PRIORITISATION

PUBLIC CONSULTATION ON SOCIO-ECONOMIC IMPACTS

The objective of this consultation is to inform policy makers about the economic and social consequences of the authorisation requirement. You are invited to provide specific information about the use of the substance and available alternatives, impacts on the environment, public health and society, and impacts on the supply chain and competitiveness.

This questionnaire contains 32 questions and is aimed at individuals, organisations, companies, as well as Member States. Due to the variation of the questions, it is possible that you are not able to answer to all of them.

Thank you for your contribution!

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28 April 2022 - This is the joint contribution of the European Space Industry, represented by ASD-EUROSPACE – with the support of European and national space agencies, and the European Defence Agency as observer – to the call for information by the European Commission on socio-economic impacts of adding metallic lead to Annex XIV of REACH. It has been prepared in the frame of the Lead (metal) REACH Space Task Force (LTF),[1] 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, REACHLAW as consultant, the following corporations:

> **AIRBUS DEFENCE AND SPACE – ARIANEGROUP – ESR TECHNOLOGY – JENA-OPTRONIK – RUAG SPACE (from 1.5.2022: BEYOND GRAVITY) – SODERN – TESAT SPACECOM – THALES ALENIA SPACE – TNO**

space agencies:

> **EUROPEAN SPACE AGENCY (ESA) – CENTRE NATIONAL D'ETUDES SPATIALES (CNES) – GERMAN AEROSPACE CENTER (DLR)**

and the EUROPEAN DEFENCE AGENCY (EDA) as an observer.

[1] The LTF was initiated by the Materials and Processes Technology Board of the European Space Components Coordination (ESCC MPTB) in response to the Candidate List proposal for lead in 2018. 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.

The contribution has been prepared in co-ordination with the AeroSpace and Defence Industries Association of Europe (ASD) and a cross-sector "Lead Authorisation Task Force" (International Lead Association 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 ILA / Lead REACH Consortium (PbRC) and the European Copper Institute (ECI) to the same consultation.

The contribution builds on, updates and expands on our comments on the Candidate List proposal for lead (metal) of 20 April 2018,[2] the ESCC *'Roadmap for Lead-free Transition in the European Space Sector'* adopted in April 2020[3] and the case study *'Lead remains critical to the safety and reliability of space systems'* of November 2020.[4]

SUBSTANCE

1. **What is the name of the substance on which you comment. Please specify if your replies concern more than one substance, e.g. a group of substances with similar uses:**

Lead metal (EC# 231-100-4, CAS# 7439-92-1, symbol "Pb")

USES

2. **What is the use of the substance (sectors, types of uses, categories of products, etc.)?**
   a. **In general?**

Used across the industry for decades, lead plays an integral part in 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 industrial uses, are listed and detailed hereafter.

In relation to **Electrical and Electronic Equipment (EEE) parts** lead is used today in all the elements of an electronic assembly, as permitted under the RoHS Directive (2011/65/EU):

- EEE terminations and finishes
- Printed Circuit Board (PCB) surface finishes
- Solder alloys
- Others (columns, Ball-Grid Arrays (BGAs), etc.)

The use in Tin/Lead (SnPb) solder alloys for EEE constitutes the main space related use of lead. 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.

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[2] Doc ref. LTF-2018-C1-20042018, available at https://eurospace.org/metallic-lead-targeted-by-reach-joint-response-by-dedicated-space-task-force.
[3] The Roadmap is attached to this contribution as a *confidential* Appendix 1.
[4] https://leadmatters.org/wp-content/uploads/2020/11/Lead-Matters_Case-study_Space_FINAL-PHASE-1.pdf.

The flow in Figure 1 below shows the use of lead-containing alloys in the current space electronics manufacturing chain. All components of an electronics assembly are designed to withstand the high temperature of the soldering process (between 210 and 240°C) and that at least 3 times (to cover assembly, repair, degolding and tinning) with the use of Tin/Lead solder. One of the advantages of the current system is the fact that Tin/Lead alloys are used for the PCB finish, as solders and as well the component terminations are either Tin/Lead finished or pretinned before the assembly. This results in a uniform starting condition for the assembly, reduces the process variability and results in similar metallurgy and basic properties of the solder joint and all these aspects are controlled in a system of established ECSS[5] standards.

