ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Public version

Legal name of applicant(s):	Indestructible Paint Ltd. PPG Industries (UK) Ltd.
Submitted by:	Risk & Policy Analysts Limited (RPA Ltd.) on behalf of the Aerospace and Defence Chromates Reauthorisation (ADCR) Consortium
Date:	11 July 2024
Substance:	• Strontium Chromate • Potassium hydroxyoctaoxodizincate dichromate
Use title:	Formulation of primer products with poorly soluble Cr(VI) compounds for use in aerospace and defence industry and its supply chains
Use number:	1

DECLARATION

We, Risk & Policy Analysts Ltd, who are submitting on behalf of the Aerospace and Defence Chromates Reauthorisation Consortium are aware of the fact that further evidence might be requested by the HSE to support the 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 (11 July 2024), 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, Place: 11 July 2024, RPA Ltd., Norwich

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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

BSI – British Standards Institution

BtP – Build-to-Print manufacturer

CAGR – Compound Annual Growth Rate

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CF – Carbon Fibre

CFC – Consumption of fixed capital

CMR – Carcinogen, Mutagen or toxic for Reproduction

CRES – Corrosion Resistance Steel

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium Trioxide Authorisation Consortium

DOA – Design Organisational Approval

DtB – Design-to-Build manufacturer

DtC – Dichromium tris(chromate)

EACP – European Aerospace Cluster Partnership

EASA – European Aviation Safety Agency

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

ECHA – European Chemicals Agency

EEA – European Economic Area

EHS – Environment, Health and Safety

ESA – European Space Agency

EU – European Union

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross Domestic Product

GF – Glass Fibre

GOS – Gross Operating Surplus

GVA – Gross Value Added

HvE – Humans via the Environment

ICAO – International Civil Aviation Organisation

ISO – International Organization for Standardization

LEV – Local exhaust ventilation

MoD – Ministry of Defence

MRL – Manufacturing readiness level

MRO – Maintenance, Repair, and Overhaul

MSG-3 – Maintenance Steering Group 3

NACE – Nomenclature of Economic Activities

NATO – North Atlantic Treaty Organisation

NI – Northern Ireland

NPV – Net Present Value

NUS – Non-use scenario

OELV – Occupational Exposure Limit Value

OEM – Original Equipment Manufacturer

PCO – Pentazinc chromate octahydroxide

PHD – Potassium hydroxyoctaoxodizincatedichromate

PPE – Personal protective equipment

RAC – Risk Assessment Committee

R&D – Research and Development

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

StC – Strontium chromate

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

TRL – Technology Readiness Level

TSA – Tartaric-sulphuric acid anodising

UK – United Kingdom

WCS – Worker Contributing Scenario

Glossary

Term	Description
Active Corrosion Inhibition	The ability of a corrosion protection system to spontaneously restore corrosion protection following damage to the original coating 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.
Adhesive failure	The state when the adhesive loses adhesion from one of the bonding surfaces. It is characterised by the absence of an adhesive on one of the material surfaces.
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 without destruction of designed use except welded and bonded parts, such as equipment, a machine, or an Aerospace and Defence (A&D) product.
Aviation	The activities associated with designing, producing, maintaining, or flying aircraft.
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.
Bond strength	The amount of adhesion between bonded surfaces. It is measured by the stress needed to separate the bonded layers from each other.

Term	Description
Bonding primer	Bonding primers (sometimes referred to as adhesive bonding primers) provide corrosion resistance and promote and maintain adhesion between a substrate and an adhesive material.
Build-to-Print (BtP)	Companies that undertake specific processes, dictated by the Original Equipment Manufacturer (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 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.
Cohesive failure	A breakdown of intermolecular bonding forces in a given adhesive substance. This type of failure occurs in the bulk layer of the adhesive.
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 fatigue	Fatigue in a corrosive environment. The mechanical degradation of a material under the joint action of corrosion and cyclic loading.
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".
Dynamic performance	Dynamic performance is the requirement for combined sealant chemical resistance and mechanical cycling at high and low temperatures.
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

Term	Description
	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 localised 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.
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	A global accreditation programme for aerospace engineering, defence and related industries, administered by the Performance Review Institute (PRI).
Net Present Value	See Present Value; It is obtained by discounting future flows of net economic benefits to the present period.
Non-nutrients performance	The performance of coating not supporting any microbiological growth in the fuel tank area.
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	Present Value is the current value of future flows of benefits or costs discounted at the appropriate discount rate.
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

Term	Description
	also provide chemically active surfaces for the subsequent treatment. Pre-treatment of metallic substrates typically consists of cleaning and/or surface preparation processes.
Processing temperature	The temperature at which a process, or part of a process (such as curing cycle) takes place.
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'.
Protective primer	Those primers and speciality coatings, the use of which is authorised under Authorisation decisions C(2020)2076, C(2020)2089, C(2020)6231, and C(2020)1841, excepting bonding primers and wash primers.
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.
Rework	The process of correcting defective, failed, or nonconforming components after inspection and before delivery to the customer.
Social Cost	All relevant impacts which may affect workers, consumers and the general public which 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 the 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.
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 of 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.

Term	Description
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	Value of avoiding a fatality. It is used in monetising cancer mortality risks in this document.
Verification	The process of establishing and confirming compliance with relevant procedures and requirements.
Wash primer	A thin coating applied prior to a primer or topcoat scheme. Where higher corrosion protection is required, the wash primer has to be overcoated by a basic primer before the final coating is applied. Wash primers passivate the surface by neutralising metal (hydr)oxides and/or etching the surface.
Wear resistance	The ability of a surface to withstand degradation or loss due to frictional movement against other surfaces.
Sources: GCCA and ADCR consortia	

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 has developed several Review Reports and new applications on behalf of the applicants. These Review Reports or new applications cover all uses of chromates in primer products 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 civil and military aviation (including rotorcraft e.g. helicopters), ground-based 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 successes and levels of use have decreased significantly, the specific use of hexavalent chromium compounds in primers[1] is still required for many components. This use 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 GB society and economy more generally.

This review report or new application for authorisation is aimed at ensuring that formulation of the primers used by the A&D value chain can continue in GB until alternatives to the chromates are qualified and certified in the manufacture, maintenance, repair and overhaul of A&D components and final products. These primers are essential to the following activities for which the ADCR is also seeking authorisation for up to 12 years after the end of the current review period:

- Use of bonding primers containing strontium chromate in the aerospace and defence industry and its supply chains;
- Use of primer products other than wash and bonding primers containing strontium chromate, Potassium hydroxyoctaoxodizincate dichromate, and/or Pentazinc chromate octahydroxide in the aerospace and defence industry and its supply chains; and
- Use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in the aerospace and defence industry and its supply chains

[1] Review Reports are also being submitted by the ADCR covering the downstream use of formulations covered by this dossier in primer products other than wash and bonding primers, bonding primers, and wash primers as more narrowly defined by the ADCR.

Although there have been alternatives and levels of use of chromates have decreased significantly, the use of strontium chromate, potassium hydroxyoctaoxodizincatedichromate, in formulations used by the aerospace and defence sector (A&D) is still required as part of the primers applied to large numbers of components and final products. This document provides the analysis of alternatives and socio-economic analysis to support the continued use of these chromates in:

- *"Formulation of primer products with poorly soluble Cr(VI) compounds for use in aerospace and defence industry and its supply chains"*

Formulation forms a first step in all supply chains relevant for the ADCR consortium. The continued use of formulations covered by this assessment is essential until alternatives (formulations, substances or techniques) are developed, tested, qualified and certified for use in the manufacture of those components and final products. Their use is critical to ensuring flight safety and 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 GB economy more generally.

The applicants are members of this consortium, acting on behalf of their downstream user members which include both formulators and companies within the A&D supply chain.

1.2 Availability and suitability of alternatives

At the formulation stage, the chromates have no (separate) function, hence no analysis of alternatives can be provided.

The function played by the primers containing one or more of the two chromates developed for use by the A&D sector is described in the review reports submitted for the three uses of chromates in formulation and other primer uses listed above. The availability of alternative primers, in terms of their technical feasibility, economic feasibility and availability is also discussed for each use in its respective review report.

As detailed in the combined AoA/SEAs supporting each of the primer uses, there are several factors that affect the availability and suitability of alternatives to the downstream users of the primers using one or more of the two chromates. Of key importance is that the adoption of alternatives is subject to strict regulatory requirements to ensure the continued airworthiness, safety, and reliability of aerospace and defence final products. These requirements generate additional, complex testing and development, qualification, certification and industrialisation activities that have to be carried out component by component to ensure the continued airworthiness of aircraft and the safety and reliability of defence equipment (including air, naval and land-based systems)**.**

As a result, formulation involving the chromates is still required as there are no alternatives to the use of the resulting primers which can be considered "generally available" following the European Commission's definition[2]. Obtaining such certification across hundreds of components is a time-consuming process, given the strict testing regimes that must be adhered to achieve the qualification, validation and certification of components using an alternative.

[2] 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)

These requirements which must be met by the downstream users of the formulations are detailed further in Section 3 of this document.

1.3 Socio-economic benefits from continued use

The continued use of the two chromates in the formulation of primers over the requested 12-year review period will confer significant socio-economic benefits to the formulators and their downstream users in the A&D industry, which include civil aviation, military users (air, land and sea), emergency services and aeroderivative products. It will also protect the wider economic and employment benefits delivered by the A&D industry in GB.

The socio-economic impacts of a refused authorisation are quantified here in terms of the potential lost profits to formulators and impacts on employment at their operations. These impacts are not taken into account in the SEAs prepared to support each of the three primer uses, in order to minimise the potential for double-counting among these uses.

The estimated socio-economic benefits from the formulation of primers with Cr(VI) compounds for use in aerospace and defence industry and its supply chains for surface treatments are as follows:

- Avoided producer surplus loss: #B (<£5 million) in GB (proxy using 2 years' profits discounted at 3.5%)
- Avoided social costs of unemployment: £2.7 million in GB

These benefits are very small in comparison to the benefits from the continued use of the primers produced by the two companies involved in formulation to the A&D industry. The SEAs submitted by the ADCR as part of the review reports supporting the three primer uses in which the primers are used highlight the value of their continued availability. Lost profits due to the loss of the formulated primer products would equate to over €10 billion in GB.

This is because a decision not to grant a re-authorisation for formulation while granting re-authorisations for the three downstream primer uses would disrupt the market. It could result in transfer of formulation to non-GB countries; however, this would depend on the two companies involved in formulation being willing to invest in new facilities. Given that use of the same or similar Cr(VI) primers are certified in the manufacture of components and end products in other countries and low economic value of these products to the formulators, it is unlikely that GB formulators would relocate.

Furthermore, A&D companies would have to re-certify any primers produced at a new location for use in the manufacture, maintenance and repair of their components and end products; they would also have to re-certify use of primers should there be any changes occurring in the source of the chromate substances used in formulation or any changes to the manufacturing process (even if this is only the location). As this would have to be carried out across thousands of components, it would essentially translate to a cessation in the production of components and the manufacturing of final products, leading to lost profits from a cessation of activities in GB. Re-certification at this scale would take years.

Given that use of the same or similar Cr(VI) primers are certified in the manufacture of components and end products in other countries, it is unlikely that A&D companies would go through such re-certification while at the same time incurring the costs of qualifying and certifying alternatives.

The most plausible non-use response of A&D companies, therefore, is to relocate significant portions of their manufacturing activities outside the UK (and EEA to countries) where use of certified Cr(VI) primers remains feasible. This would result in a loss of turnover, profits and jobs to GB. In this SEA and the SEAs that support the review reports for authorisation of the primer types impacts over a period of two years have been used in calculation of NPV and ratio of benefits of continued use to risks (ECHA's default time period for estimating surplus losses), but in reality they would extend far longer into the future, due to the loss of such an important manufacturing base. These impacts would occur over several years, given that the most response of A&D companies to such a scenario is to relocate significant portions of their manufacturing activities outside GB to countries where use of certified formulated primer products remains feasible.

Overall, the benefits to A&D downstream users and the GB economy from the continued authorisation of formulation equate to hundreds of billions of Pounds in profits and avoided costs of unemployment from the continued availability of Cr(VI) primers for surface treatment and subsequent manufacturing of aerospace and defence products.

1.4 Residual risk to human health from continued use

The A&D sector is planning on substitution of the chromate-based primers over the next 12 years. As a result, the quantity of the chromates use in formulation activities should decline over this period, as should the levels of exposures to workers undertaking formulation and to humans via the environment from their use at the two sites.

Risks to workers have been estimated based on the use of exposure monitoring data, supplemented by modelling data as appropriate. Across the two GB sites, a total of 20 workers are working with Cr(VI) and may be potentially exposed.

Exposures for humans via the environment have been calculated for the local level only. Based on the population density around the two sites in which formulation takes place, an estimated 33,000 people in GB are calculated as potentially being exposed to Cr(VI) in relevant vicinity of the sites.

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:

- Up to 4.28E-05 fatal cancers and 1.14E-05 non-fatal cancers per annum over the 12-year review period, at a total social cost of £126 to £173.

1.5 Comparison of socio-economic benefits and residual risks

The ratios of the benefits of continued use to formulators to the residual risks to human health for GB is #C (over 1000) to 1 over 12 years.

