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Adaptation to Scientific and Technical Progress under Directive 2002/95/EC

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Final Report

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Content

1 Background and Objectives

Article 4 (1) of Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment provides "that from 1 July 2006, new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, PBB or PBDE." The annex to the Directive lists a limited number of applications of lead, mercury, cadmium and hexavalent chromium, which are exempted from the requirements of Article 4 (1).

Article 5 (1) (b) of the Directive provides that materials and components can be exempted from the substance restrictions contained in Article 4 (1) if their elimination or substitution via design changes or materials and components which do not require any of the materials or substances referred to therein is technically or scientifically impracticable, or where the negative environmental, health and/or consumer safety impacts caused by substitution outweigh the environmental, health and/or consumer safety benefits thereof.

Based on this provision, the Commission has received (and is still receiving) additional requests for applications to be exempted from the requirements of the Directive from industry. These requests need to be evaluated in order to assess whether they fulfil the above mentioned requirements of Article 5 (1) (b). Where the requirements are fulfilled the Commission proposes a draft decision amending the RoHS Directive.

Against this background, Öko-Institut e.V. and Fraunhofer Institute for Reliability and Microintegration IZM have been commissioned by the European Commission with technical assistance for the evaluation of requests for exemptions submitted according to Article 5 (1) (b). The main objective of this technical assistance contract consists in a clear assessment of whether the requests for exemptions are justified in line with the requirements listed in Article 5 (1) (b) and in a subsequent recommendation on whether or not to grant the exemption – including a precise wording. These recommendations as well as the description of the proceeding will be included in monthly reports between October 2006 and October 2007.

2 General Procedure

In order to provide the required clear assessment and evaluation of whether a request for exemption is justified in line with Article 5 (1) (b), the following general procedure has been followed:

The organisational and formal tasks described in

1. Table 1 below are horizontal tasks that have been carried out during the whole project period (i.e. along 12 months of contract duration) and across all exemption requests.
2. The technical and scientific evaluation described in Table 2 below has been carried out for each single exemption request. This procedure is thus a vertical task done in an iterative process.

Table 1: Organisational / formal proceeding

Work packages	**Tasks**
(I) Basic set up	• Install project-specific e-mail account • Set up database for document sharing between team members and experts • Download documents from Commissions' web site and corres-ponding CIRCA database • Work through stakeholder comments and allocate them to requests • Communicate roles of project team to Commission and nominate one main contact person • Finalise work plan in agreement with the Commission
(II) Communication with applicants and stake-holders	• Contact applicants after stakeholder consultation has closed (give a signal on start of evaluation procedure). • Offer possibility to organise briefing meetings with applicants & stakeholders in view of transparent communication of evaluation proceeding (timeline, steps etc. as described in Table 2 below) • Develop standard questions and e-mail for further request for infor-mation and need for clarification
(III) Overall project management	• Regular exchange and close liaison with Commission (e-mail, tele-phone) • Project manager responsible for every-day communication with all relevant parties (Commission, project partners, external experts, members TAC,…) • Track-record of documents provided by applicants, stakeholders and other parties
(IV) Reporting	• Deliver regular monthly reports • Interim report • Draft final report • Final report • Updates of reports when revision of recommendation is necessary due to new data / information

Table 2: Technical and scientific evaluation proceeding

(A) Basics: first assessment of exemption request & stakeholder comments	Check: • Specific application described? • Application covered by RoHS Directive? • Wording proposed? Wording precise and clear? • Quantity of substance, need for its use, substitution / elimination efforts described in comprehensive and detailed manner? • Justification in line with criteria of Art. 5 (1) (b)? • Additional evidence / information provided in stakeholder comments?	• Analyses of data and information gathered from documents downloaded from Commission online database • Elaborate questionnaire with need for clarification and further information • Consultation with applicants of exemptions (inter alia on possibly new or changed wording) • Review of literature • Contacting competitors • Exchange with external experts
(B) Assessment of technical specifications & substitution or elimination possibilities	• Identify alternative materials and components including adaptability of substitutes in similar applications to the application in question • Determine possible substitution through alternative materials: effects on characteristics and performance (e.g., reliability, manufacturing yield, appearance) • Determine possible substitution through alternative production processes: effects on characteristics and performance (e.g., reliability, manufacturing yield, appearance) • Determine alternative product design providing the same function • Assessment of the availability of alternatives within the next four years	• Analyses of data and information gathered from documents downloaded from Commission online database • Confrontation of applicants and stakeholders with opposing views on substitution possibilities • If necessary: hold meeting bringing different stakeholders together in order to clarify diverging statements • Review of scientific and patent literature • Consultations with relevant scientific and research bodies within and outside the EU • Expert consultation, esp. component and equipment manufacturers • Check (safety) standards and other related legislation • Check if substitutes have undergone a risk assessment

(C) Assessment of possible environmental, health and / or consumer safety impacts	Comparing potential assets and drawbacks caused by substitution regarding • Environmental impacts (energy use, toxicity, impact waste stream) • Impacts on occupational health • Consumer safety and protection	• Analyses of data and information gathered from documents downloaded from Commission online database; especially check whether LCA or similar has been provided as evidence • Consultation with applicants, stakeholders and external experts • Analyse hazardous properties of substances as well as expected exposure situation; main elements: human health hazard assessment, environmental hazard assessment, assessment of bioaccumulation potential and persistency, exposure assessment, risk characterisation • Regarding working place safety and environmental protection: application of standard or enterprise-specific risk management measures can be included in the exposure assessment if sufficient information is available • Relay on publicly available information on potential negative impacts of substitution
(D) Other criteria going beyond Art. 5 (1) (b)	• Identify arguments used by applicant NOT in line with Art. 5 (1) (b) (e.g. economic aspects, supply chain problems, phase-out periods etc.) • Assess whether these arguments are nevertheless valid from a general environmental, health or safety perspective • Include statement on those arguments in evaluation	• Compare argumentation line with criteria from Art. 5 (1) (b) • Consultation with applicants, stakeholders and external experts • Assess validity of arguments with regard to Community environmental, health and safety policy

(E) Over-all assessment and conclusions	• Summarise findings of tasks (A) to (D) with argumentations • Evaluate efforts made by applicant • Draw conclusions and final recommendation for the Commission including precise and clear wording • Include findings and recommendation in regular monthly reports	Consultation with • applicants of exemptions • external experts • branch associations and relevant trade organisations • European Commission • Technical Adaptation Committee • non-governmental organisations and other stakeholder if possible

The main sources for data and information used for conducting the above-described procedure were:

- Analyses of data and information available in the requests and corresponding stakeholder comments brought forward during online stakeholder consultations;
- Analyses of data and information gathered by questions sent to parties who submitted request for exemptions as well as to other stakeholders and experts;
- Consultations with applicants of exemptions and possibly also with competitors;
- Review of scientific and patent literature;
- Consultations with relevant scientific and research bodies within and outside the EU;
- Expert consultation, esp. component and equipment manufacturers.

3 Scope

Within the duration of the contract between October 2006 and October 2007, two sets of exemption requests were evaluated (set 6 and set 7). These two sets were both subject to a public stakeholder consultation. The following tables give an overview about the requests, the applicants and the recommendations given by the contractor.

On 10 November 2006 the sixth stakeholder consultation round was launched by the Commission and closed on 10 January 2007. The requests open for comments of this sixth consultation round represented the first part of the scope of this contract.

Table 3 below gives an overview over the corresponding set 6 of requests for exemption as well as the recommendation given and the monthly report in which it is contained.

Table 3: Overview requests set 6

No.	Title	Applicant	Recommendation	Report
1a	Lead used for shielding of x-radiation emissions for CRT	VDC Display Systems	Withdrawal	
1b	Hazardous materials and lead in solders in components and assemblies used in non-consumer products	VDC Display Systems	Withdrawal	
1c	Electronic equipment where reliability, durability and longevity of the equipment is paramount	VDC Display Systems	Withdrawal	
2	Lead as soldering alloy in high performance communication electronic board and hexavalent chromium (Cr-VI)	Clarity SAS	Withdrawal	
3	GemCore 410 EMV	Gemplus	Refuse	Report 6
4	SAVBIT solder	Roband Electronics PLC	Grant	Final report (cf. section 5.1)
5	Sn-Pb soldering used in Ground-based Aeronautical Communication Equipment Manufacturing	Telerad	Refuse	Report 8
6	Transducers used in professional loudspeaker systems, using tin-lead solder	Gemini Sound products Corp.	Refuse	Report 5
7	Tin-lead solder in the manufacture of professional audio equipment	Gemini Sound products Corp.	Refuse	Report 5
8	Inventory of special ICS having tin-lead solder on/in leads/balls, used in specialist/professional equipment	Gemini Sound products Corp.	Withdrawal	
9	Crystal Stones within the battery operated watch	Zeon Ltd.	Withdrawal	
10	EEE used for the broadcast and homeland security sector	Tieline Technology	Withdrawal	

No.	Title	Applicant	Recommendation	Report
11a	AM186ES-V40 containing lead in used in the leads over plating and AM79C961AKC containing lead in used in the leads over plating	Digigram	Refuse	Report 6
11b	Audio board manufacturing process	Digigram	Refuse	Report 9
12	Cadmium sulphide or cadmium selenide in polymer based thin film transistor	Silk Displays Inc.	No recommendation given	Report 9
13	Lead used in the soldering for surface finishing at the electric pole terminal on the electronic parts	ICOM Incorporated	Refuse	Report 7
14	Cadmium contained in the cadmium oxide of a thick film ceramic substrate	ICOM Incorporated	Withdrawal	Report 8
15	All electronics assemblies using lead in solder	RoHSUSA Inc.	Refuse	Report 3
16	Lead in electric overblankets for Hot Spot detection	Beurer / Especialidades Eléctricas Daga S.A.	Grant until 1 July 2008	Report 5
17	MPC10 used in automatic vending machines to achieve the payment by card	Sagem monetel	Refuse	Report 7
18	Hexavalent Chrome Cr-VI when used as a passivate	Amphenol Limited	Refuse	Report 7
19	Lead contained in circuit boards, obsolete and non-compliant Intel 80c188/86 EA\XL microprocessors, Analog Devices ADMC300 DSP, and NEC uPD7101 DART and hexavalent chromium	NBS Technologies Inc.	Refuse	Report 9
20	Component used in the manufacture of electric blankets and heating pads	Thermocable (Flexible Elements) Limited	Grant until 1 July 2008	Report 5

No.	Title	Applicant	Recommendation	Report
21	Request to delete exemption for "Lead as impurity in RIG (rare earth iron garnet) Faraday rotators used for fibre optic communications systems	Integrated Photonics	Grant	Report 6
22	Lead in Trimmer Potentiometer elements	Tokyo Denshi Ltd.	Grant	Final report (cf. section 5.2)
23	Cadmium in opto-electronic components	Marshall Amplification plc	Grant with restriction	Final report (cf. section 5.3)

A seventh stakeholder consultation round was launched on 15 June 2007 and closed on 10 August 2007 (set 7). The requests open for comments of this seventh consultation round represented the second part of the scope of this contract.

Table 4 below gives an overview over the corresponding set 7 of requests for exemption as well as the recommendation given and the report in which it is contained.

Table 4: Overview status of requests set 7

No.	Title	Applicant	Recommendation	Report
1a	Extension of Exemption #21 as listed in Annex 1 of 2002/95/EC	ELCF	Grant	Final report (cf. section 5.4)
1b	Lead in silver rings on the exterior lamp surface of induction-type fluorescent lamps	ELCF	Grant	Final report (cf. section 5.5)
2	Use of mercury in plasma displays	Babcock	Grant until 1 July 2010	Final Report (cf. section 5.6)
3	Cadmium in photocells for accurate control of lighting equipment	Silonex	Refuse	Final report (cf. section 5.7)

No.	Title	Applicant	Recommendation	Report
4	3 year grace period on the use of cadmium-based photoresistors used in professional audio equipment, for the purpose of investigating suitable alternatives and redesigning audio products accordingly	Sound Devices	Grant until December 2009	Final report (cf. section 5.3)
5	RELOCK FUSE, Model X-09, High Security Electronic lock	Kaba	Exemption obsolete – application out of scope	Final report (section 5.8)
6	Lead in glass housing of high voltage diodes	Vishay	Grant	Final report (cf. section 5.9)
7	Cadmium and cadmium oxide in thick film pastes used on beryllium oxide substrates	Apex	Grant	Monthly report 9

4 Results

In total, 34 requests were evaluated. Twelve requests were recommended to be granted, and twelve requests were recommended to be refused. Eight requests were withdrawn by the applicant. For one request, a recommendation was not possible and one request was obsolete since the application is out of RoHS scope.

The requests can be divided into the following thematic categories:

1. Electronic devices (11 requests)
2. Last time buy (9 requests)
3. Solder technology and processes (7 requests)
4. Other / miscellaneous (4 requests)
5. Glass technology (1 request)
6. Metal coating / passivation (1 request)
7. Lighting (1 request)

Figure 1 below gives an overview on the thematic repartition of the requests over these categories.

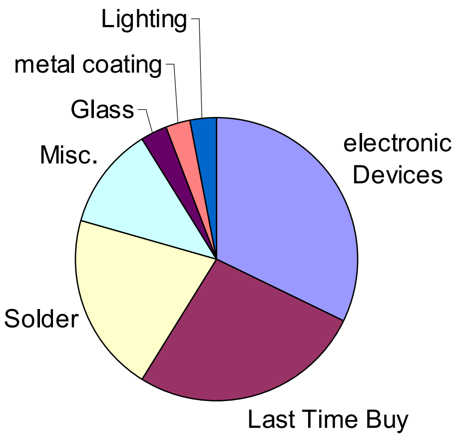


Figure 1: Thematic repartition of exemption requests

5 Requests Open for Recommendation

The following section contains nine recommendations for requests from set 6 and 7.

5.1 SAVBIT solder for soldering of thin copper wires - Roband Electronics (set 6, request no. 4)

5.1.1 Description of requested exemption

According to the applicant, the SAVBIT solder is used for soldering thin copper wires (<0.1 mm) in two joints on the secondary winding of a high voltage power transformer, as the next figure shows.

