Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment:

Study to assess renewal requests for 29 RoHS 2 Annex III exemptions [no. l(a to e -lighting purpose), no. l(f - special purpose), no. 2(a), no. 2(b)(3), no. 2(b)(4), no. 3, no. 4(a), no. 4(b), no. 4(c), no. 4(e), no. 4(f), no. 5(b), no. 6(a), no. 6(b), no. 6(c), no. 7(a), no. 7(c) - I, no. 7(c) - II, no. 7(c) - IV, no. 8(b), no. 9, no. 15, no. 18b, no. 21, no. 24, no. 29, no. 32, no. 34, no. 37]

Carl-Otto Gensch, Oeko-Institut

Yifaat Baron, Oeko-Institut

Markus Blepp, Oeko-Institut

Katja Moch, Oeko-Institut

Susanne Moritz, Oeko-Institut

Otmar Deubzer, Fraunhofer Institute for Reliability and Microintegration, IZM

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Report for The European Commission

Prepared by Oeko-Institut e.V., Institute for Applied Ecology and Fraunhofer-Institut IZM for Environmental and Reliability Engineering

Oeko-Institut e.V.

Freiburg Head Office, P.O. Box 1771
79017 Freiburg, Germany

Tel.:+49 (0) 761 – 4 52 95-0
Fax +49 (0) 761 – 4 52 95-288

Web: www.oeko.de

Fraunhofer-Institut IZM

Gustav-Meyer-Allee 25
13355 Berlin, Germany

Tel.: +49 (0)30 / 46403-157
Fax: +49 (0)30 / 46403-131

Web: www.fraunhofer.de

Approved by:

Adrian Gibbs, Eunomia	Carl-Otto Gensch, Oeko Institute e.V
(Peer Review)	(Project Director)
………………………………………………	………………………………………………

Eunomia Research & Consulting Ltd
37 Queen Square, Bristol, BS1 4QS, UK

Tel: +44 (0)117 9172250
Fax: +44 (0)8717 142942

Web: www.eunomia.co.uk

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Disclaimer:

Eunomia Research & Consulting, Oeko-Institut and Fraunhofer Institute IZM have taken due care in the preparation of this report to ensure that all facts and analysis presented are as accurate as possible within the scope of the project. However no guarantee is provided in respect of the information presented, and Eunomia Research & Consulting, Oeko-Institut and Fraunhofer Institute IZM are not responsible for decisions or actions taken on the basis of the content of this report.

30.0 Exemption 24 “Pb in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CTE	coefficient of thermal expansion
CCTV	closed circuit television, video surveillance systems
EMI	electromagnetic interference
HMPS	high melting point solders
LHMPS	lead-containing high melting point solder(s)
MLCC	multi-layer ceramic capacitors

30.1 Description of the Requested Exemption

Knowles et al. [1693] apply for the continuation of Exemption 24 in its current wording and scope. The current wording of Exemption 24 is

> *“Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors”*

[1693] Knowles Capacitors et al. 2015a: 2015 “Request for continuation of exemption 24, document "24_RoHS_V_Application_Form_E24_final_160115.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/24_RoHS_V_Application_Form_E24_final_160115.pdf

30.1.1 Background and History of the Exemption

The exemption was not yet listed in the Annex of RoHS 1 when it was published in 2003. The exemption was requested and reviewed in 2005/2006, and the Commission followed the reviewers' recommendation[1694] to grant the exemption with the same wording and scope as still valid in the current exemption. The exemption was renewed without changes after the next review in 2008/2009[1695], and was adopted into Annex III of RoHS 2 in 2011. Its foreseen expiry date would have been July 2016 if no requests for renewal had been submitted.

30.1.2 Technical Description of the Exemption

Knowles et al.[1696] use indium-lead solders with 40 % to 50 % lead content (In60Pb or In50Pb, the latter being the preferred alloy), which provides the combination of a suitable melting point and ductility. The ductility of this solder avoids cracking of the ceramic layer during and after soldering due to thermal mismatch between the ceramic capacitor and the copper pin.

Knowles et al.[1697] explain that discoidal and planar array capacitors are derivations of MLCC's (multi-layer ceramic capacitors) with the opposing terminations made to the outside periphery and the inside diameter of holes drilled through the ceramic body. They are specialist capacitors used in EMI (electromagnetic interference) filters and EMI filtered connectors for high end applications, where the elimination of electrical interference is critical. Typical applications for assemblies incorporating these components and covered by the RoHS directive include professional audio equipment, maritime monitoring (coastguard radar) and CCTV (closed circuit television, video surveillance) systems. In application, signal carrying feedthrough pins are passed through the ceramic element and connected to the internal bore to make a mechanical and electrical connection. This connection must have low electrical resistance and inductance for optimum performance, as high resistance / inductance will inhibit the high frequency electrical path to ground through the filtering capacitor. Traditionally this connection is made by lead solder, as lead-free solders cause cracks in the ceramic element.

