Paris, 20 April 2018

COMMENTS ON THE CANDIDATE LIST PROPOSAL FOR LEAD (METAL)

Space Sector Contribution to the ECHA Public Consultation on the Candidate List proposal for lead (metal) (EC number 231-100-4, CAS number 7439-92-1)

PREFACE

This is the joint contribution of the European Space Industry, represented by ASD-EUROSPACE – with the support of European and national space agencies – to the ECHA Public Consultation on the Swedish Candidate List proposal for lead (metal) (hereafter also "the Substance", "Lead" or "Pb").[1]

It has been prepared by the participants of the **Lead (metal) REACH Space Task Force (LTF)**[2] in co-ordination with the AeroSpace and Defence Industries Association of Europe (ASD), the French Aerospace Industries Association (GIFAS) and the cross-sector "Lead Authorisation Task Force" (Eurometaux as Secretariat), which the LTF attends and supports. In particular, we would like to refer to and express our support for the comments made by ASD, GIFAS, the International Lead Association (ILA) / Lead REACH Consortium (PbRC), Eurometaux and the European Copper Institute (ECI) to the same consultation.

We are aware that the current consultation focuses on the intrinsic SVHC properties of Lead, which has a legally binding harmonised classification as Toxic for Reproduction Category 1A. Nevertheless, comments on other aspects brought forward in this paper (uses, status of alternatives, impacts of candidate listing and a future Annex XIV requirement, appropriate regulatory measure) are not precluded and in our view should be taken into account by the regulators as appropriate - pursuant to the principles of proportionality, regulatory effectiveness and consistency - when deciding on the addition of the substance to the REACH Candidate List. The comments should also be used as appropriate for any additional regulatory measures under REACH.

[1] Please view Annex 4 for various abbreviations used in this document.
[2] A list of LTF participants can be found in Section 6. The LTF was initiated by the Materials and Processes Technology Board of the European Space Components Coordination (ESCC MPTB) in order to develop a space-specific contribution to the public consultation. The ESCC MPTB is a partnership between the European Space Agency (ESA), national space agencies, and space industry represented by ASD-EUROSPACE; it is chaired at present by ESA.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Lead has been used for decades for high reliability applications requiring longevity in the European space industry. Risks are well known, managed and therefore considered as negligible. The volume of use is low, but the value is very high. New technologies in the space industry require maturity (Technology Readiness Level; TRL) and Heritage before they can be implemented in space vehicles. Given the absence of viable alternatives Lead is still widely used in the industry today.

The use in **Tin/Lead solder alloys for Electrical and Electronic Equipment (EEE)** constitutes the main space related use of Lead. Further critical uses of Lead in the space industry without alternatives today include **Indium/Lead (InPb) solder** on thick gold, **some alloys (e.g. Lead containing copper or brass**), **coatings for long-life systems** and **pyrotechnical devices** affecting the system to pilot and command the launcher.

Adding Lead to Tin solder solves the major problem of the growth of "Tin whiskers", which are an unacceptable risk for launchers and satellites, where **no repair is possible** and where they can lead to total satellite failure (Tin whiskers are known to have caused at least seven spacecraft failures). Lead-free solder materials are also **more brittle** than Pb containing solder materials which would reduce the possible lifetime of the equipment or the resilience of the joint under shock or vibration conditions. The process of soldering EEE parts using Lead-based solder in launchers and satellites has been long qualified (i.e.: it has been demonstrated that the resulting solder joints are reliable for the lifetime of the launcher or satellite) and forms the basis for building space hardware. At present there are no alloys on which there is equivalent heritage and which could be space-qualified. This was a main reason for the **explicit exclusion of *"equipment designed to be sent into space"* from the scope of Directive 2011/65/EU (RoHS Article 2 (4) (b)) without a time limit**.

In order to qualify alternative Lead-free solutions in the Space Sector, there are a number of tough technical hurdles that need to be solved before the sector could safely and fully move away from using Lead. In the case of soldering standard EEE parts, where the traditional Tin/Lead coatings have been replaced with pure Tin, and with a Lead-free solder, there is the risk of Tin-whiskers growing in the electronics assemblies. Even today, **after more than 30 years of R&D efforts**, the Tin-whisker growth mechanisms are not fully understood and the activation energies; necessary for the accelerated tests, cannot be determined with the required accuracy.

The Space Sector is fully aware that, even without regulatory pressure, the transition to Lead-free alternatives is driven by the market pressures, as most suppliers no longer support Lead. This will involve a significant amount of R&D, and very high costs for qualifying the new processes in addition to requalifying the assembly of all used components with those new processes. More research is required to solve the remaining unknowns concerning Tin-whiskers formation and growth as well as Lead-free solder joint reliability. Therefore, **substitution of Lead in most electrical and electronic space hardware cannot be**

predicted. EU-level support would stimulate additional research for the best alternative solutions to ensure reliability for space equipment, mitigate the risks associated to Tin and to decrease the carbon footprint.

Candidate listing and possible future Annex XIV listing would further **exacerbate the commercial obsolescence risk** for Lead in space applications without viable alternatives. Substitution efforts would have to be accelerated to mitigate the risk. This, in turn, is negatively affecting the industry's competitiveness in a more competitive global space market. The impact would affect the entire complex EU space systems' supply chain. For SME and laboratories, the financial and human investment would be even more important and critical. A very high impact is expected in case Lead would enter REACH Annex XIV, jeopardising Europe's independent access to space as a key point of the EU's Space Policy.

The inclusion of Lead in the REACH authorisation process questions the proportionality and regulatory effectiveness of the measure, as well as the **regulatory consistency** with regard to the RoHS exclusion for space equipment. The rationale for this exclusion should be taken into account for any additional risk management option under REACH. There is also a need for the regulator to clarify how metallic alloys should be treated before taking any initiative to include the substance contained in Annex XIV or impose additional restrictions in Annex XVII.

Given the need, therefore, for Lead for space applications and for a long term secured supply, as well as the possibility of other suitable risk management options which can be aligned with RoHS and its rationale for the exclusion of space equipment from its scope (tailored restrictions with suitable derogations, taking into account the status of alternatives and socio-economic aspects), we believe that candidate listing and Annex XIV inclusion of Lead would not be an appropriate risk management option at this stage.

1. USES OF LEAD IN THE EUROPEAN SPACE INDUSTRY

Lead has been used for decades for high reliability applications requiring longevity in the European space industry. Given the absence of viable alternatives Lead is still widely used in the space industry today. Main applications identified, **covering both satellites and launchers**, which are mission-critical and exclusively professional uses, are listed and detailed hereafter.

1.1. SOLDER ALLOYS FOR ELECTRONICS, ESPECIALLY TIN/LEAD SOLDER

This constitutes the main space related use of Lead. Lead is used in a vast array of solder applications along the space supply chains in the manufacturing of high reliability electronics, including Electrical and Electronic Equipment (EEE), Printed Circuit Boards (PCB) and solder connection) designed for use in space, especially Tin/Lead (**SnPb)** solder.

