ANALYSIS OF ALTERNATIVES

Non-confidential report

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Substance:	*Potassium dichromate EC No: 231-906-6, CAS No: 7778-50-9*
Use title:	*Use of potassium dichromate for sealing after anodizing applications by aerospace companies and their suppliers*
Use number:	*1*

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CONTENTS

List of Figures:

List of Tables

Abbreviations

AA2024	Aluminium alloy, most commonly used in the aerospace sector
ACE	Aerospace Chrome Elimination
Acute Tox.	Acute Toxicity
AfA	Application for Authorisation
Al	Aluminium
AMMTIAC	Advanced Materials, Manufacturing, and Testing Information Analysis Center
AMS	Aerospace Material Specification
AMSCA	Accelerated Manufacturing with Chrome Free Sacrificial Cermet Coatings in Aerospace
ASTM	American Society for Testing Materials
AoA	Analysis of Alternatives
Aquatic Acute	Hazardous to the aquatic environment
Aquatic chronic	Hazardous to the aquatic environment with long lasting effects
BSA	Boric-Sulphuric Acid anodizing
CAA	Chromic Acid Anodizing
Carc.	Carcinogenicity
CAS	unique numerical identifier assigned by Chemical Abstracts Service (CAS number)
CASCoat	Chrome Free Aluminide Slurry Coatings for Gas Turbines
CCC	Chemical Conversion Coatings
CCST	Miscellaneous Chromium VI Compounds for Surface Treatment REACH Authorization Consortium
Cr	Chromium
Cr(III)	Trivalent Chromium
Cr(VI)	Hexavalent Chromium
CS-25	Certification Specification for Large Aeroplanes
CS-E	Certification Specification for Engines
CSR	Chemical Safety Report
DT&E	Development, Test and Evaluation
EASA	European Aviation Safety Agency
EC	unique numerical identifier of the European Community (EC number)
e.g.	exempli gratia, for example

EHS	Environmental Health and Safety
EMI	Electromagnetic Interference
EN	European Norm
EPA	Environmental Protection Agency
ESA	European Space Agency
EU	European Union
Eye Dam.	Serious eye damage
Eye Irrit.	Eye irritation
FAA	Federal Aviation Administration
Flam. Liq.	Flammable liquid
GCCA	Global Chromates Consortium for Aerospace
HITEA	Highly Innovative Technology Enablers for Aerospace
HVOF	High Velocity Oxy Fuel
IAEG	International Aerospace Environmental Group
ISO	International Organization for Standardization
Me	Metal
Met. Corr.	Substance or mixture corrosive to metals
Mg	Magnesium
Mil-DTL	United States Military Standard
MRL	Manufacturing Readiness Level
MRO	Maintenance, Repair and Operations
MSDS	Material Safety Data Sheet
Muta.	Germ cell mutagenicity
NASA	National Aeronautics and Space Administration
Ni	Nickel
OEM	Original Equipment Manufacturer
OT&E	Operational Test and Evaluation
QPL	Qualified Products List
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
R&D	Research and Development
Repr.	Reproductive toxicity
Resp. Sens.	Respiratory sensitiser

SAA	Sulphuric Acid Anodizing
SDS	Safety Data Sheet
SEA	Socio Economic Analysis
Skin. Corr.	Skin corrosion
Skin. Sens.	Skin sensitisation
Skin Irrit.	Skin irritation
STC	Supplemental Type Certificate
STOT RE	Specific target organ toxicity, repeated exposure
STOT SE	Specific target organ toxicity, single exposure
SVHC	Substance of Very High Concern
TRL	Technology Readiness Level
TSAA	Tartaric-Sulphuric-Acid-Anodizing
US	United States
USAF	United States Air Force
Zr	Zirconium

Glossary

Term	Definition
Active corrosion inhibition	The ability of a material to spontaneously repair small amounts of chemical or mechanical damage that exposes areas of metal without any surface protection ("self-healing properties"). This functionality is advantageous and enhances service life duration of parts, maintenance intervals and on-flight security of air travellers.
Adhesion promotion	Parameter describes the tendency of dissimilar particles or surfaces to cling to one another (for example adhesion of coating to substrate, adhesion of paint to coating and/or substrate).
Aeroderivative	This term describes parts used in power generation turbines which are used to generate electricity or propulsion in civil and military marine, oil and gas, and industrial applications; which are manufactured directly from existing aircraft hardware, specifically engine part design and production processes.
Aerospace	This terms comprises civil and military applications of aviation and space industry, including derivative uses (e.g., marine propulsion or power generation using products originally designed for aerospace use).
Aerospace Companies	Companies principally engaged in carrying out the design, development, manufacture, maintenance, modification, overhaul, repair, or support of civil or military aerospace and defence equipment, systems, or structures, plus any derivative uses (e.g., marine propulsion or power generation using products originally designed for aerospace or defence use).
Aerospace Components	This term comprises civil or military aerospace and defence equipment, systems, or structures, plus any derivative uses (e.g., marine propulsion or power generation using products originally designed for aerospace or defence use).
Aeronautics	This term comprises the study of the science of navigation through air and space. It defines the methodology of how to design an aircraft, spacecraft or other flying machine.
Aircraft	This term comprises military and civil fixed wing airplanes and helicopters.
Anodizing	Electrolytic oxidation process in which the surface of a metal, when anodic, is converted to an insulating coating having desirable protective or functional properties. The anodic film formation is mainly driven by the applied voltage. Chromic acid anodizing is one example of anodizing.
Bath	Typical method for surface treatment of parts. May also be referred to as dipping or immersion. Non-bath methods include brushing, spraying and pen application.
Bonding	The process where two parts are joint together by means of a bonding material; an adhesive sometimes in combination with a bonding primer and a conversion or anodizing treatment.
Candidate alternative	Potential alternative provided to the Aerospace OEM for their evaluation. These have already been evaluated in the labs of formulators.

Term	Definition
Certification	Verification that an aircraft or spacecraft and every part of it complies with all applicable airworthiness regulations and associated Certification Specifications (specs) (e.g. EASA, FAA). The term certified parts indicates that those parts have been through the certification process.
Chemical resistance	Parameter is defined as the ability of solid materials to resist damage by chemical exposure.
Civil and military applications	The flight profile in civil aviation is limited to ferrying passengers and cargo, while in military applications several missions have to be taken into account that require constant technical trade-offs. The flight frequency of military planes is very low compared to civil planes running on a daily basis. Based on these daily demands to ensure the airworthiness of civil aircraft, the requirements are much more comprehensive. As both applications follow closely the same development and approval process as indicated in chapter 5, they are covered within this dossier.
Coating	A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional, or both. A coating may be a paint, a lacquer or a metal (e.g. hard chrome, cadmium coating, zinc-nickel coating) or an inorganic substance.
Corrosion protection	Means applied to the metal surface to prevent or interrupt oxidation of the metal part leading to loss of material. This can be a metal conversion coating or anodizing, a pre-treatment, paint, water repellent coating, sealant, liquid, adhesive or bonding material. The corrosion protection provides corrosion resistance to the surface.
Counterpart	Structural zone (like assembly, component) to which a given assembly/part is fitted.
Implementation	After having passed qualification and certification, the third step is to implement or industrialise the qualified material or process in all relevant activities and operations of production, maintenance and the supply chain.
In-service evaluation	In-service evaluations are common practice to validate accelerated corrosion results obtained in the laboratory to determine correlation between accelerated corrosion testing and when used on operating aircraft.
Legacy part	A legacy part shall mean any part of an end product for aerospace which is manufactured in accordance with a type certification applied for before the earliest sunset date (including any further supplemental or amended type certificates or a derivative) **or** for defence and space which is designed in accordance with a military or space development contract signed before the earliest sunset date, and including all production, follow-on development, derivative and modification program contracts, based on that military or space development program.
Main treatment	The purpose of the surface treatment is primarily for, but not limited to, corrosion protection. The main treatment occurs after the pre-treatment and before the post-treatment. Examples include conversion coating,

Term	Definition
	anodizing and passivation of stainless steel. Sometimes conversion coating and anodizing are followed by painting; in which case these can be regarded as the pre-treatment and the painting as the main treatment.
Materials control	Portion of a specification that controls which materials may be used in the process. Products that have met all requirements may be added to this list by the OEM.
Post-treatment	Post-treatment processes are performed after the main surface treatment process to enhance corrosion protection.
Pre-treatment	Pre-treatment processes are used to remove contaminates (e.g. oil, grease, dust), oxides, scale, and previously applied coatings (e.g. electroplated coatings, anodize coatings, conversion coatings, paint). The pre-treatment process must also provide chemically active surfaces for the subsequent treatment.
Process chain	A series of surface treatment process steps. The individual steps are not stand-alone processes. The processes work together as a system, and care should be taken not to assess without consideration of the other steps of the process. In assessing candidate alternatives for potassium dichromate, the whole process chain has to be taken into account.
Qualification	OEM validation and verification that all material, components, equipment or processes have to meet or exceed the specific performance requirements which are defined in the certification specifications documented in technical standards or specifications.
Risk reduction	Classification and labelling information of substances and products reported during the consultation being used for alternatives / alternative processes are compared to the hazard profile of the used potassium dichromate.
Risk sharing partners	Business partnership in which costs and benefits are shared amongst all participating partners. The intention is to rely on the commercial success, while reducing the risk of loss. For the aerospace industry, risk-sharing arrangements were made with suppliers to reduce investments and the dependence on loans. The suppliers are responsible for design activities, development and manufacture of major components or systems.
Sealing	For a high corrosion resistance micropores of the anodized surface have to be closed by a post-treatment step (sealing after anodizing).
Use of potassium dichromate for sealing after anodizing applications by aerospace companies and their suppliers	This Use includes processes that convert the surface of an active metal or coat metal surfaces by forming/incorporating a barrier film (of complex chromium compounds) that protects the metal from corrosion and provides a base for subsequent treatments such as painting or bonding. The use includes sealing for final surface protection.

1. SUMMARY

This Analysis of Alternatives (AoA) forms part of the Application for Authorisation (AfA) for the use of potassium dichromate in the surface treatment of metals. The preparation of this AoA has been supported by the suppliers and OEMs in the value chain of potassium dichromate under the auspices of the Global Chromates Consortium for Aerospace (GCCA). The potassium dichromate covered by this application for authorisation for use on aerospace components is imported to the EEA as such or within proprietary products manufactured by non EU formulators. The supply chain for these products is not covered by other applications for authorisation; however, it is important to note that the uses of hexavalent chromium covered in the CCST AfA are still relevant and necessary for GCCA aerospace companies and their supply chain. The use, as defined, covers the sealing of anodic films, which is a part of a sequence of surface treatment processes and steps[1] involving hexavalent chromium [Cr(VI)].

It should be noted that the aerospace industry use of potassium and sodium dichromate for this application is completely interchangeable and thus this AoA addresses the use of either potassium dichromate or sodium dichromate in the sealing of anodic films. As such, the substance may be referred to as potassium/sodium dichromate throughout this AoA.

Surface treatment aims to modify the surface of a substrate so that it performs better under conditions of use. Surface treatment processes using potassium/sodium dichromate typically involve immersion of the metal component in each of a series of treatment baths containing chemical solutions or rinses under specific operating conditions. Different chemicals and operating conditions are specified for individual surface treatment processes (see Figure 1) in order to confer specific performance characteristics to the treated article. The relevant surface treatment processes which the AfA covers, the characteristics of potassium/sodium dichromate and its critical functionality in the sealing of anodic films are introduced at Chapter 3.

Aerospace companies specify surface treatment with potassium/sodium dichromate in order to meet strict performance criteria necessary for regulatory compliance, component longevity, security of power supply and most importantly, continued safety and reliability of aerospace components during use, as described further below and in Chapter 5.

This summary aims to shortly explain why use of potassium/sodium dichromate in surface treatment is essential to aerospace companies. It describes the steps and effort involved in finding and approving a replacement for potassium/sodium dichromate in these applications and evaluates potential alternatives in detail (Chapters 6 and 7).

Potassium/sodium dichromate-based surface treatment systems

Potassium/sodium dichromate has been used for more than 50 years by aerospace companies to provide surface protection to critical components and products, where the products to which potassium/sodium dichromate is applied must operate to the highest safety standards in highly demanding environments for extended time periods. Surface treatments based on potassium/sodium dichromate have unique technical functions that confer substantial advantage over potential alternatives. These include but are not limited to:

- Outstanding corrosion protection and prevention under a wide range of conditions; and
- Active corrosion inhibition (self-healing, e.g. self-repairing a local scratch to the surface).

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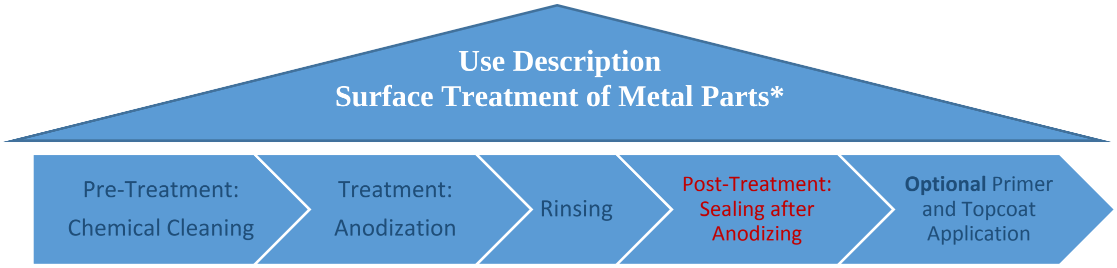
[1] See Chapter 3 for detail.

The chemistry behind potassium/sodium dichromate surface treatment systems and processes is complex. Surface treatment processes typically involve numerous steps, often including several important pre-treatment and post-treatment steps as well as the main treatment process itself. Figure 1 provides an overview of the uses included in the application for authorisation according to the process steps. These steps are almost always inter-related such that they cannot be separated or individually modified without impairing the overall process or performance of the treated product.



*** Other surface treatments requiring potassium/sodium dichromate are covered in the CCST submittal (CCST, 2015a,b).**

Figure 1: The use of potassium/sodium dichromate for the sealing after anodizing in the overall surface treatment process within the scope of the present AoA (marked in red).

This means that while the use of potassium/sodium dichromate or another Cr(VI) substance may be specified at different points in the process, it [Cr(VI)] cannot be entirely replaced in the process without impacting the technical performance of the final article. The implications of this are important as potassium/sodium dichromate-free alternatives *for some individual steps or applications* are available and used by the aerospace industry. However, where this is the case, another Cr(VI) substance, such as chromium trioxide, is mostly specified in one of the other steps within the overall surface treatment system. While the industry has identified some materials that are useful in limited, less demanding application, no complete Cr(VI)-free treatment system, providing all the required properties to the surfaces of all articles in the scope of this application, is industrially available.

This means it is imperative to consider the surface treatment system as a whole, rather than the step involving potassium/sodium dichromate on its own, when considering alternatives for such surface treatment systems. Furthermore, components that have been surface treated with potassium/sodium dichromate typically represent just one of many critical, inter-dependent elements of a component, assembly or system. In general, potassium/sodium dichromate-based surface treatment is specified as one element of a complex system with integrated, often critical performance criteria. Compatibility with and technical performance of the overall system are primary considerations of fundamental importance during material specification.

Use of potassium/sodium dichromate in surface treatment for the aerospace sector

Potassium/sodium dichromate-based surface treatments are specified by aerospace companies because they provide performance features such as superior corrosion resistance and inhibition (see Chapter 3.3). These characteristics are essential to the safe operation and reliability of aerospace company products which operate under extreme environmental conditions. These structures are extremely complex in design, containing thousands to millions of highly specified parts, many of which cannot be easily inspected, repaired or removed. Engine parts (e.g. internal components for gas turbines) are particularly vulnerable to corrosion.

Potassium/sodium dichromate surface treatment processes and performance have been refined and improved as a result of many decades of research and experience in the sector, and reliable data are available to support their performance. While corrosion cannot be totally prevented, despite the highly advanced nature of potassium/sodium dichromate-based coating systems in place today, there is also extensive experience, amassed over decades, on the appearance and impact of corrosion to support its effective management in these systems. On the other hand, while various potential alternatives to potassium/sodium dichromate, predominantly Cr(III)- and Nickel-based formulations are being investigated for anodize seal applications, results so far do not support reliable conclusions regarding their performance as part of such complex systems, in many demanding environments and test conditions representative of in-service situations. These candidate alternatives do not support all the properties of potassium/sodium dichromate-based surface treatment systems, and their long-term performance can currently only be estimated in most applications. Decreased corrosion protection performance would necessitate shorter inspection intervals in an attempt to avoid unexpected failures with potentially catastrophic results.