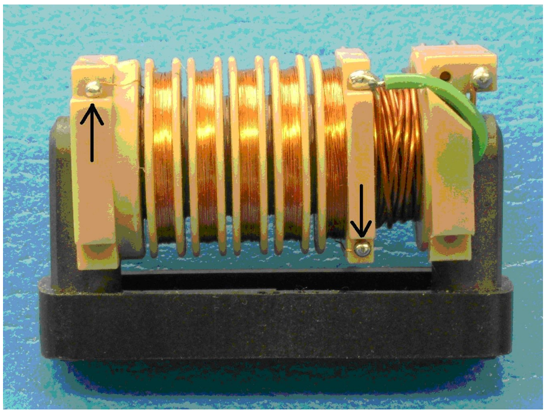


Figure 2: Solder joints containing lead for the soldering thin copper wires (<0.1mm) in two joints (arrows) on the secondary winding of a high voltage power transformer (source: Roband Electronics)

The solder contains 49 % (weight) of lead, the rest being tin (50 %) and copper (1 %). Such transformers are used in high voltage power supplies (generally two transformers per power supply). Most of the products the applicant manufactures are for military requirements, which the RoHS Directive does not cover. The applicant nevertheless applies for this application as he plans to extend his business into product groups, which the RoHS Directive covers.

It is estimated that each joint contains around 8 mg of lead, a total of 16 mg per transformer. These power transformers are a niche market with very low production rates, less than 300 per year. The annual consumption of lead for this purpose would be less than 10 g in the applicant's products. The applicant sells around 300 of such power supplies per year using SAVBIT solder (an optimistic figure because this is a specialist market), the total amount of lead used by Roband will be less than 10 g per year. The applicant estimates that the worldwide market would consume around ten time this amount, making a total usage of less than 100 g per year. The applicant says that an accurate estimate is difficult, but that, even if the real amount was a factor of ten higher, the total worldwide usage would still be only around 1kg per year.

The applicant suggests the following wording:

Use of lead in SAVBIT solder for the soldering of thin copper wires

5.1.2 Justification for exemption as submitted by applicant and stakeholders

The SAVBIT solder is used for making two joints on the secondary winding of a high voltage transformer.

Prior to any soldering operation two turns of wire are wrapped around the pin starting from the bobbin. The free end of the wire is then tinned using a soldering iron and solder. This is completed as quickly as possible. Three turns of the tinned wire are then wrapped round the pin and soldered. At this stage there is still at least one turn of untinned wire wrapped around the pin, this indicates that the soldering process has not been excessively prolonged. The pin is then cropped to the specified length. This leaves a sharp cut edge to the pin. For a low voltage winding the cut end would be quickly tinned using the soldering iron and solder to prevent subsequent corrosion of the cut end of the pin. Because this is a high voltage transformer the solder joint has to be "domed" to provide a smooth surface to eliminate concentration of electric stress which would cause electrical breakdown. This is a well known procedure in the high voltage industry and involves the addition of more solder to the joint so the joint itself become a sphere (see photos). In general all solder joints in high voltage assemblies are domed in this way. After the joints on the transformer have been domed they are inspected to ensure that there is still at least one turn of untinned wire wrapped around the pin between the solder joint and the bobbin. This provides mechanical support for this extremely fragile wire and confirms that the soldering processes have not been unduly prolonged.

Because of the high voltage (up to a peak value of 4000 V) the solder joints have to be smooth without any sharp points to minimize electrical stress and prevent high voltage breakdown. These joints are spheres less than 1.5mm in diameter. Only the SAVBIT solder, according to the applicant, allows forming this joint without the solder damaging the wire and in the respective shape and surface qualities required in the high voltage application field.

The applicant says that other than SAVBIT solders (including RoHS compliant solders) dissolve the copper wire, causing ‘necking' just where the wire enters the solder joint, making it susceptible to breakage under thermal or mechanical stress.

In extreme cases (soldering prolonged for more than a second), the wire can dissolve completely into the solder causing immediate breakage. If this happens on the ‘trapped' end of the winding then the winding has to be removed, the wire scrapped and the transformer rewound (up to 3,600 turns of 0.05 mm wire). In tin-lead solders, lead forms a eutectic alloy with tin to minimize the melting point of the solder. This together with the 1% of copper content greatly reduces the rate at which the copper wire is dissolved into the solder while making the joint.

The applicant contacted solder manufacturers directly, who provided samples of various RoHS compliant solders. The applicant claimed that he had tested various RoHS-compliant solders. The best ones were the tin-silver-copper solder with 3.6 to 4 % (weight) of silver and 0.6 to 0.8 % of copper the remainder being tin. Another alloy tested was the tin-copper alloy with 3 % of copper. This alloy yielded the best results, but its performance still fell far short of the SAVBIT solder. The higher melting temperature and the increased tin content caused by the absence of lead still damaged the copper wire during soldering. The applicant tried high melting point solder (HMP) which contains more than 85 % of lead, which is currently exempted. The applicant already uses HMP solder for one joint on the low voltage primary of the transformer. He found experimentally that because of its higher melting point, HMP solder damaged the thin wire used for the high voltage secondary winding. Consequently, it has been ruled out as an alternative. The applicant says that an Electrical Research Association (ERA) industry advisor for solders confirmed that there was no technical alternative to SAVBIT solder.

The applicant thus concludes that there is no viable substitute available to replace the SAVBIT solder in this application.

The applicant further on puts forward that he manufactures high quality high reliability products. If he does not use SAVBIT solder, he will be manufacturing an unreliable product. The high voltage transformer is encapsulated in an assembly with twenty or more high value components, so that it is not possible to repair this assembly reliably. If a transformer fails, all the components and the encapsulation material have to be scrapped. Although all these components and the encapsulation material are RoHS compliant, the applicant says that the waste of material and resources in manufacturing a new assembly is considerable.

Most of the products the applicant manufactures are for military requirements, which the RoHS Directive does not cover. The applicant says that he needs the SAVBIT solder for these products to obtain the necessary high reliability. Because of minimum order requirements (MOQ), the applicant claims to have enough SAVBIT solder (ten 500g reels) to last him for about 250 years at his present low rate of usage. The applicant says that if he does not use this solder, then it will eventually have to be scrapped and would still add to environmental waste.

5.1.3 Critical review of information as submitted by applicant and stakeholders

The applicant could not provide the above mentioned ERA solder expert confirmation that technical alternatives to the above mentioned SAVBIT solder do not exist. It is, however, a well-known effect that lead-free solders with their higher tin content and their higher melting points dissolve copper quicker than tin-lead solders do. In principle, it is therefore plausible that the higher copper dissolution rate of lead-free solders create problems as the applicant describes if applied with thin copper wires. The applicant was proposed several possibilities how the problem could be solved in principle.

5.1.3.1 Discussion of processing alternatives

The applicant was proposed to thicken the soldering end of the wire only to compensate the increasing dissolution rate of the copper wire in RoHS-compliant lead-free solders, or to apply a finish on the soldering end of the wire. The applicant answered that he did not know any way of thickening the ends of the wire, but that it would be an extremely useful process if it could be done. The wire for each single power transformer obviously is cut from a role with a long wire, and the applicant himself would have to thicken the ends. Another problem is that the enamel insulation layer, with which the wire is coated, would have to be removed in order to plate it with a finish. According to the applicant, there are three ways of doing this:

The standards way using a soldering iron and solder

Also with the tin-lead solder used up to now, the enamel has to be removed before the soldering process, using the tin-lead solder, which, at the same time, applies a tin-lead layer on the solder wire. For a RoHS-compliant solution, it would therefore be necessary to use a RoHS-compliant solder, which, however, dissolves the thin copper wire.

Mechanically using an abrasive material

The applicant says that the enamel is abrasion resistant and not easy to remove. It is very difficult to mechanically remove the enamel from fine wires without damaging the copper wire.

Chemically

The applicant says that even if he could remove the enamel from the wire it is difficult to see a practical way of plating the ends of the wire. One way would be to measure off the length of wire required, remove the enamel from the ends by some means, and then plate the ends of the wire either with more copper or some other material. The problem with this is that when wound with 3600 turns of 0.05 mm wire the length of the wire is approximately 140 meters. The applicant says that, assuming he did a trial winding to find out the exact length before plating the ends, when winding the next transformer it would only take a very short time for change in winding tension, wire gauge, or bobbin tolerance, and the finish of the winding with its thick end would end up in the wrong place, and either be too short or too long.

Alternatively, the applicant explains, he could just plate the wire at the start of the winding, wind the wire on the bobbin, then cut it off when it has reached the end. He would then have to remove the enamel from the end of the wire and plate it. According to the applicant, this would be virtually impossible to do on the short lead protruding from the winding without risking damage to the winding itself.

5.1.3.2 Use of thicker wires and efficiency

Asked whether using thicker wires might be a solution, the applicant answered that this might be a satisfactory solution for high power units over 30 W output. For high voltage low power units using a physically large transformer when only a small one is required would use more copper and ferrite and increase the core losses, which in turn reduces the energy efficiency of the unit. Additionally, the applicant says, high voltage units have to be encapsulated. The use of a physically larger transformer requires the use of more encapsulation material and a larger enclosure etc.

The applicant provided the following example calculation as evidence for his arguments:

Table 5: Effects of the use of wires thicker than necessary on energy efficiency

	Existing transformer with 0.05 mm wire	**Transformer with all dimensions doubled to permit the use of 0.1 mm wire**
Transformer dimensions (mm)	35 × 23 × 15	70 × 46 × 30
Core losses	0.6 W	1.2 W
Copper losses	0.2 W	0.4 W
Primary drive circuit losses (switching FETs)	0.1 W	1.6 W
Total losses	0.9 W	3.2 W

The calculation is only valid assuming equal use conditions for both products, as the copper losses depend on the load.

The applicant explains the details of the calculation as follows:

Core losses

The core loss is independent of load is principally determined by the size of the transformer core and is independent of the load. Doubling all the linear dimensions increases the cross sectional area of the core by a factor of four, which reduces the flux density (and the energy loss) by the same factor. However the volume of the core and the losses increase by a factor of eight. The net result is a double core loss of 1.2 W instead of 0.6 W.

Copper losses

The copper loss part of energy loss is principally determined by the size of the winding and is load dependant. High voltage windings have a large number of turns and consequently a large amount of interwinding capacitance. This capacitance results in an unwanted circulating current in the secondary winding; this in turn causes a related current to flow in the primary winding causing the copper losses. This current can easily exceed the magnetising current of the transformer. Doubling the linear dimensions of the winding increases this stray capacitance by a factor of 4. As at the same time the winding resistance is reduced by a factor of 2, the net result is a double loss in the copper.

Primary drive circuit losses (switching FETs)

The circulating current in the windings flows through the on resistance of the switching FETs driving the primary winding of the transformer. As previously stated, doubling the linear dimensions of the transformer increases the unwanted circulating currents in the transformer by a factor of four. The losses in the FETs are proportional to the square of the current. The losses hence go up by a factor of sixteen. If we use larger FETs with lower on resistance to compensate for the higher current, they would have a much larger gate capacitance which would require more power to drive them.

Example calculation of additional energy consumption and related lead emissions

As mentioned above, any given design of transformer has core and copper losses. The core loss is independent of load and is principally determined by the size of the transformer core and is independent of load. The copper loss is principally determined by the size of the winding and is load dependant. For a given application using a transformer that is too small decreases the core loss but increases the copper loss. Conversely, a transformer that is too large has a higher copper loss and a low core loss. As the copper loss is load dependent, the design of the power transformer must balance the core and the copper loss specifically for each application field to achieve the maximum energy efficiency. The diameter of the used wires is one parameter to vary in this optimization process.

In principle, using thicker wires able to withstand the soldering process with lead-free solders would be possible to avoid the use of lead-containing solders. However, it would result in products with energy efficiencies that are below the optimum. The example in Table 6 shows that going from an optimized power transformer design with 0.05 mm wire to a 0.1 mm wire design increases the performance loss for around 260 % from 0.9 W to 3.2 W. Assuming that the power transformer is used for 24 h a day, the annual additional energy loss would be around 20 kWh.

Table 6: Exemplary use scenario and additional energy consumption through lower energy efficiency

	Performance Loss (W)	*Operating time per day (h)*	***Energy loss per year (kWh)***
Thin wire version	0.9	24	8
Thick wire version	3.2	24	28
Difference	2.3		**20**

Assuming that the 0.1 mm wire could be soldered with lead-free solder, around 16 mg of lead would be saved at the cost of around 20 kWh per year of higher energy consumption.

This additional energy consumption would add up over the years of lifetime of the power transformer. Additionally, the bigger power transformer would use more materials, and the bigger size itself might be a problem in some applications.

Energy generation itself also causes lead emissions, in particular from coal-fired energy plants. The generation of 1 kWh of electricity in Europe roughly causes around 1 mg of lead emissions into air, soil and water (source: reference [1], section 5.1.5). The above scenario with the 20 kWh of additional energy consumption per year due to the lower energy efficiency would thus cause around 20 mg of lead per year. This is approximately the same amount of lead as contained in the solder joints of thin wires in one power transformer. Over the lifetime of the power transformer, the energy-related lead emissions would over-compensate the avoided lead in the power transformer in the above scenario.

The copper loss is load dependent, and both the copper and the core loss depend on the mode and time of use. If the power transformer is not used 24 h a day, but just 1 h a day, the additional energy consumption per year is around 1 kWh corresponding to around 1 mg of energy-related lead emissions per year. These additional lead emissions would also sum up over the lifetime of the power transformer and at least partially compensate the avoided lead.

The additional use of copper and other materials for power transformers with thicker wires than necessary add to the above calculated energy consumption. The production and processing of these materials requires energy as well. This could, however, not be quantified, as the respective data were not available.

The additional energy consumption and lead emissions, which are related to this application in case the exemption is not granted, cannot be quantified exactly. The above calculations are all based on the data for one example power transformer, which the applicant had provided. Possibly, other design changes might cause other, lower efficiency decreases. The rough estimates, however, show that the additional lead emissions from the lower energy efficiency would at least partially compensate the around 16 mg of lead per power transformer, if the manufacturers were forced to use thicker wires than necessary according to the example calculations in the tables above.

Countercheck of information with competitors

The consultants contacted four competitors of the applicant to countercheck the correctness of the information received from the applicant concerning the soldering of thin wires in power transformers. It was, however, not possible to obtain clear evidence that the applicant's competitors have RoHS-compliant solutions for power transformers with thin wires, which are comparable to the applicant's power transformers.

