban of Cr-VI compounds does not apply, will directly affect the competitiveness of the European suppliers and lead to a loss of market for steel packaging.
- Imported canned food will also have a direct impact on agricultural production in Europe. Moreover, without a reliable steel packaging supply in Europe, food that cannot be packed on time may become food waste.

- The development of chrome-free alternatives by the European steel producers took substantial time and effort (at least 10 years), but the successful use for packaging applications needs further development. The can makers learned from past experience that a successful development and implementation of new coating could take about 10 years. Therefore, the development of effective combination of product-packaging-coating requires continued substantial time and effort.

RECOMMENDATIONS

The current authorisation period for tinplate is until the end of 2027, whereas the one for ECCS is until the end of 2028. As a typical can is made of both materials, the tinplate for the body and the ECCS for the ends, the timeline should be aligned towards 2028 to ensure the full functionality of the cans.

Despite the enormous effort put in place by the steel packaging supply chain, more research and testing are needed and particularly for the development of specific coating for the use of chrome-free alternatives for specific products (e.g. meat, fish, vegetables, and personal care).

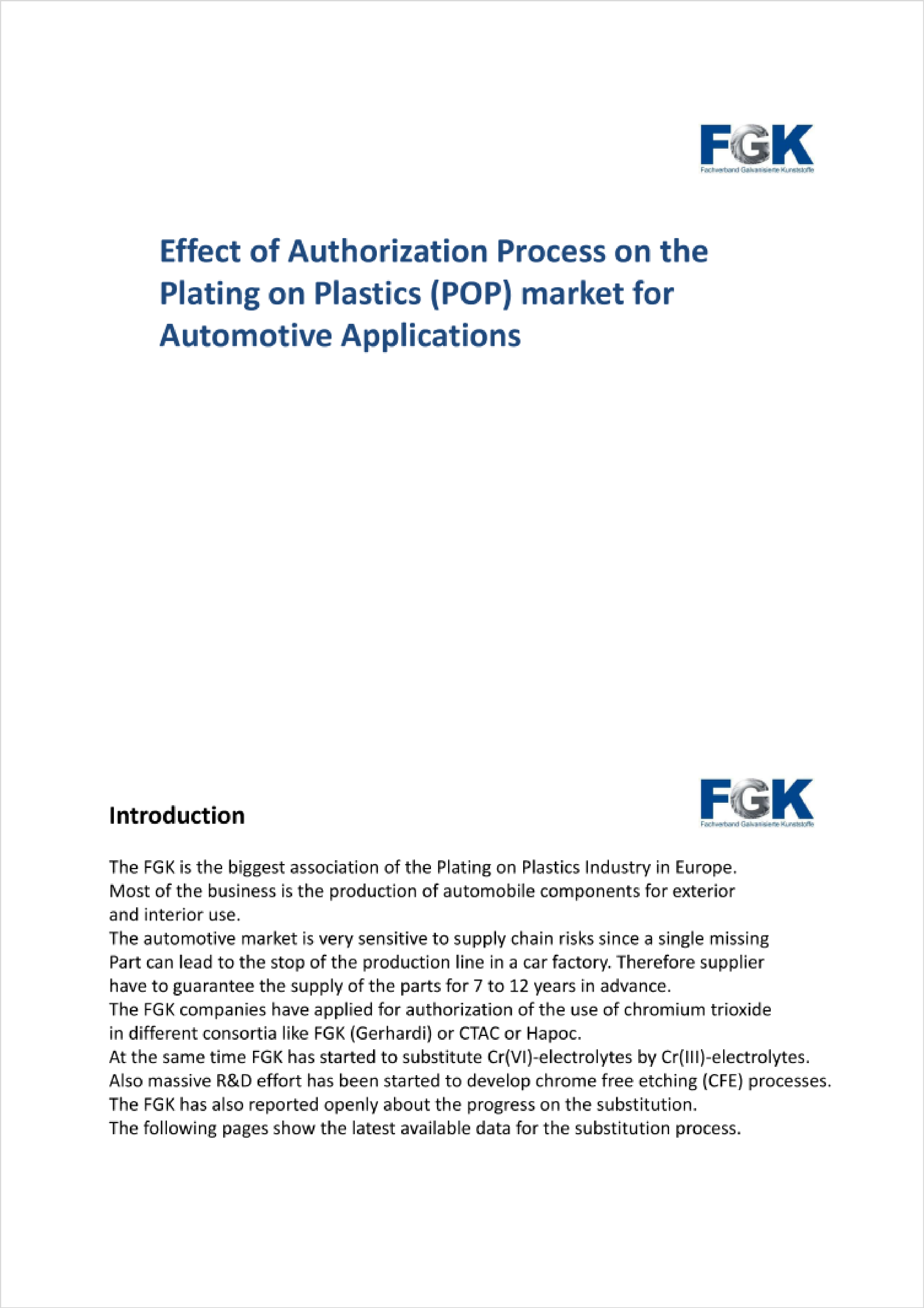
Besides the short timeframe before the phase-out date, the intention of the European Commission to restrict the use of Cr-VI compounds in REACH – which may substantially limit the possibility for extending the use of Cr-VI compounds beyond 2027/2028, represents a serious challenge for the steel packaging industry.