Identification and evaluation of potential alternatives for aerospace companies

An extensive literature survey and consultation with aerospace industry experts was carried out by CCST (CCST, 2015a,b) to identify and evaluate potential alternatives to Cr(VI). While numerous potential alternatives for all parts of the process chain were identified by CCST, they were further reviewed and supplemented by the GCCA Consortium members for the purpose of identifying alternatives to sealings of anodic films in the scope of this AoA. Four candidate alternatives are a focus for ongoing research and development (R&D) programs and are examined in further detail in this report. Here, a candidate alternative is defined as a potential alternative provided to the aerospace companies for evaluation following initial evaluation by the formulator. It should be noted that while this AoA focuses only on the 4 candidate alternatives that are felt by the GCCA members to be the most viable options, numerous other alternative formulations/processes have been screened by these companies and/or their supply chain and found to be completely inadequate. Table 1 summarises the main GCCA findings of the AoA for the aerospace sector. The various candidate alternatives are discussed in chapters 7.1 to 7.4.

Table 1: Overview of key potential alternatives for anodize seal surface treatments

Potential Alternative	Technical findings
Cr(III)-based surface treatments	- Inconsistent corrosion results - Limited active corrosion inhibition - Acceptable for some applications / design space
Nickel Acetate based	- Inconsistent corrosion results - Limited active corrosion inhibition
Nickel Fluoride based	- Inconsistent corrosion results
Zirconium-based	- Under development, testing ongoing

In summary, the analysis shows there are no technically feasible alternatives to potassium/sodium dichromate-based anodize seal surface treatment systems for all key applications required by aerospace companies. Various candidate alternatives are subject to ongoing R&D, but do not currently support the necessary combination of key functionalities to be considered technically feasible alternatives for most applications.

Ongoing development of potential alternatives for the aerospace sector

Assuming a technically feasible candidate alternative is identified as a result of ongoing R&D, extensive effort is needed beyond that point before it can be considered a validated alternative to potassium/sodium dichromate.

Aircraft are one of the safest and securest means of transportation, despite having to perform in extreme environments for extended timeframes. This is the result of high regulatory standards and safety requirements. The implications for substance substitution in the aerospace industry are described in detail in a report prepared by ECHA and European Aviation Safety Agency (EASA) in 2014, which sets out a strong case for long review periods for the aerospace sector based on the airworthiness requirements deriving from European Union (EU) Regulation No 216/2008 and the EASA CS-25 and EASA CS-E in the EU. Performance specifications defined under this Regulation drive the choice of substances to be used either directly in the aerospace components or during manufacturing and maintenance activities. It requires that all components, equipment, materials and processes must be qualified, certified, and industrialised before production can commence. The process is illustrated in Figure 2.

This system robustly ensures new technology and manufacturing processes can be considered ‘mission ready’ through a series of well-defined steps only completed with the actual application of the technology in its final form (and under mission conditions). When a substance used in a material, process, component, or equipment needs to be changed, this extensive system must be followed in order to comply with airworthiness and other customer-driven requirements. The system for alternative development through qualification, certification, industrialisation and implementation within the aerospace sector is mirrored in the defence and space sectors.

The detailed process involved in qualification, certification, and industrialisation, and the associated timeframes, are elaborated in Chapter 5. Of course, these steps can only proceed once a candidate alternative is identified. Referring to experience, it can take 20 to 25 years to identify and develop a new alternative, even assuming no drawbacks during the various stages of development of these alternatives. Experience over the last 30 years already shows this massively under-estimates the replacement time for potassium/sodium dichromate-based surface treatment systems, including anodized seal surface treatment systems. Although there have been active R&D efforts to replace Cr(VI) in aerospace applications for more than 30 years, these efforts have yet to result in the technical breakthrough necessary to replace Cr(VI) for critical aerospace uses. Taken together, available evidence clearly shows that no viable alternative for potassium/sodium dichromate in anodize seal surface treatment systems is expected for at least the next 12 or even 15 years.

Figure 2: Illustration of the development, qualification, certification and industrialisation process required in the aerospace sector.

As a further consideration, while the implications of the development process in the aeronautic and aerospace sectors are clearly extremely demanding, specification of an alternative, once available, can be built into the detailed specification for new aerospace components. This is not the situation for existing aerospace components, for which production and/or operation may still be ongoing. Production, maintenance and repair of these models must use the processes and substances already specified following the extensive approval process. Substitution of potassium/sodium dichromate-based anodized seal surface treatment systems for these certified products introduces yet another substantial challenge; re-certification of all relevant processes and materials. In practice, it will be impractical and uneconomical to introduce such changes for many such aerospace component types.

In this context, the scale and intensity of industry- and company- wide investment in R&D activity to identify alternatives to potassium/sodium dichromate anodized seal surface treatment systems is very relevant to the findings of the AoA. Serious efforts to find replacements for potassium/sodium dichromate as part of overall Cr(VI) replacement activities have been ongoing within the aerospace industry for over 30 years and there have been several major programs to investigate alternatives to potassium/sodium dichromate in the aerospace sector over the last 20 years. Although there have been, and continue to be, significant R&D efforts, to date, they have not resulted in the breakthrough innovation necessary to completely replace Cr(VI) for all critical aircraft and aeroderivative uses. The level of industry investment for the holistic replacement of Cr(VI) has been significant and is estimated to be in excess of €100 million. For example, United Technology Corporation (UTC) has validated various replacements and implemented them, as feasible, including chrome-free paint primer, the replacement of hard chrome plate with High-Velocity OxyFuel (HVOF) coatings, and hardware re-designs to eliminate the need for chromate protection. General Electric (GE) has successfully replaced chromic acid anodizing with tartaric sulphuric acid anodizing (TSAA) since 2010 for certain applications and has some Cr(VI)-free alternatives anticipated to be implemented by the end of 2016, including an alternative for a Cr(VI)-containing fuel tank sealant paste and an alternative for a chromate-free corrosion inhibiting non-drying paste for fasteners. The Rolls-Royce Group has an ongoing programme seeking to substitute Cr(VI) used within materials and manufacturing processes and has successfully substituted a number of Cr(VI)-containing manufacturing processes. Rolls-Royce is also currently working on Cr(VI)-free alternatives to sacrificial coatings and high temperature diffusion coatings as a part of collaborative efforts under the auspices of the UK's innovation agency, Innovate UK. However, there are still many applications where Cr(VI) surface treatments are still technically required, even in the newest designs, to meet safety performance requirements. In addition to the significant efforts carried out by individual companies, numerous research programs have been created under the auspices of the U.S. National Center for Manufacturing Sciences (NCMS), the National Aeronautics and Space Administration (NASA), the U.S. Department of Defense Strategic Environmental Research and Development Program (SERDP), etc. in which aerospace companies participate. Numerous industry research consortia have also been established such as the REACh Compliant Hexavalent Chrome Replacement for Corrosion Protection Highly Innovative Technology Enablers for Aerospace (HITEA). The HITEA consortium's membership includes aerospace OEMs, suppliers, paint application companies and academics with the goal to identify and evaluate suitable alternative systems. Section 6.1.1 provides a more extensive, though non-exhaustive, overview of various industry-wide and company-specific efforts.

Review Period

Extensive evaluation of potential alternatives to potassium/sodium dichromate-based surface treatments is carried out in the present AoA. Furthermore, economic aspects, as well as aspects of approval and release in the aerospace sector are assessed with regard to a future substitution of the substance. The following key points are relevant for deriving the review period:

- The aerospace investment cycle is demonstrably very long. A typical life cycle for any aircraft type is over 40 years and may even be up to 80 years or more (see SEA). Therefore, it is technically and economically meaningful to substitute only when a major investment or refurbishment takes place;
- Any alternative is required to pass full qualification, certification and implementation/ industrialisation to comply with very high standards in the aerospace sector regarding airworthiness and flight security to ensure safety of use. Before any potential alternative can be implemented, aerospace components are required to comply with all applicable

regulations and associated Certification Specifications (EASA CS-25 and EASA CS-E). Airworthiness Certification takes 6 month up to several years to ensure public safety;

- The costs for the development, qualification and certification of candidate alternatives are very high. The timescale for developing and validating potential alternatives is at least 12 years, and the testing requirements are well defined in order to ensure safety and will not change;
- Extensive research and development on viable alternatives to Cr(VI)- based surface treatments has been carried out over the last few decades but did not lead to the development of substitutes for most applications that could be available within the normal review period. However, the unique functionalities of Cr(VI) compounds make it challenging and complex to replace the substance in surface treatment, especially regarding applications where superior corrosion is crucial for public safety;
- Comparing health impacts of workers to socio-economic impacts, the ratio in the baseline scenario is at least 1: 296 (see Chapters 7 and 8 of the SEA), and there is clear evidence that this situation is not likely to change in the next decade.

Concluding remarks

An extensive amount of research over the last 30 years has been deployed to identify and develop viable alternatives to Cr(VI)-based surface treatments. Due to its unique functionalities and performance, it is challenging and complex to replace surface treatments based on potassium/sodium dichromate or other Cr(VI)-chemistries in applications that demand superior performance for corrosion to deliver safety over extended periods and extreme environmental conditions.

Candidate alternatives to potassium/sodium dichromate such as Cr(III)- and Nickel-based systems, are under investigation for the aerospace industry. However, based on experience and with reference to the status of R&D programs, alternatives are not foreseen to be commercially available for all key applications in this sector for at least 12 or 15 years. As a result, a review period of **12 years** was selected because it coincides with best case (optimistic) estimates by the aerospace industry of the schedule required to industrialise alternatives to potassium/sodium dichromate.

2. ANALYSIS OF SUBSTANCE FUNCTION

2.1. The substance

The aerospace industry use of potassium and sodium dichromate is completely interchangeable and thus this AoA addresses the use of either potassium dichromate or sodium dichromate in the sealing of anodic films. As such, the substance may be referred to as potassium/sodium dichromate throughout this AoA. The following substances are therefore subject to this analysis of alternatives (Table 2):

Table 2: Substances subject to this analysis of alternatives.

#	Substance	Intrinsic property(ies)[1]	Latest application date[2]	Sunset date[3]
1	Potassium dichromate EC No: 231-906-6 CAS No: 7778-50-9	Carcinogenic (category 1B) Mutagenic (category 1B) Toxic for reproduction (category 1B)	21.03.2016	21.09.2017
2	Sodium dichromate EC No: 234-190-3 CAS No: 10588-01-9; 7789-12-0	Carcinogenic (category 1B) Mutagenic (category 1B) Toxic for reproduction (category 1B)	21.03.2016	21.09.2017

[1] Referred to in Article 57 of Regulation (EC) No. 1907/2006
[2] Date referred to in Article 58(1)(c)(ii) of Regulation (EC) No. 1907/2006
[3] Date referred to in Article 58(1)(c)(i) of Regulation (EC) No. 1907/2006

These substances are categorized as substances of very high concern (SVHC) and are listed on Annex XIV. Adverse effects are discussed in the Chemical Safety Report (CSR).

2.2. Uses of potassium/sodium dichromate

Chromium VI containing substances have been widely used since the mid-20th century. The potassium/sodium dichromate-based surface treatment covered in this AoA for the aerospace sector is as follows:

- Sealing for corrosion protection of anodized aluminium components.

2.3. Purpose and benefits of potassium/sodium dichromate

Potassium/sodium dichromate offers a broad range of functions, mainly based on the characteristics of the Cr(VI) compound. It has been widely used for over 50 years in the industry in various applications. The multifunctionality of potassium/sodium dichromate provides major properties to the surfaces treated with the respective process. The following key functionalities for the aerospace sector are discussed in more detail in Chapter 3.3:

- Corrosion resistance: excellent corrosion protection and prevention in a wide range of environments; and

- Active corrosion inhibition: when a coating is damaged, e.g. by a scratch exposing the base material to the environment, the solubility properties of potassium/sodium dichromate allow diffusion to the exposed area and inhibit corrosion.

Various alternatives are being tested to substitute potassium/sodium dichromate. It is a challenge to find a substitute which meets all requirements for a product, for each use, and specific applications while also being technically and economically feasible. Some alternatives are already qualified for some applications, but none of them provide all the key properties of potassium/sodium dichromate as defined in the following chapters.

3. ANALYSIS OF SUBSTANCE FUNCTION

Potassium/sodium dichromate is used by aerospace companies in surface treatment in aerospace components, including related aeroderivative products as illustrated in the following sections. Aeroderivative products make up a small percentage (1 – 2%) of the total aircraft hardware volume in the EU and are used for military, marine and industrial power generation applications which are adapted directly from the manufacturing processes and supply chains that produce potassium/sodium dichromate treated parts for the aerospace sector. 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. References to the aerospace sector/components are considered to encompass the small niche aeroderivative applications undertaken by aerospace companies.

3.1. Usage

Surface treatment is aimed to modify the surface to adapt it to specific use conditions. The main uses of potassium/sodium dichromate-based anodize seal treatments by aerospace companies are to provide better corrosion resistance and active corrosion inhibition.

The complexity of aerospace components makes meeting these performance criteria a very challenging task. Inspection can be very difficult depending on location of the hardware and various levels of maintenance are continuously required based on the inspection periods and the hardware use. Metal surfaces and metal parts can be affected from corrosion by a broad variety of factors, such as:

- Temperature;
- Humidity;
- Salinity of the environment;
- Industrial environment;
- Geometry of parts;
- Surface conditions;
- Erosion;
- Radiation;
- Impurities;
- Stress;
- Pressure;
- Accumulated liquid; and
- Operational fluids.

All the factors listed above can occur alone or in combinations under certain environments at different parts of aerospace components. Not all components are equally susceptible to corrosion, especially vulnerable components are known to include gear boxes, fan cases, and compressor vanes.

Importantly, in this demanding environment, corrosion may still occur with the highly developed Cr(VI)-containing coating systems. For currently used coatings, decades of extensive experience exists relating to the appearance and impacts of corrosion. Without a well-developed Cr(VI)-free alternative, corrosion will certainly increase, as these alternative coatings do not offer all the crucial properties of Cr(VI)-based coating systems and their long-term performance can currently only be estimated. Likely, the corrosion issues would not appear suddenly but only after several years, when hundreds of aerospace components are delivered. Further, any potential for decreased corrosion protection performance would necessitate shorter inspection intervals in an attempt to avoid unexpected failures with potentially catastrophic results. For secure adaptation of the inspection intervals, a detailed knowledge of the alternatives is a prerequisite. Some of the corrosion prone areas, as well as further examples of aerospace component requiring corrosion protection are illustrated in Figures 3-7 below:

Figure 3: Left: ATR 600 aircraft (UTC Aerospace Systems – Propeller Systems, 2014). Right: U.S. Naval ship powdered by GE LM2500 (Photo courtesy of the United States Navy).

Figure 4. Left: CF6 Aircraft Engine. Right: Technology from the CF6 engine in generating power for the world's largest hospital (The General Electric Company, 2014).

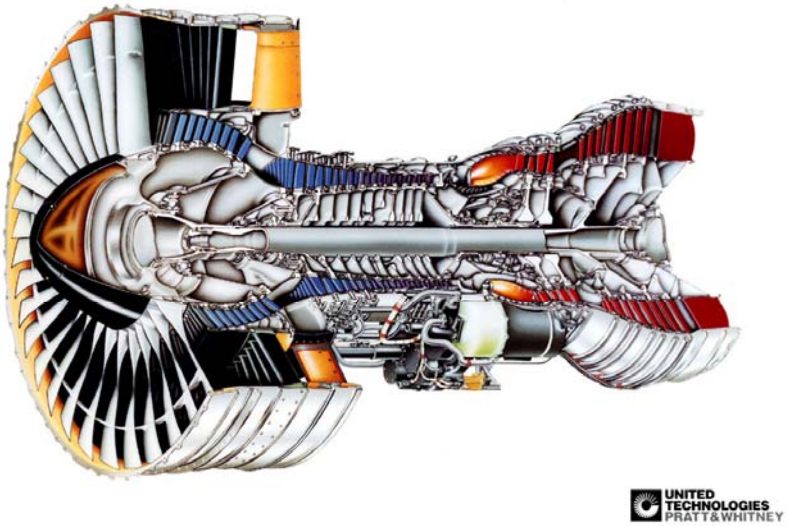


Figure 5. Gas Turbine Engine sketch example PW4000 92 inch fan engine (www.pw.utc.com/Content/PW400094_Engine/img/B-1-4-1_pw400094_cutaway_high.jpg, 2014).

