ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Complete version

Legal name of applicant(s):	Brenntag UK Ltd
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Substance:	- Sodium dichromate - Potassium dichromate
Use title:	Passivation of (non-Al) metallic coatings using sodium dichromate or potassium dichromate in aerospace and defence industry and its supply chains
Use number:	1

Note

This submission includes no confidential information declared in this document. All information contained in this document can be made public. There is no accompanying document which provides confidential information, as a result there are no justifications for claiming any information confidential.

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Abbreviations

ADCR – Aerospace and Defence Chromates Reauthorisation

A&D – Aerospace and Defence

AfA – Application for Authorisation

AoA – Analysis of Alternatives

AoG – Aircraft on the Ground

BCR – Benefit to Cost Ratio

BtP – Build-to-Print manufacturer

CAGR – Compound Annual Growth Rate

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CMR – Carcinogen, Mutagen or toxic for Reproduction

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium Trioxide Authorisation Consortium

DtB – Design-to-Build manufacturer

DtC – Dichromium tris(chromate)

EASA - European Aviation Safety Agency

EBITDA - Earnings before interest, taxes, depreciation, and amortization

ECHA – European Chemicals Agency

EEA – European Economic Area

ESA – European Space Agency

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross domestic product

GOS – Gross operating surplus

HvE – Humans via the Environment

ICAO – International Civil Aviation Organisation

MoD – Ministry of Defence

MRL – Manufacturing readiness level

MRO – Maintenance, Repair and Overhaul

NADCAP - National Aerospace and Defence Contractors Accreditation Program

NATO – North Atlantic Treaty Organisation

NUS – Non-use scenario

OELV - Occupational Exposure Limit Value

OEM – Original Equipment Manufacturer

RAC – Risk Assessment Committee

REACH - Registration, Evaluation, Authorisation and restriction of Chemicals

RR - Review Report

SC – Sodium chromate

SD – Sodium dichromate

SEA – Socio Economic Analysis

SEAC – Socio Economic Analysis Committee

SME – Small and medium-sized enterprises

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

TRL – Technology Readiness Level

UK – United Kingdom

WCS – Worker contributing scenario

Glossary

Term	Description
Active Corrosion Inhibition	The ability of a corrosion protection system to spontaneously repair small amounts of chemical or mechanical damage that exposes areas of metal without any surface protection (“self-healing properties”). Active corrosion inhibition can be provided by soluble corrosion inhibitors.
Adhesion promotion	The ability of the treatment to improve and maintain the adhesion of subsequent layers such as paints, primers, adhesives, and sealants. It also includes the adhesion of the coating to the substrate.
Aeroderivative	Parts used in power generation turbines used to generate electricity or propulsion in civil and defence marine and industrial applications that are adapted from the design/manufacturing processes and supply chains that produce parts for the aerospace industry. Typical applications include utility and power plants, mobile power units, oil and gas platforms and pipelines, floating production vessels, and for powering marine/offshore vessels such as Naval warships.
Aerospace	Comprises the civil and military aviation, and space industries.
Aerospace and Defence (A&D)	Comprises the civil and military aviation, space industries and the public organisations and commercial industry involved in designing, producing, maintaining, or using military material for land, naval or aerospace use.
Aircraft	A vehicle or machine able to fly by gaining support from the air. Includes both fixed-wing and rotorcraft (e.g., helicopters).
Airworthiness	Airworthiness is defined by the International Civil Aviation Organisation as "The status of an aircraft, engine, propeller or part when it conforms to its approved design and is in a condition for safe operation". Airworthiness is demonstrated by a certificate of airworthiness issued by the civil aviation authority in the state in which the aircraft is registered, and continuing airworthiness is achieved by performing the required maintenance actions.
Airworthiness Authority	The body that sets airworthiness regulations and certifies materials, hardware, and processes against them. This may be for example the European Union Aviation Safety Authority (EASA), the Federal Aviation Administration (FAA), or national defence airworthiness authorities.
Airworthiness regulations	Set performance requirements to be met. The regulations are both set and assessed by the relevant airworthiness authority (such as EASA or national Ministry of Defence (MoD) or Defence Airworthiness Authority).
Alternative	Test candidates which have been validated and certified as part of the substitution process.
Article	An object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition
Assembly	Several components or subassemblies of hardware which are fitted together to make an identifiable unit or article capable of disassembly such as equipment, a machine, or an Aerospace and Defence (A&D) product.
Aviation	The activities associated with designing, producing, maintaining, or flying aircraft.
Base metal	In passivation of non-aluminium coatings, the base metal is the material from which the component is made – it builds up the structure of the component. The non-aluminium metallic coating is coated on the surface of the base metal and provides the primary surface protection for the base metal
Benefit-Cost Ratio (BCR)	An indicator showing the relationship between the relative costs and benefits of a proposed activity. If an activity has a BCR greater than 1.0, then it is expected to deliver a positive net present value.
Build-to-Print (BtP)	Companies that undertake specific processes, dictated by the OEM, to build A&D components.
Certification	The procedure by which a party (Authorities or MOD/Space customer) gives written assurance that all components, equipment, hardware, services, or processes have

Term	Description
	satisfied the specific requirements. These are usually defined in the Certification requirements.
Coefficient of friction	Friction is the force resisting the relative motion of solid surfaces sliding against each other. The coefficient of friction is the ratio of the resisting force to the force pressing the surfaces together.
Complex object	Any object made up of more than one article.
Component	Any article regardless of size that is uniquely identified and qualified and is either included in a complex object (e.g., frames, brackets, fasteners and panels), or is a complex object itself (e.g., an assembly or sub-system)
Compound annual growth rate	The mean annual growth rate of an investment over a specified period of time, longer than one year.
Corrosion protection	Means applied to the metal surface to prevent or interrupt chemical reactions (e.g., oxidation) on the surface of the metal part leading to loss of material. The corrosion protection provides corrosion resistance to the surface.
Defence	Comprises the public organisations and commercial industry involved in designing, producing, maintaining, or using military material for land, naval or aerospace use.
Design	A set of information that defines the characteristics of a component (adapted from EN 13701:2001).
Design owner	The owner of the component/assembly/product detailed design. For Build-to-Print designs, the design owner is usually the OEM or military/space customer. For Design-to-Build, the supplier is the design owner of the specific hardware, based on the high-level requirements set by the OEM (as their principal).
Design-to-Build (DtB)	Companies which design and build components. Also known as “Build-to-Spec”.
Embrittlement	The process of becoming degraded, for example loss of ductility and reduction in load-bearing capability, due to exposure to certain environments.
Fatigue	Progressive localised and permanent structural change that occurs in a material subjected to repeated or fluctuating strains at stresses less than the tensile strength of the material. The “permanent structural change” is in the form of microcracks in the crystal structure that can progressively lead to potentially catastrophic macro-cracking and component failure.
Flexibility	The ability to bend easily without breaking or permanently deforming.
Formulation	A mixture of specific substances, in specific concentrations, in a specific form.
Formulator	Company that manufactures formulations (may also design and develop formulations).
Gross Domestic Product (GDP)	The standard measure of the value added created through the production of goods and services in a country during a certain period. As such, it also measures the income earned from that production, or the total amount spent on final goods and services (less imports).
Gross Operating Surplus	Equivalent to economic rent or value of capital services flows or benefit from the asset.
Gross Value Added	The value of output less the value of intermediate consumption; it is a measure of the contribution to GDP made by an individual producer, industry or sector.
Hardness	Ability of a material to withstand localized permanent deformation, typically by indentation. Hardness may also be used to describe a material’s resistance to deformation due to other actions, such as cutting, abrasion, penetration and scratching.
Heat resilience	The ability of a coating or substrate to withstand repeated cycles of heating and cooling and exposure to corrosive conditions. Also known as cyclic heat-corrosion resistance.
Hot corrosion resistance	The ability of a coating or substrate to withstand attack by molten salts at temperatures in excess of 400°C.
Industrialisation	The final step of the substitution process, following Certification. After having passed qualification, validation and certification, the next step is to industrialise the qualified material or process in all relevant activities and operations of production, maintenance, and the supply chain. Industrialisation may also be referred to as implementation.

Term	Description
Layer thickness	The thickness of a layer or coatings on a substrate.
Legacy parts	Any part that is already designed, validated, and certified by Airworthiness Authorities or for defence and space, or any part with an approved design in accordance with a defence or space development contract. This includes any part in service.
Material	The lowest level in the system hierarchy. Includes such items as metals, chemicals, and formulations (e.g., paints).
Maintenance, Repair and Overhaul (MRO)	The service of civilian and/or military in-service products. Term may be used to describe both the activities themselves and the organisation that performs them.
NACE	The Statistical Classification of Economic Activities in the European Community. It is part of the international integrated system of economic classifications, based on classifications of the UN Statistical Commission (UNSTAT), Eurostat as well as national classifications.
NADCAP	National Aerospace and Defence Contractors Accreditation Program which qualifies suppliers and undertakes ISO audits of their processes.
Net Present Value	Valuation method to value stocks of natural resources. It is obtained by discounting future flows of economic benefits to the present period.
Original Equipment Manufacturer (OEM)	Generally large companies which design, manufacture, assemble and sell engines, aircraft, space, and defence equipment (including spare parts) to the final customer. In addition, an OEM may perform MRO activities.
Part	Any article or complex object.
Pickling	The removal of surface oxides and small amounts of substrate surface by chemical or electrochemical action.
Present Value	The discounted sum of all future debt service at a given rate of interest. If the rate of interest is the contractual rate of the debt, by construction, the present value equals the nominal value, whereas if the rate of interest is the market interest rate, then the present value equals the market value of the debt.
Pre-treatment	Pre-treatment processes are used, prior to a subsequent finishing treatment (e.g., chemical conversion coating, anodising), to remove contaminants (e.g., oil, grease, dust), oxides, scale, and previously applied coatings. The pre-treatment process must also provide chemically active surfaces for the subsequent treatment. Pre-treatment of metallic substrates typically consists of cleaning and/or surface preparation processes.
Producer surplus	Represents the gain to trade a producer receives from the supply of goods or services less the cost of producing the output (i.e., the margin on additional sales).
Proposed candidate	A formulation in development or developed by a formulator as a part of the substitution process for which testing by the design owner is yet to be determined. In the parent applications for authorisation, this was referred to as a 'potential alternative'.
Qualification	1. Part of the substitution process following Development and preceding Validation to perform screening tests of test candidate(s) before determining if further validation testing is warranted 2. The term qualification is also used during the industrialisation phase to describe the approval of suppliers to carry out suitable processes.
Requirement	A property that materials, components, equipment, or processes must fulfil, or actions that suppliers must undertake.
Resistivity	Property that quantifies how a given material opposes the flow of electric current. Resistivity is the inverse of conductivity.
Social Cost	All relevant impacts which may affect workers, consumers and the general public and are not covered under health, environmental or economic impacts (e.g., employment, working conditions, job satisfaction, education of workers and social security).
Specification	Document stating formal set of requirements for activities (e.g., procedure document, process specification and test specification), components, or products (e.g., product specification, performance specification and drawing).
Standard	A document issued by an organisation or professional body that sets out norms for technical methods, processes, materials, components, and practices.

Term	Description
Sub-system	The second highest level in the system hierarchy. Includes such items as fuselage, wings, actuators, landing gears, rocket motors, transmissions, and blades.
Surface morphology	The defined surface texture of the substrate.
System	The highest level in the system hierarchy. Includes such items as the airframe, gearboxes, rotor, propulsion system, electrical system, avionic system, and hydraulic system.
System hierarchy	The grouping/categorisation of the physical elements that comprise a final product (such as an aircraft), according to their complexity and degree of interconnectedness. Comprises materials, parts/components, assemblies, sub-systems, and systems.
Temperature resistance	The ability to withstand temperature changes and extremes of temperature.
Test candidate	Materials which have been accepted for testing or are currently undergoing testing by a design owner, as a part of the substitution process. In the parent applications for authorisation, this was referred to as a 'candidate alternative'.
Type certificate	Document issued by an Airworthiness Authority certifying that an Aerospace product of a specific design and construction meets the appropriate airworthiness requirements.
Validation	Part of the substitution process following Qualification and preceding Certification, to verify that all materials, components, equipment, or processes meet or exceed the defined performance requirements.
Value of statistical life	Values the impact of risks to the length of life.
Verification	The process of establishing and confirming compliance with relevant procedures and requirements.
Wear resistance	The ability of a surface to withstand degradation or loss due to frictional movement against other surfaces.
Sources: GCCA and ADCR consortia	

DECLARATION

We, the Authorisation Holder, are aware of the fact that further evidence might be requested by HSE to support information provided in this document.

Also, we request that the information blanked out in the "public version" of the Analysis of Alternatives and Socio-economic analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today 27 February 2023 the information is not publicly available and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature: Date: 27 February 2023

Russel Argo.
Brenntag UK Ltd.

1 Summary

This combined AoA/SEA uses some terms in a manner specific to the aerospace and defence sector. Please see the glossary for explanations of the specific meaning of commonly used words, such as component, and other technical terms within the context of this report.

1.1 Introduction

The Aerospace and Defence Chromates Reauthorisation (ADCR) Consortium on behalf of the applicants has developed several review reports and new applications. These review reports or new applications cover all uses of soluble chromates considered to be relevant by the ADCR consortium members. Although formally they are upstream applications submitted by manufacturers, importers or formulators of chromate-containing chemical products, the applications are based on sector-specific data and detailed information obtained from actors throughout the supply chain.

For the purposes of this document, the term 'aerospace and defence' comprises the civil aviation, defence/security and space industries, as well as aeroderivative products. The aerospace and defence (A&D) industry has been working towards the substitution of Cr(VI) across various uses for the past 25-30 years. Although there have been numerous successes and levels of use have decreased significantly, the specific use of hexavalent chromium compounds in passivation of non-aluminium metallic coatings[1] is still required for many products. This remains critical to both flight safety and to military mission readiness, and hence to society. The socio-economic impacts of a refused authorisation are therefore significant not just for the sector but also for the EEA and UK societies and economies more generally. Furthermore, at the EU level, the A&D sector is one of the 14 sectors highlighted by the EEA's New Industrial Strategy[2] as being important to innovation, competition and a strong and well-functioning single market.

The parent authorisations to this combined AoA/SEA covered multiple surface treatments and different individual chromates. This combined AoA/SEA covers only one of the currently authorised types of surface treatment – passivation of non-aluminium metallic coatings – and therefore adopts a narrower definition of "use" compared to the original Chromium Trioxide Authorisation Consortium (CTAC) and Chromium VI Compounds for Surface Treatment (CCST) applications. The other surface treatments that are still being supported by the ADCR are covered by separate, complementary submissions for each "use".

A narrower definition of the uses of the chromates has purposely been adopted by the ADCR to ensure greater clarity on the risks posed by continued use, the availability of alternatives and the socio-economic impacts of non-use.

The specific use covered by this combined AoA/SEA (RR) is defined as:

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[1] Review Reports are also being submitted by the ADCR covering ten other uses of the chromates in formulation and other specific surface treatment activities as more narrowly defined by the ADCR.

[2] https://op.europa.eu/en/publication-detail/-/publication/52904a0b-ae95-11eb-9767-01aa75ed71a1/language-en

1) *Passivation of non-aluminium metallic coatings using sodium dichromate, chromium trioxide and/or potassium dichromate in the aerospace and defence industry and its supply chains.*

The "Applied for Use" involves the continued use of chromium trioxide, potassium dichromate and sodium dichromate across the EEA and the UK in passivation of non-aluminium metallic coatings for a further 12 year review period.

These three chromates were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate). According to Article 62 (4)(d) of this Regulation, the chemical safety report (CSR) supporting an Application for Authorisation (AfA) needs to cover only those risks arising from the intrinsic properties specified in Annex XIV. The carcinogenicity, mutagenicity and reproductive toxicities of CT, its acids, SD and PD are driven by the chromium VI (Cr(VI)) ion released when the substances solubilise and dissociate.

A grouping approach has therefore been adopted for the CSR and is also adopted here for the combined AoA/SEA. From the CSR perspective, grouping is appropriate because:

- All substances share this common toxic moiety (Cr(VI)), and are therefore expected to exert effects in an additive manner;
- At many sites various chromates are used in parallel, the exposures of which are additive; and
- For some uses, different chromates may be used for the same process where demanded by a component's or final product's certification requirements.

Grouping is also appropriate to the analysis of alternatives. The key determinant of functionality is the presence of the Cr(VI) component delivered by the chromate substance. As a result, the three chromates deliver one or more of the same key functionalities in each use and the same families of test candidates are relevant to substitution.

With respect to the SEA, the grouping approach ensures that there is no double-counting of economic impacts and the social costs of unemployment. This would occur if the assessment was carried out separately for each chromate's use in passivation due to the fact that different chromates may be used for passivation carried out via immersion versus passivation touch-up and brush activities.

The potential for double counting is significant given that approximately 100 sites in the EEA and 30 sites in Great Britain are anticipated as undertaking passivation. This includes sites involved in the production of components and end products, as well as maintenance, repair and overhaul services for both civil aviation and military bodies, as well as aeroderivative uses.

It is estimated that these sites consume the following maximum quantities of each of the three chromates of relevance, with some sites using more than one chromate in passivation activities. These figures are based on the maximum consumption per site identified from the CSR, Article 66 notifications and the percentage of sites using each of the chromates as identified in responses to the SEA questionnaire and from discussions with formulators and distributors.

Table 1-1: Maximum tonnages used in passivation

	Chromium trioxide	Sodium dichromate	Potassium dichromate
EEA	Up to 15 t/y	Up to 50 t/y	Up to 10 t/y
UK	Up to 5 t/y	Up to 10 t/y	Up to 5 t/y

1.2 Availability and suitability of alternatives

For the past several decades, ADCR members who are "design owners" [including Original Equipment Manufacturers (OEMs) and Design-to-Build manufacturers (DtB)] selling products used in civil aviation and military aircraft, ground and sea-based defence systems, and aeroderivatives have been searching for alternatives to the use of the three chromates in passivation as a specific use. At the current time, the remaining uses form part of an overall system, with the key functionalities of the chromate-based formulations in passivation being as follows (see also Section 3.2):

- Corrosion inhibition including active corrosion inhibition ("self-healing");
- Adhesion to subsequent layer;
- Chemical resistance;
- Layer thickness;
- Resistivity/conductivity; and
- Temperature resistance.

Passivation of non-aluminium metallic coatings is a key use of the chromates by the aerospace and defence industry. The process involves treatment of surfaces with already applied metallic coatings to further extend the life of the part. As a chemical process, the Cr(VI) in CT, SD or PD, reacts with the non-aluminium metallic coating to form a Cr(III) passive protective layer.

A&D products operate in highly challenging, extreme environments over extended timeframes. Due to these challenges, alongside engineering-based solutions, the A&D industry must use numerous high-performance mixtures which have passed through an extensive approval process to demonstrate their suitability for use.

OEMs in particular, (as design owners who have responsibility for certification of alternatives) have conducted a full analysis of their requirements into the future, taking into account progress of R&D, testing, qualification, certification and industrialisation activities. The companies are at different stages in the implementation of alternatives, with some indicating that they expect to be able to substitute the above chromates in passivation across some or all of their current components, final products and MRO (maintenance, repair and overhaul) processes within the next four to seven years; while others have not yet been able to identify technically feasible alternatives for all components and final products and MRO processes that meet performance requirements, and will require a further 12 years to gain certifications and then implement current test candidates; a further set are constrained by military and MRO requirements which may mean that it will take at least 12 years to implement technically feasible substitutes.

Furthermore, obtaining such certification across hundreds of components is a time-consuming and costly process, given the strict testing regimes that must be adhered to achieve the qualification, validation and certification of components using an alternative. At the sectoral level, therefore, and to ensure minimisation of supply chain disruption and associated business risks, a 12-year review period is requested. Business risks arise from the need for alternatives to be available and deployed across all components and suppliers to ensure continuity of manufacturing activities across the supply chain. A shorter period would impact on the functioning of the current market, given the complexity of supply chain relationships.

Companies engaged in maintenance, repair and overhaul (MRO) activities face particular substitution difficulties, as they are mandated to continue use of chromium trioxide, sodium dichromate, and/or potassium dichromate in passivation if this is specified in the Maintenance Manuals provided to them by the OEMs. MROs (military and civilian) are legally obliged to carry out their activities in line with the requirements set out in Maintenance Manuals, given the importance of these to ensuring airworthiness and the safety and reliability of final products. As a result, they rely on the completion of the R&D, testing and certification activities of the OEMs and the update of the Maintenance Manuals before they are able to adopt alternative substances or processes.

It should be noted that companies supporting this combined AoA/SEA are engaged in the manufacture and supply to both civilian and military customers (where the latter includes not just air forces but also non-aircraft defence systems, such as ground-based installations or naval systems), as well as emergency services. The consortium includes as formal members Ministries of Defence (MoD) located in the EEA and UK, with additional information provided by another EEA MoD concerned over the on-going mission readiness of their current military forces and equipment.

As a result of the different requirements outlined above, at the sectoral level, there will be an on-going progression of substitution over the requested 12-year review period. . It is clear from the chart that in 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a significant proportion of the substitution plans (45%) are not expected to have achieved MRL 10 and are expected to be at the qualification, validation, certification or industrialisation stages.

The expected progression of ADCR members’ substitution plans to replace Cr(VI) in passivation is shown below.

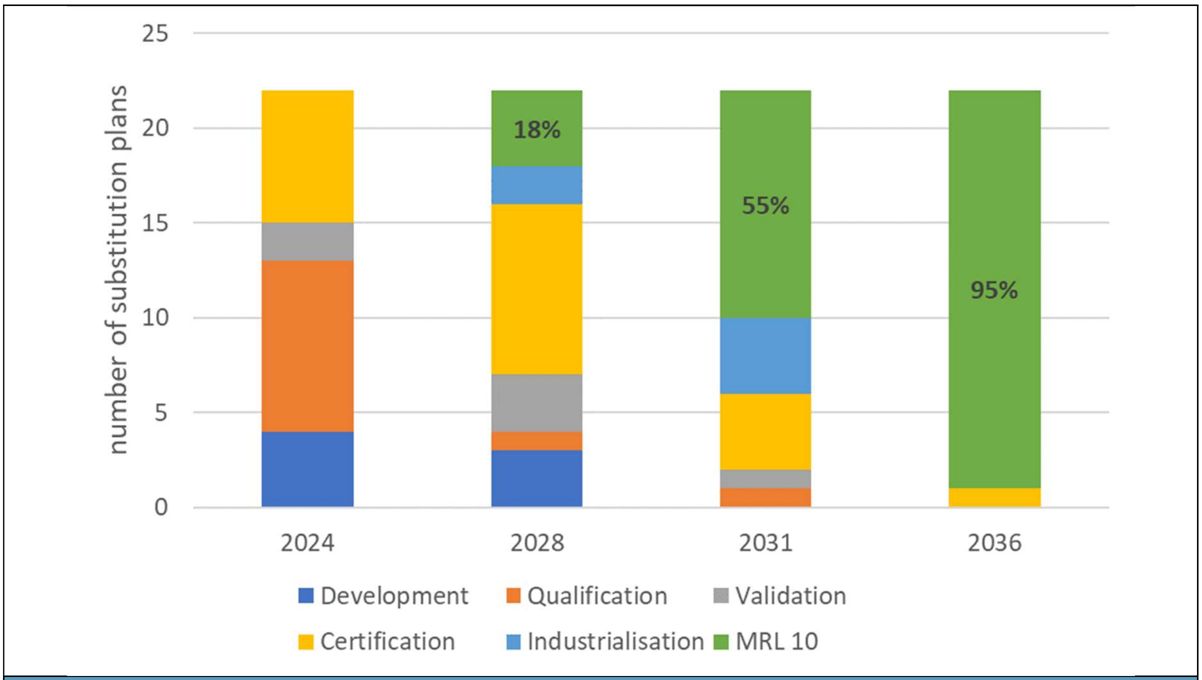

Figure 1-1: Expected progression of substitution plans for the use of Cr(VI) in passivation of non-aluminium metallic coating, by year.
The vertical axis refers to number of substitution plans (some members have multiple substitution plans for passivation of non-aluminium metallic coating). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which it is expected that Cr(VI) will be fully substituted under the relevant plan.
***Source:* RPA analysis, ADCR members**

1.3 Socio-economic benefits from continued use

The continued use of the three chromates in passivation of non-aluminium metallic coatings (Use #1) over the review period will confer significant socio-economic benefits to ADCR members, their suppliers and to their end customers which include civil aviation, the military, space, emergency services. It will also ensure the continued functioning of the aerospace and defence supply chains in the EEA and UK, conferring the wider economic growth and employment benefits that come with this.

The benefits can be summarised as follows (with the detailed calculations set out in Section 5):

- Importers of the chromates and formulators of the mixtures used in passivation of non-aluminium metallic coatings will continue to earn profits from sales to the A&D sector. These are not quantified in this SEA but are detailed in the linked Formulation AoA/SEA;

- OEMs will be able to continue to rely on the continued use of chromates by their EEA and UK suppliers and in their own production activities. The profit losses[3] to these companies under the non-use scenario would equate to between €430 million – 5,100 million for the EEA and €140 million – 800 million for the UK, over a 2-year period (starting in 2025, PV discounted at 4%). These figures exclude the potential profits that could be gained under the Continued Use Scenario from the global increase in demand for air transport;

- DtB and Build-to-Print (BtP) suppliers would be able to continue their production activities in the EEA/UK and meet the performance requirements of the OEMs. The associated profit losses avoided under the Continued Use scenario for these companies are calculated at between €180 – 500 million for the EEA and €25 – 230 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%);

- MRO companies which provide maintenance and repair services to both civil aviation and/or military forces, would not be forced to move some operations outside the EEA/UK, for which the consequent profit losses equating to between €150 – 360 million for the EEA and €10 – 20 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%). Such relocation of strategically important activities would run contrary to the EU's New Industrial Strategy;

- Continued high levels of employment in the sector, with these ensuring the retention of highly skilled workers paid at above average wage levels. From a social perspective, the benefits from avoiding the unemployment of workers involved in passivation of non-aluminium metallic coatings are estimated at €2 billion in the EEA and €300 million in the UK. These benefits are associated with the protection of more than 19,000 jobs in the EEA and 3,500 jobs in the UK;

- Critically, civil aviation and emergency services will benefit from the continued flight safety and availability of aircraft and other equipment;

- Military forces will be able to repair and maintain existing aircraft and other equipment to ensure operational readiness and the ability to respond to missions as required; and

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[3] Two different approaches have been used to calculate the economic impacts to produce lower and upper bound estimates. Profit losses are discounted over 2 years at 4% per annum.

- The general public will benefit from continued safe flights, fewer flight delays, the on-time delivery of cargo and goods, and the economic growth provided by the contributions of these sectors to the economic development, as well as R&D and technological innovation, while alternatives are qualified, certified and industrialised.

The loss to the A&D companies and to society are expected to be much larger than the losses calculated in the non-use scenario. This is because the non-use scenario does not account for the costs associated with for example, disruption and relocation in the supply chain.

1.4 Residual risk to human health from continued use

The parent authorisations placed conditions on the continued use of the three chromates in surface treatments, including in passivation. The A&D sector has made huge efforts to be compliant with these conditions, investing not only in risk management measures but also improved worker and environmental monitoring.

Furthermore, significant technical achievements have been made in developing and qualifying alternatives for use on some components/final products, although there remain technical challenges for other components and final products. As a result, it is projected that from 2024, based current company specific substitution plans where technically and economically feasible, consumption of the chromates by ADCR members and their suppliers will decline significantly over the requested 12-year review period. For the purposes of the human health risk assessment, however, it has been assumed that the quantities used and the number of sites using the chromates remains constant over the 12-year period. This will lead to an overestimate of the residual risks to both workers and humans via the environment.

Risks to workers have been estimated based on the use of exposure monitoring data, supplemented by modelling data as appropriate. Across the 100 EEA sites where chromate-based passivation is anticipated as taking place, a total of 2,800 workers (including 600 incidentally exposed workers) may be exposed to Cr(VI); for the 30 UK sites where passivation takes place, a maximum of 840 workers may be exposed (including 180 incidentally exposed workers).

Exposures for humans via the environment have been calculated for the local level only. Based on the population density of the different countries within which passivation is considered to take place, an estimated 44,000 people in the EEA and 40,000 people in the UK are calculated as potentially being exposed to Cr(VI) due to chromate-based passivation activities.

The predicted number of cancer cases per annum and the annualised economic value of these social costs for both workers and humans via the environment are:

- EEA: 0.04 fatal cancers and 0.01 non-fatal cancers per annum, at a total social cost of €150,000;
- UK: 0.01 fatal lung cancers and 0.004 non-fatal lung cancers per annum at a total social cost of €55,000.

1.5 Comparison of socio-economic benefits and residual risks

The ratios of the total costs of non-Authorisation (i.e., the benefits of continued use) to the total residual risks to human health are as follows for the EEA and UK respectively (based on two years for economic losses and 12 years for health risks @ 4%):

- EEA: 4,858 to 1 for the lower bound of profit losses and unemployment costs or 12,269 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over two years and residual risks over 12 years;
- UK: 1,974 to 1 for the lower bound of profit losses and unemployment costs or 5,722 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over two years and residual risks over 12 years.

The above estimates represent a significant underestimate of the actual benefits conferred by the continued use of chromium trioxide, sodium dichromate and potassium dichromate in the Applied for Use, as it only encompasses benefits that could be readily quantified and monetised. The true benefit-cost ratios must be assumed to also encompass:

- The significant benefits to civil aviation and military customers, in terms of flight readiness and military preparedness of aircraft and equipment;
- The avoided impacts on air transport – both passenger and cargo – across the EEA and the UK due to airplanes being stranded on the ground (AoG), reductions in available aircraft, increased flight costs, etc.;
- The avoided impacts on society more generally due to impacts on air transport and the wider economic effects of the high levels of unemployment within a skilled workforce, combined with the indirect and induced effect from the loss of portions of the A&D sector from the EEA and UK as they either cease some activities or relocate relevant operations;
- The avoided negative environmental impact associated with prematurely obsoleted final products which creates excess waste in the disposal of components, and increased scrappage in the manufacture of the replacements; and
- The avoided economic and environmental costs associated with increased transporting of components in and out of the EEA/UK for maintenance, repair and overhaul (whether civilian or military) and production activities.

1.6 Factors to be considered when defining the operating conditions, risk management measures, and/or monitoring arrangements

A range of factors should be taken into account when considering the need for additional risk management measures and/or monitoring requirements:

- The sector has reduced the volume of chromates used in passivation activities, with the estimated maximum volumes of the three chromates shown in Table 1-1.
- Occupational exposure monitoring requirements were placed on downstream users within the applicants supply chain as part of the granting of the parent authorisations. The A&D industry has responded to these requirements by increasing the level of monitoring carried out, with this including increases in expenditure on worker monitoring and adaptations to the way in which monitoring was previously carried out.

- As demonstrated in Section 4, since 2017 companies have invested in new equipment to reduce exposures to workers and to reduce environmental emissions. This has included investment in new, better performing production equipment as well as increased exhaust ventilation and other measures.

- A Binding Occupational Exposure Limit Value (OELV) has been introduced under EU Directive 2004/37/EC that will become more stringent after January 17th, 2025; this Binding OELV was recommended by the Tripartite Advisory Committee on Safety and Health based on consensus and will provide an additional level of protection for workers undertaking Cr(VI)- based passivation. The sector is working with formulators to reduce the volume of chromates used in passivation activities and, as indicated in the Substitution Plan, companies are progressing towards the certification and implementation of substitutes across on-going uses. Many sites only use very small volumes of the chromates in passivation.

1.7 Factors to be considered when assessing the duration of a review period

The ADCR's requirements for continued use meet the criteria set out by the ECHA Committees for Authorisation review periods longer than normal (seven years), as follows:

- **The applicants' downstream users face investment cycles that are demonstrably very long**, with this recognised in various European Commission reports. Final products in the A&D sector can have lives of over 50 years (especially military equipment), with there being examples of contracts to produce parts for out-of-production final products extending as long as 35 years. MROs and MoDs in particular require the ability to continue servicing older, out-of-production but still in-service aircraft and equipment. The inability to continue servicing such final products will not only impact upon civil aviation but also emergency vehicles and importantly on operationally critical military equipment. Thus, although new aircraft and military equipment designs draw on new materials and may enable a shift away from the need for passivation, there will remain a stock of in-service aircraft and equipment that will require its use as part of repairs, maintenance and overhaul activities.

- **The costs of moving to alternatives are high**, not necessarily due to the cost of the alternative substances but **due to the strict regulatory requirements that must be met to ensure airworthiness and safety**. These requirements mandate the need for testing, qualification, validation and certification of components using the alternatives, with this having to be carried out for all components and then formally implemented through changes to design drawings and maintenance manuals. In some cases, this requires retesting of entire end products for extensive periods of time, which is not only costly but may also be infeasible (due to the age of the final product, lack of testing facilities, age of available test vehicles (engines, aircraft, defence equipment, etc.). On a cumulative basis, the major OEMs and DtB companies that act as the design owners could not afford to undertake action across the range and numbers of components that still require the qualification, certification and industrialisation of the alternatives at the same time. These activities themselves are costing the companies hundreds of millions of Euros across all uses of Cr(VI), and several tens of millions for passivation alone.

- **The strict regulatory requirements that must be met generate additional, complex requalification, recertification, industrialisation activities,** to ensure the continued airworthiness of aircraft and the safety and reliability of defence equipment (including air, naval and land-based systems). These requirements mean that there is no simple or single drop-in replacement for the chromates in passivation processes, which can be considered to be “generally available” following the European Commission’s definition[4].

- **The A&D industry has been undertaking R&D into alternatives for the past 30 years.** This includes participation in research initiatives partially funded by the European Commission and national governments. Considerable technical progress has been made in developing, validating qualifying and certifying components for the use of alternatives, however, it is not technically nor economically feasible for the sector as a whole to have achieved full substitution within a four or seven year period. Although some companies have been able to qualify and certify alternatives for some of their components, others are still in the early phases of testing and development work due to alternatives not providing the same level of performance to the chromates. They will not be able to qualify and certify a proposed or a test candidate for some components within a four or seven year time frame. It is also of note that passivation is used throughout the supply chain and by large numbers of smaller suppliers. As a result, sufficient time will be required to fully implement alternatives through the value chain once they have been certified.

- Even then, **it may not be feasible for MROs to move completely away from the use of the chromates in passivation due to mandatory maintenance, repair and overhaul requirements**. MROs must wait for OEMs or MoDs to update Maintenance Manuals with an appropriate approval for each treatment step related to the corresponding components or military hardware. The corresponding timescale for carrying out such updates varies and there can be significant delays while OEMs/MoDs ensure that substitution has been successful in practice. In this respect, it is important to note that the use of the chromates in passivation is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EU level and in a wider field, e.g., with NATO.

- Given the above, **an Authorisation of appropriate length is critical to the continued operation of aerospace and defence manufacturing, maintenance, repair and overhaul activities in the EEA and UK**. The sector needs certainty to be able to continue operating in the EEA/UK using chromates until adequate alternatives can be implemented. It is also essential to ensuring the uninterrupted continuation of activities for current in-service aircraft and defence equipment across the EEA and UK.

- As highlighted above and demonstrated in Section 5, **the socio-economic benefits from the continued use of chromium trioxide, sodium dichromate and potassium dichromate in passivation significantly outweigh the risks of continued use**. The European A&D sector is a major exporter of final products and is facing a growing market for both its civilian and defence products which it can only serve if it retains its current strong industrial and supply chain base in the EEA and UK. It will not be able to respond to this increased market demand if the continued use of the three chromates in passivation is not authorised while work continues on developing, qualifying and certifying alternatives.

- Finally, the global nature of the aerospace and defence sector must be recognised. The EEA and UK A&D sector must ensure not only that it meets regulatory requirements in the EEA and

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[4] As defined with respect to the “legal and factual requirements of placing on the market” in the EC note of 27 May, 2020, available at: 5d0f551b-92b5-3157-8fdf-f2507cf071c1 (europa.eu)

UK, but also that it meets requirements in other jurisdictions to ensure that its final products can be exported and used globally.

2 AIMS AND SCOPE OF THE ANALYSIS

2.1 Introduction

2.1.1 The Aerospace and Defence Chromates Reauthorisation Consortium

This combined AoA/SEA covers all of the soluble chromates relevant for the specific use in passivation of non-aluminium metallic coatings by the ADCR consortium members and companies in their supply chain, taking into account the needs of their supply chains. In part, passivation will increase the ability of the part to withstand contact with any fluid encountered during service life, such as lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids. Additionally, passivation will encourage adhesion to subsequent layers such as paints, primer, sealants and functional coatings such as lubricants.

The use of the chromates in passivation of non-aluminium metallic coatings is limited to those situations where it plays a critical (and currently irreplaceable) role in meeting product performance, reliability, and safety standards, particularly those relating to airworthiness set by European Aviation Safety Agency (EASA). This is also true with respect to the use of passivation in defence, space and in aerospace derivative products, which include non-aircraft defence systems, such as ground-based installations or naval systems. Such products and systems also must comply with numerous comparable requirements including those of the European Space Agency (ESA) and of national MoDs.

This is an upstream application submitted by manufacturers, importers and/or formulators of chromate-containing chemical products. It is an upstream application due to the complexity of the A&D supply-chain, which contains many small and medium-sized enterprises (SME). The ADCR was specifically formed to respond to this complexity and to benefit the entire supply chain, thereby minimising the risk of supply chain disruption. The aim is also to provide the industry's major OEMs and DtB manufacturers with flexibility and to enable them to change sources of supply for the manufacture of components and assemblies; it also helps ensure that choice of supply, competition and speed of change is maintained. The importance of this type of risk minimisation has become only too apparent due to the types of supply chain disruption that has arisen due to COVID-19.

As a result, the analysis presented here is based on an extensive programme of work funded and carried out by the main OEMs and DtBs, and key suppliers where this includes small, medium and other large actors within the sector. It is based on sector-specific data and detailed information obtained from the ADCR members (which includes OEMs, DtBs, BtPs, MROs and MoDs) and collected from their A&D suppliers throughout the supply chain. In total, data were collected from companies covering over 260 A&D sites in the EEA and UK, with data for 32 of those sites used in developing this combined AoA/SEA.

In addition, to ensure consistency and continuity of global supply chains under both EU REACH and UK REACH, this document covers the requirements of A&D supply chains in both the EEA and the UK[5]. Where important, information is separated out for the EEA and UK, so that authorities in both jurisdictions have a clear view of impacts.

2.1.2 Aims of the combined AoA and SEA document

The downstream users supporting the ADCR consortium have no qualified (from a technical perspective) and economically feasible alternatives for use on all of their components and final

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[5] Both ECHA and the UK HSE agreed to this approach in pre-submission discussions.

products which can be fully implemented, across all products, components and MRO processes before the expiry of the original authorisations; they must continue to use the chromates in passivation activities carried out within the EEA and UK, including in formulations, as they are fundamental to achieving the required technical performance of aerospace components. They form part of an overall system aimed at ensuring the compulsory airworthiness requirements of aircraft and military equipment.

Although the A&D sector has been successful in implementing alternatives in certain applications with less demanding requirements, the aim of this combined AoA/SEA is to enable the continued use of the chromates in passivation beyond the end of the existing review period which expires in September 2024 for chromium trioxide, sodium dichromate and potassium dichromate, for the processes where alternative implementation has not yet been successful. It demonstrates the following:

- The technical and economic feasibility, availability, and airworthiness (i.e., safety) challenges in identifying an acceptable alternative to the use of the chromates, which does not compromise the functionality and reliability of the components treated with passivation of non-aluminium metallic coating and which could be validated by OEMs and gain certification/approval by the relevant aviation and military authorities across Europe and the globe;

- The R&D that has been carried out by the OEMs, DtBs and their suppliers towards the identification of feasible and suitable alternatives for the chromates in passivation of non-aluminium metallic coatings. These research efforts include EU funded projects and initiatives carried out at a more global level, given the need for global solutions to be implemented within the major OEMs supply chains;

- The efforts currently in place to progress proposed candidate alternatives through Technology Readiness Levels (TRLs), Manufacturing Readiness Levels (MRLs) and final validation/certification of suppliers to enable final implementation. This includes treatment of components for civilian and military aircraft and defence equipment that continue to be produced, as well as for maintenance, repair and overhaul of those products and out-of-production civilian and military aircraft and other defence systems;

- The socio-economic impacts that would arise for ADCR downstream users and their suppliers, their upstream and downstream supply chains and, crucially, for the EEA and UK more generally, if the applicants were not granted Re-authorisations for the continued use of the chromates over an appropriately long review period; and

- The overall balance of the benefits of continued use of the chromates and risks to human health from the carcinogenic and reprotoxic effects that may result from exposures to the chromates.

It should be noted that this combined AoA/SEA is one of a set of combined AoA/SEAs that have been prepared by the ADCR Consortium to cover the range of different uses of the chromates that continue to be required by the EEA (and UK) A&D industries.

2.2 The Parent Applications for Authorisation

This combined AoA and SEA covers the use of three substances for passivation:

Chromium trioxide (includes “Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0
Sodium dichromate	EC 234-190-3	CAS 10588-01-9
Potassium dichromate	EC 231-906-6	CAS 7778-50-9

The chromates shown were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate).

Chromium trioxide (CT) was included in Annex XIV of REACH (Entry No. 16) due to its carcinogenic (Cat. 1A) and mutagenic properties (Cat. 1B). As CT is mainly used as an aqueous solution in passivation, this RR also covers the acids generated from CT and their oligomers (Entry No. 17). In the remainder of this document, references to CT always include the acids generated from CT and their oligomers.

Sodium dichromate (SD; Entry No. 18) and potassium dichromate (PD; Entry No. 19) have been included in Annex XIV of REACH due to their CMR properties as they are all classified as carcinogenic (Cat. 1B), mutagenic (Cat. 1B) and reproductive toxicants (Cat. 1B).

These three chromates were granted authorisations for use in passivation of non-aluminium metallic coatings across a range of applicants and substances. Table 2-1 summarises the initial applications which act as the parent applications to this combined AoA/SEA.

It is important to note that it is not the intention of this combined AoA/SEA and the grouping of both applicants and substances, to expand the scope of the authorisation(s) held by any of they applicants. Each is applying only for a renewal of their original parent authorisation. Where one of these applicants is also seeking to cover new substance-use combinations, they will be submitting a new application for authorisation under the ADCR.

Table 2-1: Overview of the Parent Authorisations

Application ID/ authorisation number	Substance	CAS #	EC #	Applicants	Use name
0032-04 REACH/20/18/14, REACH/20/18/16, REACH/20/18/18	Chromium trioxide	1333-82-0	215-607-8	Various applicants (CTAC consortium)	Surface treatment for applications in the aeronautics and aerospace industries, unrelated to Functional chrome plating or Functional chrome plating with decorative character
0032-05/ REACH/20/18/21, REACH/20/18/23, REACH/20/18/25	Chromium trioxide	1333-82-0	215-607-8	Various applicants (CTAC consortium)	Surface treatment (except passivation of tin-plated steel (ETP)) for applications in various industry sectors namely architectural, automotive, metal manufacturing and finishing, and general engineering (unrelated to Functional chrome plating or Functional chrome plating with decorative character)
0044-02 REACH/20/3/1 22UKREACH/20/3/1	Potassium dichromate	7778-50-9	231-906-6	Various applicants (CCST consortium)	Use of potassium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites, sealings of anodic films
0043-02 REACH/20/5/3-5 24UKREACH/20/5/3	Sodium dichromate	10588-01-9	234-190-3	Various applicants (CCST consortium)	Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films

2.3 Scope of the analysis

2.3.1 Brief overview of the uses

2.3.1.1 Process description

Metallic coatings are passivated to provide surface protection to the coating. Because the passivation of non-aluminium metallic coatings is carried out after the application of a non-aluminium metallic coating, this step can also be described as a post-treatment within a process flow.

Throughout this document, the term "substrate" refers to the non-aluminium metallic coating. The non-aluminium metallic coating is coated on the "base metal", see Figure 3-1.

A variety of metals and alloys (e.g., cadmium, zinc, nickel, copper) can be applied as a coating to be passivated. Aluminium however is excluded as a coating by use definition of the ADCR consortium. The material below the metallic coating (the base metal, see Figure 3-1) is typically steel but can also be a different material.

Technically, passivation of non-aluminium metallic coatings is a conversion coating. When the passivation process is applied to a metallic coating it produces a superficial layer containing a compound of the substrate metal and elements from the processing solution. In this process, Cr(VI) containing solution is applied on the non-aluminium coating forming a passive protective layer on the surface of the non-aluminium metallic coating. The level of protection is proportional to the thickness of the passivation layer (see AoA document to application ID 0043-02).

By the presence of residual Cr(VI) retained in the passivation layer, native or self-healing corrosion protection is enabled, as shown in Figure 2-1. If the non-aluminium metallic coating is damaged locally, this residual Cr(VI) reacts with the exposed non-aluminium metallic coating, renewing the passive chromium oxy-hydroxide protective barrier (see AoA document to application ID 0043-02). Some Cr(VI) may remain in the surface, machining activities may therefore produce Cr(VI) containing dust and are therefore considered in section 4.4.

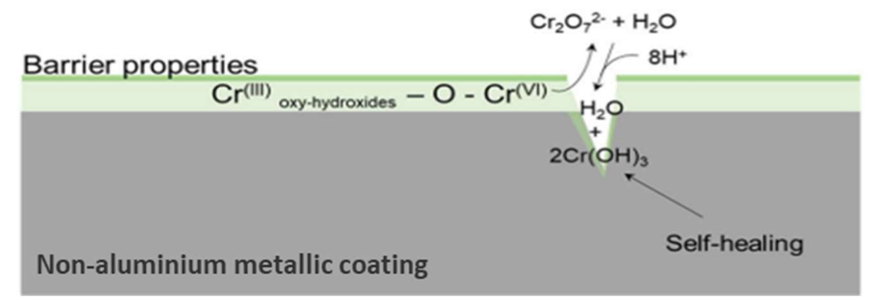

Figure 2-1: Self-healing mechanism afforded by Cr(VI) on metal substrates (Gharbi et al., 2018)

Passivation of non-aluminium metallic coatings is a chemical process which is in most cases carried out by immersion of parts in treatment baths. Typically, the treatment baths for passivation of non-aluminium metallic coatings are positioned in a large hall where also baths for other immersion processes are positioned, e.g., the preceding metal coating or other Cr(VI) or Cr(VI)-free treatments which may be unrelated to the present use. The immersion tanks can be placed individually or within a line of several immersion tanks. Usually, at least one rinsing tank with water is positioned after an immersion tank, for rinsing off the passivation solution from the part(s).

In some cases, when small components need touching up, passivation of non-aluminium metallic coatings is carried out by applying the solution with a brush or swab. This activity is usually performed next to the treatment bath.

Passivation may also be used to brighten plated surfaces discoloured by thermal treatment, in order to enhance inspectability. Thermal treatment is necessary to prevent hydrogen embrittlement after electroplating of sensitive steel.

2.3.1.2 Choice of Chromate

Either CT, SD or PD can be used for passivation of non-aluminium metallic coatings in the aerospace and defence industry and its supply chains. The three chromates do not differ in terms of functionality for this use. The reason either one or the other is used is, in most cases, due to that particular chromate containing formulation being defined in the customer specifications for a particular component and/or application; such a customer specification often has a historical or empirical background.

When no specification is given by a client, the choice of the chromate is often based on practical reasons, e. g. because a site prefers to use one of the three chromates for other processes as well, and/or the handling of one of the different substances is preferred.

2.3.1.3 Relationship to other uses

As shown in Figure 2-2 some sites and/or depending on the applied metallic coating (e.g., performed on cadmium and zinc coating), passivation of non-aluminium metallic coatings is carried out in two consecutive steps, whereby the first step serves to brighten and/or to slightly etch the metallic coating and to provide preliminary passivation. The second step then provides the full passivation. For the two steps, three different chromates may be used, with different Cr(VI) concentrations in the baths. Usually, no Cr(VI)-containing post-treatment is required after passivation of (non-Al) metal coatings, but in some cases, a Cr(VI) containing paint or primer may be applied as a post-treatment. In rare occasions, if the metallic coating is nonconforming, it is necessary to remove the metallic coating by inorganic stripping with Cr(VI), and to re-apply the metallic coating. However, more frequently, e.g., as part of MRO work, it is necessary to remove the passivation layer together with the metallic coating by inorganic finish stripping. In case the post-treatment is a Cr(VI) primer, the primer is typically first removed by blasting before the underlying layers are removed by inorganic finish stripping. At a later point in time (usually after additional processing of the component), the metallic coating is then reapplied and passivated.

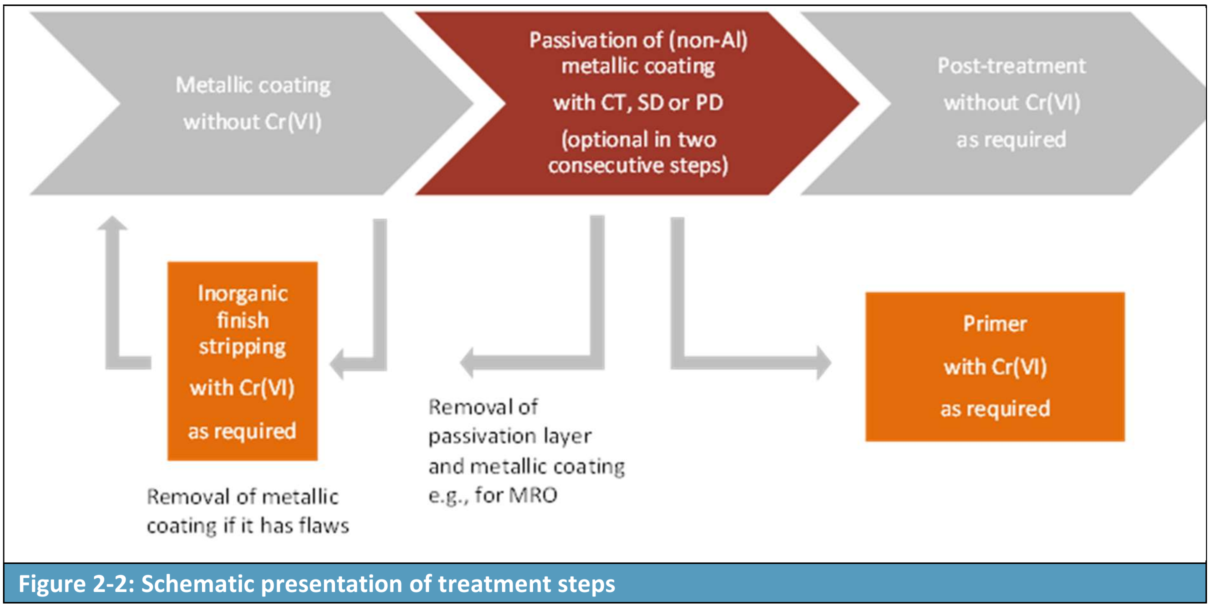

Figure 2-2: Schematic presentation of treatment steps

Please see the other ADCR combined AoA/SEAs and new Applications for Authorisation (as applicable) for further details of these other processes, the availability of alternatives and the socio-economic impacts of a refused re-authorisation.

2.3.2 Temporal scope

Because of the lack of qualified and viable alternatives for the use of the chromates in passivation of non-aluminium metallic coating for A&D components, it is anticipated that it will take a further 12 years to develop, qualify, certify, and industrialise alternatives across all components across the ADCR membership and the sector as a whole. Over this 12-year period, the temporal boundaries adopted in this assessment take into account:

- When human health, economic and social impacts would be triggered;
- When such impacts would be realised; and
- The period over which the continued use of the chromates would be required by the A&D industry as a minimum.

The impact assessment periods used in this analysis and the key years are presented in Table 2-2.

Table 2-2: Temporal boundaries in the analysis

Present value year		2021	
Start of discounting year		2024	
Impact baseline year		2024	
Scenario	**Impact type**	**Impact temporal boundary**	**Notes**
“Applied for Use”	Adverse impacts on human health	12 years following a 20-year time lag	Based on the length of requested review period
“Non-use”	Loss of profit along the supply chain	12 years	Based on the length of requested review period
	Impacts on growth and GDP	12 years	Based on the length of requested review period
	Disruption to EEA society due to impacts on civil, emergency and military aviation, as well as defence equipment	12 years	Based on the length of requested review period
	Loss of employment	1 to over 3 years	Average period of unemployment in the EEA (Dubourg, 2016)

2.3.3 The supply chain and its geographic scope

2.3.3.1 The ADCR Consortium

The ADCR is composed of 67 companies located in the EEA and the UK that act as suppliers to the A&D industry (17 importers, formulators and distributors), are active downstream users (OEMs, DtBs or BtPs), or are MRO providers (civilian or military) within the industry sector. Membership also includes Ministries of Defence due to concerns over the loss of the availability of the chromates for on-going maintenance and repair of military equipment.

