ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Complete version

Legal name of applicant(s):	Boeing Distribution (UK) Inc. Henkel Ltd
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Substance:	Strontium Chromate
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Use number:	1

Note

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

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Abbreviations

ADCR – Aerospace and Defence Chromates Reauthorisation

A&D – Aerospace and Defence

AfA – Application for Authorisation

AoA – Analysis of Alternatives

AoG – Aircraft on the Ground

BCR – Benefit to Cost Ratio

BtP – Build-to-Print manufacturer

BSI – British Standards Institution

CAA – Civil Aviation Authority

CAGR – Compound Annual Growth Rate

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CFC – Consumption of fixed capital

CMR – Carcinogen, Mutagen or toxic for Reproduction

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium Trioxide Authorisation Consortium

DOA – Design Organisation 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

GB – Great Britain

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross Domestic Product

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

NSS – Neutral salt spray

NUS – Non-use scenario

OELV – Occupational Exposure Limit Value

OEM – Original Equipment Manufacturer

ONS – Office for National Statistics

PAA – Phosphoric Acid Anodization

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

SEG – Similar exposure groups

SIC – Standard Industrial Classification

SME – Small and medium-sized enterprises

StC – Strontium Chromate

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

TRL – Technology Readiness Level

UK – United Kingdom

WCS – Worker Contributing Scenario

Glossary

Term	Description
Active Corrosion Inhibition	The ability of a corrosion protection system to spontaneously 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.
Bondline corrosion	Delamination in the adhesive bondline initiated by the combined effect of corrosion and mechanical load. Bondline corrosion starts at edges and holes.
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 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).

Term	Description
Gross Domestic Product (GDP)	The standard measure of the value added created through the production of goods and services in a country during a certain period. As such, it also measures the income earned from that production, or the total amount spent on final goods and services (less imports).
Gross Operating Surplus	Equivalent to economic rent or value of capital services flows or benefit from the asset.
Gross Value Added	The value of output less the value of intermediate consumption; it is a measure of the contribution to GDP made by an individual producer, industry or sector.
Hardness	Ability of a material to withstand 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.
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[1]	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), 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 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.

[1] *The use name 'Primer products other than wash or bonding primers' is condensed to the term 'protective primers'. This encompasses one or more of the various forms of this primer use; basic, structural, fuel tank and aluminised. 'Protective primers' are covered by another ADCR application, i.e. not in this application.'*

Term	Description
Test candidate	Materials which have been accepted for testing or are currently undergoing testing by a design owner, as a part of the substitution process. In the parent applications for authorisation, this was referred to as a 'candidate alternative'.
Type Certificate	Document issued by an Airworthiness Authority certifying that an Aerospace product of a specific design and construction meets the appropriate airworthiness requirements.
Validation	Part of the substitution process following Qualification and preceding Certification, to verify that all materials, components, equipment, or processes meet or exceed the defined performance requirements.
Value of statistical life	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 bonding primers[2] 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.

1.2 Availability and suitability of alternatives

For the past several decades, ADCR members who are "design owners" (including Original Equipment Manufacturers (OEMs) and Design-to-Build (DtB) manufacturers) selling products used in civil and military aviation, space industries and others involved in producing, maintaining, or using military material for land, naval or aerospace use have been searching for alternatives to the use of strontium chromate for bonding primers as a specific use. At the current time, the remaining uses form a part of an overall system providing the following key functions (see also Section 3.1.1.1):

- Corrosion resistance (including active corrosion resistance); and
- Adhesion promotion

[2] Review Reports are also being submitted by the ADCR covering three other uses of the chromates in formulation and other primer-types as more narrowly defined by the ADCR.

Other factors to consider include a variety of performance requirements in addition to the above key functions, see Section 3.2.1.1, which need to be taken into account when assessing test candidate alternatives.

Cr(VI)-based bonding primers are corrosion inhibiting coatings of liquid consistency. These are applied most commonly to metal substrates which have undergone prior surface treatment, such as anodising, as a thin layer which converts into a solid, adherent, and tough film that provides adhesion promotion and active corrosion inhibition. Corrosion of metal surfaces can be influenced by a broad variety of factors, such as temperature, salinity of the environment, industrial environment, and component location. A&D products operate in highly challenging, extreme environments over extended timeframes. Due to these challenges, alongside engineering-based solutions, the A&D industry must use numerous high-performance mixtures which have passed through an extensive approval process to demonstrate their suitability for use.

OEMs (as design owners), in particular, have responsibility for certification of alternatives and have conducted a full analysis of their requirements into the future, taking into account progress of research and development (R&D), testing, qualification, certification and industrialisation activities. Companies are at different stages in the implementation of alternatives. Obtaining such certification across hundreds of components is a time-consuming and costly process, given the strict testing regimes that must be adhered to achieve the qualification, validation and certification of components using an alternative. At the sectoral level, therefore, and to ensure the minimisation of supply chain disruption and associated business risks, a 12-year review period is requested. Business risks arise from the need for alternatives to be available and deployed across all components and suppliers to ensure continuity of manufacturing activities across the supply chain. A shorter period could cause uncertainty impacting the functioning of the current market, given the complexity of supply chain relationships.

Maintenance, repair, and overhaul (MRO) activities face additional constraints when implementing test candidates. This is because they are mandated to continue using the chromate primers if this is specified in Maintenance Manuals provided by the OEMs. This means they are legally obliged to carry out their activities in line with these Maintenance Manuals given their importance in maintaining the airworthiness and reliability of final products. Consequently, MROs cannot implement or adopt test candidates until OEMs have updated their Maintenance Manuals.

A number of test candidates have been developed and evaluated over decades in an effort to substitute Cr(VI)-based corrosion inhibitors in bonding primers for the A&D sector. Candidates shortlisted as potential alternatives to Cr(VI) in bonding primers for the A&D sector, include pH-buffering additives, phosphate-based and silane-based coatings, as well as blends of two or more of these chemistries in proprietary formulations. While the status of test candidates has progressed since the submission of the parent applications for authorisation (AfAs), none have yet been identified which would constitute a generally suitable and available alternative to Cr(VI) in bonding primers for the A&D sector. Key reasons for failure of test candidates have been an unacceptable regression in performance compared to the incumbent Cr(VI)-based bonding primer treatments, particularly in provision of corrosion resistance and adhesion promotion.

As a result of the different requirements outlined above, at the sectoral level, there will be an on-going progression of the test candidate alternate development and substitution over the requested 12-year review period.

1.3 Socio-economic benefits from continued use

The continued use of strontium chromate in bonding primers specifically over the review period will confer significant socio-economic benefits to ADCR members, their suppliers and to their end customers which include civil aviation, the military, space, emergency services. It will also ensure the continued functioning of the aerospace and defence supply chains in GB, conferring the wider economic growth and employment benefits that come with this.

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

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

- OEMs will be able to rely on the use of chromates by their GB suppliers and in their own production activities. The avoided profit losses[3] to these companies under the continued use scenario would equate to between £49 and 859 million, over a 2-year period (PV discounted at 3.5%). These figures exclude the potential profits that could be gained under the continued use scenario from the global increase in demand for air transport;

- Build-to-Print (BtP) and Design-to-Build (DtB) suppliers would be able to continue their production activities in GB and meet the performance requirements of the OEMs. The associated profit losses that would be avoided under the non-use scenario for these companies are calculated at £102 to 406 million over a 2-year period (PV discounted at 3.5%);

- MRO companies which provide maintenance and repair services to both civil aviation and/or military forces, would be able to continue operating within GB, with the consequent profit losses avoided equating to £5 million over a 2-year period (PV discounted at 3.5%);

- Continued high levels of employment in the sector, with these ensuring the retention of highly skilled workers paid at above average wage levels. From a social perspective, the benefits from avoiding the unemployment of workers involved in bonding primers are estimated at £271.11 million. These benefits are associated with the protection of over 2,700 jobs in GB;

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

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

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

[3] Two different approaches have been used to calculate economic impacts to produce lower and upper bound estimates. Profit losses are discounted over two years at 3.5% per annum.

The level of disruption caused to A&D customers and society in not being able to continue priming activities would outweigh the monetary losses to these companies and its value chain including OEMs, DtBs, BtP suppliers, MROs, and MoDs.

1.4 Residual risk to human health from continued use

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

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

Risks to workers have been estimated based on the use of exposure monitoring data, supplemented by modelling data as appropriate. Across the 50 GB sites where chromate-based bonding primers are anticipated as being used, an estimated total of 3,340 workers may be exposed to Cr(VI).

Exposures for humans via the environment have been calculated for the local level only. Based on the population density of GB within which use of bonding primer is considered to take place, an estimated 432,368 people in GB are calculated as potentially being exposed to Cr(VI) due to chromate-based bonding primer activities. Again, these figures are conservative due to the on-going substitution of bonding primers with alternatives.

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[4]:

- GB: 1.20 statistical fatal cancer cases and 0.10 non-fatal cancer cases, over the 12-year review period, at a total social cost of £370,529 to £450,866 per year.

1.5 Comparison of socio-economic benefits and residual risks

The ratios of the total costs of non-Authorisation (i.e. the benefits of continued use) to the residual risks to human health are as follows for GB:

- GB: 124 to 1 for the lower bound of profit losses and unemployment costs or 445 to 1 for the upper bound profit losses and unemployment costs;

The above estimates represent a significant underestimate of the actual benefits conferred by the continued use of strontium chromate (StC) in bonding primers, as it only encompasses benefits that

[4] Discounted over 12 years at 3.5% per annum, and assuming a 10-year lag in effects.

could be readily quantified and monetised. The true benefit-cost ratios must be assumed to also encompass:

- The significant benefits to civil aviation and military customers, in terms of flight readiness and military preparedness of aircraft and equipment;

- The avoided impacts on air transport – both passenger and cargo – across GB 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 within the applicants supply chain as part of the granting of the parent authorisations. The A&D industry has responded to these requirements by increasing the level of monitoring carried out, 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 Chemical Safety Report (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.

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

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

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

The ADCR's requirements for continued use meet the criteria set out by the ECHA Committees for Authorisation review periods longer than normal (7 years), as follows:

- **The applicants' downstream users face investment cycles that are demonstrably very long,** as recognised in various European Commission reports[5,6]. Final products in the A&D sector can have service lives of over 50 years (especially military equipment). While there are examples of contracts to produce components for out-of-production final products extending as long as 35 years beyond the last production date of the final product. MROs and MoDs, in particular, require the ability to continue servicing older, out-of-production but still in-service, aircraft and equipment. The inability to continue servicing such final products will not only impact upon civil aviation but also emergency vehicles and, importantly, on operationally critical military equipment. Thus, although new aircraft and military equipment designs may draw on new materials where approved and may represent a shift away from the need for the chromates in bonding primers, 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, not necessarily due to the cost of the alternative substances but due to the strict regulatory requirements that must be met to ensure airworthiness and safety**. These requirements mandate the need for testing, qualification, and certification of components using the alternative bonding primers. This process must be carried out on all components and then formally implemented through changes to design drawings and Maintenance Manuals. In some cases, this requires retesting of a final product for extensive periods of time, which is not only costly but may also be infeasible (due to the age of the final product, lack of testing facilities, age of available test vehicles (engines, aircraft, defence equipment, etc.)). On a cumulative basis, the major OEMs and DtB companies that act as the design owners could not undertake action across the range and number of components that still require the qualification, certification and industrialisation of alternatives without sufficient time and resources. These activities themselves are costing the companies hundreds of millions of Euros across all uses of Cr(VI).

- **The strict regulatory requirements that must be met generate additional, complex requalification, recertification, and 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 bonding primers, which can be considered to be "generally available" following the European Commission's definition[7]. The A&D industry has been undertaking R&D into alternatives for the past 30 years. This includes participation in research initiatives partially funded by the European Commission and national governments. Considerable technical progress has been made in developing, validating, qualifying and

[5] https://www.europarl.europa.eu/RegData/etudes/STUD/2022/699651/IPOL_STU(2022)699651_EN.pdf

[6] https://www.easa.europa.eu/en/downloads/17236/en

[7] 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)

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. Although some companies have been able to qualify and certify alternatives for some of their components, others are still in the early phases of testing and development work due to alternatives not providing the same level of performance as chromates. They will not be able to qualify and certify a proposed or test candidate for some components within a seven-year time frame. It is also of note that bonding primers are used throughout the supply chain and by large numbers of smaller suppliers. As a result, sufficient time will be required to fully implement alternatives through the value chain once they have been certified.

- Even then**, it may not be feasible for MROs to move completely away from the use of the chromates in bonding 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 components or military hardware. The corresponding timescale for carrying out such updates varies and there can be significant delays while OEM/MoDs ensure that substitution has been successful in practice. In this respect, **it is important to note that the use of the chromates is required to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the UK level, EU level and in a wider field, e.g., with NATO**.

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

- As highlighted above and demonstrated in Section 5, **the socio-economic benefits from the continued use of strontium chromate in bonding primers significantly outweigh the risks of continued use.** The European A&D sector is a major exporter of final products and is facing a growing market for both its civilian and defence products which it can only serve if it retains its current strong industrial and supply chain base in GB. It will not be able to respond to this increased market demand if the continued use of chromates in bonding primers 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, but also that it meets requirements in other jurisdictions to ensure that its final products can be exported and used globally.

2 Aims and Scope of the Analysis

2.1 Introduction

2.1.1 The A&D Chromates Reauthorisation (ADCR) Consortium

This review report covers the use of strontium chromate in bonding primers by the ADCR consortium members and companies in their supply chain. Bonding primers (sometimes referred to as adhesive bonding primers) provide corrosion resistance and promote and maintain adhesion between a substrate and an adhesive material.

The use of strontium chromate in bonding primers is limited to those situations where it plays a critical (and currently irreplaceable) role in ensuring components meet product performance, reliability, and safety standards. In particular, those relating to airworthiness set by 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 also comply with numerous other requirements including those of the European Space Agency (ESA) and of national MoDs.

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

As a result, the analysis presented here is based on an extensive programme of work funded and carried out by the main OEMs and DtBs, and key suppliers where this includes small, medium, and other large actors within the sector. It is based on sector-specific data and detailed information obtained from the ADCR members (which includes OEMs, DtBs, BtPs, MROs, and MoDs) and collected from their A&D suppliers throughout the supply chain. In total, data was collected from companies covering over 45 A&D sites in GB, with data for 12 of those sites that use bonding primers used in developing this combined AoA/SEA.

2.1.2 Aims of the combined AoA and SEA document

The downstream users supporting the ADCR consortium have no qualified (from a technical perspective) and economically feasible alternatives which can be fully implemented across all products, components and MRO processes before the expiry of the original authorisations. They must continue to use strontium chromate in bonding primer application carried out within GB, as it is fundamental to preventing corrosion of A&D components and final products. It forms part of an overall surface treatment and coating system, aimed at ensuring the compulsory airworthiness requirements of aircraft and the safe and reliable operation of military equipment.

Although the A&D sector has been successful in implementing alternatives for some components with less demanding requirements, the aim of this application is to enable the continued use of strontium chromate in bonding primers beyond the end of the existing review period which expires 22 January 2026, for the processes where suitable alternative identification, through to implementation has not yet been successful. It demonstrates the following:

- The technical and economic feasibility, availability, and airworthiness (i.e., safety) challenges in identifying an acceptable alternative to the use of strontium chromate which does not compromise the functionality and reliability of the components to which bonding primers are applied, and which could be validated by OEMs and gain certification/approval by the relevant aviation and military authorities across the globe (Section 3.1.2);

- That R&D that has been carried out by the OEMs, DtBs and their suppliers towards the identification of feasible and suitable alternatives to strontium chromate in bonding primers. These research efforts include EU funded projects and initiatives carried out at a more global level, given the need for global solutions to be implemented within the major OEMs' supply chains (Section 3.4);

- The efforts currently in place to progress proposed candidate alternatives through Technology Readiness Levels (TRLs), Manufacturing Readiness Levels (MRLs) and final validation/certification of suppliers to enable final implementation. This includes the 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 out-of-production civilian and military aircraft and other defence systems (Section 3.5);

- The socio-economic impacts that would arise for ADCR downstream users and their suppliers, downstream supply chains and, crucially, for GB more generally, if the applicants were not granted re-authorisations for the continued use of the chromates over an appropriately long review period (Section 5); and

- The overall balance of the benefits of continued use of the chromates and risks to human health from the carcinogenic and repro-toxic effects that may result from exposures to the chromates (Section 4).

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

2.2 The Parent Applications for Authorisation

The chromate identified from previous Applications for Authorisation (AfA), associated with this primer-type is:

- Strontium chromate EC 232-142-6 CAS 7789-06-2

Strontium chromate (Entry No. 29) has been included in Annex XIV of Regulation (EC) No 1907/2006 under Article 57(a) as it is classified as carcinogenic (cat. 1A).

Strontium chromate was previously granted authorisations for use in bonding primers across a range of applicants. **Table 2-1** summarises the parent AfAs:

Table 2-1: Overview of initial parent applications for authorisation					
Application ID	**Substance**	**CAS #**	**EC #**	**Applicants**	**Use name**
0117-01/ 33UKREACH/20/12/0, 34UKREACH/20/12/2	Strontium chromate	7789-06-2	232-142-6	Various applicants (GCCA consortium)	Use of strontium chromate in primers applied by aerospace and defence companies and their associated supply chains

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Cr(VI)-based bonding primers are specified within the A&D sector primarily because they provide maximum adhesion both to the substrate and to subsequently applied adhesive[8]. They also provide superior corrosion resistance and may also provide strength and improve integrity between two base materials (GCCA, 2017).

Adhesive bonding involves the joining together of two or more metal or non-metal components and is typically performed when the joints being formed are essential to the structural integrity of the final product or component. Typical bonding structures in the A&D sector include, but are not limited to, upper and rear parts of an aircraft, radome (radar dome) attachments, upper fuselage parts, and engine components (e.g., hexagonal core sandwich structures). Examples of non-structural components that are also coated with a bonding primer include, but are not limited to, stowage bins, lavatories, and sidewall, ceiling, and partition panels.

Bonding primers maintain adhesion between the substrate and adhesive material. Prior to application of the bonding primer, bonding surfaces are typically roughened mechanically or etched chemically to provide increased surface areas for the bonding, and then treated chemically to provide further adhesion between the substrate and primer, either through mechanical interlocking or chemical interaction. The surfaces are then thinly coated with the adhesive bonding primer before application of the adhesive. The components are joined together and cured at ambient temperatures, in an oven, or in an autoclave to provide a permanent bond (CCST, 2015b).

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

In addition to a number of metal substrates (e.g., aluminium and its alloys, titanium alloys and steel alloys), bonding primers are also applied to composites (CCST, 2015b).

For reference, substrates identified by the ADCR members as relevant to bonding primers are[9]:

- Aluminium and its alloys;
- Composite (carbon fibre/glass fibre);
- Copper and its alloys;
- Lead;
- Nickel and its alloys (such as Ni-Co);
- Stainless steels;
- Steel and its alloys;
- Titanium and its alloys; and
- Tungsten.

8 This is inclusive of film adhesives, paste adhesives, and spray adhesives.

9 Based on scoping questionnaires returned by 11 members in which bonding primers were referenced.

2.3.1.2 Relationship to other ADCR applied for chromate uses

Bonding primers form part of an overall system in which the subsequent layer will be an adhesive or, in some cases, a protective primer (e.g., basic primer). Prior to application of the bonding primer, the substrate will undergo a surface-treatment, such as anodising (e.g., PAA) or, in some cases, sol-gel, which help to facilitate adhesion of the primer. However, due to the enhanced adhesion requirements an anodic layer will often be unsealed.

The multilayer coating system described above is illustrated in **Figure 2-1** below:

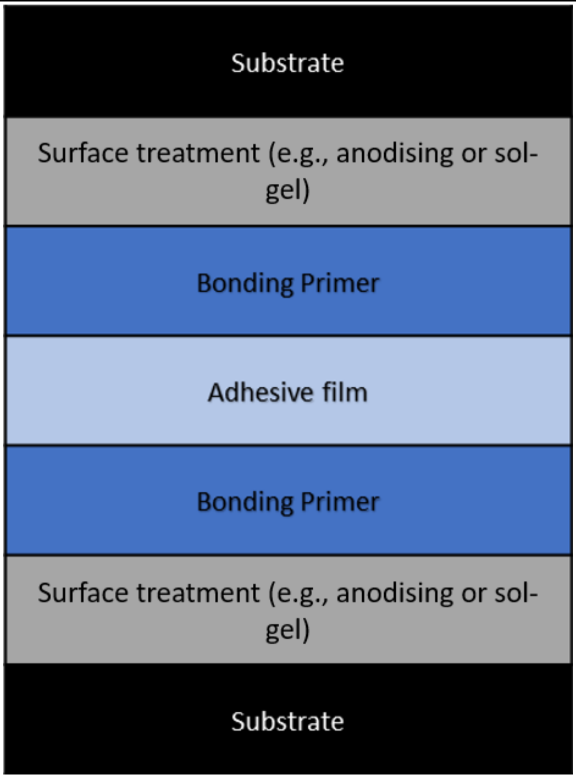

Figure 2-1: Example of a coating system valid for bonding primer
Adapted from (CCST, 2017)

2.3.2 Temporal scope

Because of the lack of viable and qualified alternatives for the use of strontium chromate in bonding primers 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 for substitution 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 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 period of unemployment in Dubourg (2016)

2.3.3 The supply chain and the estimated number of sites

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.

Over half of the larger ADCR members (14 of 24) support the use of bonding primers containing strontium chromate; this may be for their own use or for use in their supply chains. The larger members in particular may be supporting the use of bonding primers containing strontium chromate to ensure it is available to their suppliers as well as for their own use.

2.3.3.2 Downstream users of strontium chromate for bonding primers

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

- Original equipment manufacturer (OEM) – generally large companies which design, manufacture, assemble and sell engines, aircraft, space, and defence equipment to the final customer;
- Design-to-Build[10] (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[11]. 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.

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

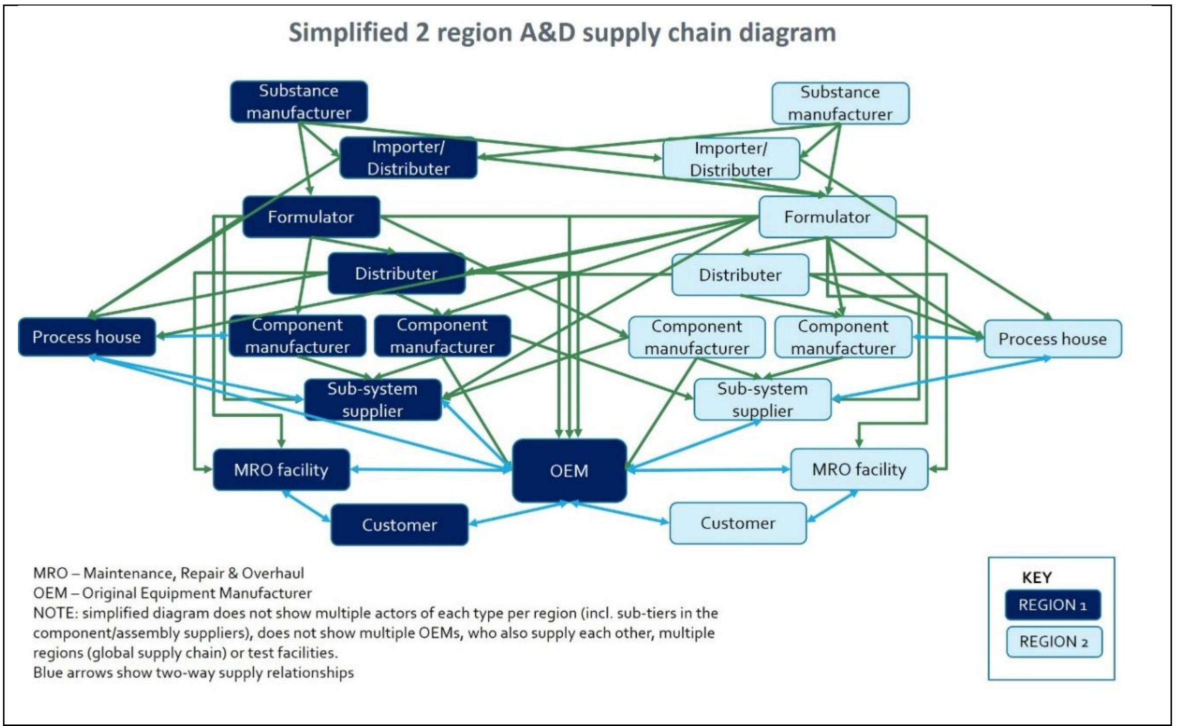

Figure 2-2: Complexity of supply chain roles and relationships within the A&D sector
Two-way supply relationships are indicated by the double headed arrows

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10 Also referred to as “design and make” or “design responsible” suppliers

11 Also common are companies categorising themselves as a BtP and MRO

The SEA provided in this combined AoA/SEA document is based on the distribution of companies by role given in **Table 2-3**, where this includes ADCR members, and their suppliers involved in application of protective primers. It is important to note that these companies operate across multiple sites within GB, with the total number of sites covered by the data provided also reported below. Note that some ADCR members supported use of primers in order to cover their value chain (e.g., BtP suppliers or MROs) and did not provide responses themselves to the SEA questionnaire. Instead, they distributed the questionnaires to relevant suppliers. As a result, the number of SEA responses indicated in **Table 2-3** below varies from the number of ADCR members requiring use of bonding primers for themselves or their supply chain.

Table 2-3: Numbers of companies providing SEA information on bonding primers

Role	Number of companies
OEMs	1
Design-to-Build	2
Build-to-Print	6
MRO mainly (civilian and/or military)	2
Total	**11**

2.3.3.3 OEMs, DtB and BtP Manufacturers

The OEMs will often act as the design owner and define the performance requirements of the components required for an aerospace, defence, or space product, as well as the materials and processes to be used in manufacturing and maintenance. OEMs, as design owners, are responsible for the integration and validation of the final product and certification approval. While they may apply bonding primers themselves, as part of their own manufacturing activities, the primers are also used by a range of companies within the supply chain. The OEMs operate at the global level, and therefore may have facilities in GB, and located in other regions. They may also be global exporters of final A&D products. In the case of GB-based OEMs, the suppliers are often located in the same country (if not the same region) as their main OEM customer.

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

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

Both DtBs and BtPs tend to be located relatively close to their customers, which sometimes results in the development of clusters across GB.

2.3.3.4 Maintenance, Repair and Overhaul

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

A representative life cycle of a typical aerospace product – a commercial aircraft - is illustrated in **Figure 2-3**. This highlights that: the development of a new aerospace system can take up to 15 years; the production of one type of aerospace system may span more than 50 years; and the lifespan of any individual aircraft is typically 20-30 years. **Figure 2-4** provides an overview of the life cycle of weapon systems, which are usually used much longer than the originally projected lifetime. Such life cycles can be significantly longer than 50 years. For such systems, it is extremely costly to identify and replace legacy applications of chromates without impacting performance, where performance has been assured for many decades.

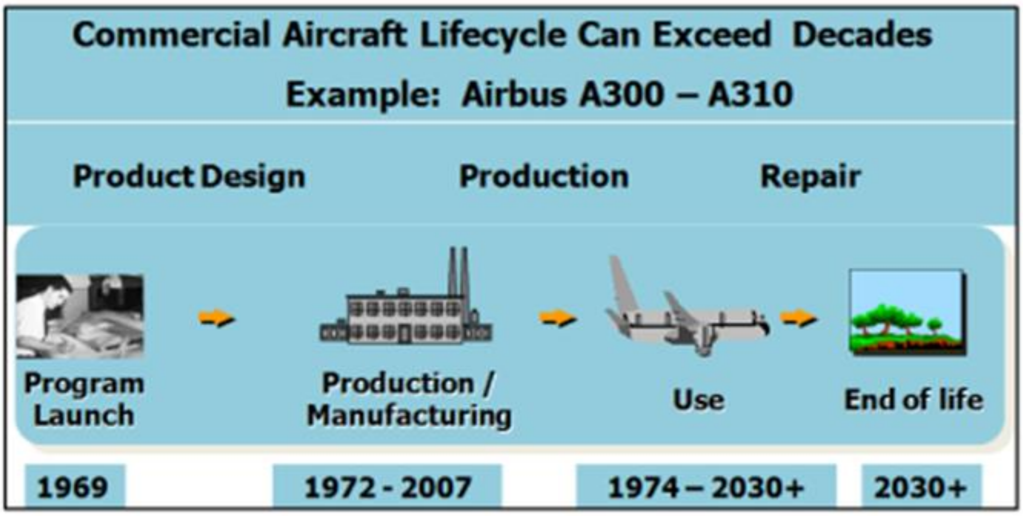

Figure 2-3: Commercial Aircraft Service Life, from ECHA & EASA (2014)[12]

[12] https://www.easa.europa.eu/en/document-library/general-publications/echa-easa-elaboration-key-aspects-authorisation-process

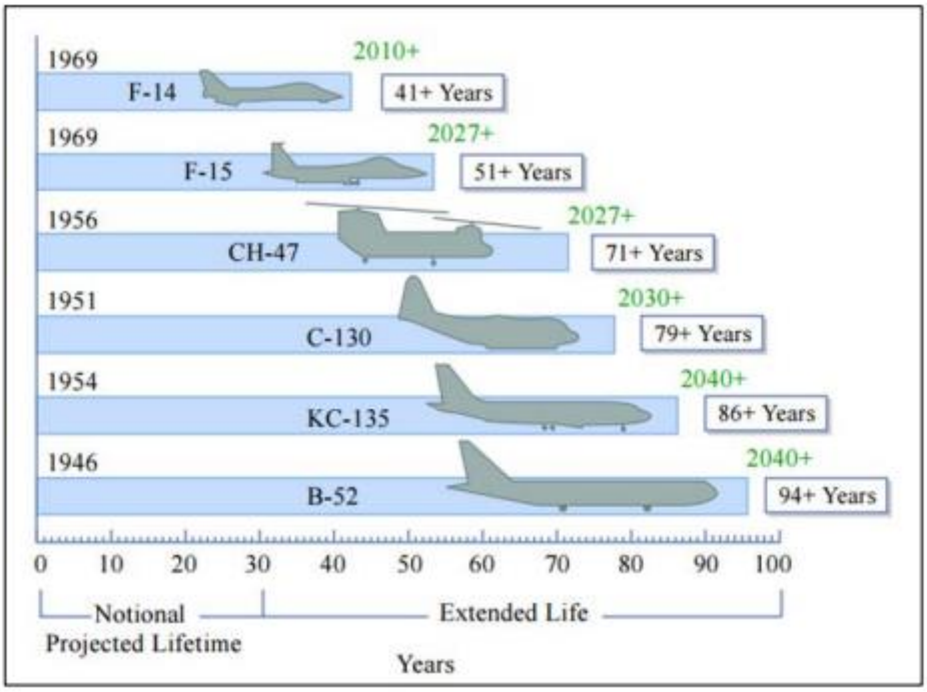

Figure 2-4: Life cycles of defence aircraft, from A Haggerty (2004)[13]

Even if new designs/components – coming onto the market, as well as those no longer being produced in the short to medium term – might succeed in dispensing with the need for use of bonding primers containing Cr(VI), products already placed on the market, as well as those no longer being produced still need to be maintained and repaired using Cr(VI)-based primers until suitable alternatives are validated for use in MRO for those existing products. Maintenance Manuals for such existing products (which the user is legally obliged to comply with) detail, amongst other information, the processes and materials initially qualified (sometimes decades ago) and required to be used, which form a substantial portion of the type certification.

As a result, MROs (and MoDs) face on-going requirements to apply bonding primers containing strontium chromate in strict adherence to the requirements of qualified repair and maintenance schemes to ensure continued safe operation of the final A&D products.

2.3.3.5 Estimated number of downstream user sites

Calculation of the estimated total number of sites is based on a combination of SEA questionnaire results, and consultation with ADCR members. It was estimated that there were around 150 total sites in GB, based on data from ADCR members and their supply chain. The ratio of SEA respondents identifying use of each primer type were then used to inform the distribution of the 150 sites across each primer type. These values were then split by supplier type using ratios derived through consultation with the ADCR members. The assumed number of total sites in GB using bonding primers has been taken to be 50.

13 https://studylib.net/doc/13484803/lifecycle-considerations-aircraft-systems-engineeering-al...

2.3.3.6 Customers

The final actors within this supply chain are the customers of A&D final products to which bonding 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[14]. 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 dominance of UK-based airlines and aircraft enhances UK connectivity, particularly on less frequented direct routes from regions outside London[15]. 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 2022/23, total government expenditure on defence across the GB equated to 1.9% of GDP. In 2022/23 defence spending totalled £54.2 billion[16].

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 Overview

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

- Consultation with the Applicants (importers and formulators) to gather Article 66 downstream user notification data, information on volumes placed on the market and numbers of customers. This has included consultation with the formulators to gather

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

[15] https://airlinesuk.org/about-us/

[16] https://researchbriefings.files.parliament.uk/documents/CBP-8175/CBP-8175.pdf

information on their efforts to develop alternatives on their own, in collaboration with the downstream users, and as part of research projects funded by national governments, the EC, and more, internationally;

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

- Consultation with component and special process suppliers within the A&D supply chain to gather socio-economic information, ability to move to alternatives, and likely responses under the Non-Use Scenario.

Further details of each are provided below.

2.4.2 Consultation with Applicants

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

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

2.4.3 Consultation with Downstream users

2.4.3.1 ADCR Consortium Members

Consultation with ADCR members was carried out over a period from 2019 to 2023 to collect a range of data relevant to both the AoA and the SEA for all ADCR dossiers. This consultation was carried out with all downstream user members of the ADCR (i.e., members located in GB), and regardless of their role. Consultation took place over different phases:

1) Phase 1 involved collection of information on use of primer products that each member undertook. This included:
    a. Supply chains,
    b. Substances used in each primer-type and associated volumes,
    c. Key functions provided by the substance,
    d. Locations for each activity, and
    e. Likelihood of substitution before 2026.

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

3) Phase 3 then took the form of detailed one-on-one consultations between ADCR members and the AoA technical service team. The focus of these discussions was to:
    a. Ensure additional critical details were collected concerning core aspects of the AoA/SP portions of the dossiers (e.g., confirm current technology readiness levels of shortlisted alternatives and address outstanding questions regarding alternatives and their comparative performance), and
    b. Confirm information on R&D and substitution timelines previously gathered was up-to-date, and that the information reflected progression up to MRL 10 in order to recognise the transition to full production.

4) Phase 4 collected information for the SEA sections of this document, including:
    a. Base data on the economic characteristics of different companies,
    b. Additional information on volumes used of the chromates and for what processes, and trends in this usage over the past 7 years and as anticipated into the future,
    c. The importance of chromate-using processes to the turnover of individual companies,
    d. Past investments in R&D into alternatives,
    e. Past investments into capital equipment related to on-going use of the chromates as well as to their substitution; this included investment in new facilities outside GB,
    f. Numbers of employees directly involved in use of the chromates as well as the total number of employees at sites that would also be directly impacted under the Non-Use Scenario, and
    g. Economic and social impacts under the Non-Use Scenario.

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

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

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

As a final count, for this primer use, data for 10 sites operated by the ADCR OEMs and their DtB and BtP suppliers was provided in response to these questionnaires. The information provided by the companies forms the basis for the SEA component of this document.

2.4.3.3 Maintenance, Repair and Overhaul suppliers

For consistency purposes, MROs were also asked to complete the BtP or DtB questionnaires. Again, these were supplied directly to MROs or were distributed by ADCR members to key suppliers.

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Substance ID and Overview of the key functions and usage

Bonding primer is defined by the ADCR as follows[17]:

"Bonding primers (sometimes referred to as adhesive bonding primers) provide corrosion resistance and promote and maintain adhesion between a substrate and an adhesive material."

The chromate identified from previous Applications for Authorisation (AfA), associated with this primer-type is:

- Strontium chromate EC 232-142-6 CAS 7789-06-2

Strontium chromate (Entry No. 29) has been included in Annex XIV of Regulation (EC) No 1907/2006 under Article 57(a) as it is classified as carcinogenic (cat. 1A).

3.1.1.1 Process steps and overview of key functions

Cr(VI)-based bonding primers are specified in the A&D sector primarily because they provide maximum adhesion both to the substrate and to subsequently applied adhesive. They also provide superior corrosion resistance and may also provide strength and improve integrity between two base materials (GCCA, 2017).

Adhesive bonding involves the joining together of two or more metal or non-metal components and is typically performed when the joints being formed are essential to the structural integrity of the final product or component. Typical bonding structures in the A&D sector include, but are not limited to, upper and rear parts of an aircraft, radome (radar dome) attachments, upper fuselage parts, and engine components (e.g., hexagonal core sandwich structures). Examples of non-structural components that are also coated with a bonding primer include, but are not limited to, stowage bins, lavatories, and sidewall, ceiling, and partition panels. An illustrative example of a bonded surface can be seen in **Figure 3-1**.

