Adaptation to scientific and technical progress under Directive 2002/95/EC

Final report

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Insitut e.V. request for technical guidance regarding the adaptation to scientific and technical progress of Annex II of the Directive 2000/53/EC (End of Life Vehicles), 2007

[15] Tailoka, F. & Fray, D. J. Selective removal of lead from aluminium, 1993

[16] Tailoka, F. et al. Electrochemical removal of lead from aluminium using fused salts. 1994

[17] EGGA (European General Galvanizers Association) Stakeholder contribution, exe. 6; 1 April 2008

4.10 Exemption No. 7a

"Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead")

4.10.1 Description of exemption

The lead-containing high melting point solders with 85% of lead and more are addressed as HMP solders in the following. High melting point solders containing no lead will be abbreviated with lead-free HMP solders.

The compositions of HMP solders typically are in the range of 90–97% lead by weight. These alloys can be found in a wide range of products, encompassing WEEE categories 1 through 10.

EICTA [2] indicates several applications of HMP solders:

1. HMP solders are used to form high reliability electrical connections. Examples of applications include large BGA or solder column packages, as well as some discrete devices in high reliability electronics. The lead content facilitates solder joints with a high resistance to thermal fatigue and to electromigration failure.

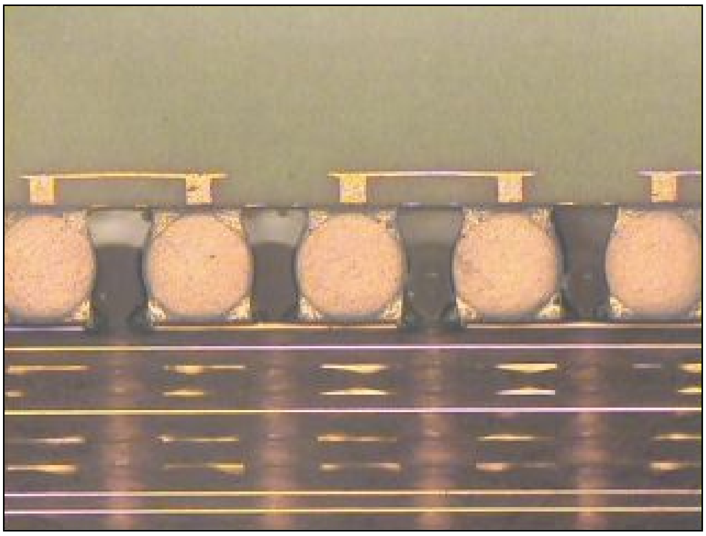

Figure 7 Ball Grid Array component with HMP balls [2]

2. HMP solders are also used to form a high conductivity thermal interface to the back of a semiconductor device, also known as die attach. The use of high melting temperature solders is required in power devices and discrete semiconductors. These typically are used in high reliability applications, such as server applications. The HMP solders enable high conductivity interfaces between the die and the lead frame/heat spreader. These are capable of meeting hierarchical reflow temperature requirements for components to be soldered to the board, while also having sufficient mechanical compliance required to prevent device damage during manufacture and operation.
   The melting point of these solders should be higher than the reflow temperature that is used for board assembly. The latter temperature has gone up to 260°C due to Pb-free assembly.
3. HMP solders are used as a sealing substance between tubular plugs and metal cases, e.g. in crystal resonators and crystal oscillators. These applications can be found in many products, including PCs, cellular phones, and other home appliances.

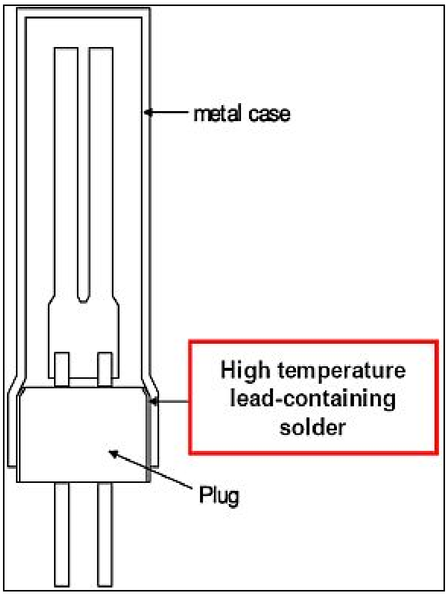

Figure 8 Schematic view of a crystal unit [4]

4. HMP solders are used for a reliable internal connection in passive components, to withstand soldering processes, especially those using lead-free solder. The varying lead content allows adjusting the melting point of the solder to the requirements of the manufacturing processes.