Of the downstream user members, 24 comprise the leading OEMs, DtBs and MROs operating in the EEA and UK. These 24 large companies (as per the EC definition) operate across multiple sites in the EEA, as well as in the UK and more globally. It is these leading OEM and DtB companies that act as design owners and establish the detailed performance criteria that must be met by individual components and final products to ensure that airworthiness and military requirements are met. The consortium also includes 21 small and medium sized companies. As stakeholders using chromates within the A&D sector their information and knowledge supplements the aims of the consortium to ensure its success in re-authorising the continued use of the chromates. These companies are involved in BtP, DtB and MRO activities, sometimes acting as a combination of these.

With respect to passivation:

- Over two thirds of the larger ADCR members - 17 of 24 – are supporting the reauthorisation of this use in the EEA; this includes for their own use as well as for use by their supply chains.
- For the UK, 9 of the 24 larger ADCR members support the use of sodium dichromate for passivation of non-aluminium metallic coatings with some companies also supporting the use of chromium trioxide and potassium dichromate.

Table 2-3: Number of ADCR members supporting each substance for use in passivation of non-aluminium metallic coating for their own activities or for their supply chain (33 ADCR members in total)

	Chromium trioxide	Potassium dichromate	Sodium dichromate
EEA	10	3	15
UK	5	2	9

2.3.3.2 Suppliers of chromate substances and mixtures

For passivation of non-aluminium metallic coatings, six generic chromate products have been identified as listed in Table 2-4.

Table 2-4: Products used in passivation of non-aluminium metallic coatings

Product A	Solid chromium trioxide (flakes), pure substance (100%)
Product B	Aqueous solution of chromium trioxide as purchased (10-50% chromium trioxide (w/w))
Product C	Solid sodium dichromate (powder), pure substance or mixture (75-100%)
Product D	Aqueous solution of sodium dichromate as purchased (50-75.5% sodium dichromate (w/w))
Product E	Solid potassium dichromate (powder), pure substance (100%)
Product F	Aqueous solution containing chromium trioxide and sodium dichromate to perform local passivation after brush plating (<2.0% CT (w/w)) and SD (<12.5% (w/w))

In broad terms, the three chromates (chromium trioxide, sodium and potassium dichromate) may be sold in solid form (including as a pure substances) or in aqueous solutions of various strengths.

The chromate substances are imported to the EEA and UK by the applicants. The formulations may either be imported or manufactured in the EEA/UK; see the Formulation combined AoA/SEA (to be submitted) for further details.

Once the products are within the EEA or UK, they will be delivered to the downstream user either directly or via distributors. Some distributors operate across many EEA countries, and the UK, while others operate nationally.

2.3.3.3 Downstream users

Passivation of non-aluminium metallic coatings within the aerospace sector is performed exclusively in industrial settings and is carried out by actors across all levels in the supply chain:

- Original equipment manufacturer (OEM) – generally large companies which design, assemble and sell engines, aircraft, space and defence equipment to the final customer;
- Design-to-Build[6] (DtB) manufacturers – companies which design and build components;
- Build-to-Print (BtP) manufacturers – companies that undertake specific processes, dictated by their customers, involving use of chromates on components; and
- Maintenance, Repair and Overhaul (MRO) – companies or military sites that service civilian and military in-service products.

Commercial aircraft, helicopter, spacecraft, satellite and defence manufacturers are involved in the supply chain, and in the use of the chromates for passivation of critical components essential to the manufacturing of their final products.

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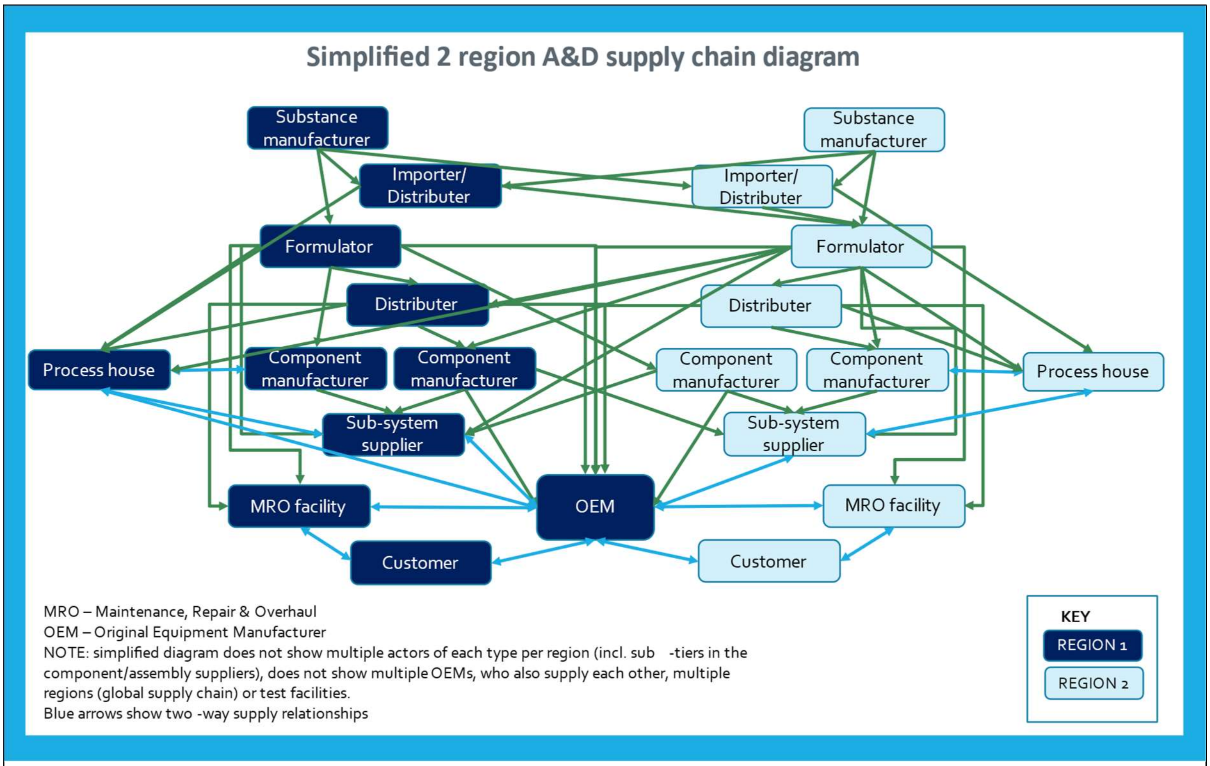
[6] Also referred to as “design and make” or “design responsible” suppliers

It is also important to note that companies may fit into more than one of the above categories, acting as an OEM, DtB, and MRO[7], where they service the components they designed and manufactured, and which are already in use. Similarly, a company may fall into different categories depending on the customer and the component/final product. In addition, downstream users range from sites and repair shops (MROs) who carry out passivation only infrequently (e.g., twice a year) as part of “touch-up activities” to sites with a higher throughput using baths to immerse or dip components, as well as carrying out touch-up activities. In some of the latter cases, there is a low level of automation, while in others there is a high level of automation. This variability was also observed in extensive consultation processes during the preparation of this combined AoA/SEA. The complexity of the supply chain relationships is illustrated in Figure 2-3 below, with this highlighting the global nature of these relationships and the interlinkages that exist between suppliers in different geographic regions.



Simplified 2 region A&D supply chain diagram

MRO – Maintenance, Repair & Overhaul
OEM – Original Equipment Manufacturer
NOTE: simplified diagram does not show multiple actors of each type per region (incl. sub -tiers in the component/assembly suppliers), does not show multiple OEMs, who also supply each other, multiple regions (global supply chain) or test facilities.
Blue arrows show two -way supply relationships

Figure 2-3: Complexity of supply chain roles and relationships within the A&D sector
Two-way supply relationships are indicated by the double headed arrows

The SEA provided in this combined AoA/SEA document is based on the distribution of companies by role given in Table 2–5, where this includes ADCR members, and their suppliers involved in passivation. It is important to note that these companies operate across multiple sites within the EEA and/or UK, with the total number of sites covered by the data provided also reported below. Note that some ADCR members supported passivation in order to cover their value chain (e.g., BtP suppliers or MROs) and did not provide responses themselves to the SEA questionnaire. Instead, they distributed the questionnaires to relevant suppliers. As a result, the number of SEA responses indicated in Table 2–5 below varies from the number of ADCR members supporting passivation.

It is important to note the numbers of BtP and MRO sites for which data was provided. This highlights the large number of actors undertaking passivation and the associated implications for the levels of

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[7] Also common are companies categorising themselves as a BtP and MRO

effort required by design owners (OEMs and DtB companies) in implementing an alternative throughout their value chains.

Table 2–5: Distribution by role of companies providing information on passivation of non-aluminium metallic coatings

Role	Number of companies	Number of sites
OEMs	6	11
Design-to-Build	5	5
Build-to-Print	5	6
MRO mainly (civilian and/or military)	9	10
Total	25	32

Note: Some of the OEMs have sites in both the EU and UK. In total, 25 companies provided a response, but some reported for the purposes of both EU and UK REACH. There is therefore overlap in the number of companies but there is no overlap in the figures given for the number of sites.

2.3.3.4 OEMs, DtB and BtP Manufacturers

While the OEMs do undertake passivation (especially as part of touch-up activities), it is clear that passivation is also carried out by a range of companies within the supply chain. In the case of EEA/UK-based OEMs, these suppliers are often located in the same country (if not the same region) as their main OEM customer.

The OEMs will often act as the design owner and define the performance requirements of the components required for an A&D product, as well as the materials and processes to be used in manufacturing and maintenance. OEMs, as design owners, are responsible for the integration and validation of the final product and certification approval. The OEMs may themselves treat components in a similar manner to their suppliers. They operate at the global level, and therefore may have facilities both in the EEA, the UK and located in other regions. They may also be global exporters of final A&D products.

DtB manufacturers develop in-house designs to meet the performance requirements of their customers, and therefore will also act as design owners. These suppliers may have more control over the substances that they use in manufacturing their components but must still ensure that they achieve the strict performance requirements set by OEMs or their customers. They may carry out research into alternatives and act as test facilities for their customers.

BtP manufacturers produce components to the technical drawings provided by their customers, which often mandate directly (on the drawing) or indirectly the specific chromates to be used to meet the requirements set by their customers. The components are then used by DtBs or OEMs in the final production of A&D equipment. These suppliers have no choice in the substances and formulations that they are required to use within their processes. They, therefore, carry out no research into alternatives (although they may act as test facilities for their customers).

Both DtB and BtP suppliers may undertake passivation using dip/immersion methods and/or involving brush or swap. Both types of suppliers tend to be located relatively close to their customers, which sometimes results in the development of clusters across the EEA and within the UK.

A BtP supplier may be requested to sign a manual or code of conduct by the OEM, to ensure expectations for work and awareness of requirements is achieved. Once the BtP supplier is qualified, periodic audits are performed to ensure continued compliance with contractual requirements.

2.3.3.5 Maintenance, Repair and Overhaul

Products for the A&D industry are designed, manufactured, and maintained for service lives of several decades. In terms of civil aircraft and defence systems, service lives typically comprise 30-40 years. MRO shops (including those servicing MoDs) carry out the maintenance, repair, and overhaul activities involved in ensuring that A&D final products continue to meet airworthiness and safety requirements. This includes chromate-based passivation of non-aluminium metallic coating as part of such activities.

A representative life cycle of a typical aerospace product – a commercial aircraft – is illustrated in Figure 2-4. This highlights that: the development of a new aerospace system can take up to 15 years; the production of one type of aerospace system may span more than 50 years; and the lifespan of any individual aircraft is typically 20-30 years.

Figure 2-5 provides an overview of the life cycle of weapon systems, which are usually used much longer than the originally projected lifetime. Such life cycles can be significantly longer than 50 years. For such systems, it is extremely costly to identify and replace legacy applications of chromates without impacting performance, where performance has been assured for many decades.

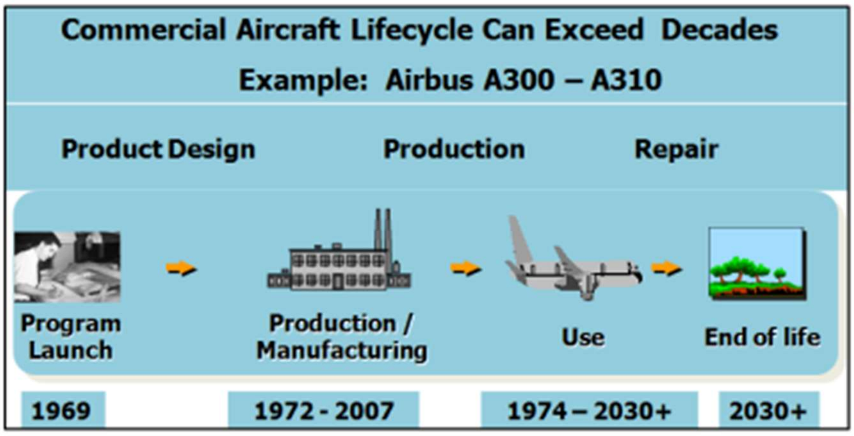

Figure 2-4: Commercial Aircraft Service Life, from ECHA & EASA (2014)

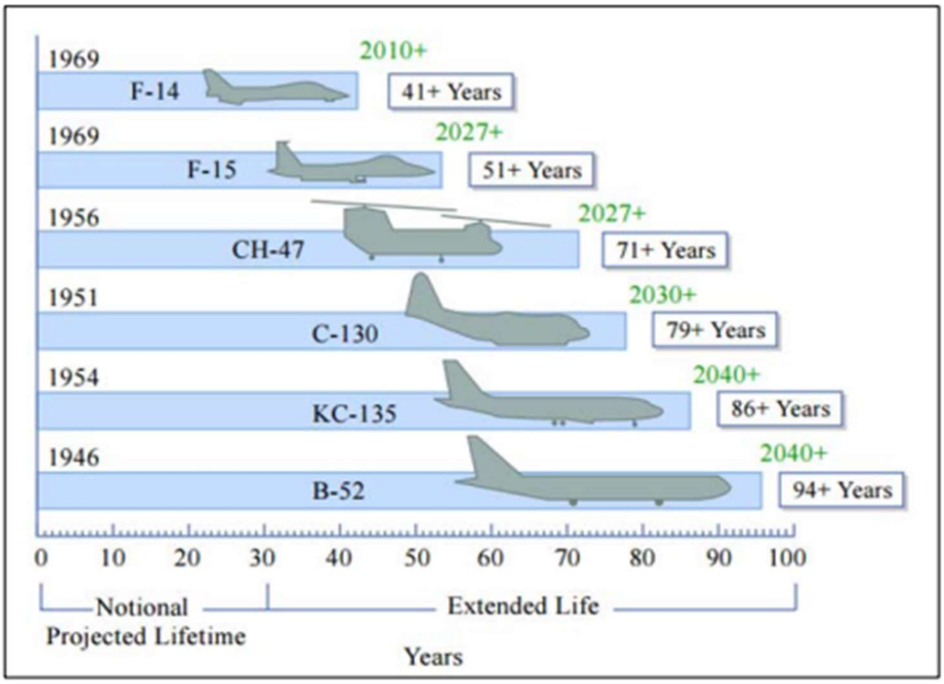

Figure 2-5: Life cycles of defence aircraft, from A Haggerty (2004)

Even if new designs/components – coming onto the market in the short to medium term – might succeed in dispensing with the use of chromate-based passivation, products already placed on the market still need to be maintained and repaired using chromate-based passivation until suitable alternatives are validated & certified for use in MRO for those existing products. Maintenance manuals for such existing products (which the user is legally obliged to comply with) detail, amongst other information, the processes, and materials initially qualified (sometimes decades ago) and required to be used, which form a substantial portion of the Type Certification or defence approval.

As a result, MROs (and MoDs) face on-going requirements to undertake passivation of non-aluminium metallic coating, using dip/immersion methods and/or by brush, cloth or swap.

It is important to note that there will be an overlap between those companies undertaking work exclusively as MROs and those also involved as DtB suppliers, who also carry out MRO activities. As a result, companies falling into this category will be spread geographically across the EEA and UK.

2.3.3.6 Estimated number of downstream user sites – ADCR members data

Based on the information provided by the OEMs and DtB companies, it would appear that each of these companies has, on average, about ten approved suppliers and/or their own sites involved in the passivation of non-aluminium metallic coatings. However, four of these OEMs are UK focused and have therefore been excluded. This would suggest that there could be up to 100 (= 10 x 10) sites involved in the passivation of non-aluminium metallic coatings across the EU.

Based on the information provided by the OEMs and DtB companies as well as reviewing relevant data on companies undertaking passivation of non-aluminium metallic coatings for the aerospace and defence industries, it would appear that there are at least 20 sites (across the UK) involved in the provision of passivation services to ADCR members – and an estimate of 30 sites has been assumed. Assuming a similar consumption distribution as for EEA sites, the following table was constructed.

Under Article 66 of REACH, downstream users covered by an authorisation up their supply chain must notify ECHA of their use[8]. As of 31 December 2021, ECHA had received 450 notifications relating to the REACH Authorisations listed above covering 587 sites across the EU-27 (and Norway).

The distribution of notifications by substance and authorisation is summarised below.

Table 2–6: Number of sites using CT, PD and SD for surface treatment, including passivation as notified to ECHA as of 31 December 2021

Substance	Authorisation	Authorised Use	Notifications	Sites
Chromium trioxide	20/18/14-20	Surface Treatment for aerospace	263	357
Potassium dichromate	20/3/1	Surface Treatment for aerospace	15	18
	20/2/1*	Surface Treatment for aerospace	53	61
Sodium dichromate	20/5/3-5	Surface Treatment for aerospace	61	84
	20/4/1*	Surface Treatment for aerospace	58	67
Totals			**450**	**587**

Source: Number of downstream uses covered by granted authorisations as notified to ECHA by 31 December 2021, data available from https://echa.europa.eu/du-66-notifications
Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for passivation, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting
**Use of sodium dichromate and potassium dichromate by the aerospace and defence industry under parent Authorisations, which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness*

Since there are more sites than notifications, it is assumed that some notifications cover more than one site. It will be noted that the authorisations cover 'surface treatment' which extends more widely than just passivation of non-aluminium metallic coatings. As such the number of sites undertaking passivation of non-aluminium metallic coatings will be much less than the indicated 587.

Furthermore, some sites will be using more than one of the chromates for the passivation of non-aluminium metallic coatings lowering the figure still.

With these points in mind, the estimated 100 sites are consistent with the ECHA data on downstream user notifications of REACH authorised uses.

2.3.3.7 Geographical distribution

The distribution of the 587 sites notified to ECHA is summarised in the table below. This percentage distribution is adopted for the later analysis carried out as part of the SEA. As there is no comparable publicly available data for the UK, so no breakdown is provided by country for Great Britain.

Table 2–7: Number of authorised sites (of relevance to passivation of non-aluminium metallic coatings) using Chromium Trioxide, Potassium Dichromate and Sodium Dichromate notified to ECHA as of 31 December 2021

Country	Notified Sites	% Total
France	210	36%

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[8] Article 66 reporting is by legal entity, which can have multiple sites using a chromate for passivation. Closer inspection of the (publicly available) data from ECHA suggests that some sites are associated with confidential military activities. These may or may not be relevant to the ADCR given that members include Ministries of Defence (MoDs) and information has been provided by non-member military organisations.

Germany	78	13%
Italy	69	12%
Poland	53	9%
Spain	43	7%
Czech Republic	25	4%
Sweden	14	2%
Norway	14	2%
Netherlands, Finland, Hungary, Ireland, Belgium, Bulgaria, Denmark, Romania, Malta	6-11 each	1-2% each
Portugal, Greece, Lithuania, Slovakia	1 or 2 each	< 0.5% each
EU-27 plus Norway	**587**	
Number of sites relates to specific authorisations listed in earlier tables		

Broadly speaking, it would be expected that the distribution of the estimated 100 sites used for passivation of non-aluminium metallic coatings would be similar to the table above with the majority of sites being in France, Germany, Italy and Poland.

2.3.3.8 Customers

The final actors within this value chain are customers of A&D final products treated via passivation of non-aluminium metallic coatings.

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver in a normal year some 120,000 flights and 12 million passengers a day. In 2017, airlines worldwide carried around 4.1 billion passengers. They transported 56 million tonnes of freight on 37 million commercial flights. Every day, airplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, subsequent impacts and jobs in tourism made possible by air transport, assessments show that at least 65.5 million jobs and 3.6% of global economic activity are supported by the industry.[9] More specifically to Europe, in 2019 over one billion passengers travelled by air in the European Union, with net profits of over US$ 6.5 billion (€5.8 billion, £5.1 billion).[10] These benefits cannot be realised without the ability to undertake regular maintenance works and to repair and maintain aircraft as needed with replacement components manufactured in line with airworthiness approvals.

In 2020, total government expenditure on defence across the EU equated to 1.3% of GDP, with Norway spending around 2% of GDP[11]. Roughly 38% of this expenditure related to military aviation, with an uncertain but significant proportion also spent on non-aviation defence products that rely on the use of passivation, including naval systems, ground based radars, ground vehicles etc.

Focusing on military aircraft, the dynamics of aircraft development and the market are significantly different than for commercial aircraft. Military aircraft are extremely expensive and specialised projects. As a result, to have an effective military force, Ministries of Defence require equipment that is well-maintained and mission ready. Although the in-service military fleet is expected to grow rapidly in the future, older aircraft and other equipment will continue to require more frequent scheduled maintenance to replace components that are reaching the end of their "life", which would not have needed replacing on younger aircraft. Upgrades will also be required to extend the service life of aging

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[9] https://www.icao.int/annual-report-2020/Pages/the-world-of-air-transport-in-2020.aspx

[10] https://www.statista.com/statistics/658695/commercial-airlines-net-profit-europe/

[11] *Source:* Eurostat (gov_10a_exp)

aircraft given the costs of new military aircraft. Maintenance of aircraft and products is already reported to face difficulties due to material obsolescence issues over the extremely long service lives of such hardware. A major issue is obtaining readily available components for the vast number of aircraft flying beyond their originally expected lifecycles.

2.4 Consultation

2.4.1 Overview

Three types of consultation were undertaken for the purposes of this combined AoA/SEA:

- Consultation with the Applicants (importers and formulators) to gather Article 66 downstream user notifications data, and information on volumes placed on the market and numbers of customers; this has included consultation with the formulators to gather information on their efforts to develop alternatives on their own, in collaboration with the downstream users, and as part of EC funded research projects.

- Consultation with ADCR members to gather information on their uses, supply chains, R&D into alternatives, qualification processes and responses under the Non-Use Scenario;

- Consultation with parts and component suppliers within the aerospace and defence supply chain to gather socio-economic information, ability to move to alternatives and likely responses under the Non-Use Scenario.

Further details of each are provided below.

2.4.2 Consultation with applicants

Information was gathered from the applicants on their supply chains and on quantities sold per annum. The applicants may act as an importer, a downstream user (e.g., formulator, distributor involved in repackaging) and/or as a distributor for other applicants/formulators of the chromates for use in passivation.

Only a minimal amount of economic data was collected from the applicants, as losses in profits to this group of companies is not what drives the requested re-authorisations by this Combined AoA/SEA. Information on alternatives and substitution was, however, collected.

2.4.3 Consultation with Downstream users

2.4.3.1 ADCR consortium members

Consultation with ADCR members was carried out over a period from 2019 to 2022 to collect a range of data relevant to both the AoA and the SEA. This consultation was carried out with all downstream user members of the ADCR (i.e., members located in both the EEA and UK), and regardless of their role within the supply chain. Consultation took place over different phases:

1) Phase 1 involved collection of information on surface treatment activities that each member undertook. This included:
    a. Supply chains
    b. Substances used in each activity and associated volumes
    c. Key functions provided by the substance

   d. Locations for each activity
   e. Likelihood of substitution before 2024

1) Phase 2 involved collection of data on R&D activities undertaken by each company. This included confidential and non-confidential information on:
   a. Successes and failures
   b. Alternatives tested and for what uses
   c. Reasons for failures, where this was the outcome
   d. Alternatives still subject to R&D and their progression in terms of technical readiness, and if relevant manufacturing readiness

2) Phase 3 then took the form of detailed one-on-one discussions between ADCR members and the AoA technical service team. The focus of these discussions was to ensure:
   a. A common understanding of information provided by individual ADCR members concerning substitution activities and test candidates;
   b. Full agreement and understanding concerning the confidentiality of AoA and SP information provided by individual ADCR members, and how this information will be reported within Authorisation dossiers; and
   c. Additional critical details are collected concerning core aspects of the AoA/SP parts of the Authorisation dossiers (e.g., clarify R&D and substitution timelines and address outstanding questions regarding alternatives and their comparative performance).

3) Phase 4 collected information for the SEA component of this document, with this including:
   a. Base data on the economic characteristics of different companies
   b. Additional information on volumes used of the chromates and for what processes, and trends in this usage over the past seven years and as anticipated into the future
   c. The importance of chromate-using processes to the turnover of individual companies
   d. Past investments in R&D into alternatives
   e. Past investments into capital equipment related to on-going use of the chromates as well as to their substitution; this included investment in new facilities outside the EEA
   f. Numbers of employees directly involved in use of the chromates as well as the total number of employees at sites that would also be directly impacted under the Non-Use scenario
   g. Economic and social impacts under the Non-use scenario.

2.4.3.2 Design-to-Build and Build-to-Print to ADCR members

SEA questionnaires were also developed for completion by suppliers to the ADCR members. This included separate questionnaires for BtP and DtB suppliers given their different roles within the supply chain and the potentially greater flexibility for DtB suppliers to move to alternatives certified for the manufacture of their components and products as part of their own design activities.

These questionnaires were distributed to key suppliers by the larger ADCR members and were also made available to any company within the ADCR supply chain requesting they provide information and participate in the re-authorisation work to ensure their conditions of use were covered. The scope of these questionnaires was similar to that described above for the ADCR members.

As a final count, data for 32 sites operated by the ADCR OEMs and their DtB and BtP suppliers was provided in response to these questionnaires. The information provided by the companies forms the basis for the SEA components of this document.

2.4.3.3 MROs

For consistency purposes, MROs were asked to also complete the BtP questionnaire. Again, these were supplied directly to MROs or were distributed by ADCR members to their key suppliers. MoDs were also asked to participate in the work and a number of military MROs provided data on their activities to ensure that these would also be covered by a renewed Authorisation. Their data is included in the SEA as appropriate to their activities.

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Overview of the key functions

Non-aluminium metallic coatings such as cadmium, zinc or zinc-nickel are applied on base metals such as steel to provide: (i) improved corrosion resistance by acting as a “sacrificial” coating that corrodes before the substrate (in the case of cadmium, zinc and zinc-nickel); (ii) improved corrosion resistance by using barrier properties (in the case of copper, nickel and silver); and (iii) heat and electrical conductivity, anti-oxidation and anti-corrosion properties, and anti-seizing properties (in the case of silver).

These non-aluminium metallic coatings themselves can be passivated to improve their corrosion performance (see Figure 3-1 below). The base metal builds up the structure of the component; the non-aluminium metallic coating provides the primary surface protection for the base metal.

Passivation of non-aluminium metallic coatings is a chemical process that is applied to a substrate[12] non-aluminium metallic coating to produce a superficial layer containing a compound of the non-aluminium coating metal and elements from the processing solution. Passivation removes the native oxide and replaces it with an oxide that has predictable and stable properties, formed from the non-aluminium coating metal and the processing solution. Note the passivated layer itself is not corrosion resistant but provides improved corrosion resistance and other beneficial properties to the non-aluminium coating. Technically, this passivation process is a form of chemical conversion coating.

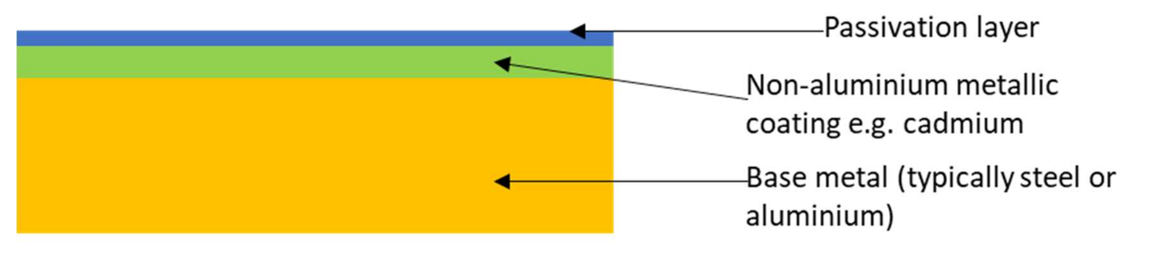

Figure 3-1: Schematic of passivation of non-aluminium metallic coatings (NOT TO SCALE)
In some cases there may be more than one non-aluminium metallic coating layer applied on the base metal. Passivation is applied on the non-aluminium metallic coating and not on the base metal .

In general, passivation of non-aluminium metallic coating forms an adherent, fixed, insoluble, inorganic crystalline or amorphous surface film of complexes from chromium trioxide as an integral part of the metal surface by means of a chemical reaction between the metal surface and the immersion solution.

The typical thickness of the non-aluminium metallic coating is 2 to 55 microns depending on the type of non-aluminium metallic coating, and the typical thickness of the passivated layer is 0.2-1.0 microns.

Several factors determine the quality of the final passivation of non-aluminium metallic coating such as the base alloy composition and phase structure, pre-treatment processes, composition and

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[12] Throughout this document, the term “substrate” refers to the non-aluminium metallic coating. The non-aluminium metallic coating is coated on the “base metal”, see Figure 3-1.

concentration of bath chemicals, bath temperature and pH, immersion time, degree of agitation and post-treatment conditions (Saji, 2019)[13].

The hexavalent chromate (Cr(VI)) substances that are of relevance to the Applied for Use are:

Chromium trioxide (includes “Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0
Sodium dichromate	EC 234-190-3	CAS 10588-01-9
Potassium dichromate	EC 231-906-6	CAS 7778-50-9

The key functions of the three chromates in passivation of non-aluminium metallic coatings are: corrosion resistance (including active corrosion inhibition); adhesion to subsequent layer; chemical resistance; layer thickness; electrical resistivity; temperature resistance; and pre-treatment compatibility.

These are discussed in further detail in Section 3.2.

3.1.1.1 Usage

Components and assemblies that may be treated with the Annex XIV substance

As detailed above, passivation of non-aluminium metallic coating, like all surface treatments, aims to modify the surface of the substrate (the non-aluminium metallic coating) to improve the substrate properties and adapt it to its specific use conditions. There are many corrosion and wear prone areas on A&D products which require the application of surface treatments. Examples of these are included in Table 3-1 below:

Table 3-1: Examples of corrosion and wear prone areas of A&D products (non-exhaustive)

Structural/flight	Propeller/rotor	Engine/power plant	Additional Space- and Defence-specific
Aileron and flap track area	Blade tulip and hub	Auxiliary Power Units (APUs)	Air-transportable structures
Centre wing box	Gearbox	Carburettor	Fins
Cockpit frames	High bypass fan components	Data recorders	Gun barrels and ancillaries
Differential	Main and tail rotor head assemblies	Engine Booster and Compressors including Fan Containment	Interstage Skirts
Emergency valve landing gear	Propeller speed controller	Engine control unit	Launchers (rocket, satellite, etc.)
Environmental control systems	Propellers	Engine External components	Missile and gun blast control equipment
External fuel tanks	Transmission housing	Fuel pump	Missile launchers
Flight control systems		Gearbox	Pyrotechnic Equipment
Fuselage		Hydraulic intensifier	Radomes (radar domes)
Hydraulic damper		Ram air turbine	Rocket motors

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[13] This paper discusses conversion coatings but this statement is also relevant to passivation of non-aluminium metallic coatings, which are a type of conversion coating

Hydraulic intensifier		Starter	Safe and arm devices
Landing equipment		Vane pump	Sonar
Nacelles			
Pylons			
Rudder and elevator shroud areas			
Transall (lightning tape)			
Undercarriage (main, nose)			
Valve braking circuit			
Window frames			
Wing fold areas			
Source: (GCCA, 2017)			

It is important to note that even with the highly developed Cr(VI)-containing treatments available, corrosion and wear of these components still occurs, however decades of experience relating to the appearance and impacts of corrosion on Cr(VI) systems allows the A&D industry to define inspection, maintenance and repair intervals.

Cr(VI)-free alternatives cannot be introduced where they are known to result in a decreased performance, since some or all of the following consequences may occur (GCCA, 2017):

- Substantial increase in inspections, some of which are very difficult or hazardous to perform;
- Increased overhaul frequency or replacement of life-limited components;
- Possible early retirement of A&D products due to compromised integrity of non-replaceable structural parts;
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet - This could impact many or all aircraft fleets. Defence systems would be similarly impacted, affecting the continuity of national security.

In addition to the above, there may be limitations set on how far planes could fly.

Despite best efforts, hidden properties or incorrect performance predictions of any Cr(VI)-free systems that are ultimately introduced cannot be excluded, and remaining risks must be mitigated. Ultimately extensive qualification and validation testing (as described in section 3.1.2 below) is not equivalent to 50 years real-life experience with corrosion protection.

Service life and maintenance intervals of parts and assemblies

Wherever possible, A&D hardware is repaired rather than replaced. In addition to both time and cost considerations, this is a much more environmentally friendly approach from a lifecycle perspective, resulting in reduction of hazardous chemical usage, energy usage, carbon footprint, waste generation, etc. In order to maintain operational safety therefore, A&D components and products are subject to intensive MRO activities.

For aircraft, there are different maintenance activities foreseen after defined intervals of flight hours or take-off or landing cycles:

- Prior to each flight a “walk-around” visual check of the aircraft exterior and engines is completed;
- A-checks entail a detailed check of aircraft and engine interior, services and lubrication of moving systems;
- B-checks involve torque tests as well as internal checks and testing of flight controls;
- In C-checks a detailed inspection and repair programme on aircraft engines and systems is undertaken.
- D-checks include major structural inspections with attention to fatigue damage, corrosion, etc., resulting in the aircraft being dismantled, repaired and rebuilt.

As an example, for commercial aircraft the A-checks occur every 400-600 flight hours, the B-checks are performed every 6-8 months, and the C-checks are completed every 20-24 months. C-checks typically take up to 6,000 man hours to complete. The D-checks are completed every 6-10 years and typically take up to 50,000 man-hours to complete. At Lufthansa, the D-check begins with the stripping of the exterior paintwork. The aircraft is taken apart and each system is checked thoroughly using the most modern methods for non-destructive material testing such as X-rays, eddy current probes and magnetic field checks. After several weeks and thousands of hours of intensive MRO work, the aircraft is overhauled completely. The D-check is the most extensive check foreseen for aircraft. Even at the D-check, certain areas of the aircraft, such as bonded structures and inaccessible regions, cannot typically be disassembled for inspection. Corrosion protection of these regions must therefore be sufficiently robust to last throughout the life of the aircraft.

The aerospace industry has a permanent learning loop of significant events, failure analysis and decisions for safety improvements. Part of this improvement is the introduction of the Maintenance Steering Group 3 Analyse (MSG-3), specifically developed for corrosion. MSG-3 provides a system for OEMs and the regulators to identify the frequency of inspection with respect to the stress corrosion, protection and environmental ratings for any component or system. Without long-term experience the performance of a system cannot be highly rated due to hidden properties which may only be identified when extensive knowledge of in-service behaviour is available. The consequence of this is that the introduction of a Cr-free system would lead to a significant reduction in the maintenance interval, potentially doubling the frequency of the checks described above (GCCA, 2017).

3.1.2 Overview of the substitution process in Aerospace & Defence (A&D)

3.1.2.1 Introduction

Aerospace and Defence (A&D) products operate in highly challenging, extreme environments over extended timeframes. Due to these challenges, alongside engineering-based solutions, the A&D industry must use numerous high-performance mixtures which have passed through an extensive approval process in order to demonstrate their suitability for use – some of these mixtures will contain substances which are included on Annex XIV of REACH. Whilst substitution of substances of very high concern (SVHC) is a priority for the sector, and there have been extensive efforts to eliminate Cr(VI) and other SVHC wherever technically feasible, changes to A&D components offer unique challenges that are not seen in other industries. These include: the industry’s dependence on certain SVHC to meet key safety requirements; the level of qualification and regulatory controls associated with introduction of alternative chemicals or other design changes; and the complexity of supply chains and the number of stakeholders involved in the substitution process.

In the civil aviation sector of the Aerospace industry, large numbers of aircraft **safely carry billions of people every year**[14]**,** whilst defence aircraft and systems are required to operate safely and reliably for 40 to more than 90 years before they are finally taken out of service**.** This requires A&D components to successfully fulfil a wide range of extremely challenging safety-related requirements, including but not limited to:

- High utilisation rate (around 16 hours per day for commercial aircraft, whilst critical defence systems must operate continuously for extended periods);
- Environmental and service temperatures ranging from below minus 55°C at cruising altitude to in excess of plus 200°C (depending on substrate and location of final product);
- Wide ranging and varying humidity and pressure;
- High and varying loads;
- Fatigue resistance under varying modes of stress;
- Corrosive and abrasive environments (e.g., salt water and vapour, sand and grit, and exposure to harsh fluids such as cleaning solutions, de-icer, fuels, lubricants, and hydraulic fluids at in-service temperatures); and
- Maintained performance in the possible case of a lightning, bird, or other foreign object strike.

Successful, reliable, and safe performance against these parameters is the result of decades of experience and research, and a high level of confidence in the systems currently employed to provide corrosion and wear resistance. Years of performance data, as well as thorough reviews following any incidents, have resulted in improvements to the designs, manufacturing or maintenance processes employed in the industry. Such a level of confidence in the performance of Cr(VI) is essential as the treatments on some A&D components cannot be inspected, repaired, or replaced during the life of the A&D system. An inadequately performing surface treatment allows corrosion pits to form. These can turn into fatigue cracks, which potentially endanger the final product.

The civil aviation industry must comply with the airworthiness requirements derived from Regulation (EC)No 2018/1139[15] in the European Economic Area (EAA). Similar airworthiness requirements exist in all countries where aeronautical products are sold. These regulations require a systematic and rigorous framework to be in place to qualify all materials and processes to meet stringent safety requirements that are subject to independent certification and approval through the European Aviation Safety Authority (EASA), and other agencies requirements. Safety critical defence aviation and space systems are subject to similar rigorous performance requirements as seen in the civil aviation sector, while ground and sea-based defence systems are managed more adaptively based on specific system requirements.

Identification and implementation of feasible, suitable, and available alternatives in the A&D industry is a time consuming and complex process that can involve multiple stages of performance testing in laboratory trials, manufacturing trials and during inflight/in operation testing. Once a proposed candidate is identified, it must be shown that implementing it will maintain the stringent safety requirements that govern the sector. Not only this but, due to the potential implications of inadequate corrosion and abrasion protection described above, it must be ensured that the test candidate demonstrates equivalence in performance on all types of components where the original formulation/process is used. This can often be hundreds of different components, each requiring testing to ensure performance of the test candidate is acceptable.

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[14] 4.5bn passengers carried and 38.3m departures in 2019. https://www.icao.int/annual-report-2019/Pages/the-world-of-air-transport-in-2019.aspx

[15] Repealing Regulation (EC) No 216/2008

The A&D companies that design and integrate the final product (e.g., aircraft, engines, radar, and other defence systems), are each responsible for their own product qualification, validation, and certification, according to airworthiness regulations or defence/space customer requirements. Even superficially similar components, when used in different systems or under different environmental conditions, may have unique design parameters and performance requirements, driven by the requirements of the final product. Consequently, an alternative that has successfully been implemented for one component in a given subsystem will not necessarily be suitable for use in a different subsystem. Implementation of an alternative in varying scenarios of use must be individually assessed, validated, and certified across the components, subsystems and systems that make up the final product, for example an engine, aeroplane, helicopter, missile, or tank (as illustrated in Figure 3-2).

Defence OEMs have additional challenges because individual defence customers usually assume full design/change authority upon accepting the defence hardware designs. This means that any intent to change the hardware configuration, including coatings and surface treatments, must be approved by the defence agency, who are concerned with the efficacy of the hardware (i.e., mission effectiveness) as well as meeting legislative goals, and are often very fiscally constrained for such hardware configuration updates. Alternatively, an OEM can attempt to persuade their customers of such hardware changes, but typically are not allowed to spend programme budgets on these hardware changes until expressly directed/contracted by the customer, who again are very fiscally constrained. When OEMs sell the same hardware to multiple defence customers, it is often required to obtain permission from each customer prior to hardware changes and these customers rarely agree. The combination of (a) not mission essential, (b) fiscal constraints, and (c) multiple conflicting customer opinions, greatly complicates any defence OEM effort to make hardware changes to existing designs to meet legislated goals such as Cr(VI) elimination.

The processes described apply to the implementation of any new design, or changes to an existing design whether still in production or not. This means, to ensure and maintain airworthiness and operational safety requirements, they apply to every component produced for use in an aircraft or defence system. In the case of introducing Cr(VI)-free surface treatments, hundreds of individual components in each final product will be affected.

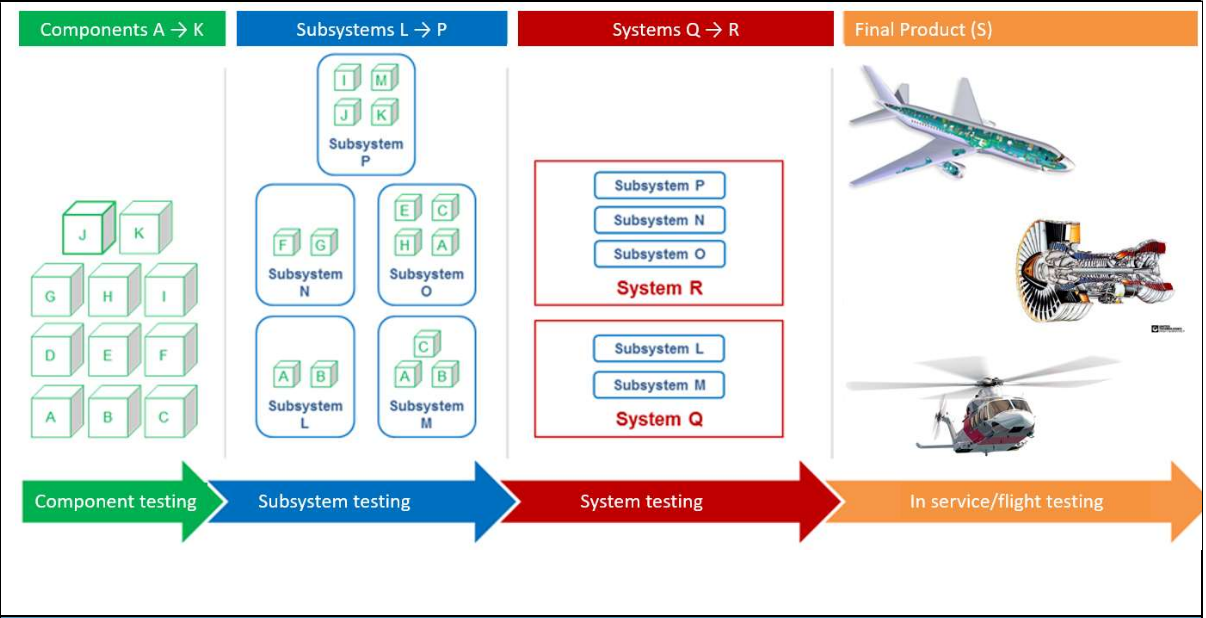

Figure 3-2: Assessment requirements in the implementation of alternatives

Source: Adapted from GCCA white paper

In the substitution process, many ADCR Consortium members use the Technology Readiness Level (TRL) scale as developed by the US National Aeronautics and Space Administration (NASA), and further defined by the US Department of Defence. This scale is used to assess the maturity level of each individual technology, and hence the potential suitability of a test candidate. The scale ranges from TRL 1, basic principles observed, to TRL 9, actual system proven.

Table 3-2: Technology Readiness Levels as defined by US Department of Defence

TRL	Definition	Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof-of-concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard[a] validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system through successful mission[b] operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.

[a] Breadboard: integrated components, typically configured for laboratory use, that provide a representation of a system/subsystem. Used to determine concept feasibility and to develop technical data.
[b] Mission: the role that an aircraft (or system) is designed to play.
Source: U.S. Department of Defence, April 2011, https://www.ncbi.nlm.nih.gov/books/NBK201356/

The TRL assessment guides engineers and management in deciding when a test candidate (be it a material or process) is ready to advance to the next level. Early in the substitution process, technical experts establish basic criteria and deliverables required to proceed from one level to the next. As the technology matures, additional stakeholders become involved, and the criteria are refined based on the relevant design parameters. A formal gate review process has been established by some companies to control passage between certain levels in the process.

Similarly, the maturity of manufacturing processes is formally tracked using the Manufacturing Readiness Levels (MRL) process. MRLs are used to assess the maturity of a given component, subsystem, or system from a manufacturing process.

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence

MRL	Definition	Description
1	Basic Manufacturing Implications Identified	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing Concepts Identified	This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs.
3	Manufacturing Proof of Concept Developed	This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.
4	Capability to produce the technology in a laboratory environment	This level of readiness acts as an exit criterion for the MSA Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.
5	Capability to produce prototype components in a production relevant environment	Mfg. strategy refined and integrated with Risk Management Plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling, and test equipment, as well as personnel skills have been demonstrated on components in a production-relevant environment, but many manufacturing processes and procedures are still in development.
6	Capability to produce a prototype system or subsystem in a production relevant environment	This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the EMD Phase of acquisition. Technologies should have matured to at least TRL 6. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself.
7	Capability to produce systems, subsystems, or components in a production representative environment	System detailed design activity is nearing completion. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies are completed and producibility enhancements and risk assessments are underway. Technologies should be on a path to achieve TRL 7.
8	Pilot line capability demonstrated; Ready to	The system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production. Technologies should have matured to TRL 9. This level of readiness is

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence

MRL	Definition	Description
	begin Low Rate Initial Production	normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation.
9	Low rate production demonstrated; Capability in place to begin Full Rate Production	The system, component, or item has been previously produced, is in production, or has successfully achieved low-rate initial production (LRIP). Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full-Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes.
10	Full Rate Production demonstrated and lean production practices in place	Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full-rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level.

Source: Manufacturing Readiness Level (MRL) - AcqNotes

Many companies combine the TRLs and MRLs in their maturity assessment criteria, as issues in either the technology or manufacturing development could affect production readiness and implementation of an alternative material/process. It should be noted that not all affected components in a system will necessarily attain the same TRL or MRL at the same time.

The process described above places limitations on the ability of the design owner, such as an original equipment manufacturer (OEM), to use “generic” commercially qualified components or “generic” commercially qualified formulations without extensive in-house testing. In general, such a component or formulation is unlikely to have been tested in a suitably qualified laboratory. The testing would need to cover all the design owner’s specific configurations, involving all relevant substrates, and to consider interactions with all relevant chemicals including, but not limited to, paints, solvents, degreasers, de-icers, hydraulic fluids, and oils. There will also be specific testing required by a design owner in specific configurations which the producer of the component or formulator is not able to test.

The following section summarises the multi-step, multi-party processes that must be completed to develop test candidates and implement a Cr(VI)-free alternative into the supply chain, whilst highlighting the anticipated time necessary to complete these highly regulated processes. It should be noted that many ADCR members have multiple projects with the aim of developing and industrialising Cr(VI)-free alternatives running in parallel, as hexavalent chromates are used in a number of steps in surface treatment processes. Whilst the proposed candidates will be different for each use, taking into account the different requirements of the existing materials, the highly specialised individual experts at both formulator and design owner, and the required testing facilities, will be common. The competing priorities, and the capacity and specialised resource constraints, created by the need to substitute multiple chromates to the same timeframe will therefore also have a negative impact on the timeframes usually associated with the substitution process.

3.1.2.2 Process, requirements, and timeframe

Identification & Assessment of need for substitution

When a substance currently used in the production of A&D components is targeted for regulatory action and needs to be replaced, a component design change may be triggered. Completely removing a substance from one component may impact upon multiple other components and systems, and involve many different processes with varying performance requirements.

The first step is to identify extent to which the substance, or the formulation containing the substance, is used. This must consider the entire life cycle of components containing the substance throughout the supply chain, including maintenance, repair, and overhaul (MRO) activities. After identifying the relevant formulations, processes, and design references, the affected component designs and related systems are identified. This is the first step to assess the impact of substituting the substance and the scale of the design changes which may be needed.

The above work requires contributions from numerous personnel from various departments including Materials & Processes, Research & Development, Design & Definition, Engineering, Customer Service, Procurement, Manufacturing, Supply Chain, and Certification. Assembling this multi-disciplinary team and co-ordinating their activity is itself a complex and time-consuming activity.

Components on which Cr(VI)-based surface treatments are currently used may have been designed 30 to 40 years ago (or more), using design methods and tools that are no longer in use. Attempting to determine the potential interactions/incompatibilities of a Cr(VI)-free formulation or surface treatment process in an old design can take a tremendous amount of work. Failing to adequately identify all interactions creates a significant risk, whilst resolving any incompatibilities between old and new treatment materials and/or techniques is time intensive and has a high chance of failure.

When an existing design specifies a formulation or process utilising Cr(VI), the design change must not only comply with the performance requirements of the newly introduced components, but also be compatible and seamlessly interact with remaining legacy designs. This is because maintenance may require a Cr(VI)-free alternative to be applied proximal to the legacy formulation, containing Cr(VI). If the re-design is going to be integrated with old components treated with Cr(VI), compatibility must be assured.

Definition of requirements

Once a project seeking to develop and industrialise an alternative is launched, materials and process specialists from engineering, manufacturing, procurement, and MRO departments at the design owner, define the requirements that the proposed candidate must fulfil in order to be a suitable test candidate.

Alternatives must satisfy numerous requirements. In many cases those identified introduce competing technical constraints and lead to complex test programmes. This can limit the evaluation of proposed candidates. Categories of technical requirements may include:

- Performance requirements (e.g., corrosion resistance, wear resistance, adhesion strength, and compatibility with other materials);
- Design requirements (e.g., compatibility of the component's geometric complexity with the coating technique);
- Industrial requirements (e.g., robustness, processability, and repeatability); and

- Environment, Health & Safety (EHS) requirements (e.g., is there an equivalent level of concern).

For some materials dozens of individual requirements may exist across these categories.

Definition of requirements itself can be complex and requires a significant timeframe. The complexity can be due to:

- The substitute exhibiting behaviours or interactions which are different to the original product. Where unexpected behaviour is seen, sufficient operational feedback to technically understand the phenomenon and refine the requirements is essential to ensure non-regression;
- Consolidating requirements from multiple customers and suppliers into an existing design;
- Evolution of EHS regulations; and
- Need to substitute multiple chromates to the same timeframe.

Development of initial requirements can take at least six months, although requirements may be added and continue to be refined during the different levels of maturity, based on learnings from the various testing/qualification stages.

Key phases of the substitution process

Once initial technical requirements are defined, test candidates can then be identified and tested by the design owner. Figure 3-3, revised from the Global Chromates Consortium for Aerospace (GCCA) Authorisation applications, shows a schematic of the various stages in the process, which are described further below. These steps are not simply performed one after the other or presented in a chronological order, but rather they represent an iterative process.

Each stage in the process comprises various steps including extensive laboratory testing programmes and, in some situations, in service/flight testing. Each step therefore requires flexibility in the time to be completed, typically taking years overall. It should be noted that there can be **failures at any stage in this process**, and failures may not reveal themselves until a large amount of testing, taking considerable time and incurring significant expense, has already been carried out. Such failures result in the need to return to earlier steps in the process and repeat the extensive testing and associated activities leading to industrialisation. The later in the process these failures occur, the greater the impact will be on schedule and cost.