Bonding primers maintain adhesion between the substrate and adhesive material. Prior to application of the bonding primer, bonding surfaces are typically roughened mechanically or etched chemically to provide increased surface areas for the bonding, and then treated chemically to provide further adhesion between the substrate and primer, either through mechanical interlocking or chemical interaction. The surfaces are then thinly coated with the adhesive bonding primer before application of the adhesive. The components are joined together and cured at ambient temperatures, in an oven, or in an autoclave[18] to provide a permanent bond (CCST, 2015b).

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

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[17] ADCR Scoping phase DU Q 14Jan, Appendix 1 Use Definitions

[18] According to the adhesive requirements

Although a number of key functions are attributed to bonding primers in the parent AfA, the key functions of the substance of very high concern (SVHC) strontium chromate in bonding primers (supported by the information on mode of action provided in the parent AfA and through member consultation) are:

- Adhesion promotion; and
- Corrosion resistance (including 'active corrosion inhibition').

Further detail on the modes of action of chromates in the delivery of the key functions listed above is given in the following sections:

Adhesion promotion

Adhesion promotion refers to the ability of the bonding primer to improve adhesion stability at both the adhesive and treated substrate interfaces. Consequently, the bonding primer serves to enhance the mechanical performance of the bonded structure. Adhesion properties may be influenced by an interplay between corrosion inhibitor, matrix, and other additives in the primer (CCST, 2015b). Cr(VI)-free test candidates must be proven to not adversely impact this relationship between the different elements of the primer composition which could cause deterioration in adhesion performance.

Corrosion resistance (including 'active corrosion inhibition')

Although the primary function of the bonding primer is adhesion promotion, the presence of Cr(VI) also provides a level of corrosion resistance. To provide adequate corrosion resistance, Cr(VI) must be available in sufficient concentration and mobility to reach unprotected or damaged surfaces. This availability facilitates two-fold corrosion inhibition properties afforded by Cr(VI) contained with the primer matrix. It combines with the naturally occurring metal oxide to form a mixed oxide layer that forms a passive corrosion resistant protective layer on the surface of the metal which prevents oxygen from contacting the metallic substrate. Secondly, 'active corrosion inhibition' is possible due to the presence of mobile Cr(VI), when in sufficient concentration, retained in the passivation layer. Should the oxide layer be damaged locally to reveal bare metal then, after the initial formation of a thin metal oxide layer, this residual mobile Cr(VI) reacts with the metal oxide, renewing the passive chromium oxy-hydroxide protective barrier and thus re-establishing a corrosion inhibiting layer (CCST, 2017). This process is illustrated in **Figure 3-1** below.

The entire mechanism of corrosion protection described above, that is attributable to presence of Cr(VI) in the bonding primer, primarily applies to aluminium metal substrates. However, the A&D industry has historically used the same Cr(VI) primers for bonding applications on other substrates listed in Section 2.3.1.1, such as steels and titanium, that typically do not corrode as readily as aluminium. One of the main reasons for the use of chromated bonding primers on these other substrates is that the volume of bonded parts involving steels or titanium is much lower compared to that of bonded aluminium parts across the A&D sector. Consequently, there has never been a sufficient economic driver for the formulators to develop and OEMs to qualify unique Cr(VI)-free bonding primers exclusively for usage on non-aluminium substrates. Finding a Cr(VI)-free, corrosion inhibiting bonding primer for aluminium substrates is a much higher priority for the OEMs and the formulators since the majority of our bonded parts are aluminium. To promote efficient use of resources, optimise substitution timelines, and control costs, Cr(VI)-free bonding primer alternatives developed for aluminium and its alloys should be compatible with these other substrates which are often adjacent to or in contact with aluminium alloys.

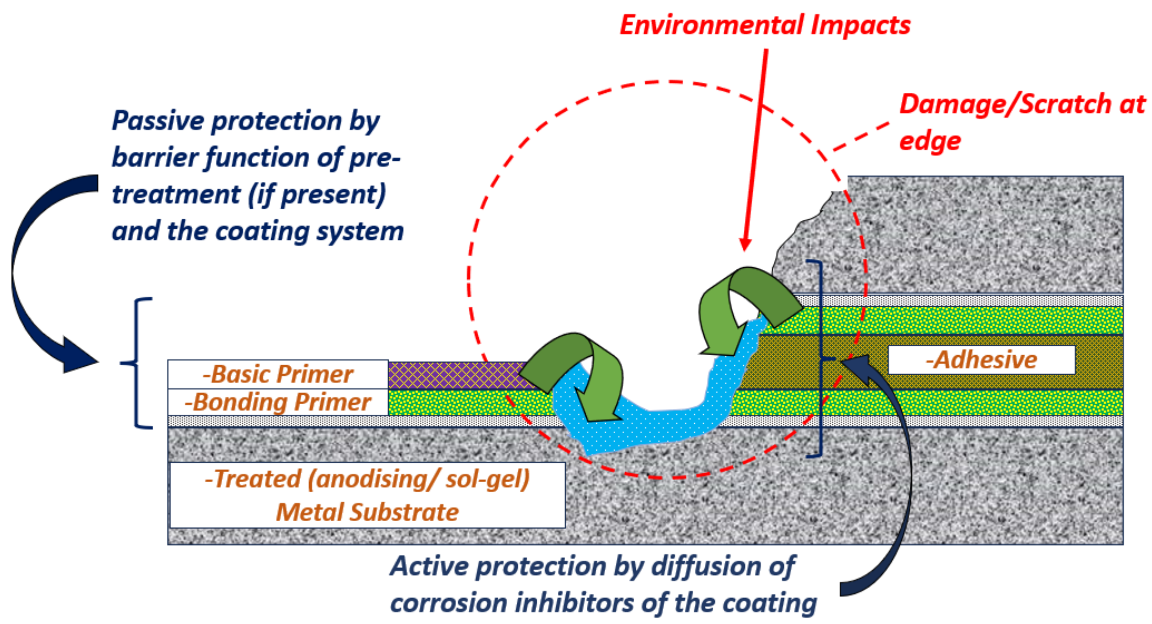


Figure 3-1: Basic functions of an example surface protection system
(CCST, 2015a)

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

The areas close to the "scratch" will become depleted in Cr(VI) thus reducing the corrosion protection offered in the immediate area. However, the diffusion mechanism operates continuously allowing further diffusion of pigment particles from adjacent areas of bond primer into the depleted area. This dynamic process represents the "self-healing" mechanism that to date, appears to be unique to Cr(VI) (CCST, 2017).

Unlike most corrosion inhibiting compounds, chromates are both anodic and cathodic inhibitors, meaning that they can restrict the rate of metal dissolution, and simultaneously lower the rate of reduction reactions (oxygen and water reduction) in many environments and over a broad range of pH. This makes the Cr(VI) compounds uniquely capable of providing/ensuring the corrosion protection required for the safety and reliability of A&D products over the wide range of use environments in which they operate. The specific physico-chemical properties and unique functionalities of Cr(VI) make it an ideal substance in bonding primers as illustrated in **Figure 3-2** below:

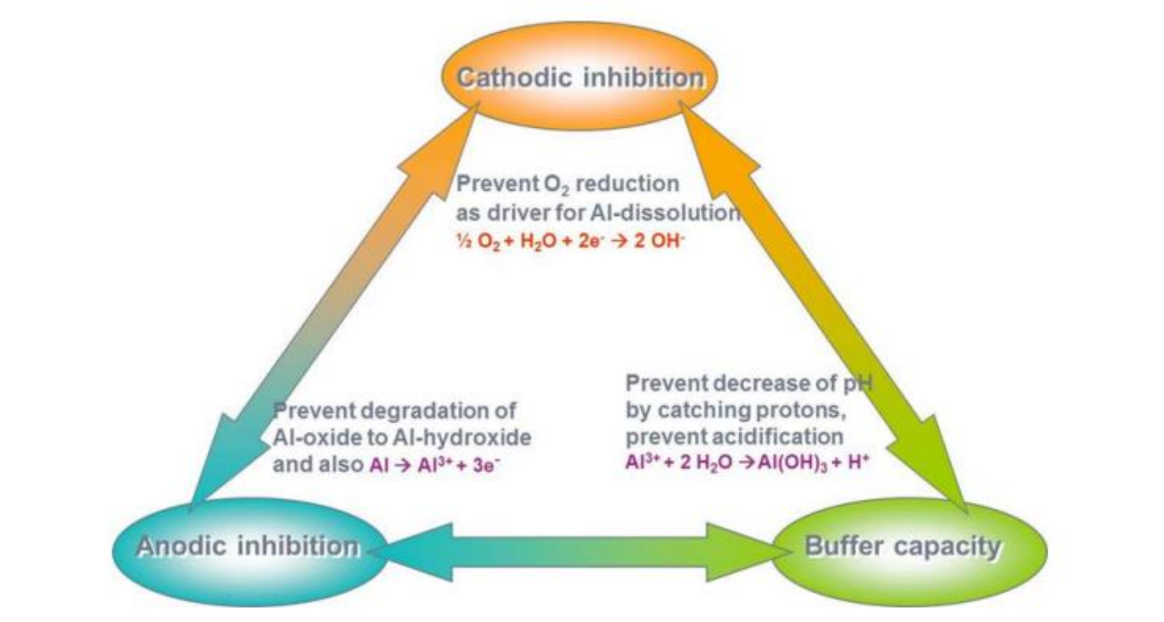


Figure 3-2: Key Cr(VI) functionalities illustrated with aluminium substrate
(CCST, 2017)

3.1.1.2 Usage

Components that may be treated with the Annex XIV substance

As detailed above, bonding primers, 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, 2017a)			

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 can only be introduced where they have been proven to have no detrimental impact on 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 (intergranular corrosion) is a type of corrosion commonly seen in components made of aluminium alloys that contain alloying elements that are less noble than aluminium (e.g., aluminium-zinc alloys like AA7050, see **Figure 3-3**) and can occur either in the presence of impurities in the grain boundaries or to the local enrichment of one of the elements;
- Galvanic corrosion can occur at locations where there is contact between dissimilar conductive materials
- Filiform corrosion occurs on painted surfaces and is localised corrosion under the coating;
- Crevice corrosion can be observed where there is a crevice between materials;
- 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. This effect may be increased by galvanic corrosion effects, if the dissimilar metals are bonded or if metals are bonded to carbon fibre composite, for example;
- 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.

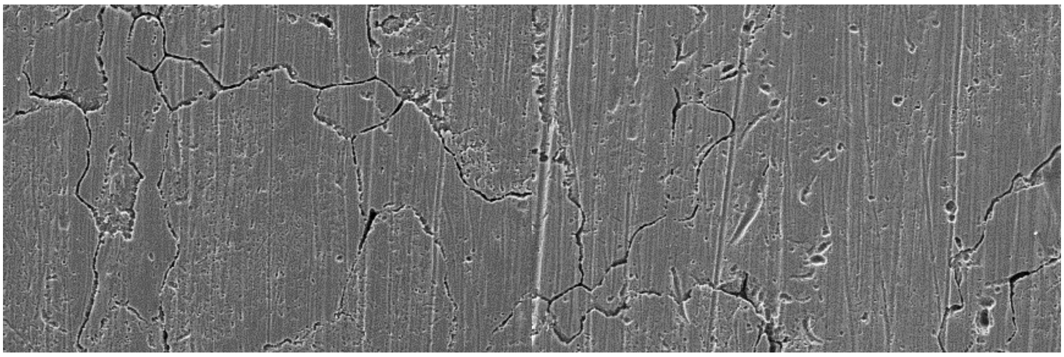


Figure 3-3: Early stage of dissolution of intergranular zinc precipitations in high strength aluminium-zinc alloy AA7050
Source: ADCR member

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 a 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, 2017a). 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, 2017a).

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

3.1.2.1 Introduction

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

In the civil aviation sector of the Aerospace industry, large numbers of aircraft **safely carry billions of people every year**[19]**,** whilst defence aircraft and systems are required to operate safely and reliably for 40 to more than 90 years before they are finally taken out of service**.** This requires A&D components to successfully fulfil a wide range of extremely challenging safety-related requirements, including but not limited to:

- High utilisation rate (around 16 hours per day for commercial aircraft, whilst critical defence systems must operate continuously for extended periods);
- Environmental and service temperatures ranging from below minus 55°C at cruising altitude to in excess of plus 200°C (Depending on substrate and location on final product);
- Wide ranging and varying humidity and pressure;
- High and varying loads;
- Fatigue resistance under varying modes of stress;

[19] 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

- 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[20] 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 Civil Aviation Authority (CAA), 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 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 3-4**).

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

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. Where added complexity arises, it is also likely to impact the time required for approval and implementation of any affected alternative.

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 bonding primers, hundreds of individual components in each final product will be affected.

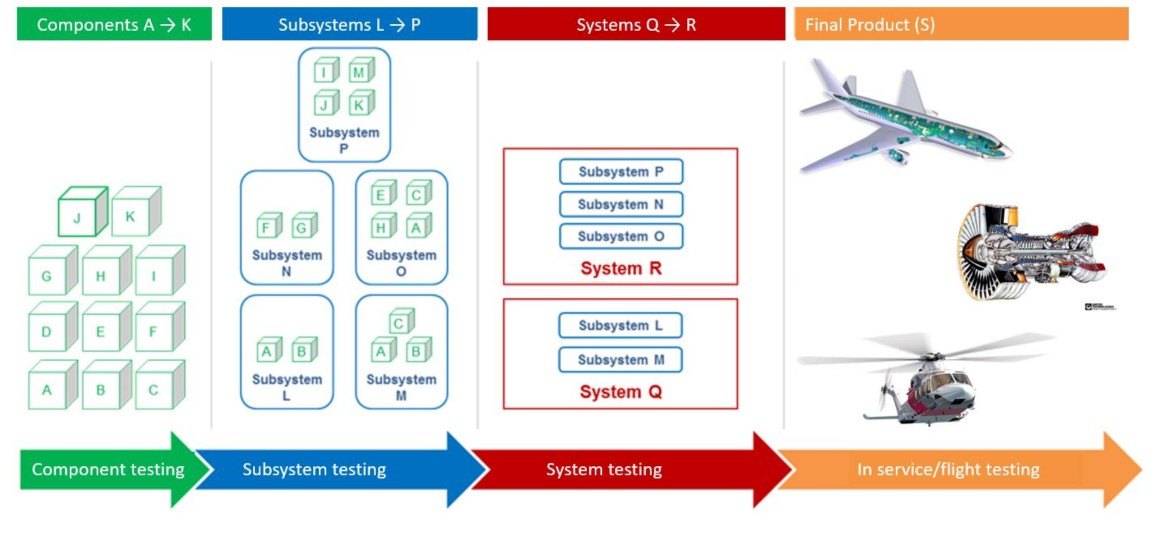


Figure 3-4: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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

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

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

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

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

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

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

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	**Definition**	**Description**
	begin Low Rate Initial Production	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: https://acqnotes.com/acqnote/careerfields/manufacturing-readiness-levelmanufact		

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.

Cr(VI) endows primers with key functionality across a multitude of designs and substrates. If a test candidate with these universal performance and compatibility properties is not available, multiple workstreams using a variety of test candidates either individually or contained in multiple proprietary formulations may be required. Resource availability, e.g., bespoke test facilities, will impact substitution of Cr(VI) with a staggered transition timeline across a breadth of designs.

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 3-5**, 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.

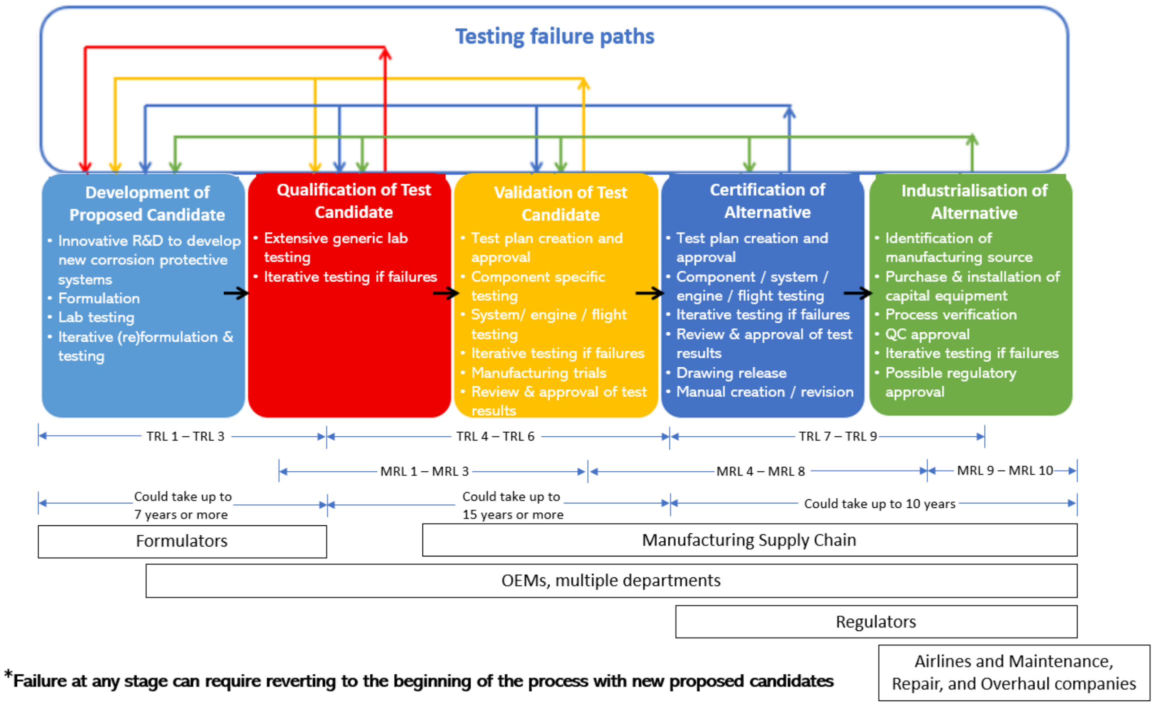


Figure 3-5: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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. As stated in 'Definition of requirements', alternatives must demonstrate non-regression across a broad range of requirements. It is not possible to accept lower performance of test candidates compared to the performance of Cr(VI) because systems have been certified with the performance derived from Cr(VI), and therefore test candidates must, at least, match this level of performance.

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; refer to ADCR Formulation dossier. 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[21].

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 (for example, see Annex 1). 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 3-5** 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.

[21] GCCA

Validation of test candidate

After a test candidate is qualified, the performance of each particular aerospace or defence use is validated based on its specific design criteria.

Validation is carried out on each relevant component, followed by system-level testing and engine/flight testing (if relevant). The activities in this stage can overlap with some of those that are carried out in the Certification stage and include:

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

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

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

Some of the components impacted by the substitution of a 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 3-6** 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[22], each of these components will need to be approved individually:

> "*Importantly, even if an alternative is in use in one component in aerospace*[23] *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.*"

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

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

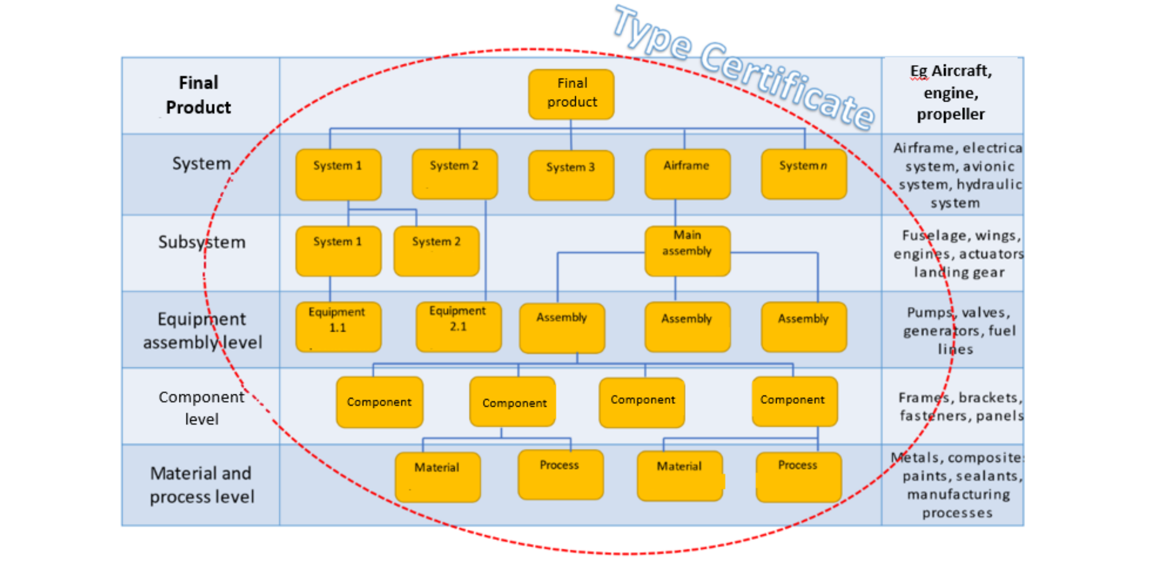


Figure 3-6: System hierarchy of a final product showing the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR member

After the alternative is demonstrated to be compliant and re-certification is achieved, 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 3-7** below.

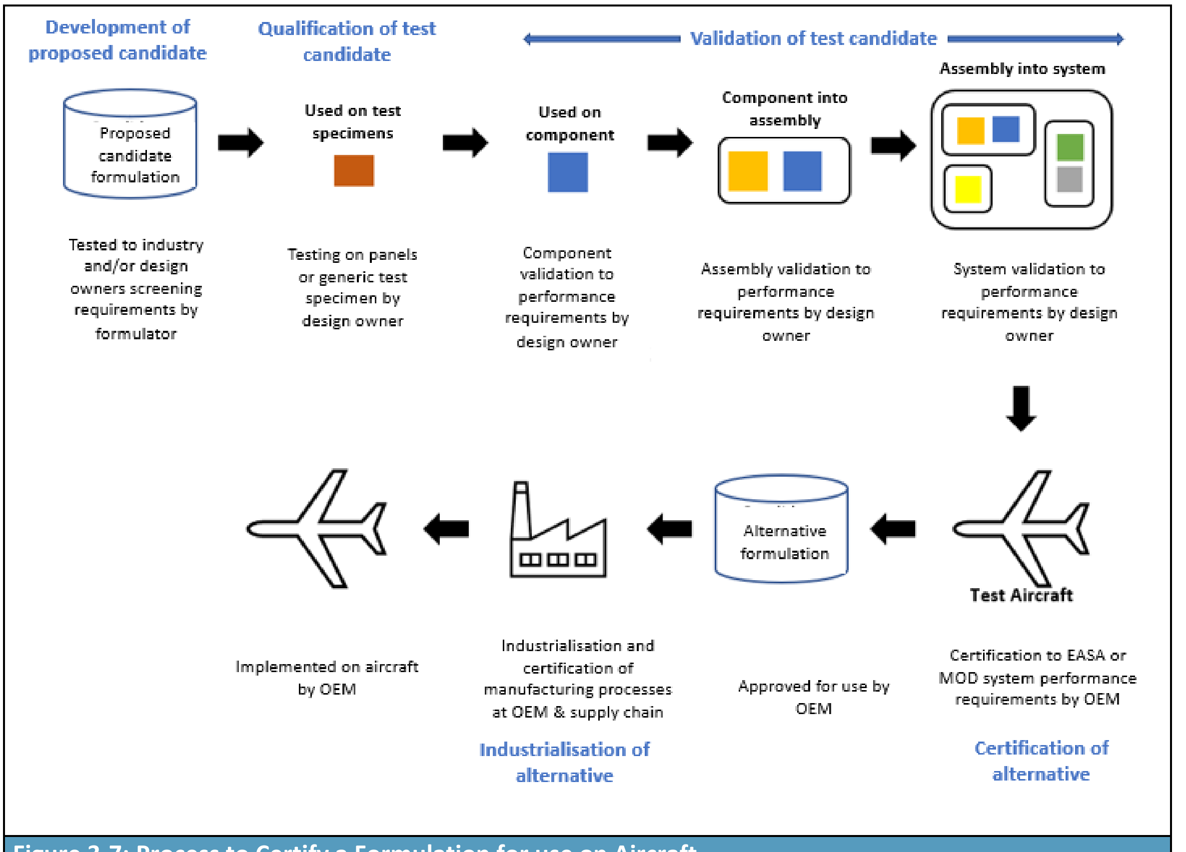


Figure 3-7: Process to Certify a Formulation for use on Aircraft.
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

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

3.2.1 Technical feasibility criteria for proposed candidates to replace chromate-containing bonding primers

3.2.1.1 Introduction

The development of technical feasibility criteria for proposed candidates to replace the use of Cr(VI) in bonding primers has been based on a combination of assessment of the parent AfAs, consultation with ADCR consortium members, and non-exhaustive reviews of available scientific literature and patents within the field.

Using detailed written questionnaires (disseminated throughout 2022 and 2023) the ADCR consortium members were asked to thoroughly describe the key functions that Cr(VI) imparts in this use, and the technical feasibility criteria and associated performance requirements that any test candidates (formulations and technologies) would need to fulfil in order to deliver the functionality currently provided by the chromate-containing bonding primers.

The technical feasibility criteria that shall be used in the assessment of proposed candidates are as follows:

- Adhesion promotion;
- Mechanical load resistance (including impact resistance);
- Corrosion resistance (inc. active corrosion inhibition);
- Layer thickness;
- Chemical resistance;
- Temperature resistance (thermal shock resistance);
- Compatibility with substrate, preparatory treatment, and adhesive;
- Handling performance; and
- Visibility/ inspectability.

3.2.1.2 Technical feasibility criterion 1: Adhesion promotion

Adhesion promotion is commonly identified as the most important functionality provided by bonding primers. The parameter of “adhesion” describes the tendency of dissimilar particles or surfaces to cling to one another (CCST, 2015b). In the A&D industry, many components are exposed to harsh environmental conditions, often in contact with other metallic components and are subjected to strong mechanical forces. This is particularly true for the structural components onto which bonding primers are applied. It is extremely important that the adhesive applied on these components can withstand these effects and keep functioning properly for the longest period possible. It is of note, that, as described above, the adhesion properties of a bonding primer are influenced by a variety of different factors including the complex interplay between Cr(VI), matrix, and other additives.

3.2.1.3 Technical feasibility criterion 2: Mechanical load resistance (including impact resistance)

Systems containing bonding primers are typically exposed to high shear and complex mechanical loads, applied cyclically over time and over a range of environmental conditions. Stresses or loads may lead to cracks in the bond line, for example.(CCST, 2015b). Moreover, it is important for the bonding primer to support the system in withstanding energy introduced by foreign objects (e.g. stone chipping, tool impact).

3.2.1.4 Technical feasibility criterion 3: Corrosion resistance (incl. active corrosion inhibition)

Corrosion describes the process of oxidation of a metallic material due to chemical reactions with its surroundings, such as humidity but also corrosive electrolytes. In this context, the parameter corrosion resistance means the ability of a metal A&D component to withstand gradual deterioration by chemical reaction with its environment, which could lead to failure if not detected soon enough. Examples of corrosion failure are described in Section 3.1.1.2 and include galvanic, filiform and crevice corrosion. Corrosion fatigue from grain boundary corrosion or intercrystalline corrosion may affect high strength aluminium alloy parts (CCST, 2015b).

For the A&D sector, this parameter is one of the most important since meeting its minimum requirements plays a key role in assuring the longest possible life cycle of final products and all the implicit components, the feasibility of repairing and maintenance activities and most importantly, the safety of all air travellers. The aluminium alloy AA2024, for example, is commonly used in the aviation sector, and contains approximately 5% copper as an alloying element to provide the material strength. However, use of copper impacts the corrosion resistance of this alloy as copper is a noble element (metal) acting as a built-in corrosion driver. To ensure long-term corrosion stability, inhibition of the copper is mandatory (CCST, 2015b).

The corrosion resistance requirements vary within the A&D sector and are dependent on the metal substrate (aluminium alloy, steel type etc.,) and the coating type. Corrosion inhibiting co-formulants can be categorised according to inhibitive efficiency, versatility, in terms of potential areas of use, and hazard profile. Ideally, the corrosion inhibitor is applicable in all surface treatment processes, compatible with subsequent layers and performs effectively on all required substrates. In addition, it has to ensure product stability (chemical and thermal) and reinforce coating properties (CCST, 2015b). The surface pre-treatment on parts awaiting assembly/ bonding is also protected by the bonding primer during storage and/or the production process.

The ability of a material to spontaneously restore corrosion protection following damage to the original coating is known as active corrosion inhibition, or self-healing. It is reported that the solubility of Cr(VI) delivered by the primer matrix is sufficient to supply an adequate number of inhibitive ions to support diffusion and the self-healing mechanism (CCST, 2015b). Bonding primer formulations contain a relatively small proportion of corrosion inhibiting pigments compared to other primer types and therefore will typically only deliver limited active corrosion inhibition. Although, without a bonding primer, bonded joints would corrode much faster than those without and there would be no guarantee of long term stability of the system. Bonded joints are designed to the strength achievable with a bonding primer. In some cases, the bonding primer is porous in structure, which provides mechanical interlocking to the adhesive at the expense of corrosion barrier properties. The required porosity is reported not to be present in bonding primer layers exceeding 7µm, resulting in insufficient adhesion and mechanical durability of the joint. The presence of a porous pretreatment-bonding primer system leaves areas of the base metal exposed and electrochemically active, since the primer does not completely infiltrate the pretreatment. The corrosion inhibitor in the bonding primer is, therefore, essential to protect vulnerable base metals, such as aluminium alloys, during storage, handling prior to adhesive bonding, and in service, under conditions where the bond primer is exposed (Kleinschmidt *et al.*, 2016).

3.2.1.5 Technical feasibility criterion 4: Layer thickness

The thickness of the different layers or coatings on the substrate, specified in nanometres or micrometres, is also crucial for optimum performance of all parts of the aircraft. The objective is to achieve maximum performance with minimum thickness, which equates to minimum weight, as weight is critical to the fuel efficiency of an aircraft. Layer thickness is also important as it affects component dimensions and tolerances, which affect the performance of the component when it is integrated into assemblies and sub-systems. For example, if layer thickness increases it can cause reduced fit of fasteners that require close compliance to the specified tolerances, and increased wear when the component is integrated with other components and where it moves in relation to those other components. Conversely, an increased layer thickness provides improved corrosion resistance. For a bonding primer, a thickness between 2-12 µm is typically specified (GCCA, 2017b).

Layer thickness is not directly influenced by Cr(VI), but any alternative must not adversely affect this attribute. Not meeting the specified requirements of this parameter could lead to deficiencies in other characteristics of the components. For example, the required porosity not developing during curing can lead to insufficient corrosion resistance, inadequate adhesion of adhesive to the bonding primer, or decreased cracking resistance. The process capability of Cr(VI)-free primer systems therefore needs to be considered in order to guarantee even coverage of components with complex geometries.

3.2.1.6 Technical feasibility criterion 5: Chemical resistance

This parameter is defined as the ability of solid materials to resist damage by exposure to chemicals. It includes no degradation of wettability properties. Especially for aeronautic applications, it is highly important that all parts withstand contact with heat, humidity, water, and different chemicals like de-icing fluids, greases, oils and lubricants and especially aggressive fire-resistant aviation hydraulic fluids used in the sector. The chemical deterioration of protective coatings or the metal components themselves could significantly increase maintenance costs and may sacrifice to some extent reliability and safety.

3.2.1.7 Technical feasibility criterion 6: Temperature resistance (Thermal shock resistance)

This parameter describes the ability of a material to withstand repeated low and high temperature cycling. For the same reasons stated above, it is a necessity that components and coatings are able to meet every functional requirement at all temperatures to which the components are going to be exposed during their service life.

3.2.1.8 Technical feasibility criterion 7: Compatibility with substrate, preparatory treatment, and adhesive

Compatibility with a wide range of substrates, other primers, and subsequent layers is a key performance characteristic within the aviation sector. It is typically the case that the manufacturer of the bonding primer will also supply an adhesive based on technical specifications and the compatibility between the bonding primer and subsequent layers. However, ADCR members indicated during consultation that tests are also internally performed on various adhesives from different manufacturers in order to determine the most suitable candidate.

3.2.1.9 Technical feasibility criterion 8: Handling performance

Any proposed candidate for the replacement of bonding primers containing strontium chromate must be able to meet various requirements regarding its handling performance. This includes its ability to be processed at suitable temperatures, and for suitable lengths of time, its ease of application (ability to spray, compatibility with existing manufacturing set up of tools/equipment), storage and working conditions (temperature and humidity), and storage stability of the primer and components coated with the primer. The surface pre-treatment on parts awaiting assembly/ bonding is also protected by the bonding primer during storage and/or the production process.

3.2.1.10 Technical feasibility criterion 9: Visibility/ inspectability

When the bonding primer is being applied to the substrate, visibility of the primer is an important factor in controlling the layer thickness of the substrate coating. Moreover, the process of inspection is made less complicated as any defects would be easier to identify compared to the use of a bonding primer with a colourless/ near colourless Cr(VI)-free alternative, whereas the presence of Cr(VI) attributes the bonding primer with a yellow/green colour. The use of a colourless primer may slow down the production rate if additional time or measures are implemented to mitigate the possibility of a defect not being discovered. The visibility of the bonding primer is also important to mitigate health & safety concerns, as workers are less likely to come in contact with it during the application process.

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

At the development phase, as described in the substitution process, Section 3.1.2, proposed candidates are at an early stage of evaluation represented by TRL 1 – 3, and not recognised as credible test candidates at this stage. These proposed candidates are screened against the technical feasibility criteria identified above. These criteria are measured against performance thresholds using standardised methodologies. The performance thresholds are most often assigned by the design owner of the component to which the primer is applied.

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

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

The role of the specification is limited within the substitution process. It provides a reproducible means of screening proposed candidates. However, it is typically unsuitable for more mature stages within the substitution process when proposed candidates transition to credible test candidates.

These subsequent phases in the substitution process are subject to in depth, often bespoke, testing as required within steps TRL 4 – 6 and above. Testing regimes to meet the requirements of TRL 4 – 6 often transition from simple specifications intended for quality control purposes, to evaluation of treated components/sub-assemblies via breadboard integrated components either within the laboratory or larger simulated operational environments. These advanced testing regimes rely upon the use of specialised equipment, facilities, and test technologies such as test rigs or prototype systems, see example in **Figure 3-8**. Attempts to replicate environmental in-service conditions are built upon bespoke testing regimes developed over decades of experience using Cr(VI) from laboratory scale test panels to test rigs housed in purpose-built facilities. However, they cannot fully reproduce natural environmental variations therefore there can be differences between what is observed in the laboratory and experienced in the field.

Figure 3-8: Multi-climate chamber for simulated environment testing
(Airbus SAS, 2022)

Examples of standards used for screening proposed candidates within the development phase of the substitution process are presented in **Table A1-1** in Annex 1. As stated above, standards serve to provide a means of reproducible testing within the development phase of the substitution process. Both standards and specifications are tools used to evaluate proposed candidates such that any suitable test candidates can be identified and further progressed.

3.3 Market analysis of downstream uses

The market analysis of downstream uses is provided in Section 4.2.

3.4 Efforts made to identify alternatives

3.4.1 Research and Development

3.4.1.1 Past Research

Although the aerospace sector is widely seen as the instigator of technology change in multiple essential engineering disciplines (including the use of new metals, composites, and plastics) (Royal Academy of Engineering, 2014), when considering the replacement of chromates this should be set against the diversity of applications of metal alloys across the sector. Aerospace and Defence sector finished products include fixed wing aircraft, rotary wing, powered lift aircraft, land-based equipment, military ordnance, and spacecraft. Examples of finished products within the scope of the ADCR are shown in **Figure 3-9**. Consequently, the industry requires a diverse range of metal alloys to fulfil all performance requirements that these various applications demand. Whilst bonding primers containing strontium chromate show a wide substrate compatibility, most Cr(VI)-free primers are more specific regarding suitability for different alloys. Considering these factors, combined with the strict safety and certification requirements as described in Section 3.1.2, the pace of research and development will not be uniform across the sector.

Figure 3-9: Examples of finished products in A&D sector
Rheinmetall – Systems & Products, n.d.; Royal Navy, 2021

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

Various R&D activities were reported within the two parent applications for authorisation relating to bonding primers. Proposed candidates for the replacement of Cr(VI) in bonding primers are shown in **Table 3-4.** This list comprises all the alternatives that were reported in the parent AfA and their technical readiness levels (TRLs)[24].