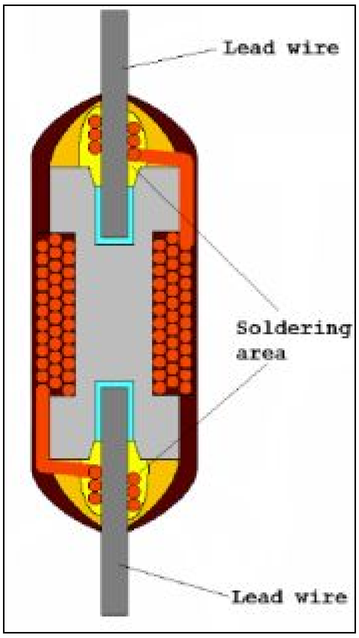

Figure 9 Passive component using HMP solders for internal solder joints [2]

High melting point solders containing lead are used in the following types of components that are commercially available and used by most electrical and electronics sectors [3]:

- Rectifiers
- Power semiconductor devices such as MOSFETs, power transistors etc.
- Voltage regulators
- Solder joints in equipment which operates at > 100°C
- Some types of fuses
- RF modules, attenuation modules and high frequency switches in telemetry medical devices
- Quartz crystal oscillators – some types
- Position sensor coils
- Inductor coils (some types)
- Surface mount transformers

JBCE [8] and EICTA [9] further complement the information on applications and technologies, in which they consider the use of HMP solders to be without alternative:

Intended Use	Reasons for Necessity	Related Products
Solders used for internally combining a functional element and a functional element, and a functional element with wire/terminal/heat sink/substrate etc. within an electronic component.	1. It is needed to achieve electrical characteristic and thermal characteristic during operation, due to electric conductivity, heat conductivity etc. 2. It is needed to gain high reliability for temperature cycles, power cycles etc. 3. When it is incorporated in products, it needs heatproof characteristics to temperatures higher than melting temperatures (250 to 260°C) of lead-free solders . 4. Stress relaxation characteristic with materials and metal materials at the time of assembly is needed.	Resistors, capacitors, chip coil, resistor networks, capacitor networks, power semiconductors, discrete semiconductors, microcomputers, ICs, LSIs, FCBGA, chip EMI, chip beads, chip inductors, chip transformers etc. (see Figure 10)

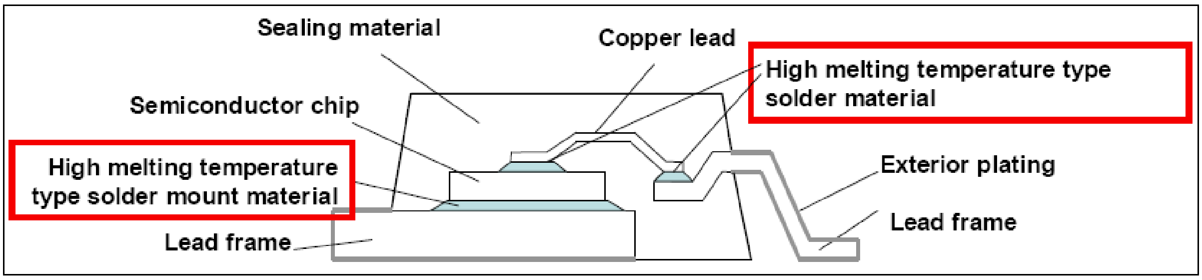

Figure 10 Schematic cross sectional view of internal semiconductor connection [8]