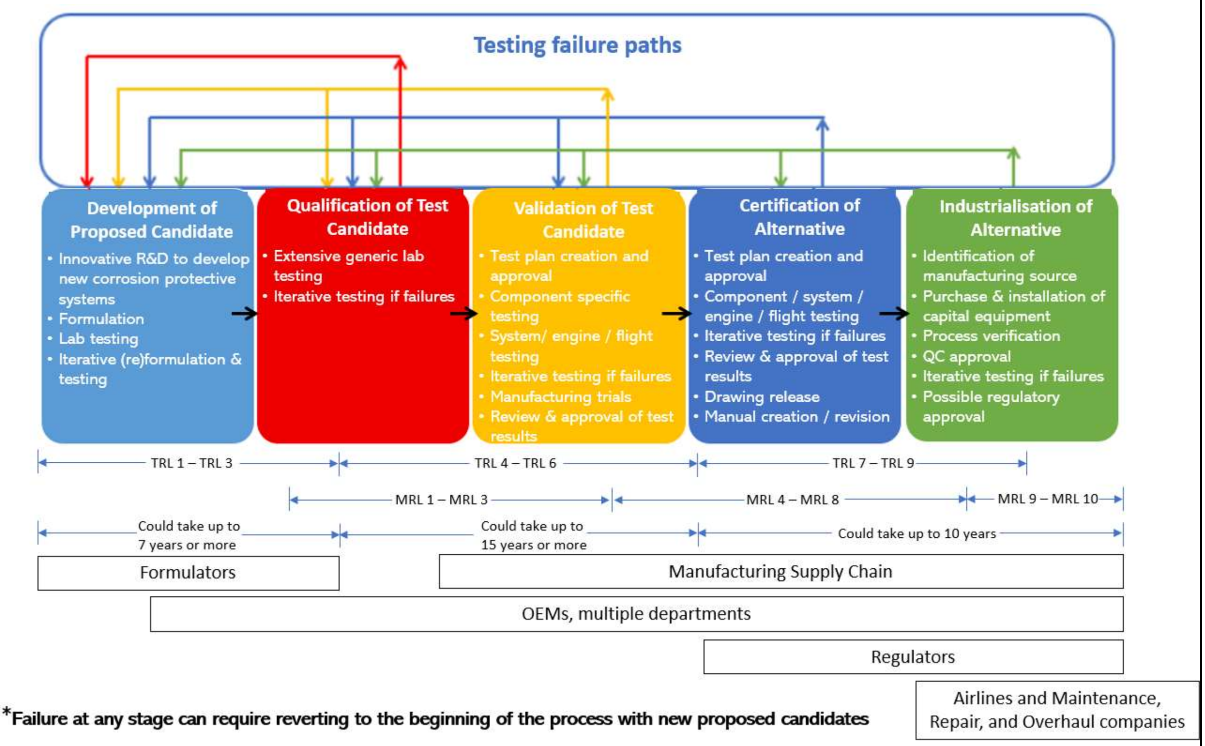

Figure 3-3: Schematic showing the key phases of the substitution process

Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note that failures may not become apparent until a late stage in the process.

Source: Adapted from "Use of strontium chromate in primers applied by aerospace and defence companies and their associated supply chains", Application for Authorisation 0117-01, GCCA (2017)

The detailed process involved in each phase of the substitution process is described below, and the associated timeframes are elaborated. Throughout the process it should be remembered that the initial qualification, validation, and certification of a final product is applicable to a single specific configuration of components and materials, assembled by a single set of manufacturing processes. Any change to the components, materials, or manufacturing processes invalidates this initial qualification and certification. The action to approve and industrialise the change can only proceed once a suitable test candidate is developed, qualified, and validated.

Development of proposed candidates

When a need to develop an alternative has been identified (for example, as in this case, because of regulatory action driving the need to make an informed substitution), the first stage comprises innovative R&D, most commonly by the formulator(s), to develop new formulations. Initial activities in the development of proposed candidates stage include:

- Innovative R&D to develop new surface treatments;
- Formulation of proposed candidates;

- Laboratory testing of proposed candidates; and
- Iterative re-formulation and testing.

The development of proposed candidates must take into consideration the complex design parameters identified in the requirements development step discussed above. Once a proposed candidate is developed, testing is carried out in the formulator's laboratory to assess quantitative performance of the new formulation against the critical criteria required by the design owner. Failure against any of these criteria may result in rejection of the proposed candidate, further modification of the formulation, or additional testing. Although it may only be the Cr(VI) compound within a mixture which is subject to regulatory action, the other constituents may also require substantial change to continue to meet the stated performance requirements.

Formulators, or sub-contractors acting on their behalf, perform screening tests on small test pieces of substrate. Such tests provide an indication of whether basic performance criteria have been met, in order to justify more extensive testing by the design owner. The predictive power of laboratory tests performed by the formulators is limited and therefore it is vital to note that a formulation that passes these screening tests is not necessarily one that will be technically suitable to ultimately be fully implemented in the supply chain. **Passing these initial tests is a *necessary, but not sufficient***, pre-requisite for further progression through the process (i.e., a building blocks approach is followed).

Development typically involves an iterative process of re-formulation and re-testing to identify one or more proposed candidate. It is important to note that many iterations of these formulas are rejected in the formulator's laboratory and do not proceed to evaluation by the design owner. Formulators estimate that it typically takes two to five years of testing potential formulations before a proposed candidate is identified for submittal to the design owner[16].

Qualification of test candidate

Qualification is the first step in the process under which a design owner begins to verify that the treatment which may ultimately replace the Cr(VI)-based surface treatment has met or exceeded the specific performance criteria defined at the beginning of the substitution process.
Qualification applies to materials, manufacturing processes, and components, and comprises:

- Extensive generic laboratory testing; and
- Iterative testing if failures occur.

Once proposed candidates are developed by the formulator, the design owner evaluates the formulations by first performing their own screening tests. If the test candidate fails, formulators may choose to reformulate. It is common to iterate multiple times before a test candidate passes the design owners' screening, potentially adding several years to the substitution process (see figure 3-2 above).

For those test candidates which pass initial screening, additional testing is performed. Each company has explicit performance requirements, test methods, acceptance testing, and other characteristics for each component that are based upon the results of research, development, and prior product experience. This phase of the substitution process can take multiple years depending upon the performance requirements and only successfully qualified test candidates can progress to the validation stage described below.

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[16] GCCA

Validation of test candidate

After a test candidate is qualified, the performance of each particular aerospace or defence use is validated based on its specific design criteria.
Validation is carried out on each relevant component, followed by system-level testing and engine/flight testing (if relevant). The activities in this stage can overlap with some of those that are carried out in the Certification stage and include:

- Test plan creation and approval;
- Component specific testing;
- Iterative testing if failures occur;
- System/engine/flight testing;
- Manufacturing trials; and
- Review and approval of test results.

The testing criteria are determined on a case-by-case basis with due regard to the design and performance requirements of each component and system. Testing in a relevant environment over an appropriate timescale is necessary, and therefore the validation stage may require full engine and aircraft flight tests, even for very low volumes of product. In the validation of manufacturing processes, the process robustness is also a vital aspect to be demonstrated at this stage.

Validation is carried out by the aerospace and defence companies, sometimes in collaboration with the manufacturing supply chain (in the Certification stage, the Regulator is also involved). Only the original design owner can determine when a test candidate is fully validated.

Some of the components impacted by the substitution of a surface treatment may form part of systems which are no longer in production. In order to conduct the testing required to validate the change on these components, it may therefore be necessary to build bespoke test hardware. Sourcing the relevant hardware and test equipment, and finding test facilities to do this, can add significant time to the process, whilst some of the testing performed at this stage will also be destructive, so failures can result in further schedule slippage. Together the Qualification and Validation processes encompass testing of the test candidate and can take more than 15 years to complete for the most challenging substitutions. At the end of the validation stage the removal of Cr(VI) from the production process is formally approved by the design owner.

Certification of alternative

Certification is the stage under which the component onto which the test candidate will be applied is certified by the Regulator or relevant authority as compliant with safety, performance, environmental (noise and emission) and other identified requirements. OEMs work with the certification authorities to develop a comprehensive plan to demonstrate that the aircraft, engine, propeller, radar system, munitions or any other final product complies with the airworthiness regulation or defence/space customer requirements. This activity begins during the initial design phase and addresses the final product in normal and specific failure conditions. The airworthiness regulations set performance criteria to be met, although they do not specify materials or substances to be used.
Steps in the Certification stage include:

- Test plan creation and approval;
- Component/system/engine/flight testing;
- Iterative testing if failures occur;
- Review and approval of test results;

- Drawing release; and
- Maintenance manual creation/revision.

For the civil aviation industry, the output of the original certification process is a Type Certificate, issued by the airworthiness authority (e.g., EASA) and granted to the engine, propeller, and airframe OEM. This is issued for the original design of the final product, rather than for each individual component, however every component of the final product must be designed, developed, and validated as meeting the requirements of the overall product and system design. The overall compliance demonstration for a new Type Certificate therefore may cover several thousand individual test plans, of which some will require several years to complete. This interconnection is illustrated using the example of an aircraft in Figure 3-4 below.

Certification therefore applies to all components, sub-systems, and systems. A change to one individual component can affect the entire assembly of which it is a part (which may contain hundreds of components), and in turn the sub-system and system. Approval of the impacted components is granted after the airworthiness certification criteria, compliance requirements and methods of compliance have been successfully demonstrated for those components, to the relevant Airworthiness Authority. The same process applies to defence products and systems, with the only distinction being how acceptable means of compliance are defined, and the certification authority (which will usually be a Ministry of Defence (MoD)). In the case of dual use aircraft (A civil and a military version of the same aircraft), or in the case of military specific aircraft, certification may need to be granted by multiple authorities (e.g., certification by the MoD could apply in addition to the EASA certification).

Removing a material or process reliant upon Cr(VI) and implementing an alternative is particularly challenging as it will involve in service or in production components. Re-certification of all components incorporating the new processes and materials is therefore required. As discussed in the description of the certification process in the GCCA AfA for strontium chromate[17], each of these components will need to be approved individually:

> *"Importantly, even if an alternative is in use in one component in aerospace[18] system A, it cannot be inserted into what appears to be the same part [component] in another aerospace system B (e.g., model B) until it is fully reviewed/validated/certified to ensure that either the design parameters are identical or that the alternative is fully acceptable for the different design parameters. Extensive experience shows that an alternative that is successfully certified in one component in one model cannot necessarily be successfully certified in another. In other words, the circumstances for each component in each model are unique and extrapolation is impossible without validation and certification."*

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[17] Application for Authorisation 0117-01 section 5.3 available at b61428e5-e0d2-93e7-6740-2600bb3429a3 (europa.eu) accessed 06 June 2022

[18] In this parent dossier, the term aerospace is defined as comprising the civil aviation, defence/security and space industries.

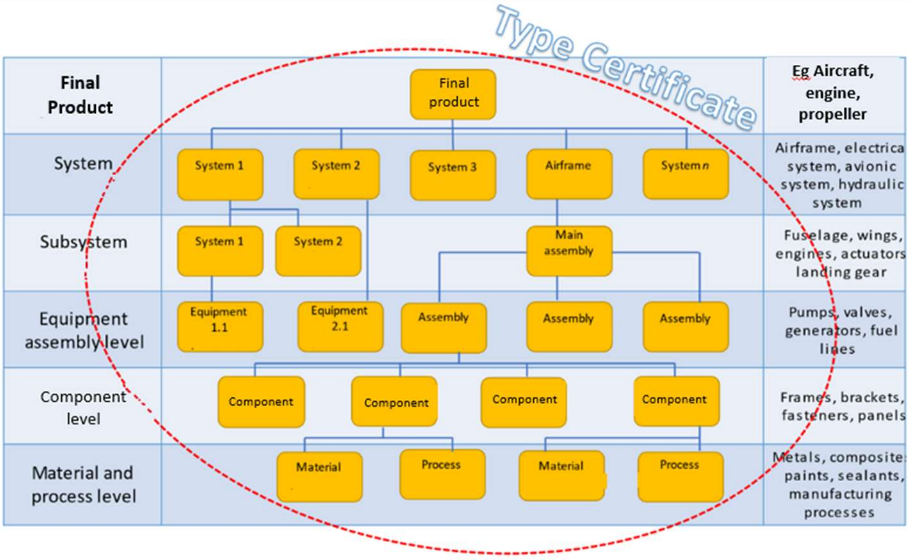

Figure 3-4: System hierarchy of a final product
Diagram shows the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR member

After the alternative is certified, design drawings and component lists need to be revised to put the requirements of the Cr(VI)-free material/process as an alternative to the legacy requirements. Thousands of components could be impacted by each process. Only once these revised design drawings have been released can industrialisation of the alternative begin.

Over their operational life A&D components are exposed to extreme mechanical forces and environmental conditions which affect their performance. In order to continue to meet requirements, and ensure operational safety, A&D components and products are therefore subject to intensive MRO activities. The strict schedule of the maintenance program, and method for repair, is stated in the maintenance manual and must be officially approved. For most A&D organisations, repair approval is distinct from design approval, although the processes are analogous and may be undertaken concurrently. Once repair approval is complete the alternative will be included in maintenance manuals.

During initial manufacture, all the components of the system are in a pristine and relatively clean condition, whereas during repair and maintenance, the components are likely to be contaminated and suffering from some degree of (acceptable) degradation. Furthermore, certain cleaning and surface preparation techniques that are readily applicable during initial manufacture may not be available or practical during repair and maintenance. Carrying out MRO activities on in-service products is further complicated due to restricted access to some components, which are much more readily accessible during initial manufacture and assembly. These factors are significant with respect to surface treatments, as their performance is strongly dependent upon the condition of the surfaces to which they are applied. As such, all of these conditions must be addressed in the repair approval process.

The certification and industrialisation stages (see below) encompass progression of the alternative from TRL 7 to TRL 9 and together these stages can take six to ten years to complete. In certain defence applications, certification alone can take more than ten years.

Industrialisation of alternative

Industrialisation follows the certification of the component design incorporating the alternative and is an extensive step-by-step methodology followed to implement the certified material or process throughout manufacturing, supply chain and MRO operations, leading to the manufacturing certification of the final product.
Elements of the Industrialisation of alternative process include:

- Identification of potential manufacturing sources;
- Purchase and installation of manufacturing equipment;
- Process verification (Due to the fact that the industry is working on special processes, the supply chain must be qualified);
- Quality Control (QC) approval; and
- Regulatory approval if needed.

A&D products consist of up to a million components provided by thousands of suppliers or manufactured internally by OEMs, making communication between OEMs and their supply chain regarding what is permissible for use on A&D products key. Suppliers must be vetted through a supplier qualification process prior to being issued a contract. This process typically involves internal approval, contract negotiation, running a specific qualification test program, and undertaking an audit on potential risks of working with a supplier. A supplier may be requested to sign a manual or code of conduct by the OEM, to ensure expectations for work and awareness of required standards is achieved. Once the supplier is qualified, periodic audits are performed to ensure continued compliance with contractual requirements. Significant investment, worker training and manufacturing documentation may be required to adapt the manufacturing processes for new alternatives, which sometimes require changes in existing facilities, the construction of new facilities, or switching to a different facility (including a different supplier’s facility).

The industrial implementation is usually scheduled to follow a stepwise approach to minimise the technical risks, and benefit from lessons learned. This implies that the replacement is not implemented simultaneously in all plants and at all suppliers but instead often uses a stepwise approach. Each OEM may operate dozens of manufacturing sites/final assembly lines worldwide.

For components already in products, long-term contractual agreements are often already in place with suppliers. When a change is made to a drawing to incorporate a new alternative, the contract with the supplier needs to be renegotiated, and additional costs are incurred by the supplier when modifying and/or introducing a new production process. These may include purchase and installation of new equipment, training of staff, internal qualification of the new process, OEM qualification of the supplier, manufacturing certification of the supplier, etc. In addition, the supplier may need to retain the ability to use the old surface treatment, or qualify different solutions for different customers/ components, which requires the supplier maintain parallel process lines to accommodate multiple surface treatments/processes. The level of complexity varies by component and process. In some cases, the supplier may be sub-contracting the process. In addition to production organisation approval, the approval of maintenance organisations is also required. This means multiple layers of activity in the industrialisation process.

The industrialisation of alternatives is constrained by many factors including: the complexity of supply chains; extent of process changes required; and the airworthiness regulations or defence/space customer requirements. Even simple changes can take up to five years. When more than one alternative process is introduced simultaneously, up to a decade or more may be necessary for full implementation of the alternative.

The industrialisation process includes the creation and approval of process documents or manufacturing/repair documents. These documents allow detailed implementation of the manufacture and/or repair of each component. Using the example of a commercial aircraft, the process, described above and leading to industrialisation of the alternative, is illustrated in Figure 3-5 below. This is a simplified example. In some cases, there are many different types of components all needing validation test and there are instances where different test candidates are used on different parts (to replace a single original Cr(VI) use).

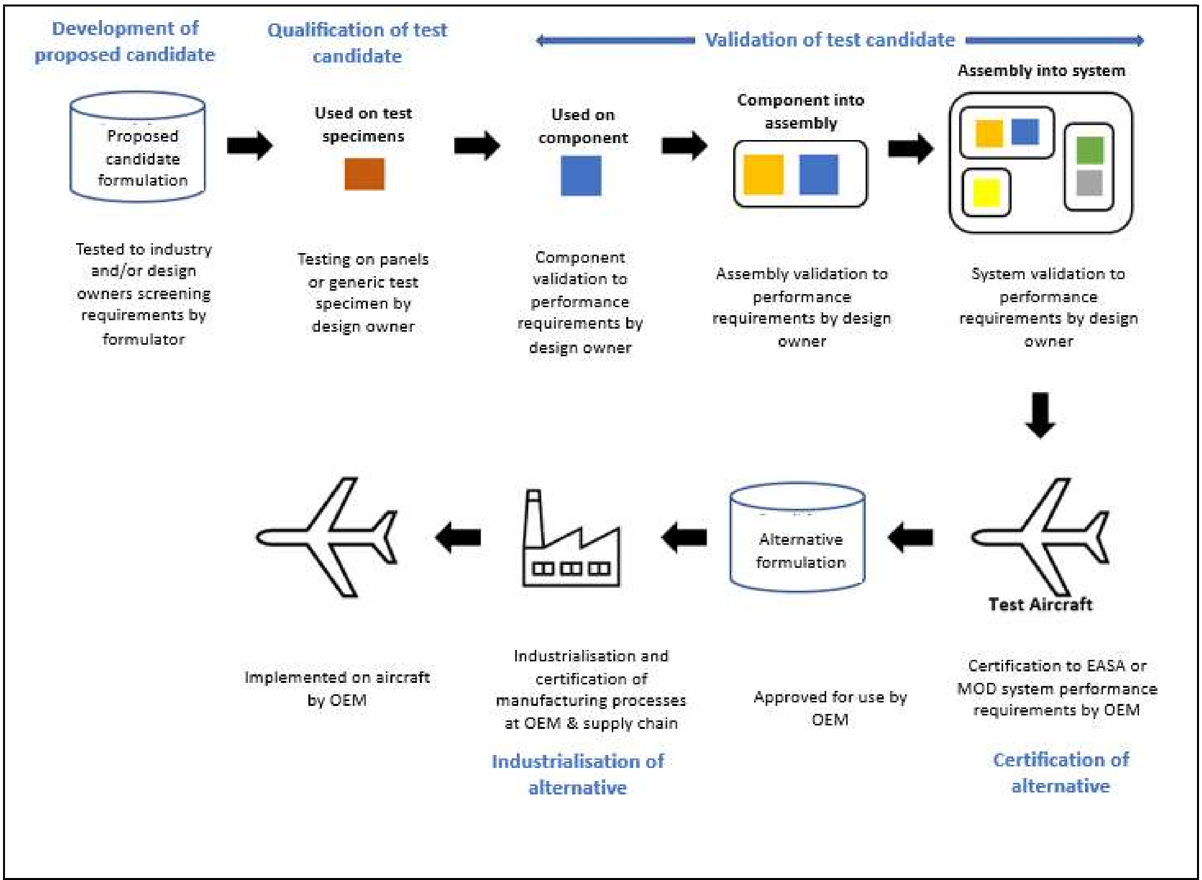

Figure 3-5: Process to Certify a Formulation for use on Aircraft
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

3.2 Description of the functions of the chromates and performance requirements of associated products

3.2.1 Technical feasibility criteria for the role of the chromates in the applied for use

3.2.1.1 Introduction

The development of technical feasibility criteria for Cr(VI) (and proposed/test candidates) in passivation of non-aluminium metallic coatings has been based on a combination of assessment of the parent applications, consultation with ADCR consortium members, and a review of available scientific literature.

Using detailed written questionnaires (disseminated throughout 2021 and 2022) the ADCR consortium members were asked to review the technical feasibility criteria and provide details of the (ideally) measurable, quantifiable technical performance criteria which the chromates impart in this use and that any alternatives (substances and technologies) would also need to impart before they are seriously considered as possible replacements. In cases where the approach is to look for an alternative to the whole coating system and not just the Cr(VI) passivation step (e.g., replacement of cadmium plating, since cadmium is also an SVHC), requirements that an alternative have to meet will be based on the properties provided by the coating system as a whole and not just the passivation step. There may be other key functionalities that have to be met, in addition to those afforded by just the Cr(VI) passivate.

In parallel, scientific literature investigating passivation of non-aluminium metallic coatings and the assessment of the technical suitability of alternatives to Cr(VI) was collected and analysed (with the assistance of the ADCR consortium members) and has been incorporated into the analysis.

Passivation is a process to treat metallic substrates so that they can withstand adverse environmental conditions and are less affected by air, water, chemical reactions, or acidic reactions. Passivation reduces the chemical reactivity of the exposed layer of a metal. Passivation works by covering the outermost metal surface with a resistant material, such as a metal oxide, which is protective and shields the substrate metal against external factors.

Metallic coatings applied on steel or aluminium (such as cadmium, zinc, or zinc-nickel) can be passivated to achieve even higher corrosion protection.

The criteria that are used in the assessment of the technical feasibility and suitability of selected test candidates to Cr(VI) for passivation of non-aluminium metallic coatings are as follows. These apply to all substrates for which passivation of non-aluminium metallic coatings is applied within the ADCR membership:

- Corrosion resistance (and active corrosion inhibition);
- Chemical resistance;
- Adhesion to subsequent layer;
- Layer thickness;
- Temperature resistance
- Low electrical resistivity (high conductivity); and
- Pre-treatment compatibility[19].

The relative importance of each of these criteria differs across the ADCR membership but all members require corrosion resistance.

Impact on fatigue life is also considered when assessing Cr(VI)-free test candidates for passivation of non-aluminium metallic coatings. Coefficient of friction and its effect on the ability to achieve acceptable torque requirements on threaded components such as fasteners and screws is also considered when assessing test candidates. This is particularly important for cadmium, in cases where the alternative being pursued is a replacement to the cadmium coating system as a whole rather than just the Cr(VI) passivate. Cadmium plating is, in some cases, referred to as “lubricious”. The tribological advantages of Cadmium plating have to be replicated in any alternative system and this introduces further challenges for alternatives development in these cases.

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[19] Pre-treatments are typically applied to the base metal prior the application of the non-aluminium metallic coating but may be applied to the non-aluminium metallic coating prior to the passivation treatment.

Tribology deals with the behaviour of surfaces in dynamic contact with respect to each other such as friction, galling, seizing, and the various wear mechanisms such as fretting, sliding, and impact. The challenge, however, is that these tribological properties, tests to characterize them, and criteria for replacement, are not well known, or at least are not standardized and, as a result, must be performed on an application-specific basis rather than via generic testing; in some cases, engine tests or simulation rigs may be required.

Tribological properties required for certain parts - tests to characterise tribological properties and the criteria that alternatives to cadmium must meet are not standardised and, as a result, must be performed for each specific case rather than via generic testing.

In addition to the above, passivation of non-aluminium metallic coatings is applied without an electrical field. It can therefore be applied to complex geometries such as tubes and pipes onto which a non-aluminium metallic coating has been applied. Such components would act as a faraday cage in the presence of an electric field, which would therefore limit or prevent the use of alternative methods such as anodising that use an electric field. It is not always possible to galvanically apply a non-aluminium metallic coating to such complex geometries. Passivation is only carried out on surfaces that have a metallic coating applied.

Passivation may also be used to brighten plated surfaces discoloured by thermal treatment, in order to enhance inspectability. Thermal treatment is necessary to prevent hydrogen embrittlement after electroplating of sensitive steel.

It should also be noted that, in many instances, technical comparison criteria are strongly interrelated, and it is not possible to consider a criterion independently of several others.

The non-aluminium coatings (coated on the base metal illustrated in Figure 3-1) identified by the ADCR members as relevant to passivation of non-aluminium metallic coatings are:

- Cadmium and its alloys;
- Nickel-cadmium alloys;
- Zinc-nickel alloys;
- Brass with zinc layer;
- Copper and its alloys (e.g., brass, bronze);
- Silver; and
- Zinc and its alloys.

Cadmium coatings are used in the aerospace industry primarily as a corrosion resistant plating, but also in applications where tribological properties and electrical conductivity are important. Due to the carcinogenic nature of cadmium, many coatings have been proposed as replacements, with zinc-nickel alloy being the leading candidate. Advantages of cadmium as a coating include good barrier corrosion protection and acting as a sacrificial anode, galvanic compatibility with aluminium alloys (relevant when the base metal is aluminium alloy), good surface lubricity, excellent electrical conductivity compared to steels, and its function as a sacrificial coating. The open-circuit potential of cadmium is more negative than that of steel so that if the coating is damaged, the cadmium plating will corrode instead of the steel (when steel is the base metal). Cadmium plating corrodes at a low rate in chloride bearing media and provides long-term protection. The application of passivation treatments to the cadmium coating further extends the life of cadmium plated parts and decreases the generation of carcinogenic and respirable cadmium corrosion products (e.g., CdO, $Cd(OH)_2$).

Electrodeposited zinc is widely used as a corrosion protective coating for steel parts. The degree of protection provided by the zinc layer is not uniform across the entire steel surface, as the coating is susceptible to localised attack when exposed to chloride-containing media. To enhance the corrosion resistance of the zinc coating, it can be alloyed with metals of the iron group (such as nickel, iron, and cobalt). Amongst the zinc alloys, zinc–nickel alloys with different nickel content have been the most successful. Zinc-nickel alloy coatings are used in the aerospace and automotive industry for corrosion protection coatings of steel. They were developed in the 1980s as a replacement for cadmium coatings due to the carcinogenic and toxic nature of cadmium.

In a corrosive medium, zinc coatings are rapidly covered by hydroxides or salts of zinc. A finishing passivation treatment applied to zinc coatings can be performed to further increase the corrosion protection and life of the plated parts.

Silver coatings are used as they are a heat and electricity conductor, are very resistant to oxidation and corrosion, and have anti-seizing properties. Silver coatings may be treated with chromate solutions which generate chemical conversion coatings, which help prevent the silver coating tarnishing in hydrogen sulphide-containing atmospheres.

Copper coatings are used for example as an efficient and effective means to mask areas of a component before carburising is caried out. Carburising is a heat treatment process applied to steel to increase its hardness.

As noted above, this combined AoA/SEA covers the use of multiple chromates in passivation of non-aluminium metallic coatings (chromium trioxide (includes “acids generated from chromium trioxide and their oligomers", when used in aqueous solutions), sodium dichromate, and potassium dichromate). In the context of technical feasibility and the wider AoA it is important to note that the mode of action for corrosion protection clearly describes the benefit as coming from the Cr(VI) species. Therefore, by extension any donor (substance) that delivers Cr(VI) is responsible for also delivering the functions attributed to Cr(VI) within the over-arching 'use'. As such the discussion of technical feasibility discusses the functions imparted by passivation of non-aluminium metallic coatings, and the mode of action/mechanism by which Cr(VI) delivers these functions. For example, one function imparted by passivation of non-aluminium metallic coatings is corrosion inhibition. The mode of action of Cr(VI) is concerned with the chemical/physical process by which the Cr(VI) and its reduced counterpart Cr(III) contribute to this corrosion protection mechanism. Mode of action is important to consider when analysing alternatives, as there may be something unique about the chemistry of Cr(III)/Cr(VI) in contributing to a particular function that cannot easily or sufficiently be replicated by another substance.

The discussion below explains the relevance and importance of each of the criteria and presents in more detail the threshold values (or ranges) that will be used in Section 3.3 for the comparison of the shortlisted alternatives to Cr(VI).

3.2.1.2 Role of standards and specifications in the evaluation of technical feasibility criteria

At the development phase, as described in the substitution process (see Figure 3-3) proposed candidates are at an early stage of evaluation represented by TRL 1 – 3, and not recognised as credible test candidates at this stage. These proposed candidates are screened against the technical feasibility criteria, or key functions imparted by the use of passivation of non-aluminium metallic coatings. These functions are measured against performance thresholds using standardised methodologies; often referred to as standards. The performance thresholds are most often assigned by the design owner of the component subject to the treatment.

As stated, test methodologies are defined within standards and specifications. Standards may be within the public domain originating externally of the A&D sector from professional bodies (e.g., BSI or ISO). Specifications are often internal to the aerospace/defence company, or a Government Defence Department (Ministry of Defence) with access to the documents controlled by the manufacturer and/or design owner of the part. As such, these documents are typically classified as confidential business information.

In the context of AoA, the importance of the performance thresholds and standards are multifold; to ensure reproducibility of the testing methodology, define acceptable performance parameters and determine if the proposed candidate exhibits regression or is comparable in performance compared to the benchmark Cr(VI) substance.

The role of the specification is limited within the substitution process. It provides a reproducible means of screening proposed candidates, however, is typically unsuitable for more mature stages within the substitution process when proposed candidates transition to credible test candidates. These subsequent phases in the substitution process are subject to in depth often bespoke testing as required within steps TRL 4 - 6 and above. Testing regimes to meet the requirements of TRL 4 - 6 often transition from simple specifications more suited to quality control purposes, to evaluation of treated components/sub-assemblies via breadboard integrated components either within the laboratory or larger simulated operational environments. These advanced testing regimes rely upon the use of specialised equipment, facilities, and test methodologies such as test rigs or prototype systems, see Figure 3-6. Attempts to replicate environmental in-service conditions are built upon bespoke testing regimes developed over decades of Cr(VI) experience from laboratory scale test panels to test rigs housed in purpose-built facilities. However, they cannot always reproduce natural environmental variations therefore there can be differences between what is observed in the laboratory and experienced in the field.

Figure 3-6: Multi-climate chamber for simulated environment testing (Airbus SAS, 2022)

Examples of standards used for screening proposed candidates within the development phase of the substitution process are presented in Table A-1. As stated above, standards serve to provide a means of reproducible testing within the development phase of the substitution process. Both standards and specifications are tools used to evaluate proposed candidates to identify suitable test candidates. Test methods and requirements contained therein do not define success criteria for alternatives validation.

3.2.1.3 Interrelationship of technical feasibility criteria and impact on the surface treatment system

When considering technical feasibility criteria, in many instances these are strongly interrelated in the delivery of the 'use', and it is not possible to consider one criterion independently of the others when assessing proposed candidates. The individual criterion collectively constitute part of a 'system' delivering the 'use' with a degree of dependency on one another.

For example, achieving corrosion resistance should not impact the adhesion of any subsequent layer, or at least be comparable to the benchmark Cr(VI) solution. It may be necessary to modify the treated surface to achieve satisfactory adhesion of subsequent layers applied after passivation of non-aluminium metallic coatings. Therefore, the selection of the surface treatment may be influenced by its compatibility with subsequent processes such as adhesion promoters, not only corrosion and chemical resistance. Additional consideration should be given to the influence and compatibility of any pre-treatments; how they interact with the passivation of non-aluminium metallic coatings process and how they impact the key technical criteria of the 'use'. Pre-treatments may include chemical alkaline cleaning to remove grease and oily residues, or mechanical cleaning such as grit blasting for example. It should be noted that the pre-treatments are predominantly for the treatment of the base metal prior to metallic plating, rather than the preparation of the plated surface prior to the passivation step. The selection of pre-treatments and the alternative chosen to deliver the passivation of non-aluminium metallic coatings use need to take into account the design parameters of each affected part. How the parts interact with each other, and with the treatment system to deliver the technical feasibility criteria should be considered. Interactions between the different elements of the surface treatment system may not be anticipated. These may only manifest themselves when more advanced testing of parts in simulated service environments is conducted or when used in multi-part assemblies with the potential to generate further operational environments that may affect the performance of the treatment system.

The GCCA Application for Authorisation 0116-01 (GCCA, 2017) considers variables that could impact essentially the same component design which can influence behaviour and compatibility with a treatment system, and therefore delivery of technical feasibility criteria. These variables are listed below[20]:

- Hardware[21] base alloys;
- Contact or mating surfaces with other parts;
- Exposure to fluids;
- Structural stress and strain; and
- External environment.

External environmental variables affecting in-service conditions for different assemblies of parts include:

- Exposure to chemicals e.g., de-icers, lubricants, salts, sea water/moisture;
- Temperature;
- Galvanic influences from different metals in contact with one another; and
- Mechanical effects; galling[22], vibration, erosion.

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[20] GCCA Response to Pre and post Trialogue SEAC Questions on DtC and SrC AoA, p.15

[21] 'Component an aerospace system', GCCA Response to Pre and post Trialogue SEAC Questions on DtC and SrC AoA, p.15

[22] Wear caused by adhesion between sliding surfaces (Wikipedia, 2021)

These can all affect the corrosion behaviour of a part and the performance requirements of the alternative delivering the passivation 'system'. Due to the complexity of these assemblies and variety of environments encountered in service, a single test candidate may not provide a universal solution to delivery of all technical criteria under all scenarios of use for a given part.

3.2.1.4 Technical feasibility criterion 1: Corrosion resistance (and active corrosion resistance)

Corrosion resistance is important to provide safe and reliable performance and assure the life of the component in service. This is especially important in situations where the component is relatively inaccessible and cannot be easily or frequently inspected. Corrosion resistance is also important to prevent corrosion of the component during intermediate steps in the manufacturing process.

As discussed in Section 3.1.1, the main corrosion protection of the base metal is provided by the sacrificial non-aluminium metallic coating (such as cadmium or zinc). For copper and silver plating, the barrier properties of the plating protects the base metal. The main goal of the passivation process is to protect the non-aluminium metallic coating.

Passivation of non-aluminium metallic coatings is a form of chemical conversion coating. If required, an appropriate pre-treatment step to prepare the non-aluminium metallic coating may be used prior to the Cr(VI) passivation surface treatment (e.g., pickling with nitric or sulphuric acid for re-activation of metallic coating surface), although pre-treatment is typically carried out before the metallic coating step. Cr(VI)-containing pre-treatment solutions permit the removal of surface oxides and exposed intermetallic particles with minimal loss of the alloy matrix and avoidance of intergranular attack. In the Cr(VI) passivation process, the Cr(VI) containing solution is applied on the non-aluminium coating forming a passive protective layer on the surface of the non-aluminium metallic coating. The degree of protection is proportional to the thickness of the passivation layer deposited onto the substrate (CCST consortium, 2015).

Active, or self-healing, corrosion protection is possible due to the presence of residual Cr(VI) retained in the passivation layer. If the non-aluminium metallic coating is damaged locally, this residual Cr(VI) reacts with the exposed non-aluminium metallic coating, renewing the passive chromium oxy-hydroxide protective barrier (CCST consortium, 2015).

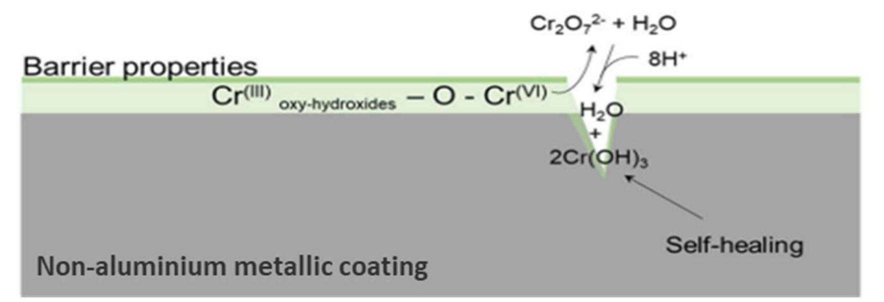

Figure 3-7: Self-healing mechanism afforded by Cr(VI) on metal substrates (Gharbi et al., 2018)

The 'active' layer is typically composed of both Cr(VI) and Cr(III) (see Figure 3-7 above). The interior of the layer is composed of the Cr(III) oxy-hydroxide, which forms a covalent bond, $Cr^{(III)} – O – Cr^{(VI)}$, with residual Cr(VI) species. This promotes a Cr(VI) enriched outermost region of the protective layer. Should the passive coating be damaged, exposing the underlying non-aluminium metallic coating to corrosive agents, the Cr(VI) is released, or diffuses, from this region of high Cr(VI) concentration, thereby renewing the passive barrier (Jiang et al., 2016a)

Unlike most corrosion inhibiting compounds, chromates are both anodic and cathodic inhibitors, meaning that they can restrict the rate of metal dissolution, and simultaneously lower the rate of reduction reactions (oxygen and water reduction) in many environments and over a broad range of pH. This makes the Cr(VI) compounds uniquely capable of providing/ensuring the corrosion protection required for the safe operation of A&D products over the wide range of use environments in which they operate.

Following reduction of Cr(VI) to Cr(III), the mechanism of passivation of non-aluminium metallic coating occurs with the formed protective coating containing a balance Cr(VI) and Cr(III) (Jiang et al., 2016a). As residual chromium trioxide is retained in the outermost layer of the coating, upon exposure to water or salt solution, Cr(VI) species are released from the coating, particularly when they are scratched to refresh the coating area. This released Cr(VI) then diffuses to a defect to passivate the surface and thus provides active corrosion inhibition to the surface (Jiang et al., 2016a), (CTAC, 2015).

The mechanisms for the inhibition of metal alloy dissolution are that the chromium trioxide is a very soluble, higher-valent, oxidizing ion (CrO_4^{2-} or $Cr_2O_7^{2-}$) with a lower valent form that is insoluble and creates an extremely protective film (Cr_2O_3 or $Cr(OH)_3$). The degree of corrosion resistance provided by passivation of non-aluminium metallic coatings is generally proportional to the coating thickness (CTAC, 2015).

Active, or self-healing, corrosion protection is possible due to the presence of residual Cr(VI) retained in the passivation layer. If the non-aluminium metallic coating is damaged locally, this residual Cr(VI) reacts with the exposed non-aluminium metallic coating, reducing to Cr(III), and renewing the passive chromium oxy-hydroxide protective barrier (CCST Consortium, 2015).

3.2.1.5 Technical feasibility criterion 2: Chemical resistance

Chemical resistance refers to the ability of the part to withstand contact with fluids encountered in the service life of the part, such as lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids. Due to its inorganic nature, the Cr(VI) passivation of non-aluminium coatings resists many organic substances such as these.

Inspection of the potential/pH (Pourbaix) diagram[23] for the chromium/chlorine/water system, shows that insoluble Cr_2O_3 is stable and prevails over the potential/pH environmental conditions experienced by aerospace components in most conditions. It is also apparent that Cr_2O_3 is immune to attack by chloride ions at pH values above 2. A similar chemical resistance holds for other corrosive species.

3.2.1.6 Technical feasibility criterion 3: Adhesion promotion

Adhesion promotion refers to the ability of the coating to improve the adhesion of subsequent layers such as paints, primers, adhesives, and sealants and other functional coatings layers such as lubricants. Adhesion promotion also includes the adhesion of the passivation layer to the non-aluminium metallic coating.

Adhesion promotion in cadmium passivation is caused by two processes. Firstly, acidic etching of the cadmium surface causes a beneficial increase of the surface area, which allows for an improved physical adhesion of subsequent coatings. This etching process is not necessarily dependent on the presence of Cr(VI) compounds, but when they are present it is understood that they have a beneficial

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[23] Pourbaix, M. (1974), Atlas of Electrochemical Equilibria in Aqueous Solutions, National Association of Corrosion Engineers p262

contribution to the etching process. Secondly, an oxidation of the metal layers is possible through the oxidative nature of chromates CrO_4^{2-} or dichromates $Cr_2O_7^{2-}$:

$$2\ H_2CrO_4 + 5\ Cd \rightarrow Cr_2O_3 + 5\ CdO + 2\ H_2$$

$$H_2Cr_2O_7 + 4\ Cd \rightarrow Cr_2O_3 + 4\ CdO + H_2$$

This oxidation will enhance the dipolar nature of the surface, which allows for enhanced adhesion of subsequent coatings.

Cr(VI) passivation coatings provide a stable and repeatable surface for adhesion by forming a mixed oxide film of stable cohesive and adhesive strength. Cr(VI) passivation coatings are initially amorphous when freshly applied but undergo dehydration to a stable crystalline form over a few hours. Cr(VI) passivation coatings provide acceptable adhesion for a wide range of adherents.

Cr(VI) passivation coatings form strong adhesion to the non-aluminium metallic coating due to the superficial dissolution of the non-aluminium metallic coating and the precipitation of a mixed material of dissolved metal ions and treatment solution. The superficial dissolution removes oxides to produce a clean, high-energy surface[24], then deposits an oxide film that minimised this surface energy, causing a high strength of adhesion between the oxide layer and the metal.

3.2.1.7 Technical feasibility criterion 4: Layer thickness

Layer thickness is important as it affects component dimensions and tolerances, which affect the performance of the component when it is integrated into assemblies and sub-systems. For example, if layer thickness increases it can cause reduced fit of fasteners that require close compliance to the specified tolerances, and increased wear when the component is integrated with other components and where it moves in relation to those other components. Any alternative to Cr(VI) must not adversely affect layer thickness, or adversely affect the ability to control layer thickness through the normal process operating conditions (such as time, temperature, pH, and degree of agitation).

Layer thickness is not directly influenced by Cr(VI) but is associated with process conditions and must be carefully controlled.

Layer thickness is also important as it affects fatigue. For passivation of non-aluminium metallic coatings the usual thicknesses lie below 1 micron as so has little impact on fatigue life. Proposed candidates to Cr(VI) for passivation of non-aluminium metallic coatings may be thicker and therefore may introduce a fatigue concern.

3.2.1.8 Technical feasibility criterion 5: Resistivity

Conductivity is the reciprocal of resistivity. Cr(VI)-based passivation of non-aluminium coatings have been shown to be electrical insulators through mercury drop contact experiments. Resistivity is not directly influenced by Cr(VI) but by the thickness and morphology of the passivation layer, which is influenced by process conditions and must be carefully controlled. Apparent surface electrical conductivity (contact resistance) is achieved by the fracture of the thin, brittle passivation coating under load between metal faces to allow for direct metallic contact. Consequently, for applications requiring apparent surface electrical conductivity (low resistivity/low contact resistance), the

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[24] Surface energy may be defined as the work required to create an area of surface from a bulk material. A surface has excess energy compared to the bulk, and a surface will therefore try to minimise its energy, e.g., by absorbing a material with a lower energy onto its surface

maximum coating weight is typically 100 mg/m^2, as opposed to 2,000-5,000 mg/m^2 for other classes of passivation coating (note that it is not typical to actually measure passivation coating weight).

Uncoated steel is known to provide poor performance in applications requiring low electrical contact resistance. To improve the conductivity required for applications in e.g., electrical connectors for aerospace and defence applications, steel substrates are plated with more conductive metals (e.g., cadmium). The contact resistivity should be minimally increased by the passivation layer to maintain sufficiently high conductivity, which must also be maintained after weathering. Examples of where low resistivity (high conductivity) is needed include applications where electrical grounding is needed across a metal interface, and when electromagnetic interference (EMI) shielding is needed at a metal interface, sometimes with a conductive gasket between. A main requirement for low resistivity is for the mitigation of lightning strikes. This mitigation damps the effect of lightning strike by allowing the high electrical current to flow through the super-structure. Any insulation (high resistivity) at a structural interface will cause a high voltage drop at the interface and once overcome, an arc will be produced resulting in localized melting of the structures and significant fire risk.

The actual thickness requirements for achieving apparent surface electrical conductivity depend on the load, ductility, and geometry of the opposing mechanical faces to be brought into metallic contact. Since thin layers of Cr(VI) passivated coating provide conductivity in many applications through localized fracture of the coating, the self-healing properties of the Cr(VI) is particularly important.

3.2.1.9 Technical feasibility criterion 6: Temperature resistance

Passivation of non-aluminium metallic coatings must withstand the in-service temperature envelopes relevant for the aerospace and defence products, which ranges between -55°C and over 200°C, depending on the substrate material or the location on the aircraft.

3.2.1.10 Technical feasibility criterion 7: Pre-treatment and post-treatment compatibility

Passivation of non-aluminium metallic coatings must be viewed as part of an overall treatment 'system'. The performance of chemical passivation of non-aluminium metallic coatings is highly dependent upon the performance of and interaction with a pre- or subsequent 'uses' for example deoxidising, pickling/etching in a pre-treatment step or application of a primer in a subsequent step. As such, it is possible that changes to any of these other steps in the overall treatment system will need to be implemented in the manufacturing process to accommodate a non-Cr(VI) alternative for the 'use' passivation of non-aluminium metallic coatings.

Test candidates to Cr(VI) for passivation of non-aluminium metallic coatings must remain compatible with relevant pre-treatments, or pre-treatments may also need to be modified for compatibility with the non-Cr(VI) proposed candidate. While it may be possible to get a Cr(VI)-free passivation of non-aluminium metallic coating treatment to work with an existing or modified Cr(VI) pre-treatment, the overall objective is to remove Cr(VI) from the entire process. This is a much higher technical challenge.

Passivation of non-aluminium metallic coating is frequently used as a touch-up for other surface treatments (not just passivation of non-aluminium metallic coatings) and its compatibility for these situations needs to be maintained when considering test candidates to replace Cr(VI).

3.3 Efforts made to identify alternatives

3.3.1 Research and Development

3.3.1.1 Past Research

As noted by Naden, 2019, "*hexavalent chromium remains the benchmark for corrosion inhibition, providing protection over a wide pH range and electrolyte concentration*". Chromates are both anodic and cathodic inhibitors, restricting the rate of metal dissolution whilst simultaneously reducing the rate of reduction reactions. The author recognised that, during corrosive attack a "self-healing" character to the coating is imparted by hexavalent chromium. Self-healing occurs via the reduction of Cr(VI) in the coating to an insoluble Cr(III) compound. Excellent anti-corrosive properties are offered by chromate-based compounds and their use has been extensive in environmental degradation protection.

With regard to the replacement of chromates, despite the fact that the aerospace sector is widely seen as the instigator of technology change in multiple essential engineering disciplines (including the use of new metals, composites and plastics) (Royal Academy of Engineering, 2014) there has been a lack of viable chromates substitutes that promise engineering quality whilst also ensuring user safety; this is despite extensive research into alternative corrosion inhibitors which has been underway since the 1980s (Naden, 2019).

The significant nature of substitution efforts in the aerospace sector is also noted by (Hughes et al., 2016), who highlights the substantial effort that has been made to develop a suitable alternative to Cr(VI)-based surface treatments such as passivation, which have a robust performance in processing, corrosion protection and adhesion performance.

As highlighted throughout this AoA-SEA, the substitution of Cr(VI)-based treatments in the aerospace and defence sector is met by particularly strong challenges. Rowbotham & Fielding (2016) highlight the nature of such challenges, noting that there are an estimated three million components in each of the 20,000-plus aircraft currently flying. The demanding nature of service environments in the aerospace sector, and potential for serious consequences if only one component should fail, dictate that very stringent measures are adopted and enforced when developing and qualifying Cr(VI)-free test candidates.

To further highlight the significant efforts being made by the aerospace and defence sector to substitute Cr(VI), a range of recent and ongoing 'R&D collaborations' are identified below. It is noted that many of these collaborations were mentioned within parent AfAs associated with the ADCR consortium Review Reports, including AfAs developed by the Global Chromates Consortium for Aerospace (GCCA), Chromium trioxide Authorisation Consortium (CTAC) and Chromium VI Compounds for Surface Treatment (CCST). However, efforts have also been made to expand upon the recognised collaborations, as well as to identify and describe additional relevant collaborations.

A short summary of the global collaborations relevant to passivation of non-aluminium metallic coating is provided below. Note that collaboration projects relevant to conversion coating have been included here as being relevant to passivation of non-aluminium metallic coatings, as passivation of non-aluminium metallic coatings is a type of conversion coating (discussed in Section 3.1.1). The exception is conversion coating projects have specifically focussed on aluminium and magnesium substrates – these have been excluded.

Please note that for many projects only limited information is publicly available due in part to issues of intellectual property and potentially patentable technologies.

Relevant collaborations/projects include:

- Multiple sub-projects under the **Highly Innovative Technology Enablers for Aerospace (HITEA)** project with partners including Innovate UK (part of UK Research and Innovation) and the Engineering and Physical Sciences Research Council (EPSRC). HITEA was initiated in 2012, with phase one ending in 2015 and two subsequent phases running. Amongst others, sub-projects considered test candidates to Cr(VI) in uses including conversion coating (hence also passivation of non-aluminium metallic coatings);

- **International Aerospace Environmental Group (IAEG) Replacement Technologies Working Group (WG2)** provides a global framework for aerospace and defence manufacturers to collaborate on widely applicable, non-competitive alternative technologies. Interlaboratory comparison testing (across several companies) of test candidates to Cr(VI) conversion coating (and hence passivation of non-aluminium metallic coating) is an ongoing project in this group. Additionally, interested member companies have worked on information exchange/survey projects on Anodise seal, Functional Chrome Plate, and Corrosion inhibiting primers. A current project is investigating the availability of alternatives to cadmium-plated industry standard components;

- **Advanced Surface Engineering Technologies for a Sustainable Defense (ASETSDefense)** consists of SERDP (Strategic Environmental Research and Development Program) and ESTCP (Environmental Security Technology Certification Program) and is a US Department of Defense initiative. ASETSDefense aim to provide information on environmentally friendly surface engineering technologies, including Cr(VI)-free alternatives. ASETSDefense's mandate is to be a promulgator/aggregator of research and although participants are engaged in active research, the primary goal and benefit of the ASETSDefense database is that it will not make a claim without a written report summarising the experimental data. Potential alternatives to Cr(VI) conversion coating (and hence also passivation of non-aluminium metallic coatings) that have been reported on include trivalent chromium, molybdenum-based compounds, rare earths and adhesion promoters, sol-gels, and silanes;

- **The Aerospace Chrome Elimination Team (ACE)** were established in the US in 1988, with members including all major A&D OEMs and US Department of Defence divisions. While this team does not conduct joint projects, members meet regularly to report on their progress/difficulties on common aerospace and defence Cr(VI) uses such as chemical conversion coating (and hence passivation of non-aluminium metallic coatings);

- **Scientific Understanding of Non-chromated Corrosion Inhibitors Function:** Collaboration between the United Technologies Research Center (UTRC) and Department of Defence Strategic Environmental Research and Development Program (SERDP), running between 2008 and 2012. The project generated understanding of the mechanisms of non-Cr(VI) corrosion inhibiting coating systems;

- **U.S. National Centre for Manufacturing Sciences (NSMS)** consortia: United Technologies Corporation has participated in two industrial consortiums with NCMS in 1995 and 2002 as reported in GCCA (2016) analysis of alternatives. In 2002, "Recent Alternatives to Chromate for Aluminium Conversion Coating" was published, noting contributions from UTRC, Raytheon, CCAD (Corpus Christi Army Dept), NAVAIR, Pratt & Whitney, and Hamilton Sundstrand. The study concluded that the chromate free alternatives tested were unsuitable for universal substitution across all existing applications of Cr(VI). Specific applications were stated to require specific alternatives that must be tested for each application, there was not a 'one size fits all' alternative (National Center for Manufacturing Sciences, 2002); and

- **Noblis Cadmium and Hexavalent Chromium Alternatives 5-Year Strategy and Roadmap**: Noblis is a not-for-profit independent organisation, based in Virginia USA. In May 2016 it published the review "Cadmium and Hexavalent Chromium Alternatives 5-Year Strategy and Roadmap" (Noblis, 2016) summarising the current status of research and implementation of Cr(VI) alternatives, primarily in US DoD applications. The review was commissioned by the Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) supporting the US Department of Defense (DoD), Environmental Protection Agency (EPA) and Department of Energy (DoE). Multiple potential alternatives to Cr(VI) conversion coating (and hence passivation of non-aluminium metallic coatings) were considered within the scope of this strategy and roadmap.