Conclusions

The applicant's information itself is plausible, and he has undertaken efforts to achieve RoHS-compliance. Design changes are possible to avoid the use of thin wires and thus achieve RoHS compliance. This would save around 16 mg of lead per power transformer, but would also increase the product size and the material use, and in particular the energy loss over the product lifetime. The additional energy consumption cannot be quantified exactly, as it depends on the specific application. The lead emissions from the additional energy consumption, however, would at least partially compensate the lead avoided in the power transformers.

Rewording of the exemption

The applicant's proposed wording "SAVBIT solder for soldering of thin copper wires" had to be altered. The non-RoHS-compliant, lead-containing SAVBIT solder is a name of a product of a specific manufacturer and should not be part of an exemption wording. Further on, the exemption would be too general allowing the use of lead-containing solders for thin wires in any product. The exemption had to be limited to power transformers. No viable, RoHS-compliant options could be proved for the processing of such thin copper wires in power transformers, and design changes implicate a decrease of energy and material efficiency. In other products, there might be different conditions and viable design options to achieve RoHS-compliance.

In accordance with the applicant, the wording therefore was changed to:

Lead in solders for the soldering of thin copper wires of 100 µm diameter and less in power transformers

5.1.4 Final recommendation

It is recommended to grant this exemption. The applicant's arguments are plausible, and there is no clear evidence that other manufacturers can solder thin wires of 100 micrometers diameter and less with RoHS-compliant solders. Design changes to avoid the use of such thin wires are possible, however, at the cost of lower energy efficiency of the power transformers. The lead emissions linked to the additional energy consumption are in the same order of magnitude like the amount of lead in the respective solder joints in the power transformers. The additional lead emissions into the environment would at least partially compensate the lead avoided in the power transformers. The exemption would thus be in line with the requirements of article 5 (1) (b).

The wording of the exemption should be:

Lead in solders for the soldering of thin copper wires of 100 µm diameter and less in power transformers

5.1.5 References

[1] Frischknecht R., Faist Emmenegger M. (2003): Strommix und Stromnetz. In: Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz (Ed. Dones R.). Final report ecoinvent 2000 No. 6, Paul Scherrer Institut

[2] Villigen, Swiss Centre for Life Cycle Inventories, Duebendorf, CH, Online-Version under: www.ecoinvent.ch.

5.2 Lead in trimmer potentiometer elements (set 6, request no. 22, Tokyo Denshi)

Explanations of specific terms:

Cermet — Heat resistant material made of ceramic and sintered metal; here the resistive layer and the ceramic body on which it is sintered upon.

5.2.1 Description of requested exemption

Trimmer potentiometers are variable resistors. They work with a wiper to adjust the resistance of the circuit. They are applied in a wide range of products like e.g. audio-visual equipment, communication equipment, toys and measuring devices, electrical household appliances.

Figure 3: Example of a trimmer potentiometer (source: Tokyo Denshi)

The trimmer potentiometer elements contain lead as lead oxide in resistive inks. The resistive ink is composed of silver, lead-ruthenium-oxide and boron trioxide. The applicant says that currently there is no viable lead-free thickfilm paste available on the market.

Trimmer potentiometer elements weigh between 0.048 g to 0.106 g, with a lead oxide content of 0.108 % to 0.35 % corresponding to around 0.052 mg to 0.3 mg of lead oxide per trimmer potentiometer. The applicant sells around 54,000,000 pieces of cermet potentiometers. The total amount of lead oxide in the applicant's products thus is between around three to 16 kg per year. Tokyo Denshi Ltd. assumes that it is currently occupying 1 % of the entire cermet trimmer potentiometer market. The total global annual volume of would then be around 5,400 million of such trimmer potentiometers resulting in around 1,600 kg of lead oxide (PbO) or 1,500 kg of lead consumed in this context.

As cermet trimmer potentiometers come in many different sizes and shapes and there are millions of manufacturers in the entire industry, it would be difficult to give any accurate figure to the annual volume and thus the amount of lead oxide used in this scope. Yet, we can still give a rough estimate based on our annual output and market share. Assuming that Tokyo Denshi Ltd. is currently occupying 1% of the entire cermet trimmer potentiometer market, our annual output of 54 million pcs. (and 16.2 kgs. of lead oxide consumed) projects a global annual volume of 5,400 million pcs. and thus 1,620 kgs. of lead oxide consumed in this context. We hope this rough estimate may help you address the possible amount of hazard that could bring about.

The applicant suggests the following wording for the exemption:

Lead in thickfilm pastes for the manufacturing of cermet-based trimmer potentiometer elements

5.2.2 Justification for exemption as submitted by applicant and stakeholders

The resistive ink is applied as a thickfilm paste, which is printed on the cermet base as a conductive agent between the wiper and the terminals. After printing, the thickfilm paste is sintered onto the cermet base. The lead-oxide in the conductive ink is necessary to evenly melt the ruthenium-oxide and bond it on the cermet base. Its low sintering temperature below 500 °C lowers the curing temperature of the ruthenium-oxide solvent, which enables bonding the ruthenium oxide to the cermet base without cracking it. Further on, the lead-oxide works as a bonding agent connecting the aluminium-oxide based cermet and the conductive film of lead-ruthenium oxide. The lead-oxide enhances the adherence of the ruthenium-oxide/ruthenium-dioxide to the cermet base ensuring proper conductivity and the functionality of the trimmer potentiometer. Compared to other thickfilm resistors, the resistive layer in trimmer potentiometers must have a higher mechanical stability. The wiper runs over the resistor to adjust the resistance, which will cause abrasion of the resistive layer over time if the layer does not have sufficient mechanical stability against abrasion. The applicant says that on cermets, there is no technically viable substitute to replace the lead-oxide as bonding agent in the thickfilm pastes for the resistive ink.

There is another type of trimmer potentiometers, which are bakelite-based. They can be manufactured RoHS-compliantly without lead, but are not appropriate for all applications. Firing RuO2 materials on a bakelite film is impossible owing to the high curing temperature. In this connection, only Pb-free carbon can be printed as the resistive track of a bakelite-based potentiometer. This carbon, according to the applicant, is too sensitive to temperature and humidity changes. The bakelite potentiometers thus can function properly at working temperatures of not more than 40°C, while that of a cermet potentiometer can operate at temperatures as high as 70°C or even more.

The applicant states that another important criterion is concerning the working power rating. A cermet (RuO2 resistive track) trimmer potentiometer can withstand power ratings as high as 0.3 W to 0.5 W. A bakelite trimmer potentiometer with carbon track would burn down at such power ratings and hence the device circuit went out of order. In this connection, it is thus not uncommon to see that devices including automobile audio/visual equipment, automobile ABS systems, telecom equipment, heaters, negative ion hair clippers, etc. are all using cermet based (RuO2 resistive track) trimmer potentiometers.

As the consumer market is producing products with more compact sizes, the use of smaller surface-mounted trimmer potentiometers is prevailing. Yet, as the working power rating of bakelite base trimmer potentiometer would drop in proportion to its size, they cannot provide a solution to the power rating requirement of these device circuits. In contrary, the cermet based trimmer potentiometers with the RuO2 resistive tracks can provide the necessary power ratings even in surface mounted, meaning miniaturised versions, according to the applicant. The applicant states that all surface mount trimmer potentiometers are of cermet base and RuO2 track. Matsushita, Kyocera, Murata, Bourns, etc. trimmer potentiometer manufacturers are all designing the surface-mounted trimmer potentiometers in cermet base and RuO2 resistive track.

5.2.3 Critical review of information as submitted by applicant and stakeholders

Electrolux had submitted a stakeholder document opposing the applicant's exemption request. Electrolux confirms that it uses fully RoHS compliant trimmer potentiometers in its products (see attached stakeholder document "Trimmer_potentiometer_stakeholder.pdf"). The consultation of both the applicant and of Electrolux cleared the situation. It showed that the stakeholder had understood the applicant's exemption request as a request for a general exemption for lead in trimmer potentiometers. The title of the exemption request in the stakeholder consultation round no. 6 was "Lead in trimmer potentiometers". The exemption request, however, is limited to the use of lead in cermet-based trimmer potentiometers.

After further investigations at a thickfilm paste manufacturer and manufacturers of trimmer potentiometers, the applicant's information could be confirmed. Bakelite-based trimmer potentiometers are not appropriate for higher power rates and higher moisture. Lead-free thickfilm pastes are not available currently for the use in cermet-based trimmer potentiometers.

Although for some ranges of resistance, lead-free pastes are possibly available, the mechanical resistance against abrasion is not yet high enough to allow a reliable product.

The respective industries so far considered the following exemptions to cover the use of such lead-containing thickfilm pastes in trimmer potentiometers:

- No. 5: lead in glass of cathode ray tubes, electronic components and fluorescent tubes, and
- No. 7: lead in electronic ceramic parts (e.g. piezoelectronic devices).

The applicant was asked whether he was aware of this situation. He replied that he had checked the RoHS Directive about this matter before he submitted his proposal. The applicant says that it is the ruthenium oxide (RuO2) resistive film printed on the ceramic sheet that contains lead. Tokyo Denshi had consulted a test laboratory technician about the exemption status. The technician replied that he would not agree with the compliance of the resistive film.

The applicant had sought a formal explanation from EU about the inclusion of leaded potentiometer elements in these exemptions, but the Commission did not take a position. Tokyo Denshi therefore believed that a formal exemption request would be the best to ease the queries in the global electronics market.

The sintering process will not change the chemical form of lead-oxide into another chemical form. The applicant as well as another manufacturer of thickfilm pastes and vendor of cermet-based trimmer potentiometers confirmed that *the resistive layer is made up of lead ruthenium oxide and lead oxide, which is by nature not a glass. Tokyo Denshi states that it is electrically conductive and the lead oxide added is to serve as an epoxy or bonding agent to get the resistive layer sintered on the ceramic base at high temperature. According to the applicant, after sintering the resistive track can be removed by grinding or lapping. Lead oxide itself stays on the cermet base surface but does not penetrate into the cermet body. The lead ruthenium oxide (i.e. the resistive layer) could not be classified as any glass component, although glass may contain lead also. Lead oxide added to enable the sintering may be similar to glass.*

A further manufacturer of thickfilm pastes and trimmer potentiometers confirmed that lead is available as lead-ruthenium-oxide and that the lead is an essential for the resistivity properties of the cermet material (document "technical fiche20000901.pdf"). He added that lead also is contained in the glass as lead-boron-silicate and as such is a constituent of the glass components in the cermet layer. The proportionate distribution of lead between the lead in glass and the lead in the resistive layer itself is not known. The stakeholder as well as the applicant confirms that the resistive layer in principle can be mechanically disjointed by grinding from the ceramic body and hence consider it as a homogeneous material.

According to the stakeholder, the thickfilm paste contains around 15 % to 20 % of lead in Pb2Ru2O7 (lead-ruthenium-oxide, see document "technical fiche20000901.pdf"). Assuming that the thickfilm paste does not considerably loose weight during the sintering process, this corresponds to a lead content of around 8.5 % to 11.4 % in the resistive layer, which is clearly above the maximum threshold of 0.1 % for a RoHS-compliant homogeneous material.

Exemption no. 7 for lead in ceramic parts can be ruled out as both the applicant as all stakeholders involved classify the non-conductive part of the resistive layer or parts thereof as glass, not as ceramic.

In order to be covered by the above exemptions listed in the RoHS Directive, the thickfilm paste <u>after</u> application, in the finished trimmer potentiometer, would have to be categorized under one of the following categories:

1. The resistive layer itself is classified as a glass after the sintering process. It would then be lead in glass of an electronic component and exemption no. 5 would apply. The applicant had ruled out this possibility.
2. The stakeholder classified the resistive layer (excluding the ceramic base) as a homogeneous material. The stakeholder says that in the sintering process, the lead in the lead-ruthenium-oxide and the glasses become inseparably connected in the resistive layer. He proposes that the lead in the lead-ruthenium-oxide could be considered as a glass, although the homogeneous material itself is not a glass. Exemption no. 5 would then apply.

   It is not clear, whether this is a viable interpretation of exemption no. 5. The interpretation of the RoHS Directive is beyond the contractor's competence. The contractors' leave the decision to the respective European entities whether this interpretation is permissible.

A new exemption would be justified in line with article 5 (1) (b) of the RoHS Directive if this application is not considered to fall under exemption no. 5

5.2.4 Final recommendation

It is recommended to grant this exemption if this use of lead is not considered to fall und exemption no. 5 allowing the use of lead in glasses of electronic components as laid out in the previous paragraph under number 2 in section 5.2.3.

The wording of the exemption would be:

Lead in cermet-based trimmer potentiometer elements

5.3 "Cadmium in optoelectronic components" (set 6, request no. 23, Marshall Amplification plc), and "3 year grace period on the use of Cadmium-based photoresistors used in professional audio equipment, for the purpose of investigating suitable alternatives and redesigning audio products accordingly" (set 7, request no. 4, Sound Devices)

Marshall Amplification had already requested this exemption in a previous stakeholder round (4^{th} stakeholder consultation, request no. 5). A final recommendation was not pronounced at that time (see final report from July 2006, http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf). Marshall therefore has submitted an almost identical request again in the sixth stakeholder consultation.

Sound Devices submitted an exemption request in the seventh stakeholder consultation, which refers to the use of cadmium in optocouplers in professional audio equipment as well. Both exemption requests target an identical exemption for identical or very similar applications in the audio industry. Hence, they are reviewed together in the following.

5.3.1 Special terms and definitions

Audio limiter	A device that permits a high compression to be applied above a set threshold. It limits the output level from rising much above the set threshold. Vice versa, it facilitates the maximization of an audio signal to the upper limits of the capabilities of the audio circuitry. Audio limiters prevent overload distortion, or "clipping". Further on, it allows for maximization of the audio level of the desirable audio signal relative to the audio noise in the floor of the audio signal, an inherent artefact to audio circuitry. (Source: Sound Devices)

Clipping	An audio signal distortion, which occurs through attempts to increase the voltage or current in an amplifier beyond its threshold of power. (Source: Sound Devices)
DSP	digital signal processing
Gain	"...The power increase of a signal, usually expressed in dB." (Received from Sound Devices, source: The Sound Reinforcement Handbook, second addition)
Impedance	The electrical impedance $\underline{Z}$ is the quotient of the complex temporary values, complex amplitudes, or complex effective values of an alternate voltage and the current in a network element: $\underline{Z} = \frac{\underline{u}(t)}{\underline{i}(t)} = R + jX$ The resistance R is the real part of impedance, the reactance X the imaginary part. The unit is Ohm, like for the resistance. (Source: Taschenbuch Elektrotechnik, Band 1 Allgemeine Grundlagen, VEB Verlag Technik Berlin, 3. Auflage 1986)

5.3.2 Description of requested exemption

Although not mentioned explicitly in the proposed exemption wordings, the concrete application behind both exemption requests is the use of cadmium-containing photoresistors in optocouplers.