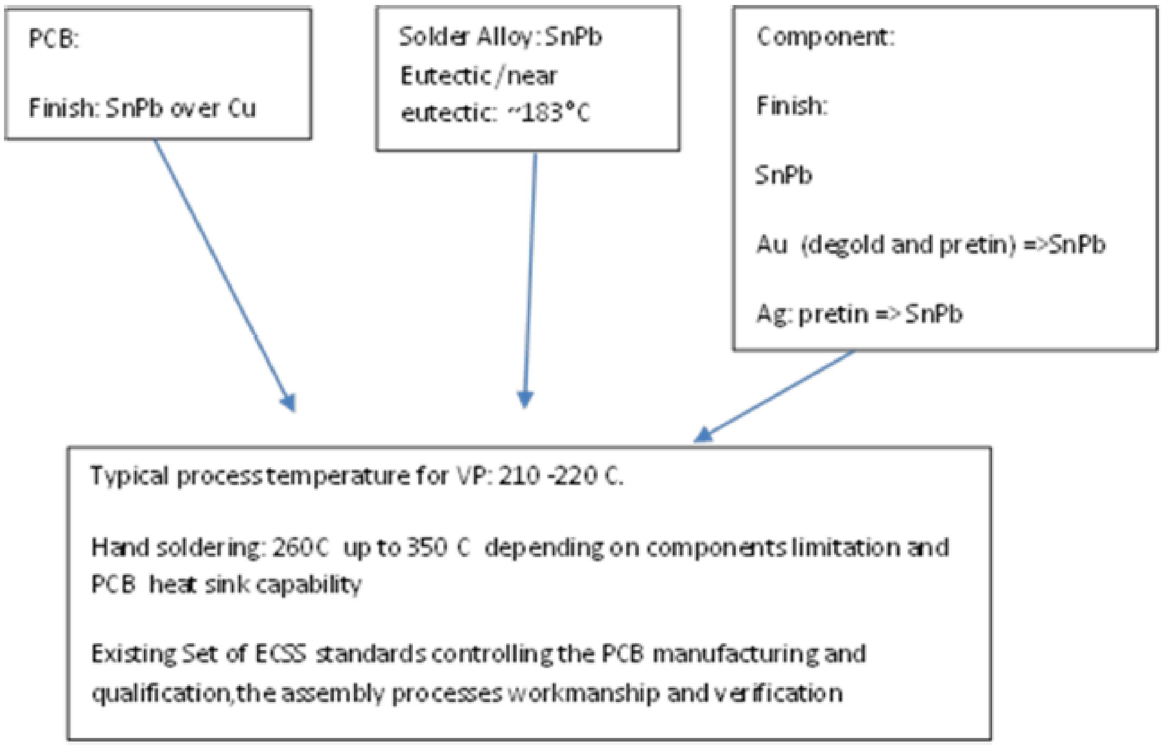

Figure 1 Use of Pb containing alloys in the current space electronics manufacturing chain (Source: ESCC Roadmap for Lead-free Transition in the European Space Sector, April 2020)

In addition, lead is present in many other subsystems of a spacecraft; further critical uses of lead in the space industry without alternatives today include:

- Indium/Lead (InPb) solder on thick gold coatings for long-life systems
- Some alloys (e.g. Lead-containing copper or brass)
- Radiation shielding (incl. massive shielding with lead structures for X-Ray functions; partially shielding by lead containing tape)
- Solid lubrication for space mechanism bearings in applications which cannot use oils and greases due to contamination, viscosity or volatility problems
- Pyrotechnical devices affecting the system to pilot and command the launcher
- Seals for applications where the high temperatures are not suited to organic materials
- Use in ceramics for sensors/actuators purposes
- Battery terminals
- Lead in adhesives

[5] European Cooperation for Space Standardisation.

- Lead in galvanic applications, e.g. as activating material in Nickel-plating bath
- Electromechanical relays contacts
- Glass of some devices
- Ceramics

With the inherent risk involved as no repair is possible after launch, new space technologies require extensive testing and a high level of maturity before they can be implemented widely. With lead’s reliable properties, it has become an **essential** element for the sector.

More details for main uses are provided hereafter.

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, manufacturing high reliability EEE, PCBs and solder connection designed for use in space, especially Tin/Lead (SnPb) solder.

Space industry has been using SnPb alloys in electronics manufacturing **since its beginning**. The Space Sector heavily relies on the knowledge of these alloys for the production of electronics that are able to operate in harsh environment meeting the high reliability requirements of space applications. This knowledge is reflected in a series of ESCC[6]/ECSS standards which are managing PCBs, components manufacturing & qualification and the assembly workmanships & processes verification.

The entire **satellite** industry is based on 60 years of cumulated experience of SnPb solder joints. This is more important in modern day satellites where electronics pervade all subsystems. 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.

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.

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.

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 PCBs (which in turn are also finished with Sn63Pb37 solder).

For further information please view Annex 1 to this document.

[6] European Space Components Coordination.

Alloys and coatings

Lead is used as:

(1) a **minor alloying element** (typically 2-5%) 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.

(2) a ***major*** **alloying element** in the typical eutectic Tin/Lead (37% or 40% lead) and Indium/Lead (18% to 26% 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[7];

(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 for 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.

In case of Pb coating for lubrication the raw material is supplied in metallic blocks of pure lead (purity >99.99%) bonded to copper backing plates as "targets" for electrical/heat extraction reasons. The lead as part of these targets appears to be a distinct substance in terms of REACH as it is consumed in the coating process, being physically delivered from the target to the surface of the item to be coated.

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.

[7] Jupiter Icy Moons Explorer.

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).

Other uses

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

Lead is also used in galvanic applications

- in electrodes as an activating material in Nickel-plating bath;
- in electrodes in anodising bath
- as addition in chemical-nickel electrolyte.

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

Other space relevant uses where 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 Metal Electrode Leadless Face (MELF) packages, optical glasses/parts[8] 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

In addition, some **primers** or **surface modifications** (overall treatments, coatings and/or pain pigments) may contain lead. Lead here is primarily added for its rust inhibition on metallic surfaces and to increase treated surface endurance.

b. By your company? *(only for companies)* - Not applicable

3. Can you specify the use in terms of volume/value?

a. Overall in the EU?

Relevant volumes in scope of a potential authorisation requirement are only uses of lead as a substance or mixture component ≥ 0,3% (e.g. solder paste). However, products containing lead (alloys, electronic components, pyrotechnical devices, etc.) are mainly semi-finished or finished products and (very) complex objects.[9]

[8] Including possible content in optical fibres within satellites.
[9] Assemblies of "articles" in terms of REACH Article 3(3), i.e. *"Article: means an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition".*

LTF participants were surveyed on the volumes/value per use in 2018.

> *Please note that the information provided (below) does not necessarily correspond to the volume of lead use as a substance or in a mixture in the EU, as the figures – estimating the total amount of lead in space products, likely include also imported articles containing Pb. Hence, the actual volume of lead use in the scope of potential authorisation is even lower.*

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 extremely low, but the value is very high.**

b. By your company? *(only for companies)* – Not applicable

4. What are the properties/functions of the substance on those uses/sectors?

We make reference to our answer on Question 2 above. In addition, we would like to provide further information below.

Tin/Lead solder alloys

In the case of leaded solder, there is vast heritage and experience under all environmental conditions, the window process is relatively large allowing a process flexibility and it presents all the needed characteristics to produce high reliability assemblies (mechanical, thermo-mechanical, physico-chemical properties).

No other material can match the safety and reliability of leaded solder. Changing such a basic process would introduce a high degree of uncertainty and risk for the components and printed circuits. Without lead, the risk of mission failure for space vehicles due to inferior equipment may increase, with far greater safety implications for old and current design.

Researchers found in the early stages of the electronics era in the 1950's, that adding lead to tin solder solves the major problem of the **growth of "Tin whiskers"**, which could cause failure in the electronic part.[10] Tin whiskers 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.