[1694] Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006 "Adaptation to scientific and Technical progress under Directive 2002/95/EC: Final Report - final version, RoHS I," http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf page 14 et sqq.

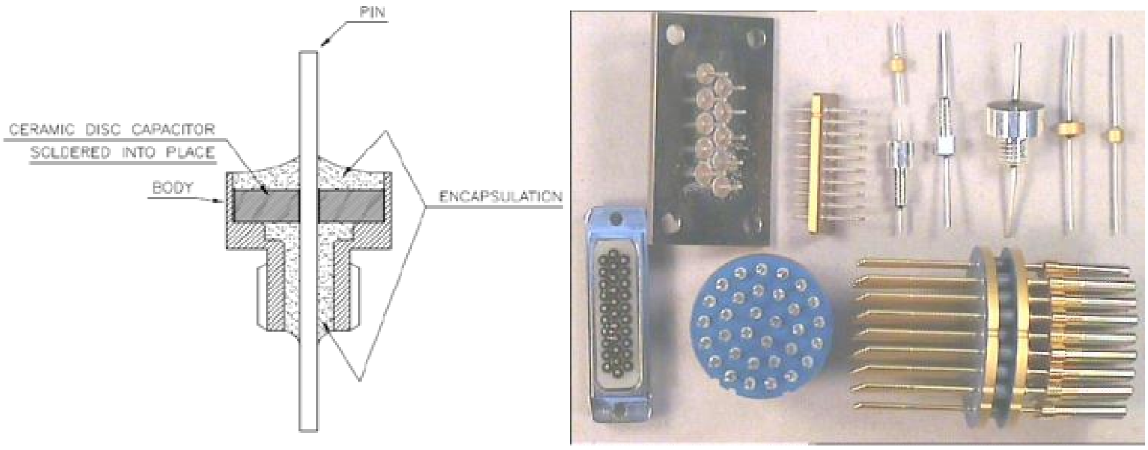
[1695] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009) Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, RoHS III, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM, http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[1696] Knowles Capacitors et al. 2016a "Answers to Second Questionnaire, document "Exe_24_Questionnaire-2_Knowles-et-al_Response_2016-02-09.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, via e-mail from Stephen Hopwood, Knowles Capacitors, on 9 February 2016" unpublished manuscript,

[1697] Op. cit. Knowles Capacitors et al. 2015a, page 214 et sqq.

Knowles et al.[1698] as component suppliers are not aware of all applications where this product is used, but in general it is for high end applications where performance is more important than cost. They are not generally used in low cost consumer electronics. Knowles et al. include category 11 to cover unknown applications. Figure 30-1 shows EMI filters as one typical application in the scope of exemption 34.

Figure 30-1: EMI filter outline (left) and examples of EMI filters and assemblies



Source: Knowles et al.[1699]

A detailed description of the technical background can be found in the report of the last review in 2008/2009.[1700]

30.1.3 Amounts of Lead Used under the Exemption

According to Knowles et al.[1701], the lead content varies with filter design, but typically is 5 mg to 10 mg per solder joint, equating to ~1.0 % of the total component weight (maximum). More complex designs such as filter connectors will be proportionally less as a percentage of the total weight. The total amount of lead put on the EU market under the exemption is estimated to be less than 50 kg as quantified from the information in the following paragraphs.

[1698] Ibid.

[1699] Knowles Capacitors et al. 2015b: "Addendum to request for continuation of exemption 24, document "Application Note AN0011 Solder Alloy Choice for Through Hole Ceramic Discoidal & Planar Array Capacitors.pdf": Addendum to request for continuation of exemption 24," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/Application_Note_AN0011_Solder_Alloy_Choice_for_Through_Hole_Ceramic_Discoidal__Planar_Array_Capacitors.pdf

[1700] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009)

[1701] Op. cit. Knowles Capacitors et al. 2015a

Knowles et al.[1702] have no accurate data available to indicate the amount of lead entering the EU in this type of application, however most applications of these components are not covered by the RoHS directive. There are two major players in the supply of planar arrays for EMI filtered connectors, and customers informed Knowles et al. that they account for ~60 % of the market. The average manufacturing of Knowles et al.[1703] is 357,000 capacitive holes per week, amounting to 18.6 million capacitive holes per year, indicating the market is around 31 million capacitive holes per year. The nature of these components is such that they are mainly used for high end applications such as aerospace and military, where technical performance outweighs cost. Knowles et al.[1704] estimate from feedback that only around 4 % of parts are supplied into applications covered by the RoHS directive, corresponding to around 1.25 million capacitive holes. Each hole takes up to 10 mg of lead in a typical solder joint, the total lead from filtered connectors entering RoHS applications per year thus being around 12.5kg maximum

With regard to EMI single line filters, Knowles et al.[1705] estimate the global market at $70 million with a typical selling price of $1.50 per line. From this, using the same 4 % estimate of parts shipping to RoHS applications, indicates the number of lines soldered would be ~1.9 million per year. Again, based on the same lead weight per solder joint of 10mg, this equates to around 19 kg of lead maximum.