5.3.2.1 Application and function of photoresistors and optocouplers

Optocouplers are used in dynamic processors such as audio compressors, expanders, limiters, and guitar amplifiers for recording studio and live sound music performances. They are also applied in portable professional digital audio recorders, where they limit the audio input AC voltage while recording audio, like for remote news gathering or major motion pictures. In addition, they are applied for voltage limiting in microphone pre-amplifier and audio mixer products.

The applicants apply for an exemption allowing the continued use of photoresistors containing cadmium sulphide. While Marshall wants a general exemption for cadmium in opto-electronic components, Sound Devices limited its exemption request to cadmium used in photoresistors for professional audio products, which are mainly optocouplers. Depending on the application different numbers of optocouplers are used in such products. In Marshall’s music instrument amplifiers, as an example, the different models use between one and nine optocouplers.

The photoresistors are combined in a single package with an LED to form an optocoupler. The optocoupler allows the transmission of analogue or digital signals between circuits using light as signal transmitter. The use of light ensures that the sending and receiving circuits are electrically unconnected (galvanic isolation).

The sending circuit controls an LED. The light of this LED strikes the surface of the photo-resistor in the receiving circuit. The photoresistor absorbs photons and changes its resistance according to the intensity of the LED-light it is exposed to. It absorbs the photons, whose energy pushes electrons into the conduction band. The electrons (and their resulting hole partners) conduct, lower the resistance of the photoresistor and thus control the electrical current in the resistor and the receiving circuit. The resistance of the photoresistor thus gradually decreases with increasing light intensity.

An important use of optocouplers is their application as optical isolators. The sending circuit operates with a low voltage direct current (5-24 V DC, direct current), the receiving circuit with a high voltage AC (alternate current, hundreds of volts) current. The optocoupler facilitates the optical control of such high currents with a low current without electrical contact between the two circuits. This physical separation is a safety protection for the user of the product. He can only access the low voltage areas of the product, but is protected from the dangerous high voltage circuit.

The semiconductor in the receiving high voltage circuit needs time to arrive at and to return from the higher to the lower resistance state. The resistance of the device falls and returns to high resistance over a matter of seconds. This gives the optocoupler device an important characteristic, the dR/dT characteristic (change of resistance over time). The gradual change from one state to another one, under a constant LED current, allows the device to switch audio signals gradually and free from distortion. The dR/dT response is a crucial parameter for the proper functioning of the product.

PMI provided the information that analogue processors account for approximately 90% of all sales of professional audio processors worldwide. Digital ones account for 10%. The annual worldwide market value of this kind of product is some 400 million US dollars (sources: audio trade publications, industry publications, US Census Bureau, PMI). This market share is expected to remain stable for the foreseeable future.

The amount of cadmium used in an optocoupler is around 100 micrograms. Sound Devices sells around 12,000 of such optocouplers in products to Europe resulting in a total amount of cadmium of around 1.2 g per year in Europe. Total figures for all producers using such devices in professional audio equipment are not available. Marshall did not provide any figures on this at all.

The applicants propose the following wordings for the exemptions:

Cadmium in optoelectronic components (set 6, Marshall)

3-year grace period on the use of cadmium-based photoresistors used in professional audio equipment, for the purpose of investigating suitable alternatives and redesigning audio products accordingly (set 7, Sound Devices)

5.3.2.2 Main discussion lines and key stakeholders

This exemption request is complex, as it has different technical argumentation lines and levels. Additionally, two applicants and several stakeholders were involved in the consultation and the exemption review process expressing contradicting, conflicting standpoints.

- Digital signal processing (DSP) is a new technology and a possible alternative to analogue technology. DSP does not require optocouplers, and hence does not depend on the use of cadmium-containing photoresistors. Part of the review process therefore is whether DSP is a viable alternative to the use of the non-RoHS-compliant optocouplers in professional audio equipment.
  The following stakeholders oppose the use of DSP as a viable substitute in professional audio equipment:
- Marshall (manufacturer of professional audio equipment, applicant in stakeholder consultation 6, Europe)
- Sound Devices (manufacturer of professional audio equipment, applicant in stakeholder consultation 7, USA)
- Casco Silonex (manufacturer of optocouplers, stakeholder, Europe)
- PMI Audio Inc. (manufacturer of professional audio equipment, stakeholder, Europe)
- Optocouplers using digital components like silicon-based photocells and phototransistors instead of cadmium-containing photoresistors are available on the market. The “On Institute for Optical & Electronic Technology”, a stakeholder from China, in the 7th stakeholder consultation submitted a document claiming that digital components can replace the cadmium-containing photoresistors in optocouplers. It must be clarified whether such devices are a viable option for the professional audio industry.
- This exemption request also is related to the exemption request no. 21 Cadmium sulphide photocells from stakeholder consultation no. 2. Applicants had requested an exemption for Cadmium in photocells for dimming lights. The request was recommended not to be granted as RoHS-compliant alternatives had been available. These alternatives might as well be suitable substitutes to achieve RoHS-compliance in optocouplers.
- Another part of the review process is the conflict whether the photoresistors and the optocouplers, which a manufacturer of optocouplers (Macron) claims to be RoHS-compliant, actually are RoHS-compliant.

Stakeholders involved are:

- Macron, a Chinese manufacturer of optocouplers, in stakeholder consultation 6 claimed to have a RoHS-compliant photoresistor that can fully replace the cadmium-containing, non-RoHS-compliant photoresistors in optocouplers for audio applications. Macron has submitted test results from two laboratories (SGS and RWTT) in the 6th and 7th stakeholder consultation, which, according to Macron, prove the RoHS-compliance of its photoresistor/optocouplers. Additionally, Macron has provided supporting letters from professional audio manufacturers confirming that the Macron optocouplers are a substitute for other manufacturers' non-RoHS-compliant optocouplers in professional audio equipment.

Other stakeholders oppose this view:

- Casco Silonex submitted test results from a laboratory (ERA) in stakeholder consultation 6 and 7, which, according to Casco Silonex, prove that the Macron photo-resistors/optocouplers are not RoHS-compliant.
- Sound Devices, Casco Silonex and PMI Audio argue that the Macron optocouplers technically are not appropriate for the use in the professional audio industry.
- Finally, it must be reviewed whether the Macron optocouplers, in case that they are RoHS-compliant, actually are a substitute for cadmium-containing photoresistors for optocouplers in professional audio equipment. Casco Silonex and PMI Audio oppose this view, while Macron had submitted letters from some of its customers supporting Macron's position.

5.3.2.3 Lack of Cooperation from Marshall

Marshall applied for a general exemption of cadmium in opto-electronic components. In order to clarify this rather broad scope and further open questions the consultant asked the applicant several times for further information. Although Marshall confirmed the receipt of the questions and announced to reply, Marshall later on cancelled the further cooperation via e-mail. Against this background the consultant decided to focus only on the almost identical exemption request no. 4 from Sound Devices (SD) in the 7^{th} stakeholder consultation, but nevertheless took into account the various documents, which several stakeholders had submitted in the 6^{th} stakeholder consultation. Marshall's wording for a general exemption of cadmium in opto-electronic components was cancelled, and the contractors' further investigations and review of information focused on the use of cadmium in photoresistors for professional audio applications, as proposed by Sound Devices.

5.3.3 Justification for exemption as submitted by applicant and stakeholders

The following subsections summarize the information from Marshall, Sound Devices, PMI Audio and Casco Silonex submitted in the 6th and 7th stakeholder round and during the review process.

5.3.3.1 Digital signal processing in professional audio equipment

RoHS-compliant digital signal processing (DSP) based on silicon-technologies, in opposite to the analogue electronics circuitries using cadmium-based optocouplers, is discussed as an alternative. The stakeholders state that digital formats are increasingly used for non-professional applications such as for music compact discs, recording and playback, but that current digital technology does not reproduce music and sound perfectly, particularly at high and low frequencies. The stakeholders say that although this is acceptable for audio equipment used by consumers, it is unacceptable for professional music recording, publishing and for real time applications like concerts where the sound quality must be an order of magnitude better than non-professional equipment. The dynamic range of the human ear is very wide and it is not possible, using current digital techniques, to accurately reproduce sound at very high and very low frequencies. The following paragraphs sum up the applicants' and stakeholders' arguments why DSP is not an alternative to the analogue technology using optocouplers with cadmium-based photoresistors for the professional audio industry.

Conversion from analogue to digital signals

Audio is an AC (alternating current) signal (see Figure 4), so the current must flow through the resistive element in both directions, and the resistance therefore must be the same for current travelling in either direction through the resistive element to achieve the linearity of the device. According to SD, photodiodes and phototransistors used in optocouplers or in DSP allow current to flow in one direction only and are therefore inherently "non-linear".

To process an analogue signal digitally, it must be sampled. Its instantaneous amplitude is measured at fixed time intervals (the "sampling rate"). While analogue has infinite resolution, the sampling process results in a finite resolution and changes the nature of the audio signal. Although the digital signal can be converted back to analogue, digitalization is an approximation process of the sampled signal to the original input signal. The faster the analogue input waveform changes, the worse the approximation.

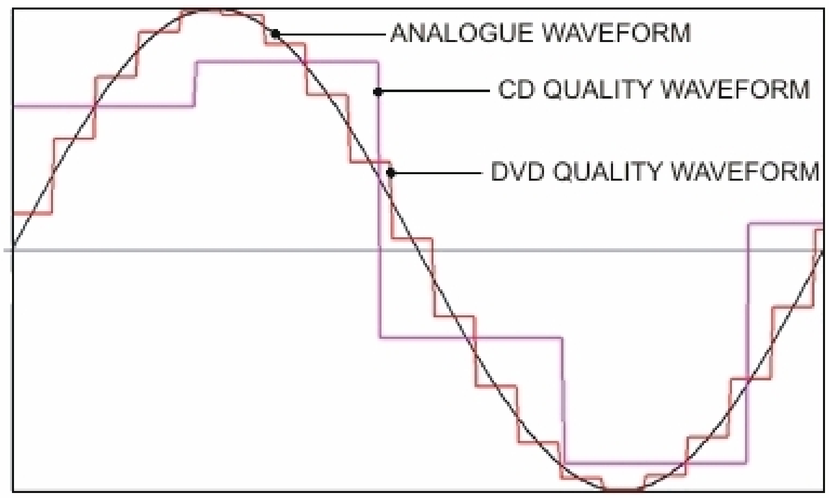


Figure 4: Digitalisation of an analogue waveform (source: PMI Audio)

Higher sampling rates reduce the error and give a better approximation, but, according to PMI Audio, remain an approximation only, while professional audio equipment must be optimised to reproduce the original input sound. PMI Audio quotes the Nyquist theory. To avoid quantification errors, the sampling frequency must be at least twice the maximum frequency of up to 100 kHz, which is actually necessary to faithfully reproduce the 20 kHz audio spectrum. Only the recent “DVD” standard with its sampling frequency of 192 kHz meets this criterion.

PMI Audio says that another source of signal information loss is that digital circuitry operates at between 3 Volts and 5 Volts, whereas analogue circuitry is ten times that. Hence an analogue signal must be attenuated by a factor of ten (20 dB) in order to be digitalised. The process of attenuation inevitably looses some information and increases noise slightly, due to the additional components required. Conversion back to analogue also worsens noise and distortion, because of the 20 dB of amplification required.

Digital signal processing

Once the analogue audio signal is digitalised, it must be processed. The amplitude of an audio signal with a resolution of 0.1 dB is a reasonable requirement for a professional audio processor. This is easy to achieve in the analogue domain, PMI says, but not in the digital one. A gain reduction of 0.1 dB requires the use of non-integer, floating-point arithmetic. This means that the digital word length used for computation needs to be much greater than that needed for sampling. ADC- (analogue-to-digital conversion) and DAC-unites (digital-to-analogue conversion) can use 24 bits to achieve a dynamic range of 140 dB, whereas the DSP needs at least 64 bits, even to approach an acceptable emulation of an analogue processor. Commonly available DSPs are currently 32-bit.

The digitalised audio signal is subjected to many stages of approximation, which produce unsatisfying results regardless of the accuracy of the emulation algorithms. Emulation further is complicated by the complex response of the photocell that is being emulated. All these factors result in approximation errors, which all reduce the sonic accuracy of the DSP system compared with an analogue one.

PMI put forward that measurable differences between analogue and digital systems very often could not be revealed by simple measurements using simple test equipment. Commonly measured parameters, such as noise and harmonic distortion of a steady-state signal, actually reveal very little about how an audio signal will “sound”. Analysis performed by the human brain is far more sophisticated. An appropriate method to compare the similarity of the analogously and digitally processed signals is the “invert and add” method. One of the two signals, either the original analogue or the processed digital one, is inverted and summed (mixed) with the other. Providing the two signals have identical amplitude, the two signals should extinguish each other such that nothing audible remains. Any residue represents the inaccuracy of the DSP in emulating the analogue process. In PMI’s experience, this method always reveals clear differences between the analogue and digital audio signals.

“Analogue sounds better than digital” has also been validated by the discipline of study known as “Psychoacoustics”. This uses the methods of experimental psychology, such as “double blind” listening tests and statistical analysis (http://en.wikipedia.org/wiki/Analog_sound_vs._digital_sound#Subjective_evaluation; source cited by PMI Audio).