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

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.

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

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

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 *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.

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.

Leaded brass

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.

5. Is the substance present in a finished article? If yes, at what concentration?

Yes (see answer to Question 3), products containing lead (alloys, electronic components, pyrotechnical devices, etc.) used in the European Space Sector are **mainly** semi-finished or finished products and (very) complex objects, i.e. "articles" as defined in REACH or assemblies thereof. Given the relatively high lead content in solder alloys (ca. 40-90% in Tin/Lead solder) the substance's concentration in EEE components is often clearly above 0.1%. For some components like Ceramic

Column Grid Arrays (CCGA) columns contain PbSn with high Pb concentration (>85%) (see also Annex 1 to this document).

ENVIRONMENT AND HEALTH

6. **Does the use of the substance imply any releases/exposure/risks for workers, consumers or environment?**

Operators use mainly finished or semi-finished products (see above) and are not directly exposed to the substance, while the end use of the equipment occurs in Space. For *launchers* it has been reported that there is no risk of exposure within the downstream supply chain.

For the equipment/board manufacturers, there can be a direct contact. But to reduce the risk, a suction has been put in place and the blood analysis performed has never shown lead presence.

Soldering processes are mainly performed by automatic process with less exposure to workers and environment.

7. **What measures have been put in place to prevent these releases/exposure/risks?**

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** (see above).

The use of **leaded solder** in the Space Sector follows strict risk management processes, and a framework of existing legislation and industry best practice protects engineers and technicians. 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 flow boxes are used, so that workers do not come into contact with lead vapour. 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 for lubrication (see further description under Question 2 above) is done under cleanroom conditions and parts are handled with gloved hands at all times by operators wearing cleanroom garments. The coating tooling items used to support the items to be lubricated during the coating process itself 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* 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).

8. **How can exposure of workers or consumers be further reduced? How can releases into the environment be further minimised?**

The lowering of the existing occupational limit values for lead under the Chemical Agents Directive (CAD) is currently ongoing and is planned to be completed by 2023/24 (Member States transposition). Compliance with the revised limit values can help to further reduce exposure of workers across EU.

9. **Are you aware of any relevant information (e.g. study or article) quantifying the cost of environmental or human health impacts related to the use of the substance?**

No

AVAILABILITY OF ALTERNATIVES

10. **Are you aware about any alternative substances, processes or technologies currently available for the use(s) of the substance?**
    a. **If yes, what are these alternatives and where are they used?**
    b. **What are the main differences between using these alternatives compared to the substance in question (e.g. whether the alternative substance provides the function and, if so, whether there is any difference in the level of performance; in case of an alternative process or technology, the function may be redundant)?**
    c. **What are the hazard properties of the alternatives compared to the substance in question?**
    d. **Are the alternatives already available, i.e. drop-in alternatives? Or do their implementation require changes in the production process and investments?**
    e. **What is the expected price of alternatives, per unit (e.g. per kilo, tonne)?**
    f. **Would an alternative require the same, more or less volume (e.g. in kilos, tonnes) compared to the substance in question?**

Alternatives to Tin/Lead soldering and brazing for electronics

10. a./b. (alternatives and main differences to lead)

Already today there are many lead-free solders on the market and used for *electronic assemblies* in other industries. However, **none is qualified for Space use** and could not safely be used in most Space projects. But there are some Space projects where reliability may also be attained through redundancy, like in satellite constellations, and in those cases the customer may be willing to accept the risks and use lead-free solders.

SAC alloys

The most promising alternatives are SAC alloys, i.e. **lead-free solder alloys based on Tin (Sn), Silver (Ag) and Copper (Cu)**. 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.

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. 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 PCB and this again can reduce the reliability of the circuit.

The fact that repairing components and reworking of soldered joints has to be performed at far greater temperatures than for eutectic Tin/Lead is therefore an important disadvantage of SAC alloys. 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.

Pure Tin

Electroplated **pure Tin** has become the standard for treatment of *terminations of electronics parts* but most space programmes specifically ban the presence of any pure Tin surface in space hardware. 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 (see answer to Question 4). 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. 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.

Pure Tin goes through a phase transformation from a ductile metal to a brittle material below about 13°C together with a volume change. The tin cannot withstand the volume change associated with the phase transformation in the embrittled state and the material disintegrates into powder, known as “Tin Pest”. Typical space electronic systems must operate between -50°C and +85°C making pure tin an impractical solder material for space systems. Lead effectively suppresses the phase transformation below -50°C allowing tin lead solders to be used.

ENIG, ENEPIG, EPIG

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.

Conclusion

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 electronics. 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. **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.

10. c. (hazard properties comparison)

The lead-free solder alloys referred to as SAC alloys are based on Tin (Sn), Silver (Ag) and Copper (Cu). **Tin** is not classified as hazardous according to the C&L Inventory.[11] **Silver** does not currently have a harmonised classification in CLP Annex VI, but such has been proposed by Sweden, including as Repr. 1B.[12] **Copper** has a new harmonised classification as Aquatic Chronic 2 (in force from March 2022); it is also undergoing assessment as Endocrine Disruptor.[13] Hence, SAC alloys are considered as less hazardous comparing to Lead as of today, but new hazards have been or are being identified for the concerned substances at the EU level.

10. d. (availability)

The alternatives are not drop-in and require brand new assembly lines. We believe that the Space Sector will follow the same pattern as the other High-Rel Sector which is Aeronautics. This sector introduced new assembly lines for Pb-free soldering while, at the same time keeping the old, lead-based, soldering lines running in parallel. As heritage built up, the load of the Pb-free lines increased while it decreased for the Pb-based lines. This will be a hugely expensive transition for the Space Sector since each existing product has to be fully requalified with the new process.

Even more, not only the solder alloy may have to be substituted, but PCB's and components would have to be re-designed (and then qualified also) to match and survive increased soldering temperatures for SAC alloys. As a consequence, the qualification perimeter would increase to include new PCB's and components, and new actors as related suppliers / producers.