Adding the two figures together gives the estimate of 32kg per year supplied into applications covered by the RoHS directive. Allowing for errors and assumptions, Knowles et al.[1706] apply a figure of less than 50 kg.

According to Knowles et al.[1707], these calculations take into account feedthrough lines (unsoldered) and filtered connectors making use of spring clip technology. They do not take into account filters manufactured using high melting point solders with a lead content of at least 85 % where the high melting point solder is needed to allow step soldering of the finished article or during final assembly of the finished article. This application is covered by exemption 7a.

Knowles et al. [1708] state that lead-containing high melting point solder (LHMPS) have the same ductility benefits as indium-lead alloys, but obviously the higher lead content and high processing temperatures (high energy usage) mean this is not a sensible substitution to make on the basis of environmental concerns.

Without exemption 24, the amount of lead used for soldering to machined through hole discoidal and planar array ceramic multilayer capacitors would increase, as the LHMPS

[1702] Ibid.
[1703] Ibid.
[1704] Ibid.
[1705] Ibid.
[1706] Ibid.
[1707] Ibid.
[1708] Ibid.

with at least 85 % of lead content would have to be used instead of the indium-lead solders used under exemption 24 which have a maximum weight share of 50 % lead.

30.2 Applicants' Justification for the Continuation of the Exemption

30.2.1 Elimination of Lead

According to Knowles et al.,[1709 1710] where it is technically necessary to use solder, there are no known replacements for lead containing alloys. In some cases it has, however, been possible to replace solder with mechanical connections, i.e. spring clips and canted coil springs. Canted coil springs fulfil the same function as spring clips. There are no other purely mechanical methods of connecting to the smooth plated inside bore of the ceramic capacitor and the plated surface of the through lead. The spring clip/coil technology allows making solderless connections.

According to Knowles et al.[1711], the clips and coils have been used in EMI filtered connector applications to make the contact between the planar capacitor array and the through connector pin where they were suitable based on the product requirements. They are the ultimate in reducing stress on the ceramic, but there are limits to their use:[1712, 1713]

1) The technique takes up more physical space, reducing available capacitance and reducing the electrical performance of the device. For this reason the use is limited to larger size filtered connectors with wide contact pitch and lower filtering requirements.
2) The technique does not provide a 100 % grounding ring, so can reduce EMI performance and allow high frequency noise to pass through.

Knowles et al.[1714] claim that the usability of spring clips depends on many factors which may interact:

- Component size;
- Contact (pin) size;

[1709] Ibid.

[1710] Knowles Capacitors et al. 2015c: 2015 "Answers to first questionnaire (clarification questionnaire), document "Ex_24_Knowles-et-al_Questionnaire-1_2015-08-10_response.pdf": Clarification questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/Ex_24_Knowles-et-al_Questionnaire-1_2015-08-10_response.pdf

[1711] Knowles Capacitors et al. 2016c "E-mail communication, document "E-mail-communication_Knowles.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, until 16 March 2016" unpublished manuscript,

[1712] Op. cit. Knowles Capacitors et al. 2015a

[1713] Op. cit. Knowles Capacitors et al. 2015c

[1714] Ibid.

- Working voltage;
- Pin pitch;
- Required capacitance / filtering performance; and
- Whether the clip can be isolated from any sealants, epoxies or coatings that are required to achieve the desired performance within the available size envelope.

Knowles et al.[1715] state that single line filters are not made using clips as the dimensions of the units do not allow it. Single line filters also do not allow for isolation of the clip from sealing resins and are too small to allow use of a clip whilst maintaining the necessary capacitance values. Larger filtered units, for example multiway filtered connectors, may use mechanical connections if the mechanical and electrical requirements allow it. However there is a general trend for smaller connectors with tighter pitches that precludes the use of mechanical connections due to the physical and electrical requirements. The clip technique takes up more physical space, reducing available capacitance and the electrical performance of the device. For this reason the use is limited to larger size filtered connectors with wide contact pitch and lower filtering requirements. Additionally, the clip technology can reduce EMI performance and allow high frequency noise to pass through.

Knowles et al.[1716] claim that the evaluation where clips/coils can be used is complex to a degree that it cannot be governed down to a set of rules as there are too many parameters that need to be considered.

Knowles et al. [1717] claim that the evaluation where clips/coils can be used is based on the many parameters listed above making it a complex task. For example, assuming a required level of filtering, it can easily be translated into a necessary capacitance value, and the voltage rating and diameter of the pin can also be defined. In a multi-element connector, the pin-pitch is also known. With this, the available mechanical area can be defined in which the capacitance must be achieved. In the available mechanical area allowance must be made for the joint area. A mechanical clip takes up much more of this area than does a solder joint. Solder has the ability to wet and flow into small gaps – typically 0.1 mm or so – between the pin and the inside bore of the capacitor. Clips will typically need to have around 0.35 mm gap between the capacitor and the pin, so around 0.7 mm per joint around the diameter of the pin. This can dramatically reduce the available area to achieve the capacitance required. In some cases it would make it impossible to fit a capacitor at all in the area that remains.