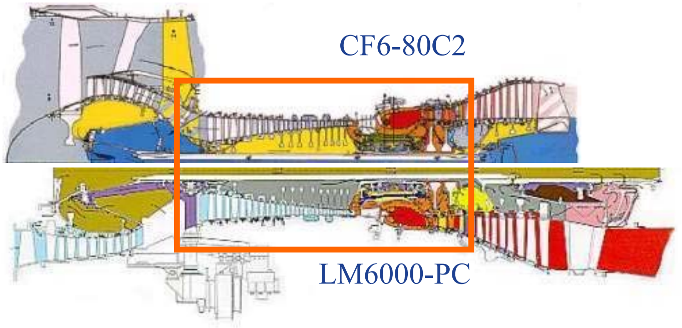


Figure 6. Cross sections of a representative aircraft engine and corresponding aeroderivative gas turbine showing location of common chrome treated parts (General Electric, 2015).

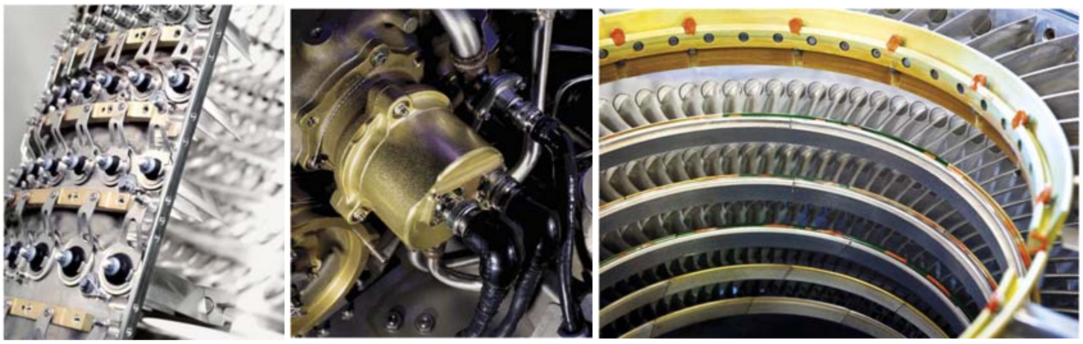


Figure 7. Cross sections of a representative aircraft engine and corresponding aeroderivative gas turbine showing location of common chrome treated parts (General Electric, 2015).

Treating surfaces susceptible to corrosion with Cr(VI)-containing products provides, in combination with the correct choice of material, the required corrosion prevention properties and functionality.

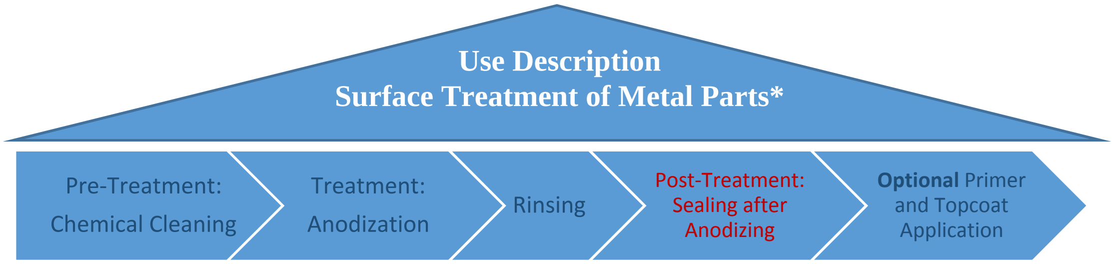
Highly corrosive environments are present in aerospace components during operations caused by extreme environmental conditions and the presence of corrosive gases and liquids. In particular, accelerated forms of corrosion can be found at the engine air inlet where airborne solids or rain erosion can damage the metal and coating surfaces. Again the use of Cr(VI) has proved to be most effective for this purpose.

In this introduction, only examples of corrosion were presented. However, there is always a combination of other critical performance criteria required for these parts as discussed further in Section 3.3.

3.2. Surface treatment processes

Surface treatment of metals is a complex step by step process in many industry sectors. For operations with high performance surfaces in demanding environments, the use of Cr(VI)-containing components is essential to ensure the long-term (over decades) quality and safety of the end product. As specifically illustrated in Figure 8**,** there are various steps within the whole surface treatment process. These are classified into pre-treatment processes (for an adequate preparation of the substrate for subsequently applied process steps), process steps (main process), and in post-treatment processes (which mostly have to be applied for final surface protection). This AoA is limited to

Potassium/sodium dichromate based sealing after anodizing. It should be noted that further Cr(VI) compounds are used within the whole process chain that are not subject to this AoA.



*** Other surface treatments requiring potassium/sodium dichromate are covered in CCST submittal (CCST, 2015a,b).**

Figure 8. The use of potassium/sodium dichromate for the sealing after anodizing in the overall surface treatment process within the scope of the present AoA (marked in red).

Only the combination of adequate pre-treatments, main process step and post-treatment leads to a well-prepared surface providing all necessary key requirements for the respective applications (as described in Chapter 3.3). To be clear, the use of potassium/sodium dichromate for sealing after anodizing in the post-treatment step is crucial to ensure the quality of the product and to meet the requirements of the industry. However, further Cr(VI) compounds might also be used within the whole process chain (i.e., the pre-treatment and main process step) that are not subject to this AoA.

As such, although single process steps can be assessed individually, they cannot be seen as stand-alone processes but as part of a whole process chain. Consequently, when assessing alternatives for potassium/sodium dichromate-based post-treatments, the whole process chain and the performance of the end product has to be taken into account. While R&D on replacement technologies in surface treatments has been ongoing for decades, industry has only developed and qualified alternate treatments for anodizing after sealing for a few specific less demanding applications. Thus there are no universally applicable qualified alternate treatments available for all design spaces. In addition, it is crucial to consider the following points:

- In each case, the performance of the alternative materials/techniques must - <u>importantly</u> - be evaluated as part of a whole system (Figure 8);
- Any change of single steps in the process chain of surface treatments will require component and/or system level testing and evaluation, (possibly including engine or flight test) (re)qualification and implementation into the supply chain; and
- Current approvals for most coating systems still incorporate <u>at least one layer prepared with Cr(VI) compounds, but mostly multiple layers where Cr(VI)-based treatments are used</u>.

We therefore clearly state that for a thorough assessment of replacement technologies, it is mandatory to include the whole process chain (including pre- and main treatments), which **in combination are technically equivalent** to the current Cr(VI) containing treatments. Completely Cr(VI)-free industrially available solutions exist for only a few applications for aerospace components, and are only applicable where corrosion risk is low.

3.2.1. Sealing after anodizing post-treatment process

The surfaces of substrates after anodizing are naturally porous, the coating cannot provide the required corrosion resistance without further treatment (Hao & Cheng, 2000); therefore, a sealing post-treatment is necessary for a broad variety of sectors and applications.

The process of anodizing is briefly described below to fully cover the process and to understand the need for a post-treatment anodize sealing. However, the AfA does not cover the use of chromates in the anodizing process.

Anodizing is an electrolytic oxidation process in which the surface of a metal, when anodic, is converted to a coating having desirable protective or functional properties. The oxide layer partly grows into the substrate and partly grows onto the surface. Anodizing is used to increase corrosion and wear resistance as well as adhesion for subsequent processes. The main commercial application is the treatment of aluminium to create Al_2O_3 on the surface (Defra, 2005).

Given the natural porous anodized surface, the micropores of the anodized surface have to be closed by a sealing post-treatment step for the requisite long-term corrosion resistance. The degree of hydration of the anodize seal needs to be monitored to insure good corrosion protection.

Sealing is often performed in a hot aqueous chromate solution (typically > 95°C but below the solution's boiling point) using potassium/sodium dichromate.

Mode of action: The sealing after anodizing step is performed with a potassium/sodium dichromate solution. During the sealing, potassium/sodium dichromate and hydroxides precipitate in the pores of the previously anodized oxide layer and are hydrated. By this process, the pores are closed and an adequate wear resistance and corrosion resistance is provided to the surface.

The hydration process (in the course of sealing after anodizing) is pH-dependent, but in all cases, the chromate is absorbed to the anodized aluminium surface. Depending on the pH, Cr(VI)-based sealing forms either aluminium oxychromate (equation 1) (at pH <6) or aluminium dioxychromate (equation 2) in the coating micropores (Steele & Brandewie, 2007).

(1) $AlOOH + HCrO_4^- \rightarrow AlOHCrO_4 + OH^-$

(2) $(AlO(OH))_2 + HCrO_4^- \rightarrow (AlO)_2CrO_4 + OH^- + H_2O$

The final step closes the pores by contact with hot water and locks in the potassium/sodium dichromate in the pores according to equation (3):

(3) $Al_2O_3 + H_2O \rightarrow 2\ AlO(OH)$

The hydrated aluminium oxide (boehmite) has a larger volume than aluminium oxide, therefore the pores are closed.

An overview on the key functionalities and the performance requirements of potassium/sodium dichromate in the respective surface treatment is provided in the paragraphs below.

3.3. Key functionalities of potassium/sodium dichromate-based sealing after anodizing

The process of sealing after anodizing relies on the use of potassium/sodium dichromate due to a number of key functionalities, which are described in detail below. During the consultation phase of CCST, the key functionalities for potassium/sodium dichromate within this use were identified taking the whole surface treatment processes into account and thus the AoA was more extensive. Nevertheless, the most important key functionality is corrosion resistance.

It should be noted that while any quantified acceptance criteria reported for key requirements here have been supplied by industry, they are not necessarily the same for all companies or even for individual applications within the same company.

Aerospace users of anodize seals have developed application-specific requirements based on long-term field experience that describe key functionalities including:

Corrosion resistance: 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 part to withstand gradual destruction by chemical reaction with its environment. For the aerospace sector, this parameter is one of the most important since meeting its requirements plays a key role in assuring the longest possible life cycle of aerospace components and all the implicit parts, the feasibility of repair and maintenance activities and most importantly, continued safety and reliability of aerospace components during use. Some aluminium alloys, commonly used in the aerospace sector, contain approximately 5% of Cu as alloying element to provide material strength. But Cu as a noble element acts as a built-in corrosion driver. Inhibition of the corrosion-promoting attributes of Cu is mandatory for long-term corrosion stability. The corrosion resistance requirements vary within the aerospace sector and are dependent on the specific application, metal substrate (aluminium alloy), the coating thickness and the respective surface treatment process. Corrosion of test coupons or components is evaluated after a specified number of hours (e.g., 750 h, 1000 h, 2000 h, etc.) per neutral salt spray tests (such as ISO 9227 and / or ASTM B117). This test can be considered a very preliminary screening test that might be introduced in the early development process (e.g., TRL 2 as further discussed in Chapter 7). When potential candidates do not pass this test, there is no confidence that it will be able to meet the challenging performance requirements mandated by the aerospace industry. Even where such a test is successfully completed, extensive further testing over many years is required.

Corrosion inhibiting substances/systems can be categorized according to basic quality criteria which are inhibitive efficiency, versatility and toxicity. Ideally, the substances/systems are applicable in all surface treatment processes, compatible with subsequent layers, and performs effectively on all major metal substrates. Furthermore, it has to guarantee product stability (chemically and thermally) and has to reinforce the useful coating properties. Most importantly, public safety is paramount and the aerospace sector has set its performance standards and specifications for Cr(VI) replacements to reflect equivalency to Cr(VI) performance in order to maintain the industry’s very high and long-standing safety record.

Active corrosion inhibition: The ability of a material to spontaneously arrest small amounts of chemical or mechanical damage is known as an active corrosion inhibition or self-healing property (Figure 9). If this characteristic is present for a certain material, it is tremendously advantageous and will reduce premature corrosion failures, enhance service life of parts, reduce maintenance intervals and improve flight security of air travellers and security of power supply.

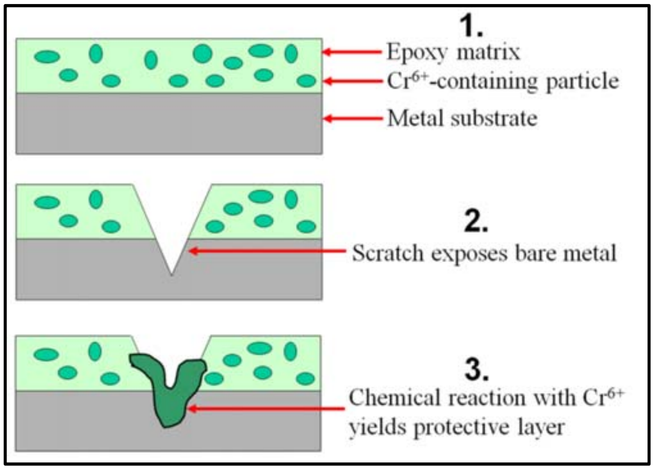


Figure 9. Active corrosion inhibition (General Electric, 2013).

The active corrosion inhibition capability of potassium/sodium dichromate-based surface treatments is seen in the positive corrosion test results of those components and is a key factor of the superior corrosion resistance of the Cr(VI) coatings seen in hardware that is already in-service. It is the lack of this capability that makes it very difficult for non-Cr(VI) seals to perform equivalently.

4. ANNUAL TONNAGE

4.1. Annual tonnage band of potassium dichromate

The annual tonnage band for the use of potassium dichromate in surface treatment for the aero sector is estimated to be approximately 5 tonnes per year.

5. GENERAL OVERVIEW ON THE SPECIFIC APPROVAL PROCESS IN THE AEROSPACE SECTOR

5.1. General overview

Much has already been written about the airworthiness and approvals process in the aerospace industry in the document "An elaboration of key aspects of the authorisation process in the context of aviation industry" published in April 2014 by ECHA and European Aviation Safety Agency (EASA). The document makes a strong case for justification of long review periods for the aerospace sector. In this section we identify key points from the ECHA EASA "elaboration" document and add additional detail and justification for long review periods with specific regard to potassium/sodium dichromate.

Some of the key points identified in the "elaboration" document are:

- "The aerospace industry must comply with the airworthiness requirements derived from EU Regulation No 216/2008 in Europe, and with similar airworthiness requirements in all countries where aeronautical products are sold."
- "All components, from seats and galleys to bolts, equipment, materials and processes incorporated in an aircraft fulfil specific functions and must be certified, qualified and industrialised." In addition the new materials must be developed and evaluated prior to these three steps.
- "If a substance used in a material, process, component, or equipment, needs to be changed, this extensive process [of development, qualification, certification and industrialisation] has to be followed in order to be compliant with the airworthiness requirements."
- "Although the airworthiness regulations (and associated Certification Specifications) do not specify materials or substances to be used, they set performance specifications to be met (e.g. fire testing protocols, loads to be sustained, damage tolerance, corrosion control, etc.). These performance specifications will drive the choice of substances to be used either directly in the aircraft or during the manufacturing and maintenance activities."
- The development [TRL (Technology Readiness Level) 1-6] process "is an extensive internal approval process with many different steps from basic technology research up to technology demonstration in a lab environment."
- "Depending upon the difficulty of the technical requirements [qualification] can easily take 3-5 years. After initial laboratory testing, each specific application must be reviewed, which means additional testing for specific applications / parts. Airworthiness Certification begins at this same time, this certification can take from 6 months to years. Additional time is needed for production scale-up and development of a supply chain."

Each one of these points is of significant importance for aerospace companies with regards to potassium/sodium dichromate. Further elaboration will be made within this section.