Latency

Conversion from analogue to digital, DSP processing and conversion back from digital to analogue takes time known as latency. Typical latencies for current digital technologies are:

Analogue to digital	1 to 2 milliseconds
DSP	3 to 4 milliseconds
Digital to analogue	1 to 2 milliseconds
Total:	5 to 8 milliseconds

According to PMI, studies have shown that a good drummer can be time-accurate to 150 microseconds. Simple changes to the “mood” of playing, for example from “rock-steady” to “laid-back”, involve a change in timing of just 1 millisecond of hits on a snare drum. A latency of several milliseconds makes it impossible to play along with Digital Audio Processors in real time. PMI states that this is completely unacceptable in many situations within the professional recording and broadcast industries. Digital audio processing would require a hundred-fold increase in processing speed to remove this objection. At the current state of the art, this is not achievable, according to PMI.

Environmental Implications of DSP and shorter usage time of portable equipment

The stakeholders say that a DSP-based system contains much more active components. Any digital system also requires analogue input and output filter circuitry, which alone uses more components than the entire circuitry of an analogue device. Figure 5 shows a DSP circuit and a Joemeek compressor (see paragraph “Tradition” in section 5.3.3.2) in approximately the same scale.

Figure 5: Typical twin-board DSP module (left) and Joemeek analogue compressor (right) (source: PMI Audio)

The analogue Joemeek version (right) uses three 8-pin chips, while the digital "equivalent" uses three 144-pin chips on the upper DSP board alone. All the circuitry for analogue to digital and the digital to analogue conversion and filtering is on the lower board. The stakeholders say that the manufacturing of the digital chips and the larger printed circuit board with far more soldered joints requires more energy and material, but did not provide quantitative data.

During operation, photoresistor-controlled circuits do not consume energy when they are not operating. According to PMI, a Joemeek compressor circuit as an example for analogue signal processing consumes less than 0.5 W, while a digital system typically consumes 5 W continuously, whether it is under operation or not. The power consumption and heat production of a DSP-unit increases with the processing power of the DSP.

According to Sound Devices (SD), energy consumption is a critical parameter in particular for portable devices operating on battery power. Analogue portable audio mixers are designed for extremely low power consumption to maximize battery life in the film and newsgathering industries. Using DSP in such devices decrease the battery-life performance and the use time of the portable devices in field shortens, while battery consumption and wastes increase.

Sound Devices says that due to their simplicity compared to DSP units, the use of optocouplers with cadmium sulphide photoresistors enable products with minimum size and weight for the broadcast and film markets. According to SD, these light and small products provide a substantial health benefit as Location Audio engineers carry them over their shoulder for a full workday. It was not uncommon for a Location Audio Engineer to retire at age 40 to 45 due to typically spinal ailments. Reduction in weight by up to 50% of audio tools in recent years has improved the health and extended the careers of these Audio Engineers.

5.3.3.2 Specific properties of cadmium-based photoresistors for optocouplers

The stakeholders and applicants explain which unique properties of cadmium-based optocouplers make them indispensable for the audio industry. The following explanations are a summary of the applicant’s and stakeholders arguments.

Suppression of electrical noise and low distortion

A crucial property of cadmium-based photoresistors for optocouplers in professional audio equipment is the change of resistance over time as a reaction to light, the dR/dT characteristics, or the inherent fast-attack/slow-release characteristic. The “attack time” refers to the time it takes for the photo-resistor to go from a high to a low resistance, and vice-versa for “release time”. The dR/dT-characteristics can be adapted to the specific requirements of the respective application. A typical attack time is 50 ms, a typical release time 500 ms.

The attack time of around 50 ms is fast enough to allow a distortion-free transfer of signals without e.g. blurring spoken words. On the other hand, the attack time is slow enough to suppress electrical noise and inharmonic distortions from the sending circuit generating short flashes of light from the LED. Such short flashes of light will not affect the resistance of the photoresistor. Electrical noise in the sending circuit is thus eliminated in the receiving circuit.

Audio equipment must reliably represent the material being mixed or recorded without adding any electrically created noise or distortion. Inharmonic distortion examples include white noise, digital pulses, initial overdriving, and electrical noises generated outside of the audio circuitry.

The long release time of photoresistors keeps the harmonic distortion low. The gain only affects the amplitude of the waveform without affecting the basic shape of the waveform, which would result in harmonic distortions. Linearity is another typical property of optocouplers with cadmium-based photoresistors. Their electrical response is a regular linear function of the input light level. The linearity of the optocoupler translates directly into minimization of harmonic distortion.

Phototransistors and diodes as a possible replacement of cadmium-based photoresistors in optocouplers do not have the unique dR/dT characteristics and their response is not linear, according to the applicant Sound Devices. They also react with resistance changes to light. The conduction of the silicon device occurs in the moment the AC signal's amplitude exceeds the photovoltaic voltage drop. The silicon device then conducts, which causes an unacceptable deformation of the audio signal. Further, audio signals are AC signals. As silicon-based components like photodiodes and phototransistors allow current to flow through it in one direction only, the audio signal deformed. Electrical noise and distortions are not eliminated, or it requires considerable additional circuitry to achieve a quality of the audio signals, which is still below the quality of the audio signal from cadmium-based optocouplers. Optocouplers for professional audio applications need components with continuously variable resistance providing a wide linear and consistent resistance change.

Dynamic range

Optocouplers with cadmium-based photoresistors can respond to a large range of light levels. Typically they react to light levels from 0.02 Lux to over 10,000 Lux with an equally large range of resistance. Resistance values are typically from 2 ohm to 50 Mega-ohm.

Professional high quality audio applications like audio limiters for field use require such high dynamic ranges to handle the broad range of audio stimuli: capturing wildlife sounds such as birds at 50 meters when a deer approaches at 10 meters, or if a gun fires at 10 meters. The loud sounds should be undistorted, and at the same time the quiet sound of the birds should not be clouded by noise produced by the audio circuitry. The nominal sound levels can be as much as 100 dB apart. Optocouplers based on photodiodes cannot provide the necessary range of light sensitivity levels and reactive resistance changes, as the next table shows.

Table 7: Dynamic range of main photocell types

Photocell type	**Dynamic range; light sensitivity for typical devices, actual vales depend on design but range is not significantly affected**	**Wavelength response**
CsS/CdSe	0.02 Lux - >10,000 Lux	400 – 700 nm
Single crystal silicon	100 Lux – 1000 Lux	~400 – 1200 nm
Amorphous silicon (a-Si)	200 Lux – 600 Lux	<400 nm – ~820 nm
GaAs, GaAlAs	100 – 1000 Lux	~ 600 – ~950 nm

Source: Casco Silonex document no. 8 in references, section 5.3.6

Low cost and short development time

Optocouplers are less expensive than other analogue circuit or DSP-based options. They allow cost-effective and, due to their simplicity, quick solutions with short development times.

According to PMI, DSP technologies are around 20 times more expensive than the existing analogue circuitry, which makes DSP commercially unacceptable.

Tradition

PMI says that its products are based on the "Joemeek Compressor Circuit", a classic piece of audio engineering using a cadmium sulphide photoresistor pioneered by record producer Joe Meek in the 1960's. PMI puts forward that the technology itself is a brand and stands for a tradition and as such cannot be replaced, even if it would be technologically possible to imitate the effect with RoHS-compliant devices. Should the exemption not be granted, an entire tradition of technology would be put beyond reach of manufacturers and consumers, both amateur and professional, and would cause enormous damage to the viability of PMI's and other manufacturers' business. It would also give the rest of the world an unfair advantage over the EU in the field of music recording and production.

5.3.3.3 Sound Devices' justification for the 3-year exemption period

Sound Devices asks for a three-year exemption for the use of cadmium in photoresistors in professional audio equipment. SD says that analogue circuitry simulating the performance of an optocoupler is possible, as due to the ongoing miniaturization the sizes of electrical components are shrinking and power requirements have been going down. The applicant foresees a strong future potential that if he is given appropriate design time, he can produce RoHS-compliant products with alternative circuits replacing the non-RoHS-compliant optocouplers within the next three years.

In February 2007, Sound Devices first attempted the implementation in a prototype of portable microphone preamplifier. It was not successful but showed promise. After two more design changes the applicant says that the circuit is close to being suitable for portable professional audio, and he believes that he can start the integration into products in February 2008. Sound Devices says that each product requires a unique design to accommodate the variations in the audio circuitry. Sound Devices says that it has ten other existing products that require modifications to this new circuit design, or a complete product redesign for the use with the new limiter circuit concept replacing the non-RoHS-compliant optocouplers. According to the applicant, the redesign for all of these products would require a minimum of two years, and a maximum of three years depending on the number of PC Board revisions required to produce acceptable results.

5.3.4 Critical review of information as submitted by applicant and stakeholders

5.3.4.1 Overview on different test results for RoHS-compliance of Macron photoresistors and role in the review process

There are different test results available leading to different conclusions about the RoHS-compliance of Macron photoresistors. To some extent, these results diverge as a result of different interpretation in the understanding of "homogeneous material". In this context, it must be taken into account that neither the Commission nor the contractor, but only the European Court of Justice decides about the interpretation of the RoHS Directive. Against this background, the contractors solely present the test procedures, results, and implausibilities, as far as possible.

Macron presents four models of photoresistors, which also contain cadmium. According to Macron, the concentration of cadmium in the homogeneous material of these photoresistors remains below 0.01 % of weight, which is the maximum allowed cadmium level for RoHS-compliance.

The supporters of the exemption request challenge Macron's claim that these photoresistors for optocouplers are RoHS-compliant. Both the supporters of the exemption request and Macron have submitted several test reports dealing with the RoHS compliance of the Macron devices. The Macron test reports confirm RoHS-compliance; the opponents' test reports the opposite.

The following sections show an overview of the most important tests and their results. For detailed information, please refer to Annex II.

Macron test reports

Macron had submitted testing documents in the 6th stakeholder consultation confirming the RoHS-compliance of the tested photoresistors and optocouplers. None of the reports, however, clearly indicated which photoresistors and optocouplers had been tested and hence are not further reviewed in this subchapter. To allow an overview of the different testing approaches and the chronological submission of the different test reports by both Macron and Casco Silonex as a reaction to each other, all tests and their results are described in detail in Annex II.

In the review process following the seventh stakeholder consultation, Macron submitted a new test report (document no. 12 in references, section 5.3.6). The report explains that traditional photocells usually contain a layer of CdS/CdSe which acts as a photosensitive layer. Macron says it uses less cadmium it mixes cadmium into the ceramic base, which allows the ceramic base to have photosensitive function. The testing laboratory refers to this specific ceramic as "white ceramic" and considers it as homogeneous material, as the following figure underpins.

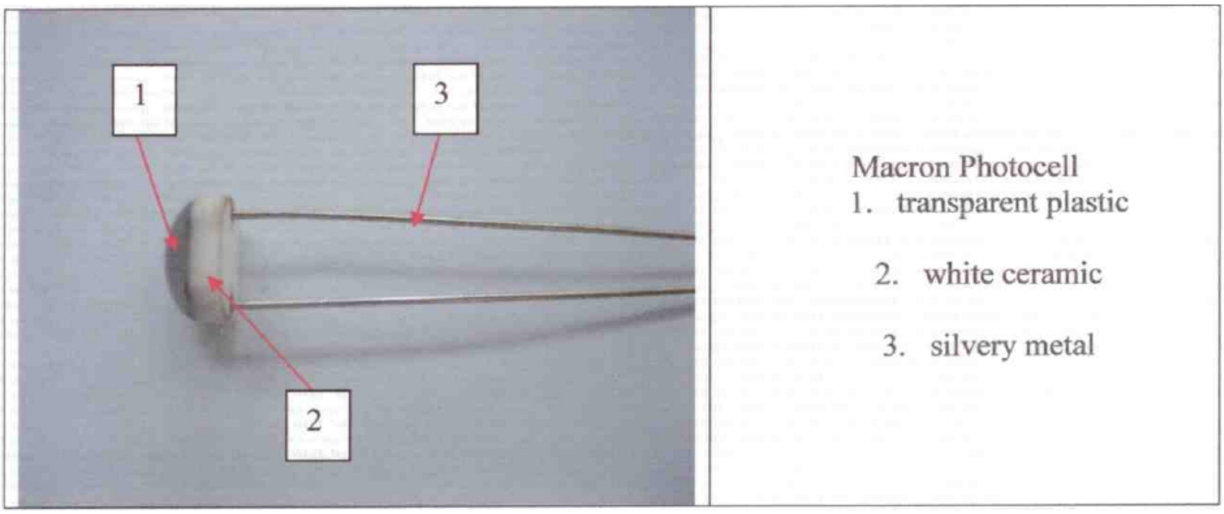
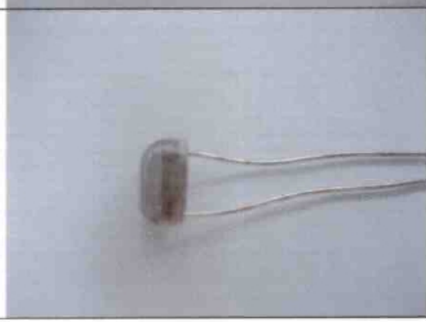
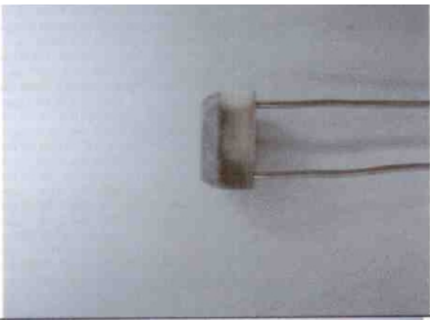
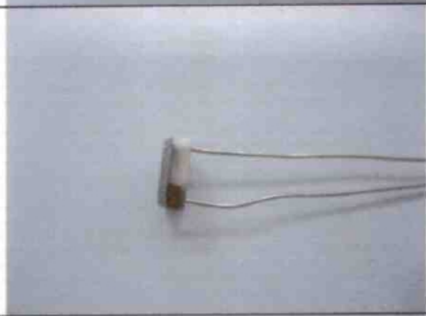
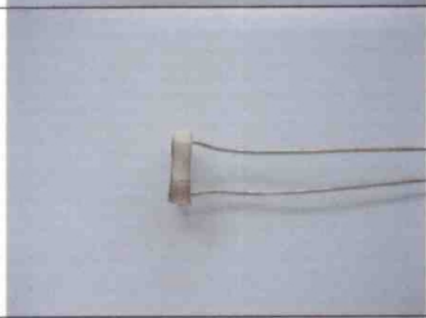


Figure 6: Physical appearance and homogeneous materials in Macron photoresistors (source: RWTT test report, document no. 12 in references in section 5.3.6)

The report specifies the tested product as Macron's MI 1210CLA-R (A-type), which according to Macron has the highest content of cadmium to achieve a high photosensitivity. The following table shows the sampling procedure and the cadmium content for each of the obtained samples. The samples were analyzed using XRF analysis.