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[11] https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/173002.
[12] https://echa.europa.eu/de/harmonised-classification-and-labelling-previous-consultations/-/substance-rev/57201/term?_viewsubstances_WAR_echarevsubstanceportlet_SEARCH_CRITERIA_EC_NUMBER=231-131-3&_viewsubstances_WAR_echarevsubstanceportlet_DISS=true.
[13] See Substance Infocard for Copper.

10. e. (price of alternatives)

The price of the solder material is **negligible** compared to the value of electronic equipment manufactured with such material, even though the alternatives are more expensive.

10. f. (volume of the alternatives)

The alternatives require about the same volume compared to lead-based solder.

Alternatives to lead in other alloys and coatings (non-electronics)

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

For *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.

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).

Alternatives to lead in galvanic applications

10. d. (availability)

Substitution is possible in principle, but very cost and time intensive due to complex and exhaustive new qualification effort needs, and - as often in the space business – with the risk to fail.

11. **Would the use of these alternative substances, processes or technologies have a positive or negative impact, or no effect, on sustainability (considering the whole life cycle: manufacture of the substance/production/consumption/waste/recycling)?**

The alternatives are not expected to have a significant impact on sustainability.

However, 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, increases the toxicity of fluxes and the pollution of air and water.

12. Are you planning to substitute the substance? If so, by when? ***(only for companies)***

The European Space Sector took in 2018 the decision to substitute the substance. For that purpose, the SCSB created in 2019 a Task Force, composed by Space Agencies and Space Industry experts, to produce a **Roadmap for the Lead-free Transition in the European Space Sector**.[14] After one and a half years of work, the Task Force delivered a detailed Roadmap with the associated costs. The overall cost for the common tasks (i.e.: tasks for which the results can be reused by all actors) was estimated between 25 and 30 M€, without counting the additional costs associated with site and products qualifications (which are company specific) which could run several times that amount. It is estimated that it will take at least 15 years (2035) for all the actors to complete the transition for soldering only.

Some Space agencies are already funding small actions identified in the Roadmap. The Roadmap was also instrumental for the Commission to retain the subject for the current call Horizon 2022 Space with a budget of €3M. Most members of the Pb-free Task Force have joined in a consortium of 12 participant entities from space industry and academy. The consortium submitted a proposal on Lead-free Transition for the European Space Sector (LETTERSS) to the Commission on 16.2.2022. The proposal, in accordance with the content of the call, only addresses the Pb-free transition for Electronics Assemblies where lead is found today in finishes for parts terminations and solder alloys.

EU-level support would stimulate additional research for the best alternative solutions to ensure reliability for space equipment and mitigate the risks associated to tin.

13. Are there uses for which there are no alternatives (substances, processes or technologies)? If yes, could you explain why?

Yes, for the space applications described in this contribution there are no known (identified) or Space-qualified alternatives today. Please see already our answers above, in particular to Question 2, Question 4 and Question 10. Further details are given hereafter.

Tin/Lead soldering and brazing for electronics

For SnPb replacement there are alternatives that need to be fully evaluated for space requirements and then qualified, see answer to Question 10.

Indium/Lead (InPb) solder

For InPb solder alloy used for optoelectronic assembly, **no alternative has been identified** and investigated. This is because gold coatings are used extensively on optoelectronic packages because of the reliability requirements demanded by the fibre optic industry. And the main reason to using InPb alloys in soldering to precious metal surfaces is that, unlike tin-containing solders, they do not leach gold. That is, gold does not dissolve in them to any appreciable extent.

Lead in other alloys and coatings (non-electronics)

For lead as an *alloying element* **no substitution activities have been initiated in the Space Sector**.[15] No substitution is currently expected because of the specific mechanical properties required, such as ratio mass/behaviour, mechanical strength and load resistance. For *brass and aluminium alloys* the

[14] The Roadmap is attached to this contribution as a *confidential* Appendix 1.
[15] 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.

lead in the alloy provides "lubrication" to improve machinability, which for some applications is very critical for the function.

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 bearings 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 (~109 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.

14. **If there are no alternatives, are you aware of any research, development and innovation efforts attempting to develop them? If so, how long do you expect that the development / testing can take?**
    a. **In the EU or in non-EU countries?**

There are already increasing pressures driving and further intensifying R&D activities for substitution, including a Roadmap for Lead-free Transition in the European Space Sector (see already answer to Question 12).

    b. By your company? *(only for companies)*

MARKET AND SUPPLY CHAIN

15. **Specifying the use of the substance, both overall in the EU and by your company, what is the annual volume/value of the substance:**
    a. Placed on the EU market?
    b. Manufactured in the EU?
    c. Imported into the EU?
    d. Exported from the EU?

See answer to Question 3, the volume of use is extremely low, but the value is very high.

16. **Could you specify the sector in which the substance is used and describe the supply chain, including your role in the supply chain?**

About the Space Sector:

The European space manufacturing industry is a strategic sector for the EU, embedded in the wider aerospace and defence industrial complex.

The space industry designs, develops and manufactures spacecraft and launchers, along with the associated ground systems for satellite control and operations. The space manufacturing industry is organised vertically with large and medium system integrators (capable of delivering a complete launcher or spacecraft to the launch pad) providing business to a wide range of equipment and service suppliers (capable of delivering integration ready subsystem, equipment and components, or providing specialised services and tools supporting system design, integration and test). The industry is highly specialised and capital intensive. The sector is also rather concentrated; despite being distributed across all ESA member states. Four large industrial groups (Airbus, Thales, Safran and Leonardo) are directly responsible for more than half of the total space industry employment via dedicated Business Units (BUs) and/or Joint Ventures (JVs). In 2020, the largest dedicated space business units and industrial capabilities are located mainly in Airbus Defence & Space, Thales Alenia Space and ArianeGroup. Smaller, but sizeable space players such as GMV, RUAG SPACE (from 1.5.2022: BEYOND GRAVITY) and OHB provide additional employment and capabilities to the European space industry. Small space units are very common in the Space Sector, but they are often part of, or owned by, a larger company. These units often face the same issues as SMEs in the sector but cannot benefit from the dedicated support measures proposed by public institutions. Industry is distributed across all Europe, with the main industrial sites located in France, Germany, Italy, and, to a lesser extent, United Kingdom, Spain and Belgium (see also answer below to Question 19). In 2020, the European space industry successfully delivered 89 spacecraft to the launch pad of which 50 large satellites and 39 pico and nano satellites. It also delivered 5 launchers for operations in Kourou.