The last bullet point highlights that it can take a significant period of time to develop and implement new alternatives. It should be noted that in the case of potassium/sodium dichromate, the stated time needed for taking an alternative from the development phase through qualification, certification and implementation has been significantly underestimated. Efforts to find replacements for potassium/sodium dichromate have been ongoing within the aerospace sector for over 30 years. In this time, some successful substitutions have been made, but large challenges remain. Efforts thus far to identify equivalents for substances with critical, unique properties like corrosion inhibition have proven that there are no 'drop-in' replacement substances for Cr(VI). Depending on the specific application and performance requirements, many more years may be required before alternatives are identified and implemented.

In this section the general process for alternative development through qualification, certification, industrialisation and implementation within the aerospace sector is described. This process is also followed closely by the military and space sectors.

Apart from the complexity of the supply, the aerospace sector faces particular unique challenges related to the operating environment, compliance with airworthiness requirements and the longevity of aerospace components that constrain its ability to adopt changes in materials and processes in the short, medium or even longer terms.

Because of the stringent requirements for qualification and certification, a formal process for technology readiness and manufacturing readiness is followed.

The process for qualification, certification and industrialisation as described in the ECHA EASA “elaboration” document is shown in Figure 10.

Figure 10. Illustration of the qualification, certification and industrialisation processes.

This diagram is perhaps overly simplified and doesn’t indicate the significant level of research and development work required prior to achieving qualification. As stated in the “elaboration” document “This process is an extensive internal approval process with many different steps from basic technology research up to technology demonstration in a lab environment.” The actual process followed by Original Equipment Manufacturers (OEMs) in the aerospace sector more closely follows the framework for TRLs and Manufacturing Readiness Levels (MRLs) originally developed by the National Aeronautics and Space Administration (NASA). OEMs usually adapt this TRL/MRL approach resulting in individual versions which are considered proprietary and cannot be presented here. The NASA version is shown in Table 3.

Table 3: Technology Readiness Levels – Overview (US Department of Defence, 2011, adapted 2014).

TRL#	Level Title	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 validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity”

TRL#	Level Title	Description
		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 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.

In general, the TRL assessments guide engineers and management in deciding when a candidate alternative (be it a material or process) is ready to advance to the next level. Early in the 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. As specific applications are targeted as initial implementation opportunities, design and certification requirements are added to the criteria. Many more factors have to be taken into account prior to making a decision about transition of technology or replacing a material. A formal gate review process has been established by some companies to control passage between certain levels in the process.

A similar set of guidelines for MRLs exist for the management of manufacturing risk and technology transition process. MRLs were designed with a numbering system similar and complementary to TRLs and are also intended to provide a measurement scale and vocabulary to discuss maturity and risk. It is common for manufacturing readiness to be paced by technology or process readiness. Manufacturing processes require stable product technology and design. Many companies combine the aspects of TRLs and MRLs in their maturity assessment criteria, as issues in either the technology or manufacturing development will determine production readiness and implementation of any new technology.

The following sections describe the highlights of the entire process from definition of needs before technology development begins through to implementation. The emphasis here is to provide a description of the general process while highlighting the inherent complexities.

One additional point to keep in mind when reviewing the process description that follows is that there is no guarantee that the initial process to identify an alternative for a substance is successful. Failure is possible at every stage of the TRL process. The impact of failure can be significant in terms of time.

5.2. Development and qualification

5.2.1. Requirements development

A need for a design change may be triggered due to many reasons. The one of interest here is when a substance currently used for production of aerospace parts is targeted for sunset (e.g. potassium/sodium dichromate). Completely removing one substance may impact various parts and systems and may involve many different processes with different performance requirements.

Once a substance is identified to be targeted by a regulation, a first step is to identify the materials and processes containing the specific substance. Most companies rely upon the information provided by the chemical manufacturer in the safety data sheet (SDS). This information source has many limitations when used for substance identification including: lack of reporting due to protection of proprietary data; reporting large concentration bands to protect specific formulary data; different disclosure requirements based upon country (articles exemption, thresholds, de minimis, specific substance classifications, etc.) to name a few. After identifying the materials and processes and associating them with specifications and other design references, parts get identified along with applications and products potentially impacted. This is the first step in order to assess the impact for the company.

This work requires contributions from numerous personnel from various departments of an aerospace company including Materials & Processes, Research & Development, Engineering, Customer Service, Procurement, Manufacturing, Certification, as well as affiliates in other countries and Risk Sharing Partners.

Current production aerospace components may have been designed 20 to 30 years ago (or more) using design methods and tools that are not easily revisited, nor were they necessarily standardized between OEMs. Checking and changing the drawings implies updating, e.g. creating the drawings under the new formats and tools, which can involve a tremendous amount of design work.

Note: When a new design is needed (e.g. to remove a substance), it may not be compatible with the existing one; this means that spare part designs of the original materials / configurations may need to be preserved in order to be able to produce spare parts using the original (baseline) configuration. This is an additional impact to be taken into account.

Once a substitution project is launched, technical specialists, from engineering and manufacturing departments, must define the requirements that the alternatives have to fulfil.

Alternatives must satisfy numerous requirements. In many cases requirements are identified that introduce competing technical constraints and lead to complex test programmes. This can limit the evaluation of alternatives. For instance, for some materials, dozens of individual engineering requirements with similar quantities of industrial requirements may be defined.

Categories of technical requirements may include:

- Materials and processes requirements (e.g. corrosion resistance, adhesion strength),
- Design requirements (e.g. compatibility of the component's geometry complexity and with the coating application technique),
- Industrial requirements (e.g. robustness and repeatability),
- Environment, Health & Safety (EHS) requirements.

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

- Different behaviour of the substitute compared to original product: new requirements may be defined. In this case, sufficient operational feedback to technically understand the phenomenon and to reproduce it at laboratory scale is a must in order to be able to define acceptance criteria.
- Requirements may come from suppliers and have an impact on the design.
- EHS regulations evolution.

Once initial technical requirements are defined, potential solutions can then be identified and tested. The timeframe for initial requirements development can last up to 6 months. Note that requirements may be added and continue to be refined during the different levels of maturity.

5.2.2. Technology development

The development process (typically TRL 4-6) is complex, and several years are often necessary before reaching development phase end (TRL 6) (see Figure 11). The following points explain why it may be long and complex:

- Developing solutions usually necessitates several testing phases before meeting the numerous requirements, which often induce several loops to adjust the formulation / design.
- Some tests are long lasting (e.g. some corrosion tests last 3000 h or longer).
- In some cases, potential alternatives are patented, preventing multiple sources of supply, which is an obstacle to a large supply-chain deployment due to increases in legal costs and in some cases a reduction in profitability for the business.
- When no 1 to 1 replacement solution is available, each alternative process must individually be considered to determine for which specific quantitative application it is suitable. This work represents a significant resources mobilization, especially in terms of drawings update and implementation of alternatives which, due to the multiple work streams, takes longer with higher costs. Moreover, spare parts and maintenance processes redesign may result in complex management both at the OEM and the end users. Additionally, substance-specific regulations are evolving throughout the long research and development phase and life cycle of aerospace components, which is another challenge for OEMs. There is a risk that significant investments could be made to develop and qualify alternative solutions involving substances with low EHS impacts identified at that point in time. Solutions may be developed and finally qualified; however, in the meantime, EHS constraints on those substances increased to a point where they now meet the SVHC criteria.
- When the suppliers have no "off the shelf" solutions, they have to develop new ones considering the list of requirements that are often highly complex to combine (see the description of requirements in the above paragraph).
- Drawings impact: The replacement of a material / process may impact the complete design of a part. Additionally, the mating part / counterpart functionality must be analysed too (materials compatibility, dimensional compatibility, stress compatibility). This may lead to redesign of the complete part plus mating parts.
- Process instructions shall be elaborated.

The description of the development process is included in the qualification section of the ECHA EASA "elaboration" document. The text is reproduced here for continuity.

> "Qualification precedes certification and is the process under which an organisation determines that a material, process, component or equipment have met or exceeded specific performance requirements as documented in a technical standard or specification. These specifications, often abbreviated as

> spec(s), contain explicit performance requirements, test methods, acceptance testing, and other characteristics that are based upon the results of research, development and prior product experience.
>
> The industry relies upon standards issued by government-accredited bodies, industry or military organisations, or upon company-developed proprietary specs. Most materials and process specifications include either a "Qualified Products List" (QPL) or "Materials Control" section that identifies products that have met the requirements. Application and use of these qualified products must be assessed and certification implications addressed before being used on aircraft hardware.
>
> OEMs rely upon the expertise of the chemical formulators to provide viable candidates to test against specific material and process specs."

It is important to note that many iterations of these formulas are rejected in the formulator's laboratory and do not proceed to OEM evaluation. Formulators estimate 2 to 5 years before candidates are submitted to OEMs.

> "Once candidate(s) are developed, the OEM evaluates candidates by performing screening testing. If the candidate passes screening, testing is expanded to increase the likelihood that the preparation will pass qualification. If the candidate fails, which is often the case, material suppliers may choose to reformulate. It is not uncommon to iterate multiple times before a candidate passes screening. In some technically challenging areas, over 100 formulations have been tested with no success. This phase of development can take multiple years depending upon the material requirements. For those materials that pass screening, production scale-up, development of process control documents, manufacturing site qualifications, and extensive qualification testing is required to demonstrate equivalent or better performance to that which is being replaced. This phase of the process can also result in formulation or manufacturing iterations and may take several additional years. Depending on the complexity of the change and the criticality of the application (for example, fire protection or corrosion prevention have high safety implications and require development and testing against multiple, rigorous performance standards), re-certification may be required. The industry is ultimately limited by the material formulators' willingness to expend their resources to develop alternative materials and technologies to be tested."

The small volumes of materials sold, demanding performance requirements, and tightly controlled manufacturing processes for aerospace company customers provide insufficient incentive for reformulation in some cases. When material formulators are not willing to reformulate their materials, new sources need to be sought.

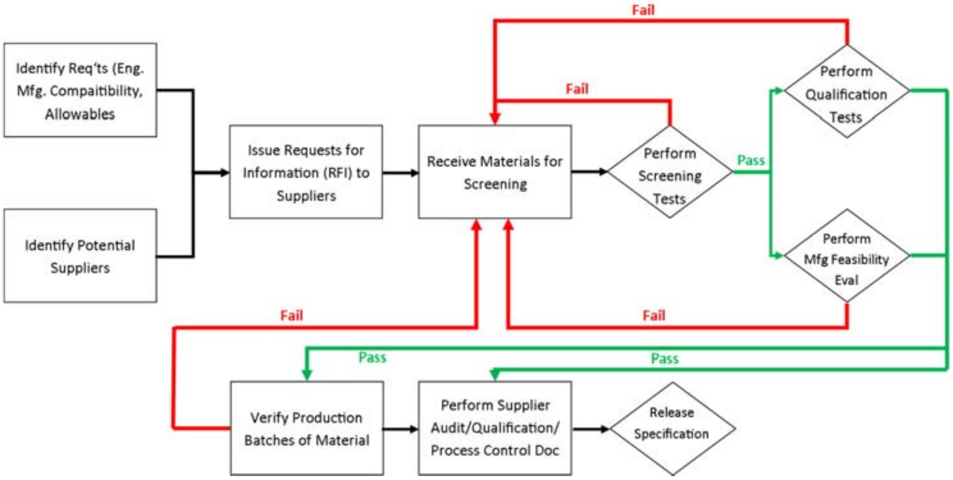


Figure 11. Illustration of the technology development and qualification process. (EASA, 2014; amended)

> "This process [TRL 1-6 development] is an extensive internal approval process with many different steps from basic technology research up to technology demonstration in a lab environment. Depending

> upon the difficulty of the technical requirements, these initial steps can easily take 3-5 years. After initial laboratory testing, each specific application must be reviewed, which means additional testing for specific applications / parts. Airworthiness Certification begins at this same time, this certification can take from 6 months to years. Additional time is needed for production scale-up and development of a supply chain."

It should be noted that the timeframes for development and qualification stated in the "elaboration" document have been combined and may be understated in the case of potassium/sodium dichromate. Depending on the application and the complexity of material and process requirements, this process can easily take multiple years. As noted in the "elaboration" document the timeframe for development alone is typically a minimum of 3 to 5 years. Our experience with replacement of the substances addressed in this dossier is that the development takes much longer. For typically successful projects, the duration is 3 to 5 years. For unsuccessful projects, the development goes through repeated iterations and has taken over 30 years and still continues with limited success.

5.2.3. Qualification

All material, components, equipment or processes have to meet or exceed the specific performance requirements which are defined in the Certification Specifications documented in technical standards or specifications as described in Chapter 5.3. These are issued by military organisations, government-accredited bodies, industries or upon company-developed proprietary specifications.

The main reasons for qualification are:

- To fulfil requirements by the Airworthiness Authorities (EASA); this is the first level of the Aircraft Certification Pyramid.
- To ensure that only approved, reliably performing materials, parts and processes are used to produce aerospace components.
- To ensure that the product, the process or method is compliant with the Industry Regulations and aerospace components manufacturer requirements to fulfil a specified function.
- To provide a level of confidence and safety.
- To ensure consistent quality of products and processes.
- To ensure supplier control, and to guarantee production and management system robustness, throughout the supply chain.

The qualification process is mandatory to demonstrate compliance with airworthiness and certification requirements; the qualification process ensures that the technical and manufacturing requirements documented in the relevant material and/or process specifications are met. The qualification process comprises several steps before materials / processes are qualified. Even if most showstoppers are identified during the development phase, process confirmation / production verification are performed during the qualification phase. In case of failure, product qualification will be cancelled and the development phase must start again from the beginning.

Based upon OEM experience, the time period needed to pass the qualification process is estimated to be on the order of 8 years and can be even longer when major test failures occur. This is one of the main challenges for potassium/sodium dichromate replacement. Depending upon the materials, processes and criticality of the applications being evaluated, in-service evaluation and monitoring will be required and can extend to 15 years or more depending upon the application.

5.3. Certification

This next step is to certify that aerospace components comply with all applicable airworthiness regulations and associated Certification Specifications (specs). This step is also well described in the "elaboration" document and is reproduced here for continuity.

> "Certification is the process under which it is determined that an aircraft, engine, propeller or any other aircraft part or equipment comply with the safety, performance environmental (noise & emissions) and any other requirements contained in the applicable airworthiness regulations, like flammability, corrosion resistance etc.
>
> Although the airworthiness regulations (and associated Certification Specifications) do not specify materials or substances to be used, they set performance specifications to be met (e.g. fire testing protocols, loads to be sustained, damage tolerance, corrosion control, etc.). These performance specifications will drive the choice of substances to be used either directly in the aircraft or during the manufacturing and maintenance activities. Some examples of performance requirements are the following:
>
> - Resistance to deterioration (e.g. corrosion) Environmental damage (corrosion for metal, delamination for composites) and accidental damage during operation or maintenance.
> - Corrosive fluids - Hydraulic fluids; Blue water systems (toilet systems and areas); leakage of corrosive fluids/substances from cargo.
> - Microbiological growth in aircraft fuel tanks due to moisture/contamination in fuel cause severe corrosion. Such corrosion debris has the potential to dislodge from the fuel tanks, migrate through the fuel system, and lead to an in-flight engine shutdown.
> - Resistance to fire – Flammability Requirements Fire-proof and fire-resistance. Aircraft elements are expected to withstand fire for a specified time without producing toxic fumes; this leads to using products like flame retardants, insulation blankets, heat protection elements in hot areas (e.g. around engines).
>
> The primary certification of the aircraft (or engine and propeller) is granted to the manufacturer by the Competent Aviation Authority of the "State of Design" which is typically the authority of the state where the manufacturer of the aircraft (or engine or propeller) is officially located (EASA in the case of aircraft designed and manufactured in the EU and European Free Trade Association countries). Aircraft that are exported to other countries will have to be certified (validated) also by the authority of the "State of Registry".
>
> Manufacturers work with the certification authorities to develop a comprehensive plan to demonstrate that the aircraft meets the airworthiness requirements. This activity begins during the initial design phase and addresses the aircraft structure and all systems in normal and specific failure conditions (e.g. tire failure, failure of structural components, hydraulics, electrical or engines). The tests needed to demonstrate compliance, range from thousands of coupon tests of materials, parts and components of the airplane, up to tests that include the complete aircraft or represents the complete aircraft (system). The performance and durability of the various materials have to be confirmed while the behaviour of the parts, components and the complete airplane will have to be tested in the applicable environmental and flight conditions including various potential damage or failure conditions. For a new Type Certificate, this overall compliance demonstration covers several thousands of individual test plans of which some will require several years to complete. Often, after the initial issuance of the Type Certificate, the tests that have the objective to demonstrate durability of the aircraft during its service life, will continue.
>
> All the different aspects covered by the Type Certificate together define the "approved type design" which includes, among other aspects, all the materials and processes used during manufacturing and maintenance activities. Each individual aircraft has to be produced and maintained in conformity with this approved type design.
>
> Changes to the approved type design may be driven by product improvements, improved manufacturing processes, new regulations (including those such as new authorisation requirements

> under REACH), customer options or the need to perform certain repairs. When new materials or design changes are introduced, the original compliance demonstration will have to be reviewed for applicability and validity, in addition to a review of potential new aspects of the new material or design change that could affect the airworthiness of the aircraft. Depending on the change, this review could be restricted to coupon or component tests, but for other changes this could involve rather extensive testing. E.g. changes in protective coatings could affect not only the corrosion resistance but could also affect the friction characteristics of moving components in actuators in the different environmental conditions, changing the dynamic behaviour of the system, which in the end affects the dynamic response of the airplane.
>
> Before the new material or design change can be introduced on the aircraft, all test and compliance demonstrations have to be successfully completed and approved by the Competent Authority. This approval results in the issuance of a Supplemental Type Certificate (STC), change approval or repair approval.
>
> It is important to note that, according to the EU Regulation No 216/2008, EASA is the design competent authority for civil aircraft only. Any other aircraft (e.g. military, fire-fighting, state and police aircraft) will have to follow similar rules of the corresponding State of Registry.
>
> To be able to maintain and operate an aircraft the responsible organisations must be approved by the competent authority and compliance is verified on a regular basis. Maintenance of an aircraft requires that the organization complies with specific procedures and materials described in the maintenance manuals which are issued by and the responsibility of the OEMs."