The above estimates represent a significant underestimate of the actual net benefits from the continued use strontium chromate (StC) and potassium hydroxyoctaoxodizincatedichromate (PHD) in formulation activities in GB. It only encompasses the benefits that could readily be quantified and monetised and it does not include any benefits to downstream users in the A&D value chain to ensure no double-counting of impacts in combination with the other review reports being submitted by the ADCR. The true benefit-cost ratios would also encompass:

- The avoided profit losses and social costs of unemployment due to the ability of downstream A&D companies and military forces to continue to undertake the three primer uses that are the products of the formulation activities within scope of this review report;

- The avoided impacts on air transport – both passenger and cargo – across GB that would arise due to stranded aircraft 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 GB as they either cease some activities or relocate relevant operations; and

- The avoided economic and environmental costs associated with increased transporting of components in and out of GB 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:

- Occupational exposure monitoring requirements were placed on downstream users, including formulators, as part of the granting of the parent authorisations. The affected companies have 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. In the Risk Characterisation parts of the CSR, each of the Worker Contributing Scenario (WCS) sections compare the ADCR applications larger database of occupational exposure monitoring studies with those from the parent applications.

- A Binding Occupational Exposure Limit Value (OELV) was 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 involved in formulation.

- The formulators are working with the A&D downstream users to reduce the volume of chromates used in surface treatment activities, and the A&D companies are implementing development plans across all current uses, as indicated in the Development plans included in the review reports submitted by the ADCR supporting the three primer uses in which use of the chromates remains essential.

- The requested review period is 12 years, with the demand for the formulated primer products expected to reduce over this period as substitution takes place. As a result, lifetime excess cancer risks to workers involved in formulation activities will reduce over time, as will risks to the general public.

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

These include the following, which result in the need for longer (12 years) than normal (7 years) review periods:

- **The applicants' downstream users face investment cycles that are demonstrably very long,** as recognised in various European Commission reports. Final products in the A&D sector can have lifespan 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. Maintenance, repair and overhaul companies (MROs) as well as Ministries of Defence (MoDs) require the ability to continue servicing older, out-of-production but in-service aircraft and military equipment (including air, land and sea). The inability to continue servicing such final products will not only impact upon civil aviation but also emergency vehicles and importantly operationally critical military equipment. Thus, although new aircraft and military equipment designs may draw on new materials where approved and may represent a shift away from the need for the chromates in primer products, there will remain a stock of in-service aircraft and equipment, including new designs, that will require its use as part of repairs, maintenance, and overhaul activities.

- **The costs of moving to alternatives are high for the downstream users of the formulations, not necessarily due to the cost of the alternatives but due to the strict regulatory requirements that must be met to ensure airworthiness and safety** for military and civil use. The requirements placed on A&D companies 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 a 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 undertake action across the range and numbers of components that still require the qualification, certification and industrialisation of the alternatives without sufficient time and resources.

- **The strict regulatory requirements that must be met by A&D companies in the manufacture of components and final products 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 formulation of primer products which can be considered to be "generally available" following the European Commission's definition[3]. 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

[3] 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)

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 the seven-year period of the original authorisation. As a result, sufficient time for the continued use of the chromates in formulation of the primers used by A&D companies is required to enable these downstream users to fully implement alternatives through the value chain once the alternatives have been certified.

- Even then, **it may not be feasible for military MROs to move completely away from the use of Cr(VI)-containing primers 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 aircraft 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 two chromates in the formulation of primer products 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 including at the UK level, EU level and in a wider field, e.g. with NATO**.

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

- As indicated in Section 5, **the socio-economic benefits from the continued formulation and use of Cr(VI) primer products significantly outweigh the risks of continued use.** The GB 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 GB. It will not be able to respond to this increased market demand if the continued use of the Cr(VI) primer products 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 GB A&D sector must ensure not only that it meets regulatory requirements in GB, 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 A&D Chromates Reauthorisation (ADCR) Consortium

The ADCR was specifically formed by the major European A&D companies to respond to the complexity of the aerospace and defence supply chain (which contains many small and medium-sized enterprises (SME)) and to benefit the entire supply chain, thereby minimizing the risk of supply chain disruption across the A&D sector. This includes ensuring that the industry's major OEMs and Design-to-Build companies are able to change sources of supply for the manufacture of components and parts; the importance of this type of risk minimisation has become only too apparent due to the incidents of supply chain disruption that has arisen due to COVID-19 pandemic. This review report is submitted by formulators of chromate-containing primers; and importers of the chromates.

This combined AoA and SEA provides an updated assessment from that presented in the parent Applications for Authorisation (AfA) for the purposes of this Review Report (RR). The scope includes all the poorly soluble chromates – strontium chromate and potassium hydroxyocta-oxodizincate-dichromate – relevant for formulation of primer products by ADCR consortium members who act as formulators, taking into account the needs of their supply chains. These chromate-based primers will impart different functions in their different uses, including improving corrosion resistance, and promoting adhesion to subsequent layers (such as a coating or adhesive).

The use of the formulated primer products is limited to those situations where they play a critical (and currently irreplaceable) role in meeting product performance, reliability, and safety standards, particularly those relating to airworthiness set by the Civil Aviation Authority (CAA). This is also true with respect to their use 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 must comply with numerous other requirements including those of the European Space Agency (ESA) and of national Ministries of Defence.

2.1.2 Aims of the combined AoA and SEA document

Although the formulators covered by this review report have been successful in working with the A&D sector to implement alternatives in some applications, the continued use of the chromates in primer formulations is required beyond the existing review period which expires in January 2026 for strontium chromate and potassium hydroxyocta-oxodizincate.

The downstream users supporting the ADCR consortium have not been able to industrialise alternatives for all primer products currently in use and must continue to rely on the use of the chromate-based primers until they have fully developed, qualified and certified alternatives for use in the manufacture of components and final products. These primers are essential to the delivery of a range of functions to the component onto which they are applied. In particular, they are fundamental and integral to preventing corrosion, forming part of an overall corrosion protection system aimed at ensuring the on-going airworthiness of aircraft and safety and reliability of military products.

The aim of this combined AoA/SEA is to demonstrate:

- The technical and economic feasibility, availability, and airworthiness (i.e., safety) challenges in identifying an acceptable alternative to the use of the chromate-based primers, which does not compromise the functionality and reliability of the parts treated with primer products and which could be certified by OEMs and gain approval by the relevant aviation and military authorities across the globe;

- The efforts currently in place to progress potential alternatives through Technical Readiness Levels (TRLs), Manufacturing Readiness Levels 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 as well as out-of-production civilian and military aircraft and defence equipment;

- The socio-economic impacts that would arise for the ADCR value chain and, crucially, for GB more generally, if the applicants were not granted re-authorisations for the continued use of the poorly soluble chromates in formulation activities over an appropriately long review period; and

- Comparison of the overall benefits of continued use of the chromates in formulation activities and risks to human health from the carcinogenic that may result from exposures to the chromates from these activities.

2.2 The Initial Applications for Authorisation

This combined AoA and SEA covers the use of the following chromates in formulation:

- Strontium chromate (StC) EC 232-142-6 CAS 7789-06-2
- Potassium hydroxyoctaoxodizincatedichromate (PHD) EC 234-329-8 CAS 11103-86-9

Strontium chromate (StC; Entry No. 29) and potassium hydroxyoctaoxodizincatedichromate (PHD; Entry No. 30)) have been included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic carcinogenic property. StC is classified as carcinogenic Cat. 1B while PHD is classified as carcinogenic Cat. 1A.

These two chromates were granted authorisations for use in formulation to a range of upstream applicants, with **Table 2-1** summarising the initial applications on which this Review Report is based.

Table 2-1: Overview of Initial Applications for Authorisation					
Application ID/ authorisation number	**Substance**	**CAS #**	**EC #**	**Authorisation Holder**	**Authorised use**
0046-01 28UKREACH/20/7/3, 29UKREACH/20/7/7	Strontium Chromate	7789-06-2	232-142-6	Various legal entities (CCST consortium)	Formulation of primers intended exclusively for uses bearing authorisation numbers REACH/20/7/10 to REACH/20/7/19
0047-01 26REACH/20/6/0,	Potassium hydroxyoctaoxodizincate dichromate	11103-86-9	234-329-8	PPG Industries (UK) Ltd. (CCST consortium)	Formulation of primers intended exclusively for uses REACH/20/6/5 to REACH/20/6/9

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Cr(VI)-containing primer products are produced at industrial sites specialised in formulation activities. Primer products are liquid, water- or solvent-based dispersions of StC and PHD. The products contain further resins and additives to achieve the required performance characteristics. Primer products are liquid dispersions of low viscosity (solvent-based products are slightly higher viscous than water-based; viscosity is also influenced by the size of the dispersed particles). Production of primer products comprises the main steps:

- Preparation of concentrated liquid dispersions from solid chromates
- Milling (wet-grinding) and dispersion, potentially followed by further dilution with resins, additives and solvents
- Filling of product containers (including small volume packages).

The chromates do not have an own functionality during formulation. The purpose of this activity is to provide primers adequate for fulfilling technical requirements in subsequent surface treatment processes in the aerospace and defence industry and its supply chains.

2.3.1.2 Relationship to other ADCR applied for chromate uses

Primers (products) containing Cr(VI) compounds are manufactured to meet the high quality standards in the A&D supply chains. This step therefore is a prerequisite for achieving the required results in downstream coating systems. This combined AoA/SEA covers the manufacture of products with strontium chromate and potassium hydroxyocta-oxodizincate relevant for all uses described in the other dossiers prepared by the ADCR consortium.

For the avoidance of doubt, the resulting primers are relevant to all of the following surface treatments:

- Use of bonding primers containing strontium chromate in the aerospace and defence industry and its supply chains
- Use of primer products other than wash or bonding primers containing strontium chromate, pentazinc chromate octahydroxide or potassium hydroxyoctaoxodizincate dichromate in the aerospace and defence industry and its supply chains
- Use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in the aerospace and defence industry and its supply chains

2.3.2 Temporal scope

Because of the lack of viable and qualified alternatives for the use of the primer products containing one or more of the three poorly soluble chromate-based for aerospace and defence components, it is anticipated that it will take ADCR members and their supply chains between four and 12 years to develop, qualify, certify, and industrialise alternatives; the longest timeframes are required by

MROs and companies acting as suppliers of defence products. Over this 12-year period, the temporal boundaries adopted in this assessment take into account:

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

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			
Price year		2022 (values are expressed in 2022 prices)	
Start of discounting year		2026	
Impact baseline year		2026	
Scenario	**Impact type**	**Assessment period**	**Notes**
"Applied for Use"	Adverse impacts on human health	12 years, following a 10-year time lag	Based on the length of requested review period
"Non-use"	Loss of profit along the supply chain	12 years; profit estimates of 2 years are used as proxy for the societal producer surplus loss	Based on ECHA guidance and the length of requested review period
	Impacts on growth and GDP	12 years	Based on the length of requested review period
	Disruption to GB 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	12 years; note that some costs such as lost wages, search and recruitment costs do not incur for whole 12 years due to temporary nature of unemployment	Average duration of unemployment in Dubourg (2016)

2.3.3 The supply chain and its geographic scope

2.3.3.1 The ADCR Consortium

The ADCR is composed of 17 companies located in the EEA and the UK that act as suppliers to the A&D industry (importers, formulators, and distributors), and 45 companies which 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 (MoDs) 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, Design-to-Build (DtB) and MROs operating in the EEA and UK. These 24 companies operate across multiple sites in the EEA, as well as in the UK and more globally. It is the leading OEMs and DtB companies that act as design owners and establish the detailed performance criteria that must be met by individual components and final products in order 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.

All downstream user members of the ADCR are supporting this formulation review report, with this reflecting the importance of the chromate primers to the A&D value chain.

2.3.3.2 Producers of primers

The chromate substances are imported to GB by the applicants and are then sold to the formulators for use in production of the primers used by the A&D sector. Formulation is carried out at two sites in GB, with the relevant products listed in **Table 2-3**.

Table 2-3: Products used in formulation	
Product Type A	Solid StC, pure substance (100%); 26% Cr(VI)
Product Type B	Solid PHD, pure substance (100%); 25% Cr(VI)

2.3.3.3 Downstream users of soluble chromate formulated primers

As already noted, the chromate-based primers produced by the formulators are used by the ADCR value chain in a range of applications all of which are subject to their own review reports.

The primers are used in industrial settings, where their use may take place either by: Manual spraying in spray room/booth; or via a more local treatment including brush or swab. In some cases, use of the primers may involve a low level of automation, while in others there is a high level of automation.

Use of primer products within the A&D sector is carried out by actors across all levels in the supply chain:

- Original equipment manufacturer (OEM) – generally large companies which design, manufacture, assemble and sell engines, aircraft, space and defence equipment to the final customer;
- Design-to-Build[4] (DtB) – companies which design and build components;
- Build-to-Print (BtP) – companies that undertake specific processes, dictated by the OEM, to build A&D components; and
- Maintenance, Repairs and Overhaul (MRO) – companies that service aircraft, space and defence equipment.

It is important to note that companies may fit into more than one of the above categories, acting as an OEM, DtB, and MRO[5], where they service components they designed and manufactured which are already in use. Similarly, a company may fall into different categories depending on the customer and the component/final product.

[4] Also referred to as "design and make" or "design responsible" suppliers

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

The complexity of the supply chain relationships is illustrated in **Figure 2-1** below, with this highlighting the global nature of these relationships and the interlinkages that exist between suppliers in different geographic regions.