Intended Use	Reasons for Necessity	Related Products
Solders for mounting electronic components onto sub-assembled module or sub-circuit boards.	1. It is needed to achieve electrical characteristic and thermal characteristic during operation, due to electric conductivity, heat conductivity etc. 2. It is needed to gain high reliability for temperature cycles, power cycles etc. 3. When it is incorporated in products, it needs heatproof characteristics to temperatures higher than melting temperatures (250 to 260°C) of lead-free solders 4. Stress relaxation characteristic with materials and metal materials at the time of assembly is needed. 5. It is needed to prevent copper leaching that occurs when connecting it in the product using the copper wire.	Hybrid IC, modules, optical modules etc. (see Figure 11)

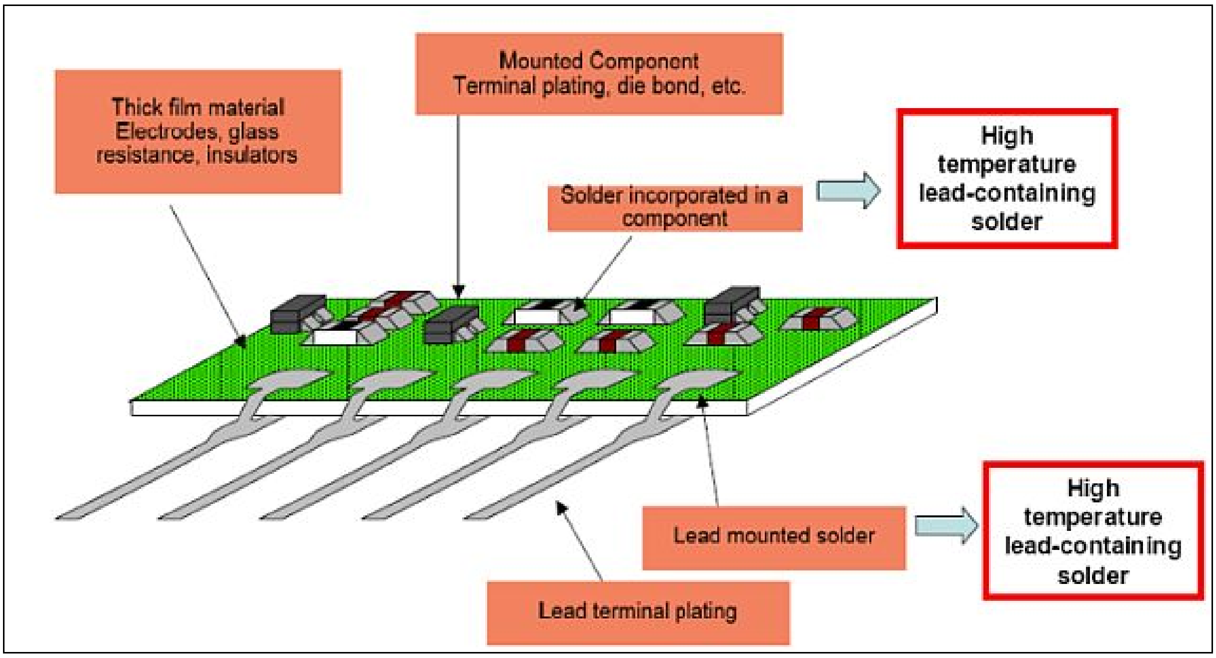

Figure 11 Schematic view of a circuit module component [8]

Intended Use	Reasons for Necessity	Related Products
Solders used as a sealing material between a ceramic package or plug and a metal case	1. Stress relaxation characteristic with materials and metal materials at the time of assembly is needed. 2. When it is incorporated in products, it needs heatproof characteristics to temperatures higher than melting temperatures (250 to 260°C) of lead-free solders. 3. It is needed to gain high reliability for temperature cycles, power cycles etc.	SAW (Surface Acoustic Wave) filter, crystal unit, crystal oscillators, crystal filters etc. (see Figure 8)

Annually, the production of such solders is estimated at around 10,000 t [1] containing about 9,000 t of lead. There is no information in this source neither on how this amount of solder relates to specific applications, nor how much of it is put on the market in electrical and electronics products in the European Union every year.

JBCE [7] estimates the amount of HMP solders put on the EU market with 3,600 t/year, corresponding to around 3,000 t of lead. This figure does not include the HMP solders contained in products imported into the EU market.