As noted in the "elaboration" document, in optimal cases certification can take as little as 6 months but typically will take several years. The duration really depends on the specific material and application.

5.4. Implementation / industrialisation

Aerospace company products consist of thousands to several million parts which are provided by thousands of suppliers or manufactured internally by OEMs. Significant investment, worker training and manufacturing documentation may be required to adapt the manufacturing processes which sometimes require changes in existing facilities or the construction of new facilities.

The industrial implementation is usually scheduled to follow a stepwise approach to minimize the technical risks and benefit from lessons learned. This implies that the replacement is not implemented in one shot in all plants and at all suppliers but stepwise. Each OEM may own several plants, e.g. multiple manufacturing sites / final assembly lines worldwide for some of them.

Furthermore, the implementation of an alternative process may induce new development and modification in the complete process flow.

The following text is reproduced from the "elaboration" document and describes the process for implementation of an alternative:

> "Industrialisation is an extensive step-by-step methodology followed in order to implement a qualified material or process throughout the manufacturing, supply chain and maintenance operations, leading to the final certification of the aerospace product. This includes re-negotiation with suppliers, investment in process implementation and final audit in order to qualify the processor to the qualified process.
>
> Taking into account that an aircraft is assembled from several million parts provided by several thousand suppliers, this provides an indication of the complexity for the industrialisation stage of replacement materials/processes, and the supply chain which provides these parts.
>
> Special challenges are:

> - Low volumes limit influence on changes to suppliers' materials / processes
> - Procurement & insertion of new equipment
> - Scale-up & certification of new process
> - Incompatibility of coatings could be a risk.
> - Re-negotiation of long term agreements with suppliers*.
> - Increased complexity of repairs – Multiple different solutions for different applications as a substitute for a single, robust process. For example, currently all aluminium parts can be repaired with one chromated conversion coating. In some specific cases, the future state could require different conversion coatings for each aluminium alloy and application environment. Since different alloys are not easily distinguishable on the shop floor, ensuring that the proper repair procedures are used will be much more difficult. If alternate means of compliance approvals are requested for repair facilities or airlines, regulatory agencies are unlikely to have adequate knowledge or technical data to make informed assessments.
>
> The operating environment, longevity of the aircraft, supply chain complexity, performance and above all airworthiness requirements are some of the considerations which can constrain the ability of the industry to make changes and adopt substitutes in the short, medium or long term."
>
> *Changes to the design or manufacturing may require re-negotiations with suppliers which can be time-consuming, especially when long-term contracts are concerned. The supply chain is complex in the aerospace sector; it includes but is not limited to chemical manufacturers, importers, distributors, formulators, component manufacturers, OEMs, Airline operators, power plant operators, and aftermarket repair and overhaul activities.

The timeframe for implementation and industrialisation is unknown. Even simple changes can take up to 5 years. Our experience with replacement of the substance addressed in this dossier is that a complete replacement has yet to be identified.

When the alternative process is included in the maintenance documents, challenges described above have to be faced by customers and MROs to implement the alternative. Here, for operating supplies and testing time frames, another 3 years might be necessary, depending on the complexity of the alternative. When more than one alternative process has to be established simultaneously, as would be the case for sulphuric acid anodizing plus the seal coat, more than a decade might be necessary to fully implement the alternatives.

It is important to note that the implementation/industrialisation step ('TRL10') refers to the whole supply chain. This includes external as well as internal industrialisation. In case a suitable chrome free alternative is developed in the future, it needs to be implemented across a vast and complicated supply chain, which in turn is time and cost intensive requiring significant additional investment in new machinery and plants on the part of existing suppliers. Additionally, any substitution is linked to major resourcing exercises at new suppliers with the capabilities of industrialising the application of the new products or processes. The switch-off of one production process and the belonging supply chain without validating and qualifying the new alternative process and corresponding supply chain is not feasible.

6. IDENTIFICATION OF POSSIBLE ALTERNATIVES

6.1. Description of efforts made to identify possible alternatives

The preparation of this AoA has been supported by the suppliers and OEMs in the value chain of potassium/sodium dichromate under the auspices of the Global Chromates Consortium for Aerospace (GCCA). The potassium/sodium dichromate covered by this application for authorisation for use on aerospace components is imported to the EEA as such or within proprietary products manufactured by non EU formulators. The supply chain for these products is not covered by other applications for authorisation; however, it is important to note that the uses of hexavalent chromium covered in the CCST AfA are still relevant and necessary for GCCA aerospace companies and their supply chain.

6.1.1. Research and development

As mentioned earlier in this document, a large amount of research over the last few decades has been commissioned to identify and develop viable alternatives to potassium/sodium dichromate and Cr(VI) compounds in general. The unique functionalities of potassium/sodium dichromate (explained in detail in Chapter 3.3) make it challenging and complex to replace the substance in surface treatment applications where superior corrosion properties are required to ensure safe performance in a demanding environment. Confidence of Cr(VI) performance for corrosion protection and other parameters across many different types of technologies has been built over many decades of service, and this informs the lifetime predictions for components. This factor has a significant influence on the level of risk created through substitution with alternative chemistries in the aerospace industry's safety-critical applications. Therefore, a rigorous approach to research and design of alternative technologies is needed to minimize risk.

In broad terms, substitution of REACH-affected technologies can be broken down into three distinct phases: development, validation / qualification and industrialisation / deployment, as seen in Figure 12. Depending on the application, the Certification (or in some cases recertification) process typically spans across the Validation / Qualification and Industrialisation / Deployment phases. Each of these phases can be closely aligned to Technology Readiness Levels (TRLs), as described in Chapter 5. New technologies are required to meet the pass criteria of each phase before it can proceed to the next. If a technology does not meet these pass criteria, then it may be reformulated or can be discontinued as a candidate.

Figure 12: Typical phases of technology development within the Aerospace industry (Rolls Royce, 2016).

TRLs are a gated method of estimating technology maturity of a new technology during the qualification, certification and validation process. TRLs are based on a scale from 1 to 9 with 9 being the most mature technology. TRL0-TRL4 are considered development levels. TRL5-TRL6 are considered validation / qualification levels and TRL7-TRL9 are typically the industrialisation / deployment levels.

To obtain design approval, a process requires TRL 6 as a minimum. TRL 6 is the first level at which a potential alternative to potassium/sodium dichromate would be signed off for use in aerospace components. TRL 6 requires testing in a ‘relevant environment’, which could include an engine or aircraft flight test.

Significant work is required to develop and implement a testing strategy that will validate candidate alternatives to potassium/sodium dichromate according to the TRL process. The extent of the testing required to implement a new or alternative technology has to be determined on a case by case basis. Implementation depends on the scale of the modification to the existing, proven design and the requirements of the specific application. In any case, it takes considerable effort and time to establish the specific testing requirements and funding for an alternative corrosion inhibitor or design (system or component). It will take many more years to carry out the testing; the necessary testing cannot be accelerated as extrapolation from limited data is unlikely to be accepted as reliable.

After a formulator has performed extensive screening tests to prove initial feasibility, it takes about 1 - 3 years to obtain TRL 3 and up to as much as 15 years to progress through TRL 6, although this is highly dependent on the application. However, it is important to note that success is in no way assured. Several iterations of research may be required, and even then the outcome may not be favourable.

In the early development process (e.g. TRL 0 and TRL1), much of the research effort is conducted by the formulators who will carry out initial feasibility studies to assess the viability of potential alternatives before advising the OEMs of candidates that might be considered for more extensive assessment. This process in itself requires a substantial effort. A slurry coating formulator reports that the development of an alternative formulation for one very specific application required 25 years of research in-house, involving consideration of three different candidate alternative chemical families, and many varying formulations of each before the innovative coating formulation was passed forward to the OEM for comprehensive testing. A formulator does preliminary assessment of the viability of a potential alternative. However, only the design owner can determine when a candidate alternative is fully validated and certified for each of their uses of the candidate formulation.

As well as work carried out by individual companies, industry research consortia have been set up in order to develop new technology for those that are currently affected by regulations, including REACH Authorisation. Industry collaborations have the advantage of sharing development costs and knowledge of non-competitive technologies under a legal framework. However, validation and deployment of these new technologies are typically carried out by individual companies and their supply chain. Pass criteria for technologies in the development phase can be aligned to numerous industry standards such as ASTM, MIL, AMS and others. Typically combinations of these specifications are used, which means that new technologies are subject to rigorous testing before they can be considered for validation. As a result, a key aspect of industry R&D efforts is identifying the proper validation test for the specific design space to be addressed. There are numerous variables for each scenario that need to be taken into account. Some examples include the alloys used, in-use temperature ranges, environmental challenges that the part is going to see and the types of cycles the part is being designed for. Further, once an alternative progresses to detailed testing, it is critical to take into account what aerospace component the part is being validated for and what its requirements are. This can vary significantly between different engine or airframe models, for example. As a result, a potential alternative may only pass validation for a single part in a specific engine or aircraft.

Existing aerospace components, for which production and/or operation may still be ongoing, present significant additional challenges. Production, maintenance and repair of these models must use the processes and substances already specified following the extensive approval process. Substitution of potassium/sodium dichromate-based surface treatment for these certified products introduces yet another substantial challenge; re-certification of all relevant processes and materials. In practice, it will be impractical and uneconomical to introduce such changes for many such aerospace component types.

The primary focus for ongoing REACH alternatives work streams have been equivalent one-to-one replacements and some success has been achieved for limited applications. However, determination of an equivalent technology is difficult when the testing methodology used is accelerated and not fully representative of the environment to which components are subjected.

In addition to surface treatment systems, the aerospace industry continues to develop and apply new non-metallic and high strength low weight base materials that do not require surface treatment. New product development design cycles provide a new technology testing and substantiation platform to run in parallel with development of new designs and advance the use of new materials without surface treatments. Existing mature designs cannot take advantage of a product development cycle to incorporate these technologies and require a new testing and substantiation plan to ensure, at a minimum, the same level of performance exists. Complex design factors, detailed analyses, and product testing are an impediment to start incorporating an alternative base material without surface treatment replacement into existing mature designs. Some aerospace companies have had success in replacing surface treatments, including potassium/sodium dichromate, with non-surface treated base materials, but these areas are case-by-case and often in less demanding applications.

Selected Aerospace Company-Specific and Key Collaborative Research Programmes

Major aerospace companies such as Boeing, General Electric (GE), Rolls-Royce and United Technology Corporation (UTC) have been working for decades on the development of Cr(VI)-free alternatives, either on their own or as a part of collaborative efforts with industry associations, governmental organizations, or non-governmental organizations. Selected examples are discussed below.

United Technology Corporation (UTC) and its business units have been working on Cr(VI) alternatives since the early 1990's and validated replacements have been inserted whenever feasible. At Pratt & Whitney, for example, chrome-free paint primer is being used in many applications in both new and legacy engine designs. Hard chrome plate was replaced over 15 years ago with Cr(VI)-free HVOF (High Velocity OxyFuel) coatings for all applications (new and legacy) where a spray process can be used. In Pratt & Whitney's newest engine family, chromated seal coat was eliminated on most thick anodize applications. Cr(VI) sacrificial coatings were also eliminated from these new designs through both hardware re-design and substitution of a Cr-free alternative, where application appropriate. However, there are still many applications where Cr(VI) surface treatments are technically required, even in the newest designs, to meet safety performance requirements.

In addition, UTC has initiated and participated in two industrial consortium projects through the U.S. National Center for Manufacturing Sciences (NCMS) directed at the identification of alternatives to hexavalent chromium-based conversion coatings. The first of these projects was completed in 1995 and tested 29 alternative coatings for their corrosion resistance, surface electrical resistance and organic coating adhesion. The second project was completed in 2002 and evaluated an additional 17 coatings to the same test criteria. No satisfactory alternative coatings for aerospace use were documented in either study. These studies have been published as complete reports by NCMS.

UTC also participated in a NASA-based consortium project, "Hexavalent Chrome Free Coatings for Electronics Applications" from 2010-2015. This project demonstrated that some alternative coatings can address specific electrical property requirements in aerospace design application, but did not identify robust performance in corrosion protection.

United Technologies Research Center (UTRC) has conducted numerous research projects on the properties and performance of chromate conversion coatings and their alternatives. From 2008-2012, UTRC functioned as a task leader for the Department of Defence Strategic Environmental Research and Development Program (SERDP) Project WP-162, “Scientific Understanding of Non-chromated Corrosion Inhibitors Function”. This project, in combination with internally funded projects, resulted in two publications (Appl. Phys. Lett. 97, 181908, 2010, and Anal. Chem. 2011, 83, 6127–6131) that describe the growth kinetics and composition of trivalent chromium conversion coatings grown on aluminium alloys. These findings have been presented in numerous technical meetings and conferences. Although this work provides a fundamental understanding of the formation mechanism and composition of these coatings, it does not identify the source of variation in their corrosion protection performance, and further studies directed at improvement of these coatings have been unsuccessful.

UTRC has conceived and executed numerous research projects to evaluate non-chromium based conversion coatings, including coatings based on molybdate, rare earth elements, and organic corrosion inhibitors. These projects did not demonstrate non-chromium conversion coatings with sufficient inhibition of corrosion on aerospace aluminium alloys. Additional projects have been performed on other chrome-free surface treatments with varying levels of success, but no alternatives were found to be robust enough to replace Cr(VI) in all required applications.

UTRC is currently performing on SERDP project WP-2144, “Understanding Corrosion Protection Requirements for Adhesive Bond Primers”. In this project, substantial laboratory and outdoor testing of sol gel pre-treatments, which are intended to enhance adhesion of organic coatings to aluminium alloys, has demonstrated that these coatings do not impart measurable corrosion resistance to aerospace aluminium alloys and therefore are not a technically feasible alternative to chromated conversion coatings.