[1715] Knowles Capacitors et al. 2016b “Answers to third questionnaire, document "Exe_24_Questionnaire-3_Knowles-et-al_2016-03-01.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Hopwood, Knowles Capacitors, on 8 March 2016: Answers third questionnaire” unpublished manuscript,

[1716] Ibid.

[1717] Ibid.

Knowles et al.[1718] say that the spring/clip must be isolated from sealants or resins to prevent them breaking the electrical contact between the pin and the capacitor. Barrier boards are required which again increase the length of the unit so that it can be impossible to fit the required capacitance into the available space envelope.

Finally, according to Knowles et al.[1719] there is the issue of vibration resistance which can preclude the use of a clip as the contact can be lost increasing the resistance and adversely affecting the functionality of the device. A solder joint provides a guaranteed connection at all times.

Knowles et al.[1720] conclude that each case will be different, with so many variables as listed above so that they cannot provide general criteria to define where clips can replace the lead-containing solders.

30.2.2 Substitution of Lead by Lead-free Solders

Knowles et al.[1721] claim that when lead-free solder is used to connect the feedthrough pins to the internal bore to make a mechanical and electrical connection, the shrinkage of the solder and pin assembly within the bore exerts a tension force on the inside of the bore, sufficient to form micro-cracks in the ceramic element. These cracks have a recognisable shape and form. If the crack propagates through the electrically active portion of the design, where electrodes of opposing polarities overlap each other, then the result can be a low resistance path or an electrical short circuit, resulting in failure of the electrical system and potentially health and safety risks to operators. Knowles et al.[1722] tested the alloys listed in Table 30-1.

30.2.2.1 Tests of Lead-free Solders

According to Knowles et al.[1723], the tested solders specified in Table 30-1, represent the solders currently in use for the assembly of EMI filters, conventional tin lead solders and samples of proposed lead-free replacement solders. In each case, except for the two LHMPS alloys, two sample sets of filters were assembled and reflowed using a five zone hot air reflow furnace. Sample 1 had a standard solder profile with forced cooling by air blowers after zone 5. Sample 2 was reflowed using the same soldering profile but with the cooling air blowers turned off to allow gradual cooling, so as to reduce the stresses on the ceramic.

Knowles et al. [1724] explain that 95Pb/5In solder has a high melting point of between 300 °C and 313 °C, and 93.5Pb/5Sn/1.5Ag a high melting point of between 296 °C and

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[1718] Ibid.
[1719] Ibid.
[1720] Ibid.
[1721] Op. cit. Knowles Capacitors et al. 2015a
[1722] Knowles Capacitors et al. 2015b
[1723] Knowles Capacitors et al. 2015b
[1724] Knowles Capacitors et al. 2015b

301 °C, so neither could be soldered using the available hot air furnace. Instead samples of these were assembled using a hot plate at 425 °C. Preheat was not used. Sample 1 parts were force cooled by placing directly in front of a desk fan. Sample 2 parts were allowed to gradually cool. The samples were then sectioned, allowing the capacitor structure around the solder joints to be inspected for cracking.

Table 30-1: Tested solders and results

Alloy Type		Cooling	Defective 'Longbow' (%)	Defective Total (%)
62Sn/36Pb/2Ag	Traditional low melting point lead solder	forced	80	100
		gradual	20	60
60Sn/40Pb	Traditional low melting point lead solder	forced	100	100
		gradual	60	80
99.3Sn/0.7Cu	Lead free 'plumbers' solder	forced	100	100
		gradual	100	100
95.5Sn/3.8Ag/0.7	Lead free solder recommended for PCB assembly	forced	100	100
		gradual	40	80
50Pb/50In	Ductile stress relieving solder	forced	0	0
		gradual	0	0
95Pb/5In (LHMPS)	Ductile stress relieving high melting point solder	forced	0	0
		gradual	0	0
93.5Pb/5Sn/1.5Ag (LHMPS)	Ductile stress relieving high melting point solder	forced	10	10
		gradual	0	0

Source: Knowles et al.[1725]*, modified*

Knowles et al.[1726] that the LHMPS joints were made using capacitors without solder pads as available jigging did not allow padded parts to be assembled. This eliminated corner