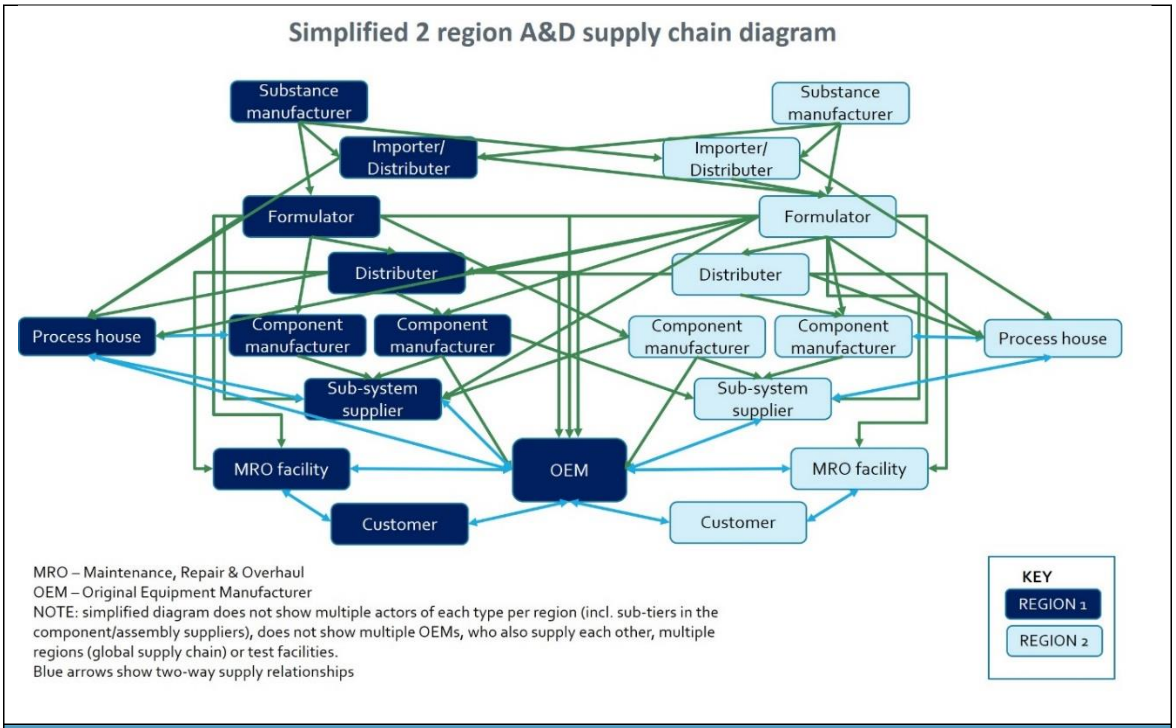

Figure 2-1: Complexity of supply chain roles and relationships within the A&D sector Two-way supply relationships are indicated by the double headed arrows

It is estimated that there are likely to be 150 downstream user sites of the chromate-containing primer products covered by this dossier in GB.

2.3.3.4 Final Customers

The final actors within this supply chain are the customers of A&D final products to which primers have been applied.

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver some 120,000 flights and 10 million passengers a day in a normal year. In 2017, airlines worldwide carried around 4.1 billion passengers. They transported 56 million tonnes of freight on 37 million commercial flights. Every day, aeroplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, assessment of subsequent impacts and jobs in tourism made possible by air transport, show that at least 65.5 million jobs and 3.6% of global economic activity are supported by the industry[6]. More specifically to Europe, in 2019 over 1 billion passengers travelled by air in the European Union, with net profits of over US$ 6.5 billion (€5.8 billion, £5.1 billion)[7]. UK-based aircraft are responsible for the vast majority of the UK's unique international connectivity, accounting for 73%. They also serve 85% of international routes, all domestic routes, and offer 67% of all international seats. This

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

7 https://www.statista.com/statistics/658695/commercial-airlines-net-profit-europe/

dominance of UK-based airlines and aircraft enhances UK connectivity, particularly on less frequented direct routes from regions outside London[8]. 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.[9] 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 primers, 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 products. 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 "service life", which would not have needed replacing on younger aircraft. Upgrades will also be required to extend the service life of aging 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 Consultation with Formulators

Information was gathered from formulators on the quantities of chromates used in formulation activities per annum, and on the locations of these activities and the number of workers involved in such activities. Data were also collected on the end primers produced and placed on the GB market.

Only a minimal amount of socio-economic data was collected from the formulators, as losses in profits or employment for this group of companies is not what drives the requested re-authorisations covered by this combined AoA/SEA. This is driven by the fact that the continued use of the end primers is currently essential in the A&D industry to meet certification requirements for the manufacture of components and end products. Until alternatives to the primers are certified and industrialised for use in the manufacture of A&D components, and across all components, the use of the primers remains essential.

2.4.2 Consultation with Downstream users

Consultation with ADCR members was carried out over a period from 2019 to 2023 to collect a range of data relevant to both the AoAs and SEAs prepared to support the review reports for use of primer products being supported by the Consortium.

8 https://airlinesuk.org/about-us/

9 *Source:* Eurostat (gov_10a_exp)

Of relevance to this AoA-SEA is information gathered on the primer products used by members, together with the associated volumes used. Data were also collected on the substitution process and the stringent requirements that are placed on A&D companies, as well as on the availability of alternatives to the chromate primers and on the progression of development plans for each of the different primer types used.

The full extent of the consultation that was carried out is summarised in the review reports submitted for the use of the primers formulated by the authorisation holders. The combined AoA-SEA documents for each primer type also detail the potential alternatives and the overarching sectoral substitution efforts together with the development plans being progressed by the OEM and DtB members of the ADCR. It is the timing of the development plans that determines the review period requested for the continued use of the poorly soluble chromates in formulation, as these companies are the "design owners" who will obtain the certifications required to enable alternatives to be used in the manufacture of components and final products.

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Substance ID and Overview of the key functions and usage

The chromates that are of relevance to the applied for use are:

- Strontium chromate (StC) EC 232-142-6 CAS 7789-06-2
- Potassium hydroxyoctaoxodizincatedichromate (PHD) EC 234-329-8 CAS 11103-86-9

3.1.1.1 Process steps and overview of key functions

Cr(VI)-containing primer products are produced at industrial sites specialised in formulation activities. Primer products are liquid, water- or solvent-based dispersions of StC and PHD. The products contain further resins and additives to achieve the required performance characteristics. Primer products are liquid dispersions of low viscosity (solvent-based products are slightly higher viscous than water-based; viscosity is also influenced by the size of the dispersed particles). Production of primer products comprises the main steps:

- Preparation of concentrated liquid dispersions from solid chromates;
- Milling (wet-grinding) and dispersion, potentially followed by further dilution with resins, additives and solvents; and
- Filling of product containers (including small volume packages).

At the formulation stage, the chromates have no (separate) function, hence no analysis of alternatives can be provided. The functions played by the primers developed for use by the A&D sector are described in the review reports submitted for the three primer-types listed in section 2.3 above.

It should be noted that the same companies that undertake formulation using these chromates for A&D uses are also involved in research and development of non-chromate alternatives.

3.1.1.2 Usage

Components that may be treated with the Annex XIV substance

All of the chromate-containing primers covered by this combined AoA-SEA, aim to modify the surface of the substrate to provide enhanced corrosion protection and/or support adhesion of subsequent coatings. There are many corrosion prone areas on A&D products. Examples of these are included in **Table 3-1** below:

Table 3-1: Examples of corrosion 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, 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	Blade erosion shells	Gearbox	Pyrotechnic Equipment
Fuselage and floors		Hydraulic intensifier	Radomes (radar domes)
Hydraulic damper		Ram air turbine	Rocket motors
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 primers available, corrosion 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 appropriate inspection, maintenance, and repair intervals.

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

- 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 components; and
- 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 aircraft could fly.

Despite diligent adherence to qualification and validation requirements, 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.

Types of corrosion

There are a number of different kinds of corrosion which may occur at prone areas such as those listed in **Table 3-1**. Examples of some of these are given below (CCST, 2015):

- Grain boundary corrosion is a type of corrosion commonly seen in components made of aluminium alloys;
- Galvanic, filiform and crevice corrosion can occur at locations where there is contact between dissimilar materials, such as those where fasteners are in contact with the aircraft skin;
- Corrosion fatigue and stress corrosion cracking may occur where stress is concentrated, such as in structural components, or fastener holes;
- Bondline corrosion may occur in the frame of adhesive joints at the interface between adhesive and metal;
- Exfoliation corrosion may occur in unprotected metal areas where end-grain is exposed, such as countersinks or the crevices of rolled metal plates; and
- Fretting corrosion occurs when overlapping metallic joints are subject to repeated or cyclic relative movement.

Highly corrosive environments presented in certain systems can also lead to accelerated corrosion, particularly for components such as helicopter rotor heads, and aircraft engine air inlets. Any structural detail where there is an unsealed gap between adjacent components where moisture can become entrapped (like a joint) is also highly susceptible to corrosion.

Service life and maintenance intervals of components

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; and
- D-checks include major structural inspections with attention to fatigue damage, corrosion, etc. which result 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 (GCCA, 2017). 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 (MSG-3) analysis, 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(VI)-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 primers which have passed through an extensive approval process in order to demonstrate their suitability for use – some of these primers 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**[10]**,** whilst defence aircraft and systems are required to operate safely and

[10] 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

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 on 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 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 primer 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[11] in the 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 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.

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

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

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 3-1**).

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 can be 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 standards, 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.

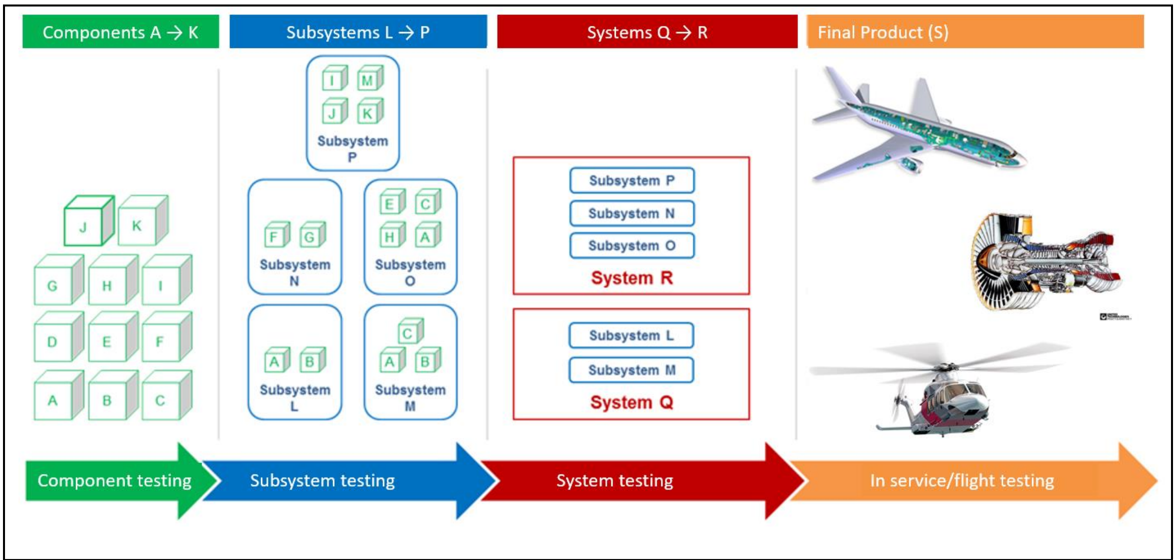

Figure 3-1: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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, which 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.

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	**Definition**	**Description**
8	Pilot line capability demonstrated; Ready to begin Low Rate Initial Production	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 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, sealants, adhesives, 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 types of primer, as well as in other surface treatment processes. Whilst the proposed candidates will be different for each use, considering 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 contained in a product 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 the extent to which the formulations containing the substance, are used. This must consider the entire life cycle of components onto which the formulations are applied 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 primers 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 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 containing 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, adhesion strength, scratch resistance, dynamic performance, 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 3-2**, 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.

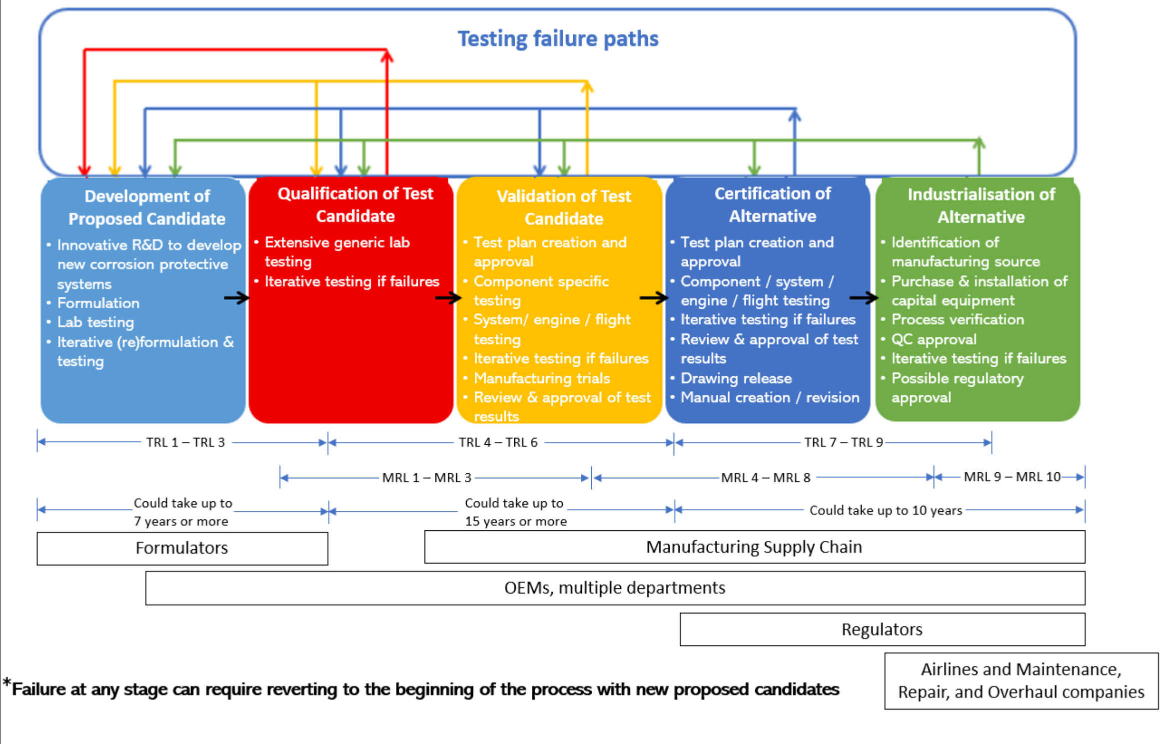

Figure 3-2: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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 corrosion inhibitors/primer products;
- 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 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[12].