- **Project NAPOLET** Replacement of surface anticorrosive materials used in aerospace with more environmentally friendly technologies, reference number FW01010017. This project is within the TREND Programme. Work Package 5 of this project is concerned with replacement of cadmium coatings[25]**;**

- **TREND programme.** The TREND programme supports industrial research and development projects financed from the state budget by the Technology Agency of the Czech Republic and Ministry of Industry and Trade under 'CzechInvest'. Projects encompass advanced production technologies, advanced materials, nanotechnology, industrial biotechnology), digital technologies (micro & nanoelectronics, photonics, artificial intelligence), and cyber technologies (security, connectivity) (*TREND Programme - Research & Development in the Czech Republic*, n.d.)

3.3.2 Consultations with customers and suppliers of alternatives

Details on consultation activities associated with the development of this AoA-SEA are provided in Section 2.4.

3.3.3 Data Searches

3.3.3.1 High level patent review

A non-exhaustive patent search was performed with the aim to identify patents related to passivation of non-aluminium metallic coatings. The search was performed using Espacenet, the European Patent Office (EPO) open access search portal. Espacenet contains over 120 million patent documents held by patent offices around the world, including North America and Asia (EPO, 2020). Using Espacenet, a search containing all the terms "passivation", "of", "cadmium", "coatings", "chromate" and "free", applying the filters C23[26] and C23C2, and publication date 1 January 1997 to 31 December 2019, returned 20 results.

As with all patents, they introduce concepts and developments that may be advantageous within a given field in the fullness of time. However, it should be remembered that patents are granted for their novelty. Novelty does not necessarily translate to feasibility or applicability. Patented technologies are still bound to the requirements of the substitution process which will determine if a

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[25] ADCR member

[26] C23: Coating metallic material; coating material with metallic material; chemical surface treatment; diffusion treatment of metallic material; coating by vacuum evaporation, by sputtering, by ion implantation or by chemical vapour deposition, in general; inhibiting corrosion of metallic material or incrustation in general

novel concept can be transformed into a feasible test candidate. Patents can also introduce limitations on the availability of a particular technology for example through the requirements for licencing. Where this is the case, a third party may obtain access to the technology if a licensing or some other commercial arrangement is available and meets the requirements of both parties.

Table 3-4 below briefly summarises selected patents from the above search criteria. These contain elements of technologies broadly from the same, or similar, fields of research, as described in Section 3.3.4.

Table 3-4: Brief summary of non-exhaustive patent search, potentially relevant for passivation of non-aluminium metallic coatings

Patent number	Title	Technology
US2019145009A1	Conversion coatings for metal surfaces	Zinc/zinc alloy conversion coating: Composition containing Cr(III), without Co (II) salts.
CN107250434B	Metal-surface treatment agent for zinc-coated steel or zinc-based-alloy-coated steel, coating method, and coated steel	Silane/vanadium/phosphate/zirconium/silicate-based corrosion resistant coating for zinc galvanised steel;
CN106700701A	High temperature resistance environment-friendly Dacromet paint, preparation method thereof, high temperature resistance environment-friendly Dacromet coating and preparation method thereof	Zn/Al/Mg/Mn based slurry coat in three phase Cr(VI) free matrix for corrosion resistant coating for steel substrate.
EP3153551A1	Anti-corrosion and/or passivation compositions for metal containing substrates	Corrosion inhibition organic coating containing Mo and Zn salts
CN104388913A	Hot galvanizing chromate-free passivation liquid and preparation method thereof	Zirconium/cerium/lanthanum nitrate corrosion inhibitor with PTFE additive
US8936836B2/ US2010062200A1	Method for coating metal surfaces using an aqueous compound having polymers, the aqueous compound, and use of the coated substrates	Organic coating containing a silane/silinol and/or siloxane, inorganic cross-linker and dispersed inorganic particles

3.3.3.2 High-level literature review

A non-exhaustive review of scientific journal articles was carried out using Science Direct[27]. The purpose of this search was to identify any alternatives to Cr(VI) in passivation of non-aluminium metallic coatings that have been investigated in the academic field and was intended to augment the patent search. It is acknowledged that technical requirements for passivation of non-aluminium metallic coatings in another sector may not be relevant within A&D, this non-exhaustive review demonstrates any potential sources of cross-fertilisation from other industries or academic research. This exercise is an example of initial screening for candidates from industry and academia.

A search using the terms "chrome free passivation of metallic coatings"[28] returned over 1,000 results, of which 67 were available in open access (documents with unrestricted access, that are available in full without payment of a licence fee). The identified documents are not directly relevant to

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[27] https://www.sciencedirect.com/, a search tool for scientific publications

[28] Science Direct search results available at https://bit.ly/30zociY accessed 5 October 2020

passivation of non-aluminium metallic coatings as they related to aluminium or magnesium substrates.

It should be noted that the publication of novel methods in scientific literature does not equate to these solutions being under consideration as proposed candidates by the A&D sector. Whilst the methods described may offer some insights into innovative chemistries, process methods, deposit morphologies, and analysis methods, these solutions must be investigated by formulators and presented to industrial end users as viable proposed candidates, with the potential to meet customer requirements before they can be progressed as test candidates. Proposed candidates based on these technologies have not been presented, which may be because initial investigations by formulators have concluded that they would not meet customer requirements or could be because test candidates are already available for which substitution plans are being progressed. If qualification, certification, or industrialisation of the test candidates currently being progressed were to fail for particular components or passivation processes, formulators and downstream users may look to develop proposed candidates based on these novel methods.

3.3.4 Shortlist of alternatives

Potential test candidates for alternatives to Cr(VI) in passivation of non-aluminium metallic coatings are shown below. This list comprises all the test candidates that were reported in the parent AfAs, and others that have been investigated by members. Note that only a small sub-set of these test candidates have been the focus of research and progression by the members, based on an assessment of their technical feasibility and potential to be viable alternatives to Cr(VI), and these have been identified accordingly in the following list.

Test candidates that have been the subject of a greater amount of focus and progression by the ADCR members are:

- Cr(III)-based passivation; and
- Zinc-nickel electroplating (passivated by Cr(III)).

Proposed candidates that were previously highlighted in the parent applications but that have not been reported as being further pursued or developed by the ADCR members are listed below:

- Physical vapour deposition (PVD) for passivation of copper foils;
- Benzotriazole-based processes;
- Zirconium and titanium-based organometallics (hexafluorozirconate);
- Sol-gel coatings.

These test candidates are discussed in more detail from Section 3.5.

3.3.5 Performance requirements and testing

Performance of test candidates needs to be equal to or better than the incumbent Cr(VI) treatment or coating system and this is driven by safety and performance requirements.

It should be noted that members' experience has shown that there can be difficulty in transferring good laboratory test results to an industrial environment. Decades of experience with existing coating systems using Cr(VI) passivation has contributed to the design and development of testing methods and protocols by the industry. Nevertheless, it is impossible to exactly reproduce in the laboratory environment the conditions that hardware will experience in its operating environment over its lifetime, or to correlate an accelerated test to actual in-service behaviour. The laboratory tests have been designed to give the best and most realistic information possible, but because of these unavoidable limitations it is necessary, as a minimum, to ensure that results in the laboratory of test candidates are at least as good as Cr(VI). Additionally, service life of equipment can be extended beyond its designed service life, requiring a high amount of effort and approval from stakeholders. This increases the importance that test candidates' performance needs to be at least as good as Cr(VI).

There are different application methods for passivation of non-aluminium metallic coating. Dip/immersion is carried out in baths/tanks. For maintenance/repair/touch-up, application methods are pen, brush, swab, and wipe. The different application methods need to work together, and Cr(VI)-free test candidates need to work for all of these application methods.

The functionalities required of passivation of non-aluminium metallic coatings are:

- Corrosion resistance (and active corrosion inhibition);
- Chemical resistance;
- Adhesion to subsequent layer;
- Layer thickness;
- Temperature resistance
- Electrical resistivity; and
- Pre-treatment compatibility.

Corrosion resistance also applies to the provision of temporary corrosion resistance during manufacturing stages.

Note that not all of these functionalities are relevant to all non-aluminium metallic coatings for passivation of non-aluminium metallic coating, and this distinction is discussed further in Section 3.2.1 above.

Critical to quality tests that are carried out to assess performance of the alternatives in the laboratory environment include corrosion resistance (salt spray test chamber), coating weight test/analysis, electrical contact resistance (possibly after thermal cycle is applied to simulate the conditions of the actual parts in the field), and wet/dry paint adhesion.

Corrosion resistance is assessed in a neutral salt spray chamber. ASTM B117, ISO 9227, and ISO7253 are examples of test methods against which corrosion is assessed.

For some applications, these test methods can be used as a quality control measure of the production process for passivation of metallic coatings. For example, no visible pitting or corrosion after 168 hours of testing in a salt spray chamber is a typical test requirement for routine quality control to detect process upsets. Although properly passivated coatings will typically withstand a significantly greater exposure to the corrosion test conditions, processes that are running outside of acceptable process control limits will generally produce corrosion failures within 168 hours in this example, so such batches can be screened out.

In addition, passing tests on coupons[29]/panels at the laboratory scale does not mean that the alternative will perform as intended when applied to a component and tested in its operating environment. Failures at this testing stage can still occur.

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[29] A testing coupon is a small panel of alloy used in performance testing of coatings

Adhesion is measured according to for example ISO 2409:2013 GT0 dry, GT1[30] wet after water immersion. This specifies a test method for assessing the resistance of paint coatings to separation from substrates when a right-angle lattice pattern is cut into the coating, penetrating through to the substrate.

Examples of standards used in the evaluation of the above technical feasibility criteria are provided in Annex 1. Test methods and requirements contained therein do not define success criteria for test candidate validation.

The ability to visually determine that the passivation of non-aluminium metallic coating has been appropriately and uniformly applied (inspectability) is also an important factor in the manufacturing and quality control process. This is important for bath/immersion treatment, but particularly important for manual application/touch-up for treatment of a part that has been damaged. Cr(VI) passivation of non-aluminium metallic coatings are coloured but many test candidates are not easily visible and this is a significant impediment to their adoption. This is challenging to overcome. For example, in trialogue discussions with the GCCA consortium, SEAC asked whether X-ray based methods could be used in place of visual inspection. GCCA responded that X-ray photoelectron spectroscopy (XPS) and X-ray fluorescence (XRF) are not suitable. For example, XPS has too small a field of view and is impractical due to size of the equipment, whilst XRF cannot distinguish between chromium in the coating and chromium in the base alloy, amongst other issues. GCCA also responded that some work based on the inclusion of inorganic colorants has been done to improve residual colour, however this impaired the coating adhesion performance.

3.4 Progression reported by ADCR members

3.4.1 Introduction

To achieve certification or approval by the relevant authority and/or design owner, each component must meet the required performance and safety requirements provided by the incumbent Cr(VI) based treatment. A complete suite of tests should include evaluation of all alloys subject to passivation of non-aluminium metallic coating, thereby highlighting impacts on niche alloys to be addressed prior to adoption of the test candidate.

Approval of the test candidate must include a complete understanding of the influence of the adjacent treatments to passivation of non-aluminium metallic coating within the process flow. This is to understand the influence of all processes representing the surface treatment 'system' including pre-treatments and post-treatments. Evaluation of the technical feasibility of the test candidate for passivation of non-aluminium metallic coating should consider its behaviour in contact with different alloy substrates, as well as in combination with other supporting treatments within the system. Any change in these system variables may lead to irregular or unacceptable performance of the test candidate delivering passivation of non-aluminium metallic coating, and consequently impact or delay approval of the test candidate for different component designs. This scenario is a leading reason for the graduated implementation of test candidates in combination with different component/design families. Different designs exhibiting varying degrees of complexity have the potential to interact with elements of the treatment system differently and thus effect the performance of the test candidate.

Progression of the test candidates is assessed against the following criteria:

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[30] GT0 and GT1 are classifications of the cross-cut test for adhesion. GT0 is achieved if none of the squares of the cross-cut lattice are detached; GT1 is achieved if up to 5% of the cross-cut area is detached.

- Technical feasibility/Technical Readiness;
- Economic feasibility;
- Health and safety considerations;
- Availability; and
- Suitability.

3.4.1.1 Suitability of a test candidate

When assessing the suitability of an alternative reference is made to the European Commission note dated 27 May 2020 which clearly defines the criteria by which a test candidate may be judged as suitable[31]. In order to be considered as suitable in the European Union (EU) the test candidate should demonstrate the following:

- Risk reduction: the test candidate should be safer;
- The test candidate should not be theoretical or only available in the laboratory or conditions that are of an exceptional nature;
- Technically and economically feasible in the EU;
- Available in sufficient quantities, for substances, or feasible as an alternative technology, and in light of the “legal” and factual requirements of placing them on the market; and
- Feasibility for the applicant: Are alternatives established during the authorisation procedure technically and economically feasible for the applicant?

To be available, a test candidate should meet the regulatory requirements of placing it on the market. Until the technical feasibility criteria and associated performance requirements of the use and wider treatment system are fulfilled, including all certification obligations as stipulated in the Airworthiness Directives[32], the test candidate cannot be deemed ‘available’.

All civil aircraft operating in the EU are subject to Airworthiness Directives issued by the EASA on behalf of the EU and its Member States, and European third countries participating in the activities of EASA. Changes to design of a product are subject to certification (EU, 2018), and can only be made following approval from the Regulator and compliance with the requirements of the appropriate Airworthiness Regulation, such as (EU) 2018/1139[33]. To reinforce this point, a civil aircraft’s Certificate of Airworthiness is not valid until the Type Certificate has been approved by the Regulator (EASA, 2012) Defence equipment is subject to standalone change protocols including approval by the relevant Member State Ministries of Defence. Therefore, a test candidate not deemed available from a regulatory standpoint would not meet all required criteria within the above definition of ‘suitable’.

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[31] EC (2020): Available at https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1 accessed 25 August 2022

[32] EASA (2022), available at Airworthiness Directives - Safety Publications | EASA (europa.eu) accessed 18 October 2022

[33] REGULATION (EU) 2018/ 1139 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 4 July 2018 - on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111 / 2005, (EC) No 1008 / 2008, (EU) No 996 / 2010, (EU) No 376 / 2014 and Directives 2014/ 30/ EU and 2014/ 53/ EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552 / 2004 and (EC) No 216 / 2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922 / 91 (europa.eu)

3.4.2 Status reported in original applications

The following sections discuss the progress of the development of test candidates by the ADCR members for use in passivation of non-aluminium metallic coating. For context, a short summary of the status reported in the parent applications[34] in 2015-16 is presented for each of the test candidates, followed by a description of progress by the ADCR members to date.

3.4.3 Conclusions on suitability of shortlisted alternatives

As discussed in Section 3.4.4, two test candidates are considered more promising based on the current level of development and progress achieved in substitution plans, these are:

- Cr(III)-based systems; and
- Zinc-nickel electroplating.

Some of these test candidates are in use by some ADCR members for some components on some alloys, however significant technical challenges remain before any of these test candidates can be used in all situations. The main limiting factors are failure to meet technical performance requirements, the specifics of which are discussed in detail in the following sections.

Consequently, none of these test candidates can be considered a generally available and suitable alternative to all applications of Cr(VI)-based passivation of non-aluminium metallic coating.

3.5 Cr(III)-based treatments

3.5.1 Status reported in original Applications in 2015-16

This sub-section summarises the development status of candidate alternatives to Cr(VI) for passivation of non-aluminium metallic coatings coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA (see subsequent Section 3.5.2).

Analysis of the technical feasibility of trivalent chromium as an alternative for hexavalent chrome demonstrated inferior performance for the key functionalities of:

- Corrosion resistance: Cr(III) passivation of coated or exposed steel substrates reported as less effective at providing corrosion protection compared to Cr(VI); further development required. For zinc-nickel substrates under salt spray corrosion testing, Cr(III) reported as inferior to the benchmark Cr(VI). Further still, Cr(III) reported as unsuitable for zinc plated surfaces, with an associated TRL assessment of 2 to 3. No quantitative data were reported in these tests;

- An exception to the above assessment was for cadmium passivation, where corrosion protection complied with company specific screening requirements of salt spray testing. However, this performance was only achieved with the inclusion of cobalt salts in the passivation solution. Without inclusion of cobalt salts, corrosion resistance was reported as reduced significantly below test screening requirements;

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[34] CCST consortium. (2015). *Potassium dichromate AoA, use 2 (0044-02)*; CTAC consortium. (2015). *Chromium trioxide AoA, use 4 (0032-04);* GCCA consortium. (2016a). *Chromium trioxide AoA, use 1 (0096-01);* GCCA consortium. (2016b). *Sodium chromate AoA, use 2 (0099-02)*

- Active corrosion protection; inferior in some scenarios of use, further details were not provided, and no quantitative data were reported;

- Adhesion of subsequent layer; results were not reported Cr(III) passivation of non-aluminium coating;

- There is a degree of uncertainty concerning reproducibility. Process reproducibility needed to be improved, particularly with corrosion resistance and adhesion properties (no quantitative data were reported); and

- The layer thickness using Cr(III) process treatments was reported as acceptable for aerospace applications, with layer thickness ranges between 250-600 nm being reported (Lanxess et.al. ref 0032-04, 2015).

No comments or data were reported concerning resistivity.

For sulphate and chloride-based Cr(III) systems, TRL was reported as 2-3 in the parent AoAs with an estimated 12-15 years for implementation.

Another consideration concerns the use of cobalt salts; used in conjunction with Cr(III) to supplement corrosion resistance. Cobalt salts are classed as substances of very high concern (SVHCs) and therefore there is scope for regrettable substitution if used in place of Cr(VI) (CCST consortium, 2015). Regrettable substitution, the substitution of a chemical with another of equivalent or worse hazard profile; no improvement in terms of risk to human health or the environment (ECHA, 2020).

3.5.2 Progression reported by ADCR members

3.5.2.1 Introduction

Cr(III)-based treatments have been investigated by ADCR members to replace Cr(VI) for the passivation of non-aluminium metallic coatings. This section discusses the situation in which the non-aluminium metallic coating (e.g., cadmium) is not changed, but it is passivated by Cr(III) rather than Cr(VI). Section 3.6 discusses the situation where the existing non-aluminium metallic coating is replaced by zinc-nickel, which is then passivated by Cr(III).

Multiple types of Cr(III)-based proprietary formulations, incorporating a range of different additives, are available on the market and have been variously investigated by ADCR member companies. Some ADCR members have included more than one of these Cr(III)-based formulations in their testing programmes, and these testing programmes are still ongoing. members have reported its use bath/immersion and touch-up via brush, wipe, or applicator pen.

3.5.2.2 Technical feasibility of Cr(III)-based alternatives

TRL status reported by members ranges between TRL 3 and TRL 9, depending on the member, the type of no-aluminium metallic coating and type of component being treated. For some members that have achieved TRL 6, qualification is still ongoing, and industrialisation is expected to be achieved between 2024-2027. Other individual members that have separate substitution plans based on type of non-aluminium metallic coating have achieved TRL 9 for some non-aluminium metallic coatings and expect to achieve TRL 7 in 2032-36 for other non-aluminium metallic coatings. The reason for this variation is due to the requirement to meet the performance requirement of each component, and accelerated laboratory testing may not be adequate, so in service testing may be needed to expand knowledge of performance in real conditions and allow further expansion of implementation to other types of components/areas.

In general members have reported that Cr(III) passivation has fulfilled the necessary technical performance requirements with the exception of friction/torque. The requirement for friction/torque applies to certain types of components especially e.g., screws and fasteners. With insufficient friction between the interfaces of these threaded components, it is not possible to achieve the required torque (which depends on interfacial friction). In such cases the screw or connector cannot be tightened sufficiently strongly, and there is a minimum torque requirement for such connectors. Testing for this requirement is therefore ongoing with some members not yet able to meet the requirements. This includes the testing of torque performance as a function of the use of dry lubricants between the interfaces. Further testing needs to be done to validate equivalence with current Cr(VI) passivation before supply chain validation is carried out.

Cr(VI) passivation coatings have an iridescent yellow/golden brown colour and therefore easy to visually detect and distinguish from the bare substrate. This is important for quality control inspection, to ensure the presence and uniformity of the coating. Cr(III) products are not clearly coloured and are similar in appearance to the non-aluminium metallic coating. There can be significant quality control risks/issues given this difficulty in detecting the Cr(III) passivation coating and detecting damage to the coating, resulting in risk of manufacturing delays and rework.

Options which may be considered to attempt to address this issue include:

- Adding a dye to the Cr(III) formulation (some dyed treatments are now available, with varied performance);
- Operators inspecting the applied coating against a photographic standard;
- Treating with an agent that causes a colour change (testing would be required to ensure such an agent that is applied to parts meets performance requirements);
- Testing coupons treated with passivation to determine if they are coated (this could be a quality check for immersion, but not for touch-up).

Spot testing is an option but is considered destructive and therefore can only be applied to a small proportion of the production. Other optical or electrical testing options are also being considered.

For all of the above potential options, effectiveness, practicality, and impact on the performance of the coating need to be acceptable.

Any potential solutions for detecting the coating that are not based on visible light will present technical or practical limitations and greater difficulty to implement or interpret the results compared to a visible coating.

3.5.2.3 Economic feasibility of Cr(III)-based alternatives

In general, ADCR members reported they did not expect any significant impact on the economic feasibility of the Cr(III) passivation process compared to the incumbent Cr(VI) passivation process.

One of the Cr(III)-based formulations requires heating/cooling as part of the treatment process, however this is not thought to have a significant impact on energy cost and such equipment is freely available on the market. Additional temperature controls (heating/cooling) will be required. In other cases, no new equipment is needed, or insignificant changes will be required to existing equipment.

There was a mixed view on the impact of raw material costs. For those members estimating an increase in raw material prices for Cr(III) passivation, they commented that these may decrease over time with increasing supply availability. Additionally some members observed that tank life appears to be shorter, therefore requiring more frequent recharging with the Cr(III) formulation compared to Cr(VI), potentially increasing overall raw material costs. More frequent monitoring of the bath solution would consequently be required, leading to an increase in monitoring costs.

Effluent treatment costs and waste disposal are expected to be lower due to the lack of need for a chrome reduction step in the wastewater treatment. Cr(III) can in principle be more easily and cheaply removed from the waste water than Cr(VI), although the volume of waste may be increased.

Personal protective equipment, ventilation requirements and engineering controls may be decreased but will not be eliminated. Employee exposure monitoring requirements for Cr(VI) may decrease.

Additionally, as with any new manufacturing process, the documentation needs to be updated. These include specifications and manufacturing procedures, as well as training of operators on the new procedure.

3.5.2.4 Safety considerations related to using Cr(III)-based treatments

The overall consensus of members is that the use of Cr(III)-based formulations will result in an overall risk reduction compared to Cr(VI). The Cr(III)-based formulations, although some of them have hazard warnings, are less hazardous than Cr(VI). None are carcinogenic, mutagenic, or reproductive toxicants (CMRs). Some of the substances shown below that are used in the Cr(III)-based formulations are present at relatively low concentrations, e.g., less than 5% w/w or in some cases less than 0.5% w/w. The classification and labelling requirements of the formulation depend on the concentrations of the substances therein, and this information is reported in the Safety Data Sheet. The information provided below applies to the pure substances.

Table 3-5: Substances in Cr(III)-based formulations - key identifiers and hazard properties

Substance	EC number	CAS number	Hazards (REACH)[(a)]	Hazards (CLP)[(b)]
Chromium(III) oxide	215-160-9	1308-38-9	None	May damage fertility or the unborn child, causes serious eye irritation, is harmful if swallowed and may cause an allergic skin reaction
Chromium (III) nitrate	236-921-1	13548-38-4	Toxic to aquatic life with long lasting effects, causes severe skin burns and eye damage, may intensify fire (oxidiser), is harmful if inhaled, causes serious eye damage and may cause an allergic skin reaction	
Ammonium silicofluoride (ammonium hexafluoro silicate)	240-968-3	16919-19-0	Causes serious eye damage and is harmful to aquatic life with long lasting effects	Toxic if swallowed, is toxic in contact with skin and is toxic if inhaled [(c)]

Table 3-5: Substances in Cr(III)-based formulations - key identifiers and hazard properties				
Substance	**EC number**	**CAS number**	**Hazards (REACH)[(a)]**	**Hazards (CLP)[(b)]**
Hydrofluoric acid	231-634-8	7664-39-3	Fatal if swallowed, is fatal in contact with skin, is fatal if inhaled and causes severe skin burns and eye damage	
Cobalt (II) nitrate	233-402-1	10141-05-6	May cause cancer, may damage fertility or the unborn child, may intensify fire (oxidiser), is harmful if swallowed, causes serious eye damage and may cause damage to organs through prolonged or repeated exposure	May cause cancer by inhalation, may damage fertility, is very toxic to aquatic life, is very toxic to aquatic life with long lasting effects, is suspected of causing genetic defects, may cause an allergic skin reaction and may cause allergy or asthma symptoms or breathing difficulties if inhaled [(c)]
Notes: (a) – Hazard classification according to the notifications provided by companies to ECHA in REACH registrations (b) – Hazard classification provided by companies to ECHA in CLP notifications (c) - According to the harmonised classification and labelling approved by the European Union *Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*				

Chromium(III) oxide, which as discussed in Section 3.5.2.1 is the most promising and most investigated alternative to Cr(VI) for passivation of non-aluminium metallic coating, is included in the Community Rolling Action Plan (CoRAP). It was added to the CoRAP in 2019 for being suspected of being both reprotoxic and a sensitiser, as well as its high (aggregated) tonnage. In January 2022, ECHA published a substance evaluation conclusion document. The evaluating Member State (France) concluded that:

- Identification as Substance of Very High Concern (SVHC, and first step towards Authorisation) deemed not applicable;
- Restriction deemed not applicable; and
- Harmonised Classification and Labelling – a group assessment is currently under development for chromium(III) compounds, it has been considered that chromium(III) compounds whole group should be classified for their skin sensitisation properties and that a CLH dossier on the group should be initiated.

3.5.2.5 Availability of Cr(III)-based alternatives

The various Cr(III)-based formulations are expected to be accessible on the EU market in the required quantities, although some member companies reported that no qualified supply chain is currently in place. Similarly, all equipment required to use the Cr(III)-based passivation processes is readily available.

A transition in the supply chain is expected as suppliers need to be identified and qualified, as well as considering the existing installations of baths for the Cr(VI) process and the needed transition to new baths. There may be a case to implement the change for all standard components at once for economic reasons.

Given the range of TRLs achieved by different members (TRL 3-9), with qualification still ongoing at some companies, at present it is concluded that the availability of Cr(III)-based test candidates for passivation of non-aluminium metallic coatings is limited.

3.5.2.6 Suitability of Cr(III)-based alternatives

The use of Cr(III) does constitute a reduction in hazard profile compared to Cr(VI).

Cr(III)-based passivation requires additional temperature controls (heating/cooling) in some cases.

Some companies have reached TRL 9 and in these cases the Cr(III)-based passivation can be considered technically and economically feasible, although qualification is still ongoing. However, Cr(III)-based passivation is by no means fully implemented, the main technical feasibility issue to be resolved is friction/torque performance for threaded connectors and similar components with a torque performance requirement. Therefore overall, Cr(III)-based passivation cannot be considered a generally available and suitable alternative to Cr(VI)-based passivation.

3.6 Zinc-nickel electroplating (passivated by Cr(III))

Zinc-nickel electroplated coatings passivated by Cr(III) have been developed to replace cadmium coatings passivated by Cr(VI) or Cr(III).

3.6.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for passivation of non-aluminium metallic coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this Combined AoA/SEA (see subsequent Section 3.5.2).

Research was reported as at an early stage and technical feasibility yet to be proven for aerospace applications. Key functionality deficiencies centred upon:

- Corrosion resistance – this was reported as not sufficient, although no quantitative data were reported;
- Resistivity, inadequate conductive properties, problematic for metallisation applications (no quantitative data were reported) (Brenntag et.al. ref.0043-02, 2015); and
- MRO, repair and touch-up processes - the incumbent treatment of cadmium coatings with a Cr(VI) passivation could be touched-up in cases where the cadmium plating thickness was less than the minimum standard. This could be achieved by adding cadmium and re-immersing the parts. This touch-up option was not generally qualified with the zinc-nickel bath, and it was reported R&D studies were in progress to deal with this problem.

In contrast to the above deficiencies, other key functionalities were reported as comparable to Cr(VI):

- Chemical resistance (no quantitative data were reported);
- Adhesion to subsequent layer (no quantitative data were reported); and
- Layer thickness reported as equivalent to the Cr(VI) passivated cadmium coating (no quantitative data were reported).

No information was reported on reproducibility.

TRL level was not reported but implementation was expected to take >15 years.

3.6.2 Progression reported by ADCR members

3.6.2.1 Introduction

Zinc nickel electroplating passivated by Cr(III)-based treatments has been investigated by ADCR members to replace Cr(VI) for the passivation on non-aluminium metallic coatings. This section discusses the situation in which the non-aluminium metallic coating (cadmium) is replaced by a zinc nickel coating, which is then passivated by Cr(III) rather than Cr(VI). Section 3.5 discusses the situation where the existing non-aluminium metallic coating is retained, but is passivated by Cr(III).

Multiple types of Cr(III)-based proprietary formulations, incorporating a range of different additives, are available on the market and have been variously investigated by ADCR member companies to passivate zinc nickel. Some ADCR members have included more than one of these Cr(III)-based formulations in their testing programmes, and these testing programmes are still ongoing. Members have reported its use bath/immersion and touch-up via brush, wipe, or applicator pen.

3.6.2.2 Technical feasibility of zinc nickel passivated with Cr(III)

TRL status reported by members for zinc nickel passivated by Cr(III) ranges between TRL 4 and TRL 9, for bath/immersion and touch-up/repair applications.

Zinc-nickel electroplating passivated by Cr(III) is considered a very promising test candidate to replace cadmium-plated surfaces which have been passivated by Cr(VI) or Cr(III). In some cases it is considered a drop-in replacement for cadmium plating passivated by Cr(VI), is approved in aircraft producer manuals, and is in use by some aerospace OEMs. However, it is not considered a suitable replacement in all cases. Generally, it is not in use on connectors and fasteners, although one company has qualified its use for certain types of connector in the military sector and used it on production parts. The performance (in particular the final colour) compared to cadmium plating is not acceptable for some military customers.

For connectors and fasteners, friction testing is still to be carried out to ensure equivalence to Cr(VI), before the supply chain can be validated. Time is also needed for supply chain deployment. Performance requirements need to be met for each component and accelerated testing may not be adequate, so in service testing may be needed to expand knowledge of performance in real conditions and allow further expansion of implementation to new types of components/areas.

Zinc nickel passivated by Cr(III) has the same thickness as cadmium passivated by Cr(VI) and so does not adversely affect component dimensional tolerances.

One member has reported poorer conductivity of the zinc-nickel plating passivated with Cr(III) compared to cadmium/Cr(VI), which means in their case it cannot be used on electrical grounding connectors.

Once engineering validation has been achieved for the change to zinc nickel passivated by Cr(III), the changeover for all components must be performed by changing the design. For large numbers of components (for some companies, in excess of 1,000) this is a major task requiring significant time that will extend beyond the current expiry date of the authorisation.

3.6.2.3 Economic feasibility of zinc-nickel passivated with Cr(III)

Generally ADCR members reported an expected increase in the production costs of the zinc nickel Cr(III) passivation process compared to the incumbent Cr(VI) passivation process.

Investment in new equipment may be needed. The zinc nickel plating and Cr(III) treatment may be done in same tanks that were originally used for cadmium plate Cr(VI) treatment. However it is possible that one or both would need to be changed.

There may be an additional requirement for sand blasting to be carried out on parts before the plating process, which increases production costs and time. The zinc-nickel plating process takes significantly longer than, for example, the cadmium plating process (up to five times longer).

The chemical analysis and control of the zinc nickel plating solution is more complex, requires more operator attention, and requires more time. It also requires additional specialist analytical equipment.

Some members observed that tank life of the passivation solution appears to be shorter, therefore requiring more frequent recharging with the Cr(III) formulation compared to Cr(VI), potentially increasing overall raw material costs. More frequent monitoring of the bath solution would consequently be required, leading to an increase in monitoring costs.

Waste disposal costs for the passivate waste stream likely to rise, as it needs frequent disposal and renewal.

In some cases, the relatively higher resistivity of the zinc-nickel plating passivated with Cr(III) (compared to cadmium/Cr(VI)) means that it cannot be used for electrical grounding connectors, and a more expensive alternative plating needs to be used.

One of the Cr(III)-based formulations requires heating/cooling as part of the treatment process, however this is not thought to have a significant impact on energy cost and such equipment is freely available on the market. Additional temperature controls (heating/cooling) will be required. In other cases, no new equipment is needed, or insignificant changes will be required to existing equipment.

Effluent treatment costs and waste disposal are expected to be lower due to the lack of need for a chrome reduction step in the wastewater treatment. Cr(III) can in principle be more easily and cheaply removed from the waste water than Cr(VI).

Personal protective equipment, ventilation requirements and engineering controls may be decreased but will not be eliminated. Employee exposure monitoring requirements for Cr(VI) may decrease.

Additionally, as with any new manufacturing process, the documentation needs to be updated. These include specifications and manufacturing procedures, as well as training of operators on the new procedure.

3.6.2.4 Safety considerations related to using zinc nickel passivated with Cr(III)

A summary of the key identifiers and hazard properties of substances used in zinc nickel electroplating passivated with Cr(III) are shown in Table 3-6. This table includes substances used in the zinc-nickel plating process as well as substances used in the Cr(III)-based formulations used to passivate the zinc-nickel coating. Some of the substances shown below that are present at relatively low concentrations. The classification and labelling requirements of the formulation depend on the concentrations of the substances therein, and this information is reported in the Safety Data Sheet. The information provided below applies to the pure substances.

Table 3-6: Substances used in zinc-nickel electroplating passivated by Cr(III) - key identifiers and hazard properties

Substance	EC number	CAS number	Hazards (REACH)[a]	Hazards (CLP)[b]
Chromium(III) oxide	215-160-9	1308-38-9	None	May damage fertility or the unborn child, causes serious eye irritation, is harmful if swallowed and may cause an allergic skin reaction
Zinc oxide	215-222-5	1314-13-2	May damage fertility or the unborn child, is harmful if swallowed, is harmful if inhaled and may cause damage to organs through prolonged or repeated exposure	Very toxic to aquatic life and is very toxic to aquatic life with long lasting effects (c)

Table 3-6: Substances used in zinc-nickel electroplating passivated by Cr(III) - key identifiers and hazard properties

Substance	EC number	CAS number	Hazards (REACH)[a]	Hazards (CLP)[b]
Nickel sulphate	232-104-9	7786-81-4	Causes serious eye irritation	May cause cancer by inhalation, may damage the unborn child, causes damage to organs through prolonged or repeated exposure, is very toxic to aquatic life, is very toxic to aquatic life with long lasting effects, is harmful if swallowed, is harmful if inhaled, is suspected of causing genetic defects, causes skin irritation, may cause an allergic skin reaction and may cause allergy or asthma symptoms or breathing difficulties if inhaled (c)
Disodium tetrahydroxy zincate	235-342-1	12179-14-5		Causes severe skin burns and eye damage and is very toxic to aquatic life with long lasting effects
Nickel dichloride	231-743-0	7718-54-9	May cause cancer and may damage fertility or the unborn child	Toxic if swallowed, is toxic if inhaled, may cause cancer by inhalation, may damage the unborn child, causes damage to organs through prolonged or repeated exposure, is very toxic to aquatic life, is very toxic to aquatic life with long lasting effects, is suspected of causing genetic defects, causes skin irritation, may cause an allergic skin reaction and may cause allergy or asthma symptoms or breathing difficulties if inhaled (c)

Notes:
(a) – Hazard classification according to the notifications provided by companies to ECHA in REACH registrations
(b) – Hazard classification provided by companies to ECHA in CLP notifications
(c) - According to the harmonised classification and labelling approved by the European Union
Source: ECHA – Search for chemicals (https://echa.europa.eu/home)

The consensus of members 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. The test candidates, although some of them have hazard warnings, are less hazardous than Cr(VI).

Chromium(III) oxide, which as discussed in Section 3.5.2.1 is the most promising and most investigated alternative to Cr(VI) for passivation of non-aluminium metallic coating, is included in the Community Rolling Action Plan (CoRAP). It was added to the CoRAP in 2019 for being suspected of being both reprotoxic and a sensitiser, as well as its high (aggregated) tonnage. In January 2022, ECHA published a substance evaluation conclusion document. The evaluating Member State (France) concluded that:

- Identification as Substance of Very High Concern (SVHC, and first step towards Authorisation) deemed not applicable;
- Restriction deemed not applicable; and
- Harmonised Classification and Labelling – a group assessment is currently under development for chromium(III) compounds, it has been considered that chromium(III) compounds whole group should be classified for their skin sensitisation properties and that a CLH dossier on the group should be initiated.

3.6.2.5 Availability of zinc nickel passivated with Cr(III)

The various Cr(III)-based formulations are expected to be accessible on the EU market in the required quantities, although some member companies reported that no qualified supply chain is currently in place. Similarly, all equipment required to use the Cr(III)-based passivation processes is readily available.

Zinc-nickel plating is established in the aerospace plating supply chain and is commercially available. Some additional equipment is required, although it is freely available.

A transition in the supply chain is expected as suppliers need to be identified and qualified, as well as considering the existing installations of baths for the Cr(VI) process and the needed transition to new baths. There may be a case to implement the change for all standard components at once for economic reasons.

Given the range of TRLs achieved by different members (TRL 3-9), with qualification still ongoing at some companies, at present it is concluded that the availability of Cr(III)-based test candidates for passivation of non-aluminium metallic coatings is limited.

3.6.2.6 Suitability of zinc nickel passivated with Cr(III)

The use of zinc nickel passivated with Cr(III) does constitute a reduction in hazard profile compared to Cr(VI).

Production costs are generally expected to increase. Zinc nickel passivated with Cr(III) requires additional temperature controls (heating/cooling) in some cases and the plating process is more complicated and requires more time.

In some cases zinc nickel passivated by Cr(III) is considered a drop-in replacement and is in use in some situations. Some companies have reached TRL 9 and in these cases the zinc nickel passivated by Cr(III) can be considered technically and economically feasible, although qualification is still ongoing. However, zinc nickel passivated by Cr(III) is by no means fully implemented, the main technical feasibility issue to be resolved is friction/torque performance for threaded connectors and similar components with a torque performance requirement. For some situations, colour and electrical resistivity do not meet the requirements. Therefore overall, zinc nickel passivated by Cr(III) cannot be considered a generally available and suitable alternative to Cr(VI)-based passivation.

3.7 Test candidates reported in parent applications no longer being pursued

3.7.1 Introduction

As discussed in Section 3.3.4, test candidates that were previously highlighted in the parent applications but that have not been reported as being further pursued or developed by the ADCR members are listed below:

- Physical vapour deposition (PVD) for passivation of copper foils;
- Benzotriazole-based processes;
- Zirconium and titanium-based organometallics (hexafluorozirconate); and
- Sol-gel coatings.

3.8 Summary of Cr(VI) alternatives for passivation of non-aluminium metallic coating

The table below summarises the current development status of Cr(VI)-free test candidates for passivation of non-aluminium metallic coating. A qualitative assessment (low, moderate, or high) has been provided for each of the criteria technical feasibility, economic feasibility, availability and suitability. This qualitative assessment is provided as a high-level summary and is based on the detailed discussions in the preceding sections.

Table 3-7: Current development status of alternatives to Cr(VI) for passivation of non-aluminium metallic coating

Alternative	Technical feasibility	Economic Feasibility	Availability	Risk reduction	Suitability
Cr(III)-based	High	High	Moderate	High	Moderate
Zinc nickel passivated by Cr(III)	High	Moderate	Moderate	High	Moderate
Notes n/a = insufficient data or not pursued as an alternative					

3.9 The substitution plan

3.9.1 Introduction

3.9.1.1 Factors affecting the substitution plan

The substitution plan is impacted by a combination of factors affecting the implementation of the alternative, these include:

- Functionality and ability to meet performance requirements (technical feasibility);
- Availability, and suitability of the alternative;
- Process changes such as equipment, training, health and safety (*Technical challenges and economic feasibility*);
- A substitution process which is subject to regulatory controls, legal constraints, and customer requirements;

- Economic feasibility, including the capital and operational costs of moving to an alternative and the costs of implementing the alternative across the supply chain; and
- Progress and alignment with other REACH substitution workstreams.

Each factor will contribute to the achievement of milestones that must be met to realise delivery of the substitute(s) to Cr(VI) for passivation of non-aluminium metallic coating, and its relevant pre-treatments. They require continuous review and monitoring to ensure that the substitution plan progresses through its phases and all changes are clearly documented. Monitoring of progress markers associated with the substitution plan includes a timetable of steps and targeted completion dates, assessment of the highest risks to progression, and how these risks can be reduced (if possible), which may not always be the case.

3.9.1.2 Substitution plans within individual members

Each ADCR member has at least one substitution plan to remove Cr(VI) in passivation of non-aluminium metallic coatings that is uniquely reflective of their individual situation. Additionally, an individual member sometimes has multiple substitution plans for passivation of non-aluminium metallic coating, running in parallel work streams. The reason for different substitution plans within one member is that they are segmented by factors such as type of non-aluminium metallic coating, type of alternative, and whether the substitution plan is related to bath/immersion or local/touch-up applications. These different substitution plans are progressed simultaneously although they typically have differences in timing of milestones and anticipated achievement of each TRL level, based on various factors such as the technical difficulty of introducing the alternative and prioritisation of certain types of components or non-aluminium metallic coating. The test candidates of most focus and progression by ADCR members are Cr(III)-based, either with the original non-aluminium metallic coating, or with zinc nickel electroplated coating.

3.9.1.3 Interplay with pre-treatments

Development of substitution plans for alternatives to Cr(VI) for passivation of non-aluminium metallic coating are fundamentally related to and impacted by the pre-treatment. In the case where members are using Cr(VI) in the pre-treatment, they develop the Cr(VI)-free pre-treatments in parallel with the Cr(VI)-free passivation of non-aluminium metallic coating. The progression and success of the development of alternatives to Cr(VI) in passivation of non-aluminium metallic coating depends on the successful development of pre-treatment alternatives. Any unexpected technical failures in the development of the pre-treatment will impact the planned timing of the substitution plan for the passivation of non-aluminium metallic coating.

In some cases, a member will target substitution of Cr(VI) from both the pre-treatment and the passivation of non-aluminium metallic coating at the same time.

3.9.2 Substitution plan for ADCR in passivation of non-aluminium metallic coatings

3.9.2.1 Substitution plans

The expected progression of ADCR members' substitution plans to replace Cr(VI) in passivation of non-aluminium metallic coating is shown in Figure 3-8 below. The progressive stages of the substitution plan (development, qualification, validation etc.) as shown in the diagram are described in detail in section 3.1.2. Implementation and progression of substitution plans ultimately leads to reduced Cr(VI) usage. MRL 10 is the stage at which manufacturing is in full rate production/deployment and is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.

Recognising the SEAC's need for information which reflects the position of individual companies and their value chains, the substitution plans have been developed based on a granular analysis of the progression made by each OEM and DtB company supporting passivation of non-aluminium metallic coating in achieving substitution. As design owners, the substitution plans of these companies impact on their suppliers (other DtBs, BtPs) and MROs, who are unable to also substitute until the design owners have fully implemented the alternatives (i.e., progress to TRL 9 and MRL 10).

The data in the figure show the expected progress of 22 distinct substitution plans for Cr(VI) in passivation of non-aluminium metallic coating, covering different plans across different members, and also multiple plans within individual members. These data have been aggregated to present the expected progress of the substitution of Cr(VI) from passivation of non-aluminium metallic coating for the ADCR consortium as a whole.

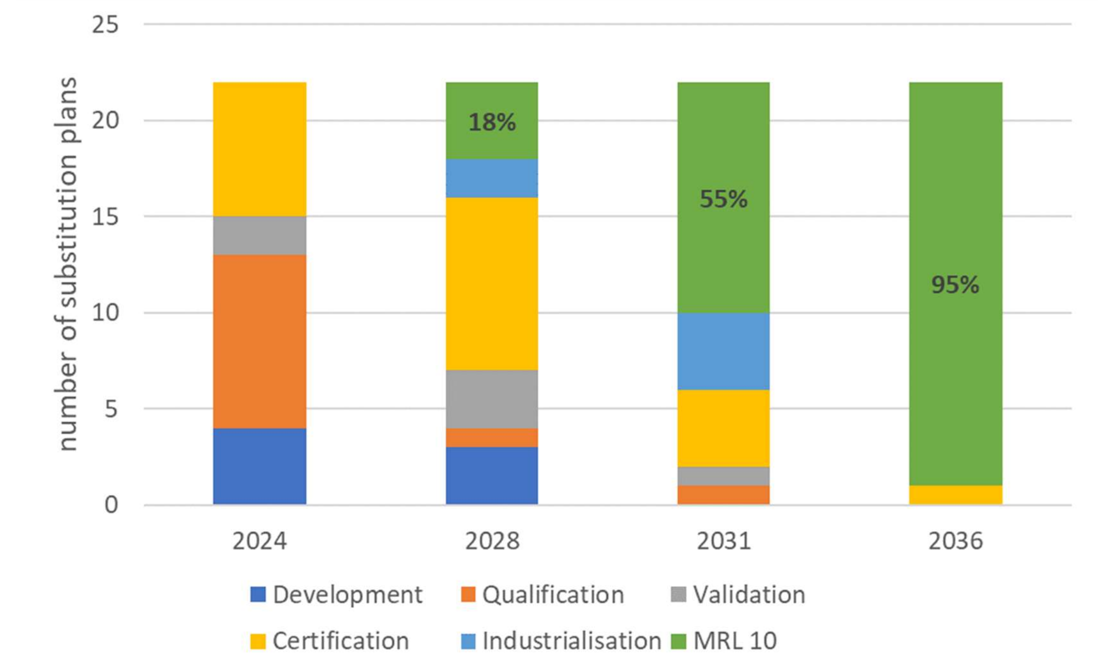


Figure 3-8: Expected progression of substitution plans for the use of Cr(VI) in passivation of non-aluminium metallic coating, by year.
The vertical axis refers to number of substitution plans (some members have multiple substitution plans for passivation of non-aluminium metallic coating). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which it is expected that Cr(VI) will be fully substituted under the relevant plan.
***Source:* RPA analysis, ADCR members**

The above summary shows:

- Variation in the status of different substitution plans in each of the years (this variation is due to issues such as technical difficulty (including consequential compatibility issues), types of non-aluminium metallic coatings, types of parts); and
- Expected progression in future years as an increasing proportion of the substitution plans reach MRL 10.

The dates at which each substitution plan is expected to achieve each stage are estimates provided by the members based on each members' substitution plans, and there are uncertainties due to, for example, unexpected technical failures which may only reveal themselves at more advanced stages of testing (see description of TRL stages in Section 3.1.2). Consequently, the expected progress of substitution plans, especially in the outer years 2031 and 2036 where there is more uncertainty, may be slower (or faster) than estimated today, as presented in figure 3-8. The actual status of the substitution plans 12 years from now could be different to our expectations today.

Because many members have multiple substitution plans for passivation of non-aluminium metallic coating, it is the case that for those substitution plans that are not expected to have achieved MRL 10 by a given date, other substitution plans from the same member will have progressed to this level. This highlights the complexity of multiple substitution plans within members resulting from differences in, for example, type of non-aluminium metallic coating, types of components and type of test candidate being developed.

There are various factors that affect the progress of these substitution plans. Key technical reasons are related to the type of non-aluminium metallic coating and type of component being treated and include the requirement to meet torque requirements for threaded components/connectors. Some types of components for military applications do not yet achieve the required final colour of the coating. Process limitations include the requirement to complete the process of validation, certification, qualification, and industrialisation, including identification and qualification of suppliers.

The timeframes associated with the activities presented in Figure 3-8 result from the requirements of the substitution process which are presented in Section 3.1.2. To be noted is that approval of suppliers cannot always occur in unison; qualification may need to cascade down the supply chain depending upon the number of tiers and actors involved. As resources are not available to action this simultaneously across all suppliers, the timescale for supplier qualification may be extended. Modifications may be required to the supply chain to allow for the installation of new equipment in some cases, although this can be mitigated by sourcing from existing established suppliers familiar with the requirements of qualification protocols.

3.9.2.2 Requested review period

It can be seen in Fig. 3-8 that despite ongoing and concerted efforts of the members to develop alternatives to Cr(VI) in passivation of non-aluminium metallic coating, it has not proved possible to replace Cr(VI) by the end of the review periods granted in the parent Authorisations (which end in September 2024). It is clear from the chart that in 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a significant proportion of the substitution plans (45%) are not expected to have achieved MRL 10 and are expected to be at the qualification, validation, certification or industrialisation stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

As a result of the individual members' substitution plans summarised above, **the ADCR requests a review period of 12 years for the use of Cr(VI) in passivation of non-aluminium metallic coating.**

4 Continued use scenario

4.1 Introduction

Section 3 provided an analysis of the alternatives with respect to the technical feasibility, economic feasibility, availability and suitability of alternatives. The assessment highlights the importance of Cr(VI) to the mode of action for corrosion protection and the other key functions delivered by passivation, in its application to non-aluminium metallic coatings such as cadmium and zinc. Although some of the companies supporting this use have implemented alternatives at the industrial level (e.g., Cr(III) alternatives) for some components, this is not across all components or products given varying geometries, operational performance requirements and types of non-aluminium metallic coatings.

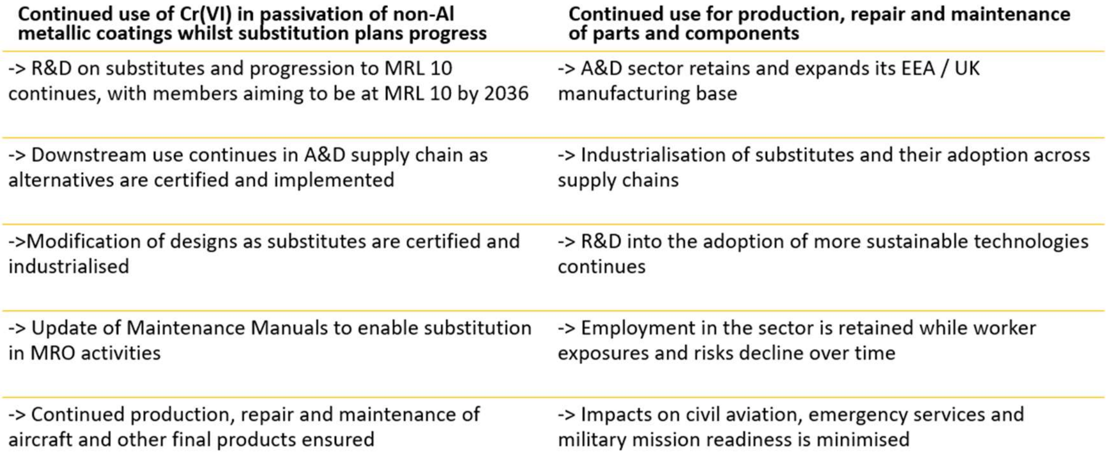
Until alternatives which are compatible also with pre- and post-treatment steps as relevant, and which deliver an equivalent level of functionality (as required) on all substrates are tested, qualified, validated and certified for the production of components and products, use of the Cr(VI) chromates in passivation will continue to be required; their use is essential to meeting airworthiness and other safety requirements. Even then, issues may remain with legacy spare parts and where certification of components using alternatives is not technically feasible or available due to design control being held by MoDs, who will not revisit older designs in the near future.

In some cases, alternatives are technically qualified and certified but time is needed to industrialise and implement them across all industrial sites in the value chain, implementation itself may take several years).

Even then, issues may remain with legacy spare parts and where certification of components using alternatives is not technically feasible or available due to design control being held by MoDs, who will not revisit older designs in the near future.

As demonstrated by the substitution plan, MRL 10 is expected to be achieved in some cases by 2028, but in other cases is not expected to be reached until 2031 or 2036. Even in 2036, there are some cases where substitution plans are not expected to have reached MRL 10. As a result the aerospace and defence industry and its supply chains require at least a further 12-years to complete substitution across all components and final products.