Table 8: Sampling and XRF analysis results of obtained samples (accuracy ± 50 ppm)

Removal stage	Cadmium concentration (ppm)	Other element detected	Physical Appearance
With complete resin layer	N.D.	Sn, Pb, Cu, Fe	
After 1st abrasion to remove a layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	

After 2nd abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 3rd abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 4th abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 5th abrasion to remove all the transparent plastic, white ceramic and metal silvery pin has been exposed	31.1	Sn, Pb, Cu, Fe	
After 6th abrasion to remove a layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	

Source: Macron test report/RWTT, document no. 12, section 5.3.6

The testing laboratory conducted a total of ten abrasions, but did not detect any cadmium in any of the further abrasions after the fifth one.

According to these test results, only the last bit of transparent layer (material of 5th abrasion) would contain 0.0031 % (31.1 ppm) of cadmium, which is below the maximum allowed level of 0.01 % for RoHS compliance. The photoresistor would thus be RoHS-compliant. For details refer to document no. 12 in references in section 5.3.6.

Macron was asked to explain the results. The cadmium, according to the process description in the test report, is mixed into the ceramic base. The test result, however, indicates no detectable cadmium in the ceramic base, but only in the last bit of abraded transparent plastic. Macron explained that the cadmium was detected in the 5th abrasion of the transparent layer because RWTT might have abraded parts of the white ceramic with the last bit of transparent layer. There is no cadmium in the transparent layer, according to Macron, but the cadmium concentration should be higher nearer to the photo-sensitive surface of the ceramic and it was therefore detected with the first abrasions of the white ceramic.

Macron further on states the test result might as well have to do with the XRF analysis. The XRF analysis deviates within ± 50 ppm (± 0.005%), as also mentioned in the ERA report. Macron states that its photosensitive ceramic contains cadmium under the surface layer, too, but that it cannot be detected due to the inaccuracy of the XRF analysis.

In another statement, Macron says that for each of its optocouplers, a total of around 80 ppm of CdS and CdSe referring to the weight of the solid ceramic is added into the ceramic liquid for mixing. For further details, please refer to Annex II.

ERA test reports

The most important ERA test by the order of Casco Silonex was submitted in the review process following the 7th stakeholder consultation (document no. 11, section 5.3.6). The following Macron devices had been tested:

- MI 1210CLA-R (type “A”)
- MI 1210CLB-R (type “B”)
- MI 1210CLH-R (type “C”)

The above models are the models of the Macron MI1210CL-R series, for which Macron claims RoHS compliance. The “C”-denomination of the last of the three series, the MI1210CLH-R, however, is not congruent with Macron’s information. According to Macron, this is the “H”-series, and there is no information from Macron whether a “C”-series actually exists. In the ERA test report, the MI 1210CLH-R model is sometimes addressed as “C”-type, sometimes as “H”-type (e.g. in Table 9).

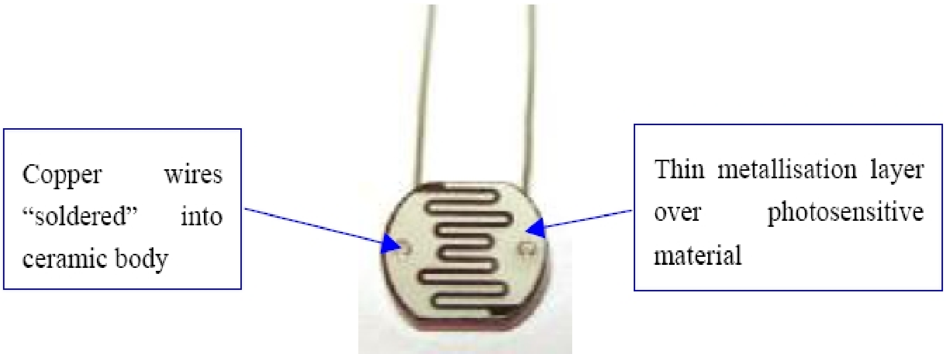


Figure 7: Image of Macron photocell (source: ERA, see document 7 in references, section 5.3.6)

ERA challenges the homogeneous material definition of the RWTT test reports. ERA says that the "white ceramic" (sample 1 in the Macron test report) can be mechanically disjointed into two homogeneous materials:

- the ceramic base
- photosensitive layer containing cadmium and the metallisation (cannot be mechanically disjointed from cadmium layer)

ERA describes that the light dependent resistors have coatings of a transparent gel over a thin metal mask that defines the resistor path which is made of the photosensitive material."

Figure 8: Light dependent resistors from Macron optocoupler type "A", type "B" and type "C" (left to right) (source: ERA, see reference document no. 11, section 5.3.6)

ERA scraped off the transparent gel with a surgical scalpel. The very thin metal layer could not be separated from the photosensitive layer. The photosensitive layer with metal mask was removed from the substrate from between the metal pins as one material with the scalpel.

Figure 9: Light dependent resistors from Macron optocoupler type “A”, “B”, “C” (left to right) after the gel and photosensitive material coatings had been removed (source: ERA, document no. 11, section 5.3.6)

The scraped off material was analyzed with a Scanning Electron Microscope (SEM) and energy dispersive X-ray (EDX) analysis.

Table 9: SEM/EDX analysis of photosensitive coating from Macron optocouplers

	Results (weight percent)	Comments
“A“	Cadmium 60,6 %, sulphur 15,5%, selenium 5,5 %	This material is cadmium sulphide/selenide
“B“	Cadmium 70 %, sulphur 18,4 %, selenium 4,1 %	This material is cadmium sulphide/selenide
“H“	Cadmium 58,2 %, sulphur 15,1 % selenium 2,3 %	This material is cadmium sulphide/selenide

(Source: ERA, document no. 11, section 5.3.6)

ERA explains that the figures in the table for the cadmium-containing elements do not add up to 100% because small amounts of impurities from the gel coating (carbon and oxygen) and the alumina substrate (aluminium and oxygen) have not been included.

According to the test results in Table 9, the cadmium content in the analyzed Macron photoresistors would be clearly above 0.01 %. The optocouplers would thus not be RoHS-compliant. For details, refer to document no. 11 in references, section 5.3.6.

Conclusions

The test reports submitted by Macron and Casco Silonex arrive at contradicting statements on the RoHS-compliance of the Macron photoresistors and optocouplers. The consultant cannot take a position on the correctness of the testing and the test results, as mentioned before.

The question whether the tested Macron photoresistors actually are a technically appropriate substitute for the other, non-RoHS-compliant photoresistors in optocouplers of professional audio equipment thus becomes obsolete. The potential users of such devices are in the best position to decide whether or not the Macron products are a viable option for their specific professional audio applications.

5.3.4.2 Non-cadmium-based optocouplers as alternative to cadmium-containing optocouplers

A stakeholder from China, the ON institute, had submitted a document opposing the exemption of cadmium in optoelectronic components (see document 10 in references, section 5.3.6). The stakeholder reasons that appropriate RoHS-compliant optocouplers are available on the market and lists examples:

- PC817 from different manufacturers,
- HCNR200 (USA, Avagotech, www.avagotech.com),
- TIL300 (USA, Burr Brown Inc.).

A crosscheck on the internet showed that the Burr Brown component is no longer available on the market. The Avagotech component, however, was found on the manufacturer's website. It is an optocoupler, which does not use photoresistors, but photodiodes. Whether this component is actually RoHS-compliant was not clear from the information available on the manufacturer's website. It was not possible to obtain a list with RoHS-compliant optocouplers including the necessary application-relevant technical data.

Nevertheless, Sound Devices was asked to explain why such optocouplers are not appropriate for its products. Sound Devices explained that audio is an AC (alternating current) signal, so current must flow through the resistive element in both directions, and the resistance therefore must be the same for current travelling in either direction through the resistive element. Sound Devices says that this is the essence of what is called the "linearity" of the device. According to SD, photodiodes and phototransistors allow current to flow in one direction only and are therefore inherently "non-linear", thus making them inapplicable for implementation as resistive elements around an operational amplifier. Further information on silicon-based elements as substitutes for cadmium-based photoresistors in optocouplers was already explained in subchapter 5.3.3.2.

This exemption request is also related to the exemption request no. 21 Cadmium sulphide photocells from stakeholder consultation no. 2. Applicants had requested an exemption for cadmium in photocells for dimming lights. The request was recommended not to be granted as RoHS-compliant alternatives had been available. These alternatives were presented to Sound Devices as well in order to check whether they might be a possible solution or part of a solution. Sound Devices replied that the devices are not variable resistors, but only light sensors with a current output, which cannot be used in an audio gain stage.

They cannot be used to achieve the required properties of cadmium-based photoresistors in optocouplers as described in chapter 5.3.3.2.

5.3.5 Final recommendation

Apart from some economical arguments and the argument that a traditional circuit like the Joemeek circuit must be allowed an exemption, the applicants and stakeholders technical and environmental arguments justifying an exemption.

The applicants and stakeholders explained that DSP at the current state of technology is not an alternative to replace analogue sound processing circuits in order to avoid the use of cadmium-based optocouplers in all professional audio applications. The applicants and stakeholders are not fully in line where DSP might already be used today and where not. They showed, however, that forcing the professional audio industry to switch to DSP or other possible alternatives would arise technical and environmental impacts. Increased energy consumption linked to shorter product battery times in case of in-field-use devices, use of more and more complex electronics components and printed wiring board materials, and possibly heavier products burdening the health of workers in in-field-use of these products.

Technically, the use of DSP in many cases will not allow the sound quality sufficing the high demands of professional audio applications as with analogue technologies based on cadmium-containing optocouplers. The same applies to the use of alternative optocouplers that work with photodiodes or other RoHS-compliant, photosensitive elements as substitutes for the basic, light-depending functionality of cadmium-dependent photoresistors.

The above technical and environmental drawbacks must be weighted against the use of minor amounts of cadmium. Sound Devices ships around 1 g of cadmium into Europe annually. The applicants did not provide total figures for Europe. Assuming, however, that the total amount is 1,000 times higher, it is around 1 kg of cadmium involved in the requested exemption in Europe.

The contradicting RoHS-compliance tests did not allow assessing whether the Macron cadmium-based photoresistors contain cadmium below the allowed threshold level of 0.01 % and therefore are RoHS-compliant. The technical properties of the Macron components regarding their appropriateness as a substitute for non-RoHS-compliant photoresistors were not assessed, as the RoHS-compliance could not be decided either. It is thus currently not possible to recommend a RoHS-compliant, cadmium-based alternative for optocouplers.

The applicants and stakeholders have different opinions about the future possibilities of DSP and alternative analogue technologies to substitute the cadmium-dependent analogue technologies. Sound Devices presented a roadmap suggesting that a RoHS-compliant solution is possible within three years and proposes an exemption limited to three years starting in beginning of 2006.

Taking into account all the facts reviewed the contractors assume that the technical and environmental arguments might suffice the requirements of article 5 (1) (b). As for some applications, RoHS-compliant alternatives like DSP might be a solution; the exemption could be limited to specific applications, which would require a further investigation and information gathering round to assess the products where technically viable RoHS-compliant alternatives are possible and where not. The environmental implications, however, at the current status of technology might allow a general exemption for the use of cadmium in optocouplers for professional audio equipment providing that the Commission gives higher priority to these environmental and possible health implications than to the avoidance of a maximum of 1 kg of cadmium, probably less.

In this case, the contractors recommend granting an exemption with the following wording, which was changed from the original wording in accordance with the applicant Sound Devices:

Cadmium in photoresistors for optocouplers applied in professional audio equipment until 31 December 2009.

5.3.6 References

The below files are attached to this report.

The following documents are stakeholder documents submitted in the 6th and 7th stakeholder consultation rounds:

1. Stakeholder document “Attachment 1 SGS Photocell report1.jpg” submitted by Macron Electronics Limited (testing laboratory: SGS),
2. Stakeholder document “Attachment 1 SGS Photocell report2.jpg” submitted by Macron Electronics Limited (testing laboratory: SGS),
3. Stakeholder document “Attachment 3 SGS Optocoupler report1.jpg” submitted by Macron Electronics Limited (testing laboratory: SGS),
4. Stakeholder document “Attachment 3 SGS Optocoupler report2.jpg” submitted by Macron Electronics Limited (testing laboratory: SGS),
5. Stakeholder document “RoHS_and_WEEE_Macron_Photocell_RT069686.pdf” submitted by Macron Electronics Limited (testing laboratory: RWTT),
6. Stakeholder document “RoHS_and_WEEE_Macron_Optical_Isolator_RT069701.pdf” submitted by Macron Electronics Limited (testing laboratory: RWTT),
7. Stakeholder document “Silonex Macron RoHS status letter.pdf” submitted by Silonex (testing laboratory: ERA),
8. Stakeholder document “Marshall_Marshall support letter 01 08 07A-1.doc”, submitted by Marshall,
9. Stakeholder document “PMI Support Cadmium in Optocouplers.htm” submitted by PMI Audio Inc.,
10. Stakeholder document “About Cd.doc” submitted by the On Institute for Optical & Electronic Technology.

The next documents were submitted or referenced in documents submitted to Ökoinstitut and Fraunhofer IZM during the RoHS exemption review process:

11. Report “ERA opto coupler analysis Aug 2007-new.pdf”, received in August 2007 via e-mail from Euan Davidson, Chromotechnic Ltd. (testing laboratory: ERA),
12. Report “RT079366_R2.pdf”, received in August 2007 via e-mail from Stephen Leung, Macron.
13. RoHS Enforcement Guidance Document, Version 1 – issued May 2006, (http://www.rohs.gov.uk/Docs/Links/RoHS%20Enforcement%20Guidance%20Document%20-%20v.1%20May%202006.pdf); the document is informative and advisory, but has no legal authority.