For decades, the Space Sector has reached a level of maturity that allows reliable and autonomous access to space, extraordinary space and earth science, as well as fully operational programmes delivering strategic services for governments and answering citizens' needs. Satellite imagery and communications (including localisation) have become a staple for a range of major applications such as for meteorology, disasters monitoring, surveillance purposes, providing localisation, navigation and cartography software and services, emergency and/or secured communication, delivering connectivity everywhere (in-flight and to the most isolated places), just to mention a few. Many of those applications address Europe's societal challenges (such as the Maritime Strategy, the Arctic Strategy, the Digital Agenda, the Common Security and Defence Policy and the Sustainable Development Strategy for example).

Role in the supply chain:

The impact would affect the entire complex EU space systems' supply chain, 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). Space companies as assemblers are located at the end of the supply chain; they are also downstream users of solder paste.

Please see Annex 4 'Space market and supply chain' for further information.

17. Can you provide data on the turnover of the concerned sectors and the number of people employed? How much of these data is related to the EU market? What is the turnover of the substance/substance-related products vs. the total turnover of the sector?

Turnover of the European Space Sector and number of people employed: In 2020, the European space industry posted sales worth 7707 million € and employed a total of 50121 workers (FTE: Full Time Equivalents).

Beyond the contribution to European space programmes, the Space Sector is also a positive contributor to the European trade balance with an average net surplus of more than 1B$ per year in the past decade, thanks to its performance in exports of both satellite systems and launch services. Furthermore, while the European public space infrastructure provides unmeasurable, but significant, social, scientific and strategic benefits via the provision of free services (weather, climate and environmental data, timing and position information, tactical and strategic intelligence, television broadcast, etc.), it also creates more than 200B€ of revenues through its value chain thanks to the induced markets for applications and terminals (source EUSAP EO and GNSS Market report 2022). Space applications permeate all areas of the global digital economy, they have contributed and benefited from its growth in the past decades, and it is projected that the sector will further accelerate its economic development in the next decade.

Turnover of the substance/substance-related products vs. the total turnover of the sector: No specific figures are available, but all satellites and launchers are using lead for PCB.

18. Can you estimate the relative weight of SMEs in the concerned sectors (in terms of number of companies and employment) in your country /in the EU?

Considering the uncertainties described hereafter, it is ascertained that within the sector of space systems manufacturing and development in Europe, the proportion of SMEs is comprised between 11% and 19% of total employment.

The Eurospace economic model considers 398 space units in Europe. Of these only a fraction are SMEs (according to the EC definition), despite the fact that the vast majority of space units in Europe are quite modest in size, from both the employment and the revenues point of view. In the Eurospace 2020 facts&figures survey, 145 companies are formally qualified as SMEs (representing a total of 5738 employees), out of a total of 319 small space businesses. For the other small space units in the model the status is unknown, some may be SMEs, some may not. The number of small space units (and relative employment) has been growing fast in recent years, stimulated by company creation (the 'newspace' trend) since most start-ups qualify as SMEs. The European space start-up ecosystem has often benefited from institutional support such as the ESA-BIC incubator programme and/or from the EU EASME and H2020 instruments.

19. Are the manufacturers of the substance or downstream users concentrated in a single/limited number of Member States or in a limited number of regions?

The European space industry is distributed across all Europe, resulting in an important fragmentation, particularly in the smallest contributors to ESA. Yet, the 6 major ESA member states (France, Germany, Italy, United Kingdom, Spain and Belgium) provide about 90 % of European space industry employment. In principle, personnel are allocated to the country of activity. This is particularly relevant to companies who provide engineering and other specialised services to space agencies and industry throughout Europe

Currently qualified PCB manufacturers are located in Belgium, France, Germany and UK. Eastern Europeans companies have started manufacturing electronic hardware in space equipment as well.

COMPETITIVENESS

20. **What would be, or has been, the overall cost and time of substitution for the particular use you are providing information on? This includes (if relevant) the need of changes in the production process, need for new product testing, qualification and certification, etc.**

Tin/Lead soldering and brazing for electronics

Please see already the answer above to Question 12, as well as below to Question 22.

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**.

The transition requires the costly setup of new assembly lines (both Tin/Lead, for old designs, and lead-free, for new designs, lines will run in parallel) and the requalification with the new solder of all EEE parts used.

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.

For the *launcher* segment, the cost for design, development and qualification of "piloting and controlling" devices 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, would be jeopardised if these economic impacts of REACH materialised.

21. **What is the expected impact of substitution costs on the costs of your inputs or final products? What is expected impact on your sales in the EU/outside the EU countries? *(only for companies)***

As explained for previous questions, the substitution costs will be huge for the European Space Sector and need to be spread out in order not to impact negatively the affected companies. These negative impacts could be diversion of R&D budgets to requalification activities. The use of new solder technology with little space heritage could also hinder competitiveness in the market if other suppliers still proposed solutions based on well proved lead-based solders.

22. **Please describe the typical length of the order cycle / investment cycle.**
    a. **To the concerned sectors?**
    b. **To your company? *(only for companies)***

The cycle for the introduction of a new solder technology comprises the following steps:

i. **R&D**: Identify, evaluate end validate the replacement solder(s): 3-5 years – *This is not company specific.*
ii. **Investment**: Invest in new assembly lines using the validated solders and qualify the chosen replacement solders. 5-7 years – *This is company specific.*
iii. **Requalification**: Requalify the assembly of all components used by each company in each assembly line of that company with the new solder. 4-6 years – *This is company specific.*

23. **Please describe what the impacts of including the substance in Annex XIV of REACH would be? This includes changes in the competitive position with respect to non-EU competitors in the EU market and in third markets.**
    a. **To the concerned sectors?**
    b. To your company? *(only for companies)*

In our view Annex XIV inclusion of lead would only add to the administrative burden and costs (for compliance) for our companies and their suppliers, adding to the direct substitution costs (verification costs) already addressed (see Questions 12, 20, 21 above).