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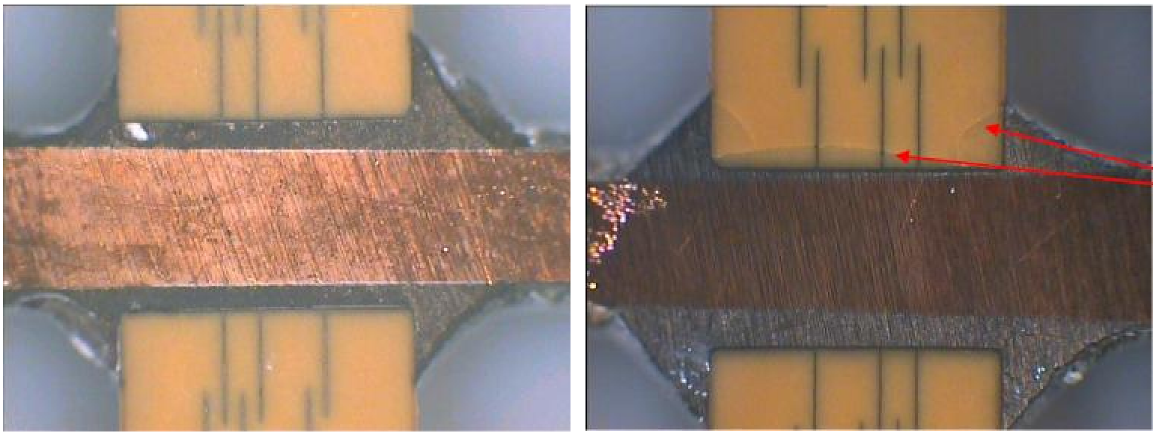
[1725] Knowles Capacitors et al. 2015b

cracking and may have slightly shifted the results towards a too positive result for the LHMPS. However, the very low level of longbow cracking found in HMP-soldered parts (10% of force cooled 93.5Pb/5Sn/1.5Ag joints only) still indicates the improved performance of these alloys.

Figure 30-2 shows the example of a test sample without cracks (50Pb/50In with gradual cooling) and a gradually cooled test sample soldered with SnAgCu solder.

Figure 30-2: Test sample without cracks (50Pb/50In, left) and sample with long bow and corner cracks (SnAgCu, arrows, right)



Source: Knowles et al.[1727]

Knowles et al.[1728] conclude that lead containing solders, often in conjunction with other metals such as indium, impart a degree of ductility to the solder joint, allowing stress release within the joint and absorbing the forces applied to the ceramic. Alternative solder alloys, such as tin-based lead-free alloys and SnPb alloys, do not have sufficient ductility to prevent stress damage to the ceramic and can represent a reliability / safety risk during the operating life of the component.

30.2.2.2 Use of Alternative Materials with Less Difference in CTE

Knowles et al.[1729] explain that dielectric ceramic - the same material as used by chip capacitor MLCC - is a sintered brittle material selected primarily for its electrical properties. All ceramic dielectrics are liable to mechanical stress cracking. There are no ceramic dielectric materials currently available with sufficient ductility or crack resistance.

According to Knowles et al.,[1730] the pin material used in this type of component is copper, brass and very occasionally steel, chosen for its machinability and electrical

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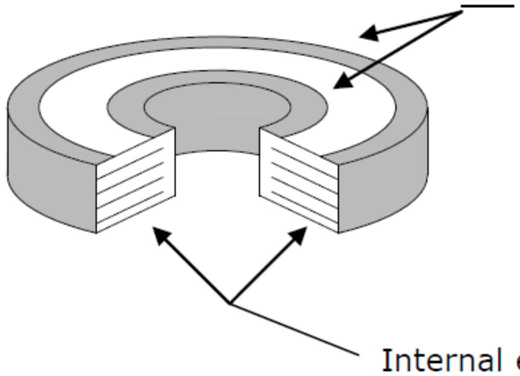
[1726] Knowles Capacitors et al. 2015b
[1727] Knowles Capacitors et al. 2015b
[1728] Ibid.
[1729] Op. cit. Knowles Capacitors et al. 2015c
[1730] Ibid.

conductivity. The lead-free soldering tests (c.f. Table 30-1) were conducted with silver-plated copper pins, which is the most malleable of the pin materials normally used. The use of other pins and platings would thus even aggravate the crack problem.

In combination with palladium-silver (PdAg) platings, as an alternative approach to enable lead-free soldering, lead-free solders cause failures as well, even though different ones.

Figure 30-3: Typical stray capacitor discoidal construction



Source: Knowles et al.[1731]

Knowles et al.[1732] describe that PdAg platings reduce the bond strength between the termination and the ceramic, compared to gold plating. The effect of this is that the contraction forces tend to stress relieve the assembly at the termination / ceramic interface rather than inside the ceramic structure in the form of a crack. Tests were carried out using capacitor arrays with the electrical design shown above and terminated with PdAg termination material. The advantage with this type of construction is that any failure of the internal termination or ceramic cracking is demonstrated by a drop in the capacitance. This is because of the introduction of an alternative dielectric material – air – in the area of the failure. Prior to assembly, the capacitance of the holes with this design was recorded. The assembly was soldered using 95.5Sn/3.8Ag/0.7Cu lead-free solder and hot air reflow. After assembly, the capacitance was re-measured. Table 30-2 shows the results of the tests undertaken. Knowles et al.[1733] state the drop in capacitance for both soldered arrays indicates failures in all assemblies. Details about the failure mechanism are explained in Knowles et al. 2015b.[1734]

[1731] Op. cit. Knowles Capacitors et al. 2015b
[1732] Ibid.
[1733] Ibid.
[1734] Ibid.