MPE calls the European Commission to consider a functional transition period (beyond 2028) or other risk management measures for the application of Cr-VI compounds for steel packaging, to allow the industry to ensure the supply of high-quality material with equivalent performance and safety for all food and non-food applications.

Contact information

- Romeo Pavanello, Metal Packaging Europe, Environment & LCA manager, romeo.pavanello@mpe-eu.com

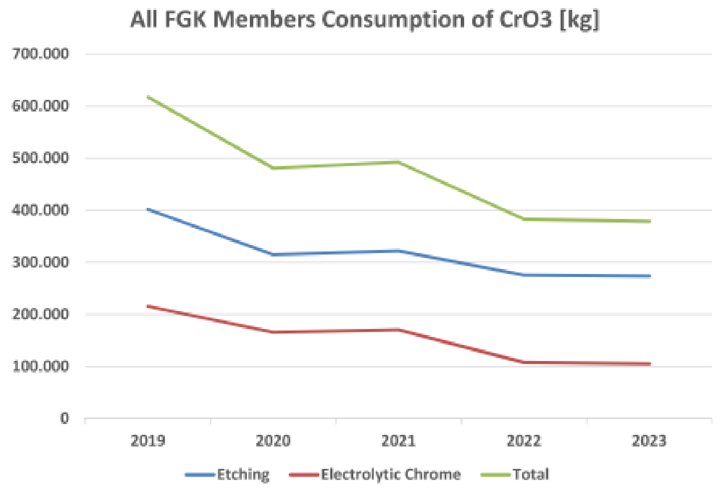
G.4.2. FGK



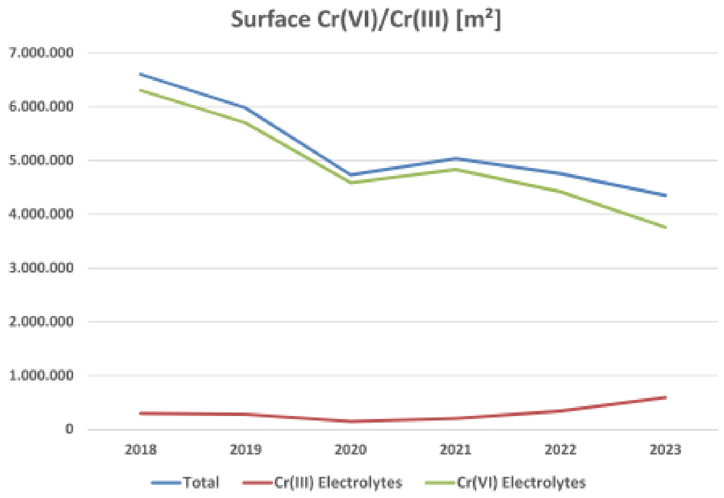
Effect of Authorization Process on the Plating on Plastics (POP) market for Automotive Applications

Introduction

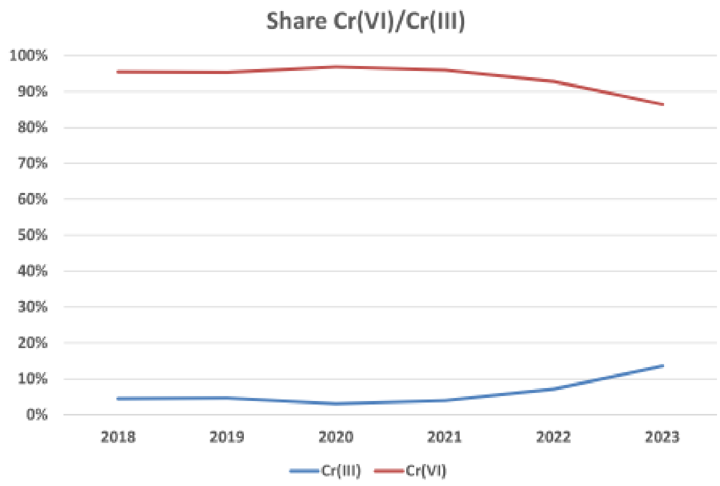
The FGK is the biggest association of the Plating on Plastics Industry in Europe.
Most of the business is the production of automobile components for exterior and interior use.
The automotive market is very sensitive to supply chain risks since a single missing Part can lead to the stop of the production line in a car factory. Therefore supplier have to guarantee the supply of the parts for 7 to 12 years in advance.
The FGK companies have applied for authorization of the use of chromium trioxide in different consortia like FGK (Gerhardi) or CTAC or Hapoc.
At the same time FGK has started to substitute Cr(VI)-electrolytes by Cr(III)-electrolytes.
Also massive R&D effort has been started to develop chrome free etching (CFE) processes.
The FGK has also reported openly about the progress on the substitution.
The following pages show the latest available data for the substitution process.