This burden and costs would further **reduce resource availability for product improvements**, leading to 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.

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.

Annex XIV inclusion would also add to the legal uncertainty for industry because the uses of lead are indeed wide-spread, supply chains are very complex and it will be challenging to define a viable strategy for applications for authorisation (AfAs) covering all operators, including many SMEs.

Also, with view to a defined Sunset Date some customers (within and outside the EU) could 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 Space Sector is very important, this is a big advantage for any non-EU competitor who does not need to make this change.

Non-EU operators will not have this burden from authorisation, thereby creating a disadvantage in the competitive position for their EU counterparts. Hence, the EU space industry's competitiveness in the global space market would suffer.

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, could occur against the spirit of the EU's policy for non-dependence in space technology.

Related loss of know-how and a decrease in the skilled workforces for design, development, manufacturing and testing are also feared.

OTHER IMPACTS OF INCLUSION IN ANNEX XIV (innovation and business opportunities)

24. If the substance is included in Annex XIV to be eventually phased out, would it create business opportunities (e.g. gaining new markets or higher market share, development of alternative substances / products / production techniques)?
   a. In your sector?

Ultimately, transitioning to lead-free alternatives for solders offers no benefits for the space industry. The lack of heritage is a serious risk to be mitigated. With strong risk prevention measures already in place, engineers and technicians are already well protected (see answer to Question 7), while with the significant investment required to identify and implement a suitable replacement, pursuing a lead-free solution comes with no guarantee a suitable replacement could be found.

   b. For your company? *(only for companies)* – Not applicable

25. What effects do you expect on enterprises' capacity to innovate? (The capacity to produce more efficiently and/or higher quality and a larger scale of products and services and the capacity to bring R&D to the market)

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.

26. Are you aware of any likely effects on recycling or sustainability?

See answer to Question 11. Recycling does not apply to products sent into space and not returning to Earth or the EU territory.

27. In your opinion, if the substance is included in Annex XIV to be eventually phased out, would the economy, society or the environment be better or worse off (all factors considered)? Why?

In our opinion, Annex XIV inclusion of lead is not the right regulatory option to address the concerns for human health from its use(s). For the Space Sector, the reasons have been provided comprehensively in the different answers to this contribution.

Precedent case for metallic alloys

We would also like to note that there is no precedent for an authorisation requirement to apply to alloys as ***"special mixtures"*** according to REACH and CLP Regulations. 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 or impose additional restrictions in Annex XVII.

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).

APPLICATION FOR AUTHORISATION *(only for industry actors)*

28. If the substance is included in Annex XIV, would you consider applying for an authorisation? Are you aware if your suppliers/downstream users would consider to apply?

Yes, the Space Sector would have to resort to AfAs to continue using lead.

Solder

The main relevant use where space companies would have to make their own AfAs as downstream users is the **use of solder paste**, especially for PCBs. They are found on most satellites; industry buys them and sometimes solders on them. All European PCB manufacturers as well as satellite motherboard manufacturers are concerned.

Given the complex supply chain for solders (see above Question 16) upstream operators would also have to apply for their own uses (e.g. the solder paste producer, PCB manufacturers). Given the ubiquitous presence of lead this would exacerbate the major AfA challenges that were encountered for chromates.

Other alloys used as "mixtures" containing lead

Other alloys (e.g. parts made of lead-containing copper, brass or aluminium) are typically procured in a machined state by space companies and will therefore often be (semi-/finished) "articles" as defined in REACH (see already above Question 3 and Question 5) when applying the ECHA *Guidance on requirements for substances in articles*[16], in particular the indicative questions 6a-d (p21) and the example of *'Aluminium processing as an example of metal processing'* (p79-82); the latter suggests a rather early transition point from "mixture" to "article". This has also been concluded in a study on the REACH status of Lead-containing Copper Alloys conducted for ESA with the support of the LTF and consultation of the *European Copper Institute* in 2021 for identified examples such as brass or round rods and plates. In those cases, the authorisation requirement would be limited to upstream operators who process raw materials qualifying as "mixtures". However, uncertainties remain due to the subjective nature of some of the ECHA Guidance indicative questions, which could imply a possible need for an AfA to be on the safe side, unless the article status in a specific case is sufficiently backed by the competent authorities. This, in turn, would result in the possible need for multiple AfAs in the same alloy supply chain with dependency on upstream authorisation, as is the case for solder.

Pb coating for lubrication

As described above (see answer to Question 2), Pb coating for lubrication (as part of "targets") could also be in the potential scope of authorisation, since lead is used as a distinct substance.

Other uses potentially requiring authorisation

[16] https://echa.europa.eu/documents/10162/2324906/articles_en.pdf.

Other applications that could qualify as the use of a substance on its own or in a mixture exceeding 0.3% and therefore require authorisation unless alternatives are implemented successfully before a sunset date are (*not exhaustive*):

- Lead in adhesives
- Addition in chemical-nickel electrolyte

29. How would you envisage that the submission of an application for authorisation could be organised, considering your specific uses and the structure of the supply chain: would you envisage an application by manufactures/importers of the substance or formulators (upstream the supply chain)/ or applications by downstream users or a combination of all)?

Given the uncertainties encountered with upstream AfAs in the chromates case on the one hand and the multiple use steps in the supply chain leading to the production of lead-containing articles and complex objects on the other hand we expect that a **"hybrid" AfA strategy** will be needed, including

- ***Individual* DU AfAs** by many companies in the Space Sector to cover their own uses; and
- **AfAs further *upstream*, e.g. by formulators** of solder paste or (other) producers of raw materials qualifying as "mixtures" and containing lead as a component

Sector-level cooperation to prepare core dossier elements for an AfA (e.g. AoA, SEA) and collaborate with upstream actors (e.g. formulator) would need to be considered too.