Table 30-2: Test results of PdAg-plated discoidal MLCC soldered with lead-free solders

Array No. 1			Array No. 2		
Start Capacitance (pF)	Capacitance after Soldering (pF)	Change (%)	Start Capacitance	Capacitance after Soldering	Change (%)
551	296	-46.3	539	331	-38.6
550	242	-56.0	540	256	-52.6
550	300	-45.5	535	196	-63.4
552	249	-54.9	536	189	-64.7
553	244	-55.9	532	323	-39.3
546	474	-13.2	538	151	-71.9
544	351	-35.5	536	91	-83.0
543	418	-23.0	539	175	-67.5
551	339	-38.5	544	353	-35.1
551	520	-5.6	536	168	-68.7
546	368	-32.6	536	176	-67.2
550	289	-47.5	534	317	-40.6
544	451	-17.1	544	173	-68.2
544	443	-18.6	543	153	-71.8
550	242	-56.0	543	285	-47.5

Source: Knowles et al.[1735]

Knowles et al. conclude that the use of lead solders is currently still required and ask for the continuation of exemption 24.

30.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

Knowles et al.[1736] see no scope for replacing solder as the primary method of making electrical and mechanical connection between the capacitor and the through conductor pin. They continue to monitor the solder industry through web searches and in conjunction with their partner solder supplier Indium Corporation, but they claim no viable alternatives to lead containing alloys to be available at the present time.

30.4 Critical Review

30.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead and cadmium in various articles and uses.

[1735] Ibid.

[1736] Op. cit. Knowles Capacitors et al. 2015a, page 17 et sqq.

The exemption reduces the amount of lead used in some of the applications in the scope of Exemption 24. Indium replaces part of the share of lead in the lead-containing solder so that Annexes XIV and XVII need to be checked for entries regarding lead and indium.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as a directly added substance nor as a substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds and indium phosphide shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 28 and Entry 30 of Annex XVII does not apply to the use of lead and indium in this application. The use of lead and indium in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead and indium are part of an article and as such, Entry 28 and Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds…

1) *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."* This restriction, however, does not apply to internal components of watch timepieces inaccessible to consumers;
2) *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable*

conditions of use, be placed in the mouth by children." This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under Entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

30.4.2 Elimination of Lead

Knowles et al. explain that the usability of spring clips depends on multiple parameters. Neither during the stakeholder consultation, nor at a later stage of the review process, have other sources of information or contrary information become available disproving the statement of Knowles et al. While it is possible to eliminate the use of lead in some cases, the consultants conclude, based on the available information, that it is not possible to define an exemption wording with a clear-cut demarcation of applications where these clips can be used.

30.4.3 Substitution of Lead

30.4.3.1 Use of Lead-free Solders

The applicant plausibly shows that lead-free solders currently cannot replace the lead-containing solders. One key reason for this is the higher ductility of lead-solder, which thus can better balance the different coefficients of thermal expansion (CTE) between the pin and the ceramics.

One possible approach could thus be to use a different material for the pin with a CTE closer to the other materials involved. Knowles et al.[1737] claim that the pin materials are fixed as copper alloys by application. No other material is acceptable to the industry as offering the appropriate combination of physical and electrical characteristics. Alternative pin materials are thus not considered an option.

30.4.3.2 Replacement of Lead-containing High Melting Point Solders

In the 2008/2009 review[1738], Knowles – at that time named "Syfer" – said that some of its customers are tending towards using higher lead alloys typically containing 95 % of lead rather than 50 % as preferred by Syfer/Knowles to overcome the limitations of the RoHS Directive. Knowles/Syfer at that time considered this solution to represent a negative environmental impact. Lead-containing high melting point lead solders (LHMPS, as currently still exempted under Exemption 7a) with Pb content > 90 % also tend to

[1737] Op. cit. Knowles Capacitors et al. 2015c: 2015
[1738] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009)

have the ductility demanded, 92.5Pb/5In/2.5Ag or 95Pb/5In being the most likely solutions. However, alloys with this content of lead have much higher reflow temperatures - 92.5Pb/5In/2.5Ag has a liquidus temperature of 310 °C compared with 210 °C for 50Pb/50In alloy. This will demand new equipment capable of reaching much higher temperatures. Trials have shown that an inert atmosphere will also be necessary to prevent oxidisation problems. The use of these LHMPS would increase the use of lead as well as the energy consumption due to the higher soldering temperatures and for the production of the inert gas. Syfer/Knowles state, however, that some applications require the use of LHMPS in such capacitors.