GE Aviation has focused considerable effort in identifying Cr(VI) alternatives for their mechanical systems with some limited successes:

- GE has replaced chromic acid anodizing with tartaric sulphuric acid anodizing (TSAA) since the start of the Airbus A350 program in 2010. However, both anodizing methods still require sodium/potassium dichromate sealing and it has not proven possible to replace the Cr(VI)-based primer.
- A program to identify a chromate-free alternative for a fuel tank sealant paste that has corrosion inhibiting properties was commenced in 2011. An alternative was identified that demonstrated improved corrosion resistance and equivalent resistance to hydrocarbons, operating temperature and physical properties. As a result, the transition to the new alternative sealant paste is ongoing and is expected to be completed by the end of 2016.
- Following several years working with a customer on a joint development program, an alternative for a Cr(VI)-free corrosion inhibiting non-drying paste for fasteners has been approved for use on propeller installations. The transition is ongoing and is also expected to be completed by the end of 2016.
- Recent developments in a multi-year program investigating the potential to replace bonding primers in composite applications have led to a significant improvement in potential alternative product performance. As the tests are ongoing, GE expects to identify a potential candidate by the end of 2016 and begin internal specification testing with a goal to start the transition by 2019 for specific applications.

- A multiyear collaborative program investigating the potential to replace a Cr(VI)-containing inorganic matrix coating has identified a potential alternative to specific applications. The program is at a TRL 4 currently as GE locks down processes and proceeds towards internal specification testing having a goal to transition by 2020.
- An ongoing program to identify a chromate-free alternative to Alodine 1200 touch-up has identified a potential alternative on 6000 and 7000 series aluminium alloys. The program is currently at a TRL 4 with a goal to complete testing and transition by 2019.
- Following several years of development and testing, GE has approved and implemented two Cr(VI)-free assembly primer alternatives used in the Fan modules.
- Currently there are numerous ongoing aerospace collaborative efforts at different TRL levels investigating potential alternatives to Cr(VI)-free bonding primers, primers, plating, CAA, sealing, stripping, chemical conversion coatings, etc. As potential Cr(VI)-free candidates are identified they are then screened against internal specification requirements and considered against specific performance requirements.

The Rolls-Royce Group also has an ongoing programme seeking to substitute Cr(VI) used within materials and manufacturing processes. The business continuity risk created by chemical substance regulations such as REACH has increased the importance of this programme. Success in substituting a number of Cr(VI)-containing manufacturing processes has already been demonstrated by Rolls-Royce in this programme.

In order to share best practise and influence wider supply chain usage, Rolls-Royce has also led the creation of a number of industry consortia to develop alternative technologies to those that demand the use of Cr(VI). The REACH Compliant Hex Chrome Replacement for Corrosion Protection, HITEA (Highly Innovative Technology Enablers for Aerospace) funded project was led by Rolls-Royce and is discussed in further detail below. The consortium was successful in establishing that a number of commercially available proposed alternatives were not suitable for a majority of Aerospace applications.

More closely related to the REACH Authorisations being sought by this dossier, Rolls-Royce is currently participating in consortia tasked with the development of hex chrome-free sacrificial and high temperature diffusion coatings.

Accelerated Manufacturing with Chrome Free Sacrificial Cermet Coatings in Aerospace (AMSCA) is a 3 year, £2.35 million project partially funded by the UK's innovation agency, Innovate UK, which aims to develop hex chromium-free sacrificial coatings. This consortium is made up of 7 partners, including 2 universities, and is led by Monitor Coatings Ltd. Since the consortium's creation in 2014, the role of chromium trioxide in the formulation of currently used sacrificial coatings has been investigated using advanced spectroscopic methods. It is now understood that chromium trioxide has a much more complex chemistry effect than solely providing its most well-known property of corrosion resistance.

Chrome Free Aluminide Slurry Coatings for Gas Turbines (CASCoat) is a 2 year, £0.65 million project partially funded by the UK's innovation agency, Innovate UK, which aims to develop a Cr(VI)-free high temperature diffusion coating. The consortium contains 3 project partners, led by Monitor Coatings Ltd and development is expected to be complete in 2016.

Any coating developed by these projects will still have to be validated and deployed by any OEM's, which can take up to 12 years. As stated elsewhere in this document, substitution is complicated by the fact that they must be deployed into legacy products.

At Boeing, work on a replacement for CAA began in 1982. The initial driver for this R&D effort was to reduce emissions of Cr(VI) and comply with federal and local clean air regulations in the US. Initial requirements were identified and four candidate solutions were evaluated. One candidate solution was down selected in 1984. Qualification testing began in 1985. A process specification for boric sulphuric acid anodizing was released in 1990. In 1991 and 1992 industrialisation began as several Boeing facilities began producing parts using the BSA process. One outside supplier also began processing parts to the Boeing specification in 1992. Evaluation of additional applications continued into the mid-1990s. In 2015, industrialisation of the BSA alternative for CAA was still not complete. Many Boeing suppliers are shared with other OEMs and industries impeding the conversion to BSA from CAA because they must continue to support multiple customer requirements. Note that for unprimed parts a dilute chromium trioxide seal is still required to provide required corrosion resistance. Work is ongoing to develop alternatives for this application. It is also worth noting that boric acid is now being proposed for Annex XIV requiring authorisation. Should this happen alternatives may need to be developed for BSA. Other OEM solutions will need to be evaluated, qualified and certified by Boeing.

While aerospace companies have made significant investments in alternatives development, it should be noted that some programs that looked promising ultimately had to be abandoned. For example, GE commenced work evaluating boric-sulphuric acid anodizing as an alternative to chromic acid anodizing in 2011; however, this activity has recently been cancelled due to the inclusion of Boric Acid on the Candidate List of Substances of Very High Concern. Likewise, before boric acid was placed on the Candidate List, UTC implemented BSA for limited applications to replace CAA. Further, in some instances promising programs can hit significant and unforeseen roadblocks. For example, GE commenced in 2005 a program to eliminate Cr(VI)-based primer. A series of potential alternatives were identified for testing; however, whilst samples were available from formulators, the readiness level and maturity of the formulations were such that no significant progress could be made. As a result, the project was postponed in 2007 pending formulatory R&D completion.

Industry is not only working on one-to-one replacements for Cr(VI) applications, but is also reconsidering whole current coating systems. The large investment in innovative coating technologies may lead successively to a paradigm shift within the next decades.

The REACh Compliant Hexavalent Chrome Replacement for Corrosion Protection, HITEA (Highly Innovative Technology Enablers for Aerospace) funded project was initiated in 2012; a 17-member consortium was formed consisting of aerospace OEMs (including GE, Rolls Royce and UTC), suppliers, paint application companies and academics with the goal to identify and evaluate suitable alternative systems. At the end of the project, over 45 candidates were tested in over 160 systems and there were no equivalent one-to-one alternatives for the main application groups that were being assessed. However, there were candidates that delivered some of the required properties for specific applications. Further development and validation of these candidates is required before they can be deployed onto Aerospace products, which may take up to another 10 years. Moreover, significant development is required for the applications where no suitable alternatives were identified.

The Aerospace Chrome Elimination (ACE) team has been working to reduce the use of hexavalent chromium since 1988. ACE is a collaboration of US OEMs and the US Department of Defense (DoD). The focus is on sharing information between members on all chromate uses and on-going replacement efforts in aerospace – this necessarily includes uses of chromium trioxide in surface finishing. The information exchanged between ACE team members is restricted for use by members only.

The International Aerospace Environmental Group (IAEG) has been working on several fronts to address environmental and chemical regulations facing the aerospace industry since its formation in

2011. One of the IAEG efforts involves working through its member companies to conduct research to pursue the development and implementation of hazardous chemical alternatives throughout the value stream that meet aerospace performance and safety requirements. This effort has focused on Cr(VI) free alternatives for passivation of corrosion resistant steel and anodizing of aluminium parts – including anodize seal. Additional efforts are planned to focus on alternatives for other surface finishing processes involving the use of Cr(VI).

Numerous research programmes have also been conducted under the EU clean sky initiative (MASSPS, ROPCAS, LISA, DOCT, MUST, MULTIPROJECT) as well as programmes funded by United States Air Force (USAF) or other national funded programmes (e.g. LATEST in UK).

6.1.2. Data searches

For the analysis of alternatives, extensive literature and test reports were provided by the technical experts of the CCST consortium members (CCST, 2015a,b) which were further reviewed for applicability to the GCCA scope and supplemented as needed. Furthermore, searches for publically available documents were conducted to ensure that all potential alternate processes to Cr(VI)-containing applications were considered in the data analysis. In addition to databases for scientific literature, the following programmes were intensively consulted: Toxics Use Reduction Institute, Massachusetts, US (www.turi.org/); The Advanced Materials, Manufacturing, and Testing Information Analysis Center (AMMTIAC: http://ammtiac.alionscience.com/) (CCST, 2015a,b). Searches for SDS for Cr(VI)-containing and chrome-free applications were also conducted.

6.2. Consultations

Based on the data search results, primary scoping by the CCST Consortium led to the development of a generic questionnaire containing potential alternatives to potassium/sodium dichromate-based surface treatment processes. As a result of this, additional alternate processes mentioned by companies from the aerospace sector were included in the initial list of candidate alternatives, which can be found in Appendix 1 of the CCST Analysis of Alternatives (CCST, 2015a,b).

A questionnaire was also provided to all GCCA consortium members to get an overview of and experience with the alternatives, completeness and prioritisation of critical parameters for their specific processes and the minimum technical requirements specific to the use of potassium/sodium dichromate as an anodize seal treatment. During this survey, additional alternatives have been identified which are further discussed in Chapter 7.

At this stage of the data analysis, several alternatives had been screened out after bilateral discussions with the companies, based on confirmation that they might be general alternatives to potassium/sodium dichromate-based processes (e.g. stainless steel passivation), but are not applicable for the use defined here (i.e. anodize sealing).

To verify data and obtain more detailed quantitative information, further focused technical discussions were carried out with the GCCA consortium members. Discussions with technical experts followed by a final data analysis led to the formation of a list of candidate alternatives that are considered promising.

6.3. List of candidate alternatives

The most promising candidate alternatives to sealing after anodizing using potassium/sodium dichromate are discussed in the following chapter. An overview is given in Table 4. These alternatives are currently the focus of GCCA members with relevant R&D on these substances ongoing through the continued development and testing of various proprietary formulations.

Table 4: List of candidate alternatives to the potassium/sodium dichromate-based sealing after anodizing post-treatment.

Candidate Alternative
Cr(III)-based surface treatments
Nickel Acetate
Nickel fluoride
Zirconium-based seals

It should be noted that numerous other experimental and emerging technologies for anodize seal alternatives have been, or are being, considered by the GCCA member companies including, but not limited to, transition or rare earth metal-based seals, other acetates (sodium, lithium, cobalt), other fluorides (potassium and hydrogen), phosphate seals, hot water processes, etc. All of these have demonstrated clear limitations and may only be suitable for other industry sectors or for very specific less demanding applications. However, none have been identified as being appropriate as a broad alternative for Cr(VI) seals. Many of these remain at low levels of maturity (i.e., TRL1/TRL2) and R&D continues to identify potential alternatives.

7. SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES

In the following chapter, possible alternatives are assessed specifically for the industry sector where they may be potential alternatives. Initially, general process or substance properties are described, followed by the assessment of the technical feasibility, availability and reduction of overall risk.

The alternative assessments each comprise a non-exhaustive overview of substances used with the alternatives and alternative processes as well as the risk to human health and environment. These tables are provided in Appendix 1.

CANDIDATE ALTERNATIVES

The alternatives assessed in this section are considered the most promising ones, where considerable R&D efforts are carried out within the aerospace sector. In most cases, they are in early research stages and still showed technical limitations when it comes to the demanding requirements from the aerospace sector, such as corrosion performance. While R&D on replacement technologies in surface treatments has been ongoing for decades, industry has only developed and qualified alternate treatments for a few specific, less demanding applications. Thus there are no universally applicable qualified alternate treatments available for all design spaces.

7.1. Alternative 1: Cr(III)-based anodize seal treatments

7.1.1. Substance ID and properties

Cr(III) processes are generally based on the same principle as Cr(VI) processes. However, there are major differences in the distinct chemical composition of the proprietary formulations and required additives as well as the operating parameters and ancillary equipment, depending on the kind of surface treatment. In general, two types of Cr(III) solutions are used: sulphate- and fluoride-based.

An overview of general information on substances used within this alternative and the risk to human health and the environment is represented within Appendix 1.1.1.

7.1.2. Technical feasibility

Cr(III)-based surface treatments are assessed as applicable alternatives to the potassium/sodium dichromate-based sealing after anodizing for aluminium and aluminium alloys.

Sealing after anodizing – one process step

Corrosion resistance: Tests performed within the aerospace sector on anodized surfaces sealed with Cr(III) showed varying corrosion protection results depending on the anodizing process used (e.g., thick versus thin layer anodizing). The test results of Cr(VI)-free sealing with Cr(III)-based conversion product showed that an adequate corrosion resistance performance (e.g. based on Salt Spray Test results) may only be achieved under controlled conditions in the laboratory. When tested under industrial conditions, this performance was clearly not reached, except for a few less demanding applications. This is in line with statements from other companies on Al alloys from the 2000 and 7000 series, where corrosion protection has been found to be only 10% of that provided by Cr(VI). Suitability needs to be validated in additional tests which are more representative for specific in-service relevant conditions.

Conclusion: Cr(III) sealing has been implemented for limited, less demanding aerospace applications. In consequence, further R&D is ongoing.

Sealing after anodizing – two-step process

After applying Cr(III)-based sealing, a certain level of porosity of the sealed surface may remain in comparison to the conventional potassium/sodium dichromate-based sealing processes. In addition, the corrosion performance of the Cr(III) chemical conversion coating layer itself might be insufficient. This remaining porosity negatively influences the corrosion resistance of the coating. Several companies within the aerospace sector have performed R&D on this issue showing that the remaining pores can be closed by an additional post-treatment process (CCST 2016a,b). Consequently, the whole sealing process must be expanded by using an additional process step. For this process, a two-step post-treatment after anodize using Cr(III) plus rare earth elements is under evaluation. The process is patent protected by one company in the aerospace sector.

Conclusion: Work is currently ongoing to further improve the corrosion resistance of the layer by closing the remaining pores. The process is stated to be technically feasible, development is in TRL 2.

7.1.3. Economic feasibility

Against the background of significant technical failure of these alternate systems for most applications, no detailed analysis of economic feasibility was conducted. First indications were made, stating that the process is in general economically feasible.

7.1.4. Reduction of overall risk due to transition to the alternative

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. As worst case scenario, chromium (III) fluoride is classified as Skin Corr. 1B, Eye Dam. 1, Acute Oral Tox. 3, Acute Dermal Tox. 4, Acute Inhal. Tox. 4 and STOT RE 1. As such, transition from potassium/sodium dichromate – which is a non-threshold carcinogen – to one of these substances would constitute a shift to less hazardous substances.

7.1.5. Availability (R&D status, timeline until implementation)

Cr(III) solutions as sealing alternatives were stated to be a promising alternative for equipment and structural parts and plans are underway within the aerospace sector to implement Cr(III) sealing of anodized parts where technically feasible. Cr(III) seal is already in production for some less demanding applications. Further research at the laboratory scale is ongoing to improve the final quality of the sealed coating and to validate suitability with further testing. In addition, there are still substantial efforts needed to develop alternatives for the most challenging applications including aerospace components that are especially vulnerable for corrosion and other areas where moisture and liquids are entrapped. For the use in established programs and especially vulnerable parts, additional R&D efforts are needed. For these applications, the developmental process will certainly include multiple iterations and testing until successful implementation. Here, at least 12 to 15 years are necessary until full implementation of alternatives for all applications into the supply chain.

Additionally, the development of a two-step sealing process comprising Cr(III) sealing after anodizing process is at TRL 2. Further R&D is needed to determine the viability of this alternative.

7.1.6. Conclusion on suitability and availability for Cr(III)-based processes

Taking all these extensive R&D efforts for the different processes and the first products on the market into account, it can be stated that Cr(III)-based anodize seal surface treatments are not yet technically feasible as a general alternative to the described potassium/sodium dichromate-based surface treatments within the aerospace sector. Where feasible, some one step Cr(III) anodize seals have been implemented for limited, less demanding aerospace applications. The major technical limitation is the corrosion performance of the coated substrates, especially on the widely used Al alloys from the 2000 and 7000 series. With regard to Cr(III)-based sealing, the two-step alternative is in early development, while a single-step sealing is further along in the development process.

In summary, to date Cr(III) is not a validated alternative to the current systems in the aerospace sector for replacement of Cr(VI) anodize seals for most applications, but represents a promising potential alternative for additional applications. Further implementations may be possible for sealing after anodizing; however, current estimates are that a minimum of 12 to 15 years will be needed.