SnPb is used on all/mostly all the electronic equipment of the **satellite**, both with lower Lead content for low temperature soldering applications and rich Lead alloy for high temperature applications. Indium/Lead **(InPb)** is used for cryogenic applications and soldering on gold. For InPb solder, no alternative has been identified and investigated.

Solders involving Lead are also widely used in electronic equipment embarked on **launchers**; in sensors (e.g. pressure sensors) and more generally in all avionic equipment in charge of controlling and piloting the launcher on the ground but also during the flight. Solders containing Lead are also used in electronic devices in "ground equipment" required to communicate with the launcher.

Adding Lead to Tin solder solves the major problem of the **growth of Tin whiskers** (see Section 3.1. for more information), which are an unacceptable risk for satellites, where no repair is possible and where they can lead to total satellite failure. Lead-free solder materials are also more brittle than Pb containing solder materials which would reduce the possible lifetime of the equipment or the resilience of the joint under shock or vibration conditions. This was a main reason for **excluding *"equipment designed to be sent into space"* explicitly from the scope of Directive 2011/65/EU (RoHS) without a time limit**.[3]

For industrial space and military applications, Tin/Lead (60/40, and high Lead content >80%) is used in electronic equipment as solder alloy, electronic component finish, printed circuit finish, internal bumping of components, manufacturing of printed circuit, tinning of cables, solder balls of ball grid arrays (BGA packages), flux cored solder wire, solid bars of SnPb alloy as feed stock for SnPb solder dipping baths.

[3] See RoHS Article 2 (4) (b).

Different types of solder (e.g. Sn63Pb37, Sn62Pb36Ag2, Sn20Pb80, Sn15Pb85, Sn10Pb90, Sn60Pb36Ag4) are used for soldering and brazing at various temperatures. Some are used for high temperature solders within electronic components, as solder columns, some at lower temperatures for example when mounting the components to printed circuit boards (which in turn are also finished with Sn63Pb37 solder).

For further information please view Annex 1 of this document.

1.2. ALLOYS AND COATINGS

Lead is used as:

(1) a **minor alloying element** in metal systems that fills voids formed during the initial casting process allowing further processing and providing lubrication during machining;

Lead is included in several metallic alloys (such as steel and aluminium alloys, e.g. AA2011, AA6012, AA6262, brass), improving machinability. The final machined state is for example the centre of the sliding electrical contact and very critical for the brass slip ring functionality, which are used in many areas within satellites.

(2) a **major alloying element** in the typical eutectic Tin/Lead and Indium/Lead solders used on all spacecraft;

(3) the **base alloy for Lead rich solders** being used to replace eutectic solders in high power applications where the operational temperature range exceeds the capabilities of eutectic solder;

(4) **radiation shielding** on high radiation missions or applications, e.g. JUICE;

(5) **solid lubrication** (syn. dry lubrication) with Lead as a vacuum compatible lubricant applied by Physical Vapour Deposition (PVD) (“sputtering” in vacuum). This is applied to the surfaces of ball bearings, gears and other tribological components in contamination sensitive applications where organic lubricants (e.g. synthetic hydrocarbons or perfluorinated lubricants) cannot be used due to temperature or contamination concerns. This kind of PVD or “Sputtered” Lead is one of the best dry lubricants, especially for space gear applications, since it can outperform other lubricants either when used alone for long life or high contact stress applications or synergistically to extend the life of organic lubrication systems. The applied Lead film is very thin – mainly around 0.5-1µm thick and up to around 2µm in a worst case.

Sputtered Lead has been supplied by the sole producer in Europe, ESR Technology (www.esrtechnology.com) to 100-200 spacecraft of all types for Earth Observation, Communications and Science missions. As well as satellites, lead has been used on some parts of launcher engines (e.g. Vinci).

In **Pb plating** the Substance is used as the pure metal as a coating.

For some cases Lead is there for self-lubricating applications (**leaded brass**). Brass (CuZn39-40Pb2-3, CuZn37Mn3Al2PbSi, CuSn10Pb10) is used in some component pins, sliding bearings, rivets, screw locks, power- and signal tracks in slip rings.

In ball bearings PVD Lead is used in conjunction with a monolithic **Lead-bronze** cage (to keep the balls within the bearing apart): Leaded-bronze alloy CuSnPb9 to EN CC494K (or ASTM UNS 93500 /SAE66).

For more details on lead as a solid lubricant please see Annex 2.

1.3. PYROTECHNICAL DEVICES

Lead and Lead salts are a constituent of launcher pyrotechnic devices, including e.g. transmission lines in detonators and lines. Pyrotechnic devices are used for functional reasons (motor ignition, stage separation, satellite release), but also for safety reasons (launcher / stage neutralisation).

1.4. OTHER USES

Pb metal is embedded in **adhesives** to manufacture equipment which are assembled into payloads and satellites.

Lead is also used as an **activating material** in Nickel-plating bath.

In space applications **electromechanical relays** contacts contain Pb. There is currently no alternative solution for this material.

Other space relevant uses where metallic Lead is present on an article or may be used as pre-cursor include:

- **Glass** of some devices (surface mount diodes or resistors in so-called MELF packages, optical glasses/parts[4] in satellite payloads). Not using Lead would lead to a change/loss in functionality.
- **Ceramics** such as:
    - Actuators and sensors for adaptive structures (active noise and vibration control, active shape control)
    - Actuators and sensors for structural health monitoring (SHM)
    - Ultrasonic transducers for non-destructive material evaluation
    - Sonotrodes for the production of dispersion

[4] Including possible content in optical fibres within satellites.

1.5. VOLUMES / VALUE PER USE

LTF participants were surveyed on the volumes/value per use in preparation to this document. Products containing Lead (alloys, electronic components, pyrotechnical devices, etc.) are mainly semi-finished or finished products and (very) complex objects. (Therefore) in most cases data are not currently available and cannot be aggregated on the sector level.

Anecdotal evidence suggests that around 1 to a few kilogrammes (kg) of Lead are used per *satellite* (covering solder applications). For EEE components received by a system integrator the total weight of the common Sn63Pb37 solder is reportedly in the area of less than 100 to a few hundred kg per year covering several hundred thousand components received.

For *launchers*, the mass of Lead is roughly estimated to be less than one ton per launcher. For launcher pyrotechnic equipment the weight can be some kg.

Whereas the mass of Lead used in all leaded-bronze cages for space bearing applications is ~ 300 grammes, the total quantity of Lead applied as a PVD film lubricant for all space applications per year is a minute amount, less than 5 grammes (!).

In terms of *value*, the price of SnPb solder material is negligible compared to the value of electronic equipment manufactured with such material.

Hence, the volume of use is low, but the value is very high.