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 primer 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.

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.

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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 primer 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. OEM’s 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 3-3** 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 standards/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 formulation whose key function is 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[13], each of these components will need to be approved individually:

> "*Importantly, even if an alternative is in use in one component in aerospace[14] 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.*"

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

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

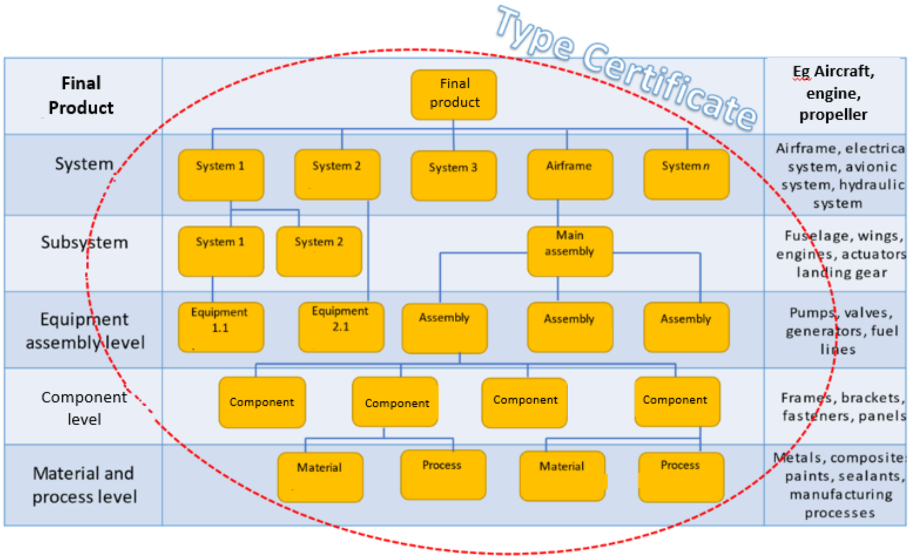

Figure 3-3: System hierarchy of a final product showing the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR member

After the alternative is certified, design drawings and part 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 programme, 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. All 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 programme, 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. 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, a simplified example of the process, described above and leading to industrialisation of the alternative, is illustrated in **Figure 3-4** below.

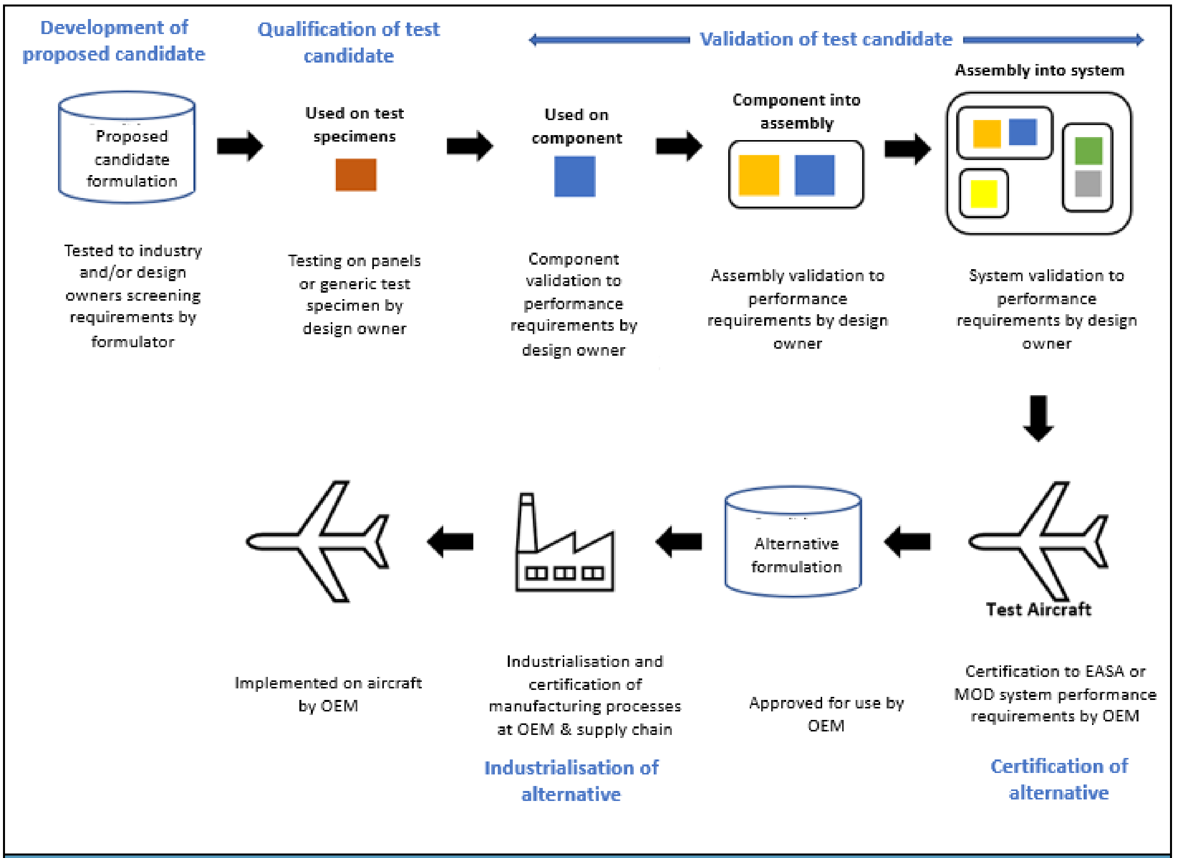

Figure 3-4: Process to Certify a Formulation for use on Aircraft.
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

4 Continued Use Scenario

4.1 Introduction

Cr(VI)-based primers have been used in the A&D sector for decades in order to meet requirements for corrosion protection (resistance and inhibition) and other functional requirements. Although research and development activities have been carried out with the aim of finding substitutes for the last 30 plus years, alternatives are still in the development and testing phase for us in the manufacture maintenance and repair of some A&D products.

These research activities are carried out jointly by the A&D companies and the formulators of primers for the sector.

4.2 Market analysis of downstream uses

The formulators covered by this combined AoA-SEA supply primers containing StC and PHD for use in the aerospace and defence sector and its supply chains. These products are all used as a part of a system which ensures components and final products meet the performance requirements set by certifying authorities (such as EASA). For many organisations operating within the sector, use of the products covered by this combined AoA-SEA are mandated through inclusion on technical drawings and in maintenance manuals, and alternatives cannot be used until Design Owners (including OEMs and MODs) update the documents. An update can only take place after the alternative has been demonstrated to provide an equivalent level of performance to the current primer, and the change has been approved by certifying authorities.

4.2.1 Upstream Supply of Chromatess

Chromates used by formulators are sourced from both within GB and outside GB. StC and PHD are manufactured in a multi-step process starting from chromite ore[15], which is mined in countries outside GB, including South Africa and Kazakhstan, and can be chemically processed into chromate substances which may be used in GB alongside other raw materials to produce the chromate used within formulation.

4.2.2 Quantities of Cr(VI) used in formulation

Table 4-1 shows the total tonnes of chromates used in formulation per year based on responses from the formulators who operate the sites within scope of this review report. As stated above, these chromates are both manufactured within GB and imported from outside GB.

[15] Chromite ore is a naturally occurring Cr(III) substance with the formula $FeCr_2O_4$.

Table 4-1: Quantities of chromates used per year in formulation activities - tonnes per year	
Chromate	**Tonnes per year used in formulation (t/y)**
Strontium chromate (StC)	#A (<20)
Potassium hydroxyoctaoxodizincatedichromate (PHD)	[redacted] (<10)
Source: Consultation with formulators	

4.3 The continued use scenario

4.3.1 The continued use scenario for the formulators

The primers used by the A&D industry contain varying concentrations weight/weight of the chromates. To calculate an illustrative market value for these primers, data was collected directly from the formulators and combined with data on the concentration of the chromates in primers. The prices of primers were gathered from leading specialist distributors of chemical consumables used throughout the aerospace and defence industry. Concentrations of the chromates in the primers are based on the primers being supported across all three review reports for the use of primers prepared by the ADCR.

The results of this analysis are provided in **Table 4-2**, based on average prices for primers placed on the market and an assumed 10% profit margin (typical of the chemicals industry). Although use of average prices for the most common primers placed on the market may underestimate the economic value across all formulation activities, it protects the commercial interests of the formulators covered by this combined SEA-AoA. Protecting such information is considered appropriate in this case, as justification for the continued use of the chromates in formulation is based on the critical role that the primers play in downstream activities rather than in generating profits for the formulators.

Table 4-2: Illustrative profit estimates for the sale of Cr (VI)-containing primer products in GB

	Max concentration w/w	Tonnes Chromate	litres of product	Average price for formulation placed on the market per kg/litre	Market value	Profit at typical 10%
Strontium chromate	12%	[redacted]			#A, B, C (whole table)	
Potassium hydroxyoctaoxodizincatedichromate	9%					
Totals						

As can be seen from the analysis in **Table 4-2** the economic value of A&D related formulation activities is estimated as being in the region of a few tens of millions of Pounds. It provides an indication of the lower bound value of the market. This is in the context of the billions of pounds of turnover and profits generated by the A&D industry under the continued use scenario, and the avoided costs to civil aviation and military forces (as discussed below).

4.3.2 The continued use scenario for the downstream users

4.3.2.1 Summary

The A&D industry as represented by the major OEMs, DtBs, BtPs and MROs comprising the ADCR 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 A&D components and products in GB; and
- The linked continuity of supply of critical products containing hexavalent chromium.

The scope of this RR is driven by A&D qualification, validation and certification requirements, which can only be met by use of the primers that provide the required performance as mandated by airworthiness authorities. This constrains OEMs, DtBs, and hence their BtP suppliers and MRO facilities (civilian and military) to the use of the Cr(VI) primers until alternatives can be qualified and certified across all the relevant components. In many cases, the choice of the primer to be used is further affected by the fact that it forms part of a surface treatment process flow, which has been developed over time to meet specific performance requirements as part of ensuring airworthiness.

The assessments of the availability of alternatives provided in the individual, primer specific AoA-SEAs prepared for the three uses of the chromates supported by the ADCR detail the importance of Cr(VI) to corrosion protection and the other key functions delivered by Cr(VI) containing primers. Although some of the ADCR members – as design owners – will have found alternatives to the continued use of these primers and implemented these at the industrial level for some components and products, they have not been able to do so across all of their uses and associated products. As a result, all members of the ADCR are supporting the authorisation of the continued use of the two chromates in formulation. This includes continued formulation of primers for use in the production of components, as well as in MRO activities.

The continued use of the primer products covered by this review report is also essential in the manufacture of legacy spare parts and where certification of components using alternatives is not technically feasible or available due to design control being held by MoD, who will not revisit older equipment designs in the near future and rely on use of the primers to maintain the mission readiness of their equipment.

As a result, the continued use scenario for these A&D downstream users and their customers can be summarised as follows. This is based on the design owners' development plans, the longest review period being requested of the primer uses reliant on formulation activities continuing is 12 years.

Continued use of Cr(VI) in formulation of primers while development plans progress	Continued use for production, repair and maintenance of parts and components
-> R&D on substitutes and progression through TRL 2/3 to 9 and to MRL10 continues	-> A&D sector retains and expands its GB 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

Figure 4-1: Continued use scenario

4.3.2.2 The downstream A&D market

Size of the market

In 2020, the European A&D industry comprised over 3,000 companies of all sizes and employed over 880,000 highly skilled employees. Approximately 10% of these companies will be involved in the use of chromate-containing primers, and those that are not involved in their direct use are likely to be linked to or reliant upon the activities of companies that either use the chromates themselves or have suppliers that do.

Based on consultation with ADCR members, it is estimated that there are approximately 150 sites using chromate based primers in GB. These GB sites play important roles in the A&D market in Europe described below.

Some of these sites will be using only small quantities of the chromate containing primers, while others use much larger quantities and more than one chromate-containing primer.