A rough estimate of the minimum number of AfAs required only in the European Space Sector and only for individual soldering processes is 80-85. This minimum estimate is based on information from ESA, according to which around 75 companies are performing electronic assemblies for ESA projects. In addition, several harness manufacturers are also likely to perform some soldering. Different soldering activities include manual soldering (using soldering wire); automatic soldering (using solder paste); and wave soldering (using ingots). Further differences could arise due to different solder compositions.

This minimum estimate is also in line with a Eurospace survey from 2015 ('AI 42.3 Eurospace EEE panel to provide realistic estimate of how many additional lines and extensions of existing SMT lines should be needed in the short and medium term'), which found that there are 36 Surface Mounted Technology (SMT) lines, including 32 lines certified by ESA in 12 different countries, and the remainder planned to be qualified in the next 5 years. In each of those lines there are normally two separate processes: Automatic and manual soldering; they are probably assimilated to 2 different uses to be applied for.

The minimum estimate does not consider companies which are manufacturing Commercial Off-The-Shelf (COTS) equipment, and is without making a distinction for different processes or solder compositions. In addition, for an upper end estimation of AfAs, it could be estimated according to LTF participants that there are an equivalent number of smaller subcontractors not covered by the Eurospace survey, that would need an authorisation for lead. Also, ESA information is only for its own projects.

Hence, the total number of AfAs in the European Space Sector (including subcontractors) and only for individual lead-based soldering processes could go up to 200 or more AfAs.

This estimate does not even include uses subject to authorisation by upstream operators outside the European Space Sector (e.g. soldering by PCB manufacturers, solder paste formulation) and other than soldering uses. Hence, the total estimated number of AfAs would be even higher.

It is expected that all or at least the vast majority of the mentioned sites/soldering processes will require an AfA for continued operations as there will be no alternative in place at the expected Sunset Date.

The challenges of upstream authorisation for Cr(VI) would thus be exacerbated for lead, which has a higher diversity of uses and soldering activities are very site specific.

30. **What main challenges in preparing an application do you expect for your specific case? Would you envisage applying for your own uses or would you apply to cover uses of your downstream users? Would you apply jointly with other downstream users covering the same use?**

See answers to the previous Questions 28 and Question 29. As downstream users in the Space Sector are located at the end of the supply chain, they are not able to cover uses of upstream actors. As mentioned for Question 22, the investments and requalification steps for the introduction of a new solder technology are company-specific, thus questioning the viability of joint dossiers.

REGULATORY OPTIONS

31. **Do you consider that other regulatory options could better address the concerns for human health or the environment for which the substance is recommended for inclusion in Annex XIV? What are these regulatory options and why would they better address the concerns?**

Yes (see already answer to Question 27).

REACH Art. 58(3)3 sets out that "[t]*he number of substances included in Annex XIV and the dates specified under paragraph 1 shall also take account of the Agency's capacity to handle applications in the time provided for."* We refer to the contribution by ILA / PbRC, which indicates an excessive number of expected AfAs. This is not only an issue for ECHA, but even more for the Commission and REACH Committee, as evident from the persisting backlog of ECHA AfA opinions to be processed for a Commission decision.

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 exclusions, including for EEE designed to be sent into space. Requiring AfAs for the prior solder use would undermine this exclusion and favour imported EEE (which could still contain lead without the need for an authorisation).

In addition, we seriously question the **timeliness** of this Annex XIV (draft) recommendation for lead being the first element (metal) ever intended to be proposed for REACH authorisation. This ECHA initiative for such an important substance comes in the midst of the Commission's activities to prepare a proposal for a revision of the REACH Regulation by the end of 2022, including a substantial Reform of the Authorisation and Restriction processes (one of the options even being the removal of the authorisation title from REACH!) and the development of an Essential Use Concept to better protect uses without alternatives that are necessary for health, safety or are critical for the functioning of society.

Further to the REACH revision, a substantial review of the RoHS Directive 2011/65/EU is currently carried out by the Commission. A public consultation is on-going until 2 June 2022. RoHS includes lead as an important substance. The review also addresses the interface with REACH as one of its central elements.

OSH

Workplace-related risks are already being addressed through the proposed lowering of the existing occupational limit values for lead and its compounds under the CAD, which is planned to be completed by 2023/24 (Member States transposition); this action is explicitly identified in the Commission's Chemicals Strategy for Sustainability (CSS).[17] In our view, the updating under OSH as a regulatory risk management tool should have a deprioritisation effect for lead under REACH authorisation/restriction in relation to the workplace and human health concerns which are presently at stake.

Targeted restriction

To achieve regulatory consistency, a **targeted restriction** – *if justified in the first place under REACH Article 68(1) beyond existing legislation such as OSH* – with suitable **derogations** for space applications (covering both EEE and non-EEE) appears the most appropriate risk management option.

In this regard the European Commission's paper *"REACH and Directive 2011/65/EU (RoHS) A Common Understanding"* (2014)[18] 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.

Exemption according to REACH Article 58(2)

Even in case of an Annex XIV inclusion an exemption can be included in the entry, if it fulfils 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 Commission's REACH/RoHS Common Understanding paper (see above) 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 existing market and regulatory pressures. Industry is willing to replace lead

[17] See action #25 at https://ec.europa.eu/environment/system/files/2021-11/Table_implementation_CSS_actions.pdf.
[18] Available at https://ec.europa.eu/growth/sectors/chemicals/reach/special-cases_en.

as much as possible 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.

OTHER REMARKS

32. Would you like to provide additional comments/information on the possible socio-economic impacts?

The transition toward lead-free shows that an automatic soldering line is better than the manual soldering. For space applications, it has been observed that a lot of SMEs solder the components with an iron. There is a risk that these small and very small companies would be obliged to invest in an automatic line or subcontract to another company – with a risk of closure.

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Annex 1. Use of lead in manufacturing of space electronics

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

- 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: 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%.

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

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.

In the space and launchers industry, development and production phases cover generally several years/decades (see picture 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.