1.6. EXCHANGE WITH THE PBRC ON SPACE RELEVANT USES

LTF has been in contact with the PbRC in order to ensure that the information on space relevant uses of Lead metal are reflected properly in the joint registration dossier for Lead.

2. EXPOSURE AND RISK INFORMATION

Space companies have been working with Lead and have managed related risks for decades. Risks are well known and considered as negligible. They are already reduced by the fact that operators use mainly finished or semi-finished products and are not directly exposed to the substance, while the end use of the equipment occurs in Space.

Solder process operators and inspectors who work on spacecraft equipment and satellite manufacturing are all trained and certified to ECSS standards. These standards require the use of some protective equipment: *"Areas used for assembly or cleaning of parts and areas where toxic or volatile vapours are generated or released shall include a local air extraction system"* (ECSS-Q-ST-70-08C). All solder materials are only allowed to be used under sufficient ventilation or in a closed machine. Cleanroom or flowboxes are used, so that workers do not come into contact with Lead vapour.[5] There are also cleanliness rules in electronic manufacturing areas. Individual extractor/filters are advised for safety to avoid inhalation/contact. Machining after soldering is only performed in laboratory when micro sectioning of assembled components are examined, but the machining is performed with water, mitigating the risk of airborne particles. Any waste containing Tin/Lead solder is put into containers for electronic waste that is disposed following the rules and the law for this kind of waste, and residues are recycled.

Parts made of **brass and aluminium alloys** are typically procured in a machined state, most often with surface treatment. Machining (where release of Lead might be of risk) is only performed in a laboratory in cases of investigations into a failure, for example in metallurgical studies of the micro structure. Polishing is performed with water, mitigating the risk of airborne particles. A few items are machined from raw material to finished state in-house.

Pb coating is done under cleanroom conditions and parts are handled with gloved hands at all times by operators wearing cleanroom garments. The Lead raw material is supplied in metallic blocks on “targets”. The coated items are cleaned by a specialised disposal company periodically using an acid bath process. Used targets are re-cycled. Except during the PVD process which takes place in a sealed vacuum chamber, all processing is in solid phase and materials are controlled.

For *launchers* it has been reported that there is no risk of exposure within the downstream supply chain. No maintenance is subcontracted when the launcher is delivered to the customer. Moreover, all **pyrotechnical devices** require strict security because of the risk of detonation; this risk is well known and managed in the launcher supply chain. Procedures are clear, and operators must undergo specific training procedures (such as ATEX risk). In the upper supply chain soldering processes are mainly performed by automatic process with less exposure to workers and environment.

3. ALTERNATIVES

New technologies in the space industry require **maturity** (Technology Readiness Level; TRL) and the building-up of **Heritage** before they can be implemented in space vehicles. Heritage involves using the experience of parts and technologies from previous missions to give credibility and confidence in the performance of this technology for future missions.[6]

For a number of space applications containing the Substance there are no known and qualified alternatives (substances, processes or technologies) today, as detailed hereafter.

[5] Similar solutions are used for producing optical parts.

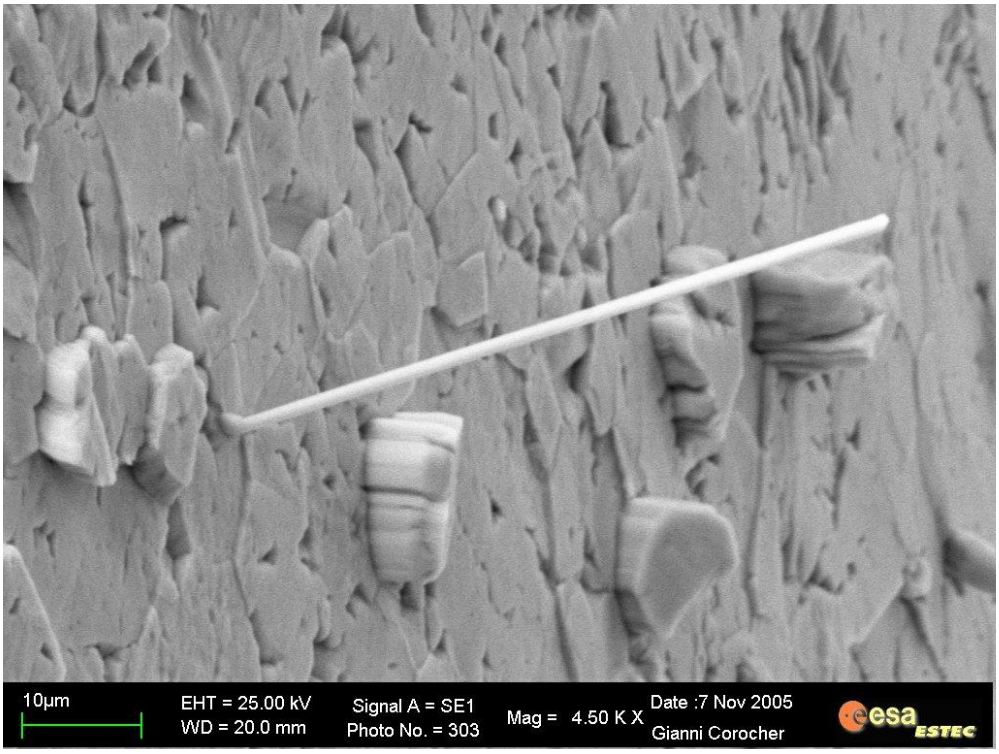
[6] See STF comment to ECHA of 6.10.2015, including a description of the challenges faced by the Space Sector for substitution in general, Sections 2.1 and 2.2.1. (Standards Development).

3.1. ALTERNATIVES TO TIN/LEAD SOLDERING AND BRAZING FOR ELECTRONICS

Thanks to its heritage and reliability Lead is considered as indispensable for EEE component finishes and electrical connection between the PCB and the EEE parts. The process of soldering EEE parts using Lead based solder in launchers and satellites has been long qualified (i.e.: it has been demonstrated that the resulting solder joints are reliable for the lifetime of the launcher or satellite) and forms the basis for building space hardware. At present there are no alloys on which there is equivalent heritage and which could be space-qualified.

3.1.1. FUNCTIONAL REQUIREMENTS FOR LEAD USE

Researchers found in the early stages of the electronics era in the 1950's, that adding Lead to tin solder solved a major problem at the time which was the growth of **"Tin whiskers"** (see illustration in Picture 1 below) which could cause failure in the electronic part.[7]



Picture 1 Tin whisker

[7] https://nepp.nasa.gov/whisker/background.