Economic importance of the market

As noted by the European Commission, the industry is "characterised by an extended supply chain and a fabric of dynamic small-, medium-, and large enterprises throughout the EU, some of them world leaders in their domain"[16]. Figure 4-2 provides details of turnover and employment for the industry in 2021, based on the Aerospace and Defence Industries Association of Europe (ASD) publication "2022 Facts & Figures".[17]

16 https://ec.europa.eu/defence-industry-space/eu-aeronautics-industry_en

17 ASD, 2021: Facts & Figures, available at: https://www.asd-europe.org/facts-figures

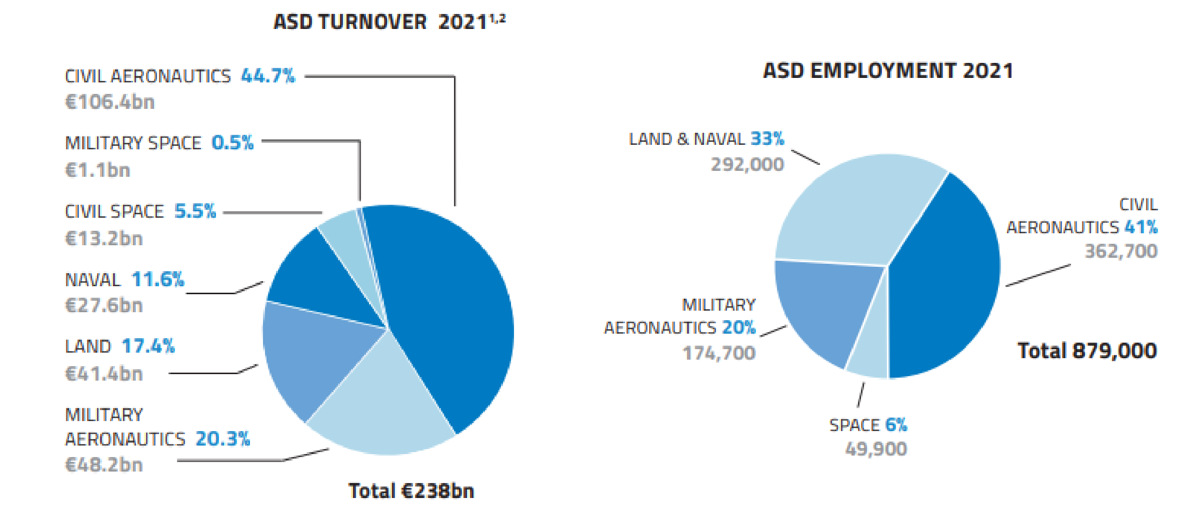

Figure 4-2: Turnover and Employment for the European A&D Industry in 2021 (adapted from ASD, 2022) Available at: https://asd-europe.paddlecms.net/sites/default/files/2022-11/ASD_Facts%20%26%20Figures%202022.pdf

As can be seen from **Figure 4-2**, civil and military aeronautics alone accounted for 65% of turnover and 61% of employment in 2021.

Civil aeronautics alone accounted for 362,700 jobs, revenues of €106.4 billion and exports of €92.5 billion. Across Europe, the civil aeronautics industry turnover increased by over 30% from the year 2020, rising to €106.4bn for the year 2021, which compares to €81.6bn seen in 2020. The defence industry accounted for around 467,000 jobs, revenues of over €118 billion and exports of €45.1 billion.

The A&D sector is recognised as important to the ongoing growth and competitiveness of the UK and EEA 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 service over long time periods. For example, the Boeing 747 first entered service in 1970, and continued to be flown and produced in 2022 (although it will now go out of production but remain in service). 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 components for maintenance, repair and overhaul of existing aircraft and equipment, as well as for models that are still in production long periods after the first aircraft or military products were placed on the market.

- 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 involving the testing and development of new formulations are applied in the market. As part of the development and roll-out of new A&D products, OEMs must be ready to demonstrate fully developed technologies, or they risk losing contracts that may have a lasting effect on business.[18]

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

- 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. Research on substitution of the chromates has been underway for several decades, with the development of substitute primer products underway but proving difficult for all use scenarios, in part because these primers are used in a process flow with surface treatments also historically reliant on hexavalent chromates.

- There are over 20,000 commercial aircraft and 15,000 business jets currently in operation globally. Given the global nature of civil aviation, it is important that global solutions are found to the use of chromate-containing primer products, 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 components and products. They have no ability to substitute away from primers containing the chromates where these are mandated by the original equipment manufacturers.

A&D products 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, salt spray and altitudes). Because the chromate-containing primers cannot be fully substituted at present, they play a critical role in ensuring the reliability and safety of final products.

Thus, although the economic importance of the formulated primer products is indirect in nature, its significance is clear with respect to ensuring that aircraft retain their airworthiness, given the importance of the sector to the transport of passengers and cargo, and hence the EEA and UK economies (for example, the number of air passengers transported in the European Union in 2019 was over 1 billion).

Growth in the civilian market

Furthermore, as detailed in the various primer AoA-SEAs, the continued availability of the chromate-based primers over the requested review period will help ensure that the GB A&D industry is able to respond to the global demand for new aircraft and defence equipment. 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 (€50.4 billion, £44.3 billion) in 2020.[19]

The demand for civilian aircraft is expected to grow between 2020 and 2031 at a compound annual growth rate of 2.5%[20], with the growth rate for passenger air traffic projected at between 3.6% and 3.8%[21] (see also the other review reports submitted by the ADCR). Under the continued use scenario, GB A&D companies would be able to expand their manufacturing output to achieve the levels of growth implied by these compound annual growth rates. This would result in increased growth for the GB economy, due to increased turnover, retained profits and employment. It also means that GB

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

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

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

would continue to benefit from any increases in technological know-how associated with the move to newer generation aircraft.

Growth in the aftermarket parts segment would also be maintained. The aircraft spare components/final product market encompasses the market for both new and used ratable[22] 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 pandemic. 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.

Similarly, the MRO market is expected to have a CAGR of over 3% over the period from 2022-2027.[23, 24] This growth is due to three factors: 1) 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; 2) Airlines face very stringent MRO requirements so are not able to postpone MRO requirements; and 3) Increases in fleet sizes over the next 5 years will also lead to a continued growth in demand for maintenance and repair activities.

Growth in the defence sector

The military importance of ensuring that military aircraft, land and naval hardware maintain their mission readiness cannot be quantified; however, the involvement of MoDs (as well as the MROs supporting military forces) in the ADCR through the provision of information demonstrates the critical nature of chromate-based primers to the on-going preparedness of their military forces in particular.

The war in Ukraine has led 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[25]. The increase in investment will equate to hundreds of billions of Euros (e.g., Germany alone has pledged €100 billion in defence spending).

Such investment, which will include new spending on existing technologies, may also result in a continued reliance on the use of the chromate-based primers 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.

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[22] 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.

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

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

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

4.4 Risks associated with continued use

4.4.1 Classifications and exposure scenarios

4.4.1.1 Human health classifications

The poorly soluble chromates within scope of this review report 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).

Strontium chromate (StC; Entry No. 29) and potassium hydroxyoctaoxodizincatedichromate (PHD; Entry No. 30) have been included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic property to be carcinogenic. StC is classified as carcinogenic Cat. 1B while PHD is classified as carcinogenic Cat. 1A. 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. Therefore, only the human health risks related to the classification of the chromate as carcinogenic are addressed in the CSR. This requires investigating the potential exposure of workers as well as exposure of humans via the environment.

It has to be noted that some primer products may contain additional chromates, which can contribute to Cr (VI) exposure. This may be either a combination of several poorly soluble chromates covered by the ADCR consortium) or a combination of one of these chromates with barium chromate (RAC Opinion for harmonised classification as carcinogenic, Cat. 1B, adopted in June 2023[26]). Barium chromate is currently not listed in Annex XIV.

4.4.1.2 Overview of exposure scenarios

Table 4-3 below shows the exposure scenarios and their contributing scenarios. This RR covers formulation at two companies operating two sites, and therefore scenarios may slightly differ between companies.

Table 4-3: Overview of exposure scenarios and their contributing scenarios

ES number	ES Title	Environmental release category (ERC)/ Process category (PROC)
ES1-F1	Formulation of primer products with poorly soluble Cr (VI) compounds for use in aerospace and defence industry and its supply chains	
Environmental contributing scenario(s)		
ECS 1	Formulation into mixture	ERC2
Worker contributing scenario(s)		
WCS 1	Operators handling solid chromates Sub-scenario 1: large batches Sub-scenario 2: small batches	 PROC 5, 8a, 8b, 28 PROC 5, 8a, 8b, 28
WCS 2	Operators preparing liquid products	PROC 5, PROC 8b, PROC 9, PROC 28
WCS 3	Laboratory technicians	PROC 15
WCS 4	Maintenance and cleaning workers	PROC 28
WCS 5	Incidentally exposed workers	PROC 0

[26] Registry of CLH intention until outcome for barium chromate: https://echa.europa.eu/de/registry-of-clh-intentions-until-outcome/-/dislist/details/0b0236e1848d1fab; assessed in October 2023

Table 4-3: Overview of exposure scenarios and their contributing scenarios		
ES number	ES Title	Environmental release category (ERC)/ Process category (PROC)
Exposure scenario for formulation: ES1-F1		

Both 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 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.

4.4.2 Exposure and risk levels

4.4.2.1 Worker assessment

The complex process of formulating primers is outlined in detail in the CSR. As described in the CSR, there are five worker contributing scenarios to the exposure scenario for formulation. These are explained in more detail in the CSR and include:

- WCS1: Operators handling solid chromates
- WCS2: Operators handling liquid products
- WCS3: Laboratory technicians
- WCS4: Maintenance and cleaning workers
- WCS5: Incidentally exposed workers

As outlined in the CSR, the relevant human exposure pathways at the production facilities are chronic inhalation and dermal exposure. The CSR concludes that the dermal pathway is negligible in the context of the total exposure. Therefore, inhalation exposure is the only pathway relevant to worker exposure that is considered in this SEA. Total cancer risks for inhalation exposure are calculated by adding up risk estimates for the two main tumour body locations (bladder and lung).

Table 4-4 sets out the excess lifetime cancer risk for workers involved in each of the above tasks for the two sites. It also indicates the number of workers exposed in total. These figures are based on the data collected for the CSR from the sites undertaking formulation activities specific to the A&D sector and form the basis for determining the number of workers exposed to the chromates.

Note that WCS3 relates to laboratory technicians and is not considered further here as the handling of substances in laboratories for quality control purposes is under controlled conditions and in amounts below 1 t/a, falling under the REACH Art. 56(3) exemption. Furthermore, the sampling activities that may be carried out by laboratory technicians are covered under other WCS.

Table 4-4: Excess lifetime cancer risk estimates for workers					
WCS #	Group of workers	Number of workers exposed (Site A)	Excess lifetime lung cancer mortality risk (Site A)	Number of workers exposed (site B)	Excess lifetime lung cancer mortality risk (Site B)
WCS1	Operators handling solid chromates	2	1.74E-04	2	8.67E-06
WCS2	Operators preparing liquid products	5	5.28E05	2	2.34E-05

Table 4-4: Excess lifetime cancer risk estimates for workers

WCS #	Group of workers	Number of workers exposed (Site A)	Excess lifetime lung cancer mortality risk (Site A)	Number of workers exposed (site B)	Excess lifetime lung cancer mortality risk (Site B)
WCS3	Laboratory technicians	NA	NA	NA	NA
WCS4	Maintenance and cleaning workers	2	6.00E-05	1	1.62E-06
WCS5	Incidentally exposed workers	2	2.65E-05	4	1.17E-05
Total		**11**		**9**	

Source: CSR Section 9.2.3
Note: Excess lung cancer risk refers to 40 years of occupational exposure

4.4.2.2 Humans via the environment

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.

The CSR takes into account measured data for emission to air and wastewater and provides estimates of the combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route. These estimates for both sites are presented.

Table 4-5: 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
Site A	1.22E-05	3.54E-07	6.03E-08	4.82E-11	3.54E-07
Site B	4.18E-07	1.21E-08	2.06E-09	1.65E-12	1.21E-08

a) RAC dose-response relationship based on excess lifetime lung cancer risk (ECHA, 2013): 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 (ECHA, 2013): 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.

Exposed local populations

Exposure to the general population can happen via the environment by means of inhalation and oral exposure. The relevant local population for humans via the environment has been estimated based on the location of the two sites and the estimated population within a 1000m radius[27].

The resulting estimates of the number of people exposed within the general population (rounded up to the nearest thousands) are given in **Table 4-6**.

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 4-6: Estimated exposed population by site	
Company/site	**Exposed local population within 1000m radius**
A	#C [redacted]
B	
Total EU	[redacted] **<40,000**

4.4.3 Residual health risks

4.4.3.1 Introduction

Under the continued use scenario, use of poorly soluble chromates for formulation of primers will continue after the end of the Review Period for a total of 12 years.

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[28]. 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.

4.4.3.2 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[29] cancer cases were derived from the Cancer Today database, see **Table 4-7** below.

27 Estimated using https://www.datadaptive.com/pop/

28 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).

29 Colorectum is taken as a proxy for intestinal cancer cases.

Table 4-7: Estimated incidence and mortality of cancers across the EU-27, 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: 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:

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

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

Since the dose-response relationship gives the incidence (instead of cancer mortality), the figures from Cancer Today reported in **Table 4-7** above are applied to the estimates to calculate the number of fatal and non-fatal intestinal cancer cases.

- 0.45 x total number of cases (fatal + non-fatal) = δ
- 0.55 x total number of cases (fatal + non-fatal) = η

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 estimated number of intestinal cases are found to be orders of magnitude lower than the number of lung cancer cases (for humans via the environment). Therefore, combined risk figures carried forward for valuation in the following sections.

4.4.3.3 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 are 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 SEG to calculate the total excess cancer cases arising from the continued use of poorly soluble chromates in formulation activities.