[24] Includes alternatives that failed to meet the substitution criteria, and any reasons given

Table 3-4: Cr(VI)-free proposed candidates for the replacement of StC in bonding primers reported in parent AfAs		
Proposed candidate	**Implementation status (TRL level) reported in parent AfA**	**AfA ID**
Cr(VI)-free inhibitors (confidential)	For a full implementation on all substrates, plus for MRO applications, at least 8-15 years will be necessary.	0046-02
Calcium-based corrosion inhibitors	Technically not equivalent. Questionable if they will qualify for further R&D efforts.	0046-02
Molybdate-based corrosion inhibitors	Technically not equivalent. Questionable if they will qualify for further R&D efforts.	0046-02 0117-01
pH-buffering additives (Calcium carbonate, calcium hydroxide, magnesium hydroxide, magnesium oxide)	Technically not equivalent.	0117-01
Phosphate-based corrosion inhibitors	Technically not equivalent.	0046-02 0117-01
Rare earth-based corrosion inhibitors (Praseodymium trihydroxide, praseodymium oxide)	Technically not equivalent. Questionable if they will qualify for further R&D efforts.	0046-02
Rare earth, enhanced corrosion inhibitors (Rare earth complexes combined with molybdate or tungstate corrosion inhibitors)	Not broad alternative due to base alloy and pre-treatment sensitivity.	0117-01
Silane-based coatings	TRL 2. At least 15 years required after development of viable candidate for implementation into supply chain.	0046-02
Silicate-based corrosion inhibitors	Technically not equivalent.	0117-01
Source: (CCST, 2015b; GCCA, 2017b)		

Within the period since the parent authorisations were granted, further R&D has been conducted by members on some of the proposed candidates show in **Table 3-4** above.

Since the initial AfAs, further R&D has been undertaken by the A&D sector to evaluate and improve the performance of existing and new Cr(VI)-free test candidates. During this time, an additional candidate which was not on the shortlist of alternatives in the parent AfA, graphene oxide, has been added to the aforementioned shortlist. In the scientific literature, graphene oxide was shown to provide high water dispersibility and corrosion inhibition performance. Although, it is still deemed as a prospective technology and, as such, has not yet been distributed to OEMs by formulators for initial testing. Incidentally, candidate groups 'rare earth-based corrosion inhibitors' and 'rare earth, enhanced corrosion inhibitors' have been reported as being distributed to members of the ADCR by formulators; however, due to the early stages of R&D for these test candidates, no further information can be provided at this time.

The remaining shortlisted alternatives which have not been entirely eliminated from evaluation since the parent applications have been further researched and developed by the consortium members to varying degrees of success. Namely, the test candidates eliminated from further evaluation are calcium-based corrosion inhibitors, molybdate-based corrosion inhibitors, and silicate-based corrosion inhibitors. While these alternative categories have been dismissed on grounds of poor technical performance, some of the chemistries may be used as a part of formulations under other shortlisted alternative categories.

The most commonly identified test candidates were those reported as Cr(VI)-free inhibitors (confidential). As many OEMs are not informed of the proprietary constituents of the formulation by formulators, it is not always possible to identify the specific corrosion inhibitors of a Cr(VI)-free test candidate. It may be the case that this category of test candidates may contain any of the other specific chemistries listed within the shortlist of alternatives, or other chemistries known only to the formulators. This category of test candidates comprises potential alternatives where a proprietary mixture of test candidates has been formulated to achieve greater functional performance than achieved with the individual test candidates used in isolation. The specific composition of inhibitors used in these blends is often confidential business information to the formulators and could therefore not be disclosed to the ADCR consortium or its members. Further information on shortlisted alternatives is presented in Section 3.5.

To further highlight the significant efforts being made by the aerospace and defence sector to substitute chromates, examples of internal R&D projects and ongoing R&D collaborations are identified below. It is noted that multiple projects and collaborations are mentioned within the parent AfAs associated with the ADCR consortium Review Reports. However not all include research into the development of alternatives for bonding primers.

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

- **Airbus Chromate-Free project** aims to progressively develop new, environmentally friendly, Cr(VI)-free alternatives to qualified products and processes used in aircraft production and maintenance. At the time of submission of the parent AfAs, the project was ongoing and is organised into several topics, specifically addressing applications where chromates are used in production or applied to aircraft. Bonding primers were reported to be within the remit of the project.
- **'Chrome Free Bond Primer Systems' (CFBPS)** is a test programme for which Bombardier, along with academic and industrial partners were reported to be assessing high-TRL potential replacements for bonding primers.
- Multiple sub-projects under the **Highly Innovative Technology Enablers for Aerospace (HITEA)** project with partners including Innovate UK (part of UK Research and Innovation) and the Engineering and Physical Sciences Research Council (EPSRC). HITEA was initiated in 2012, with phase one ending in 2015 and two subsequent phases running (total funding £1.06 million). None of the solutions identified and tested at the time of publication of the parent AfA were reported to meet the qualification requirements for either adhesion or corrosion prevention. Work was reported to be ongoing to further improve the products.
- **Future Advance Nacelle Technologies and Structural Integration Concepts (FANTASTIC)** was referenced by an ADCR member as being linked to HITEA and considered alternatives to strontium chromate for bonding primers. The project was reported as stating in October 2018, with the funded period estimated to finish in September 2023.
- The **International Aerospace Environmental Group (IAEG)** Replacement Technologies Working Group (WG2), formed in 2011 provides a global framework for aerospace and defence manufacturers, including a number of companies within the ADCR, to collaborate on widely applicable, non-competitive alternative technologies. It was reported that interested member companies have worked on information exchange/survey projects focussed on

Cr(VI)-free alternatives for passivation of stainless steel and anodising of aluminium components, whilst it was stated two Cr(VI)-free primer projects have been recently launched.

- **NASA Technology Evaluation for Environmental Risk Mitigation (TEERM)** was reported to have a bond primer replacement project, where the aim was to produce joint test protocol to provide data necessary to justify use of Cr(VI)-free bond primers for aerospace applications. A number of bonding primers were tested through the developed protocol and were reported to have passed the first stage. It was reported that the next stage of testing would begin in 2017.
- **The US Strategic Environmental Research and Development Program (US SERDP)** concluded in its 2016 study "Understanding Corrosion Protection Requirements for Adhesive Bond Primers" chromated corrosion inhibitors in adhesive bond primers might not be as crucial for bonded joint durability as previously believed. Tests found little difference between chromated and non-chromated primers in adhesive bondlines. While some tests showed chromated primers improve environmental durability, surface preparation emerged as the primary factor influencing aluminium bonded joint performance.

Members of the ADCR also indicated involvement in the US Department of Defence Strategic Environmental Research and Development Program (SERDP), the objective of which was to investigate the primary functions of bonding primers and evaluate the necessity of corrosion inhibitors properties of Cr(VI). R&D partnerships between design owners and formulators formed under the bounds of Cooperation Research Agreements (CRAs) and Non-Disclosure Agreements (NDAs) have resulted in identification and shortlisting of specific bonding primer products which have shown varying degrees of success.

3.4.2 Consultations with customers and suppliers of alternatives

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

3.4.3 Data Searches

3.4.3.1 High level patent review

A patent search was performed with the aim of identifying examples of potential technologies related to bonding primers. The search was performed using Espacenet[25], the European Patent Office (EPO) open access search portal. Espacenet contains over 120 million patent documents held by patent offices around the world, including North America and Asia (EPO, 2020).

By way of example, the search terms "Bonding primer" and "Corrosion" were filtered via the main group classification filters C09 and C23 (description below):

- C09: Dyes; paints; polishes; natural resins; adhesive; compositions not otherwise provided for; applications of materials not otherwise provided for
- C23: Coating metallic material; coating material with metallic material; chemical surface treatment; diffusion treatment of metallic material; coating by vacuum evaporation, by sputtering, by ion implantation or by chemical vapour deposition, in general; inhibiting corrosion of metallic material or incrustation in general

[25] Espacenet Patent Office (2022): Available at https://worldwide.espacenet.com/ accessed 20 February 2023

This search returned 26 results. These 26 patents were screened by reading of the abstracts, and those identified as potentially relevant are presented in **Table 3-5 below**.

Table 3-5: Patent search technology summary		
Title	**Patent publication reference**	**Summary**
Primer composition for adhesive bonding and method of using the same	WO2021087238A1	Date of publication: 2021-05-06 The patent describes a solvent-based bonding primer composition containing one or more organic solvents, one or more epoxy resins, one or more curing agents, a silane compound, and a low amount of core-shell rubber particles in nanometer size, submicron or micron size. Also disclosed is a method of applying the solvent-based bonding primer composition onto a metallic surface of a first substrate prior to bonding the metallic surface to a second substrate via a curable adhesive. **Curable primer film with corrosion inhibitor. Non-chromate corrosion inhibitors cited:** metavanadate anion, e.g. sodium metavanadate, molybdate, phosphate, phosphonate, cerium or borate, and graphene. Also cited encapsulated releasable organic corrosion inhibitors described in US2010247922
Water Based Non-chromated primers for structural Bonding Applications	US2010247922A1	Date of publication: 2010-09-30 Non-chromated corrosion inhibiting primer formulations having one or more active corrosion inhibitors covalently anchored, or optionally covalently anchored, onto an organic and/or inorganic reactive specie are provided herein. **Cr(VI)-free corrosion inhibitors:** Organic or inorganic corrosion inhibitors drawn from: Amino benzothiazole-based compound, phenylmaleimide-based compound, inorganic compound comprising an ion chosen from $NaVO_3$, molybdate, cerium, and combinations thereof

Table 3-5: Patent search technology summary		
Title	**Patent publication reference**	**Summary**
Thermal spraying ceramic insulating coating and preparation method thereof	CN112458394A	Date of publication: 2021-03-09 The thermal spraying ceramic insulating coating comprises a priming coat, a potassium titanate middle layer and an aluminium oxide surface layer. The priming coat is located on the outer surface of a base body, the potassium titanate middle layer is located on the priming coat, the aluminium oxide surface layer is located on the potassium titanate middle layer, the priming coat is formed by a plasma spraying process, the thickness of the priming layer is 50-100µm, the middle layer is formed by potassium titanate powder by the plasma spraying process, and the thickness of the middle layer is 100-200µm. **Cr(VI)-free primer:** Selected from nickel-chromium-molybdenum, composite powder, nickel-clad aluminum, nickel-chromium-aluminum composite powder and molybdenum powder.
Preparation method of corrosion-resistant and ablation-resistant composite coating	CN110093579A	Date of publication: 2019-08-06 The invention relates to a preparation method of a corrosion-resistant and ablation-resistant composite coating. The preparation method includes the following steps in order: (1) pre-treating a workpiece; (2) spraying McrAlY alloy powder onto the surface of the workpiece by cold spraying to form a bonding bottom layer; (3) spraying 8YSZ ceramic powder onto the surface of the bonding bottom layer by plasma spraying to form a ceramic layer; (4) spraying Ta refractory metal powder onto the surface of the ceramic layer by cold spraying to form a corrosion-resistant metal layer; and (5) repeating the step (3) and (4) to alternately prepare ceramic layers and corrosion-resistant layers. **Corrosion and heat resistant composite layer** formed from McrAlY alloy powder where M represents Co or Ni, to form a bonded underlayer.

Table 3-5: Patent search technology summary		
Title	**Patent publication reference**	**Summary**
Aqueous primer composition for enhanced film formation and method of using the same	US2015096680A1	Date of publication: 2015-04-09 A water-based bonding primer composition and a method of applying the same onto a metallic surface prior to adhesive bonding. The bonding primer composition is a water-based dispersion containing water, one or more epoxy resins, one or more curing agents, a silane compound, a low amount of propylene carbonate (PC), and optional additives. The bonding primer composition can form substantially smooth films by spraying, and at the same time, meet environmental regulations and provide high bonding performance. **Cr(VI)-free corrosion inhibitors:** Inorganic examples cited, $NaVO_3$, VO_4 , V_2 O_7 , phosphate, phosphonate, molybdate, cerium, and borate. Organic examples; reference US2010247922
Waterborne epoxy derived adhesive primers	US5266611A	Date of publication: 1993-11-30 An aqueous structural adhesive bonding primer composition containing a water-dispersible, modified phenoxy resin, an amine-aldehyde resin and a catalyst for reaction between the resins. The primer may contain corrosion inhibitors, including a novel chromate-free inhibitor system. **Cr(VI)-free corrosion inhibitors:** Metal salt, and carboxylic acid families. Metal salt examples cited; cerium molybdate, sodium thioglycolate, barium tungstate, lithium borate, a calcium silicate on an amorphous gel of silica, and a precipitated calcium silicate. Carboxylic acid example (2-benzothiazolylthio)succinic acid

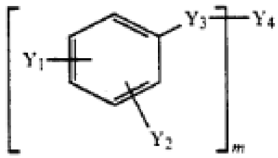
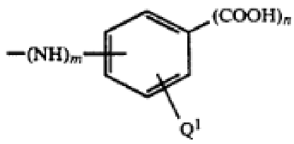
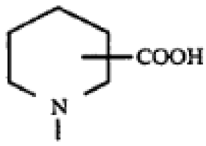
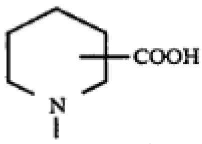
Corrosion resistant waterborne adhesive primers	US5260357A	Date of publication: 1993-11-09 Adhesive bonding primer composition containing a water-dispersible, modified epoxy resin and a water-dispersible corrosion inhibitor mixture of components I. and II. In which: Component I. is at least one, but not more than two of: (a.) a zinc salt of a carboxylic acid of the formula:  Y_4 is hydroxyl or a radical of the formula:  or  Y_3 is CO or SO_2, Y_2 is hydrogen, Y_1 is C_1-C_8 alkyl, C_1-C_8 alkoxy or halogen hydrogen when Y_4 is other than hydroxyl, carboxyl when Y_4 is hydroxyl, or hydrogen when Y_4 is;  Or Q^1 is nitro, or m is 2, Y_2 is hydrogen, C1-C8 alkyl, nitro, hydrogen or halogen, Q^1 is hydrogen, nitro or halogen, m and n each 1 or 2. (b.) zinc phosphate, and (c.) zinc molybdate

Table 3-5: Patent search technology summary		
Title	Patent publication reference	Summary
		Component II is at least one other corrosion inhibitor from groups (i) or (ii) below: (i) (2-benzothiazolylthio)succinic acid (ii) Metal salt, other than chromium, from Groups 1,2,3,4,5,6,7, and 12 of the Periodic Table. **Cr(VI)-free corrosion inhibitors:** Mixtures of zinc salt of a carboxylic acid, zinc phosphate, or zinc molybdate and (2-benzothiazolylthio)succinic acid, or metal salt, other than chromium, from Groups 1,2,3,4,5,6,7, and 12 of the Periodic Table.

As with all patents, those listed in **Table 3-5** introduce concepts and developments that may be advantageous within a given field in the fullness of time. However, it should be remembered that patents are granted for their novelty. Novelty does not necessarily translate to feasibility or applicability. The presence of these published patents within the public domain is by no means an indicator of their applicability within the demanding requirements of the A&D sector. Patented technologies are still bound to the requirements of the substitution process which will determine if a novel concept can be transformed into a feasible test candidate. Patents can also introduce limitations on the availability of a particular technology for example through the requirements for licencing. Where this is the case, a third party may obtain access to the technology if a licensing or some other commercial arrangement is available and meets the requirements of both parties.

Of those technologies listed above all are understood to include at least one alternative reported in the parent AoA. However, there are examples of more bespoke applications or refinements; for example, within US5260357A including the use of carboxylic acid(s).

One ADCR member who reviewed the output of this high-level patent search suggested that "thermal spraying ceramic insulating coating and preparation method thereof" and "preparation method of corrosion-resistant and ablation-resistant composite coating" were not suitable for bonding primers. In regard to the former method, it was indicated by the member that the unsuitability was attributed to the coating being metallic based[26]. For the latter, the member stated that this method was used as a primary layer on the substrate and does not provide the necessary functions generally required from the bonding primer coating.

Further, as reported in Section 3.1.2.2 it is the role of formulators to incorporate novel chemistries into viable proposed candidates for design owners to screen. Proposed candidates containing carboxylic acids have not been presented to members by formulators at this time, which may be because initial investigations by formulators have concluded that they would not meet performance

[26] This method deposits molten metal on the surface of the substrate surface, which is unsuitable for substrates that cannot withstand localized heating.

requirements of customers' designs or could be because other more mature test candidates are already available for which test candidate development plans are being progressed. If qualification, validation, certification, or industrialisation of the test candidates currently being progressed were to fail for particular components, formulators and downstream users may look to develop proposed candidates based on the novel method described in this or other patents, if the necessary licencing agreements could be reached.

3.4.3.2 High-level literature review

A non-exhaustive technical literature review was carried out using Science Direct (Journals and Books)[27] on-line service using the keyword search term 'Chromate-free corrosion resistant bonding primer'[28]. The purpose of this search was to identify examples of alternatives to Cr(VI) for bonding primers that have been investigated in the academic field or within other industry sectors. Although it is acknowledged that technical requirements for bonding primers in another sector may not be relevant within A&D, this non-exhaustive review demonstrates any potential sources of cross-fertilisation from other industries or academic research. This exercise is an example of initial screening for candidates from industry and academia. The high-level literature review compliments the parallel non-exhaustive patent search. The results returned from the search are summarised in **Table 3-6.**

Table 3-6: Literature search for Chromate free corrosion resistant bonding primer in Science Direct

Search term	Time period	Research articles	Review articles	Open access
Chromate-free corrosion resistant bonding primer	2010 – 2023	21	22	7

The title and abstracts of the 43 articles found were reviewed to identify those which were of genuine relevance to the analysis of alternatives to the use of chromates as corrosion inhibitors in bonding primers. An expanded review is presented below for the 5 that were deemed to be of most relevance, these articles are summarised in **Table 3-7.**

Table 3-7: Expanded review of selected scientific publications

Ref.	Article Title
1	Senani et al (2013), "Potentiality of UV-cured hybrid sol-gel coatings for aeronautical metallic substrate protection" Surface and Coatings Technology, Volume 227, 25 July 2013, Pages 32-37 https://doi.org/10.1016/j.surfcoat.2013.01.051 Abstract: The necessity of being compliant with the Health, Safety and Environment European rules and with the new assembly technologies is now more than ever an important driving force to replace existing aeronautical protection schemes. Hybrid sol–gels have been found to provide good corrosion resistance for metal substrates based on their ability to form dense barriers to the penetration of corrosion initiators (Raps et al., 2009; Wang and Bierwagen, 2009; Voevodin et al., 2003; Zheludkevich et al., 2005; Campazzi et al., 2007). To decrease diffusion ways of corrosive species, some organic groups of organoalkoxysilanes can react via a light-induced process to form an organic

[27] ScienceDirect.com | Science, health and medical journals, full text articles and books.

[28] Literature search conducted February 2023

Table 3-7: Expanded review of selected scientific publications	
Ref.	**Article Title**
	network. Moreover, compared to conventional thermal curing, photopolymerization presents numerous advantages. Indeed, on the one hand the fast curing allows to decrease production cycles and consequently manufacturing costs. And on the other hand, the curing at room temperature with low energy consumption and without solvents presents clear eco-friendly benefits. In this context, the aim of our approach is to assess if the UV-curing can replace, or decrease, the conventional thermal curing to obtain hybrid sol–gel coatings able to protect aeronautical metallic substrates against corrosion. **Cr(VI)-Free corrosion inhibitor:** Silane based coating
2	Bastos et al (2010), "Modification of zinc powder to improve the corrosion resistance of weldable primers" Progress in Organic Coatings, Volume 69, Issue 2, October 2010, Pages 184-192 https://doi.org/10.1016/j.porgcoat.2010.04.021 Abstract: This paper reports the modification of zinc powder to improve the corrosion resistance of weldable primers. These primers are thin zinc rich organic coatings applied by roll coating at the steel manufacturer. The automotive industry uses them to protect areas in the car body that become inaccessible after joining processes. In this work, with the objective of increasing the corrosion resistance of these systems, the zinc particles were chemically treated or simply replaced by powder of 55AlZn alloy. The rest of the formulation remained intact. The performance of the commercial and modified formulations was compared by SEM, SVET and EIS. The best results were obtained when the zinc powder was replaced by powder of the aluminium zinc alloy. **Cr(VI)-Free corrosion inhibitor:** zinc-based
3	Park et al (2020), "Analysis of process factors on corrosion resistance of adhesive bonded joints for aluminium alloys" Journal of Materials Processing Technology, Volume 276, February 2020, 116412 https://doi.org/10.1016/j.jmatprotec.2019.116412 Abstract: In the adhesive bonding process, the hydrolytic stability or corrosion resistance is of significant importance in achieving acceptable joint durability. The aim of this study is to identify the process factors affecting corrosion durability of adhesive bonded joints for aluminum alloys. For this purpose, experiments were carried out to investigate the influence of varying the surface treatment-primer-adhesive combination. The tests used for the evaluation of corrosion resistance included neutral salt spray and floating roller peel testing. In addition, the residual peel strengths after 300 days of exposure to salt spray were statistically analyzed using analysis of variance (ANOVA) and Tukey test (α=0.05) in order to understand the interaction effects between the process factors. The surface morphology, chemical composition and oxide thickness played a major role in the control of adhesion performance and joint durability. In particular, a hybrid sol-gel coating consisting of TPOZ (zirconium n-propaxine) and γ-GPS (γ-glycidoxypropyltrimethoxysilane) produced a microscopically rough surface with an increased surface energy compared with the standard phosphoric oxide. Furthermore, a non-chromate

Table 3-7: Expanded review of selected scientific publications	
Ref.	**Article Title**
	primer exhibited adequate corrosion protection efficiency when used with a sol-gel coating. The incorporation of zirconium oxide (ZrO2) in the sol-gel coating increased surface densification through pore-filling and planarization, finally resulting in high corrosion durability. **Cr(VI)-Free corrosion inhibitor:** silane-based
4	Chauhan et al (2020), "Graphene and graphene oxide as new class of materials for corrosion control and protection: Present status and future scenario" Progress in Organic Coatings, Volume 147, October 2020, 105741 https://doi.org/10.1016/j.porgcoat.2020.105741 Abstract: Graphene and graphene derivatives with the large surface area are receiving significant attention as good additives into anti-corrosion coatings due to their excellent hydrophobicity, chemical resistance, stability, high mechanical strength. The graphene oxide (GO), on the other hand, has shown high water dispersibility because of its hydrophilic nature, attributed to the presence of oxygen-containing functional groups. Moreover, the presence of functional groups on the surface of GO facilitates chemical functionalization, which enhances the dispersibility and corrosion inhibition performance. The GO-based aqueous corrosion inhibitors is a new area gaining attention from the corrosion scientists. The chapter features the major works on graphene and its derivatives as a new class of materials for corrosion control and covers the synthesis of modified GO and their salient features as corrosion-resistant coatings and inhibitors. The major objectives of this article are to explore the various covalent/ non-covalent approaches for the modification of graphene and GO. An outline of the different types of single and multi-layer graphene-based anticorrosion coatings is discussed. An overview of the literature on the chemically modified GO-based aqueous corrosion inhibitors is outlined with a focus on the different mechanisms underlying the corrosion protection behavior. Finally, the research prospects on some newly emerging 2D material-based corrosion protecting agents is also explored. **Cr(VI)-Free corrosion inhibitor:** graphene oxide
5	Gupta et al (2012), "Anti-corrosion performance of eco-friendly silane primer for coil coating applications" Progress in Organic Coatings, Volume 74, Issue 1, May 2012, Pages 106-114 https://doi.org/10.1016/j.porgcoat.2011.11.023 Abstract: In this paper, corrosion resistance and adhesion of environmentally friendly silane primer on coil substrate was studied. Primer was formulated by using methyltrimethoxysilane and 3-glycidoxypropyltrimethoxysilane via acid hydrolysis and condensation reaction. Three different formulations (5%, 15% and 30%) were developed on the basis of sol/water ratio. Aluminium coils was dipped into primer and cured at 120 °C for 20 min. Fourier Transform Infrared Spectroscopy and Scanning Electron Microscope was used to analyse the structural and morphological behaviour of the coating. Corrosion resistance of the coating was evaluated by salt-spray test and potentiodynamic polarization measurement. The adhesion behaviour of the coating was investigated by cross hatch test, before and after salt-spray immersion. Results showed that 15 wt%

Table 3-7: Expanded review of selected scientific publications	
Ref.	**Article Title**
	sol content showed significant improvement in the corrosion resistance, adhesion of the coating and its UV resistance. Silane primers have excellent adhesion with substrate and commercial grade polyester, polyurethane and 62olyvinylidene fluoride top coats. **Cr(VI)-Free corrosion inhibitor:** silane-based

Whilst most of the Cr(VI)-free corrosion inhibitors identified in **Table 3-7** are based on the same substances as those identified in the parent AfAs, graphene oxide represents a novel technology not previously considered. Therefore, it should be considered as a distinct proposed candidate. When this technology was presented to members, they reported that graphene oxide can pose major formulation challenges when used in practice. One member also reported that the use of graphene oxide may be prohibitively expensive if a viable proposed candidate based on this patent was presented.

3.4.4 Identification of alternatives

Proposed candidates for the replacement of Cr(VI) in bonding primers are shown in **Table 3-8** below. This list comprises all the alternatives that were reported in the parent AfAs, as well as any further proposed candidates identified during the above data searches.

Table 3-8: Proposed candidates for the replacement of StC in bonding primers
Proposed candidate
Cr(VI)-free inhibitors (confidential)
Calcium-based corrosion inhibitors
Molybdate-based corrosion inhibitors
pH-buffering additives
Phosphate-based corrosion inhibitors
Rare earth-based corrosion inhibitors
Rare earth, enhanced corrosion inhibitors (Rare earth complexes combined with molybdate or tungstate corrosion inhibitors)
Silane-based coatings
Silicate-based corrosion inhibitors
Graphene oxide

Note, those solutions identified following the high-level literature patent review presented above are not included in this list as at present they have not been presented as proposed candidates by the formulating companies and performance has not been assessed. This may be because initial investigations by formulators have concluded that they would not meet performance requirements of customers’ designs. If qualification, certification, or industrialisation of the test candidates currently being progressed were to fail for particular components, formulators and downstream users may look to develop proposed candidates based on these novel methods if the necessary licencing agreements can be reached.

As stated in Section 3.2.1, the technical feasibility criteria of test candidates for the substitution of Cr(VI) in bonding primers which must show equal or better performance compared to the incumbent wash primers are:

- Adhesion promotion;
- Mechanical load resistance (including impact resistance);
- Corrosion resistance (inc. active corrosion inhibition);
- Layer thickness;
- Chemical resistance;
- Temperature resistance (thermal shock resistance);
- Compatibility with substrate, preparatory treatment, and adhesive;
- Handling performance; and
- Visibility/ inspectability.

In support of initial screening, testing, also referred to as “critical-to-quality-tests”, is conducted to assess performance of proposed candidates in the laboratory environment for each of the criteria.

For bonding primer applications, corrosion resistance may be tested according to ASTM B117 or ISO 9227 (both salt spray tests), or EN 3665 (filiform corrosion test). In general, adhesion is tested according to ISO 2409 or ASTM 3359, and the adhesion of the bonding primer in combination with the corresponding adhesive is tested in shear, tensile, and peel tests (for example, EN2243-1, -2, -3). Bondline corrosion is typically tested through internal specific test procedures. The most relevant method for the assessment of layer thickness is ISO 2808 and general methods are available in the A&D sector for the testing of temperature resistance (for example, BS 2X 33, PR EN 4160, and HMDC 0097A). Chemical resistance can be tested using ISO 2812, whilst compatibility with substrates is also tested according to ISO 2409.

Further details on the above standards, as well as other examples of standards used for screening proposed candidates within the development phase of the substitution process are given in **Table A1-1** in Annex 1.

Not every proposed candidate will be tested according to all the standards listed above for a number of reasons. In the AoA questionnaire distributed to ADCR members, question 7 investigated the applicability of the technical feasibility criteria across each member’s substitution activities. It was unanimously agreed upon by ADCR members that adhesion promotion, mechanical load resistance, and compatibility with substrate/ preparatory treatment, and adhesive were required technical criteria for the potential candidates in the replacement of Cr(VI) incumbent bond primers.

Moreover, it was generally agreed upon that corrosion resistance (including active corrosion resistance) was an applicable technical feasibility criterion. However, one member stated that, in their case, only passive corrosion resistance was a requirement for the bonding primer. Similarly, chemical resistance was agreed to be a required technical feasibility criterion, with the exception of one member who indicated that bond primer surfaces are not exposed in service life and, therefore, only require resistance against non-aqueous solvents. Temperature resistance and processing temperatures were identified by at least one member to not be applicable technical feasibility criteria in their test candidate development plans.

Interrelationship of technical feasibility criteria and impact on the suitability of alternatives

Potential candidates to replace the use of Cr(VI) in bonding primers must meet the technical feasibility criteria, as described in Section 3.2.1.1. The interrelationship of the technical feasibility criteria plays a crucial role in determining the suitability of potential candidates, as it would be detrimental to the component during operation if certain criteria are limited due to the mechanisms of other criteria.

The relationship between corrosion resistance and layer thickness of the bonding primer should be considered. It is necessary for the potential candidate to attribute sufficient corrosion resistance while also having a minimal layer thickness, since bonding primers are commonly applied to components with restricted dimensions or tight geometric intolerances, i.e., bolts, screws, and moving parts. The bonding primer coating must also attribute a sufficient layer thickness as to not impede the adhesion of adhesives to the substrate. Crucially, maintaining minimum thickness of the coatings on the substrate equates to minimum weight of an aircraft, which is critical to the fuel efficiency.

Another consideration to be made is the relationship between processing temperature and temperature resistance, as it would be detrimental to the manufacturing process if the temperature resistant properties of the Cr(VI)-free candidate impeded the ability to process the primer at low temperatures; however, it is currently the case that the bonding primer cure temperature is identical to that of the adhesive, which is set by the temperature expected in service. Several curing temperature ranges are in common use in the A&D sector.

The bonding primer, in many cases, must also be compatible with multiple substrates while also retaining optimal adhesion promotion. It should be acknowledged that it is common for substrates to undergo preparatory steps before a bonding primer is applied in order to achieve optimal bonding conditions. The methods used for the surface treatment include, but are not limited to, chemical etching, mechanical grinding, or anodising. Considering this stage of the manufacturing process, it is beneficial for the adhesion promoting properties of the bonding primer to be relatively unform across substrates in order to decrease the likelihood of complicating the coating process.

Visibility of the bonding primer is key to controlling its layer thickness and is an important factor explained earlier in Section 3.4.4. It is a possibility that a Cr(VI)-free alternative will not make the bonding primer clearly visible and, as such, specialised inks/ pigments may need to be added to help control application across parts that are already treated, ensuring a uniform layer. While no specific cases were mentioned by ADCR members, there is potential for dyes to detrimentally impact the performance of the bonding primer.

The GCCA application for authorisation (GCCA, 2017a) considers design and operating parameters that could impact similar components which can influence behaviour and compatibility with a primer, and therefore delivery of technical feasibility criteria. These are listed below[29]:

- Hardware[30] base alloy(s);
- Contact or mating surfaces with other components;
- Exposure to fluids (e.g., de-icer, lubricants, salts, sea water/moisture);
- Structural stress and strain;
- External environment (including temperature, humidity, wind/rain erosion, etc.);
- Functional characteristics; and
- Service life.

Interaction effects such as galvanic influences from dissimilar metals, galling, erosion, and mechanical vibration can fundamentally affect the corrosion behaviour of a component and the performance requirements which any Cr(VI)-free primer alternative must meet. Due to the complexity of these

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

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

assemblies and the variety of environments encountered in service, a single alternative may not provide a universal solution to delivery of all technical criteria under all scenarios of use.

3.4.5 Shortlist of alternatives

Based on the ongoing assessment of those proposed candidates listed in **Table 3-8** against the technical criteria listed in Section 3.4.4, the following proposed candidates have been progressed to test candidate status:

Table 3-9: Shortlisted alternatives for the replacement of StC in bonding primers
Shortlisted alternatives
Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors
pH-buffering additives
Phosphate-based corrosion inhibitors
Silane-based coatings

These are discussed in more detail in Section 3.5.

It is worth noting that there is no single most promising alternative, despite the identification of the six shortlisted alternatives in **Table 3-9** above. No single shortlisted alternative should be considered more promising than any other, due to the range and coating requirements of components which require a layer of bonding primer. Namely, one potential candidate may not attribute the correct requirements for two identical components used in two separate systems, nor has any one shortlisted alternative been identified to match or exceed the technical performance of Cr(VI)-based bonding primers in the literature review or in discussion with ADCR members.

As showed in **Table 3-9**, several of the potential candidates that were identified as suitable alternatives to strontium chromate in the parent AfA (shown in **Table 3-4**) have not been shortlisted in this AfA because of poor technical performance observed. This includes:

- Calcium-based corrosion inhibitors;
- Molybdate-based corrosion inhibitors; and
- Silicate-based corrosion inhibitors.
- Rare earth-based corrosion inhibitors
- Rare earth, enhanced corrosion inhibitors (Rare earth complexes combined with molybdate or tungstate corrosion inhibitors)

Graphene oxide was identified in the bonding primer background paper literature review (discussed in Section 3.4.3) as another potential candidate after not being considered in the parent AfA. However, after receiving ADCR members' responses to the AoA questionnaire, graphene oxide was deemed to either not be relevant to bonding primers or to not have achieved a high enough TRL to warrant further investigation.

Calcium-based, molybdate-based, silicate-based, rare earth-based, and enhanced rare earth corrosion inhibitors were not included in the shortlist, either due to insufficient internal testing done by ADCR members at this time, or poor technical performance observed during testing that was carried out.

3.5 Assessment of shortlisted alternatives

3.5.1 Introduction

To achieve certification or approval by the relevant authority and/or design owner each component must meet the performance and safety requirements provided by the incumbent Cr(VI) based primer.

Approval of the test candidate must include a complete understanding of the influence of the treatments applied prior to the primer, and the layers applied after the primer, within the surface treatment and coating system as a whole. This is to understand the influence of all processes involved in the treatment 'system' including surface treatments and coating layers. Evaluation of the technical feasibility of a test candidate for bonding primers should consider its behaviour in combination with other supporting treatments within the 'system'. Any change in these system variables may lead to irregular or unacceptable performance of the test candidate for replacement of the primer and consequently impact or delay approval of the alternative for different component designs. This scenario is a leading reason for the graduated implementation of viable test candidates in combination with different component/design families. Different designs exhibiting varying degrees of complexity, have the potential to interact with elements of the treatment system differently and thus effect the performance of a test candidate.

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

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

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

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

To be available, a test candidate should meet the regulatory requirements of placing it on the market. Until the technical feasibility criteria and associated performance requirements of the use and wider

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

treatment system are fulfilled, including all certification obligations as stipulated in the Airworthiness Directives[32], the test candidate cannot be deemed 'available'.

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

3.5.2 Test candidate 1: Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

3.5.2.1 Introduction

For bonding primer applications, some Cr(VI)-free epoxy/PU-based alternatives were reported in the parent AfA to be available on the market, however composition of the alternative was reported as confidential business information and the specific corrosion inhibiting substance was not disclosed.

Continuous innovation and development of test candidates, often in mixed form, in the period since the parent authorisations were granted is a consequence of the need to replicate the key functions and performance requirements delivered by chromated primers used across a wide range of substrates and in-use conditions. The specific composition of inhibitors used in these blends is confidential business information to the formulators and could therefore not be disclosed to the ADCR consortium or its members. However, during consultation with ADCR members, it is understood that some proprietary blends are comprised primarily of test candidates 2, 3, and 4.

These primers are stated to show equivalent performance with regard to standard corrosion testing, adhesion performance and are partly compatible with substrates. R&D was reported to be advanced for steel substrates, where the implementation phase was about to start. For other substrates, further time is necessary. In laboratory tests conducted by multiple ADCR members, no corrosion pits were seen on AA2024-T3 Al alloy. However when tested on alloys pre-treated with Cr(VI)-free conversion coatings, performance was clearly not sufficient. The tested system did not provide active corrosion inhibition, as tarnishing with aluminium hydroxide appeared inside the scratch. With regard to adhesion, chemical resistance and compatibility with the substrate, sufficient performance results were achieved (CCST, 2015b).

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

[33] UK CAA (2024), available at Our role | Civil Aviation Authority (caa.co.uk) accessed 20 June 2024

3.5.2.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

ADCR members have reported multiple technical results from the ongoing development of confidential Cr(VI)-free alternatives for bonding primers, which are discussed in the following sections. Of the relevant performance criteria discussed in Section 3.2.1, corrosion resistance, adhesion promotion, and handling performance were reported by ADCR members as key reasons for failure of the proprietary blends of Cr(VI)-free test candidate bonding primers. Typically, candidates under this category are at TRL 3, although it has been reported that some candidates are at <TRL 3 as testing has not yet concluded. It was also indicated by one ADCR member that two candidates have reached TRL 6 for their application.

Corrosion resistance

A number of ADCR members reported a general regression in the corrosion resistance performance of Cr(VI)-free inhibitors when undergoing salt spray testing, some examples of which can be seen in **Figure 3-10** below. Certain test candidates that are being tested by ADCR members are providing various degrees of success depending on the substrate in use. For example, while sufficient corrosion resistance was experienced on 2000 series aluminium alloys, the opposite was observed for 7000 series aluminium alloys.