The applicants were asked whether the above statement is still correct. Knowles et al.[1739] replied that they recommend their customers always to use indium-lead solders where possible, with LHMPS being used where the technical demands require a higher melting point alloy. They believe that customers they are in regular contact with generally follow this advice. The comments regarding the processing limitations for LHMPS, i.e. high process temperatures, higher energy consumption and inert atmospheres, still hold true.

Exemption 24 thus offers an alternative to LHMPS with less use of lead involved. Vice versa, the use of lead in this application would increase without exemption 24 because LHMPS with higher lead contents as exempted in the current exemption 7a may remain as the only alternative.

Exemption 24 thus offers an alternative to reduce the use of lead. LHMPS contains at least 85 % of lead and typically even more than 90 % in the application in the scope of exemption 24, while the alternative indium-based solders apply a maximum of 50 % of lead. The use of lead in this application would therefore increase without exemption 24 because LHMPS with higher lead contents as exempted in the current exemption 7a remains as the only alternative.

Knowles et al.[1740] use indium-lead solders with melting points of around 210 °C. This means that the components within existing designs would not survive a standard soldering process with the most frequently used lead-free solders, which have melting points above 210 °C. Knowles was therefore asked how they can use these indium-lead solders without problems in subsequent soldering processes, in which the component is, for example, bonded onto a printed circuit board.

Knowles et al.[1741] [1742] explain that the types of MLCC covered by exemption 24 are chiefly used in applications where subsequent assembly is by selective soldering, usually

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[1739] Op. cit. (Knowles Capacitors et al. 2016a)
[1740] Op. cit. (Knowles Capacitors et al. 2015a)
[1741] Op. cit. (Knowles Capacitors et al. 2016a)
[1742] Knowles Capacitors et al. 2016d "Answers to questionnaire 2 related to exemption 7a, document "Exe_7a_Questionnaire-2_Knowles_2016-03-29.pdf", received from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript

by hand and only to the end pin of the filter/connector. Where a low melting point alloy such as Pb50In50 is used for the assembly of the component, it is preferable from both a lead content and a process point of view. In such cases, the finished component or connector would not be expected to be processed through a standard reflow soldering practice. Otherwise, where a component is designed to be subsequently mounted using standard reflow soldering techniques, it will be assembled using LHMPS. This type of component would then be rated for assembly using conventional lead-free solders, in contrast to those assembled with for example with Pb50In50. The current scope of Exemption 24 covers both of these cases, thus allowing the use of high melting point solders with 85 % and more of lead as well as other solders with lower lead contents.

The consultants tried to clarify[1743] why not all capacitors in the scope of exemption 24 can be soldered selectively so that the use of LHMPS would no longer be required, but this information was not available until the end of the review process. Given the considerable efforts undertaken and the limited time and resources available, it was not possible to follow this technical discussion further.

30.4.4 Conclusions

30.4.4.1 Substitution and Elimination of Lead

The applicants plausibly explain that lead-solders are required to solder the pins into discoidal and planar array multilayer capacitors. Lead-free solders are not sufficiently reliable. Alternative approaches to enable the use of lead-free solders, i.e. the use of different pin materials with more appropriate coefficients of thermal expansion, and alternative plating's, in order to allow the use of lead-free solders, are not technically viable either.

Elimination of soldering via the use of spring clips is an option in some cases, but such cases cannot be clearly demarcated from those areas, which require the use of lead-solders as already determined in the 2008/2009 review[1744]. The situation remains that it is not possible to define a functional exemption wording with a clear-cut demarcation of applications where spring clips can be used.

In the absence of Exemption 24, LHMPS with at least 85 % of lead would have to replace the indium-lead solders with a maximum of 50 % of lead. Exemption 24 thus contributes to reduce the amount of lead as long as the situation persists that lead-free solutions are not available. Based on the available information, the reviewers conclude that renewing Exemption 24 would be in line with the requirements of Art. 5(1)(a).

The current scope of the exemption covers both the use of high melting point solders with 85 % and more of lead as well as other solders with lower lead contents such as Pb50In50. As it has not been possible to detail why the selective soldering of the components in the scope of Exemption 24 could not be generally applied to avoid the

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[1743] Ibid.

[1744] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), page 214 et sqq.

use of LHMPS, a rewording targeting a reduction of the maximum content of lead in the solders to less than 85 % could not be proposed.

Even though lead cannot yet be fully substituted, restricting the scope of Exemption 24 to exclude the use of LHMPS would at least reduce the amounts of lead used. Granting the continuation for the maximum of five years would not be justified in line with the requirements of Art. 5(1)(a). To further clarify the scope of the exemption, the consultants recommend granting the exemption for 30 months. As a sound justification why selective soldering cannot be used for all capacitors in the scope of this exemption to avoid the use of LHMPS, in the consultants' opinion does not require further research and development, 30 months should be sufficient time to apply for the renewal of the exemption in time 18 months prior to its expiry.