Table 4-8: Number of excess lifetime cancer cases to workers (Site A)				
WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	LUNG CANCER - Number of excess fatal cancer cases	LUNG CANCER - Number of excess non-fatal cancer cases
WCS1	2	1.74E-04	**3.48E-04**	**9.25E-05**
WCS2	5	5.28E-05	**2.64E-04**	**7.02E-05**
WCS4	2	6.00E-05	**1.20E-04**	**3.19E-05**
WCS5	2	2.65E-05	**5.30E-05**	**1.41E-05**
	Years - Lifetime	**40.00**	**7.85E-04**	**2.09E-04**
	Years - Review period	**12.00**	**2.36E-04**	**6.26E-05**
	Years - Annual	**1.00**	**1.96E-05**	**5.22E-06**

Table 4-9: Number of excess lifetime cancer cases to workers (Site B)				
WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	LUNG CANCER - Number of excess fatal cancer cases	LUNG CANCER - Number of excess non-fatal cancer cases
WCS1	2	8.67E-06	**1.73E-05**	**4.61E-06**
WCS2	2	2.34E-05	**4.68E-05**	**1.24E-05**
WCS4	1	1.62E-06	**1.62E-06**	**4.31E-07**
WCS5	4	1.17E-05	**4.68E-05**	**1.24E-05**
	Years - Lifetime	**40.00**	**1.13E-04**	**2.99E-05**
	Years - Review period	**12.00**	**3.38E-05**	**8.98E-06**
	Years - Annual	**1.00**	**2.81E-06**	**7.48E-07**

4.4.3.4 Predicted excess cancer cases with continued use: Humans via the environment

The total number of people exposed via the environment as given in **Table 4-10** is multiplied by the combined risk estimates to calculate the total excess cancer cases arising under the Continued Use scenario. The results are given in **Table 4-10**.

Table 4-10: Excess lifetime cancer risks for the general public (local assessment)					
Company/site	**Exposed population**	**Combined excess lifetime cancer risk**	**Number of excess cancer cases**	**Number of excess fatal cancer cases**	**Number of excess non-fatal cancer cases**
Company A	[redacted]	**3.54E-07**	[redacted]		
Company B		**1.21E-08**			
Total	[redacted] <40000				
	Years - Lifetime cases		**70.00**	**1.43E-03**	**3.79E-04**
	Years - Review period		**12.00**	**2.44E-04**	**6.49E-05**
	Years - Annual		**1.00**	**2.04E-05**	**5.41E-06**

4.4.4 Economic valuation of residual health risks

4.4.4.1 Economic cost estimates

In order to monetise human health impacts, a timeframe that goes from 2026 (inclusive of the end of 2026) to the end of 2038 (i.e., a 12-year review period) has been adopted and a 3.5% discount rate has been employed for calculating present values[30]. It has been assumed that the levels of exposure to Cr(VI) for workers and members of the general population remain 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 the 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[31] 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[32]. The values used are:

- Value of statistical life for the avoidance of a death by cancer: €3.5 million to €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[33]. This suggests that the aforementioned figures should be multiplied by a factor of 1.14. Thus, the following values are employed in the analysis below:

- Value of statistical life lower bound (mortality): €3.5 million × 1.14 = €3.97 million (rounded);
- Value of statistical life upper bound (mortality): €5 million × 1.14 = €5.68 million (rounded); and
- Value of cancer morbidity: €0.41 million × 1.14 = €0.47 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.

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

31 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.

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

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

Table 4-11: Alternative estimates of medical treatment costs			
Study	**Year for prices**	**Average direct costs in original units (per annum)**	**Direct costs in € 2021**
Lung cancer[34]			
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)[35]			
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 figures are high compared to the UK data; as a result, the average across the two UK studies is taken here, with this being around €14,295 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 5 years, 5% after 10 years[36]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after one year since diagnosis, 59% after five years, and 57% after 10 years. Based on these time periods, the Present Value (PV) of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 3.5% future discount rate. The PV 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.

An average of lung cancer and intestinal cancer treatment costs is used in the subsequent calculations.

[34] 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.

[35] 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.

[36] 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.

The values 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 calculations for the value of an excess cancer case are presented below:

- Fatal cases × € 3,970,000 + (fatal and non-fatal cases) × (€ 470,000 + (€ 30,840+€84,790)/2) = **Lower bound value of cancer cases**

- Fatal cases × € 5,680,000 + (fatal and non-fatal cases) × (€ 470,000 + (€ 30,840+€84,790)/2) = **Upper bound value of cancer cases**

These values are converted to GBP applying an exchange rate of €1:£0.897[37]. Taking into account the latency period of cancer after exposure, a 10-year lag is applied[38]. Not that this is a conservative assumption because 10 years is based on occupational lung cancer exposure. A longer lag (i.e., discounted more heavily) is more relevant to other types of cancers (e.g., intestinal cancer) and exposure of general population via the environment. In short, the cancer cases occur after the 10-year latency period for 12 years corresponding to the applied for review period.

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

The costs associated with mortality and morbidity are applied to the estimated annual number of excess statistical fatal and non-fatal cases for workers at the two sites undertaking formulation in GB. The annual human health costs are then discounted following a 10-year lag over a 12-year period, at a rate of 3.5%.

Table 4-12: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years 3.5% per year)

	Lower Bound		Upper Bound	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	2.69E-04	7.16E-05	2.69E-04	7.16E-05
Annual number of cases	2.24E-05	5.96E-06	2.24E-05	5.96E-06
Present Value (PV, in 2021 prices)	£620	£18	£855	£18
Total PV costs	**£639**		**£874**	
Total annualised cost	**£66**		**£90**	

4.4.4.3 Predicted value of excess cancer cases with continued use: humans via the environment

Due to the small number of cases estimated for intestinal cancer (orders of magnitude lower than the number of lung cancer cases for humans via the environment), all cases are assumed to have a 10-year latency period, and include medical costs considered for the average of lung and intestinal cancer

37 https://www.exchangerates.org.uk/EUR-GBP-spot-exchange-rates-history-2023.html#:~:text=Average%20exchange%20rate%20in%202023,GBP%20on%2011%20Jul%202023.

38 https://echa.europa.eu/documents/10162/17228/echa_review_wtp_en.pdf/dfc3f035-7aa8-4c7b-90ad-4f7d01b6e0bc

(on top of value of statistical life and value of cancer morbidity). This has been done to err on the side of overestimation.

The selected values for mortality and morbidity were applied to the estimated annual number of excess statistical fatal and non-fatal cancer cases amongst the general population. The annual human health costs are then discounted from year 10 over 12 years at a rate of 3.5%. The results are given in **Table 4-13** below, including the estimated number of cancer cases and associated costs in present value terms over the 12-year assessment period.

Table 4-13: Present value and annualised economic value of mortality and morbidity effects to HvE (discounted over 12 years 3.5% per year, 10 year lag)

	Lower Bound		Upper Bound	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	2.44E-04	6.49E-05	2.44E-04	6.49E-05
Annual number of cases	2.04E-05	5.41E-06	2.04E-05	5.41E-06
Present Value (PV, 2021)	£563	£17	£776	£18
Total PV costs	**£579**		**£794**	
Total annualised cost	**£60**		**£82**	

4.4.5 Human health impacts for workers at customers sites

The human health impacts associated with use of the primers at A&D sites in GB are assessed in each of the dossiers submitted by the ADCR for the three primer uses essential to the A&D sector.

4.4.6 Summary of human health impacts

Table 4-14 provides a summary of the economic value of the human health impacts across the worker and local populations. These estimates are specific to formulation activities relevant to primers used by the A&D sector at two sites in GB.

Table 4-14: Combined assessment of health impacts to workers and general population (discounted over 12 years 3.5% per year, 10-year lag, figures rounded)

	Lower Bound		Upper Bound	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	5.14E-04	1.37E-04	5.14E-04	1.37E-04
Annual number of cases	4.28E-05	1.14E-05	4.28E-05	1.14E-05
Present Value (PV, in 2021 prices)	**£1,183**	**£35**	**£1,631**	**£37**
Total PV costs	**£1,218**		**£1,668**	
Total annualised cost	**£126**		**£173**	

4.4 Environmental impacts

Releases to the environment are governed by, and comply with, local worker and environmental regulatory requirements. As a result, environmental impacts should be minimised under the continued use scenario.

Cr(VI) containing water mainly arises from using water for cleaning purposes. At both sites, contaminated water is collected and sent to an external waste management company (licensed contractor) for disposal. There is no emission of Cr(VI) to wastewater from the manufacture of primer products. The only exemption is a small volume of shower water from one site using StC (approx. 14 m^3 of water per year from a shower in the room where solid StC is handled): shower water is tested for its Cr(VI) concentration and reduced by ascorbic acid to ascertain a concentration <50 µg/L. The overall release to wastewater from this site is <1 g Cr(VI) per year.

Production facilities are equipped with local exhaust ventilation. Emissions are treated by abatement technology, consisting of particle filters.

Particle filters are checked and changed regularly. Used filters are collected and disposed by an external company certified for disposing hazardous waste.

5 Socio-Economic Analysis of the Non-Use scenario

5.1 The Non-Use Scenario

5.1.1 Overview

The inability of companies to undertake formulation activities across GB using one or more of the two poorly soluble chromates within scope of this review report would be severe. This use is critical to A&D industry as the resulting primers provide a range of key functions, including corrosion resistance (including active corrosion inhibition); Adhesion promotion; and compatibility with substrate. The primers are applied to a broad range of components and final products and cannot be substituted until alternatives are certified for use in the manufacture of those components and end products. They also cannot be substituted in maintenance, repair and overhaul activities until substitutes are certified for use in such activities and maintenance manuals are updated to this effect by A&D design owners.

It may be possible for A&D companies to import and use primer products formulated outside of GB, however, given that the poorly soluble chromates are contained in the primer products at concentrations of 50% or less (and in many cases significantly less) this would result in a significant increase in transport requirements. **Larger volumes of hazardous product would need to be imported and transported throughout GB** compared to the import of the chromate substances followed by the shorter distances involved in transport of the formulated primer products internally across GB. This would increase both transport and logistic costs. This is especially the case if the imported products would originate from the US, for example, to ensure that they met the stringent quality control requirements of the A&D sector.

These imported products would also trigger the need for new certification activities. Any change in the source of the chromate or in the manufacturing of the primers will result in the need for their use to be newly qualified and certified for the manufacture of components and in maintenance and repair activities, due to the stringent airworthiness and safety and reliability requirements that must be met by the A&D sector. Even if such certifications could be achieved within a few months for each component (or families of similar components), the fact that this would be required across thousands of components would make it infeasible for OEMs and DtB companies.

The outcome, therefore, would be a relocation where formulation using chromates is permitted by the OEMs and major DtBs of some or all of their parts production and aircraft manufacturing activities out of GB **to locations where qualified and certified alternatives are currently available.**

Further justification for this outcome is provided in the individual - AoA-SEA documents for use of the primer products submitted as part of other ADCR review reports.

5.1.2 Summary of effects across the value chain

The series of events that would be triggered by formulation no longer being authorised include the following (see overpage).

Formulation of Cr(VI)-based primer products in GB would cease.

The loss of such formulations would result in either relocation of manufacturing, maintenance and repair activities or the import of the chromate-based primer products.

The import of formulations would result in the need for new certifications due to potential changes in the source of the chromate or in manufacturing (and hence quality and other parameters).

Gaining new certifications across all components and products would take years and would not be technically or economically feasible for downstream users on top of substitution efforts.

As a result, the major OEMs would relocate significant portions of their A&D manufacturing activities to countries where certified primers are available. This would also disrupt the current R&D being undertaken jointly by the formulators with their A&D customers.

Due to qualification and certification requirements, suppliers to the OEMs in the A&D value chain would be forced to relocate activities involving use of Cr(VI)-based primers together with other manufacturing activities linked to those applications, or to shift to suppliers outside of GB where feasible (taking into account the fact that it would be costly to transport components and products outside GB for priming only, especially due to the need for rework and touch-up repairs.

MROs, which make up a significant percentage of users, would have to shift at least some (if not most) of their activities outside GB, as use of Cr (VI)-containing primers is an essential part of maintenance, repair and overhaul activities.

Relocation of MRO activities would cause significant disruption to the A&D sector itself as well as its customers.

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 other countries.

Civil aviation, passengers, freight shippers and emergency services would face reduced flight availability and routes, as well as increased costs.

5.2 Economic impacts of non-use

5.2.1 Introduction

This section summarises the expected quantitative and qualitative economic impacts for all applicants/formulators of products, downstream users, competitors, and end customers under the non-use scenario. The primary social impacts considered are job losses at the formulators resulting from a cessation of their activities. Job losses at downstream users' sites are not taken into account to avoid double-counting with those quantified for the three primer use dossiers.

5.2.2 Economic impacts on formulators

Under the Non-use scenario, GB based formulators of products would be impacted by the loss of sales and therefore profits associated with the primers containing StC and PHD.

As reported in Section 4.3.1, the economic value of the primers sold to the A&D industry is in the order of several hundreds of millions per annum with profit levels assumed to be at around 10% of these. The economic value of the primers over a 2[39] and 12-year period is given in **Table 5-1**. These figures should be treated as indicative; as profit margins may be greater than the assumed 10%, and market values of the primers have been averaged.

Note that the figures for the 12-year review period will represent an overestimate as they do not assume any decrease in use over the period from 2026 levels. Based on the development plans currently in place by the downstream users across the three primer uses reductions in use of the primers are already taking place and will increase over time as alternatives are qualified and certified for use in the manufacture, maintenance and repair of more and more components.

Table 5-1: Discounted value of sales and profits over 2 and 12 year periods (@ 3.5%) (UK)

	Tonnes used in 2022	Market value over 2 years	Profits over 2 years	Market value over 12-year period	Profits over 12-year period
Strontium chromate	[redacted] #B, C				
Potassium hydroxyoctaoxodizincatedichromate					
Totals					

The value of the associated profit losses to formulators under the non-use scenario based on the above illustrative analysis is marginal compared to the economic impacts on downstream users and their customers. This is the key reason why the ADCR members have financed and supported this review report; the driving economic value associated with the continued formulation of the primer products containing poorly soluble chromates is held by the downstream users.

Other economic costs may be incurred by the formulators, depending on whether or not authorisation is granted for the continued use of the chromates in the manufacture of formulations for non-A&D uses. Should formulation involving the chromates not be authorised for any uses, additional costs would be incurred from requirements regarding:

- Dismantling of existing equipment (decommissioning); and
- Site decontamination, including e.g. soil remediation costs.