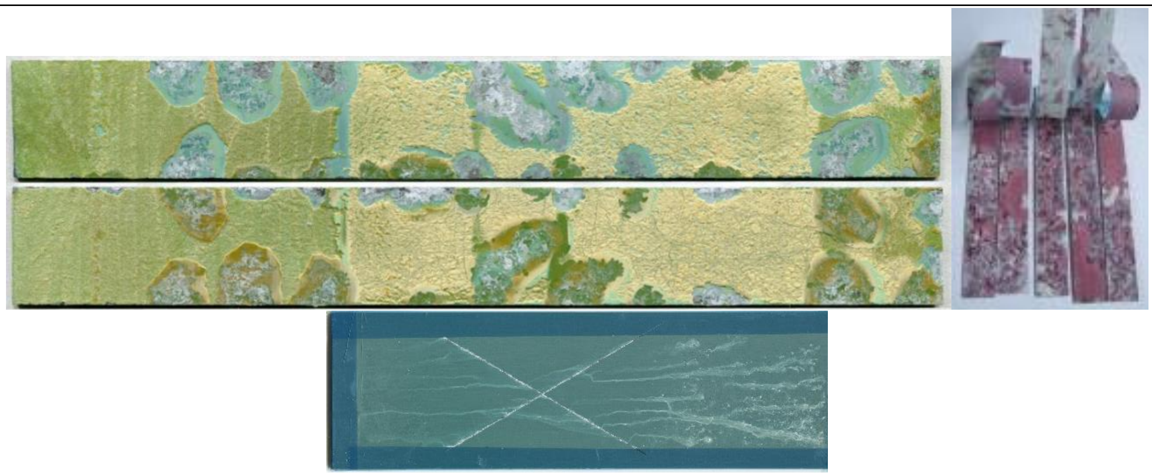


Figure 3-10: Photographic evidence from ADCR members to convey performance of proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors
Source: ADCR member

Further corrosion resistance failures were experienced by another ADCR member after 500 hours of salt spray testing. Heavy levels of corrosion were recorded in a scribed 'X' as well as the field area surrounding the scribe.

Adhesion promotion

One ADCR member indicated that the majority of their test candidates did not meet the adhesion promotion requirements and exhibited inferior peel strength under certain conditions and paired with the in-use adhesive. It was reported by another ADCR member investigating an identical test candidate that the adhesion promotion performance requirements were met on certain 2000 series aluminium alloy (either phosphoric acid anodising or phosphoric sulphuric acid anodising preparatory step) while using a different adhesive. However, the former-mentioned ADCR member's testing of the aforementioned candidate did not meet performance requirements when tested on 7000 series aluminium alloys, and that a further change in adhesive needs to be actioned.

Economic feasibility of proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

Multiple ADCR members indicated that the material price would likely increase, with a single member indicating an increase of up to 200%. While it was generally agreed upon by members that a replacement/ modification of equipment would not be necessary (and, therefore, no costs associated with a transition), one member did indicate that the time to apply the bonding primer layer would triple with the currently used recommended spray gun settings. Moreover, another member indicated that entirely new spray equipment would need to be implemented, costing both time (to train staff) and money. Members estimated that the cost of R&D, testing, and certification of the implementation of short-listed alternatives would be, at a minimum, €1 million per company.

Health and safety considerations related to the use of proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

Due to the confidential nature of the main point of difference between Cr(VI)-based and Cr(VI)-free bonding primer formulations, it is not possible to assess the specific health and safety considerations for these test candidates. However, since Cr(VI)-free formulations are developed with the intention of removing the CMR hazard arising from the presence of Cr(VI), it is likely that all confidential Cr(VI)-free inhibitors used do not present carcinogenic, mutagenic or reprotoxic properties, and would therefore constitute a reduction in overall risk compared to the incumbent Cr(VI)-based bonding primers.

One ADCR member indicated that one of their potential candidates demonstrated an unacceptable risk to human health; therefore, it was removed from further consideration as to avoid a regrettable substitution.

Availability of proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

ADCR members generally agreed that the Cr(VI)-free inhibitors would be available in the quantities required to meet the demands for their activities, despite being in the early stages of development, as the majority of confidential candidates are commercial products.

Suitability of proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

This category of test candidates have shown the most progression within the A&D sector so far for some applications of bonding primers. TRLs range from TRL 2 to TRL 6, depending on the specific requirements of each substitution. While these alternatives have shown the most maturity since the submission of the Parent AfAs, they have shown a regression in technical performance compared to Cr(VI)-incumbent bonding primers. Therefore, they cannot be considered a generally available suitable alternative for the A&D sector.

3.5.3 Test candidate 2: pH-buffering additives

3.5.3.1 Introduction

pH-buffering additives contain substances such as magnesium oxide, magnesium hydroxide, calcium carbonate, and calcium hydroxide that serve to neutralise acidic conditions that support corrosive attack. In the parent AfA, several primer formulations of this class were reported to have been tested by formulators and OEMs, with the result showing insufficient performance with regards to corrosion requirements for the majority of A&D applications (GCCA, 2017).

In summary, these systems were not concluded to be technically equivalent to Cr(VI)-based products.

3.5.3.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of pH-buffering additives

While pH-buffering additives were determined to be unsuitable alternatives to Cr(VI)-based bonding primers in most situations, one ADCR member identified a confidential candidate as part of a blend formulation as having reached TRL 6. The candidate was identified to have been tested on aluminium and its alloys solely. It has been indicated that tests are currently ongoing to determine the performance of each technical criteria explained in Section 3.2.1. Moreover, it was reported by the ADCR member that tests for handling performance and inspectability have concluded, with the test candidate meeting both requirements.

Economic feasibility of pH-buffering additives

It was reported by the ADCR member who identified the blend pH-buffering additives as a potential candidate that any Cr(VI)-free bonding primer will incur a larger cost of material. Although that increase is expected to decline when their use is extended over an undetermined period of time. Moreover, it was indicated that an additional process step would further increase costs, although an estimate was not provided.

Health and safety considerations related to the use of pH-buffering additives

Due to the confidential nature of the identified candidate, it is not possible to assess the specific health and safety considerations for the test candidate. However, since Cr(VI)-free formulations are developed with the intention of removing the CMR hazard arising from the presence of Cr(VI), it is likely that the candidate in question does not present carcinogenic, mutagenic, or reprotoxic properties, and would therefore constitute a reduction in overall risk compared to the incumbent Cr(VI)-based bonding primers.

Availability of pH-buffering additives

The ADCR member who identified the confidential pH-buffering additive candidate stated that a supply chain is currently in place and stock is expected to be available.

Suitability of pH-buffering additives

pH-buffering additives may be used to replace Cr(VI)-based bonding primers in some capacity in the future, supported by the advanced TRL stage reported by one ADCR member. However, the majority of the technical feasibility criteria have not yet been conclusively tested, namely corrosion inhibition and adhesion promotion, to determine the suitability of this test candidate. Taking into consideration the opinions drafted in the parent AfA by formulators, as well as the lack of supporting data by the ADCR member in question, pH-buffering additives cannot be considered a generally suitable alternative.

3.5.4 Test candidate 3: Phosphate-based corrosion inhibitors

3.5.4.1 Introduction

Phosphate produces a surface layer on the applied substrate which provides a degree of corrosion protection. Polyphosphates were identified in the parent AfAs as amongst the technically most promising Cr(VI)-free anticorrosive inhibitors where high performance protection is required, and several phosphate-based inhibitors were undergoing R&D by formulators. The exact substance identity and composition in primers was not reported as this was confidential business information (CCST, 2015a).

It was reported that a water-based chromate-free epoxy-based bonding primer containing aluminium metaphosphate is commercially available for use on several metals and alloys (titanium, titanium alloys, aluminium, aluminium alloys, steel and stainless steel). Its standard corrosion performance is stated to be only equal to strontium chromate in bonding primers for specific space applications where corrosion resistance requirements are lower than for the main processes within the A&D sector. Furthermore, no information on long-term corrosion performance is reported to be available. Like all phosphate-based corrosion inhibitors, this inhibitor does not provide active corrosion inhibition. Adhesion was stated to be equal to that of bonding primers containing strontium chromate (CCST, 2015b). Inhibitors of this type are also used in primers on steel, galvanised steel and aluminium for the non-A&D applications such as painting of trucks, buses and agricultural vehicles. It was reported however, that commercially available products were not sufficient for bonding primer applications in the A&D sector (GCCA, 2017).

R&D for the A&D sector was reported as ongoing in the field of phosphate-based corrosion inhibitors. It was reported that formulators consistently reported a large variety of different phosphate-based substances that are or have been included in R&D programs (preferentially on aluminium alloys). However, none of the companies succeeded in developing a phosphate-based primer which provides sufficient performance with regard to the requirements of the A&D industry (CCST, 2015b).

3.5.4.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of phosphate-based corrosion inhibitors

A number of technical results from the ongoing development of phosphate-based corrosion inhibitors have been reported by ADCR members. The majority of members indicated that at TRL 3 tests are still ongoing, so no conclusion of the modes of failure can be drawn. One member, whose test candidate failed at the TRL 3 stage and is no longer in consideration, indicated that the failure of the candidate was due to a regression in adhesion promotion and handling properties. Specifically, the adhesion promotion was deemed to be inferior to that of another phosphate-based test candidate. Therefore, it was removed from consideration, and new spray techniques and adhesion promotors would have to be introduced to elicit the change. As for the candidate with superior adhesion promotion, the ADCR member indicated that this is currently undergoing TRL 6 tests. In total, across all members who reported to be investigating the eligibility of phosphate-based candidates, two test candidates are at the TRL 6 stage, and four are at TRL 3.

Economic feasibility of phosphate-based corrosion inhibitors

It was generally agreed upon by members who identified phosphate-based corrosion inhibitors that any move away from Cr(VI)-based bonding primers towards Cr(VI)-free bonding primers would incur an increase in cost for the Cr(VI) replacement. One member reported that there would be a necessary change to equipment, which would also require the retraining of staff – costing both time and money. Conversely, this change to equipment was deemed nonessential by a different member, and the only cost increase would be a product of an increase in material cost.

Health and safety considerations related to the use of phosphate-based corrosion inhibitors

The identified candidate of one ADCR member was reported to present endocrine disrupting properties, resulting in no reduction in risk compared to the incumbent chromate and, as such, the test candidate was removed from contention. Of the four candidates identified to be at TRL 3, all presented no properties that would qualify the switch to Cr(VI)-free inhibitors as a regrettable substitution.

One member, who identified a test candidate currently being tested for TRL 6, indicated that the formulation presented the following classifications: Highly flammable liquid and vapour (H225), Causes serious eye irritation (H319), May cause an allergic skin reaction (H317), Suspected of damaging the unborn child (H361d), May cause drowsiness or dizziness (H336), and Toxic to aquatic life with long lasting effects (H411). The most significant cause for concern from the above list is H361d, and while the test candidate may be deemed a lesser harm to human health than strontium chromate, measures would likely have to be implemented (or existing safety measure modified) in order to mitigate exposure levels to workers.

Availability of phosphate-based corrosion inhibitors

The ADCR members who identified the confidential phosphate-based corrosion inhibitors as test candidates stated that a supply chain is currently in place and stock is expected to be available.

Suitability of phosphate-based corrosion inhibitors

While some phosphate-based test candidates are in a more advanced TRL stage than reported previously in the Parent AfA, a clear pattern of regression has been shown across multiple of the technical feasibility criteria, including the critical performance parameters adhesion promotion and corrosion inhibition. These limitations in technical performance show that these test candidates will not likely be considered a viable alternative for the wider A&D sector. Furthermore, as stated, one candidate was reported to attribute endocrine disrupting properties, resulting in no reduction in risk compared to Cr(VI)-incumbent bonding primers.

3.5.5 Test candidate 4: Silane-based coatings

3.5.5.1 Introduction

It was reported in the parent AfA that silanes and organic resins had been combined to form “superprimers”, intended to replace the existing “chemical conversion + primer” combination on aluminium alloys. The superprimer contains more silanes than required for crosslinking of the polymer, and therefore the silanes are able to form a siloxane network. Silanol groups contained within the network are also able to react with the metal hydroxide. These “superprimers” however demonstrated insufficient corrosion resistance, as well as showing significant deficiencies relating to mechanical properties and chemical resistance (CCST, 2015b).

Commercial sol-gel coatings were also reported to be available on the market, however they clearly did not provide sufficient corrosion protection to meet the majority of requirements of the A&D sector. Systems which would provide sufficient corrosion resistance were reported to be in early research stages (TRL 2).

3.5.5.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of silane-based coatings

One ADCR member indicated to be testing the feasibility of silane-based coatings, of which the candidate was said to currently be subject to TRL 3 tests. While no definitive statements on readiness level or test evidence was provided, the member described the corrosion inhibition performance of a test candidate as ‘promising’. Moreover, a different ADCR member stated that silane-based coatings offer inferior bond performance compared to epoxy bonding primers. The extent of this technical performance disparity was stated to be substantial enough for silane-based coatings to be considered as an adhesion-promoting preparatory step rather than a bonding primer.

Economic feasibility of silane-based coatings

It was generally agreed upon by members who identified silane-based corrosion inhibitors that any move away from Cr(VI)-based bonding primers towards Cr(VI)-free bonding primers would incur an increase in cost for the Cr(VI) replacement. Conversely, it was unanimously agreed that there would be no necessary changes to the production process; although, one member did indicate that new spraying equipment would be required in the case of implementation.

Health and safety considerations related to the use of silane-based coatings

One ADCR member provided the safety data sheet for their silane-based test candidate, which was revealed to attribute the following CLP classifications: Eye Dam. 1(H318), Skin Sens 1 (H317), Skin Irrit. 2 (H315), STOT SE 3 (H336), and Aquatic chronic 2 (H411). While the test candidate may be deemed a lesser harm to human health than strontium chromate, measures would likely have to be implemented (or existing safety measure modified) in order to mitigate exposure levels to workers.

Availability of silane-based coatings

The ADCR members who identified the silane-based coating candidates stated that a supply chain is currently in place and stock is expected to be available.

Suitability of silane-based coatings

Silane-based coatings cannot be considered a suitable alternative, due to reported regression in adhesion promotion properties when compared to Cr(VI)-incumbent bonding primers. Moreover, there was indication by members of the ADCR that silane-based coatings were more suitable as a intermediary coating in order to assist with achieving suitable adhesion. Furthermore, the potentially higher hazard profile of silane-based coatings compared to other test candidates may further limit their overall suitability as an alternative.

3.6 Conclusions on shortlisted alternatives

Table 3-10 summarises the current development status of the test candidates to replace strontium chromate in bonding primers. A qualitative assessment (Low, Moderate, or High) has been provided for each of the criteria: technical feasibility, economic feasibility, risk reduction, availability, and suitability. The qualitative assessment is provided as a high-level summary and is based on the detailed discussions in the preceding sections. To confirm, 'high', 'moderate' and 'low' represent an acceptable, partial, and poor level of compliance with the individual criterion, respectively.

Table 3-10: Summary of the suitability of shortlisted alternatives to Cr(VI)-based bonding primers

Test candidate	Technical feasibility	Economic Feasibility	Risk reduction	Availability	Suitability
Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors	Low-Moderate	Moderate	Moderate	Moderate	Moderate
pH-buffering additives	Low-moderate	Low	Moderate	Moderate	Low
Phosphate-based corrosion inhibitors	Low-moderate	Moderate	Moderate	Low-Moderate	Moderate
Silane-based corrosion inhibitors	Low	Moderate	Low	Moderate	Low

As seen in the summary table above, the only test candidates whose overall suitability as a potential alternative to Cr(VI)-based bonding primers is Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors and phosphate-based corrosion inhibitors. This is based on the grounds of being the only test candidates to show sufficient technical feasibility to progress beyond early TRL levels, where candidates under these categories are typically at TRL 3, with TRL 6 being reached in some cases. While it was reported than a pH-buffering additive test candidate reached TRL 6, the majority of the technical feasibility criteria have not yet been conclusively tested, namely corrosion inhibition and adhesion promotion, to determine the suitability of this test candidate. Silane-based corrosion inhibitors were stated to still be at, or before, TRL 3. Aside from technical feasibility, alternative categories generally show good promise in other assessment areas, where no particular issues in economic feasibility, risk to human health or availability were identified during consultation. On the other hand, detailed assessments in these areas are not generally carried out before the candidate has achieved higher technical maturity as to not waste valuable resources on a candidate which is likely to be technically infeasible.

3.7 The test candidate development plan

3.7.1 Introduction

3.7.1.1 Factors affecting the test candidate development plan

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

- Functionality and ability to meet performance requirements (technical feasibility);

- Availability, and suitability of the alternative;
- Process changes such as equipment, training, health and safety (*Technical challenges and economic feasibility*);
- A substitution process which is subject to regulatory control, legal constraints, and customer requirements;
- Economic feasibility, including the capital and operational costs of moving to an alternative and the costs of implementing the alternative across the supply chain; and
- Progress and alignment with other REACH substitution workstreams.

Each factor will contribute to the achievement of milestones that must be met to realise delivery of the substitute(s) to Cr(VI) for bonding primers. They require continuous review and monitoring to ensure that the test candidate development plan progresses through its phases and all changes are clearly documented. Monitoring of progress markers associated with the test candidate development plan includes a timetable of steps and targeted completion dates, assessment of the highest risks to progression, and how these risks can be reduced (if possible), which may not always be the case. One of the major risks continues to be the severely limited availability of non-chromated bonding primer test candidates, due to the small volumes of bonding primer used in the A&D industry, coupled with the very high-performance requirements needed on bonded parts. In practicality, there is not much of an economic incentive for the formulators to develop a variety of new test candidates for such niche applications.

3.7.1.2 Test candidate development plans within individual members

Each ADCR member has a test candidate development plan to replace bonding primers containing Cr(VI) that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple development plans for bonding primers, running in parallel work streams. The reason for different plans within one member is that they are segmented by factors such as type of substrate, type of component, type of alternative, and type of coating system. These different development plans are progressed simultaneously although they typically have differences in timing of milestones and anticipated achievement of each milestone (TRL/MRL level). Various factors such as the technical difficulty of introducing the alternative, the number of components onto which the existing primer is applied, the availability of expert resource, specialist test facilities, and prioritisation of certain types of component influence progress of the development plan.

3.7.1.3 Interplay with other test candidate development plans

As noted in Section 2.3.1.2, a surface treatment is often undertaken prior to application of the bonding primer, and this is commonly chemical in its nature (e.g., anodising or sol-gel). Both of these surface treatments have historically used Cr(VI), and in many cases members have already implemented Cr(VI)-free anodic processes for use prior to primer application. However, there are still a number of ongoing development plans for this use and particularly for the replacement of Cr(VI)-based chemical conversion coating; a process used prior to primer application by some members.

The progression and success of development plans for the replacement of bonding primers containing strontium chromate is dependent on the development and implementation of Cr(VI)-free formulations for use in these associated treatments. Any unexpected obstacles affecting the progression of these test candidate development plans will impact the planned timing of the test candidate development plan for bonding primer replacement.

In many cases, a member will target substitution of Cr(VI) from both the surface treatment and bonding primer at the same time.

3.7.2 Test candidate development plans for ADCR members in bonding primers

3.7.2.1 Test candidate development plans

The expected progression of ADCR members' development plans to replace bonding primers containing strontium chromate is shown in **Figure 3-11** below. The progressive stages of the development plan (development, qualification, validation etc.) are shown in the diagram and described in detail in Section 3.1.2. Implementation and progression of development plans ultimately leads to reduced Cr(VI) usage. MRL 10 is the stage at which manufacturing is in full rate production and is therefore where Cr(VI) use is expected to be eliminated due to replacement with an alternative within the use covered by the relevant development plan.

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

The data in the figure below shows the expected progress of 23 distinct test candidate development plans for bonding primers containing strontium chromate. This covers different plans across different members, and multiple plans within individual members. The data has been aggregated to present the expected progress of the substitution of bonding primers containing strontium chromate for the ADCR consortium as a whole.

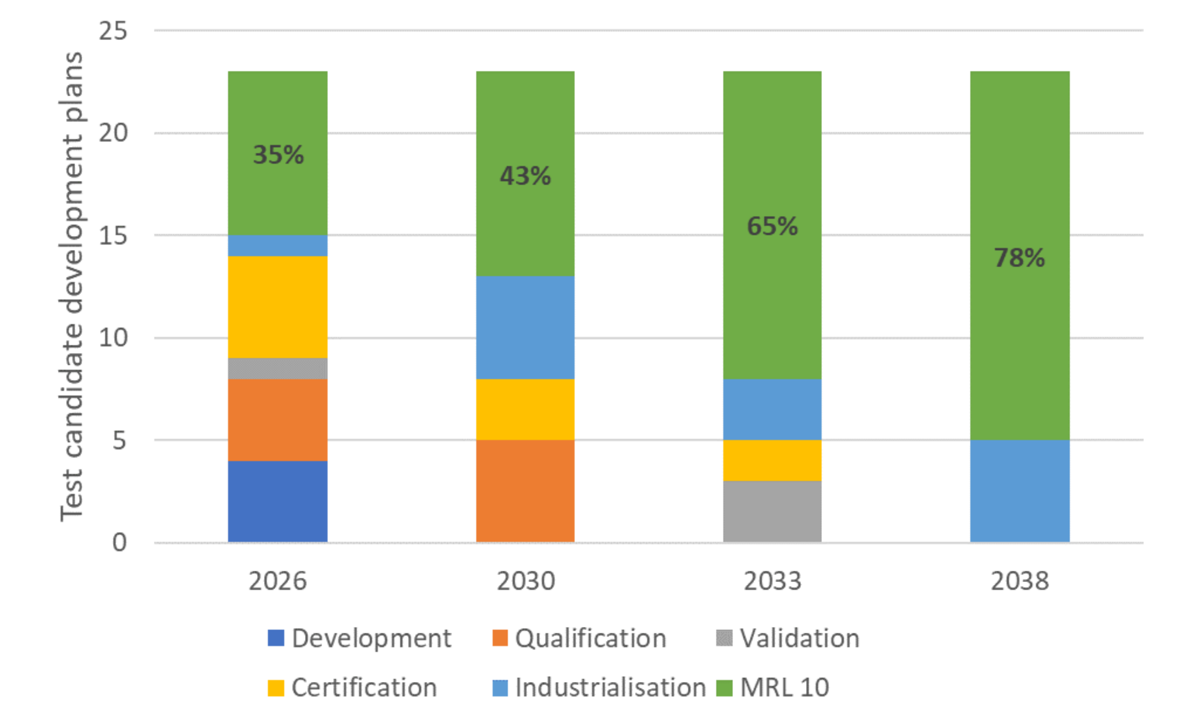


Figure 3-11: Expected progression of test candidate development plans for the use of bonding primers containing strontium chromate by year.
The vertical axis refers to number of test candidate development plans (some members have multiple test candidate development plans for bonding primers). The percentage value shown on each of the green bars indicates the proportion of test candidate development plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which manufacturing is in full rate production/deployment and it is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.
Source: RPA analysis, ADCR members

The above summary shows:

- Variation in the status of different test candidate development plans in each of the years (this variation is due to issues such as technical difficulty, types of surface treatment, types of substrates, types of components); and
- Expected progression in future years as an increasing proportion of the test candidate development plans reach MRL 10.

The dates at which each test candidate development plan is expected to achieve each stage are estimates provided by the members. There are uncertainties in these estimates due to, for example, unexpected technical failures which may only reveal themselves at more advanced stages of testing. Consequently, the expected progress of the development plans, especially in the outer years 2033 and 2038 where there is more uncertainty, may be slower (or faster) than estimated today, as presented in **Figure 3-11**. The actual status of the test candidate development plans 12 years from now could be different to our expectations today.

Because many members have multiple test candidate development plans for bonding primers, it is the case that for those development plans that are not expected to have achieved MRL 10 by a given date, other development plans from the same member will have progressed to this level. This highlights the complexity of multiple development plans within members. The timeline associated with any individual substitution activity will dependent on a multitude of factors including: the number and nature of technical criteria associated with the formulation to be substituted; the level of research into proposed candidates which has already been undertaken by formulators; the number of components onto which the existing formulation is applied; the availability of expert resource and specialist test facilities; the interrelationships with other processes which are also being substituted; the availability of a supply chain to industrialise the new process; and the level of process change, for example, commissioning equipment, staff training, and health and safety considerations associated with implementation of the alternative.

The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any technically feasible alternatives to date. This is illustrated by the near equivalence between the number of test candidate development plans at the development phase in 2026, and the number where it is anticipated MRL 10 will not be reached by 2038. For proposed candidates which have not yet progressed beyond TRL 3, predicting the length of time until industrialisation will be completed can be a particularly difficult task because iterative re-formulations of a proposed candidate are not uncommon. Each of these re-formulations results in the timeline for this development plan being reset. A proportion of those test candidate development plans which are not anticipated to progress to MRL 10 until 2038 or beyond are also impacted by the needs of MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

The timeframes associated with the activities presented in **Figure 3-11** result from the requirements of the substitution process which are presented in Section 3.1.2. To be noted also is that approval of suppliers cannot always occur in unison; qualification may need to cascade down the supply chain depending upon the number of tiers and actors involved. As resources are not available to action this simultaneously across all suppliers, the timescale for supplier qualification may be extended. Modifications may be required to the supply chain to allow for the installation of new equipment in some cases, although this can be mitigated by sourcing from existing established suppliers familiar with the requirements of qualification protocols.

It is of note that for 35% of test candidate development plans shown, MRL 10 is anticipated to be reached before the end of the existing review period. As discussed in Section 3.1.2.2, industrialisation of alternatives is usually scheduled to follow a stepwise approach to minimise technical risks. However significant investment, worker training and support documentation may be required to adapt the manufacturing processes before alternatives can be implemented. Unforeseen delays in any of these areas may impact on substitution being completed prior to 2026. Additionally, for those development plans within this 35% for which certification is currently ongoing, additional actions may arise as an outcome of the certification process, which could delay implementation beyond 2026.

3.7.2.2 Requested Review Period

It can be seen in **Figure 3-11** that despite ongoing and concerted efforts of the members to develop and implement alternatives to bonding primers containing strontium chromate, it has not proved possible to replace Cr(VI) by the end of the review periods granted in the parent authorisations (which end in 2026).

It is clear from the chart that in 2033 (equivalent to seven years beyond the expiry date for the existing applications), while many test candidate development plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a proportion are not expected to have achieved MRL 10 and are expected to be at the validation, certification or industrialisation stage. The bespoke nature of test hardware; to validate treatment changes can extend development plans, refer to Section 3.1.2.2 – Validation. Time may be required to build bespoke test rigs or identify and procure appropriate test facilities. As introduced in Section 3.1.2.1, where multiple design owners are progressing individual development plans, demand may exceed supply for out-sourced test facilities, including specialised expertise, potentially delaying some development plans. Where this isn't a restriction and internal test facilities and expertise are available, test programme prioritisation may still be necessary. For example, availability of human resources may be finite over a given time period preventing parallel rate of progression for multiple development plans. It may be preferable to prioritise testing of in-production designs over out of production legacy aircraft and equipment, depending on individual design owners' commercial requirements. For these development plans there is still expected to be a need for the use of Cr(VI). Moreover, Cr(VI) incumbent bonding primers are expected to be required in 2038 due to the number of test candidate development plans still at the industrialisation stage.

As a result of the individual members' test candidate development plan summarised above, the ADCR requests a review period of **12 years** for the use of bonding primers containing strontium chromate.

4 Continued Use Scenario

4.1 Introduction

Section 3 provided an analysis with respect to the technical feasibility, economic feasibility, risk reduction, availability, and suitability of alternatives. The assessment highlights the importance of Cr(VI) for adhesion promotion and corrosion protection (resistance and inhibition) in bonding primers. Although some of the companies supporting this use have industrialised Cr(VI)-free alternatives for some components, this has not yet been achieved across all components or products.

Until suitable alternatives which are compatible with all the relevant primer processes and which deliver an equivalent level of functionality are qualified, validated and certified for the production of individual components and products, use of strontium chromate in bonding primers will continue to be required; their use is essential to meeting airworthiness and other safety requirements. Therefore, there are no alternatives which can be considered “generally available” in the context of A&D.

In some cases, alternatives are technically qualified and certified, such as in instances where sufficient corrosion resistance is supplied by the primer while suitable adhesion is provided by the adhesive layer, but time is needed to industrialise and implement them across all industrial sites in the value chain. Given the large numbers of BtP suppliers and MROs involved in the use of bonding primers, implementation itself may take several years (e.g. 6-8 years within the larger value chains).

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

As a result, as demonstrated by the test candidate development plan, the OEMs and DtBs (as design owners) require at least 12 years to complete substitution across all components and final products.

The Continued Use Scenario can be summarised in **Figure 4-1** below:

Continued use of Cr(VI) in bonding 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 EEA/UK manufacturing base
-> Downstream use continues in A&D supply chain as alternatives are certified and implemented	-> Industrialisation of substitutes and their adoption across supply chains
-> Modification of designs as substitutes are certified and industrialised	-> R&D into the adoption of more sustainable technologies continues
-> Update of Maintenance Manuals to enable substitution in MRO activities	-> Employment in the sector is retained while worker exposures and risks decline over time
-> Continued production, repair and maintenance of aircraft and other final products ensured	-> Impacts on civil aviation, emergency services and military mission readiness is minimised

Figure 4-1: Continued use scenario

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

- The market analysis of downstream uses in the A&D markets;
- Annual tonnages of the strontium chromate used in bonding primers, including projected tonnages over the requested review period; and
- The risks associated with the continued use of strontium chromate.

4.2 Market analysis of downstream uses

4.2.1 Introduction

Separate companies within the A&D industry have jointly assessed and continue 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
- Continuity of supply of critical products containing hexavalent chromium.

The requirements of the ADCR members, as downstream users and design owners supporting this application, have been carefully identified and analysed, taking as the starting point the parent authorisations and the substance-use combinations covered by these. The original Authorisation decision issued to members of CCST for potassium hydroxyoctaoxodizincatedichromate (Authorisation decision C(2020)2089) allowed for the continued use of this substance in bonding primers, and it was originally the intention that this review report would also cover this chromate. Over the lifetime of the ADCR consortium the chromates present within bonding primers used by members has continuously been monitored, and subsequently the scope of this review report reduced to only cover strontium chromate. This ensures that an authorisation is only sought for those cases where there is no substitute that is fully qualified as per stringent airworthiness requirements and industrialised by members and their supply chains.

Furthermore, the scope of this combined AoA/SEA is driven by A&D qualification, validation, and certification requirements, which can only be met using substances that provide the required performance as mandated by airworthiness authorities. This constrains OEMs and DtBs, and hence their suppliers and MRO facilities (civilian and military), to the use of bonding primers containing Cr(VI) until alternatives can be qualified and certified across all relevant components.

4.2.2 Overview of the European aerospace and defence sector

In 2020, the European A&D industry comprised over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[34]). As noted by the European Commission, the industry is "characterised by an extended supply chain and a fabric of dynamic small- and medium- sized enterprises throughout the EU, some of them world leaders in their domain"[35]. **Figure 4-2** provides details of turnover and employment for the industry in 2021, based on the

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

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

Aerospace, Security and Defence Industries Association of Europe (ASD) publication "2022 Facts & Figures".[36]

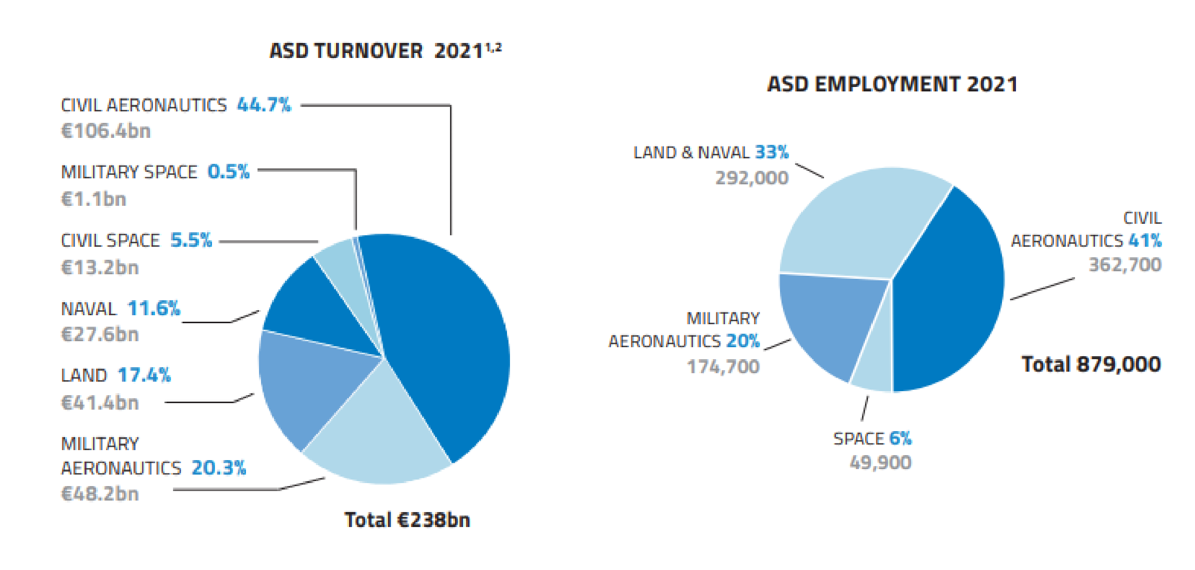


Figure 4-2: Turnover and Employment for the European A&D Industry in 2021 (snip taken from ASD, 2022), available at https://asd-europe.paddlecms.net/sites/default/files/2022-11/ASD_Facts%20%26%20Figures%202022.pdf

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 therefore recognised as important to the ongoing growth and competitiveness of the GB economy. 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 products remain in service over long time periods. For example, the Boeing 747 first entered service in 1970, and continues 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 primers containing strontium chromate for maintenance of existing aircraft and equipment, as well as in the production of components for models that are still in production for 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 are applied in the market. As part of the development and roll-out of new A&D products, OEMs have to

[36] ASD, 2022: Facts & Figures, available at: https://www.asd-europe.org/facts-figures

be ready to demonstrate fully developed technologies, or they risk losing contracts that may have a lasting effect on business[37].

- 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 strontium chromate. As indicated below with respect to R&D activities, research on substitution of hexavalent chromates has been underway for several decades, with the substitution of strontium chromate in bonding primers proving a difficult task for some products (and in particular some military final products).

- 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 bonding primers containing strontium chromate 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 products containing hexavalent chromates where these are mandated by the original equipment manufacturers.

4.2.3 Economic characteristics of Companies using bonding primers

4.2.3.1 Profile of downstream users

As noted in Section 2, use of bonding primers containing strontium chromate is common within the aerospace sector. The primers are applied in-house by some of the OEMs, as well as being used by BtP suppliers, DtB suppliers and MROs.

Examples of parts treated with bonding primers include:

- Landing gear
- Propellers
- Avionics
- Trailing edges
- Skin panels
- Stringer
- Doubler
- Fan cases

Table 4-1 provides an indication of numbers of respondents by role in the supply chain and by size of company. Respondents to the SEA survey tended to be small and medium sized companies for BtP and DtB, and large sized companies within MRO and OEM.

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

Table 4-1: Numbers of SEA respondents using strontium chromate in bonding primers		
Role	Number of companies/sites	Company Size[38]
Build-to-Print	6/7	2 small3 medium
Design-to-Build	2/2	1 small 1 medium
MRO only	2/2	1 large
OEM	1/1	1 large
Total	**11/12**	-

4.2.3.2 Economic characteristics

Table 4-2 provides a summary of the number of companies identifying their activities against different Standard Industrial Classification (SIC)codes, which are used here to develop the economic characteristics of the "typical" OEM, DtB, BtP or MRO company. Companies may have indicated more than one SIC code as being relevant to their activities, with the result that the number of relevant SIC code counts is higher than the number of SEA responses relevant to use of strontium chromate in bonding primers.

The table also provides relevant ONS data for each NACE/SIC code on turnover (weighted average provided here, based on % of respondents by company size), Gross Value Added (GVA) per employee, average number of employees, and average personnel costs per employee.

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

Table 4-2: Economic characteristics of "typical" companies by SIC in sectors involved in use of strontium chromate in bonding primers (2022 ONS data)					
	Number of responses by SIC code	Weighted average turnover per company £ million	GVA per employee £	Average personnel costs per employee £	Average GOS as a % of turnover
C2561 - Treatment and coating of metals	0	14	51,122	30,408	22%
C2540 - Manufacture of weapons and ammunition	7	650	97,239	73,284	9%
C2594 - Manufacture of fasteners and screw machine products	0	3	67,358	35,283	23%
C2599 - Manufacture of other fabricated metal products n.e.c.	2	155	56,993	30,784	19%
C263 - Manufacture of communication equipment	0	342	133,333	54,530	30%
C265 - Manufacture of instruments and appliances for measuring, testing and navigation;	0	253	104,777	67,612	16%
C2815 - Manufacture of bearings, gears, gearing and driving elements	0	210	69,726	39,863	18%
C3030 - Manufacture of air and spacecraft and related machinery	3	648	116,492	67,263	16%
C3040 - Manufacture of military fighting vehicles	0	648	116,492	67,263	16%
C3316 - Repair and maintenance of aircraft and spacecraft	5	114	80,556	41,500	18%
Note: The count total is by number of SIC code identifications by company and not by sites, with 11 companies providing data					

Turnover is calculated as the weighted average by company size, as this is the most appropriate means of reflecting the level of turnover across GB linked to use of bonding primers containing strontium chromate and taking into account the size distribution of the companies[39] that are involved in such activities[40]. GVA per employee, numbers of employees, and average personnel costs are given as the sector average and not per company size for several of the SIC codes, so it was not possible to calculate weighted averages for these. Note that the count total is by company and not by site.