4.10.2 Justification by stakeholders

HMP solders are used because they are the only alloys that provide ALL of the following properties [3]:

- Melting temperature at ~280 – 320°C
- Ductility, as very hard materials induce strain onto adjacent materials if they have dissimilar coefficients of thermal expansion (TCE) when temperature changes occur and can cause fracture
- Good thermal and/or electrical conduction
- Good performance at high frequency (other die attach materials interfere with high frequency signals and so cannot be used)
- They do not form thick and brittle tin-copper intermetallic layers from interaction of tin (from solder) and copper substrates in equipment that operates at higher temperatures. These materials fracture under low strain if they are allowed to grow in thickness.

The stakeholders explain applications, in which the substitution of lead in HMP solders is scientifically and technically impracticable:

Electrical interconnects

EICTA [2] states that alternative alloys do not meet the reliability requirements. High lead solders contain a unique combination of ductility and reflow temperature hierarchy required for high reliability applications. At this moment there is no commercially available Pb-free material as a substitute that has the necessary electrical and / or thermal conductivity as well as the right material properties (such as coefficient of thermal expansion (CTE), ductility etc.) to maintain high reliability.

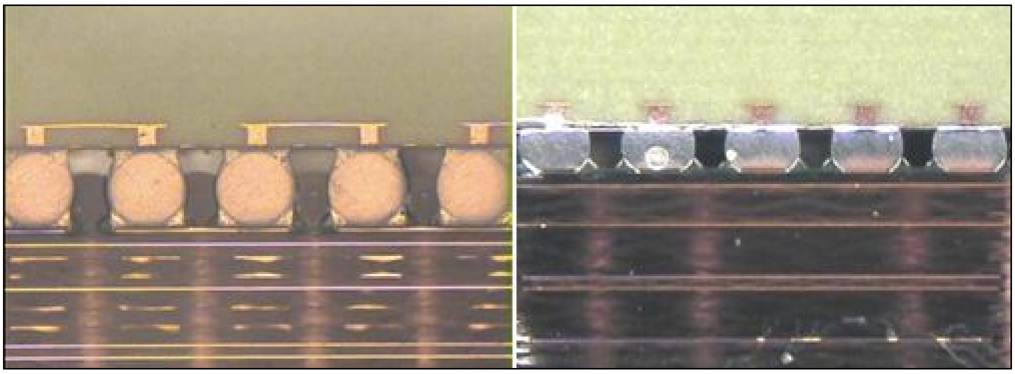

Figure 12 Ball Grid Array component with HMP balls (left) and lead-free solder balls [2]

Figure 12 shows a cross section of two versions of the same high-CTE ceramic package. One version uses HMP solder balls, while the other version used lead-free tin-silver-copper (Sn-Ag-Cu, or SAC) alloy balls. As can be seen, the distance between the package and the PCB is reduced considerably with the lead-free version. The lead-free solder balls melt during the assembly process, and collapses under the weight of the package. This reduced stand-off height significantly increases the solder joint strain for a given thermal cycle range. [2]

The replacement of high lead solder alloys in electrical interconnect will require a dramatic reduction in the solder joint stresses to enable the use of any of the known lead-free alloys. Lower solder joint stresses can only be achieved through the use of new electronic packaging materials. Selection of new packaging materials requires extensive electrical and mechanical characterization to assure long term reliability. An example of an alternative material that can reduce solder joint stress is replacement of ceramic ball grid array packages with organic laminate ball grid array packages. While these technologies have been shown suitable for many consumer applications, they have not yet been demonstrated to have adequate reliability for complex electronics interconnect, such as found in servers, networking equipment and high end gaming equipment. In addition, new Pb-free alloys will be needed to reduce electromigration (EM) failures to acceptable levels. Greater integration and higher power density of continually evolving electronic devices / systems will only exacerbate these factors. New Pb-free materials will need to handle future as well as existing conditions.