5.4 “Pb and Cd in printing inks for the application of enamel on glasses, such as borosilicate and soda lime glasses” (set 7, request no. 1a, ELCF)

5.4.1 Requested exemption

The European Lamp Companies Federation (ELCF) has submitted this request for a change in wording of an existing exemption: entry no. 21 of the Annex to the RoHS Directive reads “Lead and cadmium in printing inks for the application of enamels on borosilicate glass”. ELCF requests to have following new wording for entry no. 21:

“Lead and cadmium in printing inks for the application of enamel on glasses, such as borosilicate and soda lime glasses.”

According to the applicant, lead is used in printing inks on parts of the outer surface of lamps (e.g. fluorescent lamps). These markings are essential for product identification, as requested by safety standards. The marking has several functions, during entire life cycle:

- To identify the producer,
- to identify lamp type and wattage, which is relevant for safety, correct lamp replacement and recycling,
- CE, WEEE marking.

The applicant states:

“Product identification is required by the relevant product safety standards, which are the basis of the CE Marking according to the LVD Directive (2006/95/EC). Product identification must be legible for the consumer or other stakeholders during the entire life cycle of the product (safety, replacement, recycling etc.)

Intensive heat and light during lamp operations result in quality challenges for the marking of a lamp. Some luminaries, state a maximum wattage in order to avoid excessive heat. If a mark is not properly legible for the user, the user might place the wrong lamp into a luminaire with the consequence of a high safety risk. […] Moreover, marking of lamps at the end of life is also required by the WEEE Directive."

The amount of lead for the marking is about 0,25 mg for a normal fluorescent lamp (i.e. order of 1 ppm of glass tube by weight) and 1 mg for a relatively big mark on an incandescent lamp. The lead-based marking contains as such 20 % lead-oxide. Total EU market quantity for this application is assumed to be 1-2 tons of lead per year. For the marking of lamps, ELCF Member Companies do not need mercury.

5.4.2 Summary of justification for exemption

The applicant justifies his request for exemption with juridical and technical arguments:

- Until now, RoHS compliance is given since ELCF considers the marking as being part of the glass1 and thus considers the marked glass as homogeneous material containing lead below the maximum concentration limit of 0,1% by weight.
- Since the European Special Glass Association (ESGA) had submitted a request for exemption (cf. http://circa.europa.eu/Public/irc/env/rohs/library?l=/requests_exemptions/crystal_crystal_crystal_&vm=detailed&sb=Title) under a previous stakeholder consultation leading to entry no. 21 in the RoHS Annex, ELCF claims to also need an exemption for the same type of application in order to have legal certainty and thus requests the current wording to be enlarged to soda lime glasses.
- "ELCF Member Companies are committed to phase-out the use of hazardous substances like lead". The applicant claims that results of tests showed that using lead-free printing inks on lamps does not meet the above-mentioned requirements.
- "To some extent elimination of lead in marking has been shown to be feasible for some kind of lamps but not for all products. […] Especially for long-life products […] or products having a hot external surface during lamps operation […], attempts to eliminate lead in marking have not yet been successful." The applicant has not provided an exhaustive list of applications concerned by this statement.
- "Several years" would be needed by the applicant to completely substitute lead in the concerned application.
- A critical review of the documents made available by the applicant lead to the following observations and conclusions:
- ELCF did not take the opportunity to participate in the initial discussion around ESGA's initial exemption request; no objection has been received at that time concerning ESGA's

[1] „In the marking process the lead oxide based printing ink is heated that results in a moulding or melting diffusion process with the glass surface." The mark is then "intrinsically" bonded to the glass.

interpretation of the fact that glass marked with lead-containing printing inks cannot be considered a homogeneous material.

- ELCF uses the same argumentation concerning technical impracticability of lead substitution in glass marking as ESGA did; thus this argumentation line is consistent.
- ELCF shows some inconsistency when stating on the one hand that marked glass containing lead from the printing ink is considered a homogeneous material and on the other hand states that "one has to resort to intensive abrasion or chemical dissolution to separate the from the glass", i.e. a statement that includes both definitions of homogeneous and not homogeneous material. However, the official position published on ELCF's website is that "the mark becomes part of the lamp glass. Therefore the marked glass is considered as a homogeneous material below the maximum concentration limit of 0.1% by weight.2"
- It is not known to the contractor whether ESGA and other relevant stakeholders would in the meantime agree to this position. A separate consultation would be needed to gather information and evaluate this aspect.
- There are only two conclusions possible from the above-mentioned argumentation:

1. The current exemption under entry no. 21 of the RoHS Annex should be deleted since all relevant stakeholders could now agree on the fact that the marked glass is to be considered a homogeneous material OR
2. The current entry no. 21 of the RoHS Annex should be enlarged to soda lime glasses since the same justification applies to soda lime glass as to borosilicate glass.

5.4.3 Final recommendation

With a view to simplify EU regulations, deleting an exemption from the Annex is rather recommendable. However, since it is not known whether relevant stakeholders would as by today agree to ELCF's interpretation on marked glass as being a homogeneous material, it is recommended to grant this exemption and to thus change the existing wording of entry no. 21 of the RoHS Annex as follows:

"Lead and cadmium in printing inks for the application of enamel on glasses, such as borosilicate and soda lime glasses."

However, it is strongly recommended to review this exemption in the context of the upcoming review of the RoHS Annex including the following aspects:

- Do ESGA and ELCF represent all relevant stakeholders in this field of application or which other relevant stakeholders can be identified?

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2 See: http://www.elcfed.org/uploads/documents/-7-elc_guidance_document_on_rohs_market_surveillance.pdf

- Can all relevant stakeholders agree on the interpretation of glass marked with lead (and cadmium) containing inks as being a homogeneous material? Is this possibly valid only for only lead or cadmium?
- Can cadmium-free printing inks also be used on borosilicate glass for applications ESGA initially requested an exemption for (e.g. coffee jugs)?
- If an exemption appears to be further needed, it should be checked with stakeholders whether borosilicate and soda lime glass applications concerned – for which substitution is not feasible – can be listed exhaustively in order to narrow down the scope of the exemption.

5.5 "Lead in Silver rings on the exterior lamp surface of induction-type fluorescent lamps." (set 7, request no. 1b, ELCF)

5.5.1 Requested exemption

ELCF requests an exemption for the use of lead as lead oxide in a silver paste used to coat QL 165 W induction-type fluorescent lamps with silver rings in order to meet electromagnetic compatibility (EMC) requirements[3] ("Induction-type lamps may contain conductive rings, on the exterior of the glass surface") (see picture below).

Figure 10: QL 165 W induction-type fluorescent lamps with silver rings

Such lamps have to perform, for a long designed operating lifetime of up to 100.000 hrs (about 15 years of continuous operation is demanded).

Composition of the conductive rings is about 93 % Ag and 7% PbO. The ring is applied via a coating process, but later baked into the glass material via a heating process using flame burners. One lamp weighs about 0.175 kg. Total weight of the (5) rings is about 0.47 g

[3] European standards EN 55015 "Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment" and EN 55020 "Electromagnetic immunity of broadcast receivers and associated equipment".

material, which means about 33 mg PbO (about 188 ppm related to lamp weight). The number of lamps put on the market each year is about 15.000. This equals to about 7 kg material of Ag and about 0.5 kg PbO.

Most of the QL 165W lamp systems are used in a luminaire with a metal reflector. This reflector screens the radio-interference so that the EMC-requirements are not exceeded. Thus, not all such lamps need such conductive rings: only those lamps that are unshielded, i.e. a lamp system not inside a (partly) metal housing, and cannot ensure EMC by themselves, should have conductive rings on their surface to suppress the radiointerference and thus comply with EMC requirements.

However, the applicant has considered different design options and concluded that for the sake of simplicity for the user as well as connected safety during use of lamp, all QL 165 W induction-type fluorescent lamps should have such rings.

Currently, ELCF considers to be RoHS-compliant since “In the coating or pasting process of the silver rings, the silver and lead oxide based printing ink is heated, which results in a moulding or melting diffusion process with the glass surface. Due to the fact, that the mark is intrinsically bonded to the glass, the ELC concludes that: The silver ring becomes part of the lamp glass. Therefore the glass is considered as a homogeneous material below the maximum concentration limit of 0.1% by weight.”

However, the applicant states that this interpretation is in conflict with current entry no. 21 of the RoHS Annex and that in order to have legal certainty, would like to request an exemption nevertheless.

5.5.2 Summary of justification for exemption

The applicant justifies his request for exemption with technical arguments:

- The existing supplier of the silver and lead-based paste went out of business.
    - Since no other suitable supplier could be found, the manufacturing of this paste had to be taken up at the applicant in-house.
    - A potential supplier has been selected. However, substitute materials require a higher melting temperature, which the supporting glass surface has to withstand. This supplier has not yet released the material for continuous production.
    - The applicant could not give an exact time frame but stated that an alternative will not become available before 2009. ELCF’s Member Companies aim to finalise research and development efforts by 1 July 2010.
- The way forward towards a lead-free solution needs to look first at whether a suitable adhesion can be maintained during the long lamp life. Here, overlapping exists with exemption request no. 1a with regard to lead-containing glass marking in general (see section 5.4). As a next step, upon introducing the silver component, sufficient electrical

conductivity needs to be ensured. A few substitutes have been studied, with negative results:

- “The PbO acts as a melting glass to ensure good adhesion of the conductive rings on the lamp. In order to have effective suppression of electromagnetic interference, proper adhesion of the silver ring must be realised initially. So far no technically proven solution has been found to substitute PbO. Organic solutions cannot be applied due to detrimental effect of high temperatures combined with a long-term exposure to a relatively minor UV part of the emitted light radiation.
- A studied copper paste cannot fulfil the temperature requirements during the extreme long lifetime of 100.000 hr. Large and unreliable shortening of product life would be the result.
- Lead free marking ink has shown so far insufficient conductive properties: Potential appropriate lead-free solutions could be silicone-based. This composition has been tested for the substitution of lead oxide based marking inks for general lamp marking. The electrical conduction properties however are not sufficient for adequate suppression of electromagnetic fields. This causes inadequate suppression of electromagnetic radiation.”

A critical review of the documents made available by the applicant lead to the following observations and conclusions:

- The amount of lamps containing lead-based silver pastes to coat the glass surface of QL 165 W induction-type fluorescent lamps could be reduced, since the necessity of reducing radio interference only applies to those lamps that are unshielded.
- The same argumentation applies as described in section 5.4 above on request 1a: if stakeholders could agree on the fact that lead contained in glass marking (and in this case coating) is exempted if the marked/coated glass is considered a homogeneous material, there would be no need for an exemption.
- The applicant did neither provide evidence on the point of time he started investigations on substitutes nor on time details regarding a substitution roadmap.
- The current technical impracticability of substitution, nevertheless, was described in comprehensible and rather comprehensive way.

5.5.3 Final recommendation

With a view to simplify EU regulations, deleting an exemption from the Annex is rather recommendable. However, since it is not known whether relevant stakeholders would agree as by today to ELCF’s interpretation on marked/coated glass as being a homogeneous material, it is recommended to grant this exemption and to thus change the existing wording of entry no. 21 of the RoHS Annex as follows (taking the recommendation on exemption request 1a in section 5.4.3 into account):

Lead and cadmium in printing inks of enamel and in silver pastes used to coat QL 165 W induction-type fluorescent lamps with silver rings in order to meet electromagnetic compatibility (EMC) requirements for the application on glasses, such as borosilicate and soda lime glasses. The use of lead in silver pastes is limited until 1 July 2010.

This wording, however, would need to be agreed upon by all relevant stakeholders. Due to time constraints, this could unfortunately not take place within the duration of the current contract.

Thus, it is strongly recommended to review this exemption in the context of the upcoming review of the RoHS Annex.

5.6 "Exemption request for use mercury in plasma displays" (set 7, request no. 2, Babcock Inc.)

5.6.1 Requested exemption

Babcock (La Mirada, U.S.) requests an exemption for the use of mercury in Babcock's DC plasma displays which it considers to belong to category 4 WEEE Directive ("consumer electronics"). This request had already been submitted to the Commission before and has been subject to an online consultation as well as to a subsequent evaluation (set 5 no. 23). In this context a final recommendation could not be given due to the fact that an additional round of questions would have been necessary though exceeding the contractor's contract duration (cf. http://ec.europa.eu/environment/waste/weee/studies_en.htm, "Adaptation to scientific and technical progress under Directive 2002/95/EC; Final report, July 2006"; section 6.40). Babcock therefore was advised by the Commission to re-submit an exemption request.

According to the applicant, other plasma display manufacturers use AC technology, which does not require use of mercury. Both types of Plasma Display Panels (PDP) are already subject to entry no. 25 of the Annex to the RoHS Directive, which exempts the use of lead in such applications from restriction of use.

The particularity of DC driven Plasma technology is that they do not use phosphors to generate visible spectrum. During the manufacturing process of DC PDPs, a small amount of mercury is added to the DC plasma display to inhibit sputtering, which is a phenomenon that reduces life of PDPs (mercury is used to coat the cathode conductor and to inhibit the cathode conductor's material being sputtered onto the anode).

According to the applicant, this functionality can be summarised as follows:

- "Mercury is hermetically sealed in the DC plasma display and is used to retard the cathode sputter onto the anode electrodes. Without the use of mercury in DC plasma display the sputtering of cathode will completely deplete the cathode material. The sputtered cathode materials deposited on the anode electrodes will also cover the pixel glow viewing and render the pixel non-viewable. DC plasma display life expectancy without the use of mercury is only a few hours as apposed to 20.000 hours with the mercury inside."

The applicant's DC Plasma display has between 1 to 20 mg of mercury per display (large displays can even have up to 30 mg mercury). The amount of mercury depends on total cathode area. Average mercury percentage by weight is stated to be 0,0014 % in the DC plasma display or 13 mg. Percentage by weight in the homogeneous material is stated to be between 0,2 – 0,4 %. The total annual amount of mercury (Hg) in the applicant's DC plasma displays for use in the EU market is estimated to be less than 80 grams.

No exact wording has been proposed by the applicant in the context of the here evaluated submission for an exemption. However, the former request included the following wording proposal:

Exemption for mercury to be use in DC plasma displays, maximum amount not to exceed 30 mg per display.