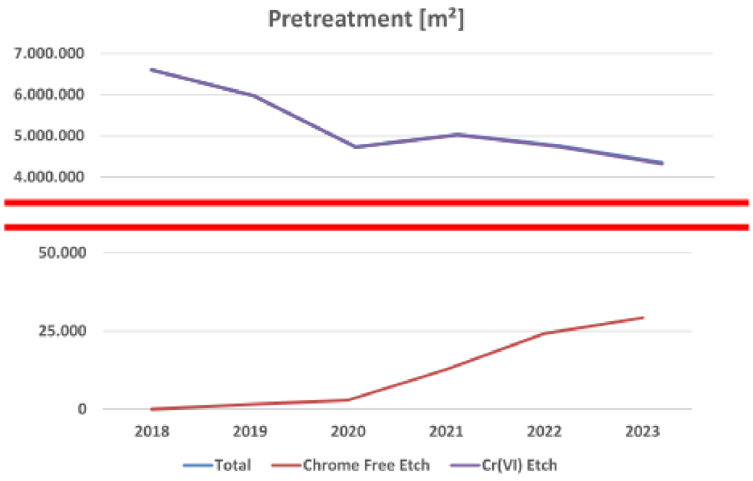
Reduction of the CrO_3 consumption by 39% (`19 -`23)



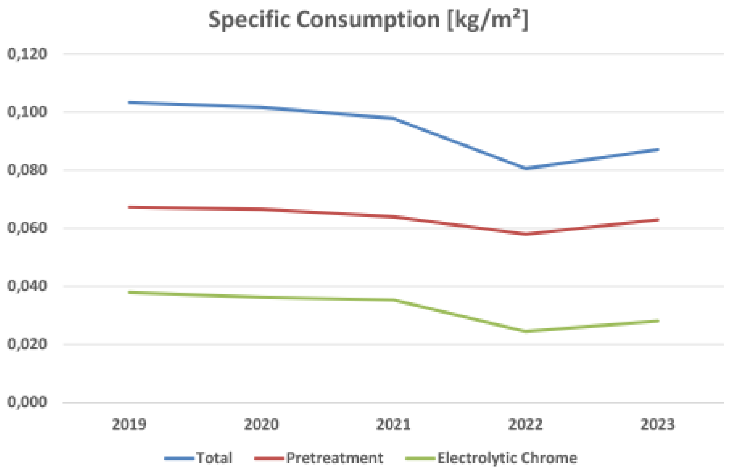
Decline of the produced surface area by 34% (`19 -`23)
Increased use of trivalent chrome does not compensate loss of hexavalent chrome finishes.
Installed production capacity for Cr(III) is 3.5 times bigger than used capacity.



Slowly the share of Cr(III) finishes is increasing. OEM start using Cr(III) with new models.
The switch will need 6 to 8 years, depending on the model policy of the OEM.

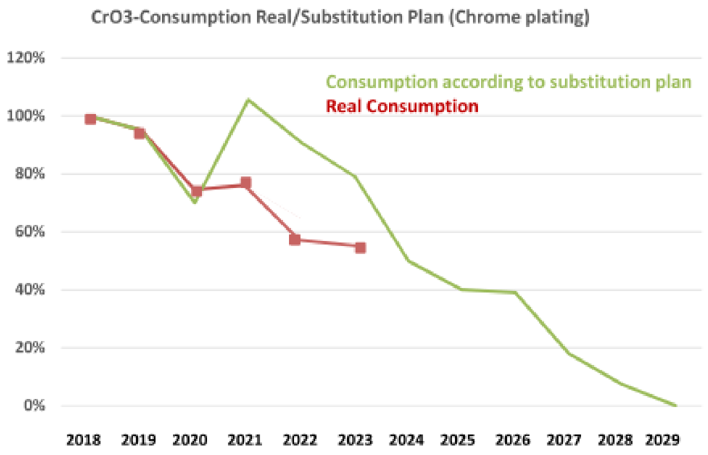


Nearly no CFE Production
Installed capacity is 6 times bigger than really used capacity.