Thermal interface die attach

HMP die attach materials have a combination of good thermal performance, electrical performance and can deform in thermal cycling without cracking or causing joined components to crack. There are no known suitable Pb-free replacements. The high melting temperature alloys like AuSn are hard and brittle. Pb-free solutions perform poorly in thermal cycling reliability tests, typically cracking in either the solder or in the joints. Conductive adhesive materials do not yet have suitable thermal conductivity. These adhesives also have inconsistent results on joint quality. Development is underway, but could take many years to approach the capability of high Pb solder. [2]

The high lead solder has a high melting point as well as good thermal conductivity. The high melting point (> 260°C) is necessary because if the die attach material melts during board assembly there is a high chance of failures inside the package due to movement of the die (bond wire crossing). Although the die attach is high in Pb content the total volume is very limited due to the fact that this solder is only applied within the package in small amounts. [2]

Crystal oscillators

After the crystal resonator and crystal oscillator are delivered to the device manufacturer, the manufacturer solders them onto printed circuit boards. Recently, this solder is often Sn-Ag-Cu solder because of the lead-free trend. The temperature used for this soldering is 250° - 260°C. Sn-Ag-Cu solder melts at a temperature lower than 250°C (close to 217°C). However, crystal resonators and crystal oscillators that are joined by solder internally have to be able to withstand soldering temperatures of 250° - 260°C at the device manufacturer. For that reason, high temperature solder of more than 85% lead content is used to seal the interior of the crystal resonator or crystal oscillator to get the melting properties needed so the solder does not melt completely even at 250° - 260°C.

As a sealant, there are organic adhesives, but these cannot withstand vacuums because they are moisture-permeable. Therefore there are no substitute measures for high temperature solder. [2]

Lead-free alternatives

According to EICTA [2], lead-free alternatives have been developed for some uses, but are not a feasible replacement for all high-lead solder applications.

Current lead-free SnAgCu systems have melting points similar to the solders used in board assembly. If these solutions were used, then the die attach would become liquid, resulting in a reliability hazard. The same applies for the use of such solders in internal solder joints of passive components. SnCu alloys melt below 250–260°C as well, and thus create the same problems like the SngCu solder alloys.

SnAgSb as a further alternative suffers from the same low reflow temperature, as well as the uncertainty of the environmental impact of Sb (antimony).

SnAu80 is a commercially available Pb-free die attach with a high melting temperature, however, several concerns exist for this system. The interconnect is brittle, CTE mismatch between die and solder prevent the use on larger dies, and gold has a negative environmental impact according to EICTA [2].

AgCu alloys have a too high melting temperature at 700–900°C and thus are not a viable alternative either.

Table 5 gives an overview on different lead-free alternatives and their main properties.

Table 5 Overview on different lead-free HMP alternatives [3]

Material	Melting temperature	Ductility	Thermal and/or electrical conductivity
Lead, tin, silver alloy	300°C	Ductile	Good
Gold tin alloy (very expensive)	280°C	Hard and brittle	Good,
Tin- antimony alloy	232°C - too low	Fairly ductile	Good
BiSi and BiAg	~260°C moderately low	Hard and brittle	Good
Conducting epoxy resins (used as die attach for low power semiconductor devices)	Cured – do not melt, damaged by use at high temperature	Semi-hard varieties available	Poor (unsuitable for most power semiconductors)
Beryllium oxide (class 2 carcinogen)	Ceramic	Hard and brittle	Equal to copper

EICTA [2] claims that in all of the applications under discussion, the use of lead-free alloys would result in significant reduction in the reliability of a wide range of products. In the best case, decreased reliability would result in increased electronic waste due to premature device failure and reduced manufacturing yield. In the worst case, unexpected failures could cause consumer safety concerns. Many of the high performance / high reliability applications that use high-Pb solders require exacting performance characteristics because there is significant risk to human life / safety, including air traffic control, other transportation systems control and governmental security or defence systems. Low reliability substitutions in these systems would result in considerable human mortality / suffering. [2]

Invention of new Pb-free solders with appropriate melting ranges and with the necessary mechanical properties for sufficient reliability is still required. Since no candidates have yet been discovered, it is unlikely that such invention and subsequent reduction to practice can occur within the next four years. [2]

4.10.3 Critical review

Consequences of the material specificity of exemption 7a

Exemption 7*a*, contrary to other exemptions in the annex of the RoHS Directive, is not application, technology or use specific, but material specific. It generally allows the use of high melting point solders with 85% of lead (HMP solders) and more in electrical and electronic equipment wherever manufacturers want to use it.