Data on Gross Operating Surplus[41] (GOS) as a percentage of turnover (the GOS rate) is also used here to provide an indication of the profits associated with the turnover generated by these sites. This is based on a figure of 15% which is an average across the various SIC codes weighted by the number of companies declaring each SIC code. GOS was calculated as GVA at basic prices minus personnel costs, according to the income approach. Then the GOS divided by the turnover is the GOS rate. **Table 4-3** demonstrates the estimated turnover and gross operating surplus based on ONS data.

Table 4-3: Key turnover and profit data for market undertaking use of strontium chromate in bonding primers (based on 2022 ONS data)

Sites covered by SEA responses/Extrapolated number of sites	Estimated turnover based on weighted average	Gross operating surplus (estimate based on 15%)
12 GB sites	£ 1,283 million	£ 235 million
Extrapolation to all sites involved in use of strontium chromate in bonding primers in GB		
50 GB sites	£ 5,964 million	£ 1,090 million

Source: Based on SEA questionnaire responses, combined with ONS data

4.2.3.3 Economic importance of use of bonding primers to revenues

Use of bonding primers will only account for a percentage of the calculated revenues, GVA and jobs associated with the results given in **Table 4-3**. To understand its importance to the activities of individual companies, a series of questions were asked regarding other processes carried out, production costs, and the share of revenues generated from the use of bonding primers containing strontium chromate.

As the supply chains covered by this SEA vary from manufacturers of small components to producers of much larger components (e.g., components for landing gear versus doors and/or skirts), the

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

40 The Weighted Average Turnover was calculated using data from ONS and Eurostat for the UK. The total turnover and the number of enterprises by turnover size for year 2022 was used from ONS (for the selected 4 digit SIC codes). The weights were calculated using turnover by turnover size band from Eurostat for UK in year 2018. With that information the proportion of turnover corresponding to small, medium and large companies was calculated. These proportions (%) were estimated only for the selected 3 digit SIC codes, as data for 4 digit SIC codes wasn't available.. In the case of C3040 the same figures as C3030 were applied due to confidential information restrictions.

41 ONS defines the GOS as profits of all companies and public corporations, and excluding profit on rental of buildings and stock appreciation; it is officially defined as the balance between GVA and labour costs paid by producers.

responses vary significantly across companies. Of key importance is that for the design owners, use of bonding primers containing strontium chromate continues to be critical. The loss of these primers would result in the loss of a significant level of turnover due to the inability to meet airworthiness requirements, even though as a process it accounts for only a very small percentage of production costs.

Table 4-4 shows the revenue linked to using chromate-containing primers for companies in GB. Responses vary, with some companies stating that less than 10% of revenue was linked to the use of primers, and others stating that more than 75% of turnover is linked to use of the primers.

Companies stating that between 50% and 75% of turnover was attributed to priming often perform other machining work within the aerospace and defence industry as well as other industries. This includes the production of Aerospace Transparencies, such as cockpit canopies and windscreens. The other industries are related to marine, power generation and industrial sectors.

As would be expected, although use of bonding primers in itself does not account for a significant percentage of turnover, all of the OEMs highlighted the critical importance of bonding primers for a wide range of aircraft and defence hardware. They stressed the impossibility of certifying an aircraft as meeting airworthiness requirements or defence equipment as meeting safety requirements without the use of Cr(VI)-based primers mandated in the drawings and performance requirements for those components unless there are certified alternatives.

Table 4-4: Number of sites reporting proportion of revenues generated by or linked to the set of Cr(VI)-using processes

	<10%	10% - 25%	25% - 50%	50% - 75%	>75%
Build-to-Print	1	0	1	2	3
Design-to-Build	0	0	0	0	2
MROs	1	0	0	0	0
OEMs	0	0	0	1	0

4.2.3.4 Investment in R&D, risk management measures and monitoring

OEMs have carried out R&D into the substitution of the chromates for over 30 years, but as detailed in the AoA, technical difficulties remain in substituting the use of strontium chromate in bonding primers. Although some have developed, validated, qualified and are currently certifying alternatives for use in the manufacture of their final products, others are still in the testing and development phase. These differences are driven by differences in operating performance requirements, previous surface treatments, and substrates across final components.

Some examples of investments made across all supplier types include:

- £450,000 investment in a new spray booth in 2019
- £3.8 million in Robotic grit paint cells in 2023-2024
- £1.5 million paint booths and equipment 2012-2022
- £50,000 spray bake system in 2022

Further information on the R&D carried out by the OEMs (and DtB companies) is provided in Section 3.4.

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

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

Across respondents, regardless of role in the supply chain, the majority of companies identified better relations with authorities as a benefit. Significant numbers also identified better public, shareholder and community relations.

4.2.4 End markets in civil aviation and defence

4.2.4.1 Importance to end-user markets

The use of bonding primers containing strontium chromate provides adhesion promotion as well as corrosion resistance to A&D products that must operate safely and reliably, across different geographies, often in extreme temperatures and in aggressive environments with a high risk of corrosion (due to extreme temperatures, humidity, precipitation, salt spray and altitudes).

Because bonding primers containing strontium chromate cannot be fully substituted at present, they play a critical role in ensuring the reliability and safety of final products because they are the only qualified solutions currently proven to meet the performance requirements of the airworthiness/defence customer certification, which ensures overall product safety, reliability and performance. Thus, although the economic importance of bonding primers containing strontium chromate is indirect in nature, their significance is clear with respect to:

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

The economic importance of ensuring that aircraft retain their airworthiness is illustrated by the figures quoted above for the number of air passengers transported in the European Union in 2019 (over 1 billion passengers), as well as the net profits of the airlines in 2019 at US$ 6.5 billion (€5.8 billion, £5.1 billion).

The military importance of ensuring that military aircraft, land and naval hardware maintain their mission readiness cannot be quantified in the same manner. However, the involvement of MoDs (as well as the MROs supporting military forces) in the ADCR consortium demonstrates the critical nature of chromates to the on-going preparedness of their military forces in particular.

4.2.4.2 Expected growth in the A&D sector

Civilian aircraft

Demand for new civilian aircraft is expected to grow into the future. Projected global compound annual growth rates (CAGR) for different aircraft classes for the period 2023-2033 are given in **Figure 4-3**[42], with this suggesting CAGR from 2023 to 2033 of around 2.9%.

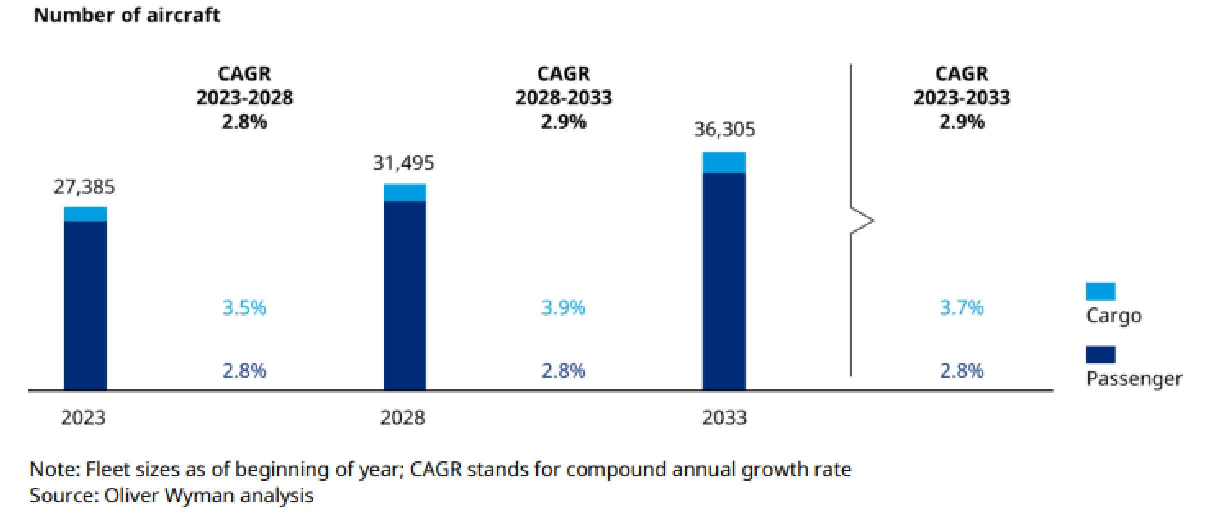


Figure 4-3: Passenger and cargo fleet forecasts, 2023-2033
***Source: Oliver Wyman analysis* (2021)**

Market reports issued by Airbus and Boeing indicate that future growth is expected to extend beyond 2033. Airbus' Global Market Forecast for 2021-2041 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.[43]

Boeing's 2023 Commercial Market Outlook[44] 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 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 majority of

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

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

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

commercial aircraft in operation will be of the latest generation. Projections based on generic neutral seating categories (100 plus seater passenger aircraft and 10 tonnes plus freighters) are given in **Table 4-5** below.

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

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

**Pax = the number of people carried by a passenger aircraft.*
*** CIS = Commonwealth of Independent States*
Source: Ascend, Airbus (undated): Global Market Forecast 2021 – 2040. Available at: https://www.airbus.com/en/products-services/commercial-aircraft/market/global-market-forecast

When considering these figures, it is important to recognise that the British aerospace sector is a significant and leading global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. For example, the UK export market (which includes NI) was around US$13.2 billion (€11.7 billion, £10.3 billion) in 2020.[45]

However, unless operations in GB can remain 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 these newer generations of aircraft and military products may shift to locations outside GB with a consequent loss in Gross Value Added (GVA) to the GB economy, with enormous impacts on employment.

The MRO market

The aircraft spare components/final products 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 2.9% over the period from 2023-2033, although this rate may now be lower due to COVID-19. Growth is due to the increase in the commercial aircraft fleet as well as the need for timely MRO services to keep aircraft in service.

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

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

10 years. Globally, the market is expected to have a CAGR of 2.9% over the period from 2023-2033, as illustrated in **Figure 4-4**.[46, 47]

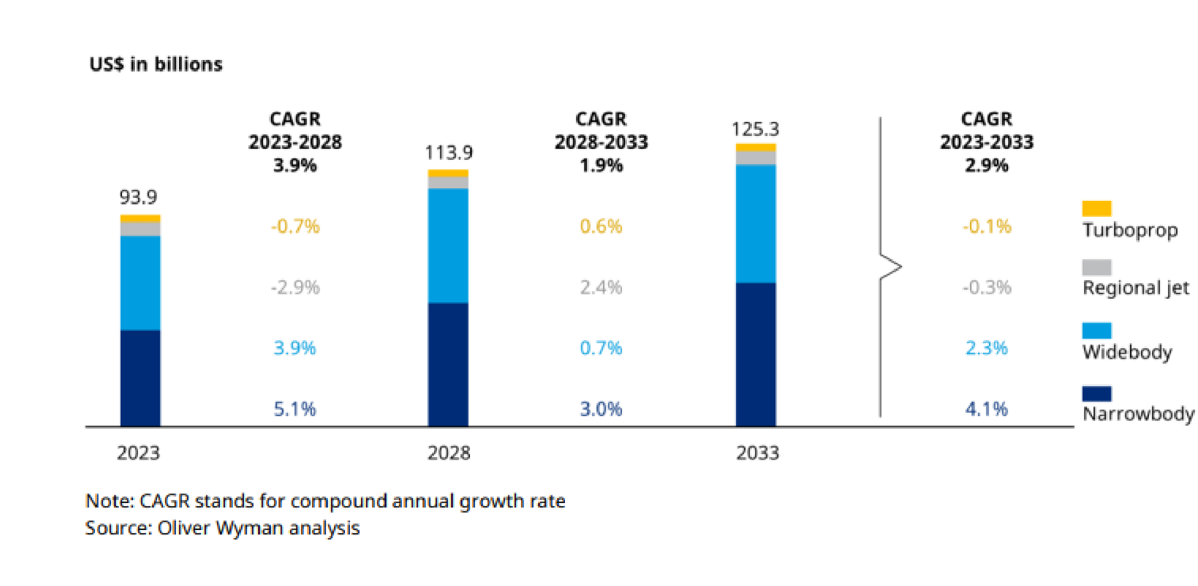


Figure 4-4: MRO market forecast by aircraft class, 2023-2032
Source: Oliver Wyman analysis (2021)

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; and
3) Increases in fleet sizes over the next five years will also lead to a continued growth in demand for maintenance and repair activities.

The defence market

The war in Ukraine has led several countries and the UK to revisit their defence expenditure. 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[48]. The increase in investment will equate to hundreds of billions of Euros (e.g., Germany alone has pledged €100 billion in defence spending).

Defence spending in the UK is expected to increase to over 2%, with projections in June 2022 suggesting 2.3% of GDP but Government commitments announced in October 2022 aim for a target

46 Mordor Intelligence, Commercial Aircraft Maintenance, Repair, and Overhaul (MRO) Market – Growth, Trends, Covid-19 Impact and Forecasts (2023 – 2033)

47 Oliver Wyman analysis: at: https://www.oliverwyman.com/our-expertise/insights/2023/feb/global-fleet-and-mro-market-forecast-2023-2033.html

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

of 3% of GDP by 2030. This equates to an increase in spending of around £157 billion between 2022 and 2030.

Such investment, which will include new spending on existing technologies, may also result in a continued reliance on the use of bonding primers containing strontium chromate 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. By contrast, the global civilian aircraft MRO market has a market size of US $70 billion (€59 billion, £51 billion) in 2021 and is growing even faster at a CAGR of over 4.6%.

4.3 Annual tonnages of strontium chromate used

4.3.1 Consultation for the CSR

As part of preparation of the CSR, site discussions were held with ADCR members and some of their key suppliers. This work included collection of data on the tonnage of strontium chromate used per site and is discussed in more detail in the CSR.

The CSR reported tonnage of:

- to 230 kg Cr(VI)/year per site based on 0.1 to 900 kg of StC used per year per site.

4.3.2 Consultation for the SEA

The SEA questionnaire also asked for information on the chromates used in bonding primers by site, with these data providing an additional basis for estimating the maximum volumes used in bonding primers per site.

Based on consultation for the SEA, it is estimated that 14.74 tonnes of StC are used in bonding primers per year across all sites.

4.3.3 Projected future use of hexavalent chromates

The A&D industry is actively working to phase out the use of Cr(VI), however it will take further time to qualify alternatives across all components and products for the A&D industry. Individual companies are at different points along this path, although there are also variations based on specific aircraft/defence application and across different types of components/final products. If test candidate development plans progress as expected, at the end of the current review period a significant proportion of members development plans (35%) are anticipated to already have reached MRL 10. This is the stage at which the use of Cr(VI) is fully eliminated in the use covered under this plan. A further 4% of plans are anticipated to be at the industrialisation phase whilst 22% are expected to be at the certification phase. The remaining plans are expected to be spread across development (17%), qualification (17%), and validation (4%).

Where possible, requirements for use of bonding primers containing strontium chromate in new designs are being phased out, however aircraft that require their use remain in production and operation. Use of strontium chromate in bonding primers therefore remains important to the protection of A&D components.

For further information refer to section 3.7.

4.4 Risks associated with continued use

4.4.1 Classifications and exposure scenarios

4.4.1.1 Human health classifications

Strontium chromate is classified as Carcinogenic 1B under the CLP Regulation with the most important route of exposure being via inhalation.

The hazard evaluation follows recommendations given by RAC[49]:

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

4.4.1.2 Overview of exposure scenarios

All A&D sites that use bonding primers containing strontium chromate within the ADCR supply chains are specialised industrial sites active in GB. They have rigorous internal, health, safety, and environment (HS&E) organisational plans. A mix of technical, organisational and personal-protection-based measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions to as low as technically and practicably feasible and use automated processes to the maximum extent possible. The feasibility and the degree of automation can vary between different sites and depend, among other factors, on the size of the site and the frequency of use of bonding primers. See the CSR for further details of measures in place.

As reported in Section 4.2.3.4, due to the conditions placed on the continued use of bonding primers containing strontium chromate additional risk management measures were implemented by A&D companies, requiring significant investment. A full summary of these conditions is provided in the CSR that accompanies this combined AoA/SEA.

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

Table 4-6: Overview of exposure scenarios and their contributing scenarios		
ES number	**ES Title**	**Environmental release category (ERC)/ Process category (PROC)**
ES1-IW1	Use of bonding primers containing strontium chromate in aerospace and defence industry and its supply chains – use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Use of bonding primers containing strontium chromate – use at industrial site leading to inclusion (of Cr(VI) or the reaction products) into/onto article	ERC 5
Worker contributing scenario(s)		
WCS 1	Spray operators for manual spraying in spray room/booth	PROC 5, PROC 7, PROC 8b, PROC 9, PROC 28
WCS 2	Operators performing brushing/rolling	PROC 10
WCS 3	Machinists	PROC 21, PROC 24
WCS 4	Sanders in a dedicated hangar	PROC 21, PROC 24
WCS 5	Workers performing media blasting in closed system	PROC 21, PROC 24
WCS 6	Workers performing media blasting in a room/hall	PROC 21, PROC 24
WCS 7	Maintenance and/or cleaning workers for spray area(s)	PROC 8b, PROC 28
WCS 8	Maintenance and/or cleaning workers (excluding spray areas)	PROC 28
WCS 9	Incidentally exposed workers	PROC 0
Exposure scenario for industrial end use at site: ES1-IW1		

4.4.2 Exposure and risk levels

The CSR provides details of the approach and assumptions underlying calculation of exposures and risks from the use of bonding primers containing strontium chromate. The calculated exposure levels and associated excess cancer risks are presented below (for further information on their derivation, see the CSR).

4.4.2.1 Worker assessment

Excess lifetime cancer risks

The findings of the CSR with respect to worker exposures, are summarised in **Table 4-7**, which presents the excess lung cancer risks to workers involved in use of bonding primers containing strontium chromate. The risks are calculated using a combination of measured inhalation data and modelling for different SEGs (Similar Exposure Groups). The SEGs include:

Table 4-7: Excess lifetime cancer risk by SEG			
#	SEG	Number of workers exposed per site	Excess lifetime lung cancer mortality risk
WCS1 Part 1	Spray operators for manual spraying in spray room/booth	10 workers per day per site	2.10E-04
WCS1 Part 2	Spray operators for manual spraying outside of spray room/booth	1 worker per day at 20% of sites	7.17E-04
WCS2	Operators performing brushing/rolling	18 workers per day per site	2.59E-04
WCS3	Machinists	18 workers per day at 30% of sites	7.68E-05
WCS4	Sanders in a dedicated hangar	16 workers per day at 30% of sites	1.23E-04
WCS5	Workers performing media blasting in closed system	6 workers per day at 30% of sites	1.55E-04
WCS6	Workers performing media blasting in a room/hall	6 workers per day at 10% of sites	7.79E-04
WCS7	Maintenance and/or cleaning workers for spray area(s)	3 workers per day per site	1.91E-05
WCS8	Maintenance and/or cleaning workers (excluding spray areas)	9 workers per day per site	5.32E-05
WCS9	Incidentally exposed workers	14 workers per day per site	6.30E-05
Source: Information from CSR 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 to 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 conducted as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations. 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 potassium hydroxyoctaoxodizincatedichromate in paints, in primer, sealants and coatings (including as wash primers) (ID 0047-02). This reference states that regional exposure of the general population is not considered relevant by RAC.

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment, combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. The resulting 90th percentile risk estimates are presented in **Table 4-8.**

Table 4-8: 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
4.88E-04	1.41E-05	3.59E-06	2.87E-09	1.41E-05
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.				

4.4.3 Populations at risk

4.4.3.1 Worker assessment

The CSR figures are taken here, as they are based on site visits and detailed discussions with companies. The average figures assumed in the CSR extrapolated out to the total numbers of sites gives the figures set out in **Table 4-9** as the number of workers exposed under each worker WCS.

Table 4-9: Number of employees undertaking use of bonding primers across GB			
Worker Contributing Scenarios		Average No. Exposed from CSR	Total No. exposed in 50 GB sites
WCS1 - Part 1	Spray operators for manual spraying in spray room/booth	10 workers per day per site	500
WCS1 - Part 2	Spray operators for manual spraying outside of spray room/booth	1 worker per day at 20% of sites	10
WCS2	Operators performing brushing/rolling	18 workers per day per site	900
WCS3	Machinists	18 workers per day at 30% of sites	270
WCS4	Sanders in a dedicated hangar	16 workers per day at 30% of sites	240
WCS5	Workers performing media blasting in closed system	6 workers per day at 30% of sites	90
WCS6	Workers performing media blasting in a room/hall	6 workers per day at 10% of sites	30
WCS7	Maintenance and/or cleaning workers for spray area(s)	3 workers per day per site	150
WCS8	Maintenance and/or cleaning workers (excluding spray areas)	9 workers per day per site	450
WCS9	Incidentally exposed workers	14 workers per day per site	700
Total			3340
Source: CSR			

4.4.3.2 Humans via the Environment

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

- Number of downstream user sites in total;
- The population density per km^2, based on an average of the population density around sites responding to the SEA questionnaire;
- The relevant distance from sites for the local assessment, taken as the default assumption of a 1,000m radius (or 3.14 km^2).

A 1,000m radius is adopted here to estimate the exposed population as, for most sites, the humans via the environment (HvE) results are driven by emissions to air. Oral exposure risks are typically much lower. As a result, adopting the EUSES default assumption related to the capacity of local sewage treatment plants would over-estimate the number of inhabitants that may be exposed due to emissions from each site.

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 4-10: Total exposed population used for HvE			
Populations	No Sites	Population Density per km2	Exposed population
GB	50	2552.54	432,368

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of strontium chromate in bonding primers would continue after the end of the current review period for a total of 12 years if the requested review period is granted.

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[50]. 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.

[50] 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).

4.4.4.2 Morbidity vs mortality

Excess cancer cases need to be split between fatal and nonfatal ones. To this end, estimates of fatality and survival rates associated with lung and colorectum[51] cancer cases were derived from the Cancer Today database, see **Table 4-11** below.

Table 4-11: Estimated incidence and mortality of cancers across the EU-27 and the UK, both males and females (in 2020)			
Type of cancer	Cases	Deaths	Survivals
Lung	370,310	293,811 (79%)	76,499 (21%)
Colorectum (intestinal)	393,547	177,787 (45%)	215,760 (55%)
Source: 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 11 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 CSR provides combined excess risk estimates. To err on the side of conservatism, the mortality versus morbidity ratio for lung cancer has been adopted for valuation of risks to humans via the environment (HvE).

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

Total excess cancer risk cases are based on the excess lifetime risk estimates derived in the CSR for the different worker contributing scenarios (WCS as presented in **Table 4-7**). These risk estimates reflect the additional safety measures that have been implemented due to the conditions placed on continued use by the initial authorisation decisions. The number of excess cancer cases is calculated by multiplying the number of workers assumed to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e., over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer cases arising from the continued use of strontium chromate in bonding primers. **Table 4-12** provides a summary of the results across all WCS for GB workers.

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

Table 4-12: Number of excess cancer cases to GB workers				
WCS	Number of workers 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 - part 1	500	2.10E-04	**0.11**	**0.03**
WCS1 - part 2	10	7.17E-04	**0.01**	**0.00**
WCS2	900	2.59E-04	**0.23**	**0.06**
WCS3	270	7.68E-05	**0.02**	**0.01**
WCS4	240	1.23E-04	**0.03**	**0.01**
WCS5	90	1.55E-04	**0.01**	**0.00**
WCS6	30	7.79E-04	**0.02**	**0.01**
WCS7	150	1.91E-05	**0.00**	**0.00**
WCS8	450	5.32E-05	**0.02**	**0.01**
WCS9	700	6.30E-05	**0.04**	**0.01**
	Years - Lifetime	**40.00**	**0.50**	**0.13**
	Years - Review period	**12.00**	**0.15**	**0.04**
	Years - Annual	**1.00**	**0.01**	**0.00**

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

The total number of people exposed via the environment as given in **Table 4-13** is multiplied by the excess cancer risk estimates to calculate the total excess cancer cases arising under the Continued Use scenario. The results are given below in **Table 4-13**. The basis for estimating the number of people exposed is given in section 4.4.3.2.

Table 4-13: Number of people in the general public exposed via the environment (local assessment)

Locations of DUs	No. of Sites	Exposed population	Combined excess lifetime cancer risk	Number of excess fatal cancer cases	Number of excess non-fatal cancer cases
GB	50	432,368	1.41E-05	6.10	3.74
		Years – Lifetime cases	**70.00**	**6.10**	**3.74**
		Years - Review period	**12.00**	**1.05**	**0.64**
		Years - Annual	**1.00**	**0.09**	**0.05**

4.4.5 Economic valuation of residual health risks

4.4.5.1 Economic cost estimates

In order to monetise human health impacts, a timeframe that goes from 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[52]. 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[53] 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[54]. 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[55]. 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. These are summarised in **Table 4-14**.

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

53 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.

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

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

Table 4-14: Alternative estimates of medical treatment costs			
Study	Year for prices	Average direct costs in original units (per annum)	Direct costs in € 2021
Lung cancer[56]			
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)[57]			
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[58]. 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 PV of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 4% future discount rate. The Present Value (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.

56 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.

57 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.

58 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 basic calculations for the value of an excess cancer case are presented below:

$$(\pi \times (€\ 3{,}970{,}000)) + (\sigma \times (€\ 470{,}000 + €\ 30{,}840) = \text{Total lung cancer costs}$$

$$(\delta \times (€\ 3{,}970{,}000)) + (\eta \times (€\ 470{,}000 + €84{,}790)) = \text{Total intestinal cancer costs}$$

These values are converted to GBP applying an exchange rate of 0.87. Taking into account the latency period of cancer after exposure, a 10-year lag is applied[59]. Not that this is a conservative assumption because 10 years is based on lung cancer relevant to occupational exposure. Longer lags (i.e., discounted more heavily) are likely to be more relevant to other types of cancers (e.g., intestinal cancer) and exposure of general population via the environment.

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

Table 4-15 applies the economic value of the associated health impacts to these additional statistical cases of cancer to generate the total economic damage costs of the excess lung cancer cases. Under the continued use scenario, the present value costs are around **£308,170 to £436,006** for GB, based on the assumption that use of bonding primers containing strontium chromate continues at the current level of use over the entire review period; this will lead to an overestimate of the impacts as the sector transitions to the alternatives over the 12-year period.

Table 4-15: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years @3.5% per year, 10 year lag, figures rounded)

	Lower bound costs		Upper bound costs	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	1.51E-01	4.02E-02	1.51E-01	4.02E-02
Annual number of cases	1.26E-02	3.35E-03	1.26E-02	3.35E-03
Present Value (PV, in 2021 prices)	£298,284	£9,886	£426,120	£9,886
Total PV costs	**£308,170**		**£436,006**	
Total annualised cost	**£31,891**		**£45,120**	

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

Due to the small number of cases estimated for intestinal cancer, all cases have been treated as lung cancer, with a 10- year latency period taken and medical costs considered for the average of lung and intestinal cancer. This has been done to err on the side of overestimation.

Table 4-16 applies the economic value of the associated health impacts to the additional statistical cases of cancer for humans via the environment to generate the total economic damage costs of the excess cancer cases. Under the continued use scenario, the present value costs are roughly £2.23 **to**

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

£3.11 million for GB, based on the assumption that use of bonding primers continues over the entire review period at consistent tonnages and number of downstream user sites; as indicated above. This reflects an overestimate of the levels of exposures as use declines with a transition to the alternatives over the 12-year period.

Table 4-16: Present value and annualised economic value of mortality and morbidity effects to the general population, local assessment (discounted over 12 years @3.5% per year, 10-year lag, figures rounded)				
	Lower bound costs		Upper bound costs	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	1.05	0.64	1.05	0.64
Annual number of cases	0.09	0.05	0.09	0.05
Present Value (PV, in 2021 prices)	£2,062,760	£167,384	£2,946,801	£167,384
Total PV costs	**£2,230,145**		**£3,114,185**	
Total annualised cost	**£325,544**		**£454,591**	

4.4.6 Human health impacts for workers at customers sites

Customers sites are not addressed in the CSR.

4.4.7 Summary of human health impacts

Table 4-17 provides a summary of the economic value of the human health impacts across the worker and local populations. When considering these figures, it should be remembered that they relate to use of bonding primers containing strontium chromate across the sector at an estimated 50 GB sites covered by this combined AoA/SEA. It should also be recognised that workers using bonding primers may also be using hexavalent chromates for other processes. As a result, their monitoring data may reflect aggregate exposures rather than just bonding primer-related exposures.

Table 4-17: 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 costs		Upper bound costs	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	1.20E+00	6.81E-01	1.20E+00	6.81E-01
Annual number of cases	9.97E-02	5.67E-02	9.97E-02	5.67E-02
Present Value (PV, in 2021 prices)	**£2,054,109**	**£154,225**	**£2,934,441**	**£154,225**
Total PV costs	**£2,208,334**		**£2,687,140**	
Total annualised cost	**£322,360**		**£392,253**	

5 Socio-Economic Analysis of Non-Use

5.1 The Non-Use Scenario

5.1.1 Summary of consequences of non-use

The inability of companies to undertake chromate-based bonding priming across GB would be severe. This use is critical to the key functions provided by the chromates: adhesion promotion and corrosion resistance (including active corrosion inhibition). These functions are essential to a broad range of components and assemblies, including structural parts such as engines, wings and landing gear assemblies. This includes application to newly produced components, touch-ups during manufacturing activities and for ensuring on-going performance following maintenance and repair activities.

If use of chromate-based bonding primers was no longer authorised and where qualified and certified alternatives are not available according to the definition of "generally available"[60], design owners (i.e. OEMs and DtB companies) would be forced to re-locate some, or all, of their parts production, manufacturing, and maintenance activities outside GB, where qualified and certified alternatives are not available.

A refused Authorisation would have impacts on the GB formulators and the critical set of key functions provided by bonding primers would be lost to A&D downstream users in GB

↓

Due to certification and airworthiness requirements, downstream users in the A&D value chain would be forced to undertake chromate-based bonding priming outside GB or shift to suppliers outside of GB

↓

OEMs would shift manufacturing outside GB due to the need for bonding priming to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside GB for bonding priming only (especially for touch-up repairs)

↓

DtB suppliers may have more flexibility and be able to shift only part their production activities outside GB, resulting in the loss of profits and jobs inside GB

↓

BtP suppliers in GB would be forced to cease chromate-based bonding priming, leading to loss of contracts and jobs due to relocation of this and related activities outside GB

↓

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 bonding priming is an essential part of maintenance, repair and overhaul activities

↓

60 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: https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1

Relocation of MRO activities would cause significant disruption to the A&D sector itself

↓

Ministries of Defence would face logistical difficulties in maintaining aircraft and other equipment, severely impacting on mission readiness. Service agreements would need to be reached with other countries

↓

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

As indicated in the above diagram, because bonding primers must be applied promptly to protect against corrosion and, depending on the follow-on process, to ensure the next process step is successful, there would be significant subsequent effects for other parts of the aerospace and defence supply chains. The most likely outcome would be the relocation of large portions of the entire value chain (production, repair, and maintenance) outside of GB, as summarised below.

5.1.2 Identification of plausible non-use scenarios

Discussions were held with the applicants, OEMs, DtBs, BtP suppliers, and MROs to establish the most likely non-use scenarios in the event of the non-Authorisation of use of strontium chromate in bonding primers. The subject of these discussions included:

- The effects from the loss of bonding primers containing strontium chromate;
- How activities could otherwise be organised; and
- What options could be available to the companies while they worked on meeting the strict qualification and certification requirements placed on the A&D sector.

These discussions acted as the basis for a series of questions in the SEA questionnaire aimed at:

- Gathering information on the role of different types of companies
- How the roles impact reasons for using bonding primers containing strontium chromate,
- Past investments and R&D, and
- The most likely impacts of a refused re-authorisation.

Information on the first three of these was summarised in Section 4 as part of the description of the continued use scenario.

Moving to a poorer performing alternative was ruled out based on the unacceptability of such an option to the OEMs due to safety and airworthiness requirements, as detailed further below. Follow-up questions were asked to establish the feasibility of producing components overseas and shipping them back to GB, with this then ruled out based on the answers received regarding the logistical difficulties and economic infeasibility. These were considered to be non-plausible scenarios and are discussed in Section 5.1.3 below.

Table 5-1 below details the choices presented in the SEA questionnaire and a count of the number of companies selecting each.

Respondents were asked to provide further comments to support their responses, and to explain any other possible responses not included in the list. These comments are presented below and demonstrate the differences that exist within the aerospace supply chain and hence how the most plausible scenarios will vary by role.

Further details on the non-use scenario for the different types of companies are provided below, starting with OEMs as the main design owners, followed by DtBs, BtPs and MROs. Note, that the responses are provided by company, not by site. Multiple sites may be represented by each company response.

Table 5-1: Responses to SEA survey on most likely non-use scenarios

	OEM/Tier 1	Build-to-Print only	Design-to-Build only	MROs – only
It is unclear at this time/The decision is up to our customer	0	1	0	0
We may have to cease all operations as the company will no longer be viable	0	1	0	0
We will focus on other aerospace uses or on non-aerospace and defence uses	0	0	0	0
We will shift our work outside GB	1	0	1	1
We will stop undertaking use of the chromate(s) until we have certified alternative	0	2	0	1
Number of responses (companies)	1	4**	1*	2
*One response left blank, **Two responses left blank				

5.1.2.1 OEMs

In discussions, the OEMs all stressed that the aim is the replacement of the use of bonding primers containing strontium chromate with an alternative that enables the components to be qualified and certified. The main points were as follows:

- **We will shift our work involving Chromates to another Country outside GB. This is the most plausible scenario for the majority of OEMs directly involved in the use of bonding primers containing strontium chromate.** It would not be possible for the OEMs (or some divisions of the larger OEMs) to maintain manufacturing activities which take place after primers have been applied inside GB while transferring use of bonding primers containing strontium chromate outside GB. This would result in huge numbers of components being transferred outside GB for repairs or touch-up, which would not be economically feasible. Furthermore, given the reliance on the use of bonding primers containing strontium chromate in supply chains, it is also the most likely response for the OEMs or divisions of them who rely on their suppliers using bonding primers containing strontium chromate on components prior to their delivery to the OEM. Wherever operations were transferred to in the event of a non-use scenario, there would need to be a qualified supply chain in place with sufficient capacity to absorb the additional demand. Granted authorisation in GB would provide access to qualified supply chains; however, it is unknown if the GB supply chain would have the required capacity or how long it would take to ramp-up capacity to meet demand.

- **We will stop using the chromates until we have certified alternatives.** It is clear that, in most cases, substitution activities and especially the industrialisation phase of moving to alternatives will not be completed before the end of the current review periods, especially given the number of BtP suppliers and MROs involved, as well as the number of components of relevance. In some cases, a significant number of additional years is required, which would mean a potential stop to both production and associated MRO activities over this period. The current "road map" for substitution and industrialisation cannot be sped-up, and some margin is needed to allow for any delays or possible failures. The potential duration of such a production stoppage would not be economically feasible.

- **We may have to cease all operations as the Company will no longer be viable.** If shifting work to countries outside GB is unacceptable due to the costs or timeframe involved in setting up the required manufacturing sites and supporting infrastructure, a cessation of all operations may be the ultimate outcome for some of the OEMs, or divisions of them. It is important to note that this scenario translates to a cessation of aircraft production within GB, with consequent reductions in revenues from aircraft assembly operations. The loss of this turnover would result in other operations (R&D, Engineering, Sales, etc.) also becoming non-viable with the final outcome being a shut-down of all activities.

- **We will focus on other aerospace uses or on non-aerospace and defence applications**. The OEMs supporting the ADCR members are mainly involved in the manufacture and repair of civilian and military aircraft. As a result, this scenario is not technically or economically feasible for most of them to switch all or most of their focus to other sectors, as their sole areas of expertise reside in the aerospace and/or defence fields.

The extent to which the OEMs would move all or only some of their manufacturing outside GB depends on the integrated "system" of activities undertaken at individual sites. Bonding primers are only used at a subset of sites, but their use may be critical to certain divisions and to the operations of suppliers to those sites.

The impact of the decisions made by the OEMs (and to a lesser degree, larger DtB companies) will determine the most likely responses across their supply chains. Due to the vertical integration of manufacturing activities, it is not feasible to cease only the use of bonding primers. All activities related to the manufacture of the relevant components, aircraft and other products may need to be moved outside GB. Note that this shifting of activity outside GB may involve either relocation or sub-contracting (for smaller components). Not only would manufacturing be impacted, but as noted above, MRO activities would also be affected with some of these operations also moving outside GB. This includes relocation of ancillary activities, such as machining, due to the increased likelihood of corrosion of machined components prior to coating.