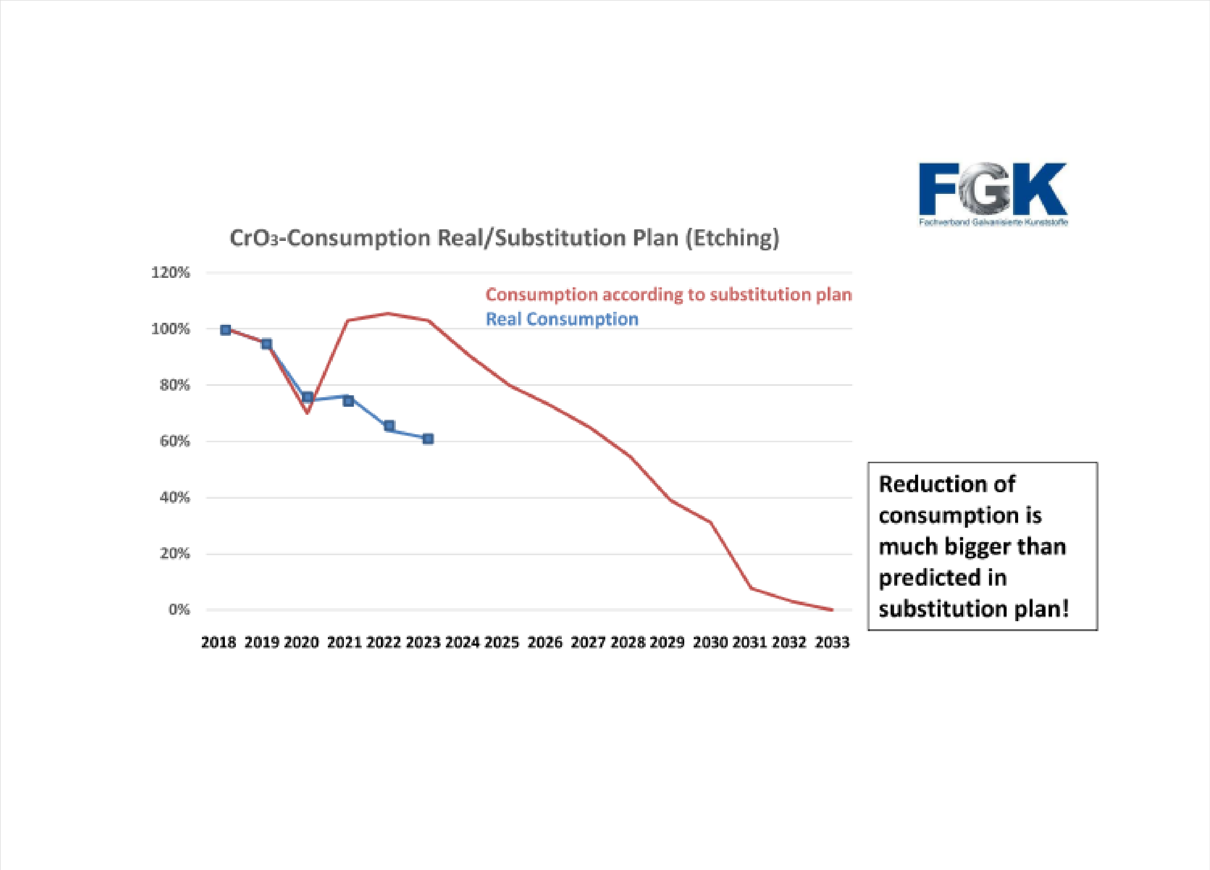
Specific Consumption [kg/m²]