The continued use scenario can be summarised as follows:



Continued use of Cr(VI) in passivation of non-Al metallic coatings whilst substitution plans progress	Continued use for production, repair and maintenance of parts and components
-> R&D on substitutes and progression to MRL 10 continues, with members aiming to be at MRL 10 by 2036	-> A&D sector retains and expands its EEA / UK manufacturing base
-> Downstream use continues in A&D supply chain as alternatives are certified and implemented	-> Industrialisation of substitutes and their adoption across supply chains
->Modification of designs as substitutes are certified and industrialised	-> R&D into the adoption of more sustainable technologies continues
-> Update of Maintenance Manuals to enable substitution in MRO activities	-> Employment in the sector is retained while worker exposures and risks decline over time
-> Continued production, repair and maintenance of aircraft and other final products ensured	-> Impacts on civil aviation, emergency services and military mission readiness is minimised

The remainder of this section provides supporting information to describe the Continued Use Scenario:

- The market analysis of downstream uses in the aerospace and defence markets;
- Annual tonnages of the chromates used in passivation, including projected tonnages over the requested review period; and
- The risks associated with the continued use of the chromates.

4.2 Market analysis of downstream uses

4.2.1 Introduction

The A&D industry has separately and jointly assessed and continues to review its needs to ensure:

- the ability to carry out the specific processes required to manufacture, maintain, and repair aircraft in the EEA/UK; and
- continuity of supply of critical products containing hexavalent chromium.

The requirements of the ADCR members – as downstream users - supporting this application have been carefully identified and analysed, taking as the starting point the parent authorisations and the substance-use combinations covered by those. Over the lifetime of the ADCR consortium, the number of uses identified as requiring authorisation and the number of OEMs and downstream users supporting each use has decreased (including the individual Cr(VI) chromate substances involved in a use), to ensure that authorisation is only sought for those cases where there is no substitute that is fully qualified as per stringent airworthiness requirements and industrialised by all members and their supply chains. The continual re-visiting of supply chain requirements fed into the narrowing of the substance-use combinations requiring re-authorisation compared to the original applications for authorisation.

Furthermore, the scope of this combined AoA/SEA is driven by A&D qualification, validation, and certification requirements, which can only be met by use of the substances/formulations that provide the required performance as mandated by airworthiness authorities. This constrains OEMs, DtBs, and hence their suppliers and MRO facilities (civilian and military), to the use of the Cr(VI) chromates in passivation until alternatives can be qualified and certified across all the relevant components. In many cases, the choice of substances and mixtures to be used is further affected by the fact that they form part of a process flow (see Figure 2-2), which has been developed over time to meet specific performance requirements as part of ensuring airworthiness.

4.2.2 Overview of the European aerospace sector

In 2020, the European A&D industry comprised over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[35]). As noted by the European Commission, the industry is "characterised by an extended supply chain and a fabric of dynamic small- and medium- sized enterprises throughout the EU, some of them world leaders in their domain"[36].

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[35] Further information on the UK is provided in Annex 3.

[36] https://ec.europa.eu/defence-industry-space/eu-aeronautics-industry_en

Figure 4-1 provides details of turnover and employment for the industry in 2020, based on the Aerospace and Defence Industries Association of Europe (ASD) publication "2021 Facts & Figures".[37]

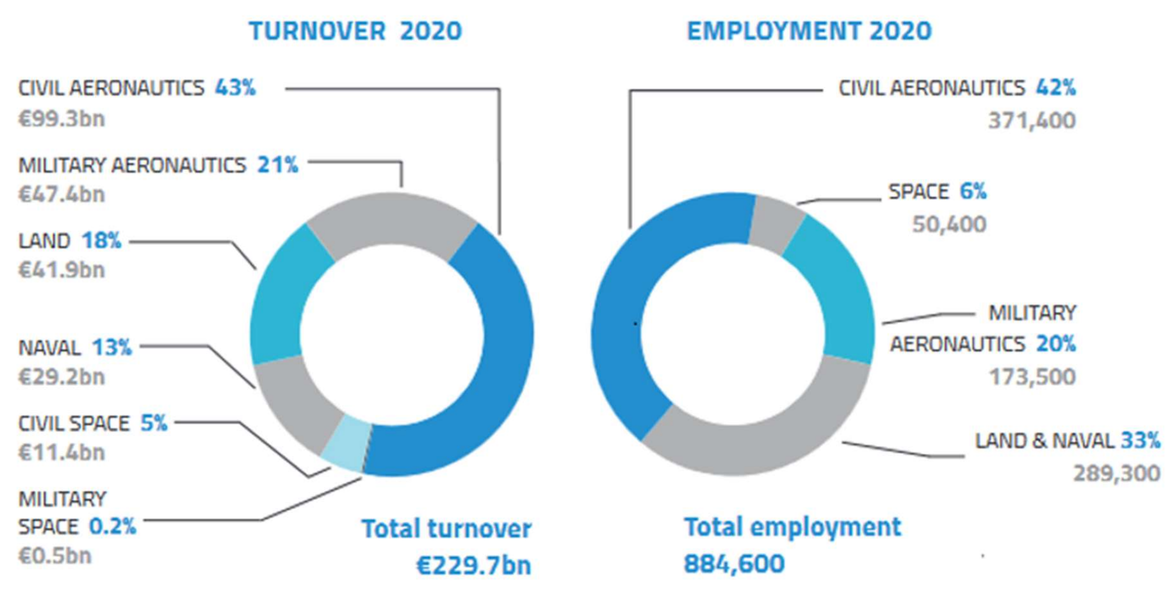

Figure 4-1: Turnover and Employment for the European Aerospace and Defence Industry in 2020
Based on ASD, 2021, available at: https://www.asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

As can be seen from Figure 4-1, civil and military aeronautics alone accounted for 64% of turnover and 62% of employment for the sector in 2020.

Civil aeronautics alone accounted for over 370,000 jobs, revenues of over €100 billion and exports of €90 billion. Note, these figures are lower than those for 2019, reflecting the impacts of COVID-19 on the sector. For example, the 2019 figures for civil aeronautics were around 405,000 jobs and €130 billion ($ 140 billion, £116 billion) in revenues, with exports amounting to around €110 billion ($120 billion, £96 billion).

The defence industry accounted for around 462,000 jobs, revenues of over €120 billion and exports of €45 billion. These figures reflect reductions in exports, employment and revenues compared to 2019, stemming from the impacts of COVID-19 on the sector.

The A&D sector is therefore recognised as important to the ongoing growth and competitiveness of the EEA and UK economies. It is also recognised that both require long-term investments, with aircraft and other equipment being in service and production for several decades:

- Aircraft and other A&D products remain in services over long time periods. For example, the Boeing 747 first entered service in 1970, and continues to be flown and produced today. Given the need to ensure on-going airworthiness and due to certification requirements, there will continue to be a "legacy" demand for the use of chromates in the production of parts for maintenance of existing aircraft and equipment, as well as for models that are still in production long periods after the first aircraft being placed on the market;

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[37] ASD, 2021: Facts & Figures, available at: https://www.asd-europe.org/facts-figures. From 10th November 2022 the ASD changed its name to the Aerospace, Security and Defence Industries Association of Europe

- A&D technologies take many years to mature. Product development is a five- to ten-year process, and it can take 15 years (or more) before the results of research projects are applied in the market. New platform developments are becoming more infrequent too. Suppliers have to be ready to demonstrate mature technology, or they risk losing contracts that may have a lasting effect on business.[38]

- The long product development process applies not only to the introduction of new technologies, but also to any activities aimed at adapting existing technologies as required for the substitution of the safety critical uses of the chromates. As indicated in Section 3.3 on R&D activities, research on substitution of the chromates has been underway for several decades, with the substitution of the chromates in passivation processes proving one of the most difficult tasks due to its “system” relationship with the chromate-based primers.

- There are over 20,000 commercial aircraft and 15,000 business jets currently in operation globally. Given the global nature of civil aviation in particular, it is important that global solutions are found to the use of the chromates, in particular with respect to maintenance, overhaul and repair operations (MRO). Actors involved in MRO activities must adhere to manufacturers’ requirements and ensure that they use certified parts and products. They have no ability to substitute away from the chromates where these are mandated by the original equipment manufacturers.

4.2.3 Economic characteristics of companies undertaking passivation of non-aluminium metallic coatings

4.2.3.1 Profile of Downstream Users

Passivation is a critical use of chromates in for example the corrosion protection of non-aluminium metallic coatings including cadmium and zinc which are applied over base metals including steel and copper. These non-aluminium metallic coatings are used on key components such as landing gear. As a treatment, it is therefore likely to be carried out across a significant number of aerospace and defence sites within the EEA and within the UK. SEA respondents are involved the manufacture of:

- Air pressure systems;
- Aircraft engines;
- Aircraft flight control and thrust reverser equipment;
- Aircraft fuel control systems and engine control units;
- Auxiliary power units;
- Ball screw assembly;
- Cockpit equipment;
- Environmental control systems;
- Fluid management systems;
- Heat exchangers;
- Horizontal stabilizer actuator systems;
- Hydraulic flight control;
- Landing gear;
- Propeller systems; and

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[38] ATI (2017): The Economics of Aerospace: The Economic Impacts of UK Aerospace Industrial Strategy.

- Wheels and Brakes.

SEA questionnaire responses were provided by 25 aerospace and defence companies undertaking passivation across the EEA and UK. These companies operate across 23 sites in the EEA and nine sites across the UK (32 in total). Table 4–1 provides an indication of numbers by role in the supply chain size of company. As might be expected by the composition of the ADCR, respondents to the SEA survey tended to be medium and larger sized companies within their sectors of activity. The number of responses covering MROs also is low compared to what might be expected.

Table 4–1: Numbers of SEA respondents undertaking passivation

Role (and total number of sites)	**Number of companies/sites undertaking passivation**				**Company Size**[39]	
	EEA		**UK**		**EEA**	**UK**
	Companies	**Sites**	**Companies**	**Sites**	**Companies**	**Companies**
Build-to-Print (5 in total)	2	2	3	4	1 small 1 medium	1 small 1 medium 1 large
Design and build (5 in total)	4	4	1	1	1 micro 2 small 1 medium	1 medium
MRO only (10 in total)	8	8	1	2	2 medium 6 large	1 medium
OEM (11 in total)	4	9	2	2	1 medium 3 large	1 medium 1 large
Total *	18	23	7	9		
*Some of the OEMs members have sites in both the EU and UK. In total, 25 companies provided a response, but some reported for the purposes of both EU and UK REACH. There is therefore overlap in the number of companies but there is no overlap in the figures given for the number of sites.						

The above figures also highlight the importance of small and medium sized companies within the supply chain, with these comprising over half of the responses (taking into account the fact that it is mainly the larger companies that have legal entities in both the EEA and UK).

As would be expected by the composition of the ADCR and by the nature of their key suppliers, respondents to the SEA survey tended to be the medium and larger sized companies within their sectors of activity.

4.2.3.2 Economic characteristics

Table 4–2 provides a summary of the number of companies identifying their activities against different NACE codes, which are used here to develop the economic characteristics of the "typical" OEM, DtB, BtP or MRO company. Companies may have indicated more than one NACE code as being relevant to their activities, such that the number of relevant NACE code counts is higher than the number of SEA responses relevant to passivation alone. It is notable that most companies identified "treatment and coating of metals" as a relevant NACE code, while at the same time identifying other relevant codes.

The table also provides relevant Eurostat data for each code on turnover (weighted average provided here, based on % of respondents by company size), Gross Value Added (GVA) per employee, average personnel costs and average GOS as a percentage of turnover.

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[39] https://ec.europa.eu/growth/smes/sme-definition_en

Table 4–2: Economic characteristics of "typical" companies by NACE in sectors involved in Passivation (2018 Eurostat data, covering the EU 28)

	Number of responses by NACE code	Weighted average turnover per company € million	GVA per employee - €	Average personnel costs per employee -€	Average GOS as a % of turnover
C2561 – Treatment and coating of metals	20	20.88	54,000	35,500	15.5%
C2540 – Manufacture of weapons and ammunition	0	306.44	70,000	42,500	12.3%
C2594 – Manufacture of fasteners and screw machine products	2	57.20	65,000	43,200	9.7%
C2599 – Manufacture of other fabricated metal products n.e.c.	6	57.20	65,000	43,200	9.7%
C265 - Manufacture of instruments and appliances for measuring, testing and navigation;	1	159.30	84,000	57,500	11.1%
C2815 – Manufacture of bearings, gears, gearing and driving elements	5	284.64	72,000	44,500	4.8%
C3030 – Manufacture of air and spacecraft and related machinery	6	1,214.65	98,000	76,400	7.9%
C3040 – Manufacture of military fighting vehicles	3	1,214.65	99,000	64,800	11.2%
C3316 – Repair and maintenance of aircraft and spacecraft	10	71.33	85,000	56,400	9.8%
Other	1	NA	NA	NA	8.4%
Total count	54				
Note: The count total is by number of NACE code identifications by company and not by sites, with 79 companies providing data					

Turnover is calculated as the weighted average by company size, as this is the most appropriate means of reflecting the level of turnover across the EEA (including UK) linked to passivation treatments and taking into account the size distribution of the companies[40] that are involved in such activities. GVA per employee, numbers of employees, and average personnel costs are given as the sector average and not per company size for several of the NACE codes, so it was not possible to calculate weighted averages for these. Note that the count total is by company and not by site.

Data on Gross Operating Surplus[41] (GOS) as a percentage of turnover (the GOS rate) is also used here to provide an indication of the profits associated with the turnover generated by these sites. This is based on a figure of 11% which is an average across the various NACE codes weighted by the number of companies declaring each NACE code.

As can be seen from Table 4–3, the 32 sites for which data were collected via the SEA questionnaire represent an estimated €14,900 million in turnover and €1,600 million in GOS as a proxy for profits. Across all 130 sites expected to be undertaking passivation in the EEA and UK, these figures rise to around €53,600 million in turnover and €5,900 million in GOS.

Table 4–3: Key turnover and profit data for market undertaking passivation (based on 2018/2019 Eurostat data)

Sites covered by SEA responses/ Extrapolated number of sites	**Estimated turnover based on weighted average € million**	**Gross operating surplus (estimate based on 11%) € million**
23 EEA Sites	11,936	1,313
9 UK sites	2,933	323
Extrapolation to all sites involved in chromate-based passivation in the EEA or UK		
100 EEA sites	45,291	4,982
30 UK sites	8,259	908

Source: Based on SEA questionnaire responses, combined with Eurostat data
Note: See Section 2.3.3.6 for basis of extrapolation from the 32 responses to 130 sites in the EEA and UK combined

4.2.3.3 Economic importance of passivation of non-aluminium metallic coating to revenues

Passivation of non-aluminium metallic coatings will only account for a percentage of the calculated revenues, GVA and jobs given in Table 4–3. To understand its importance to the activities of individual companies, a series of questions were asked regarding other processes carried out, production costs, and the share of revenues generated from the use of chromates in passivation.

Responses to the SEA questionnaire indicate that passivation of non-aluminium metallic coatings, as well as inorganic finish stripping as a pre-treatment, are important particularly in respect to turnover. At least 50% of companies providing passivation also undertake inorganic finish stripping using chromates. For OEMs this increases to 60%. Not all companies will be using inorganic finish stripping

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[40] Microenterprises have been excluded from the turnover calculations as very few such enterprises will be acting as key suppliers within the supply chain. The calculations taken into account the percentage of turnover for each relevant sector attributed to small, medium and large companies to derive the average weighted per site by role figures used in these calculations.

[41] EUROSTAT defines the GOS rate (i.e., % of turnover) as an indicator of profits. GOS equals gross output (turnover or gross premiums in Eurostat)) less the cost of intermediate goods and services to give gross value added, and less compensation of employees and taxes and subsidies on production and imports. It is gross because it makes no allowance for consumption of fixed capital (CFC).

with chromates as a pre-treatment, however, MROs will likely be using inorganic finish stripping to remove surface treatments prior to other main treatments as part of maintenance and repair. As previously stated, the need for specific pre-treatments will depend on EASA certifications and OEM requirements.

- One BtP company indicated that passivation represents less than 5% of their production cost, another indicated between 21% and 30% and another indicated over 75%. Of those that responded, two stated that inorganic finish stripping equated to more than 75% of production costs (as it is a pre-treatment for more than just passivation of non-aluminium metallic coatings), one stated less than 5%.
- Four DtBs indicated that passivation only equated to less than 5% of production costs, while another indicated between 51% and 75%. One of the companies additionally undertaking chromate based inorganic finish stripping stated that production costs from that process were between 21% and 30%.
- For MRO activities, four firms indicated that passivation equated to less than 5% of product costs, three indicated between 5% and 10% and one over 75%. Three firms additionally undertaking inorganic finish stripping state that this is less than 5% of production costs, and one indicates over 75%.
- Three responses from OEMs suggest that passivation equates to less than 5% of production costs. One company indicated between 5% and 10%, one between 11% and 20% and one 76% and 100%. Of the companies that perform both passivation and inorganic finish stripping, most suggested that passivation and inorganic finish stripping have equal production costs.

Table 4-4 provides a summary of the number of companies reporting the proportion of their revenues generated by the chromate using activities (all such activities carried out at the site, as companies were unable to provide separate figures at a use-by-use level). As can be seen from the table, the majority of firms indicate that over 75% of their revenues are attributed to chromate using processes. Only two suggest that less than 10% of their revenues are attributed to their chromate using processes. This includes but is not limited to passivation of non-aluminium metallic coatings.

Table 4-4: Number of companies reporting proportion of revenues generated by chromate using processes

	<10%	10% - 25%	25% - 50%	50% - 75%	>75%	No Response
Build-to-Print	0	0	0	1	3	1
Design-to-Build	0	0	1	0	4	0
MROs only	1	2	0	2	3	1
OEMs	0	0	1	1	3	1

The figures given in Table 4-4 also reflect the fact that some of the Build-to-Print and Design-to-Build companies will use chromate-free processes where they are able to in line with OEMs' performance requirements and EASA certifications/military qualifications. In addition, some of these companies will carry out surface treatment activities for sectors other than aerospace and defence. This includes producing parts and assemblies for e.g., machinery, food manufacturing, medical equipment, automotive uses, oil drilling and electrical equipment, which may or may not also involve the use of chromates.

4.2.3.4 Investments in alternatives, risk management measures and monitoring

4.2.3.4.1 OEMs

OEMs have carried out R&D into the substitutions of the chromates for over 30 years, but as detailed in the AoA, technical difficulties remain in use of alternatives to chromium trioxide, potassium dichromate and sodium dichromate in passivation of non-aluminium metallic coating. Although some have developed, validated, qualified and are currently certifying alternatives for use in the manufacture of their final products, others are still in the testing and development phase. These differences are driven by differences in operating performance requirements, geometries, and the type of non-aluminium metallic coatings across final products.

One example of OEM investment into capital equipment for use of Cr(VI) chromates is in new lines for passivation, including the tanks and electrical infrastructure. This has cost €315,000 and took place over 2021 and 2022, with an expected lifetime of eight years. Some OEMs have invested in automation of production lines and additional tanks at costs of hundreds of thousands (e.g., over €400,000) in 2018 and 2019. Such investments are expected to last 12 years.

Additionally, OEMs have made investments in improved PPE, ventilation, automatic time counters and tank covers for enhanced safety of workers. This has cost an average of €180,000 from 2019 to 2021.

4.2.3.4.2 Design-to-Build suppliers

DtB companies have carried out R&D into alternatives for passivation of non-aluminium metallic coating either themselves or in cooperation with their customers or suppliers (i.e., the OEMs), with the other relying on R&D carried out by their customer. This has included repurposing plant to enable pilot trial activities, as well as participation in some of the research initiatives described in Section 3.

Reasons given in responses to the SEA questionnaire by suppliers to ADCR members for not moving to alternatives include: the need for the alternative to be qualified; the alternative not being available on the market in sufficient quantities; the need for additional time to implement the alternative (i.e., to invest in new equipment and gain certifications from their customer); and the alternative not being acceptable due to inadequate technical performance. Those who cannot move cite the need for "years" until substitution is feasible.

One example of investments into equipment for the chromate using process, includes €800,000 in 2018 for National Aerospace and Defence Contractors Accreditation Program (NADCAP) required equipment. Suppliers have also invested in new bath coverings, separation of production areas, improved PPE and trials to substitute solid Cr(VI) with liquid. This has cost in the region of €17,000 over the past two years. Design-to-Build suppliers have also invested in NADCAP certification and worker exposure measures, which has cost between €4,500 and €400,000. These investments were made in 2018 and 2021.

4.2.3.4.3 Build-to-Print suppliers

BtP suppliers rely on their customers (OEMs and/or DtBs) to mandate the requirements of the products they manufacture, with this including the use of chromates in passivation. As a result, BtP suppliers have little involvement in R&D activities, unless they are supporting R&D activities such as pilot testing the use of an alternative.

Build-to-Print suppliers have made investments to improve their chromate using process, including investment in new tanks in 2017 to a cost of £750,000. This investment is expected to last 10 years.

Additionally, Build-to-Print suppliers have contributed to Research and Development into alternatives to cadmium and chromate passivate with OEMs including rewriting new specifications. This cost £250,000 and took place over 2020 and 2021, expecting to have a lifetime over 20 years. Others have spent in the region of €600,000 on research and development into alternatives since 2020.

It should also be noted that some of these suppliers will have to be National Aerospace and Defense Contractors Accreditation Program (NADCAP) accredited and will be subject to International Standards Organisation (ISO) audits of their processes using the chromates, in order to secure and hold accreditations/certifications required by their customers (in other cases, the OEM will qualify/certify their suppliers rather than require NADCAP accreditation). This expenditure varies by company size, with related costs quoted as varying from e.g., €7,000 to €70,000 per company.

4.2.3.4.4 MROs

As would be expected given their role in the value chain, MROs have not been involved in R&D regarding substitution of the chromates in passivation of non-aluminium metallic) coatings.

MROs have undertaken significant investments into new equipment which includes new baths, chemical products, bath analyses and equipment maintenance. These costs are quoted as around €80,000, with investment starting in 2019. Another example of investment includes emissions monitoring equipment at €30,000 in 2021. These firms have also invested into control of exposure and environmental monitoring and stack emission improvements such as new ducting, capture ducts and abatement systems. These cost at least €35,000 and investment started as early as 2011.

One MRO states that they have a team of four people looking into alternatives, and therefore have costs relating to laboratory and semi-industrial scale tests. This includes test pieces, chemical products, bath analyses, tanks, laboratory equipment and characterisations of the treated parts/specimens.

4.2.3.5 Potential benefits from on-going substitution under the Continued Use Scenario

In addition to collecting information on economic characteristics, companies were also asked whether they expected there to be potential benefits (under the continued use scenario) in the future with a move to alternatives once these had been certified for their components and products and implemented. A range of potential types of benefits were identified in the SEA questionnaire, with companies asked to identify those that they thought might arise as progression is made in the substitution of the chromates.

Across respondents, regardless of role in the supply chain, the majority of companies identified better relations with authorities as a benefit. Significant numbers also identified better public, shareholder and community relations, with this identified as particularly important by the OEMs and DtB companies. Increased customer satisfaction was identified by some DtB companies.

4.2.4 End markets in civil aviation and defence

4.2.4.1 Importance to end markets

The use of passivation of non-aluminium metallic coatings provides extremely important corrosion resistance properties (as well as the other properties discussed in Section 3) to civil aviation and other aerospace products that must operate safely and reliably, across different geographies, often in extreme temperatures and precipitation, and in aggressive environments with a high risk of corrosion (due to extreme temperatures, precipitation, and altitudes).

Because the use of the chromates in passivation cannot be fully substituted at present, they play a critical role in ensuring the reliability of aircraft and of meeting safety standards. Thus, although the economic importance of the chromates in passivation is indirect in nature, its significance is clear with respect to:

- The ability of MROs (civilian and military) to undertake their activities within the EEA and UK, with this including the ability to carry out repairs with short turn-around times;
- The importance of timely MRO services to airlines and military fleets, reducing the amount of time that aircraft are grounded or are out of service;
- The impacts that increased groundings of aircraft (Aircraft on the Ground - AoG) would have on the availability and costs of flights for passengers and for cargo transport, with reductions in passenger km and cargo km translating into significant economic losses not just within the EEA and UK but globally; and
- The importance of timely MRO services for military forces, given the critical importance of mission readiness and the avoidance of impaired operations, which could only otherwise be guaranteed by the purchase of additional aircraft and weapon systems to compensate for AoG or systems out of service.

The economic importance of ensuring that aircraft retain their airworthiness is illustrated by the figures quoted in Section 2 for the number of air passengers transported in the European Union in 2019 (over one billion), as well as the net profits of the airlines in 2019 at US$ 6.5 billion (€5.8 billion, £5.1 billion).

The military importance of ensuring that military aircraft, land, and naval hardware maintain their mission readiness cannot be quantified in the same manner; however, the involvement of MoDs (as well as the MROs supporting military forces) in preparing this combined AoA/SEA through the provision of information that demonstrates the critical nature of chromate-based passivation of non-aluminium metallic coating to the on-going preparedness of their military forces in particular.

4.2.5 Expected growth in the EEA and UK aerospace and defence sectors

4.2.5.1 Civilian aircraft

Demand for new civilian aircraft is expected to grow. Projected global compound annual growth rates for different aircraft classes for the period 2020-2031 are given in the Figure 4-2[42], with this suggesting an overall rate (CAGR) from 2020 to 2031 of around 2.5%.

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[42] Oliver Wyman Analysis (2021): https://www.oliverwyman.com/our-expertise/insights/2021/jan/global-fleet-and-mro-market-forecast-2021-2031.html

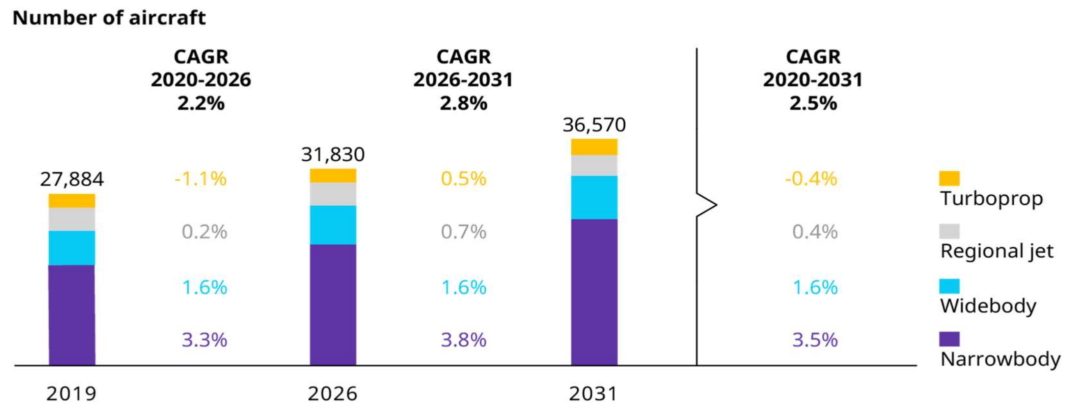

Figure 4-2: Global fleet forecast by aircraft class, 2020-2031
***Source:* Oliver Wyman analysis**

Market reports issued by Airbus and Boeing indicate that future growth is expected to extend beyond 2031. Airbus' Global Market Forecast for 2022-2041 predicts that passenger air traffic will grow at 3.6% CAGR and freight traffic will grow at 3.2% CAGR globally. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets in particular.[43]

Boeing's 2022 Commercial Market Outlook[44] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR).

Based on public figures available on Airbus' website, the demand for new aircraft will progressively shift from fleet growth to accelerated replacement of older, less fuel-efficient aircraft. This will mean a need for over 39,000 new passenger and freighter aircraft, delivered over the next 20 years - around 15,250 of these will be for replacement of older less fuel-efficient models. By 2040, the vast majority of commercial aircraft in operation will be of the latest generation. Projections based on generic neutral seating categories (100-plus seater passenger aircraft and 10-plus tonnes freighters) are given in Table 4-5 below.

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[43] https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf
[44] https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

Table 4-5: Airbus Global Market Forecast: projected new deliveries 2021-2040

Category	Africa	Asia-Pacific	CIS	Europe	Latin America	Middle East	North America	Total
Pax Units								
Small	860	13,660	1,160	5,220	2,170	1,570	5,050	**29,690**
Medium	140	2,350	120	1,040	180	420	640	**4,890**
Large	80	1,380	80	600	100	980	340	**3,560**
Total	**1,080**	**17,390**	**1,360**	**6,860**	**2,450**	**2,970**	**6,030**	**38,140**
Freight Units								
Small	-	-	-	-	-	-	-	**-**
Medium	10	120	40	40	10	20	210	**450**
Large	10	110	40	60	-	30	180	**430**
Total	**20**	**230**	**80**	**100**	**10**	**50**	**390**	**880**
Total Units								
Small	860	13,660	1,160	5,220	2,170	1,570	5,050	**29,690**
Medium	150	2,470	160	1,080	190	440	850	**5,340**
Large	90	1,490	120	660	100	1,010	520	**3,990**
Total	**1,100**	**17,620**	**1,440**	**6,960**	**2,460**	**3,020**	**6,420**	**39,020**

Source: Ascend, Airbus (undated): Global Market Forecast 2021 – 2040. Available at: https://www.airbus.com/en/products-services/commercial-aircraft/market/global-market-forecast

When considering these figures, it is important to recognise that the European aerospace sector is a global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. For example, France and Germany alone had export markets totalling over US$57 billion in 2020, while the UK export market was around US$13.2 billion in 2020.[45]

However, unless operations in the EEA and UK can remain technically and financially viable in the short to medium term, the ability of EEA/UK based OEMs to carry out manufacturing at the levels implied by these compound annual growth rates is unlikely to be feasible. As a result, manufacture of the newer generations of aircraft and military products may shift to locations outside the EEA/UK with a consequent loss in GVA to the EEA and UK economies, with enormous impacts on employment. This is despite the fact that the move to newer generation aircraft which could reduce future reliance on the chromate-based passivation of non-aluminium metallic coating.

4.2.5.2 The MRO market

Not only would the manufacture of new aircraft in the EEA and UK be impacted but anticipated growth in the aftermarket parts segment would also be affected. The aircraft spare components/final product market encompasses the market for both new and used rotable[46] components available as spares for aircraft and other products. This market was projected to grow with a CAGR of over 4% over the period from 2022-2027, although this rate may now be lower due to COVID-19. Growth is due to the increase in the commercial aircraft fleet as well as the need for timely MRO services to keep aircraft in service.

The MRO market was significantly affected by COVID-19 in 2020 but saw a gradual increase in demand as travel restrictions were lifted in 2021 and is expected to see positive growth over the next five to

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[45] https://www.statista.com/statistics/263290/aerospace-industry-revenue-breakdown/

[46] A component which is removed and replaced at pre-determined intervals measured in elapsed flight hours and/or flight cycles after which the removed item is sent for overhaul and will be subsequently re-used.

ten years. Globally, the market is expected to have a CAGR of over 3% over the period from 2022-2027, as illustrated in Figure 4-3.[47, 48]

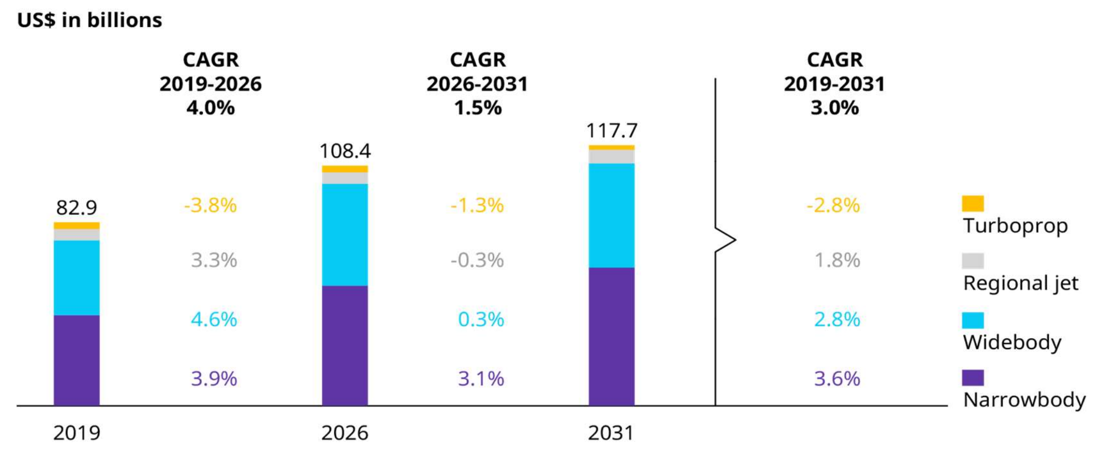

Figure 4-3: MRO market forecast by aircraft class, 2019-2031
Source: Oliver Wyman analysis

This growth is due to three factors:

- Airlines are risk averse and try to maintain their fleets in an optimum condition, so as to delay the need to procure new aircraft, owing to the high investment costs of such aircraft. With COVID-19 severely impacting revenues and profit margins, more airlines are expected to resort to MROs to maintain fleet efficiency;
- Airlines face very stringent MRO requirements so are not able to postpone MRO requirements; and
- Increases in fleet sizes over the next five years will also lead to a continued growth in demand for maintenance and repair activities.

4.2.5.3 The defence market

The war in Ukraine has led to several EEA countries and the UK to revisit their defence expenditure. In particular, several countries that are NATO members and which previously did not meet the target of spending 2% of GDP on defence are now committed to meeting that target. This compares to Eurostat figures for total general government expenditure on defence in 2020 of around 1.3% of GDP for the EU[49]. The increase in investment will equate to hundreds of billions of Euros (e.g., Germany alone has pledged €100 billion in defence spending). Similarly, defence spending in the UK is expected to increase to over 2%, with projections in June 2022 suggesting 2.3% of GDP but Government

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[47] Mordor Intelligence, Commercial Aircraft Maintenance, Repair, and Overhaul (MRO) Market – Growth, Trends, COVID-19 Impact and Forecasts (2022 - 2027)

[48] Oliver Wyman analysis: at: A forecast update on the global commercial airline fleet and aftermarket for 2020

[49] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Government_expenditure_on_defence

commitments announced in October 2022 aiming for a target of 3% of GDP by 2030[50]. This equates to an increase in spending of around £157 billion between 2022 and 2030.

Such investment, which will include new spending on existing technologies, may also result in a continued reliance on the use of the chromates for passivation in the short to medium term until alternatives are certified for use in the manufacture of the relevant components and final products.

With respect to currently in-service products, the global military aviation maintenance, repair, and overhaul market registered a value of US $38 billion (€32 billion, £28 billion) in 2021, and it is expected to register a compound annual growth rate (CAGR) of over 2.5% during the forecast period 2022-2031. The European segment of this market is the fastest growing segment. The global civilian aircraft MRO market has a market size of US $70 billion (€59 billion, £51 billion) in 2021 and is growing even faster at a CAGR of over 4.6%.[51]

4.3 Annual tonnages of the chromates used

4.3.1 Consultation for the CSR

As part of preparation of the CSR, site discussions were held with ADCR members and a set of their key suppliers. This work included collection of data on the tonnages of the chromium trioxide, sodium dichromate and potassium dichromate used in passivation per site. The tonnages assumed in the range are from 0 to 480kg of Cr(VI) per year per site. This is based on:

- 0 to 250 kg CT used per year per sites;
- 0 to 1200 kg SD used per year per site; and
- 0 to 50 kg PD used per year per site.

At most sites SD is used for passivation of non-aluminium metallic coatings. As indicated above, the upper Cr(VI) tonnage/year has been estimated based on sites using several chromates for passivation of non-aluminium metallic coating. This will be an overestimation for sites using only one chromate. Data from consultation highlight the fact that most sites will use significantly less than the maximum values quoted above.

4.3.2 Article 66 notifications data

Under Article 66 of REACH, downstream users covered by an authorisation up their supply chain must notify ECHA of their use. As of 31 December 2021, ECHA had received 450 notifications relating to the REACH Authorisations listed in section 2 covering 587 sites across the EU-27 (and Norway).

The distribution of notifications by substance and authorisation is summarised in Table 4-6.

Table 4-6: Number of notifications

Substance	Authorisation	Authorised Use	Notifications	Sites
Chromium trioxide	20/18/14-20	Surface Treatment for aerospace	263	357
Potassium dichromate	20/3/1	Surface Treatment for aerospace	15	18

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[50] https://www.bloomberg.com/news/articles/2022-09-25/defence-spending-to-increase-by-at-least-52bn-in-response-to-russian-aggression or https://rusi.org/explore-our-research/publications/occasional-papers/famine-feast-implications-3-uk-defence-budget

[51] https://www.prnewswire.com/news-releases/at-4-61-cagr-aircraft-mro-market-is-expected-to-reach-usd-97-12-billion-to-2028---exclusive-report-by-brandessence-market-research-301500861.html

	20/2/1*	Surface Treatment for aerospace	53	61
Sodium dichromate	20/5/3-5	Surface Treatment for aerospace	61	84
	20/4/1*	Surface Treatment for aerospace	58	67
Totals			**450**	**587**

Source: Number of downstream uses covered by granted authorisations as notified to ECHA by 31 December 2021, data available from https://echa.europa.eu/du-66-notifications. Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for passivation, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.

**Use of sodium dichromate and potassium dichromate by the aerospace and defence industry under parent Authorisations, which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness*

Since there are more sites than notifications, it is assumed that some notifications cover more than one site[52]. It will be noted that the authorisations cover ‘surface treatment’ which extends more widely than just passivation of non-aluminium metallic coatings. As such the number of sites undertaking passivation of non-aluminium metallic coatings will be much less than the indicated 587.

Furthermore, some sites will be using more than one of the chromates for the passivation of non-aluminium metallic coatings lowering the figure further.

Of the 587 notified sites, 45 include reference to ‘passivation’ in the additional comments. However, this is usually just one activity in a list and/or relates to passivation of stainless steel (which is considered elsewhere). In terms of consumption figures, there are no entries suggesting consumption figures above one tonne per annum for the passivation of non-aluminium metallic coatings alone.

4.3.3 Consultation for the SEA

Based on the upper bound figures quoted in the SEA responses and extrapolating to the 100 EEA and 30 UK sites, also taking into account the maximums found in the CSR work, the maximum tonnages of the chromates used in passivation have been calculated. The maximum tonnes per annum (t/a) are as follows for 2024 (assuming no decline from 2022 levels):

For the EEA:

- 15 tonnes of CT;
- 50 tonnes of SD; and
- 12 tonnes of PD.

For the UK these figures would be:

- 5 tonnes of CT;
- 10 tonnes of SD; and
- 5 tonnes of PD.

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[52] Article 66 reporting is by legal entity, which can have multiple sites using a chromate for passivation. Closer inspection of the (publicly available) data from ECHA suggests that some sites are associated with confidential military activities. These may or may not be relevant to the ADCR given that members include Ministries of Defence (MoDs) and information has been provided by non-member military organisations.

4.3.3.1 OEMs

As noted in Section 3, the OEMs are progressing their substitution plans for the use of chromates in passivation processes. One of the OEMs states that they expect to see decreases in use by 2024. Two more OEMs expect to start decreasing use by 2028, and after 2030 four of the OEMs expected to have decreased use of chromates.

Three OEMs already use chromate free processes as alternatives to chromate-based passivation of non-aluminium metallic coatings where these are technically feasible (i.e., qualified and certified).

4.3.3.2 Design-to-Build

Four of the five Design-to-Build companies state that they expect some form of increase in usage at some point up to and beyond 2030. However, these companies were additionally impacted by COVID-19 and are expecting demand to return to normal. Other Design-to-Build suppliers indicate that they are unsure or expect usage to decrease. As with BtPs, the DtBs companies are reliant on the performance requirements set by the OEMs, although they have more flexibility in how they substitute where they are the design owner for a component or final product.

Four of the Design-to-Builds also undertake passivation using a chromate-free process where feasible.

4.3.3.3 Build-to-Print

The majority of BtP suppliers state that they expect use of chromates to decrease over the short term, however are unsure of their future use over the longer term. One of the companies expected consumption to reduce into the future, but they noted that their use depended on changes in their customers' (i.e., the OEMs') specifications.

Where feasible under current conditions, two of the Build-to-Print suppliers are already undertaking passivation using a Cr(VI)-free process.

4.3.3.4 MROs

The MROs also noted that the extent to which use of the chromates would be required up to and past 2032 depended on actions by design owners and whether and when substitutes become qualified and the maintenance/ repair of products certified.

MROs all indicated that they expected to require use of chromium trioxide, sodium dichromate and potassium dichromate for passivation purposes for a further 12 years. Across the respondents, some expected use to decrease, others to increase and the remainder for use to remain steady until OEMs had qualified and re-certified alternatives and updated their Maintenance Manuals.

Two of the MROs also use a Cr(VI) free process for passivating where appropriate and feasible.

4.3.4 Trends in use and projected future use of the chromates

The A&D sector is actively working to phase out the use of the three chromates. As indicated by the substitution plan, however, it will take further time to qualify, validate, certify implement alternatives within the supply chain across all components and products for A&D industry. Individual companies are at different points along this path, although this also varies by specific aircraft/defence application and across different types of components/final products.

Where possible, the use of chromate-based passivation in new designs is being phased out, however, aircraft that require their use remain in production and in service. As discussed above, increasingly new planes will be replacing older models, potentially reducing the on-going need for the use of chromate-based passivation where alternatives have proven to meet performance requirements or the need for passivation has been designed out. As a result, by 2036, the main uses should relate to any on-going MRO /legacy parts requirements for in-service aircraft or defence products.

Responses to the SEA questionnaire indicate a downward future trend in the use of the chromates over the review period despite the increase in demand for new aircraft and defence final products (although these responses were also provided prior to the war in Ukraine). As these do not account for the total volumes of the chromates used in passivation, it is not possible to give an overall percentage reduction in volumes consumed on a year-by-year basis across the market. As noted by respondents:

- *"A 12-year review period is required to allow further development of finishes which can provide a true replacement for cadmium, followed by the extensive testing and validation required to allow its use on the safety critical systems that cadmium is currently used on."*

- *"Products in the aviation industry are designed, manufactured, and maintained for use phases of several decades. In terms of civil aircrafts, such a use phase typically comprises 30-40 years. Even if new products - placed on the market in the short -/ medium term - might succeed in dispensing with the use of CrO3/Cr (VI) containing products already placed on the market (or until the expiration of the current review periods), still need to be maintained and repaired by applying binding maintenance specifications".*

- *"Unsuccessful attempts have been made in the past to replace cadmium in certain parts, the technical difficulty of this should not be underestimated. Finding and validating a new solution is expected to take a further 10 years beyond the current authorisation expiry.*

It is important to note though that the planned reduction in usage by the OEMs will also impact on their DtB and BtP suppliers and MROs, given that OEMs are key design owners and their requirements are the driver for all suppliers/MROs. With respect to their designs, as reported above, the DtBs expect usage of chromate-based passivation to decrease over the period to 2036.

4.4 Risks associated with continued use

4.4.1 Classifications and exposure scenarios

4.4.1.1 Human health classifications

The chromates shown were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate).

Chromium trioxide is classified as a Carcinogen 1A and a Mutagen 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. The substance is also classified as a Skin and Respiratory Sensitiser 1 and is a Reproductive Toxicant 2.

Sodium dichromate is classified as a Carcinogen 1B and a Mutagen 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. The substance is also classified as a Skin and Respiratory Sensitiser 1 and a Reproductive Toxicant 1B.

Potassium dichromate is classified as a Carcinogenic 1B, a Mutagen 1B, and as a Reproductive toxicant 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. It is also classified as a Skin and Respiratory Sensitiser 1.

Reproductive toxicity for the above chromates is an effect of oral exposure. However, according to information from the Chemical Safety Report (CSR), the calculated exposure levels were below the DNEL for reproductive toxicity. Therefore, the risks associated with that endpoint are considered adequately controlled and as such it will not be examined further in this SEA.

The hazard evaluation follows recommendations given by RAC [53]:

- For assessing carcinogenic risk, exposure-risk relationships are used to calculate excess cancer risks; and
- As mutagenicity is a mode of action expected to contribute to carcinogenicity, the mutagenic risk is included in the assessment of carcinogenic risk, and low risks for mutagenicity are expected for exposures associated with low carcinogenic risks.

4.4.1.2 Overview of exposure scenarios

Due to the different levels in the supply chain to which the individual companies may be associated, and the variation in the size of the sites, the conditions under which the use is carried out can be variable. The conditions of use cover small sites and repair shops with rare and infrequent applications up to large sites with high throughput, and thus, a low to high level of automation for specific activities. This variability was also observed in extensive consultation processes during the preparation of the CSR. Table 4-7 lists all the exposure scenarios (ES) and contributing scenarios assessed in the CSR.

Table 4-7: Overview of exposure scenarios and their contributing scenarios

ES number	ES Title	Environmental release category (ERC)/ Process category (PROC)
ES1-IW1	Passivation of non-aluminium metallic coatings – use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Passivation of non-aluminium metallic coatings - use at industrial site leading to inclusion (of Cr(VI) or the reaction products) into/onto article	ERC 5
Worker contributing scenario(s)		
WCS 1	Line operators	PROC 9, PROC 10, PROC 13, PROC 28
WCS 2	Storage area workers	PROC 5, PROC 8b, PROC 28
WCS 3	Laboratory technicians	PROC 15
WCS 4	Maintenance and/or cleaning workers	PROC 28

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[53] ECHA Website: https://echa.europa.eu/documents/10162/21961120/rac_35_09_1_c_dnel_cr-vi-_en.pdf/8964d39c-d94e-4abc-8c8e-4e2866041fc6; assessed in March 2021

Table 4-7: Overview of exposure scenarios and their contributing scenarios

ES number	ES Title	Environmental release category (ERC)/ Process category (PROC)
ES1-IW1	Passivation of non-aluminium metallic coatings – use at industrial site	
WCS 5	Machinists	PROC 21, 24
WCS 6	Incidentally exposed workers	PROC 0
Exposure scenario for industrial end use at site: ES1-IW1		

All A&D sites that perform passivation of non-aluminium metallic coatings within the ADCR value chains are specialised industrial sites active in the EEA or the UK. They have rigorous internal health, safety, and environment (HSE) organisational plans. A mix of technical, organisational, and personal-protection-based measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions to as low as technically and practically feasible and use automated processes to the maximum extent possible. The possibility for and the degree of automation can vary between different sites and depend, amongst other factors, on the size of the site and the frequency with which the use in question is carried out.

As reported in Section 4.3 above, due to the conditions placed on the continued use of the chromates in surface treatments (including passivation), additional risk management measures were implemented by A&D companies with this involving significant investment. A full summary of these conditions is provided in the CSR that accompanies this combined AoA/SEA.

4.4.2 Exposure and risk levels

The CSR provides details of the approach and assumptions underlying calculation of exposures and risks from the use of the chromates in passivation. The calculated exposure levels and associated excess cancer risks are presented below. For further information on their derivation see the CSR.

4.4.2.1 Worker assessment

4.4.2.1.1 Excess lifetime cancer risks

The findings of the CSR with respect to worker exposures are summarised in Table 4-8 below, which presents the excess lung cancer risks to workers involved in passivation of non-aluminium metallic coatings related activities. The risks are calculated using a combination of measured inhalation data and modelling for different SEGs (Similar Exposure Groups). The SEGs include:

- WCS1: Line operators who may be involved in a range of activities including immersion of parts into a treatment bath, sampling of the treatment baths and touch-up application;
- WCS2: Storage area workers who decant liquids and measure solids, clean containers, handle solid wastes, undertake bath make-up and cleaning of baths as part of bath renewal;
- WCS3: Laboratory technicians may be involved in sampling of treatment baths and laboratory analysis of treatment bath solutions;
- WCS4: Maintenance and/or cleaning workers who carry out maintenance and cleaning of equipment and handling of solid wastes;
- WCS5: Machinists who carry out machining operations on passivated parts; and
- WCS6: Incidentally exposed workers, who include those workers spending part of their time in the work area where treatment baths are located but do not carry out the tasks with direct exposure themselves.

Table 4-8 sets out the excess lifetime lung cancer risk for workers involved in each of the above tasks. Table 4-8 also indicates the number of workers on average that may be exposed per typical site, with this figure taken into account in estimating the total number of workers exposed across all 100 EEA sites and 30 UK sites that would continue to carry out passivation.

Table 4-8: Excess lifetime lung cancer risk by SEG

#	SEG	Average number of workers per site	Excess lifetime lung cancer risk [1/υg/m^3)
WCS1	Line operators	4	2.00E-03
WCS2	Storage area workers	4	9.00E-05
WCS3	Laboratory technicians	9	NA
WCS4	Maintenance and/or cleaning workers	3	3.84E-04
WCS5	Machinists	2	5.08E-04
WCS6	Incidentally exposed workers	6	1.00E-03

Source: Information from CSR
Note: Excess lung cancer risk refers to 40 years of occupational exposure

Note that WCS3 related to laboratory technicians is not considered further as the handling of substances in laboratories for quality control purposes under controlled conditions and in amounts below one tonne per annum (t/a) falls under the REACH Art. 56(3) exemption[54]. Furthermore, the sampling activities that may be carried out by lab technicians are covered under other WCS.

4.4.2.2 Humans via the environment

4.4.2.2.1 Excess lifetime cancer risks

The assessment of risks for humans via the environment presented in the CSR has been carried out for the general population at the local level only. No regional assessment has been carried out as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations and therefore the effects of Cr(VI) as such are likely to be limited to the area around the source, as described in the EU Risk Assessment Report for chromates (ECB, 2005). The approach to not perform a regional assessment for human Cr(VI) exposure via the environment as part of AfAs for chromate uses was also supported in compiled RAC and SEAC (Socio-economic Analysis Committee) opinions, as described for example in the *Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films (ID 0043-02)*. This reference states that regional exposure of the general population is not considered relevant by RAC[55].

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. Data were available for 11 sites undertaking passivation treatments. The resulting 90th percentile risk estimates are presented in Table 4-9.

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[54] https://echa.europa.eu/de/support/qas-support/browse/-/qa/70Qx/view/ids/585-1442-1443-1498-1565

[55] RAC/SEAC "Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films", consolidated version, 2016; https://echa.europa.eu/documents/10162/658d42f4-93ac-b472-c721-ad5f0c22823c

Table 4-9: Excess lifetime cancer risk estimates for humans via the environment (general population, local assessment)				
Inhalation		**Oral**		**Combined**
Local Cr(VI) PEC in air [µg/m3]	**Inhalation risk**	**Oral exposure [µg Cr(VI)/kg x d]**	**Oral risk**	**Combined risk**
7.07E-04	2.05E-05	1.80E-05	1.44E-08	2.05E-05
a) RAC dose-response relationship based on excess lifetime lung cancer risk (see CSR): Exposure to 1 µg/m3 Cr(VI) relates to an excess risk of 2.9x10-2 for the general population, based on 70 years of exposure; 24h/day. b) RAC dose-response relationship based on excess cancer risk for tumours of the small intestine (see CSR): Exposure to 1 µg/kg bw/day Cr(VI) relates to an excess risk of 8x10-4 for the general population, based on 70 years of exposure; daily exposure.				

4.4.3 Populations at risk

4.4.3.1 Worker assessment

4.4.3.1.1 Numbers of workers exposed based on Article 66 data

The Article 66 data on numbers of staff – or workers – exposed to the chromates is summarised in Table 4-10 below for those Authorisations relevant to the continued use in passivation. Use of sodium dichromate and potassium dichromate by the aerospace and defence industry under parent Authorisations, which are not being renewed may shift to those covered by this combined AoA/SEA, and figures associated with them are included here for completeness.

Taking a simple total of the figures for the number of staff exposed could result in an over-estimate given that some of the Authorisations cover multiple types of surface treatment.

No similar data are publicly available for the UK.

Table 4-10: Number of workers exposed - Article 66 Notifications data		
Substance	**Authorisation number**	**Staff Exposed**
Chromium Trioxide	REACH/20/18/14 to REACH/20/18/20	1107
Potassium dichromate	REACH/20/3/1	26
	REACH/20/2/1*	473
Sodium Dichromate	REACH/20/5/3 to REACH/20/5/5	450
	REACH/20/4/1*	408
Source: Staff exposed as notified to ECHA by 31 December 2021, data available from https://echa.europa.eu/du-66-notifications *Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for passivation, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.* **Use of sodium dichromate and potassium dichromate by the aerospace and defence industry under parent Authorisations, which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness.*		

4.4.3.1.2 Number of workers based on SEA questionnaire data

Responses to the SEA questionnaire indicate that 380 workers are directly involved in passivation activities across the 32 sites that have responded. The breakdown is given in Table 4-11 below by role in the supply chain and extrapolated out to the 100 EEA and 30 UK sites.