In several applications, the substitution or elimination of the HMP solders at the current state of science and technology is impracticable. The exemption for such HMP solders therefore is fully justified for these cases according to the criteria of Art. 5. (1) (b) of the RoHS Directive. However, there are hints that HMP solders are used where alternative solutions reducing the amounts of lead are available.

1) The current general exemption for lead in HMP solders offers a loophole to bypass the use of lead-free solders or to avoid searching for other RoHS-compliant solutions that do not require the use of lead.
   Manufacturers use leaded HMP solders in applications, for which others offer lead-free solutions. The use of HMP solders in some quartz crystal oscillators where lead-free alternatives are available is an example (see [6], page 83). Although this use of lead is RoHS-compliant due to the material specific exemption for leaded HMP solders, its substitution in such applications is technically practicable. Despite of RoHS compliance due to the general character of this exemption, Art. 5 (1) (b) would not justify an exemption for such applications of leaded HMP solders. Such applications of leaded HMP solders contravene the objective of the RoHS Directive to reduce the use of lead in EEE.

2) The current general exemption unnecessarily increases the use of lead in applications, where lead-free solutions are technically impracticable and an exemption for the use of lower lead content solders would be possible or is already in place.
   "It has become more apparent that some of our customers are tending towards using higher lead alloys (typically 95% lead rather than 50% lead) ….". "…[we] have actively encouraged switching the lower lead content In/Pb solder alloys allowed by exemption 24." [5]
   Instead of using available or applying for a new exemption for the use of lead in low lead-content solders like e. g. the tin-lead solder with 37% lead (SnPb37), manufacturers may shift to HMP solders with high lead contents of 85% and more. Art. 5 (1) (b) would justify an exemption for the use of low lead content solders in these cases. Although the manufacturers achieve RoHS-compliance using the generally exempted leaded HMP solders, the use of this solder is not in line with Art. 5 1 (b).

Transition into application, technology or use specific exemptions

Considering the above-mentioned situation, and in line with the latest Commission decisions on exemptions which are application and technology oriented and thus are use specific, this exemption will be recommended to be changed into an application and technology specific one. The question for the review process hence was about the best way to achieve this transition.

Stakeholders described where the use of these HMP solders is still required. However, it cannot be assumed that these stakeholder comments cover all uses, in which the use of lead in HMP solders needs to be exempted in line with the criteria of Art. 5 (1) (b) of the RoHS Directive. Parts of the electronics industry thus might suddenly see themselves producing non-RoHS-compliant products if the general exemption would be changed into an application specific based on the available information from the stakeholder consultation for this review process. A new stakeholder consultation is required to give industry worldwide the opportunity to apply for the necessary application and technology specific exemptions.

Transition process and period

The reviewers propose leaving the exemption unchanged for now, but giving it an expiry date, which allows industry a reasonable time frame to apply for specific exemptions for the use of lead in HMP solders, where they are justifiable by the requirements set out in Art. 5 (1) (b).

The expiry date must allow for the application and technology specific exemptions to be in place before the material specific exemption ends.

Assuming the Annex will be amended until the end of 2009, the consultants propose 30 June 2013 as the expiry date for exemption 7a. This allows sufficient time to spread the information about the changes in the Annex of the RoHS Directive globally among the electrical and electronics industry. The remaining time is sufficient to reliably have the Annex of the RoHS Directive amended with the new exemptions for the high lead content HMP solders.

Necessity of exemptions for lead-containing high melting point solders

The stakeholders explained several applications and technologies, where the use of these solders is indispensable.

The consultants did not inquire whether the use of HMP solders actually is indispensable and without alternatives in each of the applications and technologies, which the stakeholders listed. Nevertheless, it is clear and common understanding, that there are several applications where the use of HMP solders with high lead content of 85% and more cannot be replaced at the current state of science and technology.

The general direction of the review in exemption 7a was the transformation process of the exemption towards an application and technology specific exemption.