30.4.4.2 Avoiding Overlaps with Exemption 7(a)

Exemption 7(a) currently covers the use of LHMPS in electrical and electronic equipment so that there is a scope overlap with Exemption 24. The use of LHMPS in the capacitors in the scope of Exemption 24 should therefore be excluded from the scope of Exemption 7(a) to avoid that the use of solders in these capacitors is covered by two different exemptions. In the course of a future scope refinement of Exemption 24, the lead-content of the solder used under Exemption 24 could be reduced to a level below 85 % thus excluding the use of LHMPS provided this is scientifically and technically practicable. In this case, the references to Exemption 24 could be removed from Exemption 7(a).

In principle, the use of LHMPS in the capacitors in the scope of Exemption 24 could also be exempted in Exemption 7(a), which would, however, require adding another entry under Exemption 7(a) for these capacitors. This part of Exemption 7(a) would then have to be revoked should it be practicable to exclude the use of LHMPS in Exemption 24, which generates an additional entry under exemption 7(a) that would have to be maintained to enable repair and reuse. Compliance may also become more difficult for industry if the soldering for a specific component is regulated in two different exemptions. Additionally, regulating the use of LHMPS in the MLCC capacitors would require restricting the lead content in the solders in Exemption 24 to a level below 85 % to avoid an overlap with Exemption 7(a). Such a restriction should be discussed with the applicants and stakeholders to ensure the concentration of lead is high enough to cover all uses of solders other than LHMPS.

Concerning the lead substitutes, the European Commission[1745] lists indium as one of 20 critical raw materials for the European Union, which calls for the substitution of indium, while in the case of Exemption 24, indium replaces lead, which the EU Commission has

[1745] European Commission: 2014 "On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions," http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0297&from=EN, page 5 et sqq.

not listed as a critical material. In this respect, Exemption 24 contravenes the strategy of the Critical Raw Materials Initiative to substitute critical materials and to reduce their use, while it is in line with the requirement of the RoHS Directive to substitute lead.

RoHS Art. 5(1)(a) stipulates that decisions on exemptions shall take into account the availability of substitutes, meaning *"[…] the ability of a substitute to be manufactured and delivered within a reasonable period of time as compared with the time required for manufacturing and delivering the substances listed in Annex II"*, i.e. the list of restricted substances. Hence, if the use of indium would cause delays in the manufacturing of components due to the limited availability of indium, Art. 5(1)(a) would allow cancelling the exemption based on the lacking availability of indium and thus moving industry to alternatively use high melting point solders with at least 85 % lead content under the current exemption 7a. Such indium shortages were not, however, identified by stakeholders, and the fact that the applicants plea for the renewal of Exemption 24 implying the use of indium can be seen as evidence that indium is sufficiently available for these applications.

It should be stressed that it is beyond the consultants' mandate to recommend the continuation or revocation of exemptions based on criteria other than those stipulated in RoHS Art. 5(1)(a). The consultants therefore recommend renewing the exemption based on Art. 5(1)(a). Any other recommendations on whether and how far to take into account strategies or requirements resulting from the Commission's Raw Material Initiative must be considered separately from this review, and such decisions should be made by the competent European Authorities.

Should the Commission prioritize the conservation of indium resources over the reduction of lead use, then Exemption 24 should not be renewed. This would require exempting the use of LHMPS as the substitution or elimination of lead in the capacitors in the scope of Exemption 24 is currently impracticable. In this case, the consultants recommend

A) to take no further action should the Commission decide to keep the current wording of Exemption 7(a).
B) adding a clause in the proposed rewording of Exemption 7(a) allowing the use of LHMPS in the capacitors in the scope of Exemption 24 with a validity period of five years. A validity period shorter than five years would not be justified as no lead-free solutions to replace LHMPS are foreseeable within the next five years.

The above option B will be addressed in an alternative rewording proposal for Exemption 7(a).

30.5 Recommendation

The applicants plausibly explain that neither the elimination nor the substitution of lead is viable to a degree that would allow the revocation or the restricting of scope of Exemption 24. Doing so would prevent the use of indium-lead solders with a maximum of 50 % of lead and instead require the use of high melting point solders with at least 85 % of lead content due to the absence of lead-free solutions.

Based on the available information, renewing the exemption with its current wording would be in line with Art. 5(1)(a). The consultants recommend granting the exemption for 30 months in order to clarify whether the scope of the exemption can be restricted to exclude the use of high melting point solders, which would reduce the amount of lead used under this exemption:

Exemption 24	**Expires on**
Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors	*21 January 2019 for categories 1-7 and 10*
	21 July 2021 for · *medical equipment in category 8* · *monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9

The European Commission lists indium as a critical material for the European Union.[1746] Recommendations on exemptions taking into account criteria beyond Art. 5(1)(a), are beyond the consultants' mandate. Taking into consideration strategies and requirements resulting from the Commission's Raw Material Initiative in the context of this exemption should be made by the competent European Authorities.

30.6 References Exemption Request 24

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Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, RoHS III. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

[1746] Ibid., page 5 et sqq.

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