Table 4-11: Number of employees undertaking passivation across the EEA and UK

Type of company	Number of sites EEA	Number of sites UK	No of employees EEA	No of employees UK	Total
Number of workers at 32 sites involved in passivation of non-aluminium metallic coatings					
Build-to-Print	2	4	22	2	24
Design-to-build	4	1	15	4	19
MRO only	8	2	123	62	185
ADCR Members	9	2	129	23	152
Total 32 sites	**23**	**9**	**289**	**91**	**380**
Average per site			**12.57**	**10.11**	**11.75**
Number of workers at 100 EEA sites and 30 UK sites involved in passivation of non-aluminium metallic coatings					
Build-to-Print	33	17	367	8	375
Design to build	17	5	63	21	84
MRO only	17	3	256	83	339
ADCR Members	33	5	478	61	539
Total 130 sites	**100**	**30**	**1,164**	**173**	**1,337**

In total, this translates to 1,160 exposed workers in the EEA and 170 in the UK, or between 10 and 13 per site. This is lower than the estimates based on the CSR, which suggest an average of 23 per site, therefore, the estimate from the CSR has been used to calculate the number of employees exposed to prevent underestimation.

Furthermore, the CSR figures are based on site visits and detailed discussions with companies. The average figures assumed in the CSR extrapolated out to the total numbers of sites gives the figures set out in Table 4-12 as the number of workers exposed under each WCS.

Table 4-12: Number of employees undertaking passivation across the EEA and UK

Worker Contributing Scenarios		Average No. Exposed from CSR	EEA sites	UK sites
WCS1	Line operators	5	400	120
WCS2	Storage area workers	4	400	120
WCS3	Laboratory technicians	9	900	270
WCS4	Maintenance and/or cleaning workers	3	300	90
WCS5	Machinists	4	200	60
WCS6	Incidentally exposed workers	3	600	180
Total		**28**	**2800**	**840**
Excluding WCS3		**19**	**1900**	**570**

4.4.3.2 Humans via the environment

The relevant local population for humans via the environment has been estimated based on the following information:

- Number of downstream user sites in total and then as assumed in terms of their distribution across the EEA/UK;
- The population density per km^2 for each relevant EEA country and the UK; and
- The relevant distance from sites for the local assessment, taken as the default assumption of a 1,000 meter radius (or 3.14 km^2).

The resulting estimates of the number of people exposed within the general population are given in Table 4-13 for the EEA and UK. The total number of humans exposed via the environment in the EEA is estimated at just over 44,450, with the UK figure being around 39,960 (with the UK figure being disproportionately higher due to its population density).

As noted above, no assessment of risks for humans via the environment at the regional level has been carried out based on RAC's previous opinion that regional exposure of the general population is not relevant.

Table 4-13: General public, local assessment exposed population from passivation across the EEA and UK

Countries with DUs	No. Sites per country	Population density per km^2	Exposed local population within 1000m radius
France	36	118	13,345
Germany	13	232	9,475
Italy	12	200	7,540
Spain	7	92	2,023
Poland	9	123	3,478
Czech Republic	4	135	1,696
Sweden	2	23	145
Finland	2	16	101
Netherlands	2	421	2,645

Belgium	1	376	1,181
Denmark	1	135	424
Hungary	1	105	330
Norway	2	14	88
Romania	1	82	258
Bulgaria	1	64	201
Ireland	2	69	434
Greece	1	82	258
Lithuania	1	43	135
Portugal	1	112	352
Slovakia	1	111	349
Total EEA	**100**		**44,457**
UK	**30**	**424**	**39,961**

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of chromates in passivation will continue after the end of the review period for a total of 12 years (and beyond in some cases).

In December 2013, the Risk Assessment Committee (RAC) agreed lifetime (i.e., for 40 years and 70 years of exposure) mortality risk estimates associated with carcinogenicity for workers and humans via the environment exposed to Cr(VI) substances[56]. It assumes a linear relationship for both lung and intestinal cancer.

As the excess cancer risk estimates apply to each exposed worker for a total working life of 40 years, they need to be adjusted to reflect exposures over the length of the review period. Exposures are thus treated as separable over time, meaning that annual risk is equivalent to 1/40 of the risk over 40 years of exposure. For members of the general population, excess cancer risks estimates apply for a lifetime of 70 years, meaning that annual risk is equivalent to a 1/70 of the risk of 70 years of exposure.

4.4.4.2 Morbidity vs mortality

Excess cancer cases need to be split between fatal and nonfatal ones. To this end, estimates of fatality and survival rates associated with lung and colorectum[57] cancer cases were derived from the Cancer Today database, see Table 4-14 below.

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[56] ECHA (2013): Application for authorisation: Establishing a reference dose response relationship for carcinogenicity of hexavalent chromium. Helsinki, 04 December 2013. RAC/27/2013/06 Rev. 1 (agreed at RAC-27).

[57] Colorectum is taken as a proxy for intestinal cancer cases.

Table 4-14: Estimated incidence and mortality of cancers across the EU-27 and the UK, both males and females (in 2020)

Type of cancer	Cases	Deaths	Survivals
Lung	370,310	293,811 (79%)	76,499 (21%)
Colorectum (intestinal)	393,547	177,787 (45%)	215,760 (55%)

Source: Source: http://gco.iarc.fr/today/home (accessed on 20/02/2022)
Note: Percentages have been rounded

To calculate the number of additional non-fatal lung cancer cases, a ratio of deaths to survivals is applied to the number of additional fatal lung cancer cases, as shown below:

(1) $(0.21/0.79) \times \pi = \sigma$

Where π is the number of additional fatal lung cancer cases and σ is the number of additional non-fatal lung cancer cases.

In a similar fashion, the figures from Cancer Today reported above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases[58].

(2) $(0.55/0.45) \text{ x } \delta = \eta$

Where, δ is the number of additional fatal intestinal cancer cases and η is the number of additional non-fatal intestinal cancer cases. Note, however, that the CSR provides combined excess risk estimates. To err on the side of conservatism, the fatality versus morbidity ratio for lung cancer has been adopted for valuation of risks to humans via the environment (HvE).

4.4.4.3 Predicted excess cancer cases with continued use: workers directly exposed

Total excess cancer risk cases are calculated per line to reflect differences in activities, task allocation and exposure levels across the different sites. The number of excess cancer cases is calculated by multiplying the number of workers expected to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e., over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer cases arising from the continued use of chromates in passivation. Table 4-15 and Table 4-16 provide a summary of the results across all WCS for EEA and UK workers.

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[58] It is assumed that here the dose response relationship pertains to both additional fatal and non-fatal intestinal cases.

Table 4-15: Number of excess lifetime cancer cases to EEA workers

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	400	2.00E-03	**0.80**	**0.63**	**0.17**
WCS2	400	9.00E-05	**0.04**	**0.03**	**0.01**
WCS4	300	3.84E-04	**0.12**	**0.09**	**0.02**
WCS5	200	5.08E-04	**0.10**	**0.08**	**0.02**
WCS6	600	1.00E-03	**0.60**	**0.47**	**0.13**
		Years - Lifetime	**40.00**	**1.31**	**0.35**
		Years - Review period	**12.00**	**0.39**	**0.10**
		Years - Annual	**1.00**	**0.03**	**0.01**

Table 4-16: Number of excess lifetime cancer cases to UK workers

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	120	2.00E-03	**0.24**	**0.19**	**0.05**
WCS2	120	9.00E-05	**0.01**	**0.01**	**0.00**
WCS4	90	3.84E-04	**0.03**	**0.03**	**0.01**
WCS5	60	5.08E-04	**0.03**	**0.02**	**0.01**
WCS6	180	1.00E-03	**0.18**	**0.14**	**0.04**
		Years - Lifetime	**40.00**	**0.39**	**0.10**
		Years - Review period	**12.00**	**0.12**	**0.03**
		Years - Annual	**1.00**	**0.01**	**0.003**

4.4.4.4 Predicted excess cancer cases with continued use: humans via the environment

The total number of people exposed via the environment as given in Table 4-13 is multiplied by the excess cancer risk estimates to calculate the total excess cancer cases arising under the Continued Use scenario. The results are given in Table 4-17. The basis for estimating the number of people exposed per country is the percentages of Article 66 notifications made to ECHA per country, as described in Section 4.2.

Table 4-17: Number of employees undertaking passivation across the EEA and UK

Countries with DUs	No. Sites per country	Population Density per km2	Exposed local population	Combined excess lifetime cancer risk	Excess number of lifetime cancer cases	Number of excess lifetime fatal cancer cases	Number of excess lifetime non-fatal cancer cases
France	36	118	13345	8.60E-06	1.15E-01	0.09	0.02
Germany	13	232	9475	8.60E-06	8.15E-02	0.06	0.02
Italy	12	200	7540	8.60E-06	6.48E-02	0.05	0.01
Spain	7	92	2023	8.60E-06	1.74E-02	0.01	0.00
Poland	9	123	3478	8.60E-06	2.99E-02	0.02	0.01
Czech Republic	4	135	1696	8.60E-06	1.46E-02	0.01	0.00
Sweden	2	23	145	8.60E-06	1.24E-03	0.00	0.00
Finland	2	16	101	8.60E-06	8.65E-04	0.00	0.00
Netherlands	2	421	2645	8.60E-06	2.27E-02	0.02	0.00
Belgium	1	376	1181	8.60E-06	1.02E-02	0.01	0.00
Denmark	1	135	424	8.60E-06	3.65E-03	0.00	0.00
Hungary	1	105	330	8.60E-06	2.84E-03	0.00	0.00
Norway	2	14	88	8.60E-06	7.56E-04	0.00	0.00
Romania	1	82	258	8.60E-06	2.22E-03	0.00	0.00
Bulgaria	1	64	201	8.60E-06	1.73E-03	0.00	0.00
Ireland	2	69	434	8.60E-06	3.73E-03	0.00	0.00
Greece	1	82	258	8.60E-06	2.22E-03	0.00	0.00
Lithuania	1	43	135	8.60E-06	1.16E-03	0.00	0.00
Portugal	1	112	352	8.60E-06	3.03E-03	0.00	0.00
Slovakia	1	111	349	8.60E-06	3.00E-03	0.00	0.00
Total	**100**		**44457**	**8.60E-06**	**0.38**	**0.30**	**0.08**
			Years – Lifetime cases		**70.00**	**3.02E-01**	**4.37E-02**
			Years - Review period		**12.00**	**5.18E-02**	**1.38E-02**
			Years - Annual		**1.00**	**0.00**	**0.00**
UK	**30**	**424**	**39961**	**8.60E-06**	**3.44E-01**	**0.27**	**0.07**
			Years – Lifetime cases		**70.00**	**2.71E-01**	**7.22E-02**
			Years - Review period		**12.00**	**4.65E-02**	**1.24E-02**
			Years - Annual		**1.00**	**0.00**	**0.00**

4.4.5 Economic valuation of residual health risks

4.4.5.1 Economic cost estimates

In order to monetise human health impacts, a timeframe that goes from the end of 2024 to the end of 2036 (i.e., a 12-year review period) has been used and a 4% discount rate has been employed for calculating net present values[59]. It has been assumed that the levels of exposure to Cr(VI) for workers and members of the general population remains constant throughout the length of the review period, even though this is a very conservative assumption. In fact, downstream users will gradually reduce the amount of Cr(VI) consumed as the transition to an alternative proceeds. Combined with the investment in risk management measures put in place by the sites to protect workers as a result of the conditions placed on continued use by the initial authorisations, this should ensure that excess lifetime cancer risks reduce over the review period.

The economic valuation of the health impacts takes into account two important welfare components, the costs associated with mortality and morbidity. The basis of our calculations is the study led by the Charles University in Prague[60] and undertaken for ECHA.

That study was critically reviewed by ECHA in 2016 and the results of that review have been the basis of the economic valuation performed here[61]. The values used are:

- Value of statistical life for the avoidance of a death by cancer: €3.5 million (2012 prices); and
- Value of cancer morbidity: €0.41 million (2012 prices).

It is appropriate to update these two figures to 2021 prices (updated to second and third quarter values of 2021, more recent data are not available). This has been achieved by use of the Eurostat EU GDP deflator[62]. This suggests that the aforementioned figures should be multiplied by a factor of 1.12. Thus, the following values are employed in the analysis below:

- Value of statistical life (mortality): €3.5 million × 1.12 = €3.92 million (rounded); and
- Value of cancer morbidity: €0.41 million × 1.12 = €0.46 million (rounded).

In addition to these valuations, for the purpose of quantifying human health impacts, consideration has also been given to annual medical treatment costs for morbidity. A range of studies were identified that provide estimates of the costs of medical treatment for patients surviving lung and intestinal cancer. These are summarised in Table 4-18.

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[59] EC Better Regulation Toolbox – Tool #61: https://ec.europa.eu/info/sites/default/files/file_import/better-regulation-toolbox-61_en_0.pdf

[60] Alberini, A. and Ščasný, M. (2014) Stated - preference study to examine the economic value of benefits of avoiding selected adverse human health outcomes due to exposure to chemicals in the European Union - Part III: Carcinogens.

[61] ECHA (2016b) Valuing selected health impacts of chemicals. Available at: http://echa.europa.eu/contact

[62] https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=teina110&plugin=1

Table 4-18: Alternative estimates of medical treatment costs			
Study	**Year for prices**	**Average direct costs in original units (per annum)**	**Direct costs in € 2021**
Lung cancer[63]			
Leal (2012)	2012	£9,071	€11,160
Braud et al (2003)	2001	€12,518	€15,800
Dedes et al (2004)	1999	€20,102	€23,460
Intestinal cancer (colon, colorectal and rectal cancer taken as proxies)[64]			
Luo et al (2010)	2000 (assumed)	US$29,196	€36,230
Lang et al (2009)	2006	US$28,626	€31,740
York Health Economics Consortium (2007)	2004	£8,808	€12,180
York Health Economics Consortium (2007)	2004	£12,037	€16,410

The average cost across the lung cancer studies is €16,807 per annum (2021 prices). The average cost figures reported for intestinal cancer are based on figures produced for colon, rectal and colorectal cancer in the US and UK. The US data are high compared to the UK data; as a result, the average across the two UK studies is taken here, with this being around €14,259 per case in 2021 prices, taking into account price inflation.

These average medical costs are annual figures and apply to survivors over the period of time that they continue to be treated. With respect to lung cancer morbidity cases, we have taken a percentage survival of 32% after one year since diagnosis, 10% after five years, 5% after 10 years[65]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after one year since diagnosis, 59% after five years, 57% after ten years. Based on these time periods, the NPV of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 4% future discount rate. The NPV of average future medical costs per intestinal cancer case is estimated at €82,620 in 2021 prices. It is noted that a large percentage of people survive intestinal cancer after a period of 10 years and any stream of health care costs incurred after that is not incorporated in our calculations. However, such costs are not likely to be relevant considering that those surviving after such a long period of time can either be considered as definitely cured or probably only in need of a small degree of medical attention.

The valuations of mortality and morbidity were multiplied by the estimated number of additional cancer cases, fatal and non-fatal, that can occur in the Applied for use scenario. The basic calculations for the value of an excess cancer case are presented below:

$$(1)\quad (\pi \times (€\ 3{,}920{,}000)) + (\sigma \times (€\ 460{,}000 + €\ 30{,}110) = \text{Total lung cancer costs}$$

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[63] Leal, J., 2012. Lung cancer UK price tag eclipses the cost of any other cancer, presentation by Health Economics Research Centre, University of Oxford to the NCIR Cancer Conference, Wednesday, 7 November. s.l.:s.n. Braud, L. & al, 2003. Direct treatment costs for patients with lung cancer from first recurrence to death in France. Pharmacoeconomics, 21(9), pp. 671-679. Dedes, K. J. & al, 2004. Management and costs of treating lung cancer patients in a university hospital. Pharmacoeconomics, 22(7), pp. 435-444

[64] Luo, Z. & al, 2010. Colon cancer treatment costs for Medicare and dually eligible beneficiaries. Health Care Finance Review, 31(1), pp. 33-50. Lang, K. & al, 2009. Lifetime and Treatment-Phase Costs Associated with Colorectal Cancer: Evidence from SEER-Medicare Data. Clinical Gastroenterology and Hepatology, Volume 7, pp. 198-204. York Health Economics Consortium, 2007. Bowel Cancer Services: Costs and Benefits, Final Report to the Department of Health, April 2007, York: University of York.

[65] These values are based on a study conducted by Cancer Research UK on adults aged 15-99 in England and Wales. https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/lung-cancer/survival.

(2) (δ × (€ 3,920,000)) + (η × (€ 460,000 + €82,620)) = Total intestinal cancer costs

4.4.5.2 Predicted value of excess cancer cases with continued use: workers

Table 4-19 applies the economic value of the associated health impacts to these additional statistical cases of cancer to generate the total economic damage costs of the excess lung cancer cases. Under the Continued Use scenario, the present value costs are **€570,000 for the EEA and €170,000 for the UK**, based on the assumption that chromate-based passivation continues at the current level of use over the entire review period; this will lead to an overestimate of the impacts as the sector transitions to the alternatives over the 12 year period.

Table 4-19: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA Workers		UK Workers	
	Mortality	Morbidity	Mortality	Morbidity
Total number of lung cancer cases	3.92E-01	1.04E-01	1.18E-01	3.12E-02
Annual number of lung cancer cases	3.26E-02	8.68E-03	9.79E-03	2.60E-03
Present Value (PV, 2024)	€ 554,276	€ 17,290	€ 166,283	€ 5,187
Total PV costs	**€ 571,566**		**€ 171,470**	
Total annualised cost	**€ 131,951**		**€ 39,585**	

Source: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR

4.4.5.3 Predicted value of excess cancer cases with continued use: man via the environment

Table 4-20 applies the economic value of the associated health impacts to the additional statistical cases of cancer for the general population (humans via the environment) to generate the total economic damage costs of the excess cancer cases. Under the Continued Use scenario, the present value costs are roughly **€76,000 for the EEA and €68,000 for the UK**, based on the assumption that passivation continues over the entire review period at 2024 tonnages; as indicated above, this reflects an overestimate of the levels of exposures as use declines with a transition to the alternatives over the 12 year period.

Table 4-20: Present value and annualised economic value of mortality and morbidity effects to the general population, local assessment (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA General Population		UK General Population	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	5.18E-02	1.24E-02	4.65E-02	1.24E-02
Annual number of cancer cases	4.31E-03	1.15E-03	3.88E-03	1.03E-03
Present Value (PV, 2024)	€ 73,266	€ 2,496	€ 65,857	€ 2,244
Total PV costs	**€ 75,762**		**€ 68,101**	
Total annualised cost	**€ 17,490**		**€ 15,722**	

Source: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR

4.4.6 Human health impacts for workers at customers sites

The machining of surfaces following passivation has been accounted for in the worker estimates presented above.

4.4.7 Environmental impacts

Releases to the environment are governed by, and comply with, local worker and environmental regulatory requirements.

Releases of wastewater containing Cr(VI) may occur from cleaning water and wash water from wet scrubbers. At all sites wastewater is collected and then treated by one or more of the following three options:

- Sending it to an external waste management company where it is treated as hazardous waste;
- Recycling and evaporation in an on-site evaporation system; the residue is discharged as hazardous solid waste;
- Discharge into a special treatment facility.

The special treatment facility is in most cases located on-site but may also be external where the water is transferred via underground pipes. Typically, contaminated water is either disposed as hazardous waste by an external company or conveyed to the special treatment facility. Wastewater from the other sources listed above is usually either collected and mixed together for treatment at the treatment facility or recycled and then led to the evaporation system. In the special treatment facility, the Cr(VI) in wastewater is reduced to Cr(III) by addition of a reducing agent (e.g., sodium metabisulphite, ferrous sulphate, or ferric chloride solutions) in excess stoichiometry. Usually, reduction efficiency is measured by a redox probe. Following the reduction step, the wastewater pH is neutralized, and Cr(III) is precipitated. After monitoring of the Cr(VI) concentration in the reduced wastewater, usually the wastewater is mixed with other (non-Cr(VI)) containing waste solutions. The wastewater is then discharged to an external municipal wastewater/sewage treatment plant for further treatment prior to discharge to receiving waters (river, canal, or sea).

Exhaust air is released via stacks, and emitted air is treated in scrubbers or by air filters before being released to the ambient air. There are no direct releases to soil and solid waste materials containing Cr(VI) are classified and treated as hazardous wastes according to EU and national regulations. Any solid or liquid waste is collected and forwarded to an external waste management company (licenced contractor) for disposal as hazardous waste.

4.4.8 Summary of human health and environmental impacts

Table 4-21 provides a summary of the economic value of the human health impacts across the worker and local populations. When considering these figures, it should be remembered that they relate to use of the chromates in passivation activities across the sector at an estimated 100 EEA sites and 30 UK sites covered by this combined AoA/SEA. It should also be recognised that workers involved in chromate-based passivation may also be using the chromates for other processes. As a result, their monitoring data may reflect aggregate exposures rather than just passivation-related exposures

Table 4-21: Combined assessment of health impacts to workers and general population value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA		UK	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	0.44	0.12	0.16	0.04
Annual number of cancer cases	0.04	0.01	0.01	0.004
Present Value (PV, 2024)	€ 627,542	€ 19,786	€ 232,140	€ 7,431
Total PV costs	**€ 647,328**		**€ 239,571**	
Total annualised cost	**€ 149,442**		**€ 55,307**	

Source: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR

5 Socio-Economic Analysis of Non-Use

5.1 Non-use Scenario (NUS)

5.1.1 Summary of consequences of non-use

The inability of companies to undertake passivation activities across the EEA and in the UK using one or more of the chromates would be severe. This use is critical to corrosion resistance (and the other functions discussed in Section 3) across a broad range of parts and assemblies, including landing gear and hydraulic flight controls. This includes application to newly produced parts and for ensuring on-going corrosion resistance (and the other functions discussed in Section 3) following maintenance and repair activities.

If passivation was no longer authorised, design owners (i.e., OEMs and DtB companies) would be forced to re-locate some or all of their parts production, manufacturing and maintenance activities out of the EEA or UK. This would have consequent effects for other parts of the A&D value chain, as summarised below.

A refused Authorisation would have impacts on the EEA/UK formulators and the critical set of key functions provided by passivation treatments would be lost to A&D downstream users in the EEA and UK

⇩

Due to certification and airworthiness requirements, downstream users would be forced to undertake chromate-based passivation activities outside the EEA or shift to suppliers outside of the EEA/UK

⇩

OEMs would shift manufacturing outside the EEA/UK due to the need for passivation to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside the EEA/UK for passivation only (and especially so for touch-up repairs)

⇩

DtB suppliers may have more flexibility and shift their production activities outside the EEA/UK, resulting in the loss of profits and jobs inside the EEA/UK

⇩

BtP suppliers in the EEA would be forced to cease chromate-based passivation treatments, leading to loss of contracts and jobs due to relocation of this and related activities outside the EEA/UK

⇩

MROs would have to shift at least some (if not most) of their activities outside the EEA, as passivation is an essential part of maintenance, repair and overhaul activities

⇩

Relocation of MRO activities would cause significant disruption to the A&D sector itself

⇩

Ministries of Defence would face logistical difficulties in maintaining aircraft and other equipment, severely impacting on mission readiness. Service agreements would need to be reached with non-EEA countries

⇩

Civil aviation, passengers, freight shippers and emergency services would face reduced flight availability and routes, as well as increased costs

As indicated in the above diagram, because passivation must ideally be applied promptly to protect against excessive corrosion of the non-aluminium metallic coating and, depending on the follow-on process, to ensure the next process step is successful, there would be significant subsequent effects for other parts of the aerospace and defence supply chains. The most likely outcome would be the relocation of a large portion of the entire value chain (production, repair and maintenance) outside of the EEA/UK, as summarised below.

5.2 Identification of plausible non-use scenarios

Consultation was carried out with the applicants, OEMs, MROs and the BtP and DtB suppliers supporting them.

These discussions acted as the basis for a series of questions in the SEA questionnaire aimed at pulling out information on the role of different types of companies and how this impacts on why they use the three chromates, past investments and R&D, and the most likely impacts of a refused re-authorisation. The first three of these were discussed in Section 4 and the continued use scenario.

Moving to a poorer performing alternative was ruled out based on the unacceptability of such an option to the OEMs due to safety and airworthiness requirements, as detailed further below. Producing components overseas, shipping them back to the EEA/UK and then warehousing them was ruled out due to logistic difficulties and economic feasibility.

Table 5-1 below presents the choices presented in the SEA questionnaire and a count of the number of companies selecting each.

Respondents were asked to provide further comments to support their responses, and to explain any other possible responses not included in the list of choices. These comments demonstrate the differences that exist within the aerospace supply chain and hence how the most plausible scenarios will vary by role.

Further details on the non-use scenario for the different types of companies are provided below, starting with OEMs as the main design owners, followed by DtBs, BtPs and MROs.

Table 5-1: Responses to SEA survey on most likely non-use scenarios				
	Build-to-Print only	Design-to-Build only	MROs – only	OEM
It is unclear at this time/the decision is up to our customer	1	1	0	1
We may have to cease all operations as the company will no longer be viable	2	0	5	1
We will focus on other aerospace uses or non aerospace and defence uses	1	3	0	0
We will shift our work involving use of the chromates to another country	0	0	0	3
We will stop undertaking use of the chromate(s) until we have certified alternative	0	1	3	1
Number of responses (companies)	1*	0	1*	0
*one responses left blank				

5.2.1.1 OEMs

The OEMs all stressed that the aim is replacement of chromium trioxide, sodium dichromate and potassium dichromate in passivation to a qualified and certified alternative. In some cases, a qualified alternative has been identified, but more time is required to implement the alternative across suppliers (particularly where a significant number of suppliers may be involved in undertaking passivation of similar parts, e.g., structural parts). In other cases, the companies have been trying to find a suitable replacement for over 25 years (e.g., in their defence applications) and have been unable to.

With respect to the plausibility of the different non-use scenarios identified in Table 5-1, the following are clear from the SEA responses and consultation with members who are representing the aerospace and defence sector supply chain (including Ministries of Defence):

- **We will shift our work involving Chromates to another Country outside the EEA.** This is the most plausible scenario for the majority of OEM companies directly involved in the use of passivation. Given the importance of passivation to the protection of metallic coatings including cadmium, it is also the most likely response for those OEM companies who are supporting the continued use of passivation in their supply chains. It must be recognised that although plausible this scenario may also be unrealistic given what such a move would entail. In addition, the ability to shift passivation activities outside the EEA/UK for defence supply chains may be restricted for security reasons.

- **We will stop using the chromates until we have certified alternatives:** It is clear that in most cases substitution activities and especially the industrialisation phase of moving to alternatives will not be completed for at least four years and for a significant number of parts/products for 12 years (or even longer). One of the OEMs indicated that this would be their most plausible scenario. For the other OEMs identifying this as the most plausible scenario, losses in turnover would be between 30 - 50%. For the other companies, the potential duration of such a production stoppage would not be economically feasible.

- **We may have to cease all operations as the company will no longer be viable.** If shifting work to countries outside the EEA/UK is unacceptable due to the costs or timeframe involved in setting up the required manufacturing sites and supporting infrastructure, a cessation of all operations may be the ultimate outcome for some of the OEMs or divisions of them. It is important to note that this scenario translates to a cessation of aircraft production within the EEA/UK, with consequent reductions in revenues from aircraft assembly operations; the loss of this turnover would result in other operations (R&D, Engineering, Sales, etc.) also becoming non-viable with the final outcoming being a shut-down of all activities. It is not technically nor economically feasible for A&D OEMs to switch all or most of their focus to other sectors, as their sole areas of expertise reside in the aerospace field and/or defence fields. As a result, this is not a plausible option for any of the companies.

Similarly, none of the companies indicated that they would move to a poorer performing alternative. This scenario is not considered plausible as a less efficacious alternative that impacted on the level of corrosion protection would not be acceptable:

- EASA would not accept a downgrade in a product's performance;
- Consequent increased maintenance requirements would lead to an increase in the downtime of civilian aircraft, increased maintenance costs, less flying hours, impacts on airlines and passengers, logistic issues including increased CO_2 emissions, etc.; and
- Consequent impacts on military equipment and its maintenance requirements may affect the mission readiness of equipment, increased costs and lead to early redundancy of equipment.

Thus, although moving to a poorer performing alternative may appear plausible, the associated risks would be unacceptable to all the OEMs and their customers. The primary objective of these companies is to move to an alternative. This objective cannot be achieved, however, without sufficient testing and flight (or other) data surrounding the use of alternatives. Without such data, the necessary approvals cannot be gained as safety risks become too great, whether related to civil aviation or military aircraft. The corrosion protection provided by passivation is crucial to the protection of parts with metallic coatings including cadmium; if there are no qualified alternatives then manufacturing would have to cease.

As a result, the OEMs indicated that if the viable alternatives are not qualified and implemented (or able to be implemented) by the end of the current review period (i.e., September 2024) on components, then their **most plausible response under the non-use scenario would be to relocate all or some of their manufacturing activities outside of the EEA or UK** (it may also not be realistic given the efforts and expenditure involved in such relocation, which may be more likely to result in the complete closure of OEMs or divisions within them, with consequent impacts for the EEA/UK economies).

The extent to which companies would move all or only some of their manufacturing outside the EEA/UK depends on the integrated "system" of activities undertaken at individual sites. Passivation is not undertaken across all sites of the larger OEM companies that may operate over more than ten sites, however, it may be carried out by suppliers to those sites. Consultation indicates that these companies' sites may each be supported by up to ten suppliers undertaking passivation regionally (with this figure used in generating the number of sites in total assumed to be carrying out passivation in the EEA in particular).

As discussed above, the impacts on individual companies may be a loss of production and turnover related to anything from around 30% to 100% of current levels, with production expected to stop completely at a significant percentage of sites where passivation is a core activity. These impacts would be experienced by sites involved in civil aviation and defence.

It was also noted that due to the vertical integration of manufacturing activities at these sites, it is not feasible to only cease undertaking passivation treatments using the chromates; all activities related to the manufacture of the relevant parts, assemblies, aircraft and other products would need to be moved outside the EEA/UK. Note that this shifting of activity outside the EEA/UK may involve either relocation or sub-contracting, and it would also impact on MRO activities in the EEA as these would need to relocate to the same locations.

In the A&D industry, reliance on proven corrosion prevention processes means that Cr(VI) and non-Cr(VI) operations/processes normally exist side-by-side, are inter-reliant and non-separable; as a result, there is no possibility to identify and distinguish manufacturing plants as Cr(VI) or Cr(VI)-free. Indeed, the aerospace industry has a very complex and interrelated supply chain. Nonetheless, for many essential parts, only one designated supplier exists. Typically, this supplier will have worked in close partnership with its customer(s) for decades to develop a product. Critical suppliers often take occupancy on, or adjacent to, the premises of their customers. Therefore, relocation will often be based on strategic decisions, e.g., if the customer relocates, the suppliers might do the same to keep proximity.

A final assembly line for aircraft, engines or other major products will require Cr(VI) touch-up protection of components, as a minimum. This activity is clearly a tiny fraction of the overall value added by the facility; however, the ability to carry out the activity on-site is critical to the viability of the wider operations. As noted above, it would not be possible to relocate just the surface protection activities, due to the potential for corrosion during transport to another location. For example, landing gear consists of several single sections (e.g., shock absorbers, wheels, the brake system, etc.) which need to be joined.

Assembling is a mechanical process and tolerances of the components need to be corrected by machining. During this process, e.g., installation of landing gear, the surface can suffer damage. Using small amounts of Cr(VI) compounds as part of rework during the assembly phase is mandatory and essential to the safety of the aircraft. These touch-up processes cannot be disconnected in time or distance from the final assembly process. When these processes are no longer available, the entire process must re-locate.

Damage on structural parts of aircraft as small as a single scratch on exposed bare metal increases the risk of corrosion, leading to loss of component strength, and, untreated, can lead to increased fatigue and cracking of the component. This damage can usually be reworked or repaired quickly without removing the part by blending out the scratch and using touch-up processes for as a localised corrosion treatment. As explained in the Analysis of Alternatives, Cr(VI) is critical for corrosion prevention, durability and for its self-healing properties, amongst others.

As a result, there are several cases to consider.

- Small Components: Currently, some small components may be able to be removed and then repaired on-site or replaced with a new part from stock (from inside or outside Europe). In the case of a denied authorisation, no on-site repair would be possible. The component would either have to be sent outside of Europe for repair, or a new component from stock would ultimately have to originate from outside Europe.

- Large Component: Some large parts, like wing or fuselage skins, are rarely removed, so processing in-situ is the primary method for touch-up. Without moving the entire aircraft outside the EEA, touch-up (and repairs) would not be possible. It would be impossible to ship the entire fuselage to a non-EEA country for touch-up repairs, ship it back into the EEA for continued assembly, and so on.

In the best case, and for some components and products, touch-ups and repairs that require in-situ use of chromate-based passivation can be planned to be performed outside Europe. This may entail the added cost of longer, non-revenue flights to the non-EEA repair centre. In the worst case, unplanned damage needs to be repaired before the aircraft can be moved. If this is in Europe, this creates an unworkable situation. From these examples, it is therefore crystal clear that relocation of single activities is in most cases not an option. Consequently, under the Non-Use Scenarios, more and more links in the supply/value chain, and associated jobs, know-how and R&D investments, will move out of Europe.

In conclusion, it is not possible to relocate the use of chromate-based passivation processes on their own in most cases. These processes are an integral part in the production chain and cannot be separated from previous or following process steps. As a result, the entire production chain would need to be relocated, which although the most plausible scenario is also not realistic and would lead to severe impacts on the viability of the entire value chain.

Particular difficulties would be faced by companies in the space and defence sectors. Possibilities for relocating some activities outside the EEA/UK are limited due to the difficulties related to achieving specific customer requirements, national security considerations, work share agreements, and financial restrictions. As a result, it is likely that there would need to be requests for “defence exemptions” so that those activities that contractually must be maintained in their current location could continue within the EEA/UK. It would also have implications for the manufacture of products for the European space industry, damaging its ability to remain independent.

5.2.1.2 Design-to-Build

The potential responses by Design-to-Build companies are more varied:

- Cease operations;
- Focus on other surface treatment activities for the aerospace or other sectors;
- Stop undertaking chromate-based passivation activities until components using an alternative are certified.

As indicated earlier, DtBs are working on development, validation, qualification and certification of alternatives to chromate-based passivation (although it was also noted that the final decision may be up to their end customers). As this may take a significant length of time (months if not years), then the lack of a certified alternative for their products means that the relevant passivation activities would cease until a certified alternative is in place.

Some DtBs indicated that they will stop undertaking the chromate-using process and continue with other operations. One of these companies indicated that they would undertake research into alternatives on behalf of the customer. DtB companies indicate that they have undertaken or been involved in research into Cr(III) for passivation. Additionally, customers of the DtB companies have undertaken research in test candidates. Cr(III) has either not yet been certified and won’t be until after 2024, or is not acceptable to customers.

Some DtB companies indicate that Cr(VI) is an important part of their turnover, and although they would continue to focus on other, non chromate-based activities, they would struggle economically. Others indicate that aerospace and defence are a small part of their turnover and therefore would be able to continue business whilst stopping chromate-based activities. Turnover losses therefore range between 4% and 60%.

5.2.1.3 Build-to-Print

For Build-to-Print companies, the following are all potential scenarios:

- Cease operations;
- Focus on other surface treatment activities for the aerospace or other sectors;
- Shift operations outside the EEA/UK; or
- Unclear at this time.

Two responses from Build-to-Print companies indicate that operations would have to cease in the event of a non-authorisation with suggesting that they would consider shifting all production activities to such facilities rather than cease production while they wait for an alternative to be qualified for passivation. This includes potentially shifting operations to the US, UK, Canada or India. One company did not provide a response.

Three out of five companies also indicate that they either rely on R&D into alternatives from customers or are unclear on what R&D is undertaken as they work to the specific requirements of the customer. In practice, the potential responses of Build-to-Print companies to the non-use scenario are constrained. Most confirmed that the choice of whether to use the chromates is not theirs but their customers'. Some noted the that they could not shift to alternatives for passivation treatments until these were qualified and certified for use in the production of components by their customers and the authorities, and that the alternatives were suitable and sustainable for their customers' uses. It is also a concern that customers may each qualify and certify a different alternative, raising economic feasibility concerns in terms of capital investments, site infrastructure, etc. Others commented that if they could not use chromate-based passivation formulations in the EEA/UK, then they would have to either cease operations, sub-contract out some passivation processes or transfer multiple processes outside the EEA (more feasible for the larger companies). The subsequent effects would include redundancies and losses in turnover for EEA operations, as well as the potential loss of NADCAP support.

5.2.1.4 MRO

For companies that undertake a combination of BtP or DtB and MRO activities, the same options as identified above may apply to their non-MRO activities. For those that operate as MROs only, there is less choice. They do not undertake manufacturing per se, only the overhaul, repair, and maintenance of different A&D components, which can differ in size and complexity (overhaul of a complete aircraft to maintenance of a single component in a land-based defence product).

When components enter under the services of an MRO, the required maintenance effort, including which surface treatment processes may be required, is not directly foreseeable. Very often, the level of work required only becomes clear after disassembling the component. The surface treatment steps required (e.g., from pre-treatment to passivation) for any given component is dependent on its condition and can differ for each maintenance event. As a result, not every component will pass through all potential surface treatment processes. Even where they do, level of throughput is also dependent on the size and complexity of the component – processing times can range from five minutes to several days. Within these process flows, even if chromate-based treatments are required to a very limited extent, they remain essential. As part of maintenance activities, they play an essential role in ensuring that airworthiness regulations are met, and in the overall, economic feasibility of maintenance events.

For example, maintenance work may be performed at a customer’s site on an assembled aircraft engine. This can involve non-destructive testing or component changes that do not require the complete disassembly of an engine. In the course of such maintenance work – depending on the findings – corrosion protection with prescribed chromate-containing materials, must be carried out on individual cases in order to complete the maintenance work to the prescribed extent and to be able to release the engine under airworthiness requirements. If this step is not possible, the entire maintenance process of the engine and thus the product is compromised.

As a result, without the ability to use the chromates for passivation as part of maintenance, repair and overhaul, such services become unviable. There is no scope for them to operate outside the requirements detailed in the OEMs’ service manuals, which are based on the qualified and approved uses of passivation. Where these requirements mandate the use of one of the three chromates, then the MRO must use that chromate as instructed unless the manuals also list a qualified alternative.

One company commented: *"Even if chromate-containing materials only have to be used to a very limited extent in the context of maintenance due to airworthiness regulations, they still play an essential role in the holistic/overall, economically viable feasibility of maintenance events.”*

MRO businesses which are based on the re-implementation of upstream processes using one of the three chromates, would no longer be viable and would have to cease in the EEA/UK. For some companies, it may be possible to shift such activities outside the EEA/UK while for others this would require major changes in infrastructure. Shifting activities outside the EEA/UK is, however, neither practical nor feasible for their defence customers or civil aviation customers.

5.2.1.5 Additional considerations

Current industry best practice does not involve identifying manufacturing plants as Cr(VI) or Cr(VI)-free. To the contrary, in the aerospace and defence industry, reliance on proven corrosion prevention systems means that Cr(VI) and non-Cr(VI) operations/processes normally exist side-by-side, are inter-reliant and non-separable. The aerospace industry has a very complex and interrelated supply chain. Nonetheless, for several essential parts, only one designated supplier exists. Typically, this supplier will have worked in close partnership with its customer(s) for decades to develop a product. Critical suppliers often take occupancy on, or adjacent to, the premises of their customers. Therefore, relocation will often be based on strategic decisions, e.g., if the customer relocates then the suppliers might do the same to keep proximity.

From an operational perspective, surface treatment using Cr(VI) substances is a small element of the overall process flow in most mixed facilities, with the combination of machining, finishing, assembly, testing and inspection dominating overall. However, as noted above, they cannot be separated from one another. The impacted operations, and therefore socio-economic impacts to industry under the non-use scenario, go far beyond the specific processes directly using Cr(VI) and have substantial implications for non-Cr(VI) processes that are indirectly affected.

Hypothetically, passivated parts could be produced outside of the EEA/UK and then be shipped back. However, this would drastically undermine the competitiveness of EEA/UK component/assembly suppliers. By adding extra transportation, lead-times, and risk of additional handling-related damages, suppliers in the EEA/UK would be put at a massive disadvantage compared with non-EEA suppliers in their bids/services. Furthermore, if manufacturing activities using chromates versus chromate-free were separated on both sides of the EEA/UK borders, the logistic requirements of managing the flow of parts/components/assemblies and the level of transportation required would have dramatic impacts on resources and the environmental footprint of the sector.

5.2.2 Non-plausible scenarios ruled out of consideration

5.2.2.1 Move to a poorer performing alternative

Moving to a poorer performing alternative would not be acceptable to the OEMs, either from a Design Organisation Approval (DOA) perspective as approved by EASA[66], MoDs and the European Space Agency (ESA), or from an engineering perspective taking airworthiness safety requirements into consideration.

As noted in the parent Applications for Authorisation, under the scenario of moving to a poorer performing alternative, OEMs would not accept an alternative that is less efficacious in delivering corrosion protection where no alternative provides an equivalent level of performance to the chromates. The use of a less effective alternative would downgrade the performance of the final product, and the reduction in the level of corrosion protection performance would give rise to several unacceptable risks/impacts:

- The highly likely risk of EASA (airworthiness authorities), MoDs or ESA not accepting a downgrade in performance;
- Increased maintenance operations, leading to an increase in the downtime of aircraft and military equipment, increased costs of maintenance, less flying hours, etc.; and
- Increased risks to passengers, cargo operators and operators of military equipment.

Corrosion issues likely would not appear suddenly, but over time they may affect hundreds of A&D components entered into service. Further, potential decreased corrosion protection performance from Cr(VI)-free coatings would necessitate shorter inspection intervals to prevent failures. Flight safety obligations preclude the aerospace industry from introducing inferior alternatives on components, and the long-term performance of alternatives that have not undergone rigorous testing and development can only be estimated.

In the purely hypothetical case where decreased or complete loss of corrosion protection is introduced to aircraft, the following risk mitigation actions may be required:

- Substantial increase in inspections – both visual checks and non-destructive evaluations, such as ultra-sound crack tests, etc. Some inspections are very difficult or hazardous to perform (e.g., inside fuselage/wing structures). All aircraft using less effective materials in repair/overhaul and/or unproven materials across the operating lifetime of an aircraft would be subjected to an increase in inspections. A very conservative inspection frequency would be set to ensure safety until adequate in-service performance experience is obtained;
- Increased overhaul frequency or replacement of life-limited components. Possible early retirement of aircraft due to compromised integrity of non-replaceable structural parts;
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet (e.g., grounding Boeing 787 fleet due to battery problems);
- Due to similarity of technologies and aircraft uses, a fleet grounding event in such a scenario could impact many or all aircraft fleets;
- An increase in the number of aircraft and engines required by each airline to compensate for inspection/overhaul downtime and early retirement; and

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[66] As defined by Commission Regulation (EU) 748/2012 which sets out the requirements that must be fulfilled by organisations that design aircraft, make changes to aircraft, repair aircraft and the parts and systems used in aircraft.

- Defence systems would have similar impacts adversely affecting the continuity of national security.

Aerospace components are portions of major systems (fuselage; wings; engines etc.) and the components in these systems are designed to withstand similar criteria mentioned above between overhauls. For example, a system is designed to achieve 25,000 cycles between overhauls and in the case where a new component is only rated for 5,000 cycles because of lower performance of a Cr(VI)-free coating. By default, the entire system would now be de-rated to 5,000 cycles. For example, if a compressor blade that is located in the middle of an engine can only survive for a portion of the life of the engine due to limitations of a new coating, the engine would require disassembly to access the blades. This means taking the engine off the wing, sending it to a repair centre, disassembling the engine and replacing the components at much shorter intervals than needed for the remainder of the engine; thus adding inherent inspection, maintenance, and repair costs to the manufacturers, operators, and end use customers, who will also be impacted by increased out of service times.

The lack of experience with Cr(VI)-free solutions can have a critical safety impact. As a result, the aerospace industry has a permanent learning loop of significant events and failure analysis and decisions for safety improvements. Part of this improvement is the introduction of the Maintenance Steering Group 3 Analyses (MSG-3), specifically developed for corrosion. MSG-3 provides a system for OEMs and the regulators to identify the frequency of inspection with respect to the stress corrosion, protection and environmental ratings for any component or system.

Without adequate experience, proven success, and therefore possible unknown or hidden properties, the performance of a chromate-free system cannot be highly rated. Consequently, a significant reduction to the maintenance interval would be required, potentially cut in half. For cases with no long-term experience or correlation to in-service behaviour, which is normally the case, a further reduction to the maintenance interval may be required.

As a result, OEMs rule out moving to a poorer performing alternative under the non-use scenario; the risks are unacceptable to all OEMs. The primary objective of these companies is to move to an alternative. This objective cannot be achieved, however, without sufficient testing and flight (or other) data surrounding the use of alternatives. Without such data, the necessary approvals cannot be gained as the safety risk becomes too great, whether related to civil aviation or military aircraft. The corrosion resistance and other benefits provided by passivation are crucial to the manufacture of aircraft components in the EEA/UK; if there are no qualified alternatives certified for use on components then manufacturing work would cease.

Given the above, this scenario is absolutely not considered plausible.

5.2.2.2 Overseas production followed by maintaining EEA/UK inventories

To be competitive, companies must keep inventory as low as possible (“just-in-time” delivery). Maintaining inventory clearly involves substantial capital costs (as elaborated below) and ties up cash. Stockpiling is also clearly not feasible for the repair and maintenance side of the business because the main aim of repair is to make components serviceable rather than replace them by spare components (which would run counter to the sector’s drive towards increased sustainability).

The reasons why holding increased inventories is not a feasible option compared to maintaining and repairing damage include, but are not limited to, the following considerations:

- If no certified alternative is available or is likely to become available within months after the end of the review period, then there is no clarity on how long such inventories of components must be available. For legacy aircraft, inventories will certainly be required for the next 20 years or more. Additionally, there is no visibility or clarity on customer demand in the short or longer term. Planned maintenance can be taken into account, but it is not possible to anticipate which components will be needed for unplanned maintenance and repair. Consequently, an assumption regarding the inventory that needs to be available for a sufficient duration would have to be made, leading to the risk of wasted resources or aircraft/equipment becoming obsolescent due to inadequate inventories.

- Stockpiling results in increased costs and would reduce the opportunity to invest in other projects/R&D, etc. The inventory costs would also have to be added to product costs and would therefore reduce competitiveness for operations in the EEA/UK.

- The costs of building adequate warehouse facilities in the EEA and the UK would be prohibitive and would not be economically feasible. In the UK, an industrial warehouse without climate control (which would be required for the storage of some A&D inventory) costs around €1000 per m^2 to construct (a conservative estimate). It is assumed here that warehouses that would act as a hub for storing inventory would be around 10,000 m^2 as a minimum, given the range of parts that would need to be stored. This implies a total build cost of around £10 million as a minimum, not taking into account the costs of land purchase, site preparation, design, construction, etc., which could easily add a further 25% even after taking into account any potential economies of scale in pricing due to the large size of the warehouse.[67] If such facilities are required at around 100 sites across the EEA and UK (to cover civilian and military requirements), then warehousing costs alone would lead to €1 billion in expenditure. These costs would be on top of the losses in profits that would occur from the need to subcontract manufacture to companies located outside the EEA/UK and the consequent profit losses and increased costs of shipping, etc.

- Facilities do not have enough production capacity to build up multi-year inventories, while also meeting current demand. Even if production capacities could be increased and adequate quantities of standard components be produced, there would be idle inventories for years beyond their need, which would in turn increase product costs for years. Importantly, the need to store this inventory under optimum conditions to avoid corrosion or damage over extended periods of stockpiling, would lead to further increases in costs.

- Existing facilities are not sized to store the amount of multi-year inventories required. Companies will need to build/invest in additional secure, high-quality warehouses to store the inventory. However, it is important to recognise that this scenario is not feasible at all for many parts, such as wing and fuselage skins, because these components are not removed from the aircraft; these parts only allow MRO activities in-situ. Therefore, the entire aircraft would need to be transported to a non-EEA country for repair. If the plane is not airworthy, the effort and cost relating to transportation alone (e.g., from Belgium to Egypt) would be overwhelming.

- When existing inventories become depleted and no longer support necessary repairs and maintenance, increasing numbers of aircraft on ground (AOG) scenarios are inevitable, with associated costs. All transportable components would have to be sourced and produced from non-EEA suppliers sooner or later.

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[67] See for example the cost model available at: https://costmodelling.com/building-costs

- Being dependent upon inventories and non-European suppliers (and in turn being vulnerable to local economic and political issues affecting non-EEA countries or the UK), and thus unable to reliably fulfil MRO activities, will lead to inevitable delays and potential cancellation of flights, and fines due to longer turn-around times and aircraft on ground scenarios.

- Companies make design modifications for single components as part of their normal course of business (for reasons other than chromate substitution). In these cases, all existing inventory would need to be written off for a loss. Furthermore, companies would not be able to produce the modified components in the EEA/UK anymore (if passivation is still required). Consequently, it is clearly not possible to rely on a long-term stock of spare parts that would fit all situations.

- It is impossible to hold a stock of all spare components at every airport. This would affect schedules, especially overnight stops as aircraft cannot be readily repaired and maintained. As a result, these aircraft would not be available for services next day and delays or flight cancellations would likely occur.

- Cost and environmental impacts of managing and disposing of waste components that could not be reused would be high. This would likely be inconsistent with the emphasis on waste reduction as a part of the circular economy.

It is challenging to elaborate these issues quantitatively as they are multi-fold (i.e., increased cost of land and construction for warehousing, worker costs to secure and maintain inventory, increased delays and ‘aircraft on the ground’, writing-off stock) and there is no precedent to rely on, as this NUS is entirely contrary to current industry practice. However, it is immediately clear that the result would be that the cost of operating in the EEA/UK would increase considerably and there would be significant impact to society as a whole.

Furthermore, for certain types of components, increasing stock inventory is not feasible at all. In a very competitive industry, this would result in a migration of the entire industry (the inter-dependency of the industry is explained below and elsewhere in the SEA) to non-EEA/UK locations. As production moves outside the EEA/UK, related activities such as R&D will also re-focus to these countries. It can also be expected that future investment in associated industries and technologies will be most efficiently located alongside these activities.

In general, the non-aluminium metallic coatings are susceptible to excess corrosion until they are passivated. Excessive handling, storage, and shipment of non-passivated plated components can damage the non-aluminium metallic coating and the underlying part due to exposure to humidity, moisture, and corrosive compounds such as atmospherically deposited chloride and sulphate compounds. The non-passivated sacrificial coatings on high strength steel also create a hydrogen embrittlement risk due to their higher rate of corrosion. This damage can be irreversible and require either re-plating or scrapping of the affected part.

Minor amounts of corrosion to these non-aluminium metallic coatings can be corrected by "reactivation", typically in an acid solution, prior to passivation. For example, low-embrittlement cadmium and zinc-nickel-plated parts can be baked for hydrogen embrittlement prior to passivation. The baking process is typically done immediately after plating with careful handling to prevent damage to presumptively embrittled parts. The passivation process in this case is done immediately after baking and includes a reactivation step.

Exporting plated parts for passivation is non-trivial. At a minimum, logistical steps such as controlled humidity packaging and storage would need to be implemented. Such an arrangement would be considered by most design owners as a significant process change that would require some testing and auditing to confirm that the controls enacted are sufficient to preserve the quality and performance of the plated and remotely passivated parts.

Given the above, this scenario was not considered plausible by the OEMs and MROs due to the need for components to have passivation treatments quickly after other surface treatments. It was confirmed though that such an approach may be feasible for a small range of components for civilian aircraft and for a limited number of parts for military aircraft and equipment. However, as an overall strategy, it would not be feasible as use of chromium-based passivation would still be required in the EEA/UK for the majority of components and on-site maintenance and repair activities.

5.2.3 Conclusion on the most likely non-use scenario

The most likely non-use scenario is driven by the responses of the OEMs in the event of a refused re-authorisation. They are the companies that carry out the R&D and testing (sometimes in collaboration with their chemical suppliers) to determine whether an alternative is technically feasible, qualify and gain approvals for that alternative and then certify their suppliers against its use. In some cases, they also help their suppliers meet the financial costs of adapting existing equipment and risk management measures to enable them to move to the alternative.

As a result, the most plausible non-use scenario for the OEMs drives the most likely non-use scenario for the sector as a whole. The most likely scenario is therefore the following:

1. EEA and UK suppliers (importers and distributers) of the chromates used in passivation would be impacted by the loss of sales, with the market for chromate passivation for A&D relocating outside the EEA/UK.