Particular difficulties would be faced by companies in the defence sector. 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 have to be maintained in their current location could continue within GB.

5.1.2.2 Design-to-Build

Two responses were received from DtB companies, one of them stated that they **would have to move their production activities outside GB, in particular to the USA**. However, more generally, DtBs highlighted that if OEMs were to stop production or move their production activities outside GB, they would face closure, or would be forced to also move their operations. Sub-contracting to companies outside GB was not viewed as feasible, given the logistics involved in shipping and warehousing components (see further discussion below).

5.1.2.3 Build-to-Print

Build-to-Print companies rely on their customers to define the production methods that they must use. As a result, **the potential responses of BtP companies to the non-use scenario are constrained.** All members of the ADCR that answered confirmed that the choice of whether to use bonding primers containing strontium chromate is not theirs, but their customers'. Some noted that they could not shift to alternative bonding primers until these were qualified and certified for use in the production of components by their customers and the authorities, and the alternatives were deemed suitable and sustainable for their customers' uses.

Four responses were received from BtP companies. Two of them stated that they will stop undertaking use of the chromates until they have certified alternative, one stated that **they may have to cease all operations as the company will no longer be viable**, and one stated that the decision is up to their customer.

One company quoted: "We will support our customers by using chromates until a feasible alternative is identified that meets our customers' requirements".

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

5.1.2.4 MROs

For companies that operate as MROs only, there is less choice. They will not undertake manufacturing per se, only the overhaul, repair, and maintenance of different aerospace and defence components, which can differ in size and complexity (ranging from the overhaul of a complete aircraft to maintenance of a single component).

When components enter under the services of an MRO, the required maintenance effort, including which primers may be required, may not be directly foreseeable. Very often, the level of work required only becomes clear after disassembling the component. The coating steps required for any given component is dependent on its condition and can differ for each maintenance event. As a result, not every component will require primer application. Levels of throughput are also dependent on the size and complexity of the component - processing times can range from five minutes to several days. Within these process flows, even if use of bonding primers containing strontium chromate is only required to a very limited extent, it may remain essential as part of maintenance and repairs carried out to ensure that airworthiness regulations are met.

The inability to use bonding primers containing strontium chromate where set out in Maintenance Manuals may make repair and overhaul services unviable for MROs. Without the ability to provide the full range of processes that may be required, it would be difficult to win business. There is no scope for them to operate outside the requirements detailed in the OEMs' service manuals, which are based on the qualified and approved uses of bonding primers. Where these requirements mandate the use of bonding primers containing strontium chromate, then the MRO must use the primer as instructed unless the manuals also list a qualified alternative.

One MROs stated that they will **stop undertaking use of the chromate until they have a certified alternative**. Another MROs stated that they **shift their work involving use of the chromates to another country**, such as the USA or Brazil.

For example, within the Mobile Engine Services (MES) product, maintenance work is performed at the customer's site on an assembled aircraft engine. This can involve non-destructive testing or component changes that do not require the complete disassembly of an engine. In the course of this maintenance work - depending on the findings - corrosion protection with prescribed chromate-containing materials must be carried out in individual cases, in order to complete the maintenance work to the prescribed extent and to be able to release it under airworthiness requirements. If this step is not possible, the entire maintenance process of the engine and thus the product is compromised.

Similarly, in the course of overhauling an airframe (Base Maintenance), the use of chromates on structural components for the purpose of corrosion protection is occasionally necessary - depending on the specific findings - and is a binding requirement under aviation law (airworthiness requirements). As a rule, the necessity of using chromate-containing materials can only be determined after partial or complete dismantling or exposure of the structural components. In this state of construction, however, a relocation of the production site is de facto impossible/ruled out, since the aircraft is then in an extremely high dismantling state. If these safety-relevant corrosion protection treatments, which are an integral part of the certification-relevant maintenance specifications, can no longer be carried out, the entire maintenance process of the aircraft is also compromised.

5.1.2.5 Additional considerations

Current industry best practice does not involve identifying manufacturing plants as Cr(VI) or Cr(VI)-free. To the contrary, in the aerospace and defence industry, reliance on proven corrosion prevention systems means that Cr(VI) and non-Cr(VI) operations/processes normally exist side-by-side, are inter-reliant and non-separable. The aerospace industry has a very complex and interrelated supply chain. Nonetheless, for several essential components, only one designated supplier exists. Typically, this supplier will have worked in close partnership with its customer(s) for decades to develop a product. Critical suppliers are often located on, or adjacent to, the premises of their customers. Therefore, relocation will often be based on strategic decisions, e.g., if the customer relocates then the suppliers might do the same to retain proximity.

From an operational perspective, application of Cr(VI)-based bond primers products is a small element of the overall process flow in most mixed facilities, with the combination of machining, finishing, assembly, testing and inspection dominating overall. However, as noted above, they cannot be separated from one another. The impacted operations, and therefore socio-economic impacts to industry under the non-use scenario, go far beyond the specific processes directly using Cr(VI) and have substantial implications for non-Cr(VI) processes that are indirectly affected.

Hypothetically, components could be produced outside of GB and then be shipped back as part of MRO activities. Additionally, the added cost of transport would drastically undermine the competitiveness of GB component/assembly suppliers. By adding extra transportation, lead-times, customs, and risk of additional handling-related damages, suppliers in GB would be put at a massive disadvantage, compared with non-GB suppliers, in their bids/services. Furthermore, if manufacturing activities using Cr(VI) versus Cr(VI)-free were separated on both sides of GB borders, the logistic requirements of managing the flow of components/assemblies and the level of transportation required would have dramatic impacts on resources and the environmental footprint of the sector.

5.1.3 Non-plausible scenarios ruled out of consideration

Move to a poorer performing alternative

Moving to a poorer performing alternative would not be acceptable to the OEMs, either from a Design Organisation Approval (DOA) perspective as approved by EASA[61], MoDs, and the European Space Agency (ESA), or from an engineering perspective taking airworthiness safety requirements into consideration.

As noted in the parent Applications for Authorisation, the scenario of moving to a poorer performing alternative is not possible. In this scenario, the reason OEMs cannot accept an alternative that is less efficacious in delivering corrosion protection is because it would downgrade the performance of the final product giving rise to several unacceptable risks/impacts:

- The highly likely risk of EASA (airworthiness authorities) and MoDs not accepting a downgrade in performance;
- Increased maintenance operations, leading to an increase in the downtime of aircraft and military equipment, increased costs of maintenance, fewer flying hours, etc.; and
- Increased risks to passengers, cargo operators and operators of military equipment.

With an inadequately performing primer, corrosion pits can form in the substrate. These can turn into fatigue cracks which potentially endanger the whole final product. This is a particularly critical risk for the aerospace industry as corrosion pits can be extremely difficult to detect. Such issues likely would not appear suddenly but after several years, when hundreds of aerospace components are in-service. The potential for decreased performance from Cr(VI)-free bonding primers would necessitate shorter inspection, maintenance and repair intervals to prevent failures, and flight safety obligations preclude the aerospace industry from introducing inferior alternatives on components.

In the purely hypothetical case where decreased, or loss of, corrosion protection is introduced to aircraft components, the following risk mitigation actions may be required:

- Substantial increase in inspections – both visual checks and non-destructive evaluations, such as ultra-sound crack tests, etc. Some inspections are very difficult or hazardous to perform (e.g., inside fuselage/wing structures). All aircraft using fewer effective materials in repair/overhaul and/or unproven materials across the operating lifetime of an aircraft would be subject to increased inspections. A very conservative inspection frequency would be set to ensure safety until adequate in-service performance experience is obtained.
- Increased overhaul frequency or replacement of life-limited components. Possible early retirement of aircraft due to compromised integrity of non-replaceable structural components.
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet (e.g., grounding Boeing 787 fleet due to battery problems).
- Due to similarity of technologies and aircraft uses, a fleet grounding event in such a scenario could impact many or all aircraft fleets.
- An increased number of aircraft required by each airline would be needed to compensate for inspection/overhaul downtime and early retirement.

[61] As defined by Commission Regulation (EU) 748/2012 which sets out the requirements that must be fulfilled by organisations that design aircraft, make changes to aircraft, repair aircraft and the parts and systems used in aircraft.

- Defence systems would have similar impacts adversely affecting the continuity of national security.

Aerospace components are portions of major systems (fuselage; wings; engines; etc.) and the components in these systems are designed to be overhauled on similar schedules. For example, a system is designed to achieve 25,000 cycles between overhauls and a new component is only rated for 5,000 cycles because of a Cr(VI)-free bonding primer. By default, the entire system would now be de-rated to 5,000 cycles. Take a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to the limitations of a change to the surface treatment system, the engine would require disassembly to access the blades. This means taking the engine off the wing, sending it to a repair centre, disassembling the engine and replacing the components at much shorter intervals than needed for the remainder of the engine. Thus, adding inherent inspection, maintenance, and repair costs to the manufacturers, operators, and end use customers who will also be impacted by increased out of service times.

As noted in Section 3.1.1.2, MSG-3 provides a system for OEMs and the regulators to identify the frequency of inspection for any component or system. Without adequate experience and proven success, and therefore possible unknown or hidden properties, the performance of a Cr(VI)-free bonding primer cannot be highly rated. The consequence of this would be a significant reduction in the maintenance interval, which would result in investment in additional spare A&D products, to be used while products being repaired are out of service. As a result, OEMs rule out moving to poorer performing alternative as a plausible scenario, as the risks are unacceptable. The primary objective of these companies is to move to an alternative. This objective cannot be achieved, however, without sufficient testing and flight (or other) data surrounding the use of alternatives. Without such data, the necessary approvals cannot be gained as the safety risk becomes too great, whether related to civil aviation or military aircraft. The benefits provided by bonding primers containing Cr(VI) are crucial to the manufacture of the relevant aircraft components in GB. If there are no qualified alternatives certified for the use on components, then such manufacturing work would cease.

Overseas production followed by maintaining GB inventories

To be competitive, companies have to keep inventory as low as possible ("just-in-time" delivery). Maintaining inventory clearly involves substantial capital costs (as elaborated below) and ties up cash. Stockpiling is also clearly not feasible for the repair and maintenance side of the business because the main aim of repair is to make components serviceable rather than replace them with spare components (which would run counter to the sector's drive towards increased sustainability).

The reasons why holding increased inventories is not a feasible option compared to maintaining and repairing damage include, but are not limited to, the following considerations:

- If no certified alternative is available or is likely to become available within months after the end of the review period, then there is no clarity on how long such inventories of components must be available. For legacy aircraft, inventories will certainly be required for the next 20 years or more. Additionally, there is no visibility or clarity on customer demand in the short or longer term. Planned maintenance can be taken into account, but it is not possible to anticipate which components will be needed for unplanned maintenance and repair. Consequently, an assumption regarding the inventory that needs to be available for a sufficient duration would have to be made, leading to the risk of wasted resources or aircraft/equipment becoming obsolescent due to inadequate inventories.

- Stockpiling results in increased costs and would reduce the opportunity to invest in other projects/R&D, etc. The inventory costs would also have to be added to product costs and would therefore reduce competitiveness for operations in GB.

- The costs of building adequate warehouse facilities in GB would be prohibitive and would not be economically feasible. In the UK, an industrial warehouse without climate control (which would be required for the storage of some A&D inventory) costs around £1,000 per m2 to construct (a conservative estimate). It is assumed here that warehouses that would act as a hub for storing inventory would be around 10,000 m2 as a minimum, given the range of components that would need to be stored. This implies a total build cost of around £10 million as a minimum, not taking into account the costs of land purchase, site preparation, design, construction, etc. which could easily add a further 25%, even after taking into account any potential economies of scale in pricing due to the large size of the warehouse . If such facilities are required at around 100 sites across GB (to cover civilian and military requirements for storage of sealed and other components affected by a refused authorisation), then warehousing costs alone would lead to £1 billion in expenditure. These costs would be on top of the losses in profits that would occur from the need to subcontract manufacture to companies located outside GB and the consequent profit losses and increased costs of shipping, etc.

- Facilities do not have enough production capacity to build up multi-year inventories, while also meeting current demand. Even if production capacities could be increased and adequate quantities of standard components be produced, there would be idle inventories for years beyond their need, which would in turn increase product costs for years. Importantly, the need to store this inventory under optimum conditions to avoid corrosion or damage over extended periods of stockpiling, would lead to further increases in costs.

- Existing facilities are not sized to store the amount of multi-year inventories required. Companies will need to build/invest in additional secure, high-quality warehouses to store the inventory. However, it is important to recognise that this scenario is not feasible at all for many components, such as airframes, because these components are not removed from the aircraft; these components only allow MRO activities in-situ. Therefore, the entire aircraft would need to be transported to a non-GB country for repair. If the plane is not airworthy, the effort and cost relating to transportation alone (e.g., from Belgium to Egypt) would be overwhelming.

- Dependency upon local inventories and non-European suppliers (and in turn vulnerability to local economic and political issues affecting non-GB countries), means being unable to reliably fulfil MRO activities, and will lead to inevitable delays and potential cancellation of flights, fines due to longer turn-around times, and aircraft on ground scenarios.

- Companies make design modifications for single components as part of their normal course of business (for reasons other than chromate substitution). In these cases, all existing inventory would need to be written off for a loss. Furthermore, companies would not be able to produce the modified components in GB anymore (if use of bonding primers is still required). Consequently, it is clearly not possible to rely on a long-term stock of spare components that would fit all situations.

- It is impossible to hold a stock of all spare components at every airport. This would affect schedules, especially overnight stops as aircraft cannot be readily repaired and maintained. As a result, these aircraft would not be available for services next day and delays or flight cancellations would likely occur.

- Cost and environmental impacts of managing and disposing of waste components that could not be reused would be high. This seems to be inconsistent with the emphasis on waste reduction as a part of the circular economy.

It is not possible to estimate these impacts quantitatively due to their multi-fold nature (i.e., increased cost of land and construction for warehousing, worker costs to secure and maintain inventory, increased delays and 'aircraft on the ground,' writing-off stock) and there is no precedent to rely on, as this NUS is entirely contrary to current industry practice.

The result would be that the cost of operating in GB would increase considerably and become economically infeasible. In a very competitive industry, this would result in a migration of the entire industry (the inter-dependency of the industry is explained below and elsewhere in the SEA) to non-GB locations. As production moves outside GB, related activities such as R&D will also re-focus to these non-GB countries. It can also be expected that future investment in associated industries and technologies will be most efficiently located alongside these activities.

Given the above, this scenario was not considered plausible by the OEMs and MROs due to the need for sensitive components to be protected by application of primer quickly after machining. It was confirmed though that such an approach may be feasible for a small range of components for civilian aircraft and for a limited number of components for military aircraft and equipment. However, as an overall strategy, it would not be feasible.

5.1.4 Conclusion on the most likely non-use scenario

The most likely non-use scenario is driven by the responses of the OEMs to the questions on the non-use scenario. They are the actors that carry out the R&D and testing (sometimes in collaboration with their chemical suppliers) to determine whether an alternative is technically feasible, qualify and gain approvals for components using that alternative and then certify their suppliers against its use. In some cases, they also help their suppliers meet the financial costs of adapting existing paint shops to enable them to move to the alternative.

As a result, the most plausible non-use scenario for the OEMs drives the most likely non-use scenario for the sector. The most likely scenario is therefore the following:

1. GB suppliers (importers and distributers) of the chromates/formulations used in bonding primers would be impacted by the loss of sales, with the market for bonding primers for A&D relocating outside GB.

2. **OEMs directly involved in use of bonding primers would move a significant proportion of their manufacturing (if not all) outside GB**, with the consequent loss of significant levels of turnover and employment. In particular, they will move those manufacturing activities reliant on the use of bonding primers where there is no qualified alternative or where implementation across suppliers is expected to take several years after the end of the current review period. **The losses to GB are estimated at 90% of manufacturing turnover based on**

the consultation. There would be a significant loss of jobs directly related to use of bonding primers, as well as across other manufacturing activities.

3. OEMs who do not carry out bonding priming themselves would still move some of their manufacturing operations outside GB due to the need for other production activities to be co-located with key BtP and DtB suppliers (i.e., to form clusters). This would facilitate the integration of manufacturing activities and associated maintenance and repair activities. As a result, there would be losses in turnover and employment associated with these companies also relocating.

4. **As OEMs shift their own manufacturing activities outside GB, they will have to carry out technical and industrial qualification of new suppliers or GB suppliers moving to the new location**, to ensure suppliers have the capability to deliver the stringent airworthiness and certification requirements. This would then be followed by a ramping up of production in order to meet the manufacturing rate objectives.

5. In some cases, these will be developed using BtP and DtB suppliers who have moved operations from GB to third countries in order to continue supplying the OEMs. However, a significant proportion of the existing BtP companies involved in use of bonding primers will cease undertaking bonding priming in GB. Those that do not know what will happen as the decision is up to their customer, will either relocate outside of GB, cease use of the primers, or cease trading altogether, depending on their reliance on use of the primers and whether it is financially viable to relocate. **For BtP companies, the turnover losses were estimated to be 52% of turnover; and, for DtB companies, turnover losses are estimated at 90%, which is based on the consultation.**

6. MROs will also be severely affected, and the majority of operators indicated that they will cease trading, due to the need to maintain vertical integration across the surface treatment processes that they are able to carry out.

7. The re-location of MRO activities will have consequent impacts for civil aviation and military fleets, as well as for the maintenance of defence products, space equipment and aero-derivative products.

8. Airlines and their passengers would be impacted by increased costs and planes on the ground, while military forces' mission readiness would be impacted with the risk that equipment would also become obsolete and unavailable due to the inability to carry out repairs and/or maintenance activities according to manufacturers' requirements.

9. Taken together there would be significant economic impacts from the loss of manufacturing and maintenance to the GB economy, together with the loss of highly skilled jobs (and potentially a highly skilled labour force) and the benefits derived from the R&D carried out by a high-tech sector.

The justification for this NUS takes into account that OEMs and DtBs will not have certified alternatives, which have been fully implemented across their supply chains for all components, by January 2026. Many will require a further 12 years to have fully implemented alternatives across all components/final products and the GB supply chains. The regulatory requirements placed on the sector mean that unless components have certified alternatives there is no substitute which can be considered "generally available"[62].

As noted previously, because of the complexity of the supply chain, and the close working partnerships that exist, a decision by an OEM or DtB to relocate will result in their suppliers relocating to retain proximity. Such relocation would involve not just priming, but the associated machining, surface treatments and coating activities due to the potential for corrosion of unprotected surfaces during transport to another place.

The impacted operations and socio-economic impacts to industry under the non-use scenario will therefore go far beyond production of just the specific components that require use of bonding primers. **Figure 5-1** illustrates the interdependency of every single component used, and the effect of only one component missing for the overall assembly process of the aircraft. In the first box, a component reliant on use of bonding primers containing strontium chromate would be impacted. If this can no longer be produced according to type certification, then manufacture of a sub-assembly is impacted. This then impacts on manufacture of an assembly and places the manufacture of the entire aircraft in jeopardy. As a result, it is not possible to relocate single Cr(VI)-based activities on their own in most cases, as they are an integral part in the production chain and cannot be separated from previous or following process steps.

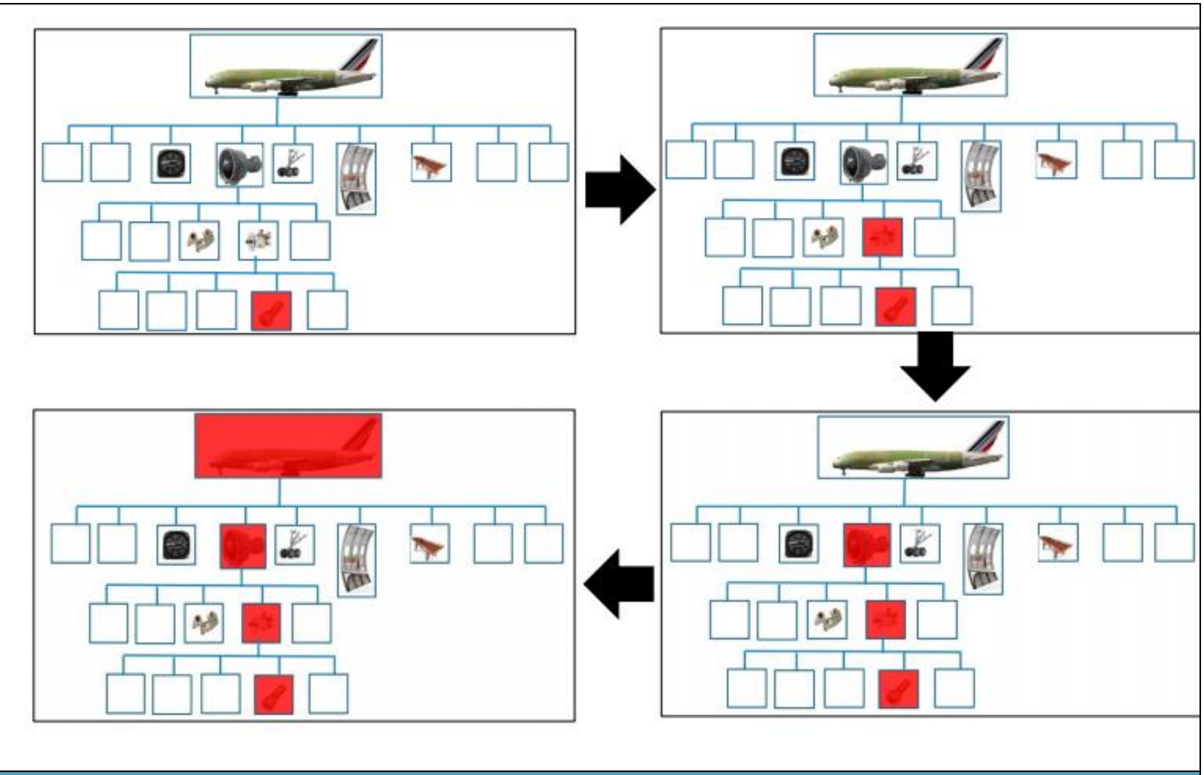

Figure 5-1: Interdependency of component availability in the manufacture of a final product
Source: GCCA (AfA 0116-01)

MROs will be similarly affected. It is technically not possible (or economically feasible) to carry out repairs to large components outside GB, and then ship them back for reassembly in a final product in GB. Apart from the fact that the surface of the component could be damaged during transport, adding

[62] 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)

to the technical infeasibility of this situation, the very tight turnaround times and budgets are impossible to hold in such a scenario.

Finally, although this is considered the most plausible scenario, OEMs note that the obstacles that would have to be overcome may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs (see also **Figure 5-3**), with smaller suppliers located around the sites operated by the larger OEMs. Not all of these smaller sites, including those of critical suppliers, would be able to shift their activities outside GB, leading to OEMs having to create entirely new supply chains outside GB, or increase capacity for existing supply chains. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their GB suppliers. This level of investment is unlikely to be feasible and, in the meantime, the OEMs would have to cease manufacturing activities in GB until the new industrial facilities were in place and ready to operate outside GB.

5.2 Economic impacts associated with non-use

5.2.1 Economic impacts on applicants

Under the non-use scenario, all applicants would be impacted by the loss of sales of bonding primers containing strontium chromate. At the specific supplier level, these impacts may vary in their significance, as the importance of bonding primers containing strontium chromate to their revenues varies across the suppliers.

In the short term (i.e., first 2 years under the non-use scenario), the losses will be in the order of Euro/Pound sterling tens of millions per annum to the applicants. Over time, as consumption of the bonding primers containing strontium chromate reduces in line with companies' test candidate development plans, sales and hence revenues will continue to decrease.

No quantitative estimates for the formulation losses are included in this SEA. These impacts are captured in the combined AoA/SEA for formulation.

5.2.2 Economic impacts on A&D companies

5.2.2.1 Introduction

It would theoretically be possible to move the use of bonding primers outside GB due to already existing supply chain sites in other countries, for example, the USA, Canada, China, Mexico, Morocco, etc. and to outsource manufacturing as the supply chain is spread around the world. Wherever operations were transferred to in the event of a non-use scenario, there would need to be a qualified supply chain in place with sufficient capacity to absorb the additional demand. Granted authorisation in GB would provide access to qualified supply chains, however it is unknown if the GB supply chain would have the required capacity or how long it would take to ramp-up capacity to meet demand. There are several obstacles to such a scenario, however, which would make this economically unattractive even if it is the most plausible scenario. When activities are shifted to another site, there is an inevitable phase of technical and industrial preparation (site design, capital procurement and installation, worker training, pilot trials) and qualification to ensure the sustainability of these activities, including an assessment of the technical capability to deliver stringent airworthiness and certification requirements. Moreover, once the qualification phase is over, it is essential to get the right ramp up in order to meet the manufacturing rate objectives.

In the remaining time before the end of the initial review period, even if alternatives were qualified and certified across the manufacture of components and products, these two aspects are not realistic. It would require a huge economic investment that would significantly affect businesses with detrimental economic impacts. As a result, OEMs have indicated that they probably would be forced to stop manufacturing activities until the new industrial facilities and infrastructure is in place and ready to operate outside of GB, with consequent impacts on the entire value chain. This could result in a reduction in longer term market shares as customers switch to competitors already established in non-EU countries and who have their own already well-established supply chains. Given the current levels of civil aviation and anticipated growth, this would be detrimental for aviation in GB and globally.

5.2.2.2 Approach to assessing economic impacts

As noted in Section 1, the ADCR has been created as a sectoral consortium and downstream user members include competitors, who may also act as suppliers to each other; the larger companies also share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). These interlinkages have been taken into account in the estimation of economic impacts, which have been calculated for the OEMs, MROs, and the associated BtP and DtB suppliers.

Two separate approaches have been used to estimate the magnitude of the potential economic impacts. Both are based on responses to the SEA questionnaire, with one taking as its starting point the number of jobs that would be lost while the other considers losses in turnover and what these imply in terms of losses in profits. Both approaches are used as a greater number of responses provided estimates of jobs lost than of the likely impacts on turnover (in percentage or actual terms).

1. **Estimates based on loss of jobs**: The first approach takes as its starting point the number of jobs that would be lost at the sites of SEA questionnaire respondents, based on their most likely response to the Non-Use Scenario. This includes loss of jobs directly linked to use of strontium chromate and losses in jobs at the site reliant upon the continuation of their use, i.e., jobs in related manufacturing and assembly activities. Importantly, it excludes losses in employment at local sub-contractors providing support services. The numbers of jobs lost are multiplied by the average Gross Value Added (GVA) per job (taking into account variations by role) to provide an estimate of total GVA lost. Personnel costs associated with this GVA are then subtracted to derive the implied losses in operating surpluses per annum.

2. **Estimates based on loss of turnover**: The second approach takes as its starting point the anticipated losses in terms of percentage of turnover reported by the respondents to the SEA questionnaire. Lost operating surplus is then calculated as an average per company based on role in the supply chain and ONS data on GOS.

Both approaches provide proxy estimates of profit losses based on current levels of employment and turnover. The approaches do not account for foregone future turnover that would be achieved under the continued use scenario due to growth in the global demand for air traffic. They also do not account for profit losses due to increased military and defence spending as a result of either a cessation in manufacturing activities or their relocating outside GB. In both approaches, the values have also been multiplied up to provide an estimation for the total number of sites across GB.

The two approaches have been applied to account for uncertainty in the data available from the SEA questionnaire responses. Together they provide an interval, with one estimate acting as an upper bound and the other as a lower bound to the economic impacts.

5.2.2.3 Estimates based on loss of jobs (and GVA lost)

The SEA questionnaire collected data on the number of employees who would lose their jobs under the NUS. This includes both those whose job directly involves use of strontium chromate and those whose jobs would be affected due to a cessation of production activities or due to companies moving outside GB. The resulting figures are presented in below.

The job losses reported by respondents, which range from a few per site where only use of bonding primers containing strontium chromate would cease to all employees in the event of closure are significant:

- Over 1,000 jobs involving workers directly involved in use of strontium chromate where this includes jobs undertaking other linked processes/treatments (chromate and non-chromate based) as well as follow-on manufacturing, assembly, repair and maintenance activities;

- Over 2,700 additional jobs due to the cessation of manufacturing activities across product lines or to the cessation of MRO services, including due to companies moving operations outside GB.

Table 5-2: SEA survey responses and extrapolations on numbers of jobs lost under the Non-Use Scenario

	No. Site Responses	Direct job losses	Additional direct job losses – due to a cessation of manufacturing/MRO activities
Build-to-Print	7	226	123
Design-to-Build	2	40	200
MROs	2	9	1
OEMs	1	0	60
Total	**12**	**275**	**384**
Job losses - Extrapolation of job losses under the Non-Use Scenario			
Build-to-Print	25	807	438
Design-to-Build	10	200	1,000
MROs	10	45	5
OEMs	5	0	300
Total	**50**	**1,052**	**1,743**
Total GB direct and indirect		**2,795**	

It is important to note that these losses do not equate to 100% of the jobs at these sites, as there would not be a full cessation of activities at all sites.

These predicted job losses have been combined with ONS on Gross Value Added (GVA) per employee to the GB economy as part of calculating the economic losses under the Non-Use scenario. A weighted GVA has been used for BtP and DtB suppliers and SIC code specific GVAs have been used for OEMs and MROs. The resulting estimated losses are given in **Table 5-3**.

Table 5-3: GVA losses per annum under the Non-use Scenario			
By role	GVA per worker assumed by role	GVA lost due to direct job losses - £	Additional GVA lost due to due to a cessation of manufacturing/MRO activities - £
Build-to-Print	52,427	11.85 million	6.42 million
Design-to-Build	52,427	2.10 million	10.49 million
MROs	80,556	0.73 million	0.08 million
OEMs	116,492	0.00 million	6.99 million
Total		14.67 million	23.98 million
		Total GB	**38.65 million**
Extrapolation of job losses under the Non-Use Scenario			
Build-to-Print	52,427	42.32 million	22.94 million
Design-to-Build	52,427	10.49 million	52.43 million
MROs	80,556	3.63 million	0.40 million
OEMs	116,492	0.00 million	34.95 million
Total		59.43 million	110.71 million
		Total GB	**167.14 million**
***Weighted average GVA calculated for Build-to-Print and Design-to-Build companies as the GVA by SIC code multiplied by the SIC code counts across responding companies, divided by the total number of relevant SIC responses. MRO and OEM GVA figures from ONS (2022).**			

The magnitude of these GVA losses reflects the fact that use of bonding primers containing strontium chromate takes place across a large number of sites in GB, including large numbers of BtP suppliers and MROs (civil and defence).

For comparison, turnover for the EU A&D industry is around €259 billion[63] per annum, while that for the UK A&D sector (including NI) is around €57 billion (£50 billion) in 2020[64]. Thus, although these figures appear high, they are considered to be underestimates by the ADCR members (particularly the OEMs) given the potential for much larger segments of the sector to move outside GB should use of bonding primers containing strontium chromate no longer be permitted.

In order to convert these GVA losses to an estimate of lost operating surplus (profits), personnel costs for each lost job are subtracted. The results of this calculation are given in **Table 5-4**. Personnel costs are based on ONS data for the relevant SIC codes, with an average weighted personnel cost adopted for BtP and DtB; the average personnel costs by SIC code from ONS for OEMs and MROs are adopted in these cases.

The estimated (implied) values of lost operating surpluses generated by this GVA-based approach equate to £76.42 million per annum extrapolated out to the 50 GB sites using bonding primers.

63 https://www.statista.com/topics/4130/european-aerospace-industry/#topicHeader__wrapper

64 https://www.statista.com/statistics/625786/uk-aerospace-defense-security-space-sectors-turnover/

Table 5-4: Implied GVA-based gross operating surplus losses under the Non-Use Scenario			
	Total GVA losses- £ per annum	Total personnel costs associated with lost jobs - £ per annum*	Implied operating surplus losses - £ per annum
Build-to-Print	18 million	11 million	8 million
Design-to-Build	13 million	7 million	5 million
MROs	1 million	0 million	1 million
OEMs	7 million	2 million	5 million
Total	**39 million**	**20 million**	**19 million**
Operating surplus losses - Extrapolation to the estimated 50 GB sites			
Build-to-Print	65 million	38 million	27 million
Design-to-Build	63 million	37 million	26 million
MROs	4 million	2 million	3 million
OEMs	35 million	9 million	26 million
Total	**167 million**	**85 million**	**82 million**
***Weighted personnel costs calculated for Build-to-Print and Design-to-Build companies as the GVA multiplied by the SIC code counts across responding companies, divided by the total number of relevant companies. MRO and OEM GVA figures direct from ONS (2022).**			

5.2.2.4 Estimates based on lost turnover

The SEA questionnaire also asked companies to provide information on the impacts that a refused authorisation would have on turnover/revenues. Fewer companies responded to this question, although the responses provided by the OEMs (as the end customer) and MROs enable estimates of the likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than use of bonding primers for the A&D sector, as well as coating processes for other sectors. They also account for potential loss in turnover from subsequent manufacturing and assembly activities.

Estimates of lost revenues per site are based on ONS data by SIC code with weighted averages used for BtP and DtB companies, and SIC code specific data for OEMs and MROs. Note that the weighted averages exclude micro-enterprises as few suppliers within the sector will fall into this size category. Gross operating surplus losses are then calculated by applying GOS rate data for the different SIC codes from ONS for 2022. GOS was calculated as GVA at basic prices minus personnel costs, according to the income approach. Then the GOS divided the turnover is the GOS rate. The resulting losses are given in **Table 5-5**.

Table 5-5: Turnover and GOS losses under the Non-Use Scenario – (avg. 15% GOS losses across all roles)			
	Turnover loss %	Turnover lost per annum - £	GOS losses per annum - £
Build-to-Print	52%	164 million	35 million
Design-to-Build	90%	81 million	17 million
MROs*65	N/A	N/A	N/A
OEMs	90%	583 million	90 million
Total		**829 million**	**143 million**
Extrapolation to the estimated 50 GB sites			
Build-to-Print	52%	587 million	126 million
Design-to-Build	90%	406 million	87 million
MROs*	N/A	N/A	N/A
OEMs	90%	2,917 million	452 million
Total		**3,910 million**	**666 million**
Note: Weighted average turnover and GOS calculated for Build-to-Print and Design-to-Build companies as the GOS multiplied by the SIC code counts across responding companies, divided by the total number of relevant companies. MRO and OEM figures direct from ONS (2022). *Since no responses from MROs were received, the GOS losses have not been extrapolated and are assumed to be zero to provide a conservative estimate.			

5.2.2.5 Comparison of the profit loss estimates

The totals presented in **Table 5-5** are higher than those given in **Table 5-4**:

- GVA based approach estimates of lost operating surplus across all sites:
  - Losses of £82 million per annum for GB
- Turnover based approach estimates of lost operating surplus across all sites:
  - Losses of £666 million per annum for GB

The two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus. It is important to note that these losses apply to commercial enterprises only.

5.2.2.6 Offsetting profit losses and impacts on rival firms

The losses in operating surplus given above would result not only from a cessation of manufacturing activities, but also from the premature retirement of existing capital equipment. Some of this capital equipment would be replaced in any event as part of substitution, over the next four to 12 years. Any such investment in new equipment would be focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next seven to 12 years would not be expected to be replaced).

As there are no suitable alternatives which are generally available, following SEAC's latest guidance, consideration has been given to the need to offset the profit losses for downstream users against the potential resale or scrappage value of the sector's tangible GB assets. However, given the potential

[65] Even though MROs stated that they will have minimal impacts on their turnover, one of them quoted that there would be a significant increase in turnaround time and an increase in cost of shipping.

scale of the impacts of a refused authorisation for the sector as a whole, any possible market for redundant equipment is likely to be overwhelmed by the number of sites ceasing activities, including related processes. As a result, it is not possible to estimate the potential scrappage value of equipment, especially as contamination from its current use for Cr(VI)-based primers may further reduce its value.

Because this is a sectoral application and the ability to shift to alternatives is driven by qualification and validation by OEMs and obtaining certification approval by airworthiness authorities, the issue of potential losses incurred by rival firms undertaking use of Cr(VI)-free bonding primers is not relevant. The OEMs determine whether there are alternatives that can be used, not individual downstream users. Furthermore, as previously indicated, the ADCR is a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other, while the larger companies share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). Relationships between the OEMs and BtP and DtB are developed over time and often reflect long-term commitments given the need for OEMs and DtB companies to certify their suppliers in the manufacturing of components. As a result, rival suppliers cannot readily step in and replace their production activity.

The economic losses are therefore based on consideration of losses in operating surplus/profits only. These have been estimated over five time periods. Discounted losses over one, two, four, seven and 12 years are given in **Table 5-6**. In the following sections, a profit loss of two years will be used as a proxy to societal producer surplus loss over the review period. The default value suggested by SEAC is 4 years for cases with no suitable alternatives generally available (no-SAGA) and 2 years for cases with SAGA. The choice of 2 years is likely an underestimate in this case given SEAC's recommendation and the absence of SAGA, (lack of) offset by competitors and the high degree of specialisation in the A&D sector.