More efficient usage of chrome trioxide



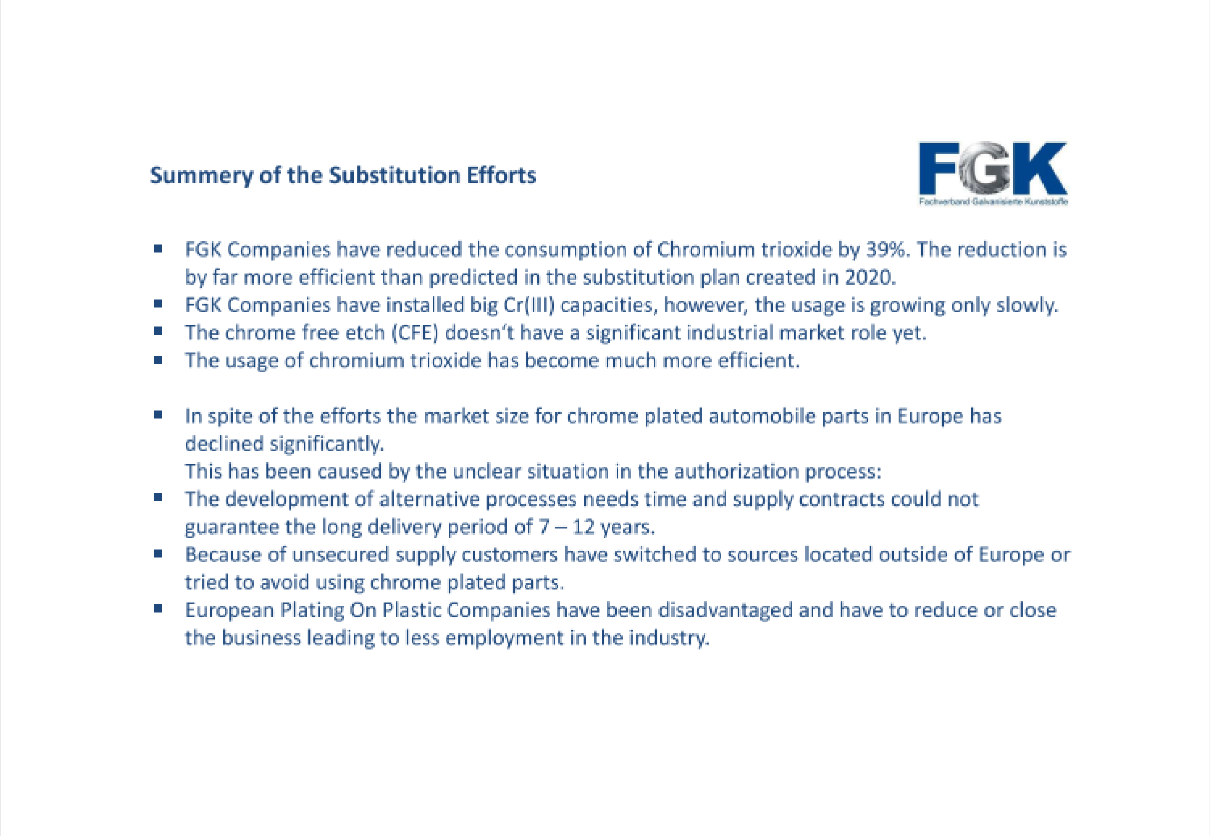
CrO3-Consumption Real/Substitution Plan (Chrome plating)

Reduction of consumption is much bigger than predicted in substitution plan!



CrO_3-Consumption Real/Substitution Plan (Etching)

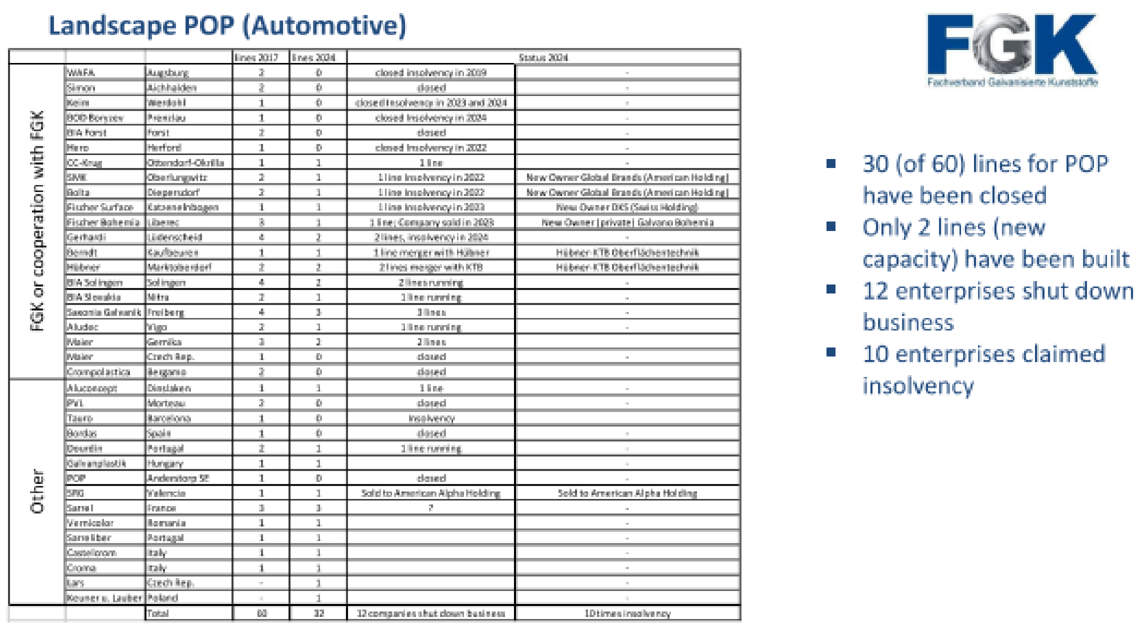
Reduction of consumption is much bigger than predicted in substitution plan!