Through the years the Tin/Lead soldering process has thus become a mature technology:

- Used to inhibit growth of "Tin Whiskers"
- Proven industry standard
- Well documented engineering characteristics
- Excellent history of reliable use
- Low cost

Tin/Lead is used both for **coating the surfaces** of electronics parts to be joined and in the **solder paste** used to perform the joining. Electroplated **pure Tin** now often substitutes the preferred fused Tin/Lead finish on electronic terminations as the main Lead-free alternative. Pure Tin is known to support the growth of whiskers. The majority of Tin whisker-induced failures occur when one whisker from one Tin plated conductor bridges a gap to cause a short circuit with an adjacent conductor. Tin whisker growth rates range from 0.03 to 9 mm per year. Usually there is an incubation period and this may be as long as 10 years before whiskers start to grow. Whiskers are particularly dangerous as they **can break off under launch vibrations and cause short circuits**, they can "float" under zero gravity. Under vacuum they can then fuse and create a plasma that can conduct hundreds of amps. **Tin whiskers are known to have caused at least seven spacecraft failures**. Whiskers are a minor issue for most terrestrial electronics hardware where gravity, vibrations and air movement will remove most of them. Satellites lack all of those mitigation factors and, in addition, **cannot be serviced**, which means they are a major concern for the Space Sector.

The **low melting temperature** of Tin/Lead eutectic melting (183°C) used today in the Space Sector means that multilayer boards, component metallisations and delicate seals will not be subjected to excessive thermal stresses or mechanical stresses caused by differences in coefficients of expansion. The **Lead-free solder alloys (based on Tin (Sn), Silver (Ag) and Copper (Cu) are referred to as SAC alloys)** are unlike eutectic Tin/Lead in that they melt over a range of temperatures and require at least an increase of 30°C in processing temperature above that needed for Tin/Lead. This causes greater stress on delicate components and is known to degrade the internal connections of multilayer printed circuit boards (internal Copper planes to the Copper plated through holes). Very critical are applications with potting (e.g. high voltage applications) because the potting material gives additional stress to the solder joints.

The **higher SAC alloy soldering temperatures** accelerate intermetallic growth, and having a greater Tin content than eutectic Tin/Lead, there will be a greater proportion of Tin-Copper intermetallics within a resulting soldered connection. This can influence the load carrying capability of the joint under dynamic conditions (i.e. more prone to brittle fracture under launch vibration).

Higher processing temperatures also cause the rapid dissolution of Copper from surfaces such as the printed circuit board and this again can reduce the reliability of the circuit.

An important disadvantage of SAC alloys is the fact that repairing components and reworking of soldered joints has to be performed at far greater temperatures than for eutectic Tin/Lead. The ECSS-Q-ST-70-28 standard incorporates many tested and verified methods for rework and repair. SAC alloys not only need to be reworked at high temperatures but they become enriched with Copper during the soldering process, and this elevates the SAC solder melting temperature even further. Re-melting such solder fillets, even by experienced and certified operators can produce lifted pads tracks on the PCB, damaged internal plated through holes and overheated components.

All of these considerations clearly show that in order to qualify alternative Lead-free soldering solutions in the Space Sector, there are a number of tough technical hurdles that need to be solved before the sector could safely and fully move away from using Lead. For example, even today, **after more than 30 years of R&D efforts**, the Tin-whisker growth mechanisms are not fully understood and the activation energies; necessary for the accelerated tests, cannot be determined with the required accuracy. Therefore it is not currently possible to abandon Lead use in the Space Sector.[8] This was a main reason for excluding space equipment from the scope of RoHS without a defined time limit. More research is required to solve the remaining unknowns concerning Tin-whisker formation and growth as well as Lead-free solder joint reliability.

Eutectic SnPb has a long track record of providing a surface finish with excellent solderability even after long storage. This surface finish provides a solder joint to the component with an intermetallic consisting Copper Tin. Other surface finishes typically form different intermetallic layers that may be less reliable. Replacing Lead in solder will continue to require major R&D efforts and sufficient time in which to properly evaluate, implement and build the required Heritage.

For *launchers*, electronic equipment has been designed with Pb containing solders part of the entire launcher design. They are all compatible and qualified at launcher level. Replacement of Pb containing solder in launcher equipment would require costly requalification at equipment, stage and launcher level.

For *satellites*, Lead associated with Tin in Tin/Lead assembly is crucial to ensure the reliability of the soldering assembly of the components embedded in the electronic equipment for a lifetime of 15 years in on-board equipment for geostationary satellites and for 5 to 10 years with low earth orbit satellites. For space applications, where electronic equipment can stay in standby mode for a long time at very low temperature, the risks described above of operating without Lead are not acceptable.

3.1.2. AVAILABLE ALTERNATIVES, R&D AND TESTING

Already today there are many Lead-free solders on the market and used for *electronic assemblies*, both in other industries but also in the Space Sector. The most common alternatives, as analysed in the previous section, are **SAC alloys**. Some LTF participants have indeed been involved in several testing programmes/projects to study SAC alloys alternatives for all their applications, but they are still very far from performing a full space qualification. Electroplated pure Tin has become the standard for treatment of terminations of electronics

[8] See also Study on the Impact of REACH and CLP European Chemical Regulations on the Defence Sector, Final Report, 16 December 2016, available on the website of the European Defence Agency, p45, link to the Report.

parts but most space programmes specifically ban the presence of any pure Tin surface in space hardware.

For *PCB finish* other surface finishes are commonly used by other industries (such as **ENIG, ENEPIG, EPIG**). However, the reliability of these for space applications needs to be further understood. Also, alternatives like ENIG and ENEPIG require more complex steps and the control of the process is more difficult.

The Space Sector is fully aware that, even without regulatory pressure, the transition to Lead-free alternatives is driven by the market pressures, as most suppliers no longer support Lead. This will involve a significant amount of R&D, and very high costs for qualifying the new processes in addition to requalifying the assembly of all used components with those new processes.

3.1.3. SUBSTITUTION TIMEFRAME

Taking into account what has been described above, especially the necessary R&D, **substitution of Lead in most electrical and electronic space hardware cannot be predicted**. Therefore, estimating a timeframe for full transition to Lead-free would be speculative.

As already detailed in previous Space Sector contributions under REACH (see STF comment on chromium trioxide; Eurospace comments on the prioritisation of NMP for Annex XIV; Eurospace Space Sector contribution to the EC REACH Review 2017 and NMP) - development and production phases cover generally several years/decades in the space and launcher industry. This has to be taken into account for the introduction of new technologies (see also Annex 3 of this document).

3.1.4. SUBSTITUTION COSTS

Provided that the Space Sector first finds and is able to finance the necessary R&D, a change from Lead alloy to Lead-free alloy would then lead to a global re-verification (in conformance with ECSS-Q-ST-70-07, ECSS-Q-ST-70-08 and ECSS-Q-ST-70-38) of the assembly processes for all the European industry, which would be an **excessive financial and schedule impact**.

Given the complexity and variety of EEE assemblies used by each of the space companies, the cost for requalification of the soldering process could vary from some hundred thousand Euros to a few million Euros per assembly site. This only takes into account the *verification* of the process. This cost does not consider any development. This cost can be spread over several months and years for some processes and risk of failure cannot be excluded.