7.2. ALTERNATIVE 2: Nickel (Ni) Acetate Seal

7.2.1. Substance ID and properties

Ni acetate processes are based on very different principles to Cr(VI) processes. Unlike Cr(VI), Ni acetate provides a barrier coating that does not chemically arrest corrosion, as does the Cr(VI). It is primarily intended for light duty applications, and is widely used in other sectors to seal thicker anodize films on lower strength aluminium alloys which do not require the level of corrosion protection common in aerospace applications. It is very useful on colored anodize applications, which is mainly limited to non-aerospace applications. There are differences in the chemical composition of proprietary formulations that provide varying levels of performance.

Certain aerospace components require local application of hard anodic coating to provide wear resistance. Due to its impact on fatigue strength, hardcoat anodize is typically applied locally, with the balance of the component protected by an anodized film. The anodized film is applied first, followed by a seal coat for certain applications. These function as a maskant for the subsequent hardcoating process, and as a permanent coating for the component. To perform effectively as a maskant, the anodized film and its seal must provide exceptional short term barrier properties to the high current density hardcoating process. Historically in the aerospace industry, chromic acid anodize with a dichromate seal has been used in this application. As a maskant, Ni acetate sealing of a sulfuric acid anodize layer is extremely effective in enabling the local application of hardcoat anodizing due to its barrier properties and, when applied in the correct design space (aluminium alloys of low corrosion susceptibility, non-corrosive environments, additionally protected by corrosion inhibitive coatings), can be used effectively.

An overview of general information on substances used within this alternative and the risk to human health and the environment is represented within Appendix 1.1.2.

7.2.2. Technical feasibility

Ni acetate surface treatments are assessed as potential alternatives to the potassium/sodium dichromate-based sealing after anodizing for a very limited scope of aluminium and aluminium alloy aerospace applications.

<u>Sealing after anodizing – one process step</u>

Corrosion resistance: Corrosion resistance afforded by Ni acetate seal is generally poor, and is very sensitive to process parameters. Because they are only barriers, Ni acetate sealed coatings tend to break down and show numerous fine pinpoints of corrosion. Overall, Ni acetate sealing is limited to applications on corrosion resistant aluminium alloys operating in non-corrosive environments such as the hardcoat maskant and seal in non-corrosive environments described in the previous section.

Conclusion: Ni acetate sealing is an implemented alternative in narrowly defined aerospace applications. The application restrictions are due to the physical nature of its sealing (i.e. forms a physical barrier with no active corrosion inhibition). As such, Ni acetate sealing cannot be further developed to satisfy most aerospace applications requiring corrosion inhibiting properties.

7.2.3. Economic feasibility

Against the background of significant technical failure of these alternate systems, no detailed analysis of economic feasibility was conducted. Although Ni acetate is widely available, and economically feasible, it is not an appropriate substitute for dichromate seal for the majority of aerospace applications.

7.2.4. Reduction of overall risk due to transition to the alternative

As the alternative is not technically feasible for most applications, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. As a worst case scenario, Ni acetate has a harmonized classification of Acute Oral Tox. 4, Acute Inhal. Tox. 4, Skin Sens. 1, Resp. Sens.1, Muta. 2, Carc. 1A, Repr. 1B, STOT RE 1, Aquatic Acute 1, and Aquatic Chronic 1. As such, transition from potassium/sodium dichromate – which is a non-threshold carcinogen – to this substance would not constitute a shift to less hazardous substances.

7.2.5. Availability (R&D status, timeline until implementation)

Ni acetate solutions as sealing alternatives are widely available due to their use in commercial applications. They have been implemented where feasible, but additional R&D is not appropriate due to their fundamental performance limitations.

7.2.6. Conclusion on suitability and availability for Ni Acetate Seal

Although Ni acetate has been implemented in the aerospace sector in the very limited applications where it provides adequate performance (as part of the maskant and anodize seal for hard anodic coating applications), Ni acetate-based surface treatments are not technically feasible as a general alternative to the described potassium/sodium dichromate-based surface treatments within the aerospace sector. The major technical limitation is the corrosion performance of the coated substrates, especially on the widely used Al alloys from the 2000 and 7000 series, due to its lack of active corrosion protection.

7.3. ALTERNATIVE 3: Nickel (Ni) Fluoride Seal

7.3.1. Substance ID and properties

Ni fluoride-based formulations have been the focus of much research due to their ability to be used for sealing processes at ambient temperatures (Hao and Cheng, 2000). Current industry research is also focused on hot water applications for these formulations. “Sealing” is believed to occur as the result of coprecipitates within the micropores of anodic coatings that may eventually plug or block the pores with the fluoride ions acting as an accelerator while forming the aluminium fluoride complex (Hao and Cheng, 2000).

A non-exhaustive overview of general information on substances used within this alternative and the risk to human health and the environment is represented within Appendix 1.1.3.

7.3.2. Technical feasibility

Ni fluoride surface treatments are assessed as potential alternatives to the potassium/sodium dichromate-based sealing after anodizing for a very limited scope.

Corrosion resistance: Currently, inconsistent results have been achieved during testing and results have not shown equivalency to the corrosion resistance provided by Cr(VI) seals; although, it is estimated that the product will exceed the capability of Ni acetate (as discussed above).

7.3.3. Economic feasibility

Against the background of significant technical failure of this alternative, no detailed analysis of economic feasibility was conducted. However, based on the literature research and consultations, there is no indication that the discussed alternative is not economically feasible in general.

7.3.4. Reduction of overall risk due to transition to the alternative

As the alternative is not technically feasible for most applications, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. In a worst case, Ni fluoride has a harmonized classification of Skin Sens. 1, Resp. Sens.1, Muta. 2, Carc. 1A, Repr. 1B, Aquatic Acute 1, and Aquatic Chronic 1. As such, transition from potassium/sodium dichromate – which is a non-threshold carcinogen – to the above mentioned alternative product would not constitute a shift to less hazardous substances.

7.3.5. Availability (R&D status, timeline until implementation)

Ni fluoride solutions as sealing alternatives are widely available due to their use in commercial applications. They have yet to be implemented in aerospace applications, with additional R&D currently underway.

7.3.6. Conclusion on suitability and availability for Ni Fluoride Seal

Ni fluoride-based surface treatments are not technically feasible as a general alternative to the described potassium/sodium dichromate-based surface treatments within the aerospace sector. The major technical limitation is the corrosion performance of the coated substrates.

7.4. ALTERNATIVE 4: Zirconium-based Seal

7.4.1. Substance ID and properties

Since the late 1970s, organometallic coatings based upon organo-zirconates have been reported and found some applications in adhesive as well as anodize seal technologies. It is generally considered that they form interfacial primary bonds to the substrate via reaction with surface protons. In the last few years, a new generation of environment-friendly conversion coatings based on zirconium oxides has attracted extensive attention owing to good corrosion and wear resistance. Moreover, the new conversion coatings can operate at lower process temperatures. These Zr-based conversion coatings have been mostly used on aluminium and magnesium alloys.

Products based on fluorozirconic acid were stated as alternatives for anodize seals in the aerospace sector. A patent protected chrome-free chemical conversion coating (CCC) was developed specifically for aluminium alloys. Current R&D efforts are underway to transition from CCC to anodize seal applications. A non-exhaustive overview of general information on substances used within this alternative and the risk to human health and the environment is represented within Appendix 1.1.4.

7.4.2. Technical feasibility

Zirconium-based surface treatments are assessed as potential alternatives to the potassium/sodium dichromate-based sealing after anodizing.

Corrosion resistance: R&D efforts on this alternative are in early stages (TRL2) and testing is ongoing.

7.4.3. Economic feasibility

As R&D efforts are in very early stages (TRL2), no detailed analysis of economic feasibility was conducted. However, based on the literature research and consultation, there is no indication that the discussed alternative is not economically feasible.

7.4.4. Reduction of overall risk due to transition to the alternative

As the alternative is currently under development, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. As worst case assumption, Ammonium hexafluorozirconate and Hexafluorozirconic acid are classified as Acute Oral Tox. 3, Acute Dermal Tox. 3, Acute Inhal. Tox. 3 and Skin Corr. 1B. As such, transition from potassium dichromate – which is a non-threshold carcinogen – to one of these substances would constitute a shift to less hazardous substances.

7.4.5. Availability (R&D status, timeline until implementation)

The development of a zirconium-based sealing after anodizing process is under development (TRL 2). Further R&D is needed to determine the viability of this alternative.

7.4.6. Conclusion on suitability and availability for Zirconium-based Seal

It can be concluded that sealing after anodizing based on zirconium compounds is in a very early stage of development (TRL 2). As such, data are not yet available to determine how this candidate alternative will perform compared to potassium dichromate-based seals. Significant R&D is still needed to determine if zirconium-based seals have the potential to be a general alternative for aerospace company applications.

8. OVERALL CONCLUSIONS ON SUITABILITYAND AVAILABILITY OF POSSIBLE ALTERNATIVES

For this Application for Authorisation, an extensive literature survey and consultation with aerospace sector industry experts was carried out to identify and evaluate potential alternatives to surface treatments of metals with potassium/sodium dichromate for sealings of anodic films.

Potassium/sodium dichromate-based surface treatments are specified in the aerospace sector because they provide superior corrosion resistance and inhibition. These characteristics are essential to the safe operation and reliability of aerospace company products which operate under extreme environmental conditions. These structures are extremely complex in design, containing thousands to millions of highly specified parts, many of which cannot be easily inspected, repaired or removed. Engine parts (e.g. internal components for gas turbines) are particularly vulnerable to corrosion.

Surface treatment processes typically involve numerous steps, often including several important pre-treatment and post-treatment steps as well as the main treatment process itself. These steps are almost always inter-related such that they cannot be separated or individually modified without impairing the overall process or performance of the treated product. This means that while the use of potassium/sodium dichromate or another Cr(VI) substance may be specified at different points in the process, it [Cr(VI)] cannot be entirely replaced in the process without impacting the technical performance of the final article. The implications of this are important as potassium/sodium dichromate-free alternatives *for some individual steps or applications* are available and used by the aerospace industry. However, where this is the case, another Cr(VI) substance, such as chromium trioxide, is mostly specified in one of the other steps within the overall surface treatment system. This means it is imperative to consider the surface treatment system as a whole, rather than the step involving potassium/sodium dichromate on its own, when considering alternatives for such surface treatment systems. Furthermore, components that have been surface treated with potassium/sodium dichromate typically represent just one of many critical, inter-dependent elements of a component, assembly or system. In general, potassium/sodium dichromate-based surface treatment is specified as one element of a complex system with integrated, often critical performance criteria. Compatibility with and technical performance of the overall system are primary considerations of fundamental importance during material specification.

Four candidate alternatives are a focus for ongoing research and development (R&D) programs and were examined in further detail in this report. Here, a candidate alternative is defined as a potential alternative provided to the aerospace companies for evaluation following initial evaluation by the formulator. It should be noted that while this AoA focuses only on the 4 candidate alternatives that are felt by the GCCA members to be the most viable options, numerous other alternative formulations/processes have been screened by these companies and/or their supply chain and found to be completely inadequate.

While various potential alternatives to potassium/sodium dichromate, predominantly Cr(III)- and Nickel-based formulations are being investigated for anodize seal applications, results so far do not support reliable conclusions regarding their performance as part of such complex systems, in demanding environments and test conditions representative of in-service situations. These candidate alternatives do not support all the properties of potassium/sodium dichromate-based surface treatment systems, and their long-term performance can currently only be estimated in most applications. Decreased corrosion protection performance would necessitate shorter inspection intervals in an attempt to avoid unexpected failures with potentially catastrophic results. In summary, the analysis shows there are no technically feasible alternatives to potassium/sodium dichromate-based anodize seal surface treatment systems for all key applications required by aerospace companies. Various candidate alternatives are subject to ongoing R&D, but do not currently support the necessary combination of key functionalities to be considered technically feasible alternatives for most applications.

Assuming a technically feasible candidate alternative is identified as a result of ongoing R&D, extensive effort is needed beyond that point before it can be considered a validated alternative to potassium/sodium dichromate.

Aircraft are one of the safest and securest means of transportation, despite having to perform in extreme environments for extended timeframes. This is the result of high regulatory standards and safety requirements. Performance specifications defined under EU Regulation No 216/2008 and the EASA CS-25 and EASA CS-E in the EU drive the choice of substances to be used either directly in the aerospace components or during manufacturing and maintenance activities. It requires that all components, equipment, materials and processes must be qualified, certified and industrialised before production can commence. This system robustly ensures new technology and manufacturing processes can be considered 'mission ready' through a series of well-defined steps only completed with the actual application of the technology in its final form (and under mission conditions). When a substance used in a material, process, component, or equipment needs to be changed, this extensive system must again be followed in order to comply with airworthiness and other customer-driven requirements. The system for alternative development through qualification, certification, industrialisation and implementation within the aerospace sector is mirrored in the defence and space sectors.

These approval steps can only proceed once a candidate alternative is identified. A formulator does preliminary assessment of the viability of a potential alternative. However, only the design owner can determine when a candidate alternative is fully validated and certified for each of their uses of the candidate formulation. Referring to experience, it can take 20 to 25 years to identify and develop a new alternative, even assuming no drawbacks during the various stages of development of these alternatives. Experience over the last 30 years already shows this massively under-estimates the replacement time for potassium/sodium dichromate-based surface treatments. Although there have been active R&D efforts to replace Cr(VI) in aerospace applications for more than 30 years, these efforts have yet to result in the technical breakthrough necessary to replace Cr(VI) for critical aerospace uses.

As a further consideration, while the implications of the development process in the aeronautic and aerospace sectors are clearly extremely demanding, specification of an alternative, once available, can be built into the detailed specification for new aerospace components. This is not the situation for existing aerospace components, for which production and/or operation may still be ongoing. Production, maintenance and repair of these models must use the processes and substances already specified following the extensive approval process. Substitution of potassium/sodium dichromate-based anodized seal surface treatment systems for these certified products introduces yet another substantial challenge; re-certification of all relevant processes and materials. In practice, it will be impractical and uneconomical to introduce such changes for many such aerospace component types.

In this context, the scale and intensity of industry- and company- wide investment in R&D activity to identify alternatives to potassium/sodium dichromate anodized seal surface treatment systems is very relevant to the findings of the AoA. Serious efforts to find replacements for potassium/sodium dichromate as part of overall Cr(VI) replacement activities have been ongoing within the aerospace industry for over 30 years and there have been several major programs to investigate alternatives to potassium/sodium dichromate in the aerospace sector over the last 20 years.

Review Period

Extensive evaluation of potential alternatives to potassium/sodium dichromate-based surface treatments is carried out in the present AoA. Furthermore, economic aspects, as well as aspects of approval and release in the aerospace sector are assessed with regard to a future substitution of the substance. The following key points are relevant for deriving the review period:

- The aerospace investment cycle is demonstrably very long. A typical life cycle for any aircraft type is over 40 years and may even be up to 80 years or more (see SEA). Therefore, it is technically and economically meaningful to substitute only when a major investment or refurbishment takes place;
- Any alternative is required to pass full qualification, certification and implementation/ industrialisation to comply with very high standards in the aerospace sector regarding airworthiness and flight security to ensure safety of use. Before any potential alternative can be implemented, aerospace components are required to comply with all applicable regulations and associated Certification Specifications (EASA CS-25 and EASA CS-E). Airworthiness Certification takes 6 month up to several years to ensure public safety;
- The costs for the development, qualification and certification of candidate alternatives are very high. The timescale for developing and validating potential alternatives is at least 12 years, and the testing requirements are well defined in order to ensure safety and will not change;
- Extensive research and development on viable alternatives to Cr(VI)-based surface treatments has been carried out over the last few decades but did not lead to the development of substitutes for most applications that could be available within the normal review period. However, the unique functionalities of Cr(VI) compounds make it challenging and complex to replace the substance in surface treatment, especially regarding applications where superior corrosion is crucial for public safety;
- Comparing health impacts of workers to socio-economic impacts, the ratio in the baseline scenario is at least 1: 296 (see Chapters 7 and 8 of the SEA), and there is clear evidence that this situation is not likely to change in the next decade.