2. EEA/UK based producers of passivation formulations would either cease manufacturing their current formulations or move manufacture outside the EEA/UK for sale to companies relocating their activities. Relocation of formulation manufacturing would require formulators to undertake necessary testing programmes to satisfy that a change in manufacturing location does not impact the performance and properties (of the formulations) that must continue to be met across all specifications that those formulations are qualified against. There is a risk that if the formulations manufactured in a new facility do not demonstrate continued ability to satisfy the specifications against which they are qualified, this could lead to the obsolescence of affected parts and products, including aircraft and military equipment. Even where relocation is possible and shown not to be of detriment, this would not be feasible before the end the current authorisation period.

3. OEMs directly involved in passivation would move a significant proportion of their manufacturing (if not all) outside the EEA/UK, with the consequent loss of significant levels of turnover and employment. In particular, they will move those manufacturing activities reliant on the use of passivation where there is no qualified alternative or where implementation across suppliers is expected to take several years after the end of the current review period. The losses to the EEA/UK are estimated at 70% of manufacturing turnover at some sites. There would be a significant loss of jobs directly related to passivation, as well as across other manufacturing activities.

4. OEMs who do not carry out passivation treatments themselves would still move some of their manufacturing operations outside the EEA/UK due to the need for other production activities to be co-located with key BtP and DtB suppliers (i.e., to form clusters). This would facilitate the integration of manufacturing activities and associated maintenance and repair activities. As a result, there would be losses in turnover and employment associated with these companies also relocating.

5. As OEMs shift their own manufacturing activities outside the EEA/UK, they will have to carry out technical and industrial qualification of new suppliers or EEA/UK suppliers moving to the new location, to ensure suppliers have the capability to deliver the stringent airworthiness and certification requirements. This would then be followed by a ramping up of production in order to meet the manufacturing rate objectives.

6. In some cases, these newly located supply chain would be developed using BtP and DtB suppliers who have moved operations from the EEA/UK to other countries in order to continue supplying the OEMs. However, a significant proportion of the existing BtP companies involved in passivation – 50 to 75% – will cease trading in the EEA as they do not also supply other sectors and are reliant on the aerospace sector; furthermore, the types of products that they manufacture are specific to the aerospace sector. This applies to those who indicated they “don’t know” what the most plausible scenario would be for them and those that would cease trading or move outside the EEA/UK. For BtP companies, 70% turnover losses are estimated, whereas 40% is estimated for DtB.

7. MROs will also be severely impacted and the larger operators indicated that they will either cease trading or move operations outside the EEA, due to the need to maintain vertical integration across the surface treatment processes that they are able to carry out. On this basis, it is estimated that around 70% of current relevant MRO activities would cease in the EEA/UK.

8. The re-location of MRO activities will have consequent impacts for civil aviation and military fleets, as well as for the maintenance of defence products, space equipment and aero-derivative products.

9. Airlines and their passengers would be impacted by increased costs and planes on the ground, while military forces’ mission readiness would be impacted with the risk that equipment would also becoming obsolete and unavailable due to the inability to carry out repairs and/or maintenance activities according to manufacturers’ requirements.

10. Taken together there would be significant economic impacts from the loss of manufacturing and maintenance to both the EEA and UK economies, together with the loss of highly skilled jobs (and potentially a highly skilled labour force) and the benefits derived from the R&D carried out by a high tech sector.

The justification for this NUS takes into account the following factors. Although OEMs are working on substitution of the chromates in passivation, they will not have components with certified alternatives which have been fully implemented across their supply chains by September 2024. Many will require a further 12 years to have fully implemented alternatives across all components/final products and EEA/UK supply chains, and some will need longer. The regulatory requirements placed on the sector mean that unless components have certified alternatives there is no substitute which can be considered “generally available”.

As noted previously, the A&D industry has a very complex and interrelated supply chain, with only one designated supplier for many essential parts. As a result, relocation by the customer may lead to relocation of suppliers in order to keep proximity. Such relocation would involve not just the surface protection activities, but all activities due to the potential for corrosion of unprotected surfaces during transport to another place. Using small amounts for Cr(VI) compounds for rework (or repairs) is mandatory and essential to the safety of the aircraft. Surface coating and touch-up processes cannot be disconnected in time or distance from assembly processes. When these processes are no longer available, the entire process must re-locate.

Moreover, the situation is the same even if a Cr(VI)-free alternative was successfully qualified for one or two components. The following set of figures demonstrate the interdependency of every single part used, and the effect of only one component missing for the overall assembly process of the aircraft. It should be noted that this figure represents a highly simplified supply chain of components needed for the final assembly of an aircraft. If only one component cannot be produced according to Type Certification, the manufacture of the entire aircraft is jeopardised.

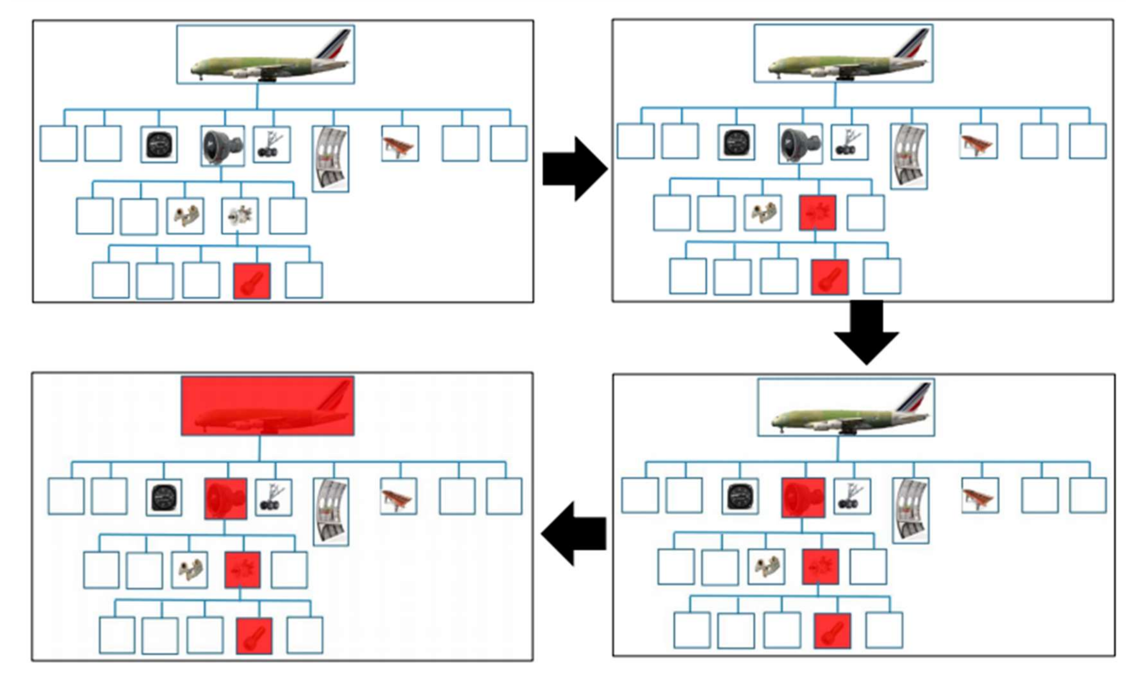

Figure 5-1: Interdependency of component availability in the manufacture of a final product
Source: GCCA (AfA 0116-01)

As noted previously, it is therefore not possible to relocate single Cr(VI) based activities on their own in most cases. The processes are an integral part in the production chain and cannot be separated from previous or following process steps.

This also holds true for MRO activities, for example overhaul of turbine parts, which would be significantly affected under the non-use scenario. It is technically not possible (or economically feasible) to do the machining and repairs of a vane or other turbine part in the EEA or UK, then ship it to a non-EEA/UK facility for surface treatment, ship it back to the EEA/UK to further process the part, ship it back to a non-EEA facility for further surface treatment and ship and put it back in the turbine in the EEA/UK. Apart from the fact that the surface of the part would likely corrode during transport, adding to the technical infeasibility of this situation, the very tight turnaround times and budgets are impossible to hold in such a scenario.

Given the above, under the NUS, the companies affected by the refused authorisation will move manufacture and repair of parts and assemblies out of Europe and the UK, together with jobs, know-how and R&D investments.

Finally, although this is considered the most plausible scenario, OEMs note that the obstacles that would have to be overcome in a short period of time may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs (see also Annex 3), with smaller suppliers located around the sites operated by the larger OEMs. Not all of these smaller sites, including those of critical suppliers, would be able to shift their activities outside the EEA/UK, leading to OEMs having to create entirely new supply chains outside the EEA/UK. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their EEA/UK suppliers. This level of investment is unlikely to be feasible and hence the OEMs would be likely to cease manufacturing activities until the new industrial facilities were in place and ready to operate outside the EEA/UK.

5.3 Economic impacts associated with non-use

5.3.1 Economic impacts on applicants

Under the non-use scenario, all applicants and the formulators of the passivation products would be impacted by the loss of sales of the three chromates or of imported formulations containing the chromates for use in passivation. At the specific supplier level, these impacts may vary in their significance, as the importance of the different chromates used in passivation formulations to their revenues varies across the suppliers (as does the level of supply of chromates for use in other treatment processes).

In the short term (i.e., the first two years under the non-use scenario), the losses will be in the order of tens of millions of Euros per annum to the applicants and their downstream formulators.

Over time, as consumption of the chromates reduces in line with companies' substitution plans, sales and hence revenues will continue to decrease. However, the formulators producing the chromate-based passivation formulations are also the same companies that will be providing formulations based on the alternatives. As a result, sales of alternative formulations once they are certified and implemented across value chains would be expected to offset profit losses from declining demand for the chromate-based formulations.

No quantitative estimates for formulation losses are included in this SEA. These impacts are captured in the combined AoA/SEA for formulation.

5.3.2 Economic impacts on the supply chain

5.3.2.1 Introduction

It would be theoretically possible to move activities involving the use of the chromates outside the EEA/UK due to already existing supply chain sites in other countries, for example, the USA, Canada, China, India, etc., and to outsource manufacturing as the supply chain is spread around the world. There are several obstacles to such a scenario, however, which would make this economically unattractive even if it is the most plausible scenario. Firstly, the due diligence principle will continue to apply to the supply chain and would be exacerbated in case of relocation out of EEA/UK. Secondly, when activities are shifted to another site, there is an inevitable phase of technical and industrial preparation (site design, capital procurement and installation, worker training, pilot trials) and qualification to ensure the sustainability of these activities, including an assessment of the technical capability to deliver stringent airworthiness and certification requirements. Moreover, once the qualification phase is over, it is essential to get the right ramp up in order to meet the manufacturing rate objectives.

In the remaining time before the end of the initial review period, even if alternatives were qualified and certified across the manufacture of components and products, these two aspects (due diligence and technical/industrial preparation described above) are not realistic; it would require a huge economic investment that would significantly affect businesses with detrimental economic impacts. As a result, OEMs have indicated that they probably would be forced to stop manufacturing activities until the new industrial facilities and infrastructure are in place and ready to operate outside of the EEA/UK, with consequent impacts on the entire value chain. Given the current levels of civil aviation and anticipated growth, this would be catastrophic for aviation in the EEA/UK and globally.

5.3.2.2 Approach to assessing economic impacts

As noted in Section 1, the ADCR has been created as a sectoral consortium and members include competitors, which may also act as suppliers to each other; the larger companies also share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). These interlinkages have been taken into account in the estimation of economic impacts, which have been calculated separately for the OEMs, DtBs, their associated BtP suppliers and MROs.

Two separate approaches have been used to estimate the magnitude of the potential economic impacts. Both are based on responses to the SEA questionnaire, with one taking as its starting point the number of jobs that would be lost while the other considers losses in turnover and what these imply in terms of losses in profits. Both approaches are used as a greater number of responses provided estimates of jobs lost than of the likely impacts on turnover (in percentage or absolute terms).

1. **Estimates based on loss of jobs**: The first approach takes as its starting point the number of jobs that would be lost at the sites of SEA questionnaire respondents, based on their most likely response to the Non-Use Scenario. This includes loss of jobs directly linked to use of the chromates and losses in jobs at the site reliant upon the continuation of their use, i.e., jobs in related manufacturing and assembly activities. Importantly, it excludes losses in employment at local sub-contractors providing support services. The numbers of jobs lost are multiplied by the average Gross Value Added - GVA - per job (taking into account variations by role) to provide an estimate of total GVA lost. Personnel costs associated with this GVA are then subtracted to derive the implied losses in operating surpluses per annum.

2. **Estimates based on loss of turnover**: The second approach takes as its starting point the anticipated losses in terms of percentage of turnover reported by the respondents to the SEA questionnaire. Lost operating surplus is then calculated as an average per company based on role in the supply chain and Eurostat data on GOS as a percentage of turnover.

Both of these approaches provide proxy estimates of profit losses based on current levels of employment and turnover. They do not account for foregone future turnover under the continued use scenario due to the inability of the EEA/UK A&D sector to respond to growth in the global demand for air traffic or to increased military and defence spending as a result of either a cessation in manufacturing activities or their relocating outside the EEA/UK.

The two approaches have been applied to account for uncertainty in the data available from the SEA questionnaire responses. Together they provide an interval, with one estimate acting as an upper bound and the other as a lower bound to the economic impacts.

5.3.2.3 Estimates based on loss of jobs (and GVA)

The SEA questionnaire collected data on the number of employees who would lose their jobs under the NUS. This includes both those whose job directly involves use of the chromates and those whose jobs would be affected due to a cessation of production activities or due to companies moving outside the EU. The resulting figures collected for the 32 sites are presented in Table 5-2 below.

Extrapolated out to the total 130 sites expected to be carrying out passivation across the EEA and UK, 22,900 jobs (around 19,400 in the EEA and 3,500 in the UK) are expected to be lost due to the cessation of passivation and linked manufacturing activities across product lines or to the cessation of MRO services, including as a result of companies moving operations outside the EU.

It is important to note, that these losses do not equate to 100% of the jobs at these sites, as there would not be a full cessation of activities at all sites. This can be clearly seen by the UK figures which assume no additional direct job losses. Although these figures may appear high, they should be seen within the context of the roughly 890,000 employees (2019[68]) within the European aerospace sector, taking into account the critical importance of the chromates in passivation.

These predicted job losses have been combined with Eurostat data on Gross Value Added (GVA) per employee to the EU/UK economy as part of calculating the economic losses under the Non-Use scenario. A weighted GVA has been used for BtP and DtB suppliers and NACE code specific GVAs have been used for OEMs and MROs. The resulting estimated losses are given in Table 5-3.

The estimated losses in GVA equate to:

- €1,600 million per annum across the EEA and €320 million per annum for the UK, extrapolated out to the 100 EEA and 30 UK downstream user sites.

For comparison, turnover for the EEA aerospace industry is around €259 billion[69] per annum, while that for the UK aerospace and defence sectors is around €57 billion (£50 billion) in 2020[70]. Thus, although these figures appear high, they are considered to be underestimates by the ADCR members (particularly the OEMs) given the potential for much larger segments of the sector to move outside the EEA /UK should chromate-based passivation no longer be permitted.

In order to convert these GVA losses to an estimate of lost operating surplus (profits), personnel costs for each lost job are subtracted. The results of this calculation are given in Table 5-4. Personnel costs are based on Eurostat data for the relevant NACE codes, with an average weighted personnel cost adopted for BtP and DtB; the average personnel costs by NACE code from Eurostat for OEMs and MROs are adopted in these cases.

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[68] Statista 2022: https://www.statista.com/statistics/638671/european-aerospace-defense-employment-figures/

[69] https://www.statista.com/topics/4130/european-aerospace-industry/#topicHeader__wrapper

[70] https://www.statista.com/statistics/625786/uk-aerospace-defense-security-space-sectors-turnover/

The estimated (implied) values of lost operating surpluses generated by this GVA-based approach equate to:

- €510 million per annum across the EEA and €90 million per annum for the UK, extrapolated out to the 100 EEA and 30 UK downstream user sites.

Table 5-2: SEA survey responses and extrapolations on numbers of jobs lost under the Non-Use Scenario

	No. Company Responses		Direct job losses – workers undertaking processes linked to passivation		Additional direct job losses – due to a cessation of manufacturing/MRO activities	
From SEA Survey	**EEA**	**UK**	**EEA**	**UK**	**EEA**	**UK**
Build-to-Print (6 sites)	2	4	102	77	159	21
Design-to-Build (5 sites)	4	1	36	30	17	15
MROs (10 sites)	8	2	823	85	2,367	65
OEMs (11 sites)	9	2	680	707	1,534	300
Total 32 sites	**23**	**9**	**1641**	**899**	**4077**	**401**
Job losses - Extrapolation of job losses under the Non-Use Scenario to the estimated 130 sites undertaking passivation treatments						
Build-to-Print (50 sites)	33	17	1,700	321	2,650	88
Design-to-Build (22 sites)	17	5	150	160	71	80
MROs (19 sites)	17	3	1,715	113	4,931	87
OEMs (39 sites)	33	5	2,519	1,885	5,681	800
Total sites (130)	**100**	**30**	**6,083**	**2,480**	**13,334**	**1,054**
Total EEA direct and indirect across 100 sites			**19,417**			
Total UK direct and indirect across 30 sites			**3,534**			

Table 5-3: GVA losses per annum under the Non-use Scenario

By role	GVA per worker assumed by role		GVA lost due to direct job losses € million		Additional GVA lost due to due to a cessation of manufacturing/MRO activities - € million	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (6 sites)	59,500*	59,500*	6.13	4.63	9.56	1.26
Design-to-Build (5 sites)	59,500*	59,500*	2.16	1.80	1.02	0.90
MROs (10 sites)	85,000	85,000	69.96	7.23	201.20	5.53
OEMs (11 sites)	98,500	98,500	66.98	69.64	151.10	29.55
Total 32 sites			145.23	83.30	362.87	37.24
		Total EU	**€ 508 million per annum**			
		Total UK	**€ 121 million per annum**			
GVA losses - Extrapolation to the estimated 130 sites undertaking passivation treatments						
Build-to-Print (50 sites)	59,500*	59,500*	102.20	19.29	159.31	5.26
Design-to-Build (22 sites)	59,500*	59,500*	9.02	9.62	4.26	4.81
MROs (19 sites)	85,000	85,000	145.74	9.63	419.16	7.37
OEMs (39 sites)	98,500	98,500	248.07	185.71	559.63	78.80
Total sites (130)			505.03	224.25	1,142.35	96.24
		Total EU	**€ 1,647 million per annum**			
		Total UK	**€ 320 million per annum**			

*Weighted average GVA calculated for Build-to-Print and Design-to-Build companies as the GVA by NACE code multiplied by the NACE code counts across responding companies, divided by the total number of relevant NACE responses. MRO and OEM GVA figures from Eurostat (2018).

Table 5-4: Implied GVA-based gross operating surplus losses under the Non-Use Scenario						
	Total GVA losses- € millions per annum		Total personnel costs associated with lost jobs - € millions per annum*		Implied operating surplus losses € millions per annum	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (6 sites)	15.69	5.89	10.25	3.85	5.44	2.04
Design-to-Build (5 sites)	3.19	2.71	2.08	1.77	1.10	0.94
MROs (10 sites)	271.15	12.75	179.92	8.46	91.23	4.29
OEMs (11 sites)	218.08	99.19	156.31	71.09	61.77	28.10
Total 32 sites	**508.11**	**120.54**	**348.56**	**85.17**	**159.55**	**35.36**
Operating surplus losses - Extrapolation to the estimated 70 EEA and 20 UK sites undertaking passivation treatments						
Build-to-Print (50 sites)	261.51	24.55	170.88	16.04	90.63	8.51
Design-to-Build (22 sites)	13.28	14.43	8.67	9.43	4.60	5.00
MROs (19 sites)	564.90	17.00	374.83	11.28	190.07	5.72
OEMs (39 sites)	807.70	264.51	578.92	189.58	228.78	74.92
Total sites (130)	**1,647.38**	**320.48**	**1,133.30**	**226.33**	**514.09**	**94.15**
*Weighted personnel costs calculated for Build-to-Print and Design-to-Build companies as the GVA multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM GVA figures direct from Eurostat (2018) for EU/UK as available.						

5.3.2.4 Estimated based on lost turnover

The SEA questionnaire also asked companies to provide information on the impacts that a refused authorisation would have on turnover/revenues. Fewer companies responded to this question, although the responses provided by the OEMs (as the end customer) and MROs enable estimates of the likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than chromate-based passivation for the aerospace sector, as well as surface treatment and other processes for other sectors. They also account for potential loss in turnover from subsequent manufacturing and assembly activities.

Estimates of lost revenues per site are based on Eurostat data by NACE code with weighted averages used for BtP and DtB companies, and NACE code specific data for OEMs and MROs. Note that the weighted averages exclude micro-enterprises as few suppliers within the sector will fall into this size category. Gross operating surplus losses are then calculated by applying GOS rate data for the different NACE codes from Eurostat for 2019. The resulting losses are given in Table 5-5.

Table 5-5: Turnover and GOS losses under the Non-Use Scenario – (avg. 10.6% losses across all roles)

	Turnover lost per annum € millions		GOS losses per annum € millions	
	EEA	**UK**	**EEA**	**UK**
Build-to-Print (6 sites)	101	202	13	25
Design-to-Build (5 sites)	116	29	14	4
MROs (10 sites)	342	86	34	8
OEMs (11 sites)	7,652	1,701	731	162
Total 32 sites	8,212	2,017	791	200
Extrapolation to the estimated 130 sites undertaking passivation treatments				
Build-to-Print (50 sites)	1,687	843	210	105
Design-to-Build (22 sites)	482	154	60	19
MROs (19 sites)	832	133	82	13
OEMs (39 sites)	28,342	4,535	2,707	433
Total sites (130)	31,342	5,665	3,058	570

Note: Weighted average turnover and GOS calculated for Build-to-Print and Design-to-Build companies as the GOS multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM figures direct from Eurostat (2018) for EU/UK as available.

5.3.2.5 Comparison of the profit loss estimates

The figures presented in Table 5-4 are lower than those given in Table 5-5 for both the EEA and UK, with the greatest differences being in the estimates for OEMs and MROs. This is considered to be due to the turnover-based estimates taking better account of the loss in associated manufacturing, maintenance or repair activities, given the importance of chromate-based passivation to both of these sets of companies.

- Losses in gross operating surpluses, taking into account impacts also on other associated chromate-based treatments:
  - Losses of €510 million per annum for the EEA
  - Losses of €90 million per annum for the UK

- Losses in EBITDA based approach:

  - Losses of €3,100 million per annum for the EEA
  - Losses of €570 million per annum for the UK

The two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus with the ratios between the two sets of estimates for the different roles shown in Table 5-6. It is important to note that these losses apply to commercial enterprises only. No data were provided by any of the military organisations reliant upon the continued use of chromate-based passivation which could be used in this analysis. These organisations simply stated that they would have to cease undertaking MRO related activities in their home country, resulting in severe impacts on impacts on their military forces.

Table 5-6: Comparison of profit loss estimates

	Total job losses		% turnover lost		Ratio of lost profits based on turnover to lost operating surplus based on jobs (based on €billions lost)	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (50 sites)	4,350	408	70%	70%	2.31	12.32
Design-to-Build (22 sites)	221	240	40%	40%	13.02	3.83
MROs (19 sites)	6,646	200	70%	70%	0.43	2.28
OEMs (39 sites)	8,200	2,685	70%	70%	11.83	5.78
Total sites (130)	19,417	3,534	€31.1 billion	€5.7 billion	5.95	6.06

Offsetting profit losses and impacts on rival firms

The losses in operating surplus given above would result not only from a cessation of manufacturing activities, but also from the premature retirement of existing capital equipment. Some of this capital equipment would be replaced in any event as part of substitution, over the next four to 12 years, with any such investment in new equipment focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next seven to 12 years would not be expected to be replaced).

As there are no suitable alternatives which are generally available, following SEAC's latest guidance, consideration has been given to the need to offset the profit losses for downstream users against the potential resale or scrappage value of the sector's tangible EEA and UK assets. However, given the potential scale of the impacts of a refused authorisation for the sector as a whole, any possible market for redundant equipment is likely to be overwhelmed by the number of sites ceasing activities, including related processes. As a result, it is not possible to estimate the potential scrappage value of equipment (e.g., immersion baths), especially as its current use for chromate-based treatments may further reduce its value.

Because this is a sectoral application and the ability to shift to alternatives is driven by qualification and validation by OEMs and obtaining certification approval by airworthiness authorities, the issue of potential losses incurred by rival firms undertaking passivation using alternatives is not relevant. The OEMs determine whether or not there are alternatives that can be used, not individual downstream users. Furthermore, as previously indicated, the ADCR is a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other, while the larger companies share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). Relationships between the OEMs and BtP and DtB are developed over time and often reflect long-term commitments given the need for OEMs and DtB companies to certify their suppliers in the manufacturing of components. As a result, rival suppliers cannot readily step in and replace their production activity.

The economic losses are therefore based on consideration of losses in operating surplus/profits only. These have been estimated over five time periods in line with SEAC's new guidance for those cases where there are not suitable alternatives available in general. Discounted losses over 1, 2, 4, 7 and 12 years are given in Table 5-7.

As discussed earlier, these losses are based on Eurostat turnover figures for 2018 (most recently available by company size). They therefore represent an underestimate of the losses in turnover that would arise over the review period under the Non-Use scenario, given the anticipated level of future growth in turnover for the sector due to the importance of the EEA and UK in the global manufacture of aerospace and defence products (as highlighted by the publicly available forecasts of the demand for new aircraft cited earlier).

Table 5-7: Discounted profit/operating surplus losses under the Non-Use Scenario – Discounted at 4%, year 1 = 2025

	Lost EBITDA/Profit € millions		**GVA-based Operating Surplus Losses € millions**	
	EEA	**UK**	**EEA**	**UK**
1 year profit losses (2025)	3,058	570	514	94
2 year profit losses (2026)	5,767	1,075	970	178
4 year profit losses (2028)	11,099	2,069	1,866	342
7 year profit losses (2031)	18,353	3,422	3,086	565
12 year profit losses (2036)	28,698	5,351	4,825	884

5.3.2.6 Other impacts to Aerospace and Defence Companies

Under the non-use scenario there would be an enormous impact on the A&D sector in the EEA /UK, leading to a second wave of negative impacts on the EEA market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Customer penalties for late/missed delivery of products;
- Extended durations of maintenance, repair, and overhaul operations for products in service leading to e.g., "aircraft on the ground" (AoG) and other out-of-service final products, with consequent penalties and additional impacts on turnover;
- Increased logistical costs; and
- Reputational damages due to late delivery or cancelled orders.

5.3.3 Economic impacts on competitors

5.3.3.1 Competitors in the EEA/UK

This combined AoA/SEA has been prepared so as to enable the continued use of the chromium trioxide, sodium dichromate and potassium dichromate in passivation of non-aluminium metallic coatings across the entirety of the EEA and UK aerospace and defence sectors. It is non-exclusive in this respect. It has been funded by the major (global) OEMs and MROs the EEA and the UK, with additional support provided by their suppliers and by Ministries of Defence, to ensure the functioning of EEA and UK supply chains for their operations.

As a result, there should be no economic impacts on competitors, especially as the major global OEMs and DtBs act as the major design owners which determine the ability of all suppliers to move to an alternative. As design owners they validate, qualify, and certify components and products with new alternatives and gain new approvals (e.g., approvals from EASA, ESA, or MoDs). Once these design owners have certified new alternatives in the manufacture of parts and components, these alternatives will be implemented throughout their value chain.

5.3.3.1 Competitors outside the EEA/UK

Under the NUS, it is likely that some of the major OEMs and DtB suppliers would move outside the EEA/UK, creating new supply chains involving BtP and MROs. This would be to the detriment of existing EEA/UK suppliers but to the advantage of competitors outside the EEA/UK. These competitors would gain a competitive advantage due to their ability to continue to use chromate-based passivation treatments and due to their proximity to the OEMs and DtB, thus minimising logistic and transport issues.

5.3.4 Wider socio-economic impacts

5.3.4.1 Impacts on air transport

Under the Non-Use Scenario there would be significant impacts on the ability of MROs to undertake repairs and to follow normal maintenance and overhaul schedules. As indicated previously, MROs are legally bound to adhere to the requirements set out in the OEMs' manuals under airworthiness and military safety requirements. Where maintenance or overhaul activities would require chromate-based passivation, they would have to be performed outside the EEA/UK until the OEMs have gained approvals and certifications for the use of alternatives on components and have adapted the manuals setting out maintenance and overhaul instructions.

If an aircraft needs unscheduled repairs (i.e., flightline or "on-wing" repairs), it will be grounded at the airport until these take place due to airworthiness constraints. This would result in AOGs and could result in an aircraft having to be dis-assembled and transported outside EEA/UK for repairs, with dramatic financial and environmental impacts.

Should MRO facilities be relocated outside the EEA/UK, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EEA. Indeed, it may take some time to build up capacity to accommodate additional demand from EEA-based operators, potentially resulting in a large number of aircraft being grounded until maintenance checks can be completed.

As a result, airlines would need to have additional spare components/engines/planes to account for the added time that aircraft would be out of commission due to extended MRO times. Airports may also have to build up large inventories of spare components to replace products (including e.g., spare engines, aircraft) that currently can be repaired, with this going against the desire to ensure sustainability within the sector.

The need to have maintenance carried out outside the EEA/UK would also lead to additional operational costs being incurred through increased fuel use. Small planes (e.g., business jets) that do not have the fuel capacity or airworthiness approvals for long haul flights would need to make multiple stops enroute to non-EEA MRO facilities and back to the EEA/UK. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco adds approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring an annual "D check" (heavy maintenance inspection of the majority of components, carried out every 6-10 years), this would involve 400 hours of flight time (return trip) or 20 days of foregone revenue, equivalent to €1.4 million. Scaling this up to the EEA passenger aircraft fleet, which stands at approximately 6,700 aircraft, suggests lost revenues in the tens of millions per annum just due to the need to have around 700 aircraft which require a "D check" each year. Using the above estimate for a fleet of 50 aircraft, this would amount to €20 million in revenue lost by European airlines for "D checks" alone. This figure excludes the costs of fuel and personnel, as well as the fact that additional flights bring forward maintenance interval requirements and impact on the total lifespan of an aircraft.

In addition, based on a leasing cost for a large passenger jet of around $500,000/month in 2021 (€421,500, £362,250)[71], the leasing costs alone of a plane being out of service would be roughly €14,000/£12,100 per day. On top of this will be the additional losses in revenues from not being able to transport passengers or cargo. For example, an Airbus A320 carries from 300 to 410 paying customers on one long-haul flight per day. If tickets cost on average €650 (£560) per customer (assuming 350 customers), the revenue lost due to being 'out of action' for one day amounts to €227,500 (£195,500). As a result, the cost of extending the period over which a plane is out of service for repair or maintenance reasons may lead to significant new costs for airlines, delays for passengers and in the transport of cargo, as well as subsequent effects for GDP and jobs due to planes being out of service for longer.

ICAO reported[72] a 49 to 50% decline in world total passengers in 2021 compared to 2019. In 2020, figures for Europe show a 58% decline in passenger capacity, 769 million passengers and a revenue loss of 100 billion USD. In addition, COVID-19 caused a 74% decrease in passenger demand for international travel in 2020 compared to 2019. The trend though is for the aircraft industry to continue expanding globally, with pre-covid estimates suggesting that demand for air transport would increase by an average of 4.3% per annum over the next 20 years, as illustrated in Figure 5-2 below. Similar growth is expected in air freight transport. If this growth path were to be achieved, by 2036 the air transport industry would contribute 15.5 million in direct jobs and $1.5 trillion of GDP to the world economy. Once the impacts of global tourism are taken into account, these numbers could rise to 97.8 million jobs and $5.7 trillion in GDP.

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[71] https://www.statista.com/statistics/1258900/aircraft-lease-rates-aircraft-model/#statisticContainer

[72] https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

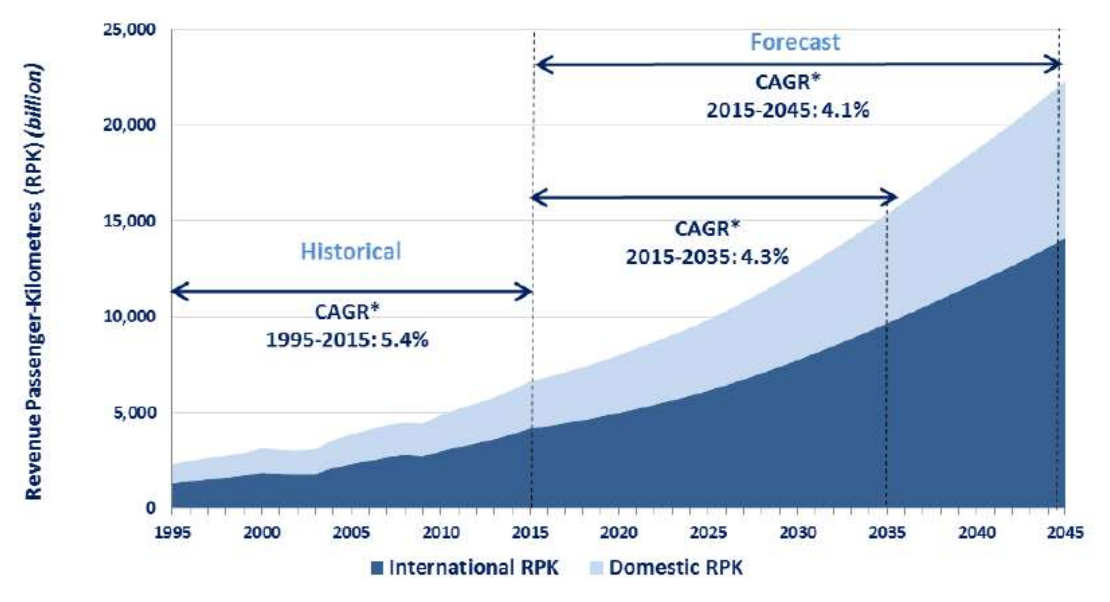

Figure 5-2: Forecast compound annual growth rates – Revenue Passenger-kilometers

Post COVID-19, projections are for a lower rate of increase in air traffic. A growth rate between 2019 and 2040 of around 3.9% CAGR is expected according to data available on the Airbus website.[73] The impact of COVID-19 has resulted in an expected 2-year lag in growth, but the forecast remains unchanged with passenger numbers expecting to increase in line with the forecasts. This growth rate is relevant to global air traffic, with Europe expected to realise a lower compound annual growth rate of about 3.3% for total traffic[74] (covering inter-regional and intra-regional/domestic) for the period between 2018 to 2038.

This level of growth in EEA air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. In particular, impacts on the ability of MROs to undertake repairs and carry out maintenance where this would require the use of chromate-based passivation to ensure the continued airworthiness of aircraft could impact on the realisation of such growth. No quantitative estimate of the level of impact can be provided, but it is clear that the closure of EU-based MRO operations in particular could impact on the availability of aircraft and hence passenger and freight transport until substitution has taken place as expected over the requested review period (unless airlines responded by buying more planes, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

5.3.4.2 Defence-related impacts

Defence related impacts under the NUS would have two dimensions: impacts on military forces; and impacts on companies acting as suppliers to military forces.

Three national Ministries of Defence have provided direct support to the ADCR out of the concern that the non-Authorisation of Cr(VI) for use in passivation could have a negative impact on their activities, while another has provided information to assist in preparation of this combined AoA/SEA. In addition, MROs providing services to a further two MODs located in the EEA have supported the ADCR

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[73] Airbus (undated): Airbus Global Market Forecast 2021 – 2040. Available at: Global Market Forecast | Airbus

[74] https://www.statista.com/statistics/1094689/annual-growth-rate-air-passenger-traffic-europe/

to ensure that they are able to continue to maintain and repair military aircraft, ships, and ground-based systems into the future. The implications of having to cease these activities are significant. Military equipment which could not be maintained to appropriate safety standards would have to be removed from service, with this also impacting on internal security services and emergency services. Not only would this impact on the availability of key equipment in the case of a military emergency, but it would also affect the size of potential operational forces.

It is also worth noting that military procurement agencies prefer key components of defence equipment to be produced in the EEA; they are likely to be reluctant to send military aircraft to MRO facilities located in non-EU countries, although there are also international agreements enabling manufacture in partner countries (e.g., the US, Canada, and Turkey as NATO members). As a result, shifting production to a non-EU territory could create a dependence on a non-EU supplier in a conflict situation, and could impact on mission readiness. This could, in fact, be far more impactful than the economic impacts linked to the defence sector.

As a result, it is likely that under the NUS, companies manufacturing components for and servicing military products would have to apply for defence exemptions under Article 2(3) of REACH; although for some companies, the turnover generated by military contracts alone may not be sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers.

The European Commission announced in July 2022 that it plans to grant a total EU funding of almost **€1.2 billion** supporting **61 collaborative defence research and development projects** selected following the first ever calls for proposals under the European Defence Fund (EDF)[75]. The aim will be to support high-end defence capability projects such as the next generation of fighter aircrafts, tanks and ships, as well as critical defence technologies such as military cloud, Artificial Intelligence, semiconductors, space, cyber or medical counter-measures. It will also spearhead disruptive technologies, notably in quantum technologies and new materials and tap into promising SMEs and start-ups. Some of these gains may not be realised if the main EU defence OEMs have to divert resources into shifting part of their manufacturing base outside of the EEA.

Companies in the European defence sector represent a turnover of nearly €100 billion and make a major contribution to the wider economy[76]. The sector directly employs more than 500,000 people of which more than 50% are highly skilled. The industry also generates an estimated further 1.2 million jobs indirectly. In addition, investments in the defence sector have a significant economic multiplier effect in terms of creation of spin-offs and technology transfers to other sectors, as well as the creation of jobs. For example, according to an external evaluation of the European Union's Seventh Framework Programme, through short-term leverage effect and long-term multiplier effects each euro spent by the Seventh Framework Programme (FP7) generated approximately an additional €11 of estimated direct and indirect economic effects through innovations, new technologies and products.[77]

If governments did allow the manufacture and servicing of military aircraft and other defence products to move out of the EEA/UK under the NUS, then some proportion of such multiplier effects would be lost to the EEA/UK economy. In addition, the ability of the EEA/UK to benefit from some of the

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[75] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4595

[76] https://ec.europa.eu/commission/presscorner/detail/de/MEMO_16_146

[77] https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

innovations and technological advances in products ahead of other countries could be lost, if the shift in manufacturing remains permanent and extends to new products.

5.3.5 Summary of economic impacts

Table 5-8 provides a summary of the economic impacts under the Non-Use scenario.

Table 5-8: Summary of economic impacts under the Non-Use scenario (12 years, @ 4%)

Economic operator	Quantitative	Qualitative
Applicants	• Not assessed	Lost profits to applicants in both the EEA and UK are assessed in the Formulation SEA
A&D companies	• Lost profits/surplus EEA: €4.8 – 28.7 billion • Lost profits /surplus UK: €0.9 – 5.4 billion	Relocation costs, impacts on R&D, impacts on supply chain coherence, impacts on future growth
Competitors	Not anticipated due to sectoral coverage of the application	Not anticipated due to sectoral coverage of the application
Customers and wider economic effects	Not assessed	• Impacts on airlines, air passengers, customers • Impacts on military forces' operation capacity and mission readiness • Lost employment multiplier effects due to impacts on civil aviation and loss of defence sector spending • Loss of spin-off effects – innovation and new technologies

5.4 Environmental impacts under non-use

As well as leading to increases in operating costs and lost revenues to airlines, the increased distances that airlines would need to fly planes in order for them to undergo normal maintenance and overhaul schedules would lead to significant increases in fuel consumption and hence CO_2 emissions.

The most plausible non-use scenario in the event of a refused Authorisation - even if it may not be practical and would involve huge levels of investment - would be to shift the activity involving use of the chromates to another country (outside the EEA or UK).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using CR(VI) and not using Cr(VI) are separated on both sides of the European border, huge logistics and transport related requirements would have to be introduced with dramatic impacts on the aerospace and defence sector's environmental footprint.

Indeed, for aircraft manufacturing activities, it means that assembly lines would be split with endless back and forth of shipments between European and non-European sites to handle assemblies composed of chromated and non-chromated elements. Depending on the large volume of parts and the size of them, several means of transport would be used at very high frequency. This would inevitably worsen the carbon footprint of the entire supply chain.

For MRO activities, each time an aircraft would need a minor repair requiring Cr(VI)-based passivation, it would force the manufacturer to go to a non-European site. In the case of a major repair, aircraft that could not fly would become stranded or, less likely, would have to be dis-assembled for transport to a non-European site. Some stranded final products would become obsolete prematurely, due to the lack of the parts needed for their maintenance and repair. This would go against the principles underlying the circular economy and the sustainable use of raw materials, by limiting the ability of the sector to repair and re-use parts and assemblies. The industry has been active in trying to decrease buy-to fly ratio (the ratio of material inputs to final component output), and the non-use scenario would significantly undermine these efforts as the more frequent production of new components would increase the waste and scrappage generated. Scrap is material that is wasted during the production process.

Today, the civil aviation industry strives to develop new technologies to reduce the amount of CO_2 emissions by 15-20% on each generation of in-service aircraft (make aircraft ground movements emission-free), since it is well aware that aviation continues to grow significantly.

Despite the impact that the COVID-19 pandemic had on air traffic and the whole civil aviation industry, air traffic is expected to double in the next 20 years. Consequently, a refused authorisation renewal would lead to aircraft manufacturing and MRO activities involving chromate uses to move outside the EEA. In addition to the socio-economic consequences this would have, the drastic increase in CO_2 emissions, would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO_2 emissions of in-service aircraft.

5.5 Social impacts under non-use

5.5.1 Direct and indirect job losses

5.5.1.1 Estimated level of job losses

As argued above, if chromate-based passivation was no longer allowed in the EEA or UK, the manufacture of entire components/final products may need to move as components need to be coated (and touched up) within the same production line to improve corrosion resistance (and other functions discussed in Section 3) of the unprotected parts, including during the intermediate steps of the production process. There are also time limits for some processes between passivation and when the previous or next process needs to be performed, such as application of primer coatings as part of ensuring the integrity of the overall corrosion protection process.

As a result, the main social costs expected under the NUS are the redundancies that would occur due to the closure or reduction of passivation-related treatment of parts and products, and the associated effects for the relocation of other manufacturing activities. As indicated in the assessment of economic costs, it is assumed that job losses will occur in proportion to the decreases in output expected under the NUS. Direct job losses will impact on both workers at the sites involved in chromate-based passivation as well as the other treatments/processes linked to this use, and those whose jobs which depend on such activities continuing at these sites. These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

While redundant workers are expected to face a period of unemployment, in line with ECHA's guidance it is assumed that such a period would be only temporary. However, the length of the average duration of unemployment varies greatly across European countries, as do the costs associated with it.

It should be noted that the ECHA methodology has been followed here despite the fact that the impacts across the A&D sector may make it difficult for workers to find another job, especially as there may be a skill mismatch if there are large scale levels of redundancies.

Estimates of the direct job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in Table 5-9 below. The magnitude of these figures reflects the importance of passivation in manufacturing, as well as to maintenance and repairs of such parts at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning and other services to the BtPs, DtBs, MROs and ORMs.

As context, the civil aeronautics industry alone employs around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million[78].

Table 5-9: Predicted job losses in aerospace companies under the NUS

Role	**Total job losses due to cessation of manufacturing activities or relocation under the NUS**	
	EEA	**UK**
Build-to-Print (50 sites)	4,350	408
Design-to-Build (22 sites)	221	240
MROs (19 sites)	6,646	200
OEMs (39 sites)	8,200	2,685
Total sites (130)	19,417	3,534

5.5.1.2 Monetary valuation of job losses

The method for estimating the social costs of unemployment follows that recommended by ECHA (Dubourg, 2016[79]). Costs of unemployment are calculated by adding lost output which is equivalent to the pre-displacement gross salary throughout the period out of work, search costs, rehiring costs for employers and scarring effects, and deducting the value of leisure time.

Dubourg (2016) estimated different ratios of the social cost per job loss over the annual pre-displacement wage for European countries and the EU-28 as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to aerospace and defence sector productions sites varying from 7 months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. Data were collected in the SEA questionnaire on the average salary for workers involved in the use of the chromates. The typical range given is from €30k to €50k. The average maximum is around €76k, across all of the companies and locations. For the purposes of these calculations, a figure of €40k[80] has been adopted and applied across all locations

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[78] https://www.eudsp.eu/event_images/Downloads/Defence%20Careers%20brochure_1.pdf

[79] Dubourg, R (2016): Valuing the social costs of job losses in applications for authorisation. Available at: https://echa.europa.eu/documents/10162/13555/unemployment_report_en.pdf/e0e5b4c2-66e9-4bb8-b125-29a460720554

[80] The weighted average personnel costs tend to be higher than €40k based on the number of companies falling into the different NACE codes. However, €40k has been adopted here to err on the side of conservatism, given the mix of companies by size and geographic location covered by this Combined AoA/SEA.

and job losses. This figure is based on the NACE code data provided by companies but may underestimate the average salary given that aerospace and defence jobs are higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are given in Table 5-10 based on consideration of the geographic distribution Article 66 notifications, the location of SEA respondents, and the location of suppliers in the ADCR members' supply chains, as well as MROs. The estimated social costs under the NUS are around €2,170 million for the EEA and €290 million for the UK due to the cessation of the passivation of non-aluminium metallic coatings and linked manufacturing activities.

Table 5-10: Social Cost of Unemployment – Job losses at A&D companies under the NUS

Country	Employment losses due to cessation or relocation of manufacturing	Social costs of unemployment (€)
France	6,990	886,332,000
Poland	1,748	164,265,000
Italy	2,330	282,396,000
Germany	2,524	262,513,333
Spain	1,359	152,226,667
Czech Republic	777	85,122,667
Netherlands	388	36,503,333
Sweden	388	34,639,333
Romania	194	18,562,333
Ireland	388	38,056,667
Hungary	388	43,352,467
Malta	194	15,766,333
Norway	388	42,250,667
Belgium	194	17,785,667
Finland	388	27,028,000
Portugal	97	8,854,000
Slovakia	97	10,096,667
Denmark	194	13,514,000
Lithuania	97	8,116,167
Bulgaria	194	17,397,333
Greece	97	10,174,333
Total EEA	**19,417**	**2,174,952,967**
United Kingdom	3,534	295,414,533
Total	**22,950**	**2,470,367,500**

5.5.2 Wider indirect and induced job losses

5.5.2.1 Aerospace and defence related multiplier effects

Employment in one sector is often the input to employment in another sector, so that fluctuations in employment in one will inevitably affect the other.

It is clear that, under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest players in the EEA/UK aerospace and defence sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in the EEA/UK.

A UK Country Report on the "Economic Benefits from Air Transport in the UK" produced by Oxford Economics (2014) indicates the following with respect to the aerospace sector's contribution to UK employment in 2012:

- Indirect employment effects: 139,000 jobs implying a multiplier effect of 1.36 indirect jobs for every direct job;
- Induced employment effects: 86,000 jobs implying an additional multiplier effect of 0.84 induced jobs for every direct job.

Indirect employment effects will to a degree be captured by the estimates of lost jobs presented in Table 5-9 given that it includes the loss of jobs in suppliers to the aerospace OEMs and DtB companies. It excludes however other service providers to these companies whose services would no longer be required. Induced effects are not captured by the above estimates and an employment multiplier of 0.84 suggests that they may be significant given the predicted numbers of jobs that would be lost across the key countries in which aerospace-related manufacturing takes place.

The loss of jobs within those companies that serve the defence industry would have their own multiplier effects. The external evaluation of FP7 referenced above[81] quotes an employment multiplier of between 2.2 to 2.4, with this covering both indirect and induced employment effects. The sector is identified as bringing a major contribution to the wider economy.

To successfully compete at a global level, the European and UK A&D industries have formed regional and industry clusters that includes local and national government partners. The clusters are part of the European Aerospace Cluster Partnership[82] (EACP) which focuses on the exchange of experiences concerning both cluster policy and the implementation of effective solutions needed to address various challenges faced by the partners. It has members located in 44 aerospace clusters across 18 countries, thus covering the entire A&D value chain in Europe. Figure 5-3 below is taken from the EACP website highlighting the location of these different hubs across Europe, to provide an indication of where effects may be experienced at the regional level.

Under the non-use scenario, the economic impact on each region could have severe consequences. For example, Aerospace Wales consists of over 180 members which employ 23,000 employees with a turnover of over £7 billion in Wales, while the Andalucía Aerospace Cluster has over 37 members, 16,000 employees with over €3 billion turnover (See Annex 3). Both of these clusters are an essential part of the local economy.

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[81] European Commission (2017): Issue papers for the High-Level Group on maximising the impact of EU research and innovation programmes. Prepared by the Research and Innovation DGs. Available at: https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

[82] https://www.eacp-aero.eu/about-eacp/member-chart.html

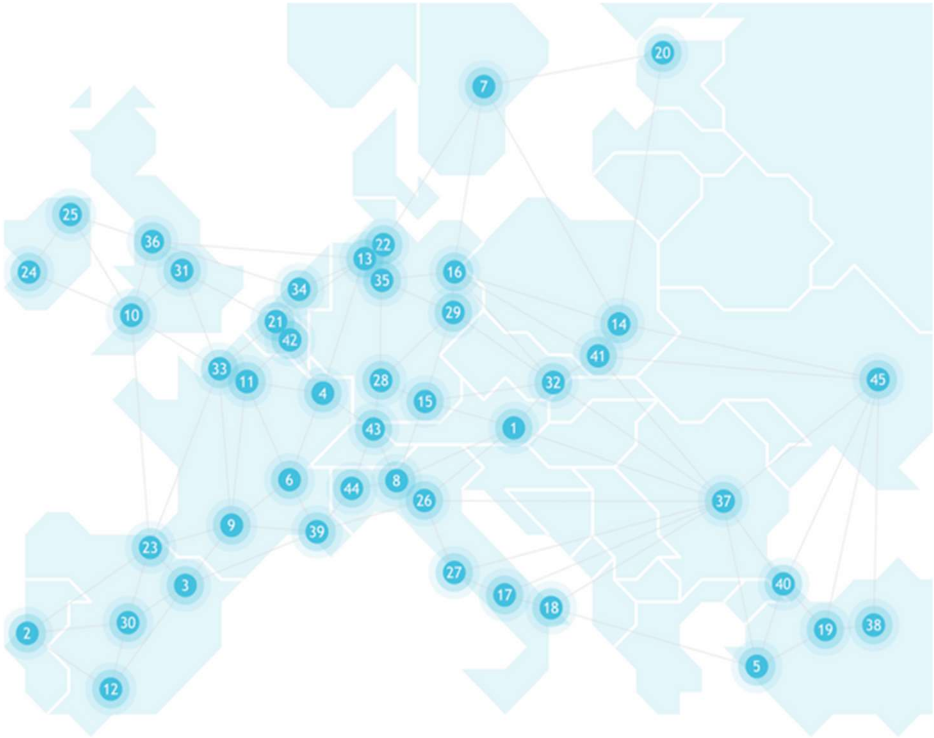

Figure 5-3: Aerospace clusters across Europe
Source: https://www.eacp-aero.eu/about-eacp/member-chart.html

5.5.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[83] produced by a high-level group formed by the International Civil Aviation Organisation (ICAO) provides an assessment of the economic impacts of the aviation sector. These are linked to its direct impact as well as indirect, induced, and catalytic effects. At a regional level, it is estimated that air transport supports 12.2 million jobs in Europe. 2.6 million of these jobs are direct within the aviation sector, with the remaining 9.6 million stemming indirectly from the aviation sector or relating to induced or catalytic effects.

Clearly not all of these jobs would be impacted under the NUS, although some impact would be expected should there be reductions in the number of flights, increased delays and other effects from the loss of EEA/UK based MRO activities in particular.