After the official amendment of the Annex in the RoHS Directive, the stakeholders will have to apply for exemptions allowing the use of HMP solders in specific technologies and applications. The detailed assessment whether and how far the use of lead-containing high melting point solders is scientifically and technically impracticable in these applications or technologies will be conducted in these review processes.

To avoid misunderstandings, it must be clearly stated that exemption 7a is not recommended to expire because it is no longer needed, but just for the transformation from a material-specific to one or several application, technology and use specific exemptions.

Further on, it must be stated that the applications and uses of HMP solders, which the stakeholders submitted during this review process, are not exclusive. There may be other applications and technologies in which the use of HMP solders containing lead is justified in line with Art. 5 (1) (b), but which are not mentioned in this report. Stakeholders may apply for such exemptions once the RoHS Annex will have been amended officially.

4.10.4 Recommendation

Exemption 7a is a material specific exemption. It allows the use of high melting point solders containing 85% of lead and more (HMP solders) in all applications and technologies, even in those where lead-free alternatives are available, or where a specific exemption could be applied for or an existing one be used allowing the use of lead solders with lower lead contents. Such uses are not in line with Art. 5 (1) (b) and they contravene the spirit of the RoHS Directive to reduce the use of lead.

The stakeholders listed several applications and technologies where they state the use of HMP solders with 85% of lead and more to be without alternative. This list is not exclusive. It must be highlighted that there may be more applications and technologies requiring the use of HMP solders. The use of these HMP solders will be necessary further on in certain applications and technologies, and exemption 7a hence cannot be revoked. Lead-free alternative materials or alternative designs cannot substitute or eliminate HMP solders in all applications and technologies.

In line with the latest Commission decisions on exemptions which are application and technology oriented, the consultants propose transforming exemption 7a from its current material specific character into an application and technology specific exemption. To achieve this, the consultants recommend the continuation of exemption 7a in its current wording, but add an expiry date. Once the Annex of the RoHS Directive is amended officially, the stakeholders can start applying for application and technology specific exemptions following the example of the other exemptions in the Annex. The expiry date must reliably allow for application and technology specific exemptions to be in place once the general, material specific exemption 7a expires.

The RoHS Directive affects the electrical and electronics industry as well as their suppliers worldwide. It will take time to spread the change of exemption 7a and to organize the necessary exemption requests. The process from the submission of an exemption request until the official amendment of the Annex in the RoHS Directive may take more than one year. Assuming that the Annex of the RoHS Directive will be officially amended end of 2009, the expiry date 30 June 2013 is considered adequate to make sure the new exemptions are in place once the general exemption in its current wording expires.

For technical reasons, the repair and reuse of equipment, which was produced using HMP solders and was put on the market before the expiry of exemption 7a in its current character, must be made possible as well.

The future wording of exemption 7a is proposed as:

Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead) until 30 June 2013, and lead in such solders for the repair and reuse of equipment put on the market before 1 July 2013.

4.10.5 References

[1] Otmar Deubzer: Explorative Study into the Sustainable Use and Substitution of Soldering Metals in Electronics; PhD thesis TU Delft, January 2007, ISBN 978-90-5155-031-3

[2] EICTA online stakeholder consultation document "Exemption_7a_EICTA_and-others_1_April_2008.pdf"

[3] Paul Goodman, ERA; stakeholder document "7 technical information final-Goodman.pdf"

[4] EICTA stakeholder document "EICTA position on Exemption 7a 28th July 2008.pdf"

[5] Stakeholder document "Exemption_7a_24_Syfer-Technology_31_March_2008.pdf"

[6] Ökoinstitut e.V., Fraunhofer IZM: Adaptation to Scientific and Technical Progress under Directive 2002/95/EC; final report July 2006; document "rohs_report.pdf", http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf; last access 22 October 2008

[7] JBCE stakeholder document "Exemption-7a_JBCE_1_April_2008.pdf"

[8] JBCE stakeholder document "JBCE Additional Input RoHS Exemption 7a-july2008.pdf"

[9] EICTA stakeholder document "EICTA position on Exemption 7a 28th July 2008.pdf"