39 https://echa.europa.eu/documents/10162/0/afa_seac_surplus-loss_seac-52_en.pdf/5e24c796-d6fa-d8cc-882c-df887c6cf6be?t=1633422139138

In addition to the above, the withdrawal of the formulated products from the market is likely to have an impact on the relationships between the formulators and A&D companies. This may result in the loss of market for other non-chromate-based products (where companies like to find a "one-stop" supplier) and may impact on joint R&D programmes currently in place involving the formulators and the A&D companies.

5.2.3 Economic impacts on downstream A&D users

The more limited economic impact on formulators compares to the billions in turnover and profits that would be lost under the non-use scenario to companies in the A&D sector, as well as to the disruption that would be caused to military forces in the EEA and UK reliant on the use of primers containing Cr(VI) in the maintenance, repair and overhaul of military (air, land and naval) equipment.

Shifting work involving primers containing Cr(VI) outside GB to locations where certified uses of the chromates can continue is the most plausible scenario for most OEMs, DtB companies and MROs; most of the larger companies already have existing supply chains in other countries.

It would not be possible for companies involved in manufacturing of components and final products (or divisions of some of these companies) to maintain manufacturing activities downstream of primer application inside GB, while transferring primer activities outside GB. This would result in huge numbers of transfers of components and products outside GB for rework or touch-up, which would not be economically feasible. Furthermore, given the reliance on the use of Cr(VI) primers in supply chains, it is also the most likely response for the divisions which rely on their suppliers.

Similarly, it would not be feasible for MROs to undertake only maintenance, repair and overhaul activities excluding use of Cr(VI)-containing primers in GB. When aircraft or equipment go in for repair and overhaul in particular, an MRO will have no clear idea of the full range of surface treatments that may be required; including the need for primer application. As a result, MROs will have to establish non-GB based sites that can undertake the full range of potential services involving the continued use of the primer products containing poorly soluble chromates.

The economic cost of moving manufacturing or maintenance and repair activities and creating new supply chains has not been estimated for the purposes of this SEA. However, the economic costs to GB from gross value added, turnover and profits have been estimated for the different primer uses. The figures are given in the combined AoA-SEA documents submitted to support the review reports submitted by the ADCR for the continued use of the primer products.

These figures highlight the enormity of the losses that would occur to the GB economy under the non-use scenario, due to the loss of the primers which are qualified and certified for use in the manufacture and maintenance of A&D components and final products before alternatives have gone through qualification and certification.

By way of example, **Table 5-2** presents the estimated lost profits (lower and upper bound) that would occur should all three primer uses no longer be authorised. These same losses would also occur should formulation of the primers used in these processes no longer be authorised. Note, that the figures cannot be combined, as companies will likely be using more than one primer type, and therefore be considered in figures for more than one primer type.

Table 5-2: Lost profits to A&D companies from a refused authorisation (2 years @3.5%)			
Primer type	**Relevant chromates[1]**	**Number of sites**	**Profit losses (2 years, lower and upper bound estimates)**
Profit losses in GB			
Bonding primers	StC	50	£145 to 3,476 million
Primer products other than wash and bonding primers	StC, PCO, PHD	130	£245 to 7,921 million
Wash primers	PCO, PHD	25	£166 to £245 million

As noted in the AoA-SEA documents supporting the primer uses, relocation is not economically desirable even if it is the most plausible result for OEMs and other A&D companies. This is because: the due diligence principle would continue to apply to supply chains but would be exacerbated in case of relocation out of GB; when activities are shifted to another site, there is an inevitable phase of technical and industrial qualification together with an assessment of technical capability to adhere to certification requirements (phases and timeframes as indicated in Figure 3-2); and once the qualification phase is over, it would be essential to get the right ramp up in order to meet manufacturing rate objectives.

Undertaking such activities would require huge economic investments that would significantly affect businesses and have severe detrimental economic impacts. As a result, companies would likely be forced to cease some manufacturing activities until new industrial facilities and infrastructure are in place and ready to operate outside of GB.

Particular difficulties would be faced by companies in the space and defence sectors. Possibilities for relocating some activities outside GB 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 GB. It would also have implications for the manufacture of hardware for the GB space industry, damaging its ability to remain independent.

5.2.4 Economic impacts on competitors

There would be few economic benefits for competitors to the current formulators (some of which are extensively involved in R&D with A&D companies) under the non-use scenario. The key constraints to the adoption of alternatives – whether alternative formulations, substances or techniques – are multi-fold and stem from the need for A&D companies to ensure that there is no reduction in performance from the adoption of an alternative. Alternatives must meet the strict performance requirements delivered by the chromates in the manufacture, maintenance, repair and overhaul of components and end products. As a result, A&D companies cannot adopt an alternative until it has gone through full R&D testing and development, been qualified, validated and certified.

Even then, an alternative must be implemented (i.e. industrialised) through the supply chain before competitors would realise any benefits under the non-use scenario. Such benefits would only be realised if the A&D industry did not relocate the use of primer products containing poorly soluble chromates to other regions where the current formulations could continue to be used.

As a result, no significant bringing forward of the use of alternatives compared to the continued use scenario is likely, leading to no significant economic benefits for suppliers of alternatives to the Cr(VI)-based primers.

5.3 Social impacts

5.3.1 Introduction

The primary social impacts considered here are the job losses that would result from a cessation of the formulation of the primer products used by the A&D industry in GB. The scale of these impacts associated with the loss of formulation specific to the production of primers for the A&D industry alone are likely to be small, but if taken together with the impacts on the downstream users of the primers could be quite significant.

This is discussed further below as part of the assessment of social impacts.

5.3.2 Methodology for monetary valuation of job losses

The Dubourg (2016) social cost methodology was used to calculate the estimated social costs of unemployment as recommended by ECHA. Costs of unemployment are calculated by adding up 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 the ratio of the social cost per job loss over the annual pre-displacement wage for GB to be 2.1.

The typical average salary adopted for employees involved in formulation activities is £50k per annum for GB and applied across all job losses. This figure is based on responses from formulators to the SEA questionnaire.

5.3.3 Calculation of direct job losses

Job losses would arise not just for those workers directly involved in formulation activities, but also workers involved in administrative roles associated with account management, distribution etc. of the final primers. As some of these roles may also be linked to other downstream uses, losses include those that would equate to less than a full time equivalent across the different sites.

The resulting estimates of the social costs of unemployment are given in **Table 5-3**. In total, approximately 20 jobs would be lost across the two GB sites involved in formulation, with the social costs of unemployment linked to formulation of primer products for the A&D sector alone equating to around £2. 10 million after a refused Authorisation. This figure is based on the directly exposed workers from the CSR.

Table 5-3: Job losses expressed as social costs of unemployment in GB

	Job losses	Social cost ratio	Average gross salary	Social costs of unemployment
Total Job losses	20	2.1	£50,000	£2,100,000

5.3.4 Wider indirect and induced job losses

Jobs would also be lost in GB due to the relocation of manufacturing and MRO activities within the A&D sector. The numbers of jobs lost could easily exceed 10,000 across companies involved in civil aeronautics, space, military and land and naval priming activities, given that these activities account for over 880,000 jobs in total. This is especially the case given that OEMs have indicated that their most likely response to the non-use scenario is relocation of manufacturing activities outside GB.

Indeed, data supplied by ADCR members, and their suppliers involved in primer activities indicates that over 5,000 jobs in GB would be lost if the use of primers not including wash or bonding were no longer available (Wash and bonding excluded to prevent double counting). Clearly these figures would increase if wash and bonding primers containing poorly soluble chromates were also no longer available, given some suppliers may be using only these primer types.

The economic impacts of the indirect job losses would therefore be enormous. The indirect effects associated with the loss of primers other than wash or bonding, for example, would be around £550 million for GB.

5.3.5 Summary of social impacts

To summarise, the social impacts that would arise under the non-use scenario include the following:

- Direct job losses: of 20 workers in GB involved in formulation and associated administrative activities linked to the primers used by the A&D sector;
- Social costs of unemployment: economic costs of around £2.1 million in GB due to direct job losses; and
- Indirect and induced unemployment at the regional and potentially national level for the A&D industry: impacts felt due to the relocation of priming and manufacturing activities, leading to tens of Pound billions in social costs in GB.

5.3.6 Wider economic impacts

5.3.7 Production of new aircraft

As noted in Section 4.3.2, demand for passenger and cargo air traffic is expected to grow into the future. 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. As a result, 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[40]. Similarly, Boeing's 2023 Commercial Market Outlook[41] indicates a similar level of increase, noting that the global fleet will increase by around 3.5% through to 2042.

Based on figures publicly 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

40 https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf

41 https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

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.

Under the non-use scenario, GB based A&D companies would no longer play a major role in meeting this demand for new aircraft, leading to losses in their contribution to gross value added and gross domestic product. As noted in Section 4.3.2, the European aerospace sector is a global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. However, unless operations in GB can remain technically and financially viable in the short to medium term, the ability of GB 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 GB with a consequent loss in GVA to the GB economy, with enormous impacts on employment.

Not only would the manufacture of new aircraft in GB 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 overhauled 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.

5.3.8 Impacts on airlines

Under the non-use scenario, the unavailability of the primer products containing poorly soluble chromates would have a significant impact on the ability of GB-based MROs to undertake repairs and to follow normal maintenance and overhaul schedules. MROs are legally bound to adhere to the requirements set out in OEMs' manuals to meet airworthiness and military safety requirements. Where maintenance or overhaul activities would require use of the primers containing poorly soluble chromates, these would now have to be performed outside GB until the OEMs had gained approvals and certifications for use of alternatives and had adapted the manuals setting out maintenance, repair and overhaul instructions.

When an aircraft needs repairs (i.e., flightline or "on-wing" repairs), it will be grounded at an airport until these take place due to airworthiness constraints. This would result in Airplanes on the Ground (AOGs) and could result in an aircraft having to be towed outside GB for repairs, with dramatic financial and environmental impacts.

If MRO facilities relocate outside GB, airlines may also experience additional delays to routine aircraft maintenance due to capacity constraints at MRO facilities located outside GB. Indeed, it may take some time to build up capacity to accommodate additional demand from GB-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 hardware 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 GB 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-GB MRO facilities and back. The impacts for larger craft 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 and would take slightly less than four hours. For an airline which has 50 aircraft requiring an annual "D check" (heavy maintenance inspection of most parts, 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 EU passenger aircraft fleet, which stands at approximately 6,700, suggests lost revenues in the tens of millions per annum just due to the need for around 700 aircraft to have 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.

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 €500 per customer; the revenue lost due to being 'out of action' for one day amounts to €175,000. In addition, the leasing costs alone of a plane being out of service is roughly $17,000 per day (based on a leasing cost for a large passenger jet of around $500,000/month).

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 knock-on effects for GDP and jobs due to planes being out of service for longer.

As illustrated in **Figure 5-1** below, the trend in air transport is for growth to occur at an average rate of over 4.0% per annum over the next 20 years. A 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.

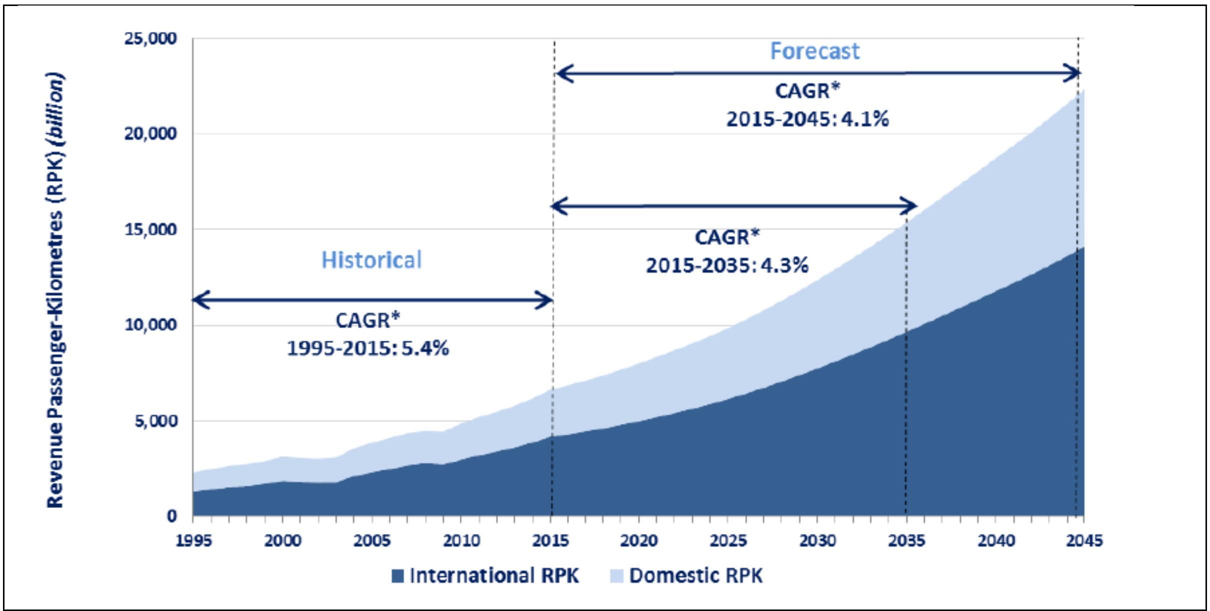

Figure 5-1: Forecast compound annual growth rates – Revenue Passenger-kilometres

The growth rate in Europe is expected to be lower at a compound annual growth rate of about 3.3% for total traffic[42] (covering inter-regional and intra-regional/domestic) for the period between 2018 to 2038. Achieving this level of growth in EU air traffic, together with the jobs and contributions to GDP that it would bring, would be impacted under the non-use scenario due to the inability of MROs to undertake repairs and carry out maintenance using the formulated primer products containing poorly soluble chromates.