Summery of the Substitution Efforts

- FGK Companies have reduced the consumption of Chromium trioxide by 39%. The reduction is by far more efficient than predicted in the substitution plan created in 2020.
- FGK Companies have installed big Cr(III) capacities, however, the usage is growing only slowly.
- The chrome free etch (CFE) doesn‘t have a significant industrial market role yet.
- The usage of chromium trioxide has become much more efficient.

- In spite of the efforts the market size for chrome plated automobile parts in Europe has declined significantly.
  This has been caused by the unclear situation in the authorization process:
- The development of alternative processes needs time and supply contracts could not guarantee the long delivery period of 7 – 12 years.
- Because of unsecured supply customers have switched to sources located outside of Europe or tried to avoid using chrome plated parts.
- European Plating On Plastic Companies have been disadvantaged and have to reduce or close the business leading to less employment in the industry.



Landscape POP (Automotive)

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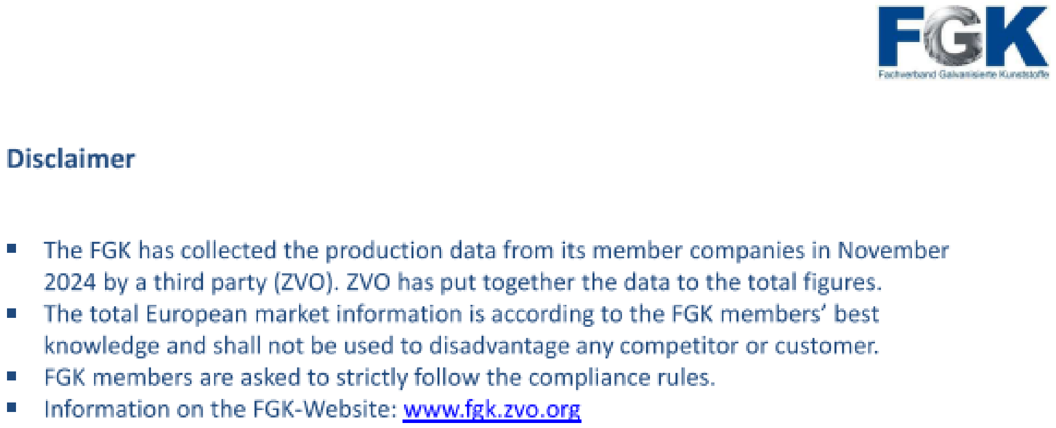
			lines 2017	lines 2024		Status 2024
FGK or cooperation with FGK	WAFA	Augsburg	2	0	closed insolvency in 2019	-
	Simon	Aichhalden	2	0	closed	-
	Keim	Werdohl	1	0	closed insolvency in 2023 and 2024	-
	BOD Boryzov	Prenzlau	1	0	closed insolvency in 2024	-
	BIA Forst	Forst	2	0	closed	-
	Hero	Herford	1	0	closed insolvency in 2022	-
	CC-Krug	Ottendorf-Okrilla	1	1	1 line	-
	SMK	Oberlungwitz	2	1	1 line insolvency in 2022	New Owner Global Brands (American Holding)
	Bolta	Diepersdorf	2	1	1 line insolvency in 2022	New Owner Global Brands (American Holding)
	Fischer Surface	Katzenelnbogen	1	1	1 line insolvency in 2023	New Owner DKS (Swiss Holding)
	Fischer Bohemia	Liberec	3	1	1 line; Company sold in 2023	New Owner (private) Galvano Bohemia
	Gerhardi	Lüdenscheid	4	2	2 lines, insolvency in 2024	-
	Berndt	Kaufbeuren	1	1	1 line merger with Hübner	Hübner KTB Oberflächentechnik
	Hübner	Marktoberdorf	2	2	2 lines merger with KTB	Hübner KTB Oberflächentechnik
	BIA Solingen	Solingen	4	2	2 lines running	-
	BIA Slowakia	Nitra	2	1	1 line running	-
	Saxonia Galvanik	Freiberg	4	3	3 lines	-
	Aludec	Vigo	2	1	1 line running	-
	Maier	Gernika	3	2	2 lines	
	Maier	Czech Rep.	1	0	closed	-
	Crompolastica	Bergamo	2	0	closed	
Other	Aluconcept	Dinslaken	1	1	1 line	-
	PVL	Morteau	2	0	closed	-
	Tauro	Barcelona	1	0	insolvency	
	Bordas	Spain	1	0	closed	-
	Dourdin	Portugal	2	1	1 line running	-
	Galvanoplastik	Hungary	1	1		-
	POP	Anderstorp SE	1	0	closed	-
	SRG	Valencia	1	1	Sold to American Alpha Holding	Sold to American Alpha Holding
	Sarrel	France	3	3	?	-
	Vernicolor	Romania	1	1		-
	Sarreliber	Portugal	1	1		-
	Castellcrom	Italy	1	1		-
	Croma	Italy	1	1		-
	Lars	Czech Rep.	-	1		-
	Keuner u. Lauber	Poland	-	1		-
		Total	60	32	12 companies shut down business	10 times insolvency