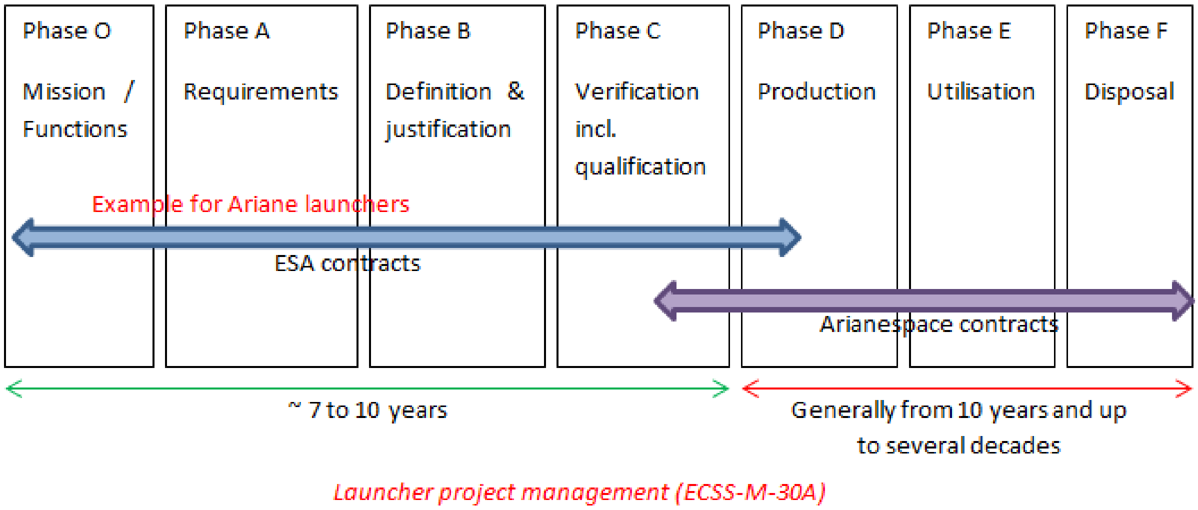

Figure 2 Timeframes for launcher development and exploitation

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. Space market and supply chain

Eurospace recognises four main product segments: launcher systems, satellite applications, scientific systems, and ground systems/services. The three first product segments in the scope are flight products. The European launch service provider also offers launch services as well as some satellite operation services.

The space market can be divided into a local institutional market and commercial and exports market. The institutional market is made up of national (e.g. military, ministries of research or agriculture) or international bodies structured at European level (e.g. ESA, EUMETSAT, the EU). European public institutions play a key role in the Space Sector and their involvement is essential to sustain the space economy.

The commercial and exports market segment includes private customers, mostly satellite operators, inside Europe and worldwide, and public entities located outside Europe. The commercial market has traditionally been dominated by the geostationary satellites and associated telecommunications services; but recently the Low Earth Orbit (LEO) constellations have become the main growth segment for this market. The public/institutional vs. private/commercial market is described in Figure 3 in terms of sales breakdown.

FIGURE 3 SALES BREAKDOWN BY SEGMENTS (PUBLIC/INSTITUTIONAL AND PRIVATE/COMMERCIAL MARKET)[19]

Sales by macro segment and by customer (M€)

M€	Launcher systems	Satellite apps	Scientific progs	Ground systems & services	Other / Unknown systems	Total
Sales to ESA (incl. delegated EC programmes - GMES & Galileo)	555	1004	911	618	44	3132
Sales to other European institutions (public)	53	957	85	586	83	1764
Sales to Public institutions RoW	2	314	36	101	5	457
Other/unknown European customers	4	8	26	41	20	99
Sales to European private operators	0	559	2	69	6	636
Sales to Arianespace	613	2	0	45	0	660
Sales Private satellite operators RoW	1	220	8	41	6	276
Sales of equipment and parts RoW	83	446	64	50	15	657
Other/unknown RoW customers	4	2	0	15	4	25
Total	1316	3511	1132	1566	183	7707

The Space Sector has a complex contractual supply chain, where one prime contractor signs with a customer and then divides the work among itself and many subcontractors. The main actors in the Space Sector are often active along entire manufacturing value chains. In particular the space prime contractors are the assemblers of launcher systems and space vehicle systems. The main prime contractors of the European space industry are members of the LTF. The space manufacturing sector in Europe is at the same time very fragmented and very concentrated. The 30 largest space companies in Europe account

[19] ASD-EUROSPACE, facts and figures (2021)

for almost 80% of total employment in the sector. The remaining smaller players, of which there are hundreds, represent barely 20% of the total employment. The smaller players work almost exclusively as subcontractors to the larger players, except where they are involved in development activities and are directly contracted by space agencies, mostly ESA.

Annex 5. List of acronyms and *terms*

AA	Aluminium Alloys
AfA	Applications for Authorisation
AoA	Analysis of Alternatives
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
COTS	Commercial Off-The-Shelf
CTB	Components Technology Board *The CTB is a body subordinate to the SCSB and charged with the formulation of strategic programmes and work plans for technology research and development in the area of European EEE space components. It harmonises the collectively funded component research, development, evaluation, qualification, standardisation and quality assurance activities*
ECSS	European Cooperation for Space Standardisation *The ESCC body is an organization established with the objective of harmonising the efforts concerning the various aspects of EEE space components by ESA, European national agencies and international public space organisations, the component manufacturers and the user industries. The goal of the ESCC is to improve the availability of strategic EEE space components with the required performance and at affordable costs for institutional and commercial space programmes.*
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
ILA	International Lead Association
InPb	Indium-Lead
JUICE	Jupiter Icy Moons Explorer (see http://sci.esa.int/juice)
LETTERSS	Lead-free Transition for the European Space Sector
LTF	Lead (metal) REACH Space Task Force
MELF	Metal Electrode Leadless Face (i.e. without leads = wires)
MPTB	Materials and Processes Technology Board
OEL	Occupational Exposure Limit
OSH	Occupational Safety and Health legislation
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)
SCSB	Space Components Steering Board *Higher ESCC level body, final responsible of coordination and ESCC system management*
SEA	Socio-Economic Analysis
SnPb	Tin/Lead
TRL	Technology Readiness Level