Taking a broader perspective, the eutectic composition of the Tin/Lead solder allows the creation of a homogeneous and reliable crystallised structure at lower temperature, thus limiting the carbon footprint of such sector of activity. The SAC technology as a (possible) alternative is more energy consuming, due to the higher soldering temperature for the processing of SAC comparing to SnPb alloys; it also causes more stress to the EEE components.

3.2. ALTERNATIVES TO LEAD IN OTHER ALLOYS AND COATINGS (NON-ELECTRONICS)

For Lead as an *alloying element* no substitution activities have been initiated in the Space Sector. No substitution is expected because of the specific mechanical properties required, such as ratio mass/behaviour, mechanical strength and load resistance. For *brass and aluminium alloys* the Lead in the alloy provides “lubrication” to improve machinability, which for some applications is very critical for the function.

There has been work on Lead-free alloys for the *water* industry over the last 30 years which has significantly reduced the Lead content, but it has not been eliminated.

For *shielding* technically viable alternatives are available but at greater cost e.g. Tungsten and depleted Uranium.

Lubrication alternatives are available for some applications, e.g. Molybdenum Disulphide (**MoS_2**) or Tungsten Disulphide (**WS_2**), but not for many long life systems or where ground test requirements in air are extensive.

For many *ball bearings* where it is not possible to use an oil or grease, *Sputtered Lead* is the preferred choice. Its low shear strength and high malleability enable it to operate at very high stress if required and its low vapour pressure leads to negligible lubricant loss due to evaporation even at elevated temperature in a vacuum. Unlike many other types of solid lubricants, Lead has been used on ball bearings which operate for very long lifetimes. In addition, these bearing must operate at very high contact stress, have very long operational lifetime at elevated temperature (in which oils and greases would simply evaporate) or those stored for long periods (>10 years) prior to launch. So far there is no alternative lubricant covering all such aspects (~10^9 revolutions, high contact stress capability, low vapour volatility and long-term storage) at the same time.

Currently no alternative exists to *Sputtered Lead* (see also Annex 2 for further information). Initial attempts to find an alternative focussed only on compatibility with processes and their potential as a lubricant, for example the use of other soft metals such as Indium (CAS 7440-74-6) and Tin (CAS 7440-31-5). However, neither has proved suitable as a replacement based on initial trials. Replacement further depends on availability of suitable development funding to identify, develop and qualify an alternative for a wide range of space applications (and some important non-space ones) and support for adoption of the replacement material by industry/ESA. As an SME the investment in an alternative material and the associated development risks would be a major one for ESR Technology.

Leaded brass is used in all *slip rings*. The slip rings and their final surface are critical to the slip ring functionality. There is a specific machining process including a final diamond cutting tool in order to achieve a very polished surface state (on the top of the machined brass a complex gold coating is applied). This final machining state is critical to the slip ring functionality, and without any further tests, it is not possible to state that the leaded brass could be replaced with brass without Lead. Lead in the brass is a good lubricant in order to achieve the final machining state. Changing the base material would also impact the gold coating qualification.

Overall, no viable alternative is seen at present for solder, copper alloys or long life lubrication.

3.3. ALTERNATIVES TO LEAD FOR PYROTECHNICAL DEVICES

Some local or partial replacement solution may be used allowing reduction of the quantity of Lead. ***"Opto-pyro"*** has been developed and will be used on the new launcher *Ariane 6*. But this technology will only replace **transmission lines**, helping to reduce the quantity of Lead on the launcher. However, this does not apply to the existing *Ariane 5* launcher, where Lead is still used today; the *Ariane 5* programme is estimated to be completed in mid-2020.

A change of electronic pyro devices with Lead to opto-pyro devices needs avionics modifications and therefore requalification. Generally, the introduction of new technologies should occur in the early design phase for a new launcher, whose timeframe for development and exploitation covers up to several decades (see Annex 3 to this document for an outline of the introduction of new technologies for launchers).

4. IMPACTS AND RISKS OF CANDIDATE LISTING AND AUTHORISATION

4.1. OBSOLESCENCE RISK

The commercial obsolescence risk for the space industry as a niche sector is increasing, as the REACH authorisation process advances. According to the conclusions of the EC REACH Review 2017 and an associated study on the impacts of REACH authorisation this process is seen as an effective driver for substituting SVHCs along the supply chain from as early as the candidate listing stage.[9] Hence, Candidate and possible future Annex XIV listing would further exacerbate the **commercial obsolescence risk** for Lead in space applications without viable alternatives, which was initially created by the RoHS Directive. RoHS, at first a purely European directive, was quickly adopted in various forms by other countries, leaders in Electronics production, resulting in a massive, global transition to Lead-free electronics. The

[9] https://ec.europa.eu/growth/content/commission-publishes-study-impacts-reach-authorisation_en.

Space Sector,[10] **while excluded from RoHS**, faced a disruption of their supply chains when their electronic component suppliers abandoned Lead. Major concerns for the sector are the long term reliability of the new, Lead-free solders (not much of an issue for consumer electronics) and the growth of Tin whiskers (see above Section 3.1.).

4.2. SUBSTITUTION AND INNOVATION

Substitution efforts would have to be accelerated to mitigate the increasing obsolescence risk. However, with the possible exception of *high melting point alloy* replacement, development of alternative substances is not foreseen for electronics soldering; the effort would be focused on testing the existing alloys. Definition of appropriate testing would also need to be determined. The complete substitution of Lead containing solder materials would require a complete design change of some of the equipment.

Impacts on **reliability**, while being difficult to estimate, have to be taken into account given that reliability is the main argument to continue SnPb soldering. Obviously any risks related to the possible loss of reliability for space flight equipment cannot be accepted.

The transition to Lead-free processes is pushed upon the Space Sector by a combination of regulatory and market pressures. From a technical stand-point existing processes provide components of required quality. The alternatives do not represent any improvement; on the contrary there are serious concerns on their impact on the reliability of European products. Reallocation of resources - financial, industrial and labour - will negatively impact the budget available for true innovations leading to better products.

4.3. COMPETITIVENESS AND EUROPE’S INDEPENDENT ACCESS TO SPACE

Direct substitution costs (verification costs) for the transition to Lead-free soldering for electronics have already been addressed above (Section 3.1.4.). They would result in **reduced resource availability for product improvements**, an **overspend** for European products during the transition phase (implying a potential risk of assembly line closure) and **increase of timeframe** for electronics manufacturing, all negatively affecting the industry’s competitiveness in a more competitive global space market. For **SME and laboratories**, the financial and human investment would be even more important and critical.

This impact would already be triggered by the **Candidate Listing**, as some customers (within and outside the EU) would claim a change of design (minimum substitution) and to start with this development as soon as possible considering the lead time; otherwise they would start looking for alternative suppliers to be prepared for a potential obsolescence. As heritage in the

[10] And the Aerospace and Defence sector at large, according to the Study on the Impact of REACH and CLP European Chemical Regulations on the Defence Sector, Final Report, 16 December 2016, available on the website of the European Defence Agency, p263, link to the Report.