- 30 (of 60) lines for POP have been closed
- Only 2 lines (new capacity) have been built
- 12 enterprises shut down business
- 10 enterprises claimed insolvency



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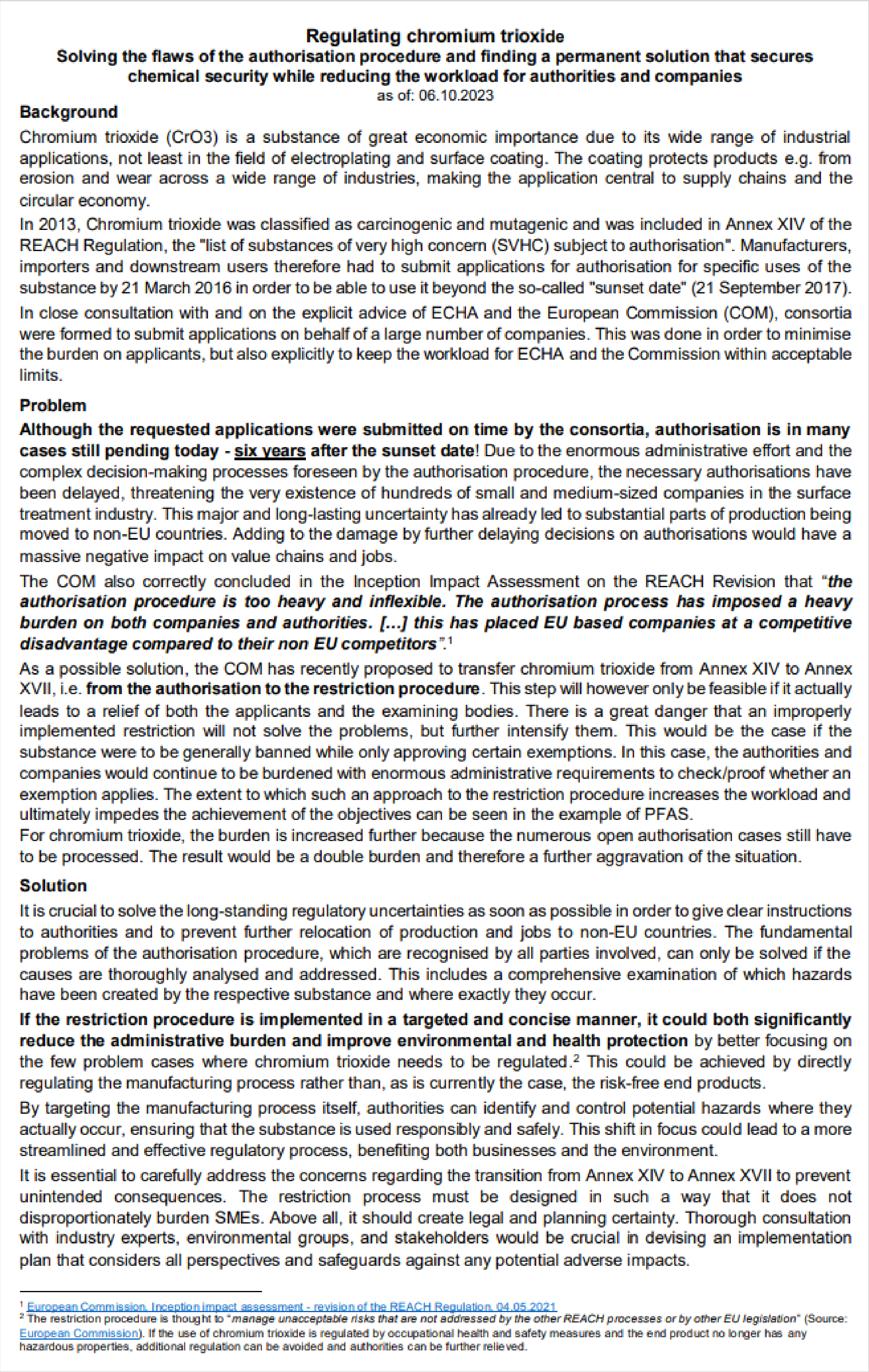
Fachverband Galvanisierte Kunststoffe