Concluding remarks

An extensive amount of research over the last 30 years has been deployed to identify and develop viable alternatives to Cr(VI)-based surface treatments. Due to its unique functionalities and performance, it is challenging and complex to replace surface treatments based on potassium/sodium dichromate or other Cr(VI)-chemistries in applications that demand superior performance for corrosion to deliver safety over extended periods and extreme environmental conditions.

Candidate alternatives to potassium/sodium dichromate such as Cr(III)- and Nickel-based systems, are under investigation for the aerospace industry. However, based on experience and with reference to the status of R&D programs, alternatives are not foreseen to be commercially available for all key applications in this sector for at least 12 or 15 years. As a result, a review period of **12 years** was selected because it coincides with best case (optimistic) estimates by the aerospace industry of the schedule required to industrialise alternatives to potassium/sodium dichromate.

9. REFERENCES

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APPENDIX 1 – GENERAL INFORMATION AND THE RISK FOR HUMAN HEALTH AND THE ENVIRONMENT FOR RELEVANT SUBSTANCES

APPENDIX 1.1: ANNODIZE SEAL POST TREATMENT

APPENDIX 1.1.1: ALTERNATIVE 1: Cr(III)-based surface treatments

Table 1: Substance IDs and properties.

Parameter	**Value**	**Physico-chemical properties**	**Value**
Chemical name and composition	Chromium trifluoride	Physical state at 20°C and 101.3 kPa	Solid
EC number	232-137-9	Melting point	>1000°C
CAS number	7788-97-8	Density	3.8 g/cm3 at 25°C
IUPAC name	Chromium trifluoride Chromium(III) fluoride	Vapour pressure	-
Molecular formula	Cr F_3	Water solubility	Insoluble to slightly soluble in water
Molecular weight	108.94	Flammability:	Non-combustible
Parameter	**Value**	**Physicochemical properties**	**Value**
Chemical name and composition	Chromium Sulfate, Basic Solution	Physical state at 20°C and 101.3 kPa	Solid
EC number	235-595-8	Melting point	>900°C
CAS number	12336-95-7	Density	1.25 g/cm³
IUPAC name	Chromium Hydroxide Sulphate	Vapour pressure	-
Molecular formula	Cr-H-O_5-S	Water solubility	Approx. 700 g/L at 35°C
Molecular weight	165.065	Flammability	Not combustible
Parameter	**Value**	**Physico-chemical properties**	**Value**
Chemical name and composition	Dipostassium hexafluorozirconate	Physical state at 20°C and 101.3 kPa	Solid
EC number	240-985-6	Melting point	> 650°C
CAS number	16923-95-8	Density	3.48 g/cm³ at 20°C
IUPAC name	Dipotassium hexafluorozirconate	Vapour pressure	-
Molecular formula	F_6Zr.2K	Water solubility	ca. 18.2 g/L at 20°C
Molecular weight	283.411	Flammability	-

Table 2: Hazard classification and labelling overview

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers*	Additional classification and labelling comments	Regulatory and CLP status
Chromium trifluoride	Acute Tox. 3	H301 (Toxic if swallowed)	53	The supplier SDS is not in EU CLP or GHS format therefore classifications cannot be determined	Currently not REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Skin Corr. 1B	H314 (Causes severe skin burns and eye damage)	83		
	Acute Tox. 4	H302 (Harmful if swallowed)	26		
	Acute Tox. 4	H312 (Harmful in contact with skin)	28		
	Eye Dam. 1	H318 (Causes serious eye damage)	26		
	Acute Tox. 4	H332 (Harmful if inhaled)	28		
	STOT RE 1	H372 (Causes damage to organs through prolonged or repeated exposure)	18		
Chromium Sulfate, Basic Solution	Not classified	-	56		Currently not REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Acute Tox. 4	H332 (Harmful if inhaled)	47		
Dipostassium hexafluorozirconate	Acute Tox. 3	H301 (Toxic if swallowed)	147	The Joint REACH registration classified as: Acute Tox. 3 and Eye Dam. 1. 84 notifiers also classified as Aquatic Chronic 3; H412 23 notifiers also classified as Skin Irrit. 2; H315, Eye Irrit. 2, STOT SE 3; H335 The supplier substance classification is not given on SDS.	Substance is REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Eye Damage 1	H318 (Causes serious eye damage)	112		

* The most prevalent classifications reported to the C&L Inventory are provided.

APPENDIX 1.1.2: ALTERNATIVE 2: Nickel Acetate

Table 1: Substance ID and physicochemical properties

Parameter	**Value**	**Physicochemical properties**	**Value**
Chemical name and composition	Nickel acetate	Physical state at 20°C and 101.3 kPa	Solid
EC number	206-761-7	Melting point	> 633 K
CAS number	373-02-4	Density	1.78
IUPAC name	Nickel (II) acetate	Vapour pressure	-
Molecular formula	$C_2H_4O_2$.1/2Ni	Water solubility	177 g/L
Molecular weight		Flammability	non flammable
Parameter	**Value**	**Physico-chemical properties**	**Value**
Chemical name and composition	Acetic acid	Physical state at 20°C and 101.3 kPa	Liquid
EC number	200-580-7	Melting point	16.64 °C
CAS number	64-19-7	Density	1.0446 g.cm3 at 25˚C
IUPAC name		Vapour pressure	20.79 hPa at 25˚C
Molecular formula	$C_2H_4O_2$	Water solubility	602.9 g/l at 25°C.
Molecular weight	60.0516	Flash point	39˚C

Table 2: Hazard classification and labelling overview

Substance Name	**Hazard Class and Category Code(s)**	**Hazard Statement Code(s) (labelling)**	**Number of Notifiers***	**Additional classification and labelling comments**	**Regulatory and CLP status**
Nickel acetate	Acute Tox. 4	H302 (Harmful if swallowed)	1166	The EU harmonised classification for this substance is: Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Acute Oral Tox. 4, Acute Inhal. Tox. 4, Resp. Sens. 1, Skin Sens. 1, Aquatic Acute 1, and Aquatic Chron. 1. The supplier SDS is not in EU CLP or GHS format therefore classifications cannot be determined.	Substance is REACH registered; Included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Skin Sens. 1	H317 (May cause an allergic skin reaction)	1166		
	Acute Tox. 4	H332 (Harmful if inhaled)	1166		
	Resp. Sens. 1	H334 (May cause allergy or asthma symptoms or breathing difficulties if inhaled)	1164		
	Muta. 2	H341 (Suspected of causing genetic defects)	1164		
	Carc. 1A	H350i(May cause cancer)	1164		
	Repr. 1B	H360D (Suspected of damaging the unborn child)	1164		
	STOT RE 1	H372 (Causes damage to organs	1164		

Substance Name	**Hazard Class and Category Code(s)**	**Hazard Statement Code(s) (labelling)**	**Number of Notifiers***	**Additional classification and labelling comments**	**Regulatory and CLP status**
		through prolonged or repeated exposure)			
	Aquatic Acute 1	H400 (Very toxic to aquatic life)	158		
	Aquatic Chronic 1	H410 (Very toxic to aquatic life with long-lasting effects)	158		
Acetic acid	Flam. Liq. 3	H226 (Flammable liquid and vapour)	>3200	The EU harmonised classification for this substance is: Flam Liq. 3 and Skin Corr. 1A. Specific Concentration limits: Eye Irrit. 2; H319: 10% ≤ C < 25% Skin Corr. 1A; H314: C ≥ 90% Skin Irrit. 2; H315: 10% ≤ C < 25% Skin Corr. 1B; H314: 25% ≤ C < 90% The supplier SDS is not in EU CLP or GHS format therefore classifications cannot be determined.	Substance is REACH registered; Included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Skin Corr. 1A	H314 (Causes severe skin burns and eye damage)	3181		

* The most prevalent classifications reported to the C&L Inventory are provided.

APPENDIX 1.1.3: ALTERNATIVE 3: Nickel fluoride

Table 1: Substance IDs and properties

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Nickel fluoride	Physical state at 20°C and 101.3 kPa	Solid
EC number	233-071-3	Melting point	Sublimes at 1000°C
CAS number	10028-18-9	Density	4.72g/L
IUPAC name	nickel(2+) difluoride	Vapour pressure	-
Molecular formula	NiF_2	Water solubility	40 g/L
Molecular weight	96.689	Flammability	Non flammable
Parameter	**Value**	**Physico-chemical properties**	**Value**
Chemical name and composition	Ammonium fluoride	Physical state at 20°C and 101.3 kPa	Solid
EC number	235-185-9	Melting point	Ammonium fluoride sublimates before reaching its melting point
CAS number	12125-01-8	Density	1.04
IUPAC name	Ammonium Fluoride	Vapour pressure	Calc. 2.37E-12 mm Hg @25°C
Molecular formula	FH_4N	Water solubility	1000 g/L
Molecular weight	37.0366	Flammability	-

Table 2: Hazard classification and labelling

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers*	Additional classification and labelling comments	Regulatory and CLP status
Nickel fluoride	Skin Sens. 1	H317 (May cause an allergic skin reaction)	1049	The EU harmonised classification for this substance is: Carc. 1A, Muta. 2, Repr. 1B, STOT RE 1, Resp. Sens. 1, Skin Sens. 1, Aquatic Acute 1, and Aquatic Chron. 1. The Joint REACH registration also classified as Acute Oral Tox. 3, H301; Skin Irrit. 2, H315; Eye Dam. 1, H318; Acute Inhal. Tox. 3. H331 (in addition to the harmonized classification). The supplier SDS is not in EU CLP or GHS format therefore	Substance is REACH registered; Included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Resp. Sens. 1	H334 (May cause allergy or asthma symptoms or breathing difficulties if inhaled)	1048		
	Muta. 2	H341 (Suspected of causing genetic defects)	1048		
	Carc. 1A	H350i (May cause cancer by inhalation)	1048		
	Repr. 1B	H360D (Suspected of damaging the unborn child)	1047		
	STOT RE 1	H372 (Causes damage to organs through prolonged or repeated exposure)	1047		
	Aquatic Acute 1	H400 (Very toxic to aquatic life)	1047		

Substance Name	**Hazard Class and Category Code(s)**	**Hazard Statement Code(s)** **(labelling)**	**Number of Notifiers***	**Additional classification and labelling comments**	**Regulatory and CLP status**
	Aquatic Chronic 1	H410 (Very toxic to aquatic life with long-lasting effects)	1047	classifications cannot be determined	
Ammonium fluoride	Acute Tox. 3	H301 (Toxic if swallowed)	1692	The EU harmonised classification for this substance is: Acute Oral Tox. 3, Acute Dermal Tox. 3, and Acute Inhal. Tox. 3. The Joint REACH registration also classified consistent with the EU harmonised classification. 355 Notifiers also classified as Skin Corr. 1C, H314; Eye Dam. 1, H318; Acute Tox. 1 H330. The supplier SDS is not in EU CLP or GHS format therefore classifications cannot be determined	Substance is REACH registered; Included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Acute Tox. 3	H311 (Toxic in contact with skin)	1649		
	Acute Tox. 3	H331 (Toxic if inhaled)	1335		

* The most prevalent classifications reported to the C&L Inventory are provided.

APPENDIX 1.1.4: ALTERNATIVE 4: Zirconium-based seals

Table 1: Substance ID and physicochemical properties

Parameter	**Value**	**Physicochemical properties**	**Value**
Chemical name and composition	Ammonium hexafluorozirconate	Physical state at 20°C and 101.3 kPa	Solid
EC number	240-970-4	Melting point	-
CAS number	16919-31-6	Density	1.154
IUPAC name	Ammonium hexafluorozirconate	Vapour pressure	-
Molecular formula	$F_6Zr.2H_4N$	Water solubility	Soluble
Molecular weight	241.29	Flammability	-
Parameter	**Value**	**Physico-chemical properties**	**Value**
Chemical name and composition	Chromium trifluoride	Physical state at 20°C and 101.3 kPa	Solid
EC number	232-137-9	Melting point	>1000 °C (>1832 °F)
CAS number	7788-97-8	Density	3.8 g/cm3 at 25°C
IUPAC name	Chromium trifluoride	Vapour pressure	-
Molecular formula	$Cr F_3$	Water solubility	Insoluble to slightly soluble in water
Molecular weight	108.94	Flammability	Non-combustible
Parameter	**Value**	**Physico-chemical properties**	**Value**
Chemical name and composition	Hexafluorozirconic acid	Physical state at 20°C and 101.3 kPa	Liquid
EC number	234-666-0	Melting point	-
CAS number	12021-95-3	Density	1.512 g/cm³ (25°C)
IUPAC name	hexafluorozirconate(2-)	Vapour pressure	-
Molecular formula	H_2F_6Zr	Water solubility	Fully miscible
Molecular weight	207.2278	Flash Point	-

Table 2: Hazard classification and labelling overview.

Substance Name	**Hazard Class and Category Code(s)**	**Hazard Statement Code(s) (labelling)**	**Number of Notifiers***	**Additional classification and labelling comments**	**Regulatory and CLP status**
Ammonium hexafluorozirconate	Acute Tox. 3	H301 (Toxic if swallowed)	54	The supplier SDS classified as Acute Tox. 3; H301, Acute Tox. 3; H311, Acute Tox. 3; H331, and Skin Corr. 1B; H314	Currently not REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Acute Tox. 3	H311 (Toxic in contact with skin)	36		
	Skin Corr. 1B	H314 (Causes severe skin burns and eye damage)	36		
	Acute Tox. 3	H331 (Toxic if inhaled)	36		

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers*	Additional classification and labelling comments	Regulatory and CLP status
	Skin Irrit. 2	H315 (Causes skin irritation)	33		
	Eye Irrit. 2	H319 (Causes serious eye irritation)	33		
	STOT SE 3	H335 (May cause respiratory irritation)	30		
	Skin Corr. 1A	H314 (Causes severe skin burns and eye damage)	18		
	STOT RE 1	H372 (Causes damage to organs through prolonged or repeated exposure)	18		
Chromium trifluoride	Acute Tox. 3	H301 (Toxic if swallowed)	53	The supplier SDS is not in EU CLP or GHS format therefore classifications cannot be determined.	Currently not REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Skin Corr. 1B	H314 (Causes severe skin burns and eye damage)	83		
	Acute Tox. 4	H302 (Harmful if swallowed)	26		
	Acute Tox. 4	H312 (Harmful in contact with skin)	28		
	Eye Dam. 1	H318 (Causes serious eye damage)	26		
	Acute Tox. 4	H332 (Harmful if inhaled)	28		
	STOT RE 1	H372 (Causes damage to organs through prolonged or repeated exposure)	18		
Hexafluorozirconic acid	Met. Corr. 1	H290 (May be corrosive to metals)	2	The Joint REACH registration classified as: Met. Corr. 1, Acute Oral Tox. 3, Acute Dermal Tox. 3, Skin Corr. 1B, and Acute Inhal. Tox. 3. 35 notifiers also classified the substance as Acute Tox. 2; H331 The supplier SDS is not in EU CLP or GHS format therefore classifications cannot be determined	Substance is REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory.
	Acute Tox. 3	H301 (Toxic if swallowed)	100		
	Acute Tox. 3	H311 (Toxic in contact with skin)	100		
	Acute Tox. 3	H331 (Toxic if inhaled)	81		
	Skin Corr. 1B	H314 (Causes severe skin burns and eye damage)	114		

* The most prevalent classifications reported to the C&L Inventory are provided.

APPENDIX 1.2: SOURCES OF INFORMATION

Information on substance identities, physicochemical properties, hazard classification and labelling are based on online data searches. All online sources were accessed between January and March 2016. The main sources are:

1. European Chemicals Agency: http://echa.europa.eu/de/
2. ChemSpider internet site: http://www.chemspider.com/
3. Sigma Aldrich MSDS: http://www.sigmaaldrich.com
4. Fisher Scientific MSDS: https://www.fishersci.com/us/en/home.html
5. IPCS INCHEM : http://www.inchem.org/pages/cicads.html
6. USEPA ACToR internet site: http://actor.epa.gov/actor/faces/ACToRHome.jsp
7. TOXNET ChemID*plus* internet site: http://chem.sis.nlm.nih.gov/chemidplus/
8. IARC Monographs Volume 49, Chromium and Chromium Compounds.
9. SDSs of commercially available Cr(VI)-free anodize seal systems.