As discussed earlier, these losses are based on ONS turnover figures for 2022 (most recently available). They therefore represent an underestimate of the losses in turnover that would arise over the review period under the Non-Use scenario, given the anticipated level of future growth in turnover for the sector due to the importance of GB in the global manufacture of aerospace and defence products (as highlighted by the publicly available forecasts of the demand for new aircraft cited earlier).

Table 5-6: Discounted profit/operating surplus losses under the Non-Use Scenario – Discounted at 3.5%, year 1 = 2025

	Lost profits estimated from turnover - £	GVA-based Operating Surplus Losses - £
1 year profit losses (2025)	666.13 million	81.93 million
2 year profit losses (2026)	1,265.44 million	155.64 million
4 year profit losses (2028)	2,446.74 million	300.93 million
7 year profit losses (2031)	4,073.07 million	500.95 million
12 year profit losses (2036)	6,437.02 million	791.69 million

5.2.2.7 Other impacts on Aerospace and Defence Companies

Under the non-use scenario there would be an enormous impact on the A&D sector in GB, leading to a second wave of negative impacts on the GB market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Customer penalties for late/missed delivery of products;
- Extended durations of maintenance, repair and overhaul operations for products in service leading to e.g. “aircraft on the ground” (AoG) and other out-of-service final products, with consequent penalties and additional impacts on turnover;
- Increased logistical costs; and
- Reputational damages due to late delivery or cancelled orders.

5.2.3 Economic impacts on competitors

5.2.3.1 Competitors in GB

This combined AoA/SEA has been prepared so as to enable the continued use of bonding primers containing strontium chromate across the entirety of the GB A&D sectors. It is non-exclusive in this respect. It has been funded by the major (global) OEMs and DtB manufacturers in GB, with additional support provided by their suppliers and by Ministries of Defence, so as to ensure functioning supply chains for their operations.

As a result, there should be no economic impacts on competitors, especially as the major global OEMs and DtBs act as the major design owners which determine the ability of all suppliers to move to an alternative. As design owners they validate, qualify and certify components and products with new alternatives and gain new approvals (e.g., approvals from EASA, ESA or MoDs). Once these design owners have certified new alternatives in the manufacture of components, these alternatives will be implemented throughout their value chain.

5.2.3.2 Competitors outside GB

Under the non-use scenario, it is likely that some of the major OEMs and DtB suppliers would move outside GB, creating new supply chains involving BtP manufacturers and MROs. This would be to the detriment of existing GB suppliers but to the advantage of competitors outside GB. These competitors would gain a competitive advantage due to their ability to continue to use bonding primers containing strontium chromate and due to their proximity to the OEMs and DtB, thus minimising logistic and transport issues.

5.2.4 Wider socio-economic impacts

5.2.4.1 Impacts on air transport

Under the Non-Use Scenario there would be significant impacts on the ability of MROs in GB to undertake repairs and to follow normal maintenance and overhaul schedules. As indicated previously, MROs are legally bound to adhere to the requirements set out in the OEMs’ manuals under airworthiness and military safety requirements. Where maintenance or overhaul activities would require use of bonding primers containing strontium chromate they would have to be performed outside GB until the OEMs have gained approvals and certifications for the use of alternatives on components and have adapted the manuals setting out maintenance and overhaul instructions.

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

Should MRO facilities be relocated outside GB, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EU. Indeed, it may take some time to build up capacity to accommodate additional demand from EU-based operators, potentially resulting in a large number of aircraft being grounded until maintenance checks can be completed.

As a result, airlines would need to have additional spare components/engines/planes to account for the added time that aircraft would be out of commission due to extended MRO times. Airports may also have to build up large inventories of spare components to replace products that currently can be repaired, with this going against the desire to ensure sustainability within the sector.

The need to have maintenance performed outside GB would also lead to higher operational costs due to increased fuel use, in addition to greater environmental impacts (as discussed in Section 5.3). 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 to GB. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco adds approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring a “D check” (heavy maintenance inspection of the majority of components, carried out every 6-10 years), this would involve 400 hours of flight time (return trip) or 20 days of foregone revenue, equivalent to €1.4 million per annum. Scaling this up to the GB passenger aircraft fleet, which stands at approximately 6,700, suggests lost revenues in the tens of millions per annum just due to the need to have around 700 aircraft which require a “D check” each year. Using the above estimate for a fleet of 50 aircraft, this would amount to €20 million in revenue lost by European airlines for “D checks” alone. This figure excludes the costs of fuel and personnel, as well as the fact that additional flights bring forward maintenance interval requirements and impact on the total lifespan of an aircraft.

In addition, based on a leasing cost for a large passenger jet of around $500,000/month in 2021 (€421,500, £362,250)[66], the leasing costs alone of a plane being out of service would be roughly €14,000/£12,100 per day. On top of this will be the additional losses in revenues from not being able to transport passengers or cargo. For example, an Airbus A320 carries from 300 to 410 paying customers on one long-haul flight per day. If tickets cost on average €650 (£560) per customer (assuming 350 customers), the revenue lost due to being ‘out of action’ for one day amounts to €227,500 (£195,500). As a result, the cost of extending the period over which a plane is out of service for repair or maintenance reasons may lead to significant new costs for airlines, delays for passengers and in the transport of cargo, as well as subsequent effects for GDP and jobs due to planes being out of service for longer.

ICAO reported[67] a 49 to 50% decline in world total passengers in 2021 compared to 2019. In 2020, figures for Europe show a 58% decline in passenger capacity, -769 million passengers and a revenue loss of 100 billion USD. In addition, COVID-19 caused a 74% decrease in passenger demand for international travel in 2020 compared to 2019. The trend though is for the aircraft industry to continue expanding globally, with pre-COVID estimates suggesting that demand for air transport would increase by an average of 4.3% per annum over the next 20 years, as illustrated in **Figure 5-2**. Similar growth is

[66] https://www.statista.com/statistics/1258900/aircraft-lease-rates-aircraft-model/#statisticContainer

[67] https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

expected in air freight transport. If this growth path were to be achieved, by 2036 the air transport industry would contribute 15.5 million in direct jobs and $1.5 trillion of GDP to the world economy. Once the impacts of global tourism are taken into account, these numbers could rise to 97.8 million jobs and $5.7 trillion in GDP.

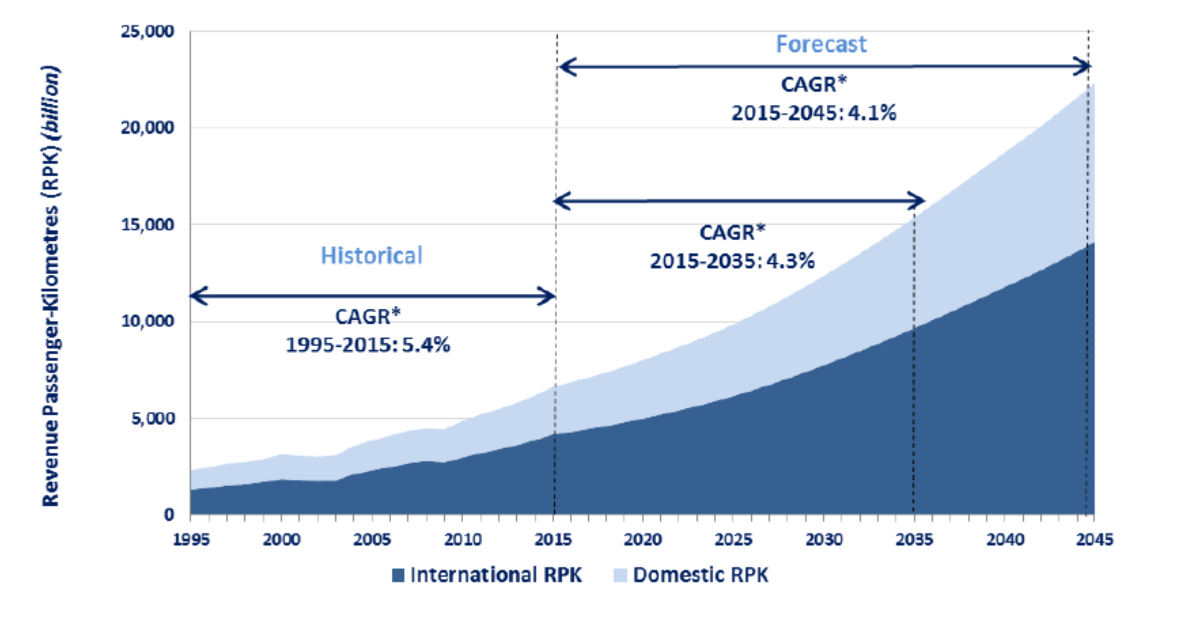

Figure 5-2: Forecast compound annual growth rates – Revenue Passenger-kilometres

Post COVID-19, projections are for a lower rate of increase in air traffic, with Airbus suggesting a growth rate between 2019 and 2040 of around 3.9% CAGR.[68] The impact of COVID-19 has resulted in an expected 2-year lag in growth, but the forecast remains unchanged with passenger numbers expecting to increase in line with the forecasts. This growth rate is relevant to global air traffic, with Europe expected to realise a lower compound annual growth rate of about 3.3% for total traffic[69] (covering inter-regional and intra-regional/domestic) for the period between 2018 and 2038.

This level of growth in GB air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. Impacts on the ability of MROs to undertake repairs and carry out maintenance requiring the use of bonding primers containing strontium chromate to ensure the continued airworthiness of aircraft could impact on the realisation of such growth. No quantitative estimate of the level of impact can be provided, but it is clear that the closure of EU-based MRO operations in particular could impact the availability of aircraft until substitution has taken place as expected over the review period. This would have a detrimental impact on the ability of airlines to transport both passengers and freight (unless airlines responded by buying more planes or stockpiling of components, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

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

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

5.2.4.2 Defence-related impacts

Defence related impacts under the NUS would have two dimensions: impacts on military forces; and impacts on companies acting as suppliers to military forces.

Two national Ministries of Defence have provided information regarding their use of bonding primers containing strontium chromate with SEA responses also provided by defence suppliers. In addition, MROs providing services to MODs have also provided information to ensure that they are able to continue to maintain and repair military final products into the future. The implications of having to cease these activities are significant. Military final products which could not be maintained to appropriate safety standards would have to be removed from service. Not only would this impact on the availability of key equipment in the case of a military emergency, but it would also affect the mission readiness of operational forces.

It is also worth noting that governments are likely to be reluctant to send military final products to MRO facilities located in non-EU countries, although the UK, US, Canada and Turkey are NATO members, and as such may be suitable candidates to service European military aircraft. There would be impacts on mission readiness if repairs cannot be done locally. This could be far more impactful than the economic impacts linked to the defence sector.

Companies in the European defence sector represent a turnover of nearly €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 the creation of spin-offs and technology transfers to other sectors, as well as the creation of jobs. For example, according to an external evaluation of the European Union's Seventh Framework Programme, through short-term leverage effect and long-term multiplier effects each euro spent by the Seventh Framework Programme (FP7) generated approximately an additional €11 of estimated direct and indirect economic effects through innovations, new technologies, and products.[70]

Indeed, the European Commission announced in July 2022 that it plans to grant a total EU funding of almost **€1.2 billion** supporting **61 collaborative defence research and development projects** selected following the first ever calls for proposals under the European Defence Fund (EDF).[71] The aim will be to support high-end defence capability projects such as the next generation of fighter aircrafts, tanks, and ships, as well as critical defence technologies such as military cloud, Artificial Intelligence, semiconductors, space, cyber or medical counter-measures. It will also spearhead disruptive technologies, notably in quantum technologies and new materials, and tap into promising SMEs and start-ups. Some of these gains may not be realised if the main GB defence OEMs have to divert resources into shifting part of their manufacturing base outside of GB.

However, under the NUS, companies manufacturing components for defence, and servicing military aircraft and other derivative defence products would most likely apply for defence exemptions; although for some companies, the turnover generated by military contracts alone may not be

[70] https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

[71] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4595

sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers.

If Governments did allow the manufacture and servicing of military aircraft and other defence products to move out of GB under the NUS, then some proportion of such multiplier effects would be lost to the GB economy. In addition, the ability of GB to benefit from some of the innovations and technological advances in products ahead of other countries could be lost, if the shift in manufacturing remains permanent and extends to new products.

5.2.5 Summary of economic impacts

Table 5-7 provides a summary of the economic impacts under the non-use scenario.

Table 5-7: Summary of economic impacts under the non-use scenario (12 years, @ 3.5%)		
Economic operator	**Quantitative**	**Qualitative**
Applicants	• Not assessed	Lost profits to applicants in GB are assessed in the Formulation SEA
A&D companies	• £0.79 billion to 6.438 billion over 12 years (£0.082 to 0.66 billion over one year)	Relocation costs, disruption to manufacturing base and future contracts, impacts on supply chain coherence, impacts on future growth in GB sector , loss of skilled workforce, impacts on R&D (and potential to deliver new more sustainable technologies)
Competitors	Not anticipated due to sectoral coverage of the application	Not anticipated due to sectoral coverage of the application
Customers and wider economic effects	Not assessed	• Impacts on airlines, air passengers, customers, cargo and emergency services, and thus society as a whole • Impacts on military forces' operation capacity and mission readiness • Lost output/value added multiplier effects due to impacts on civil aviation and loss of defence sector spending • Loss of spin-off effects – innovation and new technologies

5.3 Environmental impacts under non-use

As well as leading to increases in operating costs and lost revenues to airlines, the increased distances that airlines would need to fly planes in order for them to undergo normal maintenance and overhaul schedules would lead to significant increases in fuel consumption and hence CO_2 emissions.

The most plausible non-use scenario in the event of a refused Authorisation - even if it may not be practical and would involve huge levels of investment - would be to shift use of bonding primers containing strontium chromate to another country (outside GB).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using strontium chromate/not using strontium chromate are separated on both sides of the GB border, huge logistics and transport related requirements would have to be introduced with dramatic impacts on the aerospace and defence sectors' environmental footprint.

For MRO activities, each time an aircraft would need a repair requiring the use of bonding primers containing strontium chromate it would force the manufacturer to go to a non-GB site. In the case of a major repair, aircraft that could not fly would become stranded or, less likely, would have to be dis-assembled for transport to a non-GB site. Some stranded final products would become obsolete prematurely, due to the paucity of the components needed for their maintenance and repair. This would create excess waste and would go against the principles underlying the Circular Economy and the sustainable use of raw materials, by limiting the ability of the sector to repair and re-use components and assemblies. The industry has been active in trying to decrease buy-to fly ratios (the ratio of material inputs to final component output), and the non-use scenario would significantly undermine these efforts as the more frequent production of new components would increase the waste and scrappage generated. Scrap is material which is wasted during the production process.

Today, the civil aviation industry strives to develop new technologies to reduce the amount of CO_2 emissions by 15 - 20% on each generation of in-service aircraft.

Despite the impact that the COVID-19 pandemic had on air traffic and the whole civil aviation industry, aviation is predicted to double in the next 20 years (see **Figure 5-2**). Consequently, a refused authorisation renewal would lead to aircraft manufacturing and MRO activities involving Cr(VI) uses to move outside GB. In addition to the socio-economic consequences this would have, the increase in CO_2 emissions would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO_2 emissions of in-service aircrafts.

5.4 Social impacts under non-use

5.4.1 Direct and additional job losses

5.4.1.1 Estimated level of job losses

The main social costs expected under the NUS are the redundancies that would be expected to result from the cessation of production activities (all or some) and the closure and relocation of sites. As indicated in the assessment of economic costs, the estimated reduction in job losses is based on responses to the SEA questionnaires. Direct job losses will impact on workers at the site involved in use of bonding primers containing strontium chromate and linked processes, as well as workers involved in subsequent manufacturing and assembly steps and related activities (e.g., lab workers, etc.). These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

While redundant workers are expected to face a period of unemployment, in line with ECHA's guidance it is assumed that such a period would be only temporary. However, the length of the average duration of unemployment varies greatly across European countries, as do the costs associated with it.

It should be noted that the ECHA methodology has been followed here despite the fact that the impacts across the A&D sector may make it difficult for workers to find another job, especially as there may be a skill mismatch (if there are large scale levels of redundancies).

Estimates of the job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in **Table 5-9** below. The magnitude of these figures reflects the importance of bonding primers containing strontium chromate to the manufacture of components, as well as to maintenance and repairs of such components at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning and other services to the BtPs, DtBs, MROs and OEMs.

As context, the civil aeronautics industry alone employees around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million[72]. The figures in **Table 5-8** indicate that approximately 2,700 A&D jobs would be in jeopardy under the NUS extrapolated out to the estimated 50 sites in GB.

Table 5-8: Predicted job losses in aerospace companies under the NUS	
Role	**Total job losses due to cessation of manufacturing activities or relocation under the NUS**
Build-to-Print	1,245
Design-to-Build	1,200
MROs	50
OEMs	300
Total	**2,795**

5.4.1.2 Monetary valuation of job losses

The method for estimating the social costs of unemployment follows that recommended by ECHA (Dubourg, 2016[73]).

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 different ratios of the social cost per job loss over the annual pre-displacement wage for European countries and the EU-28[74] as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to A&D sector production sites varying from seven months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. For the purposes of these calculations, a figure of £57k has been adopted and applied across all locations and job losses for the average salary per worker. This figure is based on the SIC code data provided by companies but may underestimate the average salary, given that A&D jobs are typically higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are £271.11 million (corresponding to 2,795 job losses).

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72 https://www.eudsp.eu/event_images/Downloads/Defence%20Careers%20brochure_1.pdf

73 Dubourg, R (2016): Valuing the social costs of job losses in applications for authorisation. Available at: https://echa.europa.eu/documents/10162/13555/unemployment_report_en.pdf/e0e5b4c2-66e9-4bb8-b125-29a460720554

74 At the time of publication the UK was still an EU Member State

5.4.2 Wider additional and induced job losses

5.4.2.1 Aerospace and defence related multiplier effects

Employment in one sector is often the input to employment in another sector, so that fluctuations in employment of the latter will inevitably affect the former. It is clear that, under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest players in the GB A&D sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in GB.

A UK Country Report on the "Economic Benefits from Air Transport in the UK" produced by Oxford Economics (2014) indicates the following with respect to the aerospace sector's contribution to UK employment in 2012:

- Indirect employment effects: 139,000 jobs implying a multiplier effect of 1.36 indirect jobs for every direct job;
- Induced employment effects: 86,000 jobs implying an additional multiplier effect of 0.84 induced jobs for every direct job.

Additional employment effects will, to a degree, be captured by the estimates of lost jobs presented in **Table 5-2** given that it includes the loss of jobs at suppliers to the aerospace OEMs. The figures exclude other service providers to these companies whose services would no longer be required. Induced effects are not captured by the above estimates and an employment multiplier of 0.84 suggests that they may be significant given the predicted numbers of jobs that would be lost across the key countries in which aerospace-related manufacturing takes place.

The loss of jobs within those companies that serve the defence industry would have their own multiplier effects. The external evaluation of FP7 referenced above[75] quotes an employment multiplier of between 2.2 and 2.4, with this covering both indirect and induced employment effects. The sector is identified as bringing a major contribution to the wider economy.

To successfully compete at a global level, the European A&D industry has formed regional and industry clusters that includes local and national government partners. The clusters are part of the European Aerospace Cluster Partnership[76](EACP) which focuses on the exchange of experiences concerning both cluster policy and the implementation of effective solutions needed to address various challenges faced by the partners. It has members located in 44 aerospace clusters across 18 countries, thus covering the entire A&D value chain in Europe. **Figure 5-3** below is a "snip" taken from the EACP website highlighting the location of these different hubs across Europe, to provide an indication of where effects may be experienced at the regional level.

[75] European Commission (2017): Issue papers for the High Level Group on maximising the impact of EU research and innovation programmes. Prepared by the Research and Innovation DGs. Available at: https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

[76] https://www.eacp-aero.eu/about-eacp/member-chart.html

Under the non-use scenario, the economic impact on each region could have severe consequences. For example, Aerospace Wales consists of over 180 members with 23,000 employees with and a turnover of over £6.5 billion in Wales (See Annex 2).

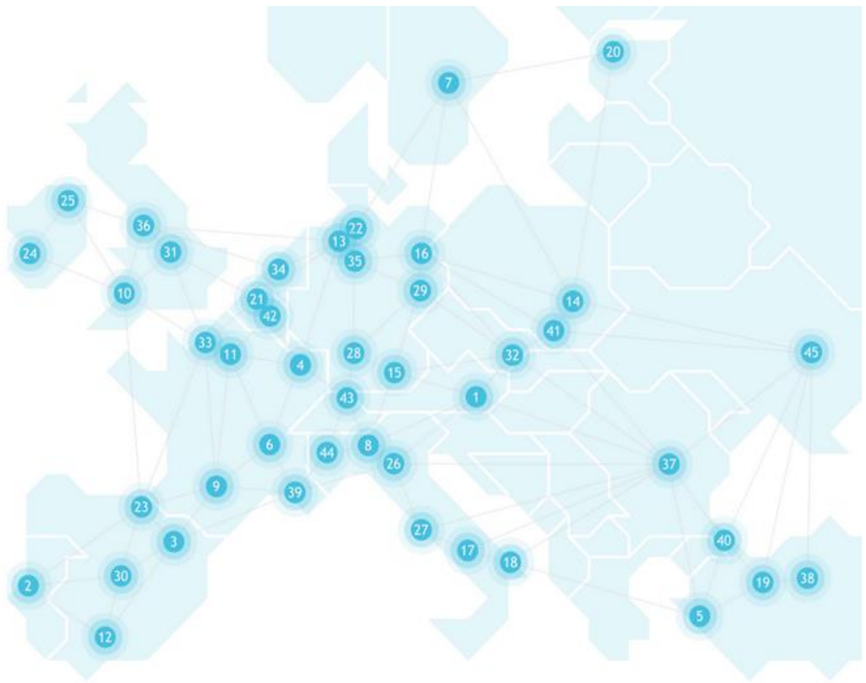

Figure 5-3: Aerospace clusters across Europe

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[77] produced by a high-level group formed by the International Civil Aviation Organisation (ICAO) provides an assessment of the economic impacts of the aviation sector. These are linked to its direct impact as well as indirect, induced, and catalytic effects. At a regional level, it is estimated that air transport supports 12.2 million jobs in Europe, 2.6 million of these jobs are directly within the aviation sector, with the remaining 9.6 million arising indirectly from the aviation sector or relating to induced or catalytic effects.

Clearly not all these jobs would be impacted under the NUS, although some impact would be expected should there be reductions in the number of flights, increased delays, and other effects from the loss of GB based MRO activities in particular.

[77] Published by the ACI, CANSO, IATA, ICAO and the ICCAIA, available at: https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf

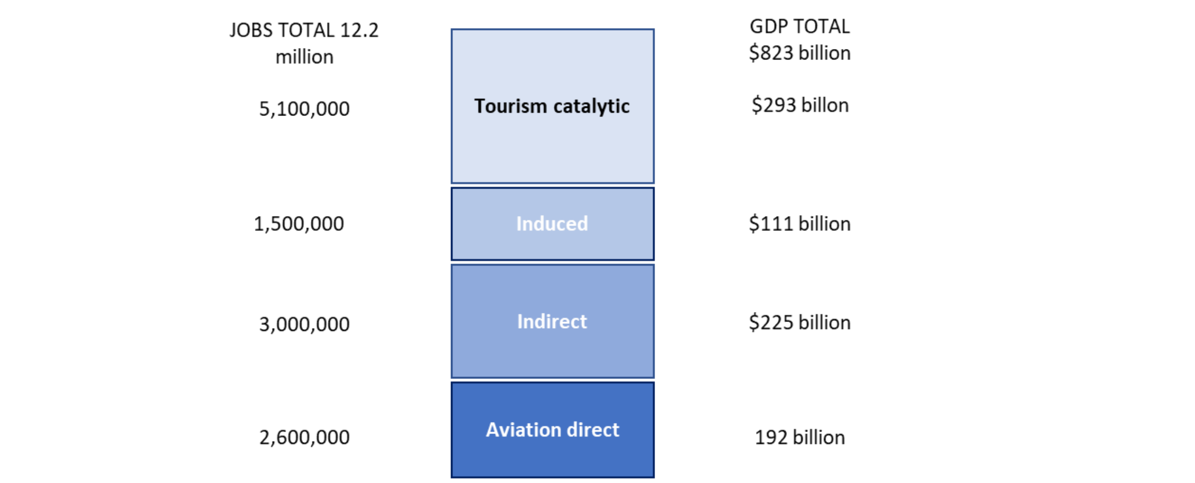

Figure 5-4: Aviation related multiplier effects
Source: Based on: https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[78]. A "COVID-19 Analysis Fact Sheet" produced by Aviation Benefits Beyond Borders reports the following:

- A reduction from 2.7 million direct aviation jobs in Europe supported pre-COVID to 2.1 million jobs post-COVID (i.e., at the end of 2021); and

- 13.5 million jobs in supported employment pre-COVID in Europe to 8.1 million at the end of 2021.

Although one would not expect the losses in supported employment (i.e., indirect, induced, and catalytic effects) to be as great due to the loss of bonding primers containing strontium chromate alone, it is clear that a disruption to civil aviation could have significant employment impacts.

5.4.3 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Direct job losses: 1,052 GB workers involved in bonding primers and linked chromate treatment processes; and 2,795 GB workers impacted by a cessation of other treatment and manufacturing activities;

- Social costs of unemployment: economic costs of around £271.11 million for GB due to direct job losses;

- Additional and induced unemployment at the regional and national level due to direct job losses; and

- Direct, indirect, and induced job losses in air transport due to disruption of passenger and cargo services.

[78] https://aviationbenefits.org/media/167482/abbb21_factsheet_covid19-1.pdf

5.5 Combined impact assessment

Table 5-9 sets out a summary of the societal costs associated with the non-use scenario. Figures are provided as annualised values and present values over the 12-year review period. Note that the true impacts of non-use are not fully reflected by the monetised impacts of non-use summarised in the table – the monetised costs of non-use are underestimated and many impacts are not monetised.

Table 5-9: Summary of societal costs associated with the non-use scenario		
Description of major impacts	**Monetised/quantitatively assessed/qualitatively assessed impacts**	
1. Monetised impacts	**£ values over the review period**	**£ annualised values**
Producer surplus loss due to ceasing the use applied for[1]: Impacts on applicants - Lost profits GB Impacts on A&D companies[1]: - Lost profits GB	Applicants: Impacts in Pound millions – see Formulation SEA A&D companies - £156 to 1,265 million	Applicants: Impacts in Pound millions – see Formulation SEA A&D companies - £16.11 to 130.95 million
Relocation or closure costs	Not monetised	Not monetised
Loss of residual value of capital	Not quantifiable	Not quantifiable
Social cost of unemployment: workers in A&D sector only[2]	2,795 jobs lost	
	£271.11 million	£28.06 million
Spill-over impact on surplus of alternative producers	Not assessed due to sector level impacts	Not assessed due to sector level impacts
Sum of monetised impacts	£427 to 1,537 million	£44.16 to 159.01 million
Additional qualitatively assessed impacts		
Impacts on A&D sector	Impacts on R&D by the A&D sector, impacts on supply chain, impacts on technological innovation	
Civilian airlines	Wider economic impacts on civil aviation, including loss of multiplier effects, impacts on airline operations, impacts on passengers including flight cancellations, ticket prices, etc.	
Ministries of Defence	Impacts on the operational availability of aircraft and equipment, premature retirement of aircraft and equipment, impacts on mission readiness	
Other sectors in GB	Loss of jobs due to indirect and induced effects; loss of turnover due to changes in demand for goods and services and associated multiplier effects. Impacts on emergency services and their ability to respond to incidents Impacts on cargo transport	
1) Lower bound figures represent lost profit estimates based on loss of jobs, upper bound based on loss of turnover. 2) Estimated using the approach set out in SEAC's guidance on social cost of unemployment 3) Totals have been rounded		

5.6 Sensitivity Analysis

below shows the scenarios considered as part of the sensitivity analysis. The two profit loss estimates are as discussed in section 5.2 and the average value of monetised human health risks form scenarios 5 and 6, which are given as central estimates in the benefits-to-risks comparison in section 6.3. The additional scenarios make use of the upper and lower bound for the human health costs, as discussed in section 4.4. These additional scenarios give a range of benefit-to-risk ratios of 124:1 to 445:1, which further strengthen the conclusion that benefits of continued use outweigh risks of continued use.

Table 5-10: Sensitivity Analysis

Scenario	Annualised Profit Losses to the A&D industry	Annualised Social Costs due to unemployment	Annualised Human Health Risks	Net Present Value	Ratio of societal costs to residual health risks
1	£131 million	£28 million	£392,253	£159 million	405:1
2	£16 million	£28 million	£392,253	£44 million	113:1
3	£131 million	£28 million	£322,360	£159 million	493:1
4	£16 million	£28 million	£322,360	£44 million	137:1
5	£131 million	£28 million	£357,307	£159 million	445:1
6	£16 million	£28 million	£357,307	£44 million	124:1

Scenario 1 - lost EBITDA/profit, upper bound human health costs
Scenario 2 - GVA-based operating surplus losses, upper bound human health costs
Scenario 3 - lost EBITDA/profit, lower bound human health costs
Scenario 4 - GVA-based operating surplus losses, lower bound human health costs
Scenario 5 - lost EBITDA/profit, average human health costs
Scenario 6 - GVA-based operating surplus losses, average human health costs

6 Conclusion

6.1 Steps taken to identify potential alternatives

When creating a test candidate development plan for substances subject to Authorisation, suitable alternatives to Cr(VI) for bonding primers should be "generally available"[79]. At present, this condition has not been met, as there are no alternatives which have met the strict regulatory requirements within the A&D industry for all components onto which bonding primers containing Cr(VI) are currently applied.

Alongside the various R&D activities, as described in Section 3.4.1, and information reported in academic literature and patent reports as described in Sections 3.4.3, members of the ADCR have undertaken extensive testing into alternative technologies and processes with many programmes still ongoing. The steps taken by members in the implementation of a substitute for Cr(VI)-based bonding primers are shown in **Figure 6-1**:

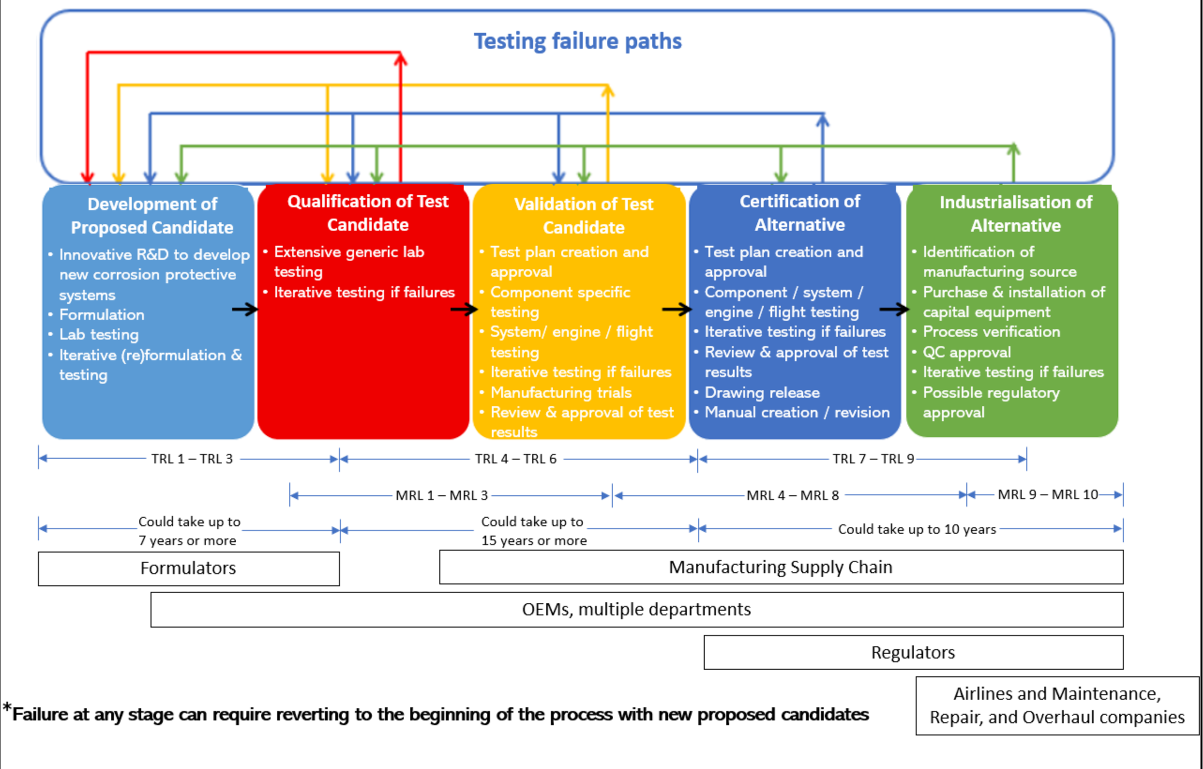

Figure 6-1: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note that failures may not become apparent until a late stage in the process.
Source: Adapted from "Use of strontium chromate in primers applied by aerospace and defence companies and their associated supply chains, Application for Authorisation 0117-01, GCCA (2017)

[79] 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: https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1

Activities undertaken include:

- Development of test alternatives in laboratory environments up to TRL 6;
- Qualification of test alternatives and suppliers including:
  - Modification of drawings;
  - Updating specifications;
  - Introduction of new processes to suppliers;
  - Negotiation of supplier(s) contracts.
- Demonstration of compliance followed by industrialisation; and
- Certification or approval.

6.2 The test candidate development plan

ADCR member companies have ongoing development plans in place to develop test candidates with the intent of replacing bonding primers containing strontium chromate.

As discussed in Section 3.7.2 and shown in **Figure 6-2** below, of the 23 distinct test candidate development plans for bonding primers assessed in this combined AoA/SEA, 35% of them are expected to have achieved MRL 10 by January 2026. MRL 10 is the stage at which it is expected production will be in operation and it is anticipated bonding primers containing strontium chromate will no longer be used for the components covered in that development plan.

The proportion of test candidate development plans that are expected to achieve MRL 10 is then expected to progressively increase to 43% in 2030, 65% in 2033, and 78% in 2038. The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any technically feasible alternatives to date, or due to the need by MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products. In 2033 (equivalent to seven years beyond the expiry date for the existing authorisations), while many test candidate development plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its strontium chromate use. A proportion are not expected to have achieved MRL 10 and are expected to be at the validation, certification, or industrialisation stage. For these test candidate development plans (which are from several member companies), there is still expected to be a need for the use of bonding primers containing strontium chromate.

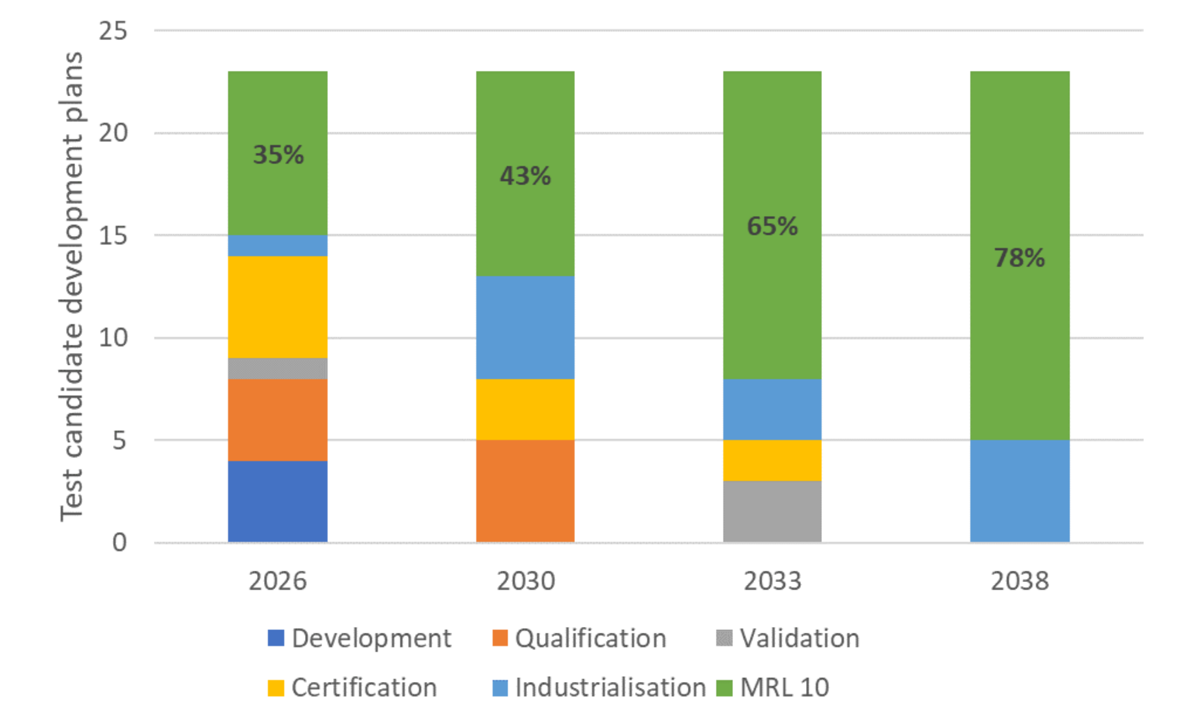

Figure 6-2: Expected progression of test candidate development plans for the use of bonding primers containing strontium chromate by year.
The vertical axis refers to number of test candidate development plans (some members have multiple development plans for bonding primers). The percentage value shown on each of the green bars indicates the proportion of development plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which manufacturing is in full rate production/deployment and it is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.
Source: RPA analysis, ADCR members

As a result of individual members' test candidate development plans summarised above, the ADCR request a review period of **12 years** for the use of bonding primers containing strontium chromate.