Disclaimer

- The FGK has collected the production data from its member companies in November 2024 by a third party (ZVO). ZVO has put together the data to the total figures.
- The total European market information is according to the FGK members' best knowledge and shall not be used to disadvantage any competitor or customer.
- FGK members are asked to strictly follow the compliance rules.
- Information on the FGK-Website: www.fgk.zvo.org

G.4.3. CETS



Regulating chromium trioxide

Solving the flaws of the authorisation procedure and finding a permanent solution that secures chemical security while reducing the workload for authorities and companies

as of: 06.10.2023

Background

Chromium trioxide (CrO_3) is a substance of great economic importance due to its wide range of industrial applications, not least in the field of electroplating and surface coating. The coating protects products e.g. from erosion and wear across a wide range of industries, making the application central to supply chains and the circular economy.

In 2013, Chromium trioxide was classified as carcinogenic and mutagenic and was included in Annex XIV of the REACH Regulation, the "list of substances of very high concern (SVHC) subject to authorisation". Manufacturers, importers and downstream users therefore had to submit applications for authorisation for specific uses of the substance by 21 March 2016 in order to be able to use it beyond the so-called "sunset date" (21 September 2017).

In close consultation with and on the explicit advice of ECHA and the European Commission (COM), consortia were formed to submit applications on behalf of a large number of companies. This was done in order to minimise the burden on applicants, but also explicitly to keep the workload for ECHA and the Commission within acceptable limits.

Problem

Although the requested applications were submitted on time by the consortia, authorisation is in many cases still pending today - six years after the sunset date! Due to the enormous administrative effort and the complex decision-making processes foreseen by the authorisation procedure, the necessary authorisations have been delayed, threatening the very existence of hundreds of small and medium-sized companies in the surface treatment industry. This major and long-lasting uncertainty has already led to substantial parts of production being moved to non-EU countries. Adding to the damage by further delaying decisions on authorisations would have a massive negative impact on value chains and jobs.

The COM also correctly concluded in the Inception Impact Assessment on the REACH Revision that "***the authorisation procedure is too heavy and inflexible. The authorisation process has imposed a heavy burden on both companies and authorities. […] this has placed EU based companies at a competitive disadvantage compared to their non EU competitors***".[1]

As a possible solution, the COM has recently proposed to transfer chromium trioxide from Annex XIV to Annex XVII, i.e. **from the authorisation to the restriction procedure**. This step will however only be feasible if it actually leads to a relief of both the applicants and the examining bodies. There is a great danger that an improperly implemented restriction will not solve the problems, but further intensify them. This would be the case if the substance were to be generally banned while only approving certain exemptions. In this case, the authorities and companies would continue to be burdened with enormous administrative requirements to check/proof whether an exemption applies. The extent to which such an approach to the restriction procedure increases the workload and ultimately impedes the achievement of the objectives can be seen in the example of PFAS.

For chromium trioxide, the burden is increased further because the numerous open authorisation cases still have to be processed. The result would be a double burden and therefore a further aggravation of the situation.

Solution

It is crucial to solve the long-standing regulatory uncertainties as soon as possible in order to give clear instructions to authorities and to prevent further relocation of production and jobs to non-EU countries. The fundamental problems of the authorisation procedure, which are recognised by all parties involved, can only be solved if the causes are thoroughly analysed and addressed. This includes a comprehensive examination of which hazards have been created by the respective substance and where exactly they occur.

If the restriction procedure is implemented in a targeted and concise manner, it could both significantly reduce the administrative burden and improve environmental and health protection by better focusing on the few problem cases where chromium trioxide needs to be regulated.[2] This could be achieved by directly regulating the manufacturing process rather than, as is currently the case, the risk-free end products.

By targeting the manufacturing process itself, authorities can identify and control potential hazards where they actually occur, ensuring that the substance is used responsibly and safely. This shift in focus could lead to a more streamlined and effective regulatory process, benefiting both businesses and the environment.

It is essential to carefully address the concerns regarding the transition from Annex XIV to Annex XVII to prevent unintended consequences. The restriction process must be designed in such a way that it does not disproportionately burden SMEs. Above all, it should create legal and planning certainty. Thorough consultation with industry experts, environmental groups, and stakeholders would be crucial in devising an implementation plan that considers all perspectives and safeguards against any potential adverse impacts.

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[1] European Commission, Inception impact assessment - revision of the REACH Regulation, 04.05.2021

[2] The restriction procedure is thought to "*manage unacceptable risks that are not addressed by the other REACH processes or by other EU legislation*" (Source: European Commission). If the use of chromium trioxide is regulated by occupational health and safety measures and the end product no longer has any hazardous properties, additional regulation can be avoided and authorities can be further relieved.

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