Space Sector is very important, this is a big advantage for any non-EU competitor who does not need to make this change.

A very high impact is expected in case Lead would enter REACH **Annex XIV**. The cost for design, development and qualification of "piloting and controlling" devices of the *launcher* would be a very high economic disadvantage regarding other launchers on the world market. Currently the economic competition with non-EU launchers is already difficult and maintaining Europe's **independent access to space**, which is a key point of the EU's Space Policy,[11] would be jeopardised if these economic impacts of REACH materialised.

With a view to **geographic impacts**, the companies of the Space Sector are distributed throughout the EU. They are found in particularly high numbers in Belgium, France, Germany, Italy, Netherlands, Spain and the UK. Currently qualified PCB manufacturers are located in Belgium, France, Germany and UK. Eastern Europeans companies start manufacturing electronic hardware in space equipment as well.

The impact would affect the **entire complex EU space systems' supply chain**,[12] which includes, for solders, the primary metal producer, the solder paste supplier, manufacturer of each independent element (component, printed circuit, alloy, cable), distributor and assembler of all these parts (internally or with a subcontractor).

4.4. NON-USE SCENARIO (ASSUMING ANNEX XIV INCLUSION)

If substitution was not successful and an authorisation not granted then the real implication would be a stop of production of high reliability spacecraft hardware or (unlikely) the delivery of lower quality of functions to the end users (risk of in-orbit failures – possibly catastrophic). Increased import of articles from non-EU suppliers, where the substance is being used, against the spirit of the EU's policy for non-dependence in space technology.[13] Related loss of know-how and a decrease in the skilled workforces for design, development, manufacturing and testing are also feared. These scenarios are similar to those described for the case of chromium trioxide in the STF comment to ECHA of 6.10.2015 (Section 3.1. and Table 1 "Non-use scenario and related impacts").

[11] See also p4 in Eurospace Comments on the prioritisation of NMP for Annex XIV, and p9-10 in the STF comment to ECHA of 6.10.2015.

[12] Space Sector and supply chain (with a focus on chromium trioxide) are further described in the STF comment to ECHA of 6.10.2015, p2-3.

[13] See also p4 in Eurospace Comments on the prioritisation of NMP for Annex XIV.

5. APPROPRIATE RISK MANAGEMENT MEASURE

This contribution on the inclusion of Lead in the REACH authorisation process questions the **proportionality** and **regulatory effectiveness** of the measure, as well as the **regulatory consistency** with regard to the RoHS exclusion for space equipment. The rationale for this exclusion (No technically viable alternative, Space strategic importance) should also be taken into account for any additional risk management option.

5.1. CANDIDATE LISTING

As shown, already the inclusion on the Candidate List would further exacerbate the **commercial obsolescence risk** for the Space Sector introduced by RoHS. This applies even if space applications of Lead were exempted / excluded from further REACH regulatory measures (authorisation or restriction).

5.2. ANNEX XIV INCLUSION WITHOUT EXEMPTION FOR SPACE APPLICATIONS

A possible future inclusion in Annex XIV without an exemption would question the regulatory consistency with regard to the RoHS exclusion for space equipment.

The inclusion of Lead on Annex XIV would reinforce that it should be progressively replaced by suitable alternative substances or technologies. However, no alternative, qualified substances or technologies exist, nor will they exist in the medium to long term, for critical uses of Lead qualified in the space supply chain.

Given that Lead has been in use for several decades, the risks are well known and managed, time-limited Authorisation Review Periods would not provide workers in the European Space Sector with any additional regulatory protections over and above existing ones.

In the absence of viable alternatives for critical Lead-based applications while substitution cannot be predicted, Annex XIV inclusion would impose on the Space Sector, and its upstream suppliers, unnecessary administrative and financial burdens – also in comparison to non-EU article suppliers – while introducing needless uncertainty to supply chains.

Furthermore, Annex XIV inclusion would add to the administrative burden of the ECHA, EC and Member States.

Also, the import of Lead-based technologies from outside of the EEA, which is potentially triggered by Annex XIV listing, does not correlate with ensuring good functioning of the internal market and could risk the loss of technical capabilities for electronics development within the EEA.

5.2.1. PRECEDENT CASE FOR METALLIC ALLOYS

We would also like to note that there seems to be no precedent to date for an authorisation requirement to apply to alloys as ***"special mixtures"*** according to REACH and CLP. There is a need for the regulator to clarify how alloys should be treated before taking any initiative to include the substance contained in Annex XIV. **REACH Annex I** "General provisions for assessing substances and preparing chemical safety reports" sets out in Section 0.11. *"When assessing the risk of the use of one or more substances incorporated into a special mixture (for instance alloys), the way the constituent substances are bonded in the chemical matrix shall be taken into account."* Similarly according to the **Guidance on the Application of the CLP Criteria** *"metal alloys, or alloy manufacturing products, are not simple mixtures of metals or metal components, since the alloy clearly has distinctive properties compared to a classical mixture of its component metals"* (IV.5.6.1 Classification of alloys and complex metal containing materials).

5.3. ANNEX XIV INCLUSION WITH EXEMPTION FOR SPACE APPLICATIONS

In case of an Annex XIV inclusion an exemption has to fulfil the criteria of REACH Article 58(2)1, which requires that *« on the basis of existing specific Union legislation imposing minimum requirements relating to the protection of human health* […] *for the use of the substance, the risk is properly controlled. »*

The European Commission's paper "REACH AND DIRECTIVE 2011/65/EU (RoHS) A COMMON UNDERSTANDING" of 14.7.2014[14] has clarified that the possibility is also open to exempt the uses of substances covered by the RoHS restriction (such as Lead) - including its exempted applications - from REACH authorisation pursuant to Article 58(2) of REACH.

The substitution pressure for the Space Sector would not be lost if uses of Lead as a substance were exempted / excluded from REACH regulatory measures, because alternatives need to be found anyway with view to the commercial obsolescence risk. Industry is willing to replace Lead in their electronic equipment but the way to achieve substitution is long, risky and costly. **EU-level support** would stimulate further research for the best alternative solutions to ensure reliability for space equipment, mitigate the risks associated to Tin and to decrease the carbon footprint.

[14] Available at https://ec.europa.eu/growth/sectors/chemicals/reach/special-cases_en.

5.4. ANNEX XVII RESTRICTION WITH DEROGATION FOR SPACE APPLICATIONS

To achieve regulatory consistency, a **tailored restriction** – if justified in the first place beyond existing legislation such as RoHS – with a suitable derogation for space applications (covering both EEE and non-EEE[15]) appears the most appropriate risk management option.[16]

Also in this regard the Commissions REACH/RoHS Common Understanding paper opens the possibility of derogations from a REACH restriction with regard to substances already listed in RoHS, if RoHS can be considered to afford adequate control of the risks. Further to this safety aspect the availability of alternatives and socio-economic aspects are also considered when adopting restrictions and related derogations. This allows transfer of the rationale for the space exclusion from RoHS (absence of alternatives, strategic importance) into a derogation from a REACH restriction.