6.3 Comparison of the benefits and risk

Table 6-1: Summary of societal costs and residual risks

Societal costs of non-use (12 years)		Risks of continued use (12 years)	
Profit losses to applicants	Losses in profits from reduced sales of the chromate substances and associated formulations. Losses quantified in the Formulation SEA	Health risks to workers at formulation sites over the review period, taking into account the reduction in risks due to adherence to the conditions placed on the initial authorisations. These risks are quantified and monetised in the Formulation SEA	
Profit losses to A&D companies	£156 to 1,265 million	Monetised excess risks to directly and indirectly exposed workers (£ per year over 12 years)	£31,891 to £45,120
Social costs of unemployment	£271 million	Monetised excess risks to the general population (£ per year over 12 years)	£325,544 to £454,591

Table 6-1: Summary of societal costs and residual risks			
Societal costs of non-use (12 years)		Risks of continued use (12 years)	
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 GB; 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):
	    o £44 to 159 million
	- Ratio of societal costs to residual health risks:
	    o 124:1 to 445:1		

It should be appreciated that the social costs of non-Authorisation could be much greater than the monetised values reported above, due to the likely 'knock-on' effects for other sectors of the economy:

A refused Authorisation would have impacts on the GB formulators and the critical set of key functions provided by bonding primers would be lost to A&D downstream users in GB

Due to certification and airworthiness requirements, downstream users in the A&D value chain would be forced to use bonding primers containing the chromates outside GB or shift to suppliers outside GB

OEMs would shift manufacturing outside GB due to the need use of bonding primers to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside GB for application of bonding primers only (especially for touch-up repairs)

DtB suppliers may have more flexibility and be able to shift only part their production activities outside GB, resulting in the loss of profits and jobs inside GB

BtP suppliers in GB would be forced to cease use of bonding primers containing the chromates, leading to loss of contracts and jobs due to relocation of this and related activities outside GB

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 application of bonding 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

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

Overall, it is clear that the benefits of the continued use of strontium chromate in bonding primers significantly outweigh the residual risks from continued use.

Additionally**, the use of bonding primers containing strontium chromate 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.**

6.4 Information for the length of the review period

6.4.1 Introduction

In a 2013 document, the ECHA Committees outlined the criteria and considerations which could lead to a recommendation of a long review period (12 years) (ECHA, 2013):

1. *The applicant's investment cycle is demonstrably very long (i.e., the production is capital intensive) making it technically and economically meaningful to substitute only when a major investment or refurbishment takes place.*
2. *The costs of using the alternatives are very high and very unlikely to change in the next decade as technical progress (as demonstrated in the application) is unlikely to bring any change. For example, this could be the case where a substance is used in very low tonnages for an essential use and the costs for developing an alternative are not justified by the commercial value.*
3. *The applicant can demonstrate that research and development efforts already made, or just started, did not lead to the development of an alternative that could be available within the normal review period.*
4. *The possible alternatives would require specific legislative measures under the relevant legislative area in order to ensure safety of use (including acquiring the necessary certificates for using the alternative).*
5. *The remaining risks are low, and the socio-economic benefits are high, and there is clear evidence that this situation is not likely to change in the next decade.*

In the context of this combined AoA/SEA, it is assumed that qualification and certification requirements combined with the need for approvals from EASA, the ESA and MoDs are consistent with the requirements under criterion 4 above.

Further discussion was held at the 25th Meeting of Competent Authorities for REACH and CLP (CARACAL) of 15 November 2017. A document endorsed by CARACAL suggests that "*in order to consider a review period longer than 12 years, in addition to the criteria for a 12-year review period established in the document "Setting the review period when RAC and SEAC give opinions on an application for authorisation", two additional conditions should jointly be met*:

6. *As evaluated by the RAC, the risk assessment for the use concerned should not contain any deficiencies or significant uncertainties related to the exposure to humans (directly or via the environment) or to the emissions to the environment that would have led the RAC to recommend additional conditions for the authorisation. In the case of applications for threshold substances, the appropriateness and effectiveness of the applied risk management measures and operational conditions should clearly demonstrate that risks are adequately controlled, and that the risk characterisation ratio is below the value of one. For applications for non-threshold substances, the applied risk management measures and operational conditions should be appropriate and effective in limiting the risks and it should be clearly demonstrated that the level of excess lifetime cancer risk is below $1x10^{-5}$ for workers and $1x10^{-6}$ for the general population. For substances for which the risk cannot be quantified, a review period longer than 12 years should normally not be considered, due to the uncertainties relating to the assessment of the risk.*

7. *As evaluated by the SEAC, the analysis of alternatives and the third party consultation on alternatives should demonstrate without any significant uncertainties that there are no suitable alternatives for any of the utilisations under the scope of the use applied for and that it is highly unlikely that suitable alternatives will be available and can be implemented for the use concerned within a given period (that is longer than 12 years)"* (CARACAL, 2017).

As far as the second criterion above is concerned, the same document provides some relevant examples, one of which (Example (d)) reads as follows:

> "(…) *the use of the substance has been authorised in accordance with other EU legislation (e.g., marketing authorisation, certification, type-approval), the substance being specifically referred to in the authorisation/certification granted and substitution, including the time needed for modification of the authorisation/certification/type-approval, would not be feasible within 12 years and would involve costs that would jeopardise the operations with regard to the use of the substance*".

6.4.2 Criterion 1: Demonstrably Long Investment Cycle

The aerospace and defence industry is driven by long design and investment cycles, as well as very long in-service time of their products, which are required to meet the highest possible safety standards throughout their service life. As noted in Section 4.4, the average life of a civil aircraft is typically 20-30 years, while military products typically last from 40 to >90 years. Furthermore, the production of one type of aircraft or piece of equipment may span more than 50 years.

These long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EU aerospace industry[80]. They are a key driver underlying the difficulties facing the sector in substituting the use of strontium chromate in bonding primers across all affected components within final products. The long service life of aircraft and other products makes it difficult to undertake all of the tests required to qualify and certify a component with the substitute, due to the level of investment and costs that would be involved in such an activity for out of production A&D products. It would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

[80] Ecorys et al (2009): FWC Sector Competitiveness Studies – Competitiveness of the EU Industry with focus on Aeronautics Industry, Final Report, ENTR/06/054, DG Enterprise & Industry, European Commission.

The ADCR would like to emphasise the crucial role every single component within an A&D product plays with respect to its safety. For example, an aircraft is a complex system involving not only the design of the aircraft itself, but also its use and maintenance history in varied climates and service. An aircraft engine is exposed to massive forces and extremely high stress levels due to high velocities and environmental impacts. Therefore, every single component needs to be designed, manufactured, and maintained with serious attention and care.

In a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an A&D product need to be adjusted to each other very precisely on the design as well as on the manufacturing level. When in the early design phase for completely new engines, for example, there is an opportunity to consider introducing a material change. Mostly such a material change will be a step improvement on a previous design, in line with the principle of proven engineering. Very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; time consuming, systematic TRL-style implementation is required to minimise the impact of unanticipated failures and the serious repercussions they might cause. Even when an OEM has been able to undertake the required testing and is in the process of gaining qualifications and certifications of components with a substitute, it may take up to seven years to implement the use of a substitute across the value chain due to the scale of investment required and the need for OEMs to undertake their own qualification of different suppliers.

In addition, MoDs rarely revise specifications for older equipment, which must nevertheless be maintained and repaired. MROs servicing military equipment therefore have to undertake any maintenance or repairs in line with the OEMs' original requirements. Similarly, MROs in the civil aviation field are only legally allowed to carry out maintenance and repairs in line with OEMs' requirements as set out in Maintenance Manuals. Long service lives therefore translate to on-going requirements for the use of primers containing strontium chromate in the production of spare parts and in the maintenance of those spare components and the final products they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly complex systems the ADCR is addressing in this combined AoA/SEA. A 12-year review period in itself may not be sufficient for the aerospace and defence industry to fully replace strontium chromate across all uses of bonding primers. However, the industry is committed to the goal of substitution. A 12-year review period will enable the implementation of the significant (additional) investment in R&D, qualification and certification of design/drawing changes and industrialisation required across the various OEMs.

6.4.3 Criterion 2: Cost of moving to substitutes

Cr(VI) coatings were validated/certified in the 1950s and 60s and extensive in-service performance has demonstrated the performance of chromated materials. This includes modifications to design practice and material selection based upon resolution of issues noted in service. The performance of Cr(VI)-based bonding primers, due to their extensive performance history, represents the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft (including helicopters) consist of between 500,000 and 6 million components, depending on the model. Depending on the materials of construction, 15-70% of the entire structure of an aircraft requires treatment using Cr(VI) at some point during the manufacturing process. Older models generally require a larger percentage of Cr(VI)-containing primers as the aerospace industry has worked diligently to incorporate new base materials and Cr(VI)-free protective coatings in newer models wherever it is safe to do so.

There are literally billions of flight hours' experience with components onto which Cr(VI)-based bonding primers have been applied. Conversely, there is still limited experience with Cr(VI)-free alternatives on components. It is mandatory that components primed using a Cr(VI)-free alternative are demonstrably at least as safe as they had been when primed using a Cr(VI) product. The performance of Cr(VI)-free products can sometimes be demonstrated at the laboratory step but then fail at industrial scale, as it is impossible to replicate all in-service conditions in a laboratory. As a result, the time taken to progress through the TRL process may be increased until it is possible for the performance of the alternative to be demonstrated as per safety requirements at the aircraft level when operating under real life conditions.

Flight safety is paramount and cannot be diminished in any way. Take, for example, a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine because of service life (and hence maintenance requirement) limitations due to a change in the primer, the engine would need to be disassembled to be able to access the blades. That means taking the engine off the wing, sending it to a repair centre, disassembling the engine and replacing the components at much shorter intervals than previously needed for the remainder of the engine. This would add inherent maintenance time and costs to the manufacturers, operators, and, eventually, end-use customers.

Where possible, and for specific components and final products, some new designs have been able to utilise newly developed alloys that do not require a Cr(VI)-based coating (as typically used to provide corrosion protection on metallic legacy components). However, even in newer designs there may still be a need for the use of Cr(VI)-based bonding primers, due to safety considerations and a lack of suitable alternatives available in general.

These technical hurdles are a fundamental reason why the A&D industry requests a review period of 12 years.

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

Research into the substitution of the chromates has been on-going for several decades. Although use continues, it should be recognised that significant achievements have been made over this period in the substitution of the use of strontium chromate with alternative substances or technologies. This is illustrated by the achievements of one OEM in reducing their use of all chromates (including those listed on Annex XIV which are not covered by this application) by 75% (by weight) (see **Figure 6-3**).

This 75% reduction (by weight) in the use of the chromates reflects the massive efforts and investment in R&D aimed specifically at substitution of the chromates. Although these efforts have enabled substitution across a large range of components and products, this OEM will not be able to substitute chromate use in the production of all components and products for at least 12 years, and perhaps longer for those components and products which must meet military requirements (including those pertaining to UK, EEA and US equipment).

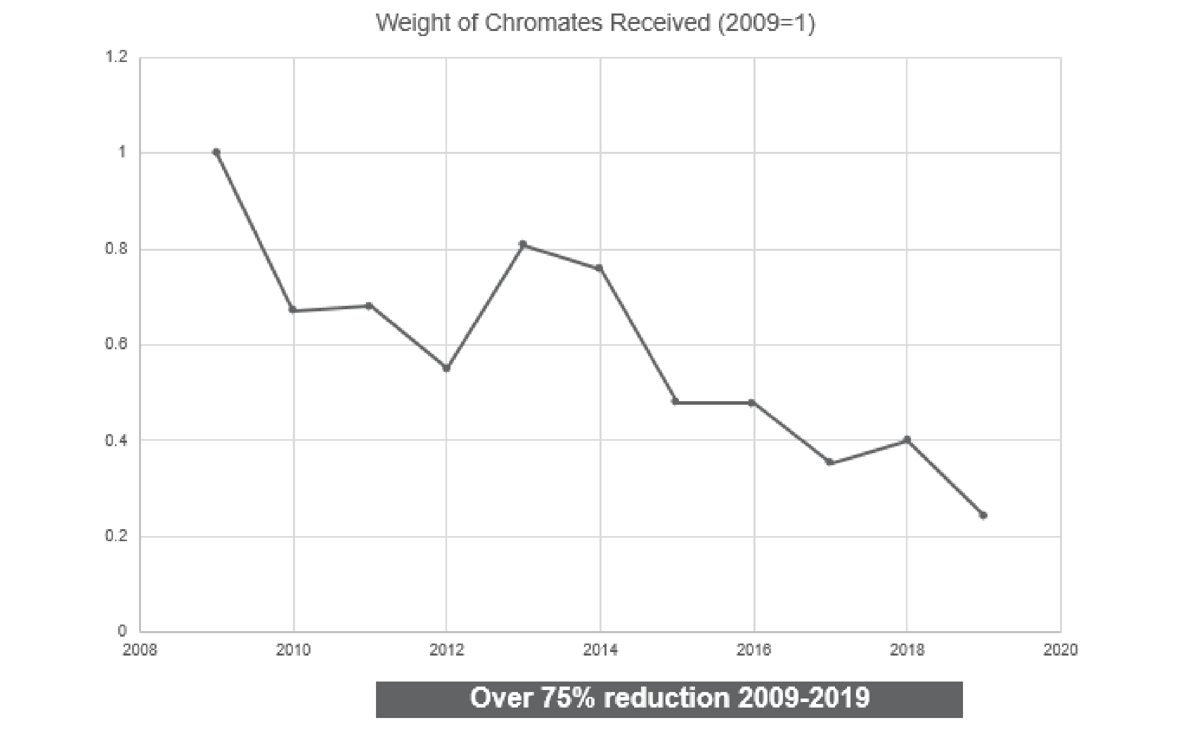

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019 as reported by one OEM.

The European aerospace and defence industry is heavily regulated to ensure passenger/operator safety. The consequence is that there are very long lead times and testing cycles before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25 plus years. In 2020, the European A&D industries spent an estimated €18 billion in Research & Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US was roughly four times higher)[81].

A PricewaterhouseCoopers (PwC) study[82] refers to the high risks of investments in the aerospace industry: "*Historically, step changes have been the norm in aircraft R&D. But recent development efforts have been so expensive that it is unclear whether the companies will earn the anticipated return on their investments. Furthermore, slips in the program schedule have worsened the economics*."

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 the case of bonding primers, it requires testing of changes in a process of corrosion protection, which may include changes in pre-treatments, main surface treatments, and post-primer layers.

Aerospace companies cannot apply a less effective corrosion protection process as aviation substantiation procedures demand component performance using alternatives to be equal or better.

81 https://www.asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

82 http://www.strategyand.pwc.com/trends/2015-aerospace-defense-trends

If such performance is not achieved, then the alternatives cannot be used. The implications for repair, replacement, and overhaul must also be understood before moving to an alternative. In particular, it must be recognised that the performance delivered by one component is dependent upon the performance of other components. Thus, the performance delivered by a final product is dependent upon all the components used. The number of configurations of components and final products is immense, and each configuration may differ from the next in terms of its behaviour with a Cr(VI)-free alternative.

As noted previously, there is a complex relationship between each component and its performance requirements within its own unique design parameters, which requires component certification for each individual substitution.

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in Section 3.1.2, the identification of a technically feasible 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 in **Figure 6-4**, 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.

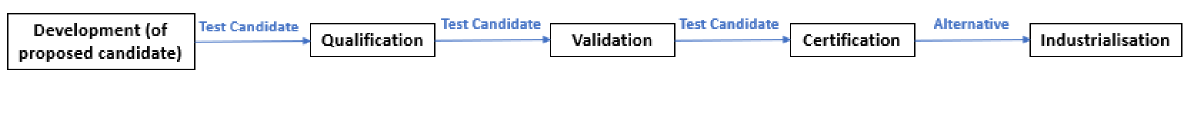

Figure 6-4: Phases of the substitution process

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 Cr(VI)-free bonding primers by 2038. Their current test candidate 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 and reliability.

In addition, several of the ADCR members note that military procurement agencies prefer key components of defence equipment to be produced in GB, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-GB territory and import of finished components or products into GB is more complex, as it could create a dependence on a non-GB supplier 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 chromates for priming purposes 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 can require the use of bonding primers 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 UK (and EEA) defence sector requires only small quantities of strontium chromate in bonding primers. Based on a defence exemption alone, the quantities demanded would not be sufficient for manufacturers, formulators, and paint applicators to continue to offer their services and products. As a result, application of bonding primers on military aircraft and equipment would not continue in the UK (and EEA) if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

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

As demonstrated by the information collected in the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of strontium chromate under the initial (parent) authorisations. This has resulted in both reduced exposures for workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of strontium chromate will decrease, and exposures and emissions will reduce further over the requested 12-year review period. As a result, the excess lifetime risks derived in the CSR for both workers and humans via the environment will decrease over the review period. These risks will also be controlled through introduction in 2017 of the binding occupational exposure limit value on worker exposures to Cr(VI) at the EU level under the Carcinogens and Mutagens Directive[83].

The European aerospace and defence industry is a world-class leader in technology and innovation. They are an essential part of the European economy contributing to job creation (880,000 direct jobs in 2020[84]) and Europe's trade balance (55% of products developed and built in GB 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.

Acknowledged market reports of both Airbus and Boeing find a growing trend in the aerospace industry. Passenger air traffic is predicted to grow at 3.6% CAGR for 2022-2041 and freight traffic to grow at 3.2% CAGR globally, according to Airbus' Global Market Forecast. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft). This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets in particular.[85]

[83] Directive 2004/37/EC of the European Parliament and of the Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work (Sixth individual Directive within the meaning of Article 16(1) of Council Directive 89/391/EEC), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0037

[84] https://asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

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

Boeing's 2022 Commercial Market Outlook[86] indicates a similar level of increase, noting that the global fleet will increase by around 3.5% through to 2041.

The socio-economic benefits of retaining the key manufacturing base of the UK A&D industries are clearly significant, given that they will be major beneficiaries of this growth in demand. As demonstrated in the socio-economic analysis presented here, even without accounting for such growth in demand under the Continued Use Scenario, the socio-economic benefits clearly outweigh the associated risks to human health at social costs to risk ratios of between 18,066 to 1 and 19,746 to 1. Substitution effort taken by the applicant if an authorisation is granted.

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been or are in the process of being implemented. However, there are still some cases where components do not have technically feasible alternatives available. **Figure 6-1** highlights the actions that are being taken by A&D design owners to develop, qualify, validate, certify, and industrialise alternatives for individual components.

This work will continue over the requested review period with the aim of phasing out all uses of bonding primers containing strontium chromate. As illustrated in Section 4, on-going substitution is expected to result in significant decreases in the volumes of strontium chromate used in bonding primers within the next seven years. However, technically feasible alternatives are still at the development phase (Phase 1 out of the 5 phases) for some components and final products, where alternatives have not been found to meet performance requirements.

6.5 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 primer products other than wash and bonding primers

[86] https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

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8 Annex 1: Standards applicable to bonding primers

Table 8-1 lists examples of standards and specifications reported by ADCR members applicable to the use of bonding primers. The specifications/standards listed here are test methods and do not define success criteria for alternatives validation.

Table A1-1: Examples of standards applicable to bonding primers

Standard Reference	Standard Description	Key function/Standard type
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ASTM 3359	Standard method for measuring adhesion by tape test	Adhesion
EN 3665	Filiform corrosion resistance test on aluminium alloys	Corrosion resistance
ISO 2409	Cross-cut test	Adhesion to subsequent coating or paint
ISO 2808	Determination of film thickness	Layer thickness
ISO 2812	Determination of resistance to liquids	Chemical resistance
ISO 9227	Corrosion tests in artificial atmospheres - Salt spray tests	Corrosion resistance

Source: ADCR members
"Standard description" obtained from https://standards.globalspec.com

9 Annex 2: European Aerospace Cluster Partnerships

Table A2-1: 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	
Aerospace Wales Forum Limited	UK	Wales	180	23000	£6.5 billion
Andalucía Aerospace Cluster	Spain	Andalusia	37	15931	2.5 billion Euros
Aragonian Aerospace Cluster	Spain	Zaragoza	28	1000	
ASTech Paris Region	France	Paris		100000	
Auvergne-Rhône-Alpes Aerospace	France	Rhône-Alpes	350	30000	3.3 billion Euros
AVIASPACE BREMEN e.V.	Germany	Bremen	140	12000	
Aviation Valley	Poland	Rzeszow	177	32000	3 billion Euros
bavAIRia e.V.	Germany	Bavaria	550	61000	
Berlin-Brandenburg Aerospace Allianz e.V.	Germany	Berlin	100	17000	3.5 billion Euros
Czech Aerospace Cluster	Czech Republic	Moravia	53	6000	400 million Euros
DAC Campania Aerospace District	Italy	Campania	159	12000	1.6 billion Euros
DTA Distretto Tecnologico Aerospaziale s.c.a.r.l	Italy	Apulia	13	6000	78 million Euros
Estonian Aviation Cluster (EAC)	Estonia	Tallinn	19	25000	3% of GDP
Flemish Aerospace Group	Belgium	Flanders	67	3300	1.2 billion Euros
Hamburg Aviation e.V	Germany	Hamburg	300	40000	5.18 billion Euros
HEGAN Basque Aerospace Cluster	Spain	Basque Country	56	4819	954 million Euros

Table A2-1: European Aerospace Clusters					
Cluster Name	**Country**	**City**	**Number of Companies**	**Employees**	**Sales/turnover**
Innovation & Research for Industry	Italy	Emilia Romagna	30	2000	500 million Euros
International Aviation Services Centre (IASC)Ireland	Ireland	Shannon	60	46000	3.6bn GVA
Invest Northern Ireland	Northern Ireland	Belfast	100	10000	£6.7 billion
LR BW Forum Luft- und Raumfahrt Baden-Württemberg e.V.	Germany	Baden-Wuerttemberg	93	15000	4.8 billion Euros
LRT Kompetenzzentrum Luft- und Raumfahrttechnik Sachsen/Thüringen e.V.	Germany	Dresden	160	12000	1.5 billion Euros
Madrid Cluster Aeroespacial	Spain	Madrid		32000	8 billion Euros
Midlands Aerospace Alliance	UK	Midlands	400	45000	
Netherlands Aerospace Group	Netherlands		89	17000	4.3 billion Euros
Niedercachsen Aviation	Germany	Hanover	250	30000	
Normandie AeroEspace	France	Normandy	100	20000	3 billion Euros
Northwest Aerospace Alliance	UK	Preston	220	14000	£7 billion
OPAIR	Romania			5000	150 million Euros
Portuguese Cluster for Aeronautics, Space and Defence Industries	Portugal	Évora	61	18500	172 million Euros
Safe Cluster	France		450		
Silesian Aviation Cluster	Poland	Silesian	83	20000	
Skywinn - Aerospace Cluster of Wallonia	Belgium	Wallonia	118	7000	1.65 billion euros
Swiss Aerospace Cluster	Switzerland	Zurich	150	190000	16.6 billion CHF 2.5 % of GDP
Torino Piemonte Aerospace	Italy	Turin	85	47274	14 billion euros

10 Annex 3: UK Aerospace sector

10.1 Aerospace

The annual ADS Industry Facts and Figures guide provides an indication of the UK aerospace, defence, security and space sectors' contribution to the economy in 2022, as shown in **Figure 10-1**. The Aerospace, Defence, Security and Space Group (ADS) notes that it has over 1,200+ member companies (including over 1,000 SMEs), supporting around 1,000,000 jobs (direct and indirect) across the country.

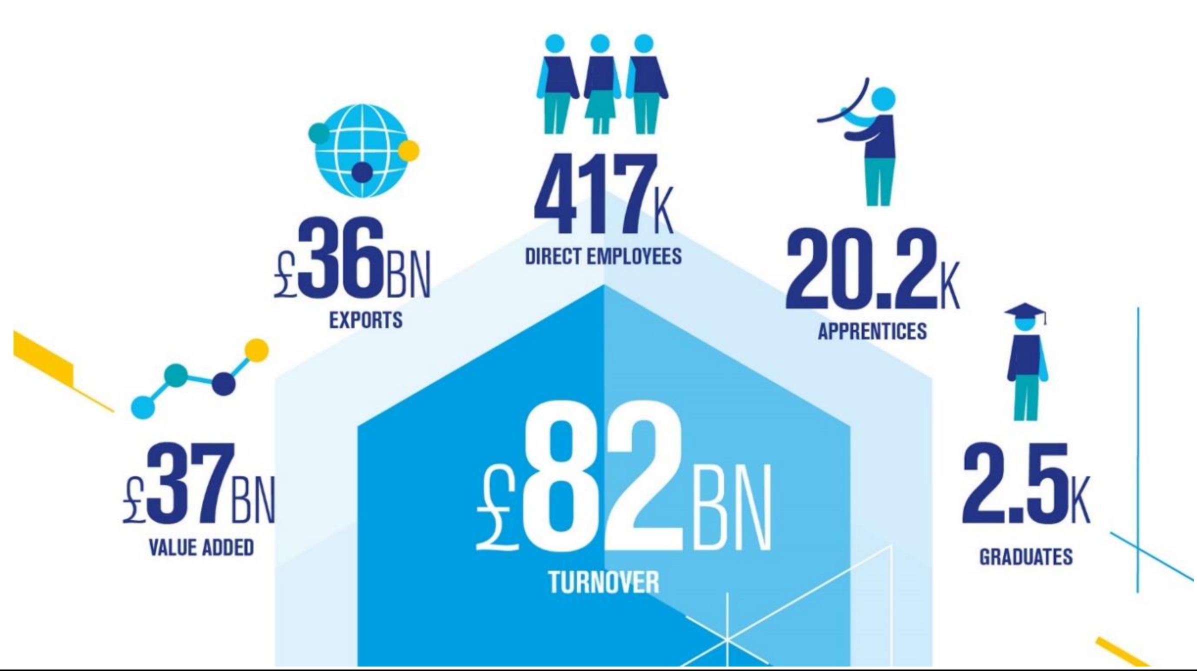

Figure 10-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2022[87]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[88], providing direct employment of over 120,000 highly skilled jobs that pay about 40% above the national average. The sector has an annual turnover of around £82bn, half of which comes from exports to the rest of the world. It is a driver of economic growth and prosperity across the UK, given that most of the jobs (92%) are located outside London and the South East – see **Figure 10-1** .

Given the economic importance of the sector, it has been the focus of an Aerospace Sector Deal launched on 6 December 2018) under the UK Industrial Strategy. The deal is aimed at helping industry move towards greater electrification, accelerating progress towards reduced environmental impacts, and has involved significant levels of co-funding by the government (e.g., a co-funded £3.9 billion for strategic research and development activities over the period up to 2026)[89]. To date, this co-funded programme has invested £2.6 billion, across all parts of the UK. It is anticipated that the UK aerospace

87 ADS Industry Facts & Figures 2023 - launched! - ADS Group

88 BEIS, Aerospace Sector Report, undated.

89 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763781/aerospace-sector-deal-web.pdf

sector will continue to grow into the future, due to the global demand for large passenger aircraft, as discussed further below.

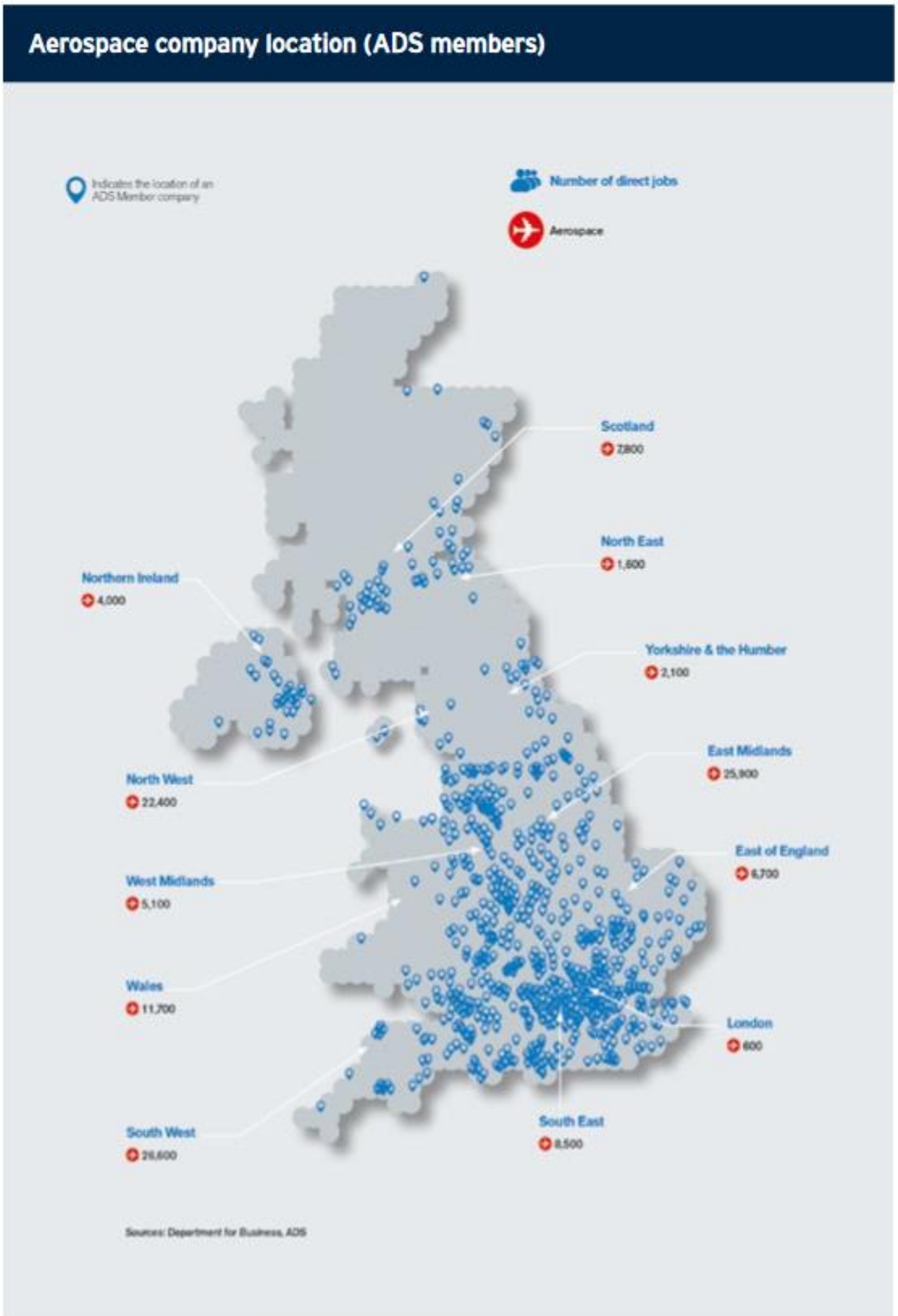

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[90]

[90] Sources: ONS, BEIS, ADS Industrial Trends Survey 2020

The National Aerospace Technology Exploitation Programme was created in 2017 to provide research and technology (R&T) funding with the aim of improving the competitiveness of the UK aerospace industry, as well as other supporting measures under the Industrial Strategy. The Government's investment in R&T is through the Aerospace Technologies Institute and is programmed at £1.95 billion in expenditure between 2013 and 2026.

This investment will help in maintaining the current expected market development in the UK, which would see a 2.3% per year growth in real terms, leading to direct added value of just over £14 billion in 2035 (compared to £9 billion in 2016). In 2016, the UK aerospace sector employed around 112,500 people, with each direct job in the aerospace industry creating at least one additional job within the aerospace supply chain. This gives around 225,000 people directly and indirectly employed by the aerospace sector in high-value design and high value manufacturing jobs. By maintaining its current direction of growth, the sector is expected to create up to a further 45,000 positions by 2035.

The value of the sectors is also significant in wider economic terms. Investment in aerospace research and technology leads to wider impacts beyond the sector. Every £100 million spent on R&T by the government crowds-in around £300 million of additional private sector investment. Furthermore, every £100 million invested benefits not only UK aerospace GVA by £20 million per year, but also the wider economy by £60 million per year through technology spill overs. These include automotive, marine, oil and gas, nuclear, electronics, composites, metals and other UK industrial sectors. In total, the return on government investment in the sector is estimated as delivering an additional £57 billion of gross value added for the UK aerospace sector and a further £57 billion to the wider UK economy between 2015 and 2035.

10.2 Defence

With respect to defence, the UK is the second largest defence exporter in the world, with its contribution to employment, turnover, and exports illustrated in **Figure 10-3**[91]. Again, the importance of the sector to UK exports and value added, as well as employment is clear from the figure below.

[91] Sources: Industry Facts & Figures 2023 - ADS Group

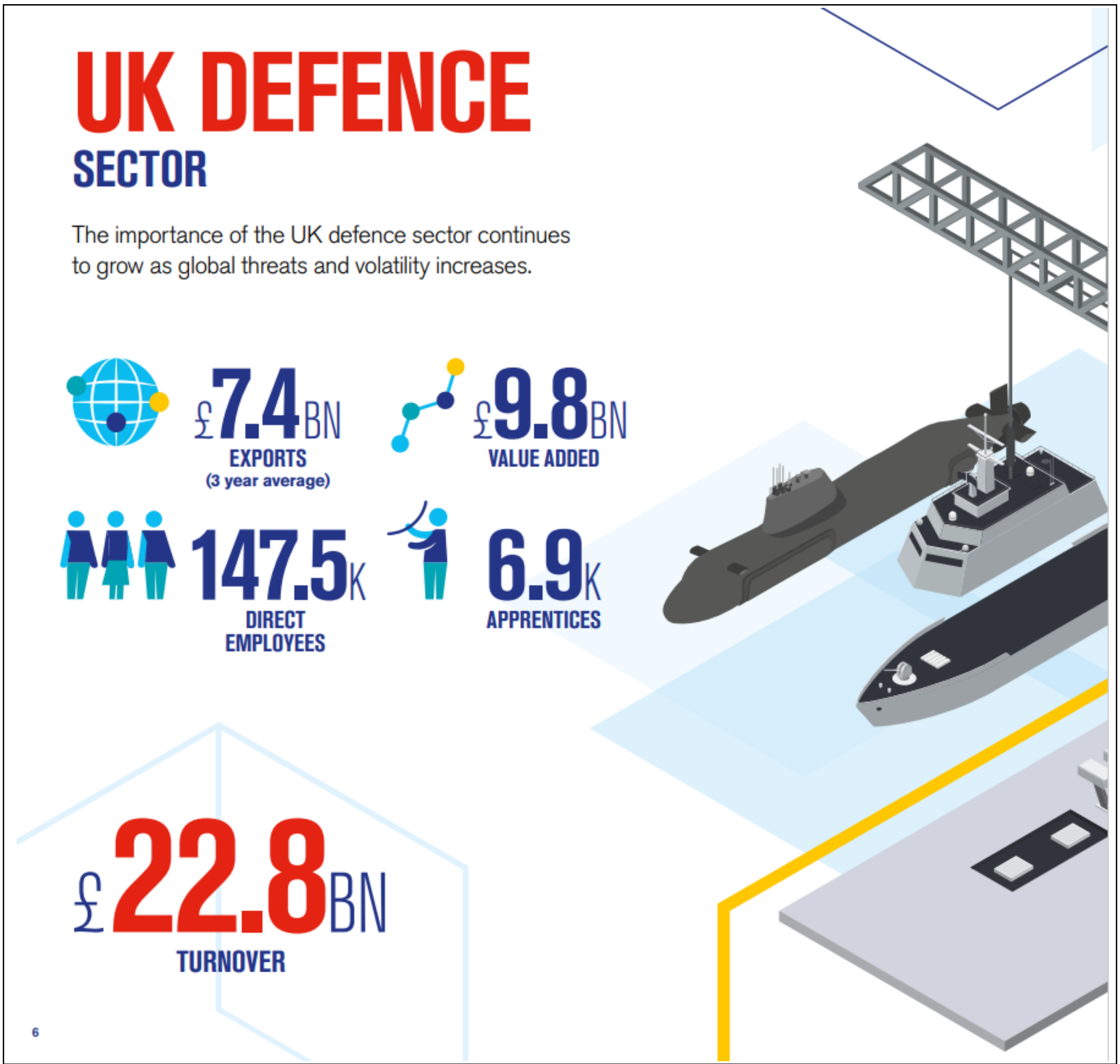

Figure 10-3: UK defence sector contribution to the economy in 2021