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[83] Published by the ACI, CANSO, IATA, ICAO and the ICCAIA, available at: https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf

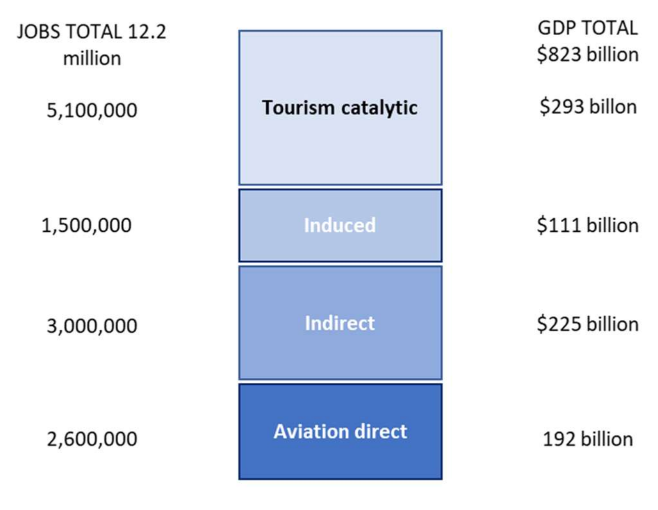

Figure 5-4: Aviation related multiplier effects
Based on: **https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf**

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[84]. A "COVID-19 Analysis Fact Sheet" produced by Aviation Benefits Beyond Borders reports the following:

- A reduction from 2.7 direct aviation jobs in Europe supported pre-COVID to 2.1 million jobs post-COVID (i.e., at the end of 2021); and
- 13.5 million jobs in supported employment pre-COVID in Europe to 8.1 million at the end of 2021.

Although one would not expect the losses in supported employment (i.e., indirect, induced, and catalytic effects) to be as great, it is clear that a disruption to civil aviation could have significant employment impacts.

5.5.3 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Direct job losses:
    - Around 19,400 jobs in the EEA due to the loss of passivation and linked assembly and/or manufacturing activities, and
    - Over 3,500 jobs in the UK due to the loss of passivation and linked assembly and/or manufacturing activities;

- Social costs of unemployment:
    - €2.2 billion for the EEA associated with direct job losses, and
    - €295 million for the UK associated with direct job losses;

- Indirect and induced unemployment at the regional and potentially national level due to direct job losses: not quantified but may be significant at the regional level; and

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[84] https://aviationbenefits.org/media/167482/abbb21_factsheet_covid19-1.pdf

- Direct, indirect and induced job losses in air transport due to disruption of passenger and cargo services: Not quantified but may be significant at the regional level.

5.6 Combined impact assessment

5.6.1 Complication of socio-economic impacts

Table 5-11 sets out a summary of the societal costs associated with the Non-Use scenario. Figures are provided as annualised values, with social costs also presented as a PV over a 2-year period as per ECHA's latest guidance; note that restricting losses to only those occurring over the first two years of non-use will significantly underestimate the profit losses to the A&D companies as well as the applicants. Most A&D companies would incur losses for at least a 4-year period, with over 60% incurring losses over the full 12-year period as the continue work towards testing, qualification, certification and industrialisation of an alternative over the full 12-year period.

Table 5-11: Summary of societal costs associated with the Non-Use Scenario

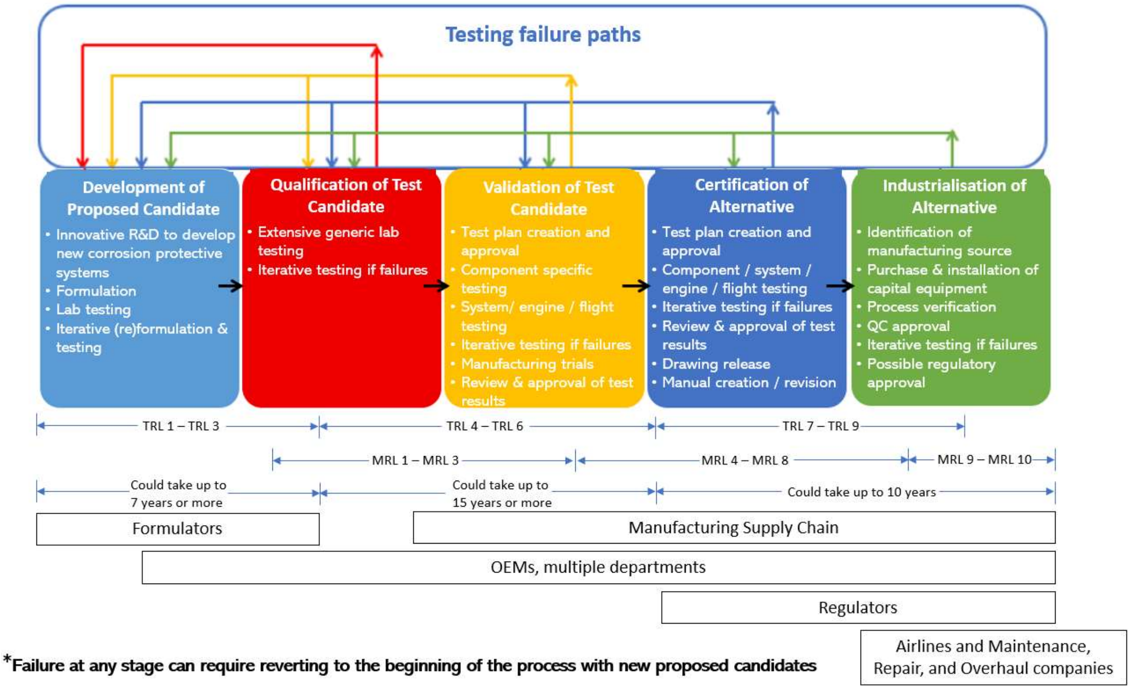
Description of major impacts	**Monetised/quantitatively assessed/qualitatively assessed impacts**	
1. Monetised impacts	**PV @ 4%, 2 years**	**€ annualised values**
Producer surplus loss due to ceasing the use applied for[1]: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on A&D companies[1]: - Lost profits EEA - Lost profits UK	Applicants: See formulation SEA A&D companies EEA: €970 million – 5.8 billion UK: €178 million – 1.1 billion	Applicants: See formulation SEA A&D companies EEA: €514 million – 3.1 billion UK: €94 – 570 million
Relocation or closure costs	Not monetised	Not monetised
Loss of residual value of capital	Not quantifiable	Not quantifiable
Social cost of unemployment: workers in A&D sector only[2]	EEA: €2.2 billion UK: €295 million	EEA: €1.1 billion UK: €148 million
Spill-over impact on surplus of alternative producers	Not assessed due to sector level impacts	Not assessed due to sector level impacts
Sum of monetised impacts	EEA: €3.1 – 7.9 billion UK: €473 million – 1.4 billion	EEA: €1.6 – 4.1 billion UK: €242– 718 million
2. Additional qualitatively assessed impacts		
Impacts on A&D sector	Impacts on R&D by the A&D sector, impacts on supply chain, impacts on technological innovation	
Civilian airlines	Wider economic impacts on civil aviation, including loss of multiplier effects, impacts on airline operations, impacts on passengers including flight cancellations, ticket prices, etc.	
Ministries of Defence	Impacts on the operational availability of aircraft and equipment, premature retirement of aircraft and equipment, impacts on mission readiness	
1) Lower bound figures represent lost EBITDA estimates, upper bound lost operating surpluses. 2) Lower bound reflects job losses for those directly involved in passivation only, upper bound reflects job losses in linked processes and subsequent manufacturing activities		

6 Conclusion

6.1 Steps taken to identify potential alternatives

Potential alternatives to Cr(VI) for passivation of non-aluminium metallic coating should be "generally available"[85].

Alongside the various R&D activities as described in Section 3.3.1 and information reported in academic literature and patent reports as described in Sections 3.3.3, members of the ADCR have undertaken extensive testing into alternative technologies and processes with many programmes still ongoing. The steps taken by members in the implementation of a substitute for Cr(VI)-based passivation of non-aluminium metallic coating are shown in Figure 6-1.



*Failure at any stage can require reverting to the beginning of the process with new proposed candidates

Figure 6-1: Schematic showing the key phases of the substitution process

Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note that failures may not become apparent until a late stage in the process.

Source: Adapted from "Use of strontium chromate in primers applied by aerospace and defence companies and their associated supply chains, Application for Authorisation 0117-01, GCCA (2017)

Activities undertaken include:

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[85] As defined with respect to the "legal and factual requirements of placing on the market" in the EC note of 27 May, 2020, available at: [5d0f551b-92b5-3157-8fdf-f2507cf071c1 (europa.eu)]()

- Development of test alternatives in laboratory environments up to TRL 6;
- Qualification of test alternatives and suppliers including:
    - Modification of drawings;
    - Updating specifications;
    - Introduction of new processes to suppliers;
    - Negotiation of supplier(s) contracts.
- Demonstration of compliance followed by industrialisation and deployment on sites along the supply chain; and
- Certification or approval.

6.2 The substitution plan

ADCR member companies have ongoing substitution plans in place to develop test candidates with the intent of replacing Cr(VI) in passivation of non-aluminium metallic coating. Individual members often have multiple substitution plans within passivation of non-aluminium metallic coating, reflecting the complexity of different components to be treated, the various types of non-aluminium metallic coatings, and the different performance resulting from test candidates in these different situations. While there have been successes, with some members having been able to implement alternatives to Cr(VI) in certain limited situations and for certain non-aluminium metallic coatings, thereby reducing their Cr(VI) usage, technical challenges remain.

As discussed in Section 3.16.2, of the 22 distinct substitution plans for passivation of non-aluminium metallic coating assessed in this combined AoA/SEA, none of them are expected to have achieved MRL 10 by September 2024. MRL 10 is the stage at which it is expected production will be in operation and it is expected that Cr(VI) will be fully substituted under the relevant plan.

The proportion of substitution plans that are expected to achieve MRL 10 is then expected to progressively increase to 18% in 2028, 55% in 2031, and 95% in 2036 (see Figure 6-2 below).

In 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a significant proportion (45%) are not expected to have achieved MRL 10 and are expected to be at the validation certification or industrialisation stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

As a result of the individual members' substitution plans summarised above, **the ADCR requests a review period of 12 years for the use of Cr(VI) in passivation of non-aluminium metallic coatings.**

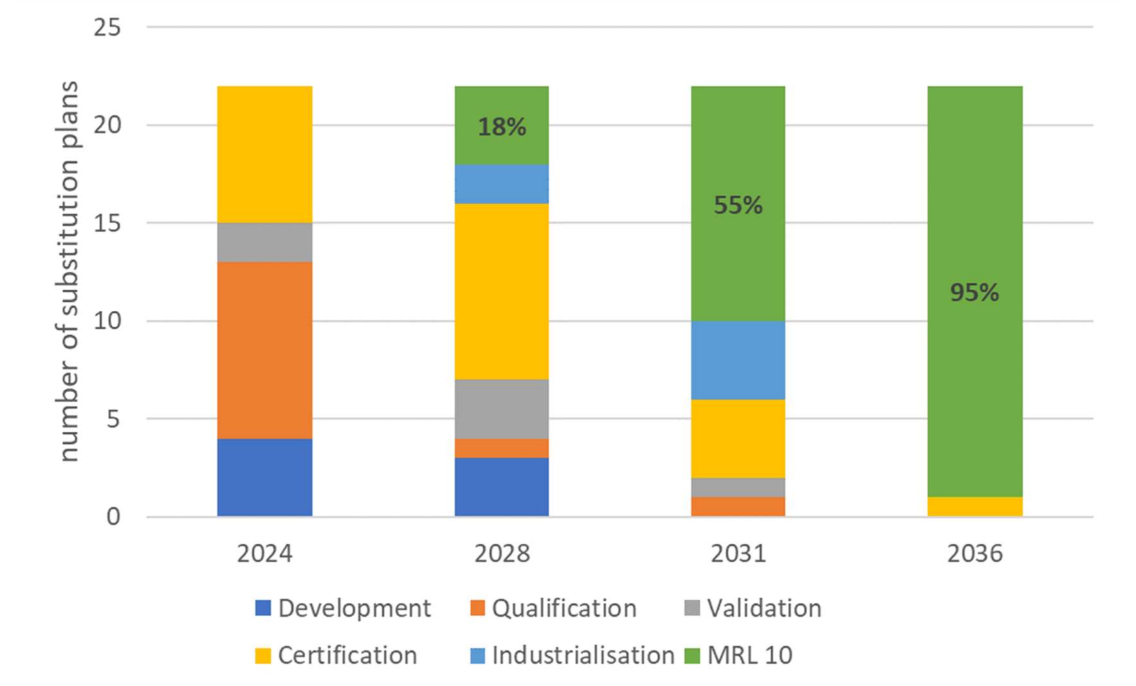

Figure 6-2: Expected progression of substitution plans for the use of Cr(VI) in passivation of non-aluminium metallic coating, by year.
The vertical axis refers to number of substitution plans (some members have multiple substitution plans for passivation of non-aluminium metallic coating). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which it is expected that Cr(VI) will be fully substituted under the relevant plan.
***Source:* RPA analysis, ADCR members**

6.3 Comparison of the benefits and risk

Table 6-1 summarises the socio-economic benefits of continued use of the chromates in passivation of non-aluminium metallic coatings by companies in the aerospace and defence sector. Overall, net benefits of between ca. €3.1 to 7.9 billion for the EEA and €473 to 1.4 billion for the UK (Net Present Value social costs over two years/risks over 12 years, @4%) can be estimated for the Continued Use scenario. These figures capture continued profits to the applicants and the A&D companies and the social costs of unemployment. They also include the monetised value of the residual risks to workers and humans via the environment (estimated at €648k and €240k for the EEA and UK respectively over 12 years).

As can be seen from Table 6-1, the ratio of the benefits of continued use to the monetised value of the residual health risks is around 10,717 on the lower bound assumptions for the EEA and 4,373 on the lower bound assumptions for the UK.

Table 6-1: Summary of societal costs and residual risks (NPV costs over two years/risks 12 years, 4%)

Societal costs of non-use		**Risks of continued use**	
Monetised profit losses to applicants	Losses in profits from reduced sales of the chromate substances and associated formulations. Losses quantified in the Formulation SEA	Substance imported/risks of formulation covered in formulation SEA	
Monetised profit losses to A&D companies	EEA: €970 million – 5.8 billion (£834 million – 5 billion) UK: €178 million – 1.1 billion (£153 million – 925 million)	Monetised excess risks to directly and indirectly exposed workers (€ per year over 12 years)	EEA: €572k (£492k) UK: €181k (£156k)
Social costs of unemployment	EEA: €2.2 billion (£1.9 billion) UK: €295 million (£254 million)	Monetised excess risks to the general population (€ per year over 12 years)	EEA: €76k (£65k) UK: €68k (£58k)
Qualitatively assessed impacts	Wider economic impacts on civil aviation, impacts on cargo and passengers. Impacts on armed forces including military mission readiness. Impacts on R&D and technical innovation. Impacts from increased CO_2 emissions due to MRO activities moving out of the EEA/UK; premature redundancy of equipment leading to increased materials use.	Qualitatively assessed impacts	
Summary of societal costs of non-use versus risks of continued use	- NPV (2 years societal costs/12 years excess health risks): ○ EEA: €3,144 – 7,942 million (£2,704 – 6,830 million) ○ UK: €473 – 1,370 million (£407 – 1,179 million) - Ratio of annualised societal costs to risks: ○ EEA: 10,717:1 to 27,738:1 ○ UK: 4,373:1 to 12,979:1		

It should be appreciated that the social costs of non-Authorisation could be much greater than the monetised values reported above, due to the likely 'knock-on' effects for other sectors of the economy:

If the Applicants are not granted an Authorisation that would allow continued sales of the chromates, critical substances and formulations would be lost to aerospace and defence downstream users in the EEA and UK

Due to certification and airworthiness requirements, downstream users would be forced to undertake passivation activities outside the EEA/UK or shift to suppliers outside of the EEA/UK

OEMs would shift most of their manufacturing activities outside the EEA/UK as it would not be technically feasible in some cases, as well as inefficient and costly, to transport parts in and out of the EEA/UK

Design-to-Build suppliers may have more flexibility and shift some or all of their production activities outside the EEA/UK, resulting in the loss of GVA and jobs to the EEA/UK

Build-to-Print suppliers in the EEA would be forced to cease processes reliant upon passivation as a follow-on surface treatment; as OEMs relocate, BtP suppliers in the EEA/UK would be replaced by suppliers outside the EEA/UK

MROs will have to shift at least some (if not most) of their activities outside the EEA/UK, as use of chromate-based passivation is an essential part of maintenance, repairs and overhaul activities

The relocation of MRO activities outside the EEA will cause significant disruption to civil aviation. This will impact on both passenger flights and cargo transport. It will also impact other aviation such as helicopters used for medical emergencies

Ministries of Defence will face logistic difficulties with respect to the maintenance of aircraft and other equipment, with this impacting on mission readiness or the need to retire equipment prematurely. This will include the need to reach servicing agreements with non-EEA countries

Passengers and freight shippers will face reduced flight availability and routes, as well as increased costs

Overall, it is clear that the benefits of the continued use of the chromates in passivation activities significantly outweigh the residual risks from continued use.

6.4 Information for the length of the review period

6.4.1 Introduction

In a 2013 document, the ECHA Committees outlined the criteria and considerations which could lead to a recommendation of a long review period (12 years)[86]:

1. *"The applicant's investment cycle is demonstrably very long (i.e., the production is capital intensive) making it technically and economically meaningful to substitute only when a major investment or refurbishment takes place.*
2. The costs of using the alternatives are very high and very unlikely to change in the next decade as technical progress (as demonstrated in the application) is unlikely to bring any change. For example, this could be the case where a substance is used in very low tonnages for an essential use and the costs for developing an alternative are not justified by the commercial value.
3. *The applicant can demonstrate that research and development efforts already made, or just started, did not lead to the development of an alternative that could be available within the normal review period.*

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[86] https://echa.europa.eu/documents/10162/13580/seac_rac_review_period_authorisation_en.pdf/c9010a99-0baf-4975-ba41-48c85ae64861

4. *The possible alternatives would require specific legislative measures under the relevant legislative area in order to ensure safety of use (including acquiring the necessary certificates for using the alternative).*

5. *The remaining risks are low and the socio-economic benefits are high, and there is clear evidence that this situation is not likely to change in the next decade."*

In the context of this combined AoA/SEA, it is assumed that qualification and certification requirements combined with the need for approvals from EASA, the ESA and MoDs are consistent with the requirements under criterion 4 above.

Further discussion was held at the 25th Meeting of Competent Authorities for REACH and CLP (CARACAL) of 15 November 2017. A document endorsed by CARACAL suggests that, "*in order to consider a review period longer than 12 years, in addition to the criteria for a 12-year review period established in the document "Setting the review period when RAC and SEAC give opinions on an application for authorisation", two additional conditions should jointly be met*:

6. *As evaluated by the RAC, the risk assessment for the use concerned should not contain any deficiencies or significant uncertainties related to the exposure to humans (directly or via the environment) or to the emissions to the environment that would have led the RAC to recommend additional conditions for the authorisation. In the case of applications for threshold substances, the appropriateness and effectiveness of the applied risk management measures and operational conditions should clearly demonstrate that risks are adequately controlled, and that the risk characterisation ratio is below the value of one. For applications for non-threshold substances, the applied risk management measures and operational conditions should be appropriate and effective in limiting the risks and it should be clearly demonstrated that the level of excess lifetime cancer risk is below $1x10^{-5}$ for workers and $1x10^{-6}$ for the general population. For substances for which the risk cannot be quantified, a review period longer than 12 years should normally not be considered, due to the uncertainties relating to the assessment of the risk.*

7. *As evaluated by the SEAC, the analysis of alternatives and the third party consultation on alternatives should demonstrate without any significant uncertainties that there are no suitable alternatives for any of the utilisations under the scope of the use applied for and that it is highly unlikely that suitable alternatives will be available and can be implemented for the use concerned within a given period (that is longer than 12 years)"* (CARACAL, 2017).

As far as the second criterion above is concerned, the same document provides some relevant examples, one of which (Example (d)) reads as follows:

> "(…) *the use of the substance has been authorised in accordance with other EU legislation (e.g., marketing authorisation, certification, type-approval), the substance being specifically referred to in the authorisation/certification granted and substitution, including the time needed for modification of the authorisation/certification/type-approval, would not be feasible within 12 years and would involve costs that would jeopardise the operations with regard to the use of the substance*".

6.4.2 Criterion 1: Demonstrably Long Investment Cycle

The aerospace and defence industry is driven by long design and investment cycles, as well as very long in-service time of their products. As noted previously, the average life of a civil aircraft is typically

20-35 years, while military products typically last from 40 to >90 years. Furthermore, the production of one type of aircraft or piece of equipment may span more than 50 years.

These long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EEA aerospace industry[87]. They are a key driver underlying the difficulties facing the sector in substituting the use of the chromates in passivation across all components within final products. The long service life of aircraft and other products makes it difficult to undertake all of the tests required to qualify and certify a component with the substitute, due to the level of investment and costs that would be involved in such an activity for out of production A&D products; it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

The ADCR would like to emphasise the crucial role every single component within an A&D product plays with respect to its safety. An aircraft is a complex system involving not only design of the aircraft itself, but also its use and maintenance history in varied climates and service. For example, an aircraft engine is exposed to massive forces and extremely high stress levels due to high velocities and environmental impacts. Therefore, every single component needs to be designed and manufactured with serious attention and care.

In a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an A&D product need to be adjusted to each other very precisely on the design as well as on the manufacturing level. When in the early design phase for completely new engines, for example, there is an opportunity to consider introducing a material change. Mostly such a material change will be a step improvement on a previous design, in line with the principle of proven engineering. Very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; time consuming, systematic TRL-style implementation is required to minimise the impact of unanticipated failures and the serious repercussions they might cause. Even when an OEM has been able to undertake the required testing and is in the process of gaining qualifications and certifications of components with a substitute, it may take up to seven years to implement the use of a substitute across the value chain due to the scale of investment required and the need for OEMs to undertake their own qualification of different suppliers.

In addition, MoDs rarely revise specifications for older equipment, which must nevertheless be maintained and repaired. MROs servicing military equipment therefore must undertake any maintenance or repairs in line with the OEMs' original requirements. Similarly, MROs in the civil aviation field are only legally allowed to carry out maintenance and repairs in line with OEMs' requirements as set out in Maintenance Manuals. Long service lives therefore translate to on-going requirements for the use of the chromates in the production of spare parts and in the maintenance of those spare components and the final products they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly substitution issues the ADCR is addressing in this combined AoA/SEA. A 12-year review period in itself may not be sufficient for the aerospace and defence industry to fully replace the chromates across all uses of passivation of non-aluminium metallic coatings, however, the industry is committed to the goal of substitution. A 12-year review period will enable the implementation of the significant (additional)

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[87] Ecorys et al (2009): FWC Sector Competitiveness Studies – Competitiveness of the EU Industry with focus on Aeronautics Industry, Final Report, ENTR/06/054, DG Enterprise & Industry, European Commission.

investment in R&D, qualification and certification of design/drawing changes and industrialisation required across the various OEMs.

6.4.3 Criterion 2: Cost of moving to substitutes

Cr(VI) coatings were validated/certified in the 1950s and 60s and extensive in-service performance has demonstrated the performance of chromated materials. This includes modifications to design practice and material selection based upon resolution of issues noted in service. Chromate-based passivation of non-aluminium metallic coatings, due to their extensive performance history, represent the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft in their entirety consist of between 500,000 to 6 million components, depending on the model. Depending on the materials of construction, 15-70% of the entire structure of an aircraft requires treatment using Cr(VI) at some point during the manufacturing process. Older models generally require a larger percentage of Cr(VI) surface treatments as the aerospace industry has worked diligently to incorporate new base materials and Cr(VI)-free protective coatings in newer models wherever it is safe to do so.

There are literally billions of flight hours’ experience with components protected from corrosion by chromate-based passivation. Conversely, there is still limited experience with Cr(VI)-free formulations on components. It is mandatory that components coated using a Cr(VI)-free alternative are demonstrably every bit as safe as they had been when coated using a Cr(VI) product. The performance of Cr(VI)-free products can sometimes be demonstrated at the laboratory step but then fails at industrial scale, as it is impossible to replicate all in-service conditions in a laboratory. As a result, the time taken to progress through the TRL process may be increased until it is possible for the performance of the alternative to be demonstrated as per safety requirements at the aircraft level when operating under real life conditions.

Flight safety is paramount and cannot be diminished in any way. Take, for example, a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to service life (and hence maintenance requirement) limitations on a new coating, the engine would need to be disassembled to be able to access the blades. That means taking the engine off the wing, sending it to a Repair Center, disassembling the engine and replacing the components at much shorter intervals than previously needed for the remainder of the engine. This would add inherent maintenance time and costs to the manufacturers; operators; and eventually end-use customers.

Where possible, and for specific components and final products, some new designs have been able to utilize newly developed alloys that do not require a Cr(VI)-based coating (as typically used to provide corrosion protection on metallic components). However, even in newer designs there may still be a need for the use of chromate-based passivation which cannot be replaced at present due to safety considerations.

These technical hurdles are a fundamental reason why the A&D industry requests a review period of at least 12 years.

6.4.4 Criteria 3 and 7: Results of R&D on alternatives and availability of alternatives over the longer term

Research into the substitution of the chromates has been on-going for several decades. Although use continues, it should be recognised that significant achievements have been made over this period in the substitution of the use of the chromates by alternative substances, formulations or technologies. This is illustrated by the achievements of one of the OEMs in reducing by 75% (reduction by weight) of their level of dependency on use of the chromates (see Figure 6-3).

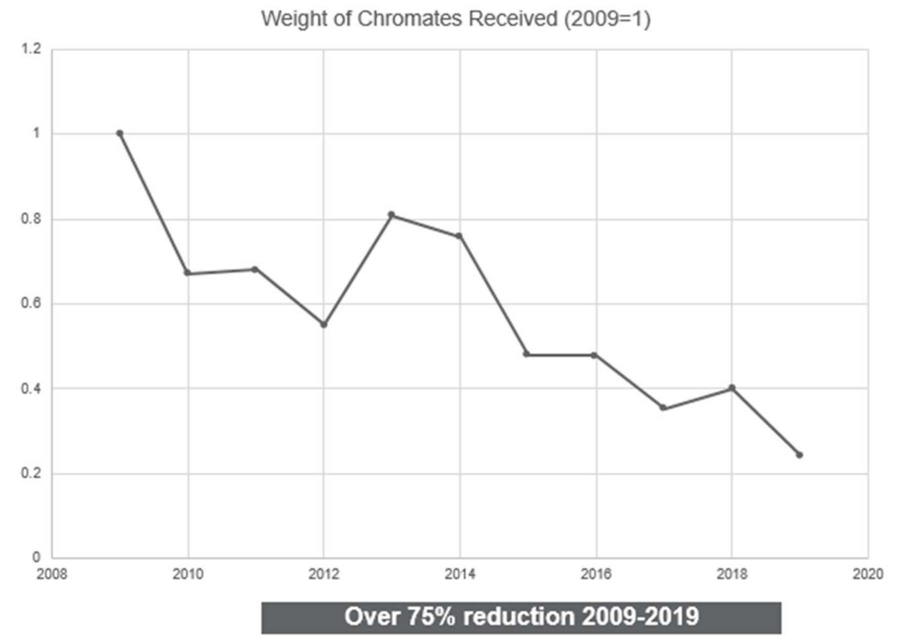

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019

This 75% reduction in the use of the chromates by weight reflects the massive efforts and investment in R&D aimed specifically at substitution of the chromates. Although these efforts have enabled substitution across a large range of components and products, this OEM will not be able to move to substitutes for chromate-based passivation across all components and products for at least 12 years, and perhaps longer for those parts and products which have to meet military requirements (including those pertaining to UK, EEA and US equipment).

Testing corrosion protection systems in environmentally relevant conditions to assure performance necessarily requires long R&D cycles for alternative corrosion prevention processes. A key factor driving long timeframes for implementation of fully qualified components using alternatives by the A&D industry is the almost unique challenge of obtaining relevant long-term corrosion performance information. In the case of passivation, it requires testing of changes in a process of corrosion protection, which may include changes in the primers (another possible step in the process) applied to a passivation treated component or product.

As a result, there are very long lead times before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25-plus years. In 2020, the European A&D industries spent an estimated €18 billion in Research and Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US roughly four times higher)[88].

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[88] https://www.asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

A PricewaterhouseCoopers (PwC) study[89] refers to the high risks of investments in the aerospace industry: “Historically, step changes have been the norm in aircraft R&D. But recent development efforts have been so expensive that it is unclear whether the companies will earn the anticipated return on their investments. Furthermore, slips in the programme schedule have worsened the economics”.

As stated many times already, A&D companies cannot simply apply a less effective corrosion protection process as aviation and defence substantiation procedures demand component performance using alternatives to be equal or better. If such performance is not achieved, then the alternatives cannot be used. The implications for repair, replacement and overhaul must also be understood before moving to an alternative. It must be recognised that the performance delivered by one component is dependent upon the performance of other components; thus, the performance delivered by a final product is dependent upon the components used. The number of configurations of components and final products is immense and each configuration may differ from the next in terms of its behaviour with a Cr(VI) alternative. There is a complex relationship between each part/component and its performance requirements within its own unique design parameters, which requires component certification for each individual substitution.

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in Section 3.1.2, the identification of a test candidate Cr(VI)-free formulation is only the first stage of an extensive multi-phase substitution process leading to implementation of the alternative. This process, illustrated below, requires that all components, materials and processes incorporated into an A&D system must be qualified, validated, certified and industrialised before production can commence. Each phase must be undertaken to acquire the necessary certification to comply with airworthiness and other safety-driven requirements.

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e., to identify, qualify, validate, certify and industrialise alternatives) for all critical A&D applications. The ADCR OEMs and DtBs as design owners are currently working through this process with the aim of implementing chromate-free passivation of non-aluminium metallic coatings by 2036; their current substitution plans are designed to ensure they achieve TRL9 and MRL 10 within the next 12 years or sooner. This includes gaining airworthiness certification or military safety approvals, both of which can take up to several years to ensure safety. It may take more than 12 years to gain final approvals for some defence uses, particularly with respect to repairs, although the design owners are working to resolve current difficulties by 2036.

Several of the ADCR members also note that military procurement agencies prefer key components of defence equipment to be produced in the EEA, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-EU territory and import of finished surface treated parts or products into the EEA is more complex, as it could create a dependence on a non-EU supplier in a conflict situation.

Furthermore, the provision of defence exemptions, as allowed for in Article 2 (3) of the REACH regulation, is **not** a suitable instrument to ensure the continued availability of the chromates for passivation purposes if the renewal of the applicants’ authorisations was not granted. While a

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[89] http://www.strategyand.pwc.com/trends/2015-aerospace-defense-trends

national Ministry of Defence might issue a defence exemption out of its own interest, military equipment production processes can require the use of passivation by several actors in several EU member states (i.e., it often relies on a transnational supply chain). In contrast, defence exemptions are valid at a national level and only for the issuing member state. Furthermore, the defence exemption process cannot be used as an alternative to the normal authorisation process unless this is necessary for confidentiality reasons and in the interest of defence. Thus, defence applications also need to be covered by the normal authorisation process.

Finally, the EEA defence sector requires only small quantities of chromate-based passivation formulations. On the basis of a defence exemption alone, the quantities demanded would not be sufficient for manufacturers, formulators and surface treatment companies to continue to offer their services and products. As a result, passivation for military aircraft and equipment would not continue in the EEA or UK if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

6.4.6 Criterion 5 and 6: Comparison of socio-economic benefits and risks to the environment and effective control of the remaining risks

As demonstrated by the information collected by the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of the chromates under the initial (parent) authorisations. This has resulted in reduced exposures for both workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of the chromates will decrease, and exposures and emissions will reduce further over the requested 12 year review period. As a result, the excess lifetime risks derived in the CSR for both workers and humans via the environment will decrease over the review period. These risks will also be controlled through introduction in 2017 of the binding occupational exposure limit value on worker exposures to Cr(VI) at the EU level under the Carcinogens and Mutagens Directive[90].

The European aerospace and defence industry is a world-class leader in technology and innovation. They are an essential part of the European economy contributing to job creation (880,000 direct jobs in 2020[91]) and Europe's trade balance (55% of products developed and built in the EEA are exported).

Civil aeronautics alone accounted for around €99.3 billion in revenues, with military aeronautics accounting for a further €47.4 billion in turnover; overall taking into account other defence and space turnover, the sector had revenues of around €230 billion. Of the €99.3 billion in civil aeronautics turnover, €88.3 billion represented exports from the EU.

Both acknowledged market reports of Airbus and Boeing find a growing trend in the aerospace industry. Passenger air traffic is predicted to grow at 3.6% CAGR for 2022-2041 and freight traffic to grow at 3.2% CAGR globally, according to Airbus' Global Market Forecast. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets.[92]

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[90] Directive 2004/37/EC of the European Parliament and of the Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work (Sixth individual Directive within the meaning of Article 16(1) of Council Directive 89/391/EEC), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0037

[91] https://asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

[92] https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf

Boeing's 2022 Commercial Market Outlook[93] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR.

The socio-economic benefits of retaining the key manufacturing base of the EEA and UK A&D industries are clearly significant, given that they will be major beneficiaries of this growth in demand. As demonstrated in the socio-economic analysis presented here, even without accounting for such growth in demand under the continued use scenario, the socio-economic benefits clearly outweigh the associated risks to human health at social costs to risk ratios of over 3,560 to one for the EEA and 1,426 to one for the UK.

6.5 Substitution effort taken by the applicant if an authorisation is granted

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been, or are in the process of, being implemented. However, there are still many cases where components do not have technically feasible alternatives available. Figure 3-2 highlights the actions that are being taken by A&D design owners to develop, qualify, validate, certify and industrialise alternatives for individual components.

This work will continue over the requested review period with the aim of phasing out all uses of chromate-based passivation of non-aluminium metallic coatings. As illustrated in Section 3.16, on-going substitution is expected to result in significant decreases in the volumes of the three chromates used in passivation within the next seven years. However, technically feasible alternatives are still at the development phase (Phase 1 out of the 5 phases) for some components and final products, where alternatives have not been found to meet performance requirements.

6.6 Links to other Authorisation activities under REACH

This combined AoA/SEA is one of a series of applications for the re-authorisation of the use of chromium trioxide in surface treatments carried out by the A&D industry. This series of combined AoA/SEAs has adopted a narrower definition of uses originally Authorised under the CTAC, CCST and GCCA parent Applications for Authorisation.

In total, the ADCR will be submitting 11 Combined AoA/SEAs covering the following uses and the continued use of chromium trioxide, sodium dichromate, potassium dichromate, sodium chromate and/or dichromium tris(chromate):

1) Formulation
2) Pre-treatments
3) Electroplating (hard chrome plating)
4) Passivation of stainless steel
5) Anodising
6) Chemical conversion coating
7) Anodise sealing
8) Passivation of non-aluminium metallic coatings
9) Inorganic finish stripping
10) Chromate rinsing after phosphating

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[93] https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

11) Slurry coatings

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Annex 1 Examples of Standards

Table A-1 below shows examples of public standards reported by ADCR members applicable to passivation of non-aluminium metallic coating. Test methods and requirements contained therein do not define success criteria for alternatives validation.

Table A-1: Examples of standards applicable to passivation of non-aluminium coating key functions

Standard Reference	Standard Description	Key function/standard type
AMS 2400	Plating, cadmium	QC spec
AMS-QQ-P-416	Plating, Cadmium (Electrodeposited)	QC spec
AMS 2417	Plating, zinc-nickel alloy	QC spec
AMS 2418	Plating, copper	QC spec
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ASTM B633	Zinc plating	QC spec
ASTM D3359 Method B	Standard test methods for measuring adhesion by tape test	Adhesion promotion
ASTM G85 Annex 4	Standard Practice for Modified Salt Spray (Fog) Testing	Corrosion resistance
DEF STAN 00-35	Environmental Handbook for Defence Material	Resistance to fluids (chemical resistance)
DIN EN ISO 1519	Paints and varnishes - Bend test (cylindrical mandrel)	Adhesion promotion
ECSS-Q-ST-70-04C	Thermal testing for the evaluation of space materials, processes, mechanical parts and assemblies(a)	Thermal testing (temperature resistance)
ECSS-Q-ST-70-14C	Corrosion – specifies the minimum requirements to qualify the materials and processes selected to provide corrosion protection(a)	Corrosion resistance
EN 3665	Test methods for paints and varnishes - Filiform corrosion resistance test on aluminium alloys	Filiform corrosion resistance
EN 4628-2	Paints and varnishes - Evaluation of degradation of coatings	Adhesion promotion
		Resistance to fluids (chemical resistance)
EN 6072	Constant amplitude fatigue testing	Influence on fatigue behaviour
EN ISO 2409	Paints and varnishes - Cross-cut test	Adhesion promotion
FED-STD-141 method 6301	Paint, varnish, lacquer, and related materials: methods of inspection, sampling and testing	Adhesion promotion
ISO 1463	Metallic and Oxide Coatings - Measurement of Coating Thickness - Microscopical Method	Film thickness (layer thickness)
ISO 1520	Paints and Varnishes - Cupping Test	Adhesion promotion
		Resistance to fluids (chemical resistance)
ISO 2409	Paints and varnishes - Cross-cut test	Resistance to fluids (chemical resistance)
		Adhesion promotion
ISO 2812	Paints and varnishes - Determination of resistance to liquids	Chemical resistance

Table A-1: Examples of standards applicable to passivation of non-aluminium coating key functions

Standard Reference	Standard Description	Key function/standard type
ISO 9227	Corrosion tests in artificial atmospheres - Salt spray tests	Corrosion resistance
MIL-DTL-5541	Chemical conversion coatings on aluminium and aluminium alloys	QC spec
MIL-DTL-81706	Chemical conversion materials for coating aluminium and aluminium alloys	QC spec
		Layer thickness (coating weight)
MIL-PRF-23377	Primer coatings: epoxy, high solids	Chemical resistance
MIL-STD-810 Method 504	Contamination by fluids[b]	Chemical resistance

Source:
ADCR members
“Standard description” obtained from https://standards.globalspec.com apart from:
(a) European co-operation for space standardization, https://ecss.nl/
(b) https://www.crystalrugged.com/

Annex 2 European Aerospace Cluster Partnerships

Table 7-2: European Aerospace Clusters

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
ACSTYRIA MOBILITÄTSCLUSTER GMBH	Austria	Styria	80	3000	650 million Euros
Aeriades	France	Grand Est	65	3100	500 million Euros 7% of total French GDP
Aerospace Cluster Sweden	Sweden	Älvängen	50		
AEROSPACE LOMBARDIA	Italy		220	16000	5.4 billion Euros
AEROSPACE VALLEY	France	Toulouse	600	147000	
Aerospace Wales Forum Limited	UK	Wales	180	23000	£6.5 billion
Andalucía Aerospace Cluster	Spain	Andalusia	37	15931	2.5 billion Euros
Aragonian Aerospace Cluster	Spain	Zaragoza	28	1000	
ASTech Paris Region	France	Paris		100000	
Auvergne-Rhône-Alpes Aerospace	France	Rhône-Alpes	350	30000	3.3 billion Euros
AVIASPACE BREMEN e.V.	Germany	Bremen	140	12000	
Aviation Valley	Poland	Rzeszow	177	32000	3 billion Euros
bavAIRia e.V.	Germany	Bavaria	550	61000	
Berlin-Brandenburg Aerospace Allianz e.V.	Germany	Berlin	100	17000	3.5 billion Euros
Czech Aerospace Cluster	Czech Republic	Moravia	53`	6000	400 million Euros
DAC Campania Aerospace District	Italy	Campania	159	12000	1.6 billion Euros
DTA Distretto Tecnologico Aerospaziale s.c.a.r.l	Italy	Apulia	13	6000	78 million Euros
Estonian Aviation Cluster (EAC)	Estonia	Tallinn	19	25000	3% of GDP
Flemish Aerospace Group	Belgium	Flanders	67	3300	1.2 billion Euros
Hamburg Aviation e.V	Germany	Hamburg	300	40000	5.18 billion Euros
HEGAN Basque Aerospace Cluster	Spain	Basque Country	56	4819	954 million Euros
Innovation & Research for Industry	Italy	Emilia Romagna	30	2000	500 million Euros
International Aviation Services Centre (IASC)Ireland	Ireland	Shannon	60	46000	3.6bn GVA

Table 7-2: European Aerospace Clusters

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
Invest Northern Ireland	Northern Ireland	Belfast	100	10000	£6.7 billion
LR BW Forum Luft- und Raumfahrt Baden-Württemberg e.V.	Germany	Baden-Wuerttemberg	93	15000	4.8 billion Euros
LRT Kompetenzzentrum Luft- und Raumfahrttechnik Sachsen/Thüringen e.V.	Germany	Dresden	160	12000	1.5 billion Euros
Madrid Cluster Aeroespacial	Spain	Madrid		32000	8 billion Euros
Midlands Aerospace Alliance	UK	Midlands	400	45000	
Netherlands Aerospace Group	Netherlands		89	17000	4.3 billion Euros
Niedercachsen Aviation	Germany	Hanover	250	30000	
Normandie AeroEspace	France	Normandy	100	20000	3 billion Euros
Northwest Aerospace Alliance	UK	Preston	220	14000	£7 billion
OPAIR	Romania			5000	150 million Euros
Portuguese Cluster for Aeronautics, Space and Defence Industries	Portugal	Évora	61	18500	172 million Euros
Safe Cluster	France		450		
Silesian Aviation Cluster	Poland	Silesian	83	20000	
Skywinn - Aerospace Cluster of Wallonia	Belgium	Wallonia	118	7000	1.65 billion euros
Swiss Aerospace Cluster	Switzerland	Zurich	150	190000	16.6 billion CHF 2.5 % of GDP
Torino Piemonte Aerospace	Italy	Turin	85	47274	14 billion euros

Annex 3 UK Aerospace sector

7.1 Overview

7.1.1 Aerospace

The annual ADS Industry Facts and Figures guide provides an indication of the UK aerospace, defence, security and space sectors' contribution to the economy in 2021, as shown in Figure 7-1. The Aerospace, Defence, Security and Space Group (ADS) notes that it has over 1,100-plus member companies (including over 1,000 SMEs), supporting around 1,000,000 jobs (direct and indirect) across the country.

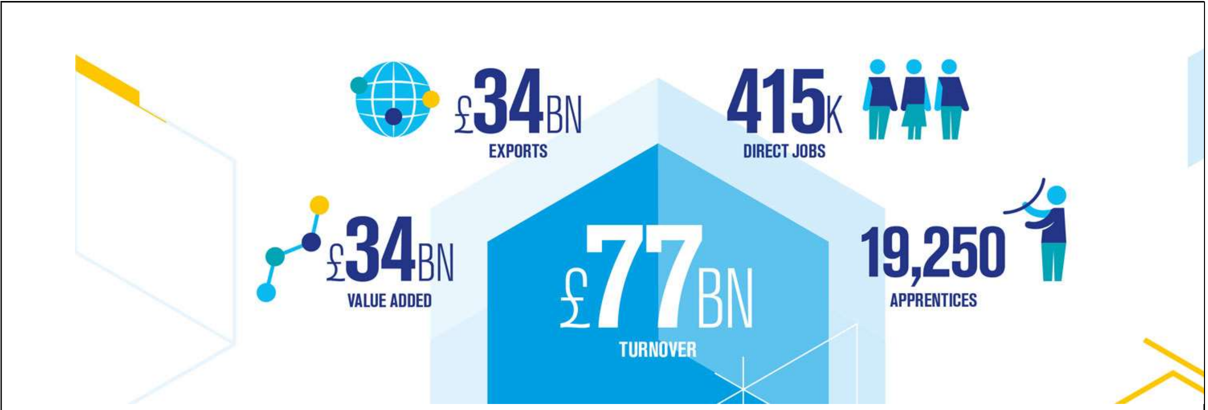

Figure 7-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2020[94]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[95], providing direct employment of over 120,000 highly skilled jobs that pay about 40% above the national average. The sector has an annual turnover of around £77bn, half of which comes from exports to the rest of the world. It is a driver of economic growth and prosperity across the UK, given that most of the jobs (92%) are located outside London and the south east – see Figure 7-2.

Given the economic importance of the sector, it has been the focus of an Aerospace Sector Deal launched on 6 December 2018) under the UK Industrial Strategy. The deal is aimed at helping industry move towards greater electrification, accelerating progress towards reduced environmental impacts, and has involved significant levels of co-funding by the government (e.g., a co-funded £3.9 billion for strategic research and development activities over the period up to 2026)[96]. To date, this co-funded programme has invested £2.6 billion, across all parts of the UK.

It is anticipated that the UK aerospace sector will continue to grow into the future, due to the global demand for large passenger aircraft, as discussed further below.

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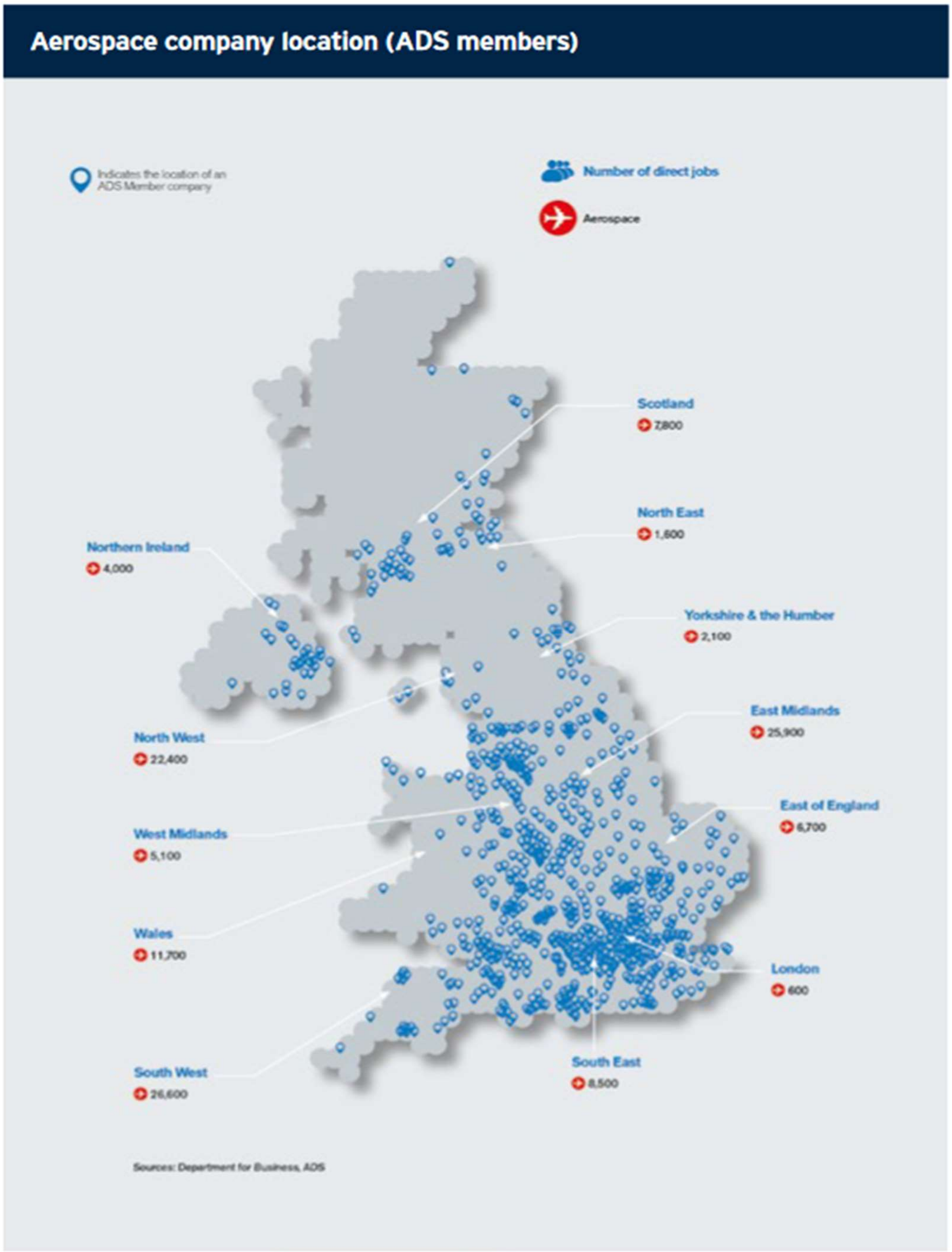
[94] https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2022/06/ADS-FF2022-Twit-header-72.jpg

[95] BEIS, Aerospace Sector Report, undated.

[96] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763781/aerospace-sector-deal-web.pdf



Sources: Department for Business, ADS

Figure 7-2: Location of aerospace manufacturing sites and associated jobs in the UK[97]

The National Aerospace Technology Exploitation Programme was created in 2017 to provide research and technology (R&T) funding with the aim of improving the competitiveness of the UK aerospace industry, as well as other supporting measures under the Industrial Strategy. The Government's

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[97] Sources: ONS, BEIS, ADS Industrial Trends Survey 2020

investment in R&T is through the Aerospace Technologies Institute and is programmed at £1.95 billion in expenditure between 2013-2026.

This will help in maintaining the current expected market development in the UK, which would see a 2.3% per year growth in real terms, leading to direct added value of just over £14 billion in 2035 (compared to £9 billion in 2016). In 2016, the UK aerospace sector employed around 112,500 people, with each direct job in the aerospace industry creating at least one additional job within the aerospace supply chain. This gives around 225,000 people directly and indirectly employed by the aerospace sector in high-value design and high value manufacturing jobs. By maintaining its current direction of growth, the sector is expected to create up to a further 45,000 positions by 2035.

The value of the sectors is also significant in wider economic terms. Investment in aerospace research and technology leads to wider impacts beyond the sector. Every £100 million spent on R&T by the government crowds-in around £300 million of additional private sector investment. Furthermore, every £100 million invested benefits not only UK aerospace GVA by £20 million per year, but also the wider economy by £60 million per year through technology spillovers. These include automotive, marine, oil and gas, nuclear, electronics, composites, metals and other UK industrial sectors. In total, the return on government investment in the sector is estimated as delivering an additional £57 billion of gross value added for the UK aerospace sector and a further £57 billion to the wider UK economy between 2015 and 2035.

7.1.2 Defence

With respect to defence, the UK is the second largest defence exporter in the world, with its contribution to employment, turnover, and exports illustrated in Figure 7-3[98]. Again the importance of the sector to UK exports and value added, as well as employment is clear from Figure 7-3.

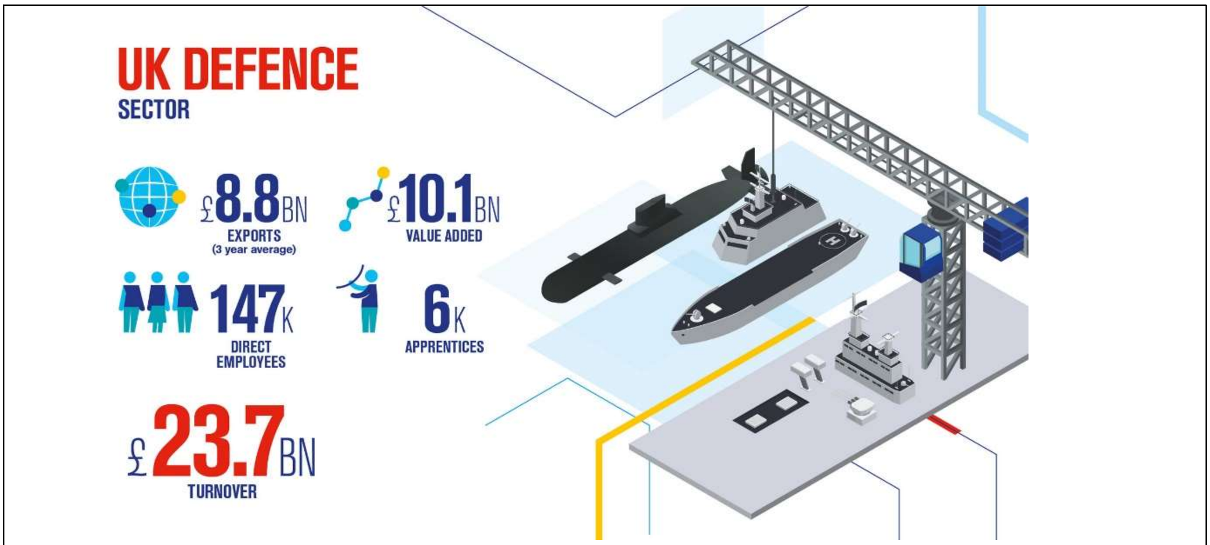

Figure 7-3: UK defence sector contribution to the economy in 2021

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[98] Sources: https://www.adsgroup.org.uk/industry-issues/facts-figures/facts-figures-2022/