6. LIST OF LTF PARTICIPANTS

This contribution has been prepared by REACHLaw Ltd. in the frame of the Lead (metal) REACH Space Task Force (LTF), following collection of relevant use-related information from the LTF participants. It reflects the best knowledge available from experts in their field, thanks in particular to the support of ASD-EUROSPACE, the following corporations:

AIRBUS DEFENCE AND SPACE

ARIANEGROUP

ESR TECHNOLOGY

RUAG SPACE

TESAT SPACECOM

THALES ALENIA SPACE

and space agencies:

CENTRE NATIONAL D’ETUDES SPATIALES (CNES)

GERMAN AEROSPACE CENTER (DLR)

EUROPEAN SPACE AGENCY (ESA)

[15] See Annex 2 for Lead as a solid lubricant.

[16] In case of an Annex XIV inclusion an exemption has to fulfil the criteria of REACH Article 58(2)1.

ANNEX 1. USE OF LEAD IN MANUFACTURING OF SPACE ELECTRONICS

The manufacturing of electronics uses elements made of alloys containing Pb:

- Printed circuit boards (PCB): PCBs used for space applications are finished with a layer of SnPb alloy (composition close to the eutectic Sn63% –Pb37%). The function is to protect the copper from oxidation and provide solderability to the boards. SnPb Plating – including the plating of the tracks and footprint – is galvanic and then refused in a hot oil bath. An alternative application method, which is not allowed for space products, is hot air levelling. In this the board is immersed in a molten solder and the excess if blown off by a flow of hot air.

- Components: SnPb alloys are used for the finishing of the terminations of several types of EEE components or parts (solder lugs…). It can also constitute the plating of the leads or the leads of the component. The composition can vary from a minimum of 3% of Pb when SnPb is used as a plating, in order to avoid the risk of generation of Sn whiskers, to 90% of Pb in the case of the columns of particular area arrays devices (BGA, CCGA). In the latter case the high content in Pb is needed to avoid the melting of the columns during the assembly process of the device to the PCB.

The plating of the components shall be in compliance with the ECSS-Q-ST-60C that is in compliance with the ESCC 23500.

The finishing to component terminations can be applied electrolytically, by immersion in molten alloy and solder columns (area array devices) are manufactured by casting.

- Solder alloys for assembly: solder alloys containing Pb are used as interconnection (low melting point alloys and high melting point alloys) for the assembly of components to PCB, assembly of connectors, and wiring, or in harnesses. The solder is available in form of solder wires cored with flux, solder paste and bars.

Solder wire and bars are produced by casting and drawing (for the wire only). Solder paste is a mix of powder of solder alloy, flux and solvent. The powder alloy is produced by atomization. Solder pastes (Sn63Pb37, Sn62Pb36Ag2) are used in soldering processes (manual and automatic).

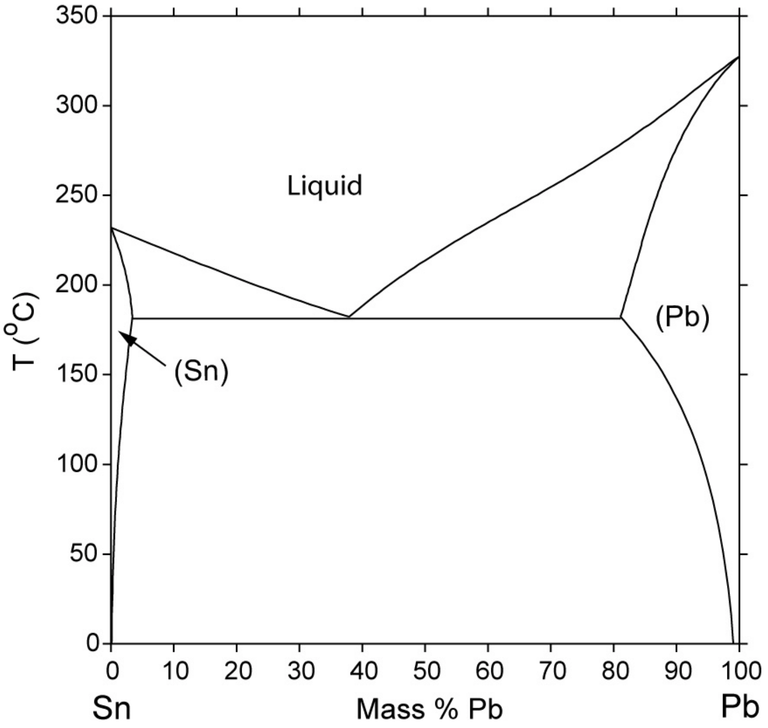
Typical solder alloys used are: Sn63Pb37, Sn62Pb36Ag2 and Sn60Pb40. Solder composition shall be in compliance with the ECSS-Q-ST-70-08C and ECSS-Q-ST-70-38C.

For particular applications, such as high temperature applications, alloys with high Lead content might be used: Pb90Sn10 or Pb95Sn5.

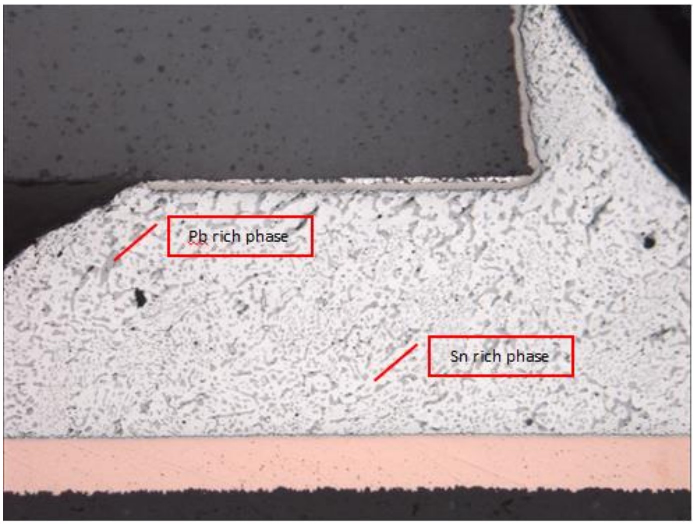
In case of assembly on gold finished substrate (typically for Hybrid manufacturing or Rf applications) or for cryogenic applications In Pb alloys can be used (In50Pb50, In75Pb25).

- Microstructure:

SnPb alloys: Sn and Pb form an eutectic alloy with composition Sn63Pb37. Solidifying from the eutectic they form two separate phases (see Picture 2 and Picture 3): a Pb rich phase which can solve 19% in weight of Sn at the melting point (183°C) and a Sn rich phase which solve about 2% of Pb at the melting point. With the solidification and cool down the solubility of Sn in the Pb reach phase decrease to about 3% and Pb in Sn decrease to about 1%.