No quantitative estimate on the level of impact can be provided, but it is clear that the closure of EU-based MRO operations would impact on the availability of aircraft and, hence, passenger and freight transport until substitution has taken place in the manufacture of components and in their maintenance and repair (unless airlines responded by buying more planes or stockpiling of parts, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

5.3.9 Defence related impacts

Defence related impacts under the non-use scenario would have two dimensions: impacts on air forces/military forces; and impacts on companies acting as suppliers to air forces/military forces.

Three national Ministries of Defence (MoDs – two in the EU and the UK MoD) have provided direct support to the ADCR out of concern over the impacts that non-Authorisation of the continued use of the chromates would have on their activities. In addition, MROs providing services to a further two MoDs located in the EEA and UK have supported the ADCR to ensure that they are able to continue to maintain and repair military aircraft, land and naval equipment into the future. The implications of having to cease these activities are significant. Aircraft (planes and helicopters) 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 and their "mission readiness".

It is also worth noting that Governments may be unwilling to send military aircraft to MRO facilities located in non-EU countries, although the US, Canada and Turkey are NATO members, and as such may be suitable candidates to service European military aircraft.

With respect to companies in the European defence sector, these represent a turnover of nearly Euro 100 billion and make a major contribution to the wider economy. 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. According to an external evaluation of the European Union's Seventh Framework Programme, through short-term leverage effect and long-term multiplier effects each €1 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[43].

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42 https://www.statista.com/statistics/1094689/annual-growth-rate-air-passenger-traffic-europe/

43 https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

If the manufacture and servicing of military aircraft and other derivative defence products was to move out of GB under the non-use scenario, as indicated by OEMs and the major Design-to-Build companies as the most likely response, then these multiplier effects would be lost to the GB economy. In addition, the ability of GB to benefit from some innovations and technological advances ahead of other countries could be lost, if the shift in manufacturing remains permanent and extends to new products.

5.4 Combined impact assessment

Table 5-4 sets out a summary of the societal costs associated with the non-use scenario.

Table 5-4: Summary of societal costs associated with the non-use scenario		
Description of major impacts	**Monetised / quantitatively assessed / qualitatively assessed impacts**	
Monetised impacts	**PV @ 3.5%, 12 years**	**£ annualised values**
Producer surplus losses to formulators due to non-authorisation of formulation using the two chromates	#B [redacted] (<£5 million)	[redacted] (<£1 million)
Producer surplus losses to A&D companies due to loss of primers based on the chromates	A&D companies: not monetised but £ billions Extensive disruptions expected even if switching formulations is possible, due to requalification and recertification requirements	
Remediation / decommissioning costs	Not quantified as formulation for other sectors may continue	
Loss of residual value of capital	Not quantified as formulation for other sectors may continue	
Social cost of unemployment: workers in A&D sector only[1]	20 workers	
	£2.1 million	£0.22 million
Spill-over impact on surplus of alternative producers	Not assessed due to role that certification plays in the technical feasibility of alternatives to A&D customers of the formulators	
Sum of monetised impacts	[redacted] (<£10 million)	[redacted] (<£2 million)
Additional qualitatively assessed impacts		
Impacts on formulators	Impacts on R&D into alternatives, potentially broader mixture supply relationships with A&D companies	
Impacts on A&D sector	Impacts on R&D, manufacturing and MRO services carried out by the A&D sector, including lost profits, unemployment, and an inability to service future growth in demand; impacts would affect the entire value chain	
Civilian airlines	Wider economic impacts on civil aviation, including loss of multiplier effects, impacts on airline operations, impacts on passengers and freight shippers, including flight cancellations, prices, etc.	
Ministries of Defence	Impacts on the operational availability of aircraft and military equipment, premature retirement of equipment, impacts on mission readiness	
GDP of UK	Impacts on the contribution of the A&D sector to GDP growth and employment into the future, as well as innovation and the adoption of new technologies	

[1] Employment costs for downstream users are not considered here and can be found in the dossiers for Uses 1 to 3.

6 Conclusion

6.1 Steps to identify potential alternatives

At the formulation stage, the chromates have no (separate) function, hence no analysis of alternatives can be provided. The functions played by the primers developed for use by the A&D sector are described in the review reports submitted for the three primer uses listed in Section 2.3 and Section 6.6.

These review reports for each of the primer uses also identify the candidate alternatives and detail their current availability, taking into account their technical feasibility and economic feasibility and the need for alternatives to be qualified and certified for use in the manufacture, maintenance and repair of alternatives.

Development plans are also provided for each of the uses based on the R&D, testing, qualification and certification work currently underway by the major design owners, i.e. the OEMs and DtBs that set the performance requirements that must be met in order to ensure the airworthiness, safety and reliability of components and end products.

6.2 Comparison of the benefits and risk

6.2.1 Comparison between the benefits and risks

The requested review period for the continued use of the two chromates in formulation activities is 12 years for use in GB. This requested period is linked to the longest period requested in review reports submitted to support the continued authorisation of the downstream primer uses that rely on use of the primers produced by the relevant formulation activities.

Table 6-1 summarises the socio-economic benefits of continued use of the two chromates in the formulation of primers for use by the aerospace and defence sector. Overall, net benefits of between ca. [redacted] #B (<£10 million) can be estimated for the continued use scenario and a benefit-to-risk ratio of over [redacted] #C (more than 1000) (Present Value social costs over 2 years/risks over 12 years, @3.5%) can be obtained. These figures do not include the economic value associated with the ability of downstream users in the A&D industry to continue manufacturing, maintaining and repairing A&D components and final products; nor do they account for the value to military forces of the continued availability of the Cr(VI) primers within scope of this review report.

It should be recognised that the social costs of non-Authorisation would be much greater than the monetised values reported above, due to the severe direct consequences that this would have for downstream users in the A&D sector and military forces, and the follow-on effects for civil aviation, passengers, freight shippers, emergency services, tourism, etc.

Table 6-1: Summary of societal costs and residual risks			
Societal costs of non-use (12 years @3.5%)		**Risks of continued use (12 years @3.5%, 10 year lag in health effects)**	
Profit losses to applicants	Losses from reduced sales of the chromate substances and associated formulations: GB: [redacted] #B (<£5 million)	Health risks to workers at formulation sites	£639-£874
		Health risks to general population	£579-£794
Profit losses to A&D companies	GB: £ billions due to relocation *See other ADCR review reports*	Monetised excess risks to exposed A&D workers *See other ADCR review reports*	
Social costs of unemployment	Lost jobs GB: 20		
	Social costs GB: £2.1 million		
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 UK; premature redundancy of equipment leading to increased materials use.		
Summary of societal costs of non-use versus risks of continued use	- NPV (societal costs minus residual health risks): [redacted] #B (<£10 million) - Ratio of societal costs to residual health risks: ○ [redacted] #C (more than 1000:1)		

6.3 Information for the length of the review period

6.3.1 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) (ECHA, 2013)[44]:

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*

[44] Note that in a recent version of the SEAC's recommendation on review period (March, 2024), it is suggested that SEAC evaluates the review period needed for the downstream uses and typically the same period for the formulation use is justified.

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.*
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 (as described in section 3.1.2) 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*".

6.3.2 Criterion 1: Demonstrably Long Investment Cycle

The continued requirement for formulation of primer products containing the poorly soluble chromates is driven by the stringent requirements placed on the A&D industry to ensure the airworthiness, safety and reliability of their products. These requirements are part of the reason for the long investment cycles within the industry, which in turn impact on the continued demand for use of the primer products containing poorly soluble chromates in manufacturing, maintenance, repair and overhaul activities. The average lifespan of a civil aircraft is typically 20 to 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 product lifespans and long investment cycles mean that it may not be feasible to carry out all of the tests required to qualify and certify a substitute, due to the level of investment and costs that would be involved in such an activity, as it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/piece of equipment).

An aircraft is a complex system involving not only design of the device, but also its use and maintenance history in varied climates and service. Every single part needs to be designed and manufactured with serious attention and care. In such a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated but also some that are not anticipated. The parts in an aircraft or piece of military equipment need to be adjusted to each other very precisely at the manufacturing level, as well as the design level. As a result, very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where small changes are 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 an alternative, whether a mixture, substance or technique, it may take up to seven years to roll out the use of a substitute across the industry due to the scale of the investment required and the need for OEMs to undertake their own qualification of different suppliers.

Ministries of Defence do not revise specifications for older equipment, which must nevertheless be maintained and repaired. MROs servicing military equipment therefore have to undertake any maintenance or repairs in line with the OEMs' original specifications, which means in line with any primers specified for use in maintenance or repairs. 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 primers containing poorly soluble chromates in the production of spare parts and in the maintenance of those spare parts and the assemblies and aircraft/equipment they are used in.

As such, a review period of at least 12 years is warranted and requested for the continued use of the three poorly soluble chromates in formulation, given the highly complex systems that are dependent upon their use.

6.3.3 Criterion 2: Cost of moving to substitutes

Modern commercial aircraft in their entirety consist of between 500,000 to 6 million parts, depending on the model. Depending on the materials of construction, 15 to 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) 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 parts protected from corrosion by formulated primer products containing chromates. On the other hand, there is still limited experience with Cr(VI)-free products on parts. It is mandatory that parts treated with a Cr(VI)-free alternative are demonstrably every bit as safe as they had been when treated with a Cr(VI) product. Flight safety is paramount and cannot be diminished in any way.

Where possible, and for specific parts and products, some new designs have been able to utilise newly developed alloys that do not require a Cr(VI) treatment (as typically used to provide corrosion protection on metallic legacy parts). However, even in newer designs there may still be a need for the use of Cr(VI) primers which cannot be replaced at present due to safety considerations.

6.3.4 Criteria 3 and 7: Results of R&D on alternatives and availability of alternatives over the longer term

Corrosion prevention systems are critical to aircraft safety. Testing 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 aerospace and defence industry is the almost unique challenge of obtaining relevant long-term corrosion performance information. In some cases, requires testing of changes in a system of corrosion protection, which includes changes in surface pre-treatments and treatments as well as primer products.

A&D companies cannot apply a less effective corrosion protection system as aviation and defence substantiation procedures demand alternatives to be equal or better. If such performance is not achieved, then the alternatives cannot be used. The implications of changes in primers for repair, replacement and overhaul must also be understood before moving to an alternative. In particular, it must be recognised that the performance delivered by one part is dependent upon the performance of other parts; thus, the performance delivered by an assembly is dependent upon the sub-assemblies used and in turn the components used in the sub-assemblies. The number of configurations of component and sub-assemblies is immense and each configuration may differ from the next in terms of its behaviour with a Cr(VI)-free alternative.

6.3.5 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 alternatives by 2038; their current development plans are designed to ensure they achieve TRL9 and MRL10 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 2038.

Several ADCR members note that most military procurement agencies require that all key components of defence equipment “shall be” produced within the European Union as a precondition. Thus, in contrast to other industry sectors, shifting production to a non-UK/non-EU territory and import of finished surface treated parts or products into the UK/EU is not a feasible option, as it would create a dependence on non-EU suppliers in a conflict situation.

They also note that 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 primer products if the renewal of the applicants’ authorisations was not granted. While a national Ministry of Defence might issue a defence exemption out of its own interest, military equipment production processes may require the use of primers containing poorly soluble chromates 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 EU defence sector requires only small quantities of the primer products containing poorly soluble chromates. On the basis of a defence exemption alone, the quantities demanded would not be sufficient for formulators and applicators of primer products to continue to offer their services and products. As a result, primer use for military aircraft and equipment would not continue in the UK if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

6.3.6 Criterion 5 and 6: Comparison of socio-economic benefits and risks to the environment and effective control of the remaining risks

The European and UK aerospace and defence industry – including the formulators servicing it – 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) 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. 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. Boeing's 2023 Commercial Market Outlook indicates a similar level of increase, noting that the global fleet will increase by around 3.5% through to 2042.

As noted in Section 4.3, it is also expected that spending on defence equipment will increase in the future due to renewal of NATO members to meeting the target of spending 2% of GDP on defence. This increase in investment will equate to hundreds of billions of Euros (e.g. Germany alone has pledged €100 billion in defence spending) by the UK and EEA countries.

The socio-economic benefits of the continued use of chromates in the formulation of primer products, enabling the key manufacturing base of the UK and EEA aerospace and defence industry to be maintained, are clearly significant; they will be the major beneficiaries of the growth in demand for civil aviation products as well as defence equipment.

6.4 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 chromates in primer products carried out by the A&D industry. This series of Review Reports has adopted a narrower definition of uses original Authorised under the CCST and GCCA parent applications for authorisation. Please see the Explanatory Note for further details.

In total, the ADCR will be submitting 4 Review reports covering the following uses and the continued use of strontium chromate, potassium hydroxyoctaoxodizincate dichromate, and pentazinc chromate octahydroxide:

1) Formulation
2) Use of wash primers
3) Use of bonding primers
4) Use of primers other than wash or bonding

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Annex 1: European Aerospace Cluster Partnerships

Table A1-1: 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	
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

Table A1-1: European Aerospace Clusters					
Cluster Name	**Country**	**City**	**Number of Companies**	**Employees**	**Sales/turnover**
International Aviation Services Centre (IASC)Ireland	Ireland	Shannon	60	46000	3.6bn GVA
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
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
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 2: Instructions on how to document confidential and public information

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Table A2-1: Justifications for confidentiality claims			
Reference type	**Commercial Interest**	**Potential Harm**	**Limitation to Validity of Claim**
[redacted]			