Picture 2 Phase diagram of Sn/Pb solder



Picture 3 Example of microstructure of a solder joint with eutectic solder alloy (Sn63Pb37). Two different phases are present: Pb rich phase (grey) and Sn rich phase (white matrix)

InPb alloys: Lead and Indium have full solubility therefore they form a single phase with the same composition of the alloy.

ANNEX 2. LEAD AS A SOLID LUBRICANT

This information was provided by ESR Technology Ltd. (www.esrtechnology.com), an SME and the only supplier of Lead-lubricated bearings for space in Europe.

Lead is one of two widely used primary space solid lubricants, the other being **MoS_2** (which is the most widely used but has considerable restrictions on test environment). **Ag** (silver) is also used but very rarely. These materials are applied by Physical Vapour Deposition (PVD or "sputtering"), an in-vacuum process where a "target" material is energetically bombarded with ions so as to eject material from the target which is then deposited on the surface of the component to be lubricated as a very thin film, typically 0.5-2µm thick (~1-5% thickness of a human hair).

The attractive properties of **Lead** are:

- Low friction and long-life performance in rolling contacts (e.g. ball bearings)
- Acceptable performance and life in air, nitrogen and vacuum (has none of the use restrictions applicable to MoS_2)
- Capability to sustain very high contact stresses whilst providing a long operational lifetime (much higher stress capability with significant lifetime than MoS_2)
- Ability to operate over a very wide temperature range without change in frictional performance or evaporation

The **Lead-bronze alloy** CuSnPb9 to EN CC494K (or ASTM UNS 93500 /SAE66) is used in the cages of bearings coated with lead; its attractive properties are:

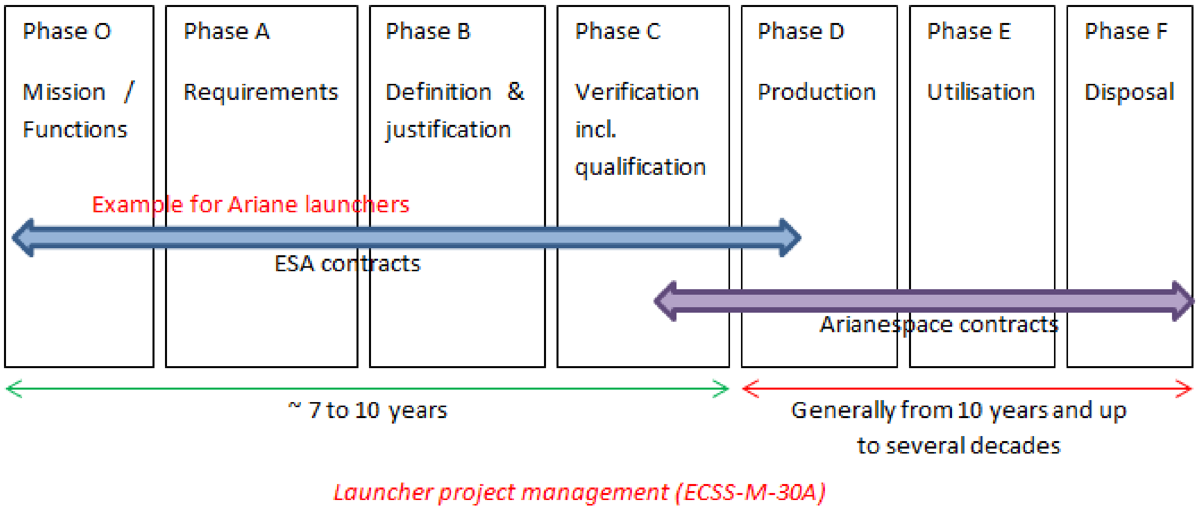
- Low friction
- The bronze matrix contains some free Lead which acts as a supplementary lubricant
- Good transfer properties (it wears and transfers to balls and races easily to supplement the deposited Lead)

The total quantity of Lead targets consumed per year in the production of lubricants for space applications is only ~30kg. The estimated total mass actually applied as a lubricant film by sputtering to all space components together per year is less than 5 grammes (!). For Lead-bronze alloy cages – the estimated total mass of Lead involved in finished items (cages) per year is < ~300g (!). Therefore, the total annual impact of Lead from space lubricants in Europe is very small.

If any additional risk management options were initiated under REACH, a derogation for space applications as a lubricant would therefore seem appropriate.

ANNEX 3. INTRODUCTION OF NEW TECHNOLOGIES FOR LAUNCHERS

In the space and launchers industry, development and production phases cover generally several years/decades (see Picture 4 below). A new development (phase A/B/C) is generally launched at mid or end of phase D. The main goal is to have a short overlap between 2 generations of launchers in order to avoid any launch interruption for example.



Picture 4 Timeframes for launcher development and exploitation

Once the launcher definition is qualified (end of phase C), there is no system requalification planned. This means that the production (phase D) has to be sustainable for the different batches.

New technology should be introduced in the beginning of phase B with a maturity >TRL5 and main performances should be sufficiently known in order to avoid inducing any unacceptable risks during the development.

Any technology introduction during phase D has to be performed with strictly equivalent technologies in order to avoid inducting important tests and justifications that may lead to huge costs to update existing definitions.

ANNEX 4. LIST OF ABBREVIATIONS

AA	Aluminium Alloys
ATEX	Les appareils et les systèmes de protection destinés à être utilisés en ATmosphères EXplosibles (referring to Directive 2014/34/EU)
BGA	Ball Grid Array
CCGA	Ceramic Column Grid Array
ECSS	European Cooperation for Space Standardisation
EEE	Electrical and Electronic Equipment
ENEG	Electroless Nickel Electroless Gold
ENEPIG	Electroless Nickel Electroless Palladium Immersion Gold
ENIG	Electroless Nickel with Immersion Gold
ESA	European Space Agency
ESCC	European Space Components Coordination
ESTEC	European Space Research and Technology Centre at ESA
InPb	Indium-Lead
JUICE	Jupiter Icy Moons Explorer (see http://sci.esa.int/juice)
LTF	Lead (metal) REACH Space Task Force
MELF	Metal Electrode Leadless Face (i.e. without leads = wires)
MPTB	Materials and Processes Technology Board
NMP	N-Methyl-2-Pyrrolidone
Pb	Lead (metal) subject to the Swedish Candidate List Proposal
PbRC	Lead REACH Consortium
PCB	Printed Circuit Board
PVD	Physical Vapour Deposition
Rf	Radio frequency
RoHS	Restriction of Hazardous Substances (Directive 2011/65/EU)
SAC	Sn, Ag, Cu (Tin Silver Copper)
SnPb	Tin/Lead
TRL	Technology Readiness Level