5.6.2 Summary of justification for exemption

The applicant justifies his request for exemption with technical arguments:

- Substitution or elimination of mercury in DC plasma display is currently technically not possible. The applicant has spent 2 years (1998-1999) working with DuPont electronic division to develop mercury free DC plasma display and so far no substitution was found that enable the DC plasma to operate more than few days without observing sputtering versus typical 20.000 hours in a DC plasma display with mercury inside.
  - Substitutes that were looked at are Al, Ru and LaB_6. Criteria that were used for the trials were luminous efficacy, glow uniformity of the cathode and cathode sputtering rates. In all four materials tested cathode sputtering and non-uniform cathode glow were observed after 66 hours. LaB_6 gave the most encouraging results according to documentation of test results.
  - Substitutes could not be found although there was a high motivation to substitute mercury, since it is more expensive than substitutes. Furthermore, heaters are added to raise the operating temperature of the glass in order to increase the vapour pressure of the mercury for a better performance of the display in cold climates. Substituting mercury would thus lead to cutting costs and power consumption of the PDP.
- The applicant states that substitution of mercury in DC PDPs is comparable to the situation manufacturers of compact fluorescent lamps face. The use of mercury in such lamps is currently exempted from the restriction of use under RoHS (entry no. 1 "mercury in compact fluorescent lamps not exceeding 5 mg per lamp").

A critical review of the documents made available by the applicant lead to the following observations and conclusions:

- The applicant has provided sound and comprehensive information about the use of mercury in DC PDPs as well as on the availability of substitutes. The only missing information is i) whether substitution will be feasible within a given timeframe, ii) whether there are other manufacturers than Babcock producing DC PDPs and iii) whether DC and AC driven PDPs provide exactly the same technical functionality or whether they each have their justification of existence due to different types of uses.
- The EEB has provided a stakeholder comment questioning the necessity of the use of mercury since mercury-free PDPs are available on the market.
- The applicant has comprehensively explained why this is true for AC PDPs and why not for his DC driven PDPs.
- As a conclusion it can be stated that i) substitution is feasible on a technological level – meaning that delivering a PDP is technically feasible without mercury – and ii) substitution is not feasible within the technology of DC driven PDPs.
- Not granting the exemption would mean that a preference is given to AC driven PDPs.
- In the context and scope of the evaluation, the contractor cannot judge whether the two technologies – be it AC or DC driven PDPs – are equivalent or whether both have their justification for certain uses.

5.6.3 Final recommendation

With a view to the above argumentation, it is recommended to grant the requested exemption for the specific technology of DC driven plasma displays since substitution is currently technically not feasible. However, the Commission is invited to consider the fact that plasma displays are available on the market in mercury-free technology. Furthermore, it is proposed to set a time limit, since research of substitutes has already been undertaken.

The proposed wording for the exemption is:

Mercury used as a cathode sputtering inhibitor in DC plasma displays with a content up to 30 mg per display until 1 July 2010.

5.7 "Cadmium in photocells for accurate control of lighting equipment" (set 7, request no. 3, Silonex)

5.7.1 Requested exemption

Silonex Inc. (Montreal, Canada) requests an exemption for "Cadmium in Photocells for accurate control of lighting equipment". According to the applicant, Cadmium sulphide/selenide (CdS/CdSe) photocells were designed to be sensitive only to visible light, and currently have a wide variety of uses, such as in night-lights and street lighting controls.

The applicant describes the assembly and composition as follows: Each photocell has a thin layer of cadmium sulphide/selenide, which as a homogeneous material contains ~50 % cadmium. Each photocell typically contains only 100 µg of cadmium. Silonex estimates that about 2 kg of cadmium is used in lighting control equipment (including street lighting) sold in EU annually. Other applications than street lighting control are to control ambient lighting in offices, factories and homes and to control the level of illumination of LCD TVs, PDAs computers, etc.

The applicant provides a proposal for the wording of the exemption as follows: "Cadmium in human eye sensitive visible light sensors for measurement of light levels for control of ambient lighting".

There are several other requests for exemption, which are overlapping with this one:

- "Cadmium sulphide photocells – Perkin Elmer/Philips" (set 1 request No. 21) and "Cadmium in opto-electronic components – TESLA" (set 2 request No. 10): for both requests it was recommended not to grant an exemption since adequate substitutes exist and are available on the market in sufficient amount by 1 July 2006 (cf. monthly report 5 of fomer contract; available at http://ec.europa.eu/environment/waste/weee/studies_en.htm, "Adaptation to scientific and technical progress under Directive 2002/95/EC; Final report, July 2006"[4]).
- "Cadmium in optoelectronic components" (set 6, request no. 23, Marshall Amplification plc): due to a lack of information this request could not be evaluated (see this report, section 5.3.2.3[5]).

4 "According to a manufacturer of silicon-based photodiodes substitutes exist and are available in sufficient amount for 1 July 2006. Several companies have developed [substitutes] which are well suited to substitute CdS-based photoresistors. […] The suitability of silicon-based photodiodes as substitute for CdS-based photoresistors has been confirmed by an independent external expert consulted on this issue".

5 "Marshall applied for a general exemption of cadmium in opto-electronic components. In order to clarify this rather broad scope and further open questions the consultant asked the applicant several times for further information. […] Marshall later on cancelled the further cooperation via e-mail. […] The contractors' further investigations and review of information focused on the use of cadmium in photoresistors for professional audio applications, as proposed by Sound Devices."

- "3-year grace period on the use of Cadmium-based photoresistors used in professional audio equipment, for the purpose of investigating suitable alternatives and redesigning audio products accordingly" (set 7, request no. 4, Sound Devices): In this case, the contractors recommend granting an exemption limited until December 2009 with an amended wording on the basis of the original wording in accordance with the applicant (see this report, section 5.3.5[6]).

5.7.2 Summary of justification for exemption

The applicants' arguments to justify the request can be summarised as follows:

Technical arguments:

- Alternative semiconductors have some light sensitivity but their electrical and optical characteristics are different so that none are suitable as direct drop-in replacements and their performance has significant limitations.
- Silicon photodiodes do not respond to visible light in the same way as the human eye and the change in their characteristics from dark to light is much smaller than cadmium based photocells.
- These limitations could partly be resolved by addition of other components but the best available technology is not yet able to match the precision that can be achieved by cadmium photocells.

Environmental, health and consumer safety impacts: The applicant assumes that alternative technologies provide inferior precision leading to several implications:

- Consumer safety: If street lighting switches on too late or off too early, this results in a risk to consumer safety as a result of road accidents. The applicant has brought forward this argument, although street lighting is clearly out of RoHS scope.
- Global warming: If the lack of precision is compensated by deliberately switching on early and off late, unnecessary energy consumption occurs potentially affecting global warming. Use of less precise sensors, which on average are 25% wrong, will produce 4.5 m t CO_2 emissions unnecessarily. Even if this is a pessimistic overestimate, ~5% error margin means that still ~1 m t CO_2 per year are emitted unnecessarily.
- Alternative technologies require additional components including filters and amplifiers. It is estimated that the typical mass of electronics for the photodiode option is at least 1.75 times greater than the cadmium photocell option. On request, this argument was justified demonstrating a typical CdS photocell circuit for accurate control of lighting compared to an alternative circuit using the photodiode option (based on SemeLab 413101 ASIC).

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6 „It is thus currently not possible to recommend a RoHS-compliant, cadmium-based alternative for optocouplers. […] Sound Devices presented a roadmap suggesting that a RoHS-compliant solution is possible within three years and proposes an exemption limited to three years starting in beginning of 2006."

During the stakeholder consultation, the Institute of Optical & Electronical Technology contributed with an opposing view to the requested exemption. The main arguments are as follows:

- There are existing substitutes available from different suppliers (namely Perkin Elmer, Osram, Microsemi, Avagotech, Toshiba, Panasonic, Kodenshi, On).
- Using photosensitive semiconductors instead of (CdS/CdSe) photocells would not lead to additional peripheral circuit.
- There are no limits for the usage of photosensitive semiconductors and the usage is convenient, as only the circuit parameter have to be regulated, but not every part of the same circuit.

Furthermore, results of a LCA on CdS, photoresistors, and photodiodes made available by Philips during the evaluation procedure of the previous requests for exemption[7] must be taken into account. As a result it can be stated that „it does not make any difference from an environmental point of view“ whether it is photoresistors or photodiodes that are used. The environmental impact is in both cases dominated by the gold in bondwires. It is thus not the CdS layer, which is responsible for the main environmental impact.

5.7.3 Critical Review and final recommendation

A critical review of the documents made available by the applicant and an evaluation of the stakeholder’s contribution led to the following observations and conclusions:

- Without doubt there are viable substitutes for CdS/CdSe photocells available.
- There are traceable information available giving evidence that beyond the question of photoresisitors and photodiodes environmental impacts in both cases are dominated by the gold in bondwires.
- Furthermore, it is clear, that possible advantages or disadvantages of photoresisitors or photodiodes respectively during the use phase of the light equipment may result in more relevant environmental impacts compared to the environmental impacts associated with the layer of cadmium sulphide/selenide[8]. However, there is no evidence that photodiodes have significant disadvantages in this respect either.
- There are conflicting arguments concerning the question if and to which extent the peripheral circuitry of photodiodes will be significantly more complex compared to CdS/CdSe photocells. This is strongly dependent on the particular application.

Against this background, the contractors recommend no to grant this exemption, unless the applicant could be able to define those specific applications, where the usage of photodiodes

7 “Cadmium sulphide photocells – Perkin Elmer/Philips” (set 1, request No. 21_a/b) and “Cadmium in opto-electronic components – TESLA” (set 2, request No. 10)

8 Provided that production and waste-management are well regulated.

would contribute to additional environmental impacts that would outweigh the benefits resulting from substitution of CdS/CdSe photocells effectively.

5.8 "RELOCK FUSE, Model X-09, High Security Electronic lock" (set 7, request no. 5, Kaba)

5.8.1 Requested exemption

Kaba Mas Corporation (Lexington, Kentucky, USA) requests an exemption for the use of lead and cadmium in a relock fuse used in the protection of the Model X-09, High Security Electronic lock used for containers that protect classified information.

During the evaluation it became clear that this application is out of RoHS scope, since the applicant himself considers it as a fixed installation and cannot allocate the application to one of the relevant WEEE categories. The request and its evaluation nevertheless are shortly described here.

The specific function of this fuse is to melt during a mechanical attack and allow a relock pin to engage the bolt so it will not retract and keep the safe container locked. According to the applicant, this function is a requirement of the US Federal Government.

The relock fuse is an alloy consisting of the following materials:

Alloy name	Number	Bi	Pb	Sn	Cd	In	Other	Melting Range ° F	Yield Temp. ° F
Wood's Metal	5050-1	50,5	27,8	12,40	9,30	n/a	n/a	158-163	159

The mass of the total lock is 945,5 g. The mass of the fuse is 1 g. Accordingly the share of Pb accounts for 0,000294% of the lock and the share of Cd accounts for 0,00009836% of the lock. The applicant states that the exemption request is necessary with respect to the amount of Cd in the homogeneous material exceeding the maximum concentration value of 0,01%.

The applicant states that less than 12 locks of the Model X-09 are sold into the EU per year.

5.8.2 Summary of justification for exemption

Upon request the applicant was able to give some further information about the specific function and application of this kind of lock:

- Environment of the lock: The Department of Defence (DOD) in the US Federal Government requires that any container that protects classified information (Secret Information) must be secured with an electronic lock that meets the government standard FFL- 2740-A. The X-09 is the only lock on the market that has been tested and approved to that specification. The lock is used in a commercial or defence environment. It is not intended for home use. It serves no purpose until it is installed on a container, safe or vault. It is considered part of a “Fixed Installation”.

- Functionality of lead and cadmium: The purpose of the fuse is to melt when the temperature in the lock gets to 170°F (76.7°C). This allows a pin to drop into a hole in the dead bolt and will not allow the door or drawer on the container which the lock is mounted to open. The container will have to be drilled. This is a security featured required by the US Department of Defence. The mixture of lead and cadmium and other elements combine to meet the high temperature requirements (see description of these temperature requirements above).
- Scope: The relock fuse does not fit any of the WEEE categories as defined by Article 1 and 2 of the WEEE Directive.
- Applicability of security standards: FF-L-2740-A is the "requirement of the US Federal Government". If a company in the European Union has a contract with the US Federal Government and there are classified documents (Secret) required for the assignment, the US Federal Government requires that the classified documents be protected by the X-09 lock when not in use. These documents are controlled and one must sign them out and back in when not in use. An US embassy or US military installation would be required to use these locks if they have classified documents.
- Efforts which have been undertaken to identify substitute materials: knowledge at Kaba Mas does not include the design of fuses. The original fuse was designed in 2001 from the specifications shown in the exemption letter. Kaba’s efforts to find a substitute have been to contact its current source and other vendors to see if they have a RoHS compliant material that would meet the same melting specifications as the current part. To this date this has been unsuccessful.

5.8.3 Final recommendation

According to the information delivered by the applicant the relock fuse does not fit to any of the WEEE categories and could be assigned as fixed installation. Therefore, the application does not fall under the scope of the RoHS Directive and an exemption is obsolete. It therefore is recommended not to grant an exemption.

5.9 "Lead in glass housing of high voltage diodes" (set 7, request no. 6, Vishay)

5.9.1 Requested exemption

Vishay Semiconductor (Austria) requests an exemption for GPR High Voltage diodes with zinc borat glass body which contains 2,5% lead in glass. This kind of diodes are mainly used for external power supplies being used in IT and telecommunication equipment and for automotive applications, too. The total number of GPR High Voltage diodes accounts for 20.000.000 pieces per year.

According to the applicant's argumentation, for the glass body of the diode an exemption exists. Upon request the applicant specified the existing exemption: "Lead in glass of cathode ray tubes, electronic components and fluorescent tubes" being applicable for the glass body of the diodes. However, an additional exemption is necessary for the use of lead in the plating layer of these diodes with a lead content <3000 ppm. This lead content is introduced unintentionally during the plating process, where the lead in the glass body contaminates the plating material.

5.9.2 Summary of justification for exemption

According to the applicant, lead in zinc borat glass is needed to reach similar extension as the touched metal pins. In addition, the change of the glass type is technically not possible, as the electrical loading of the glass type must be identical with the silicon-type being used (p-Si). Other materials than glass do furthermore not fulfil the specific surface conditions. These conditions are necessary in order to avoid flashover, as at a current of 1.800 Volt the distance between the Si-blocks only amounts to 180 µm. Furthermore, the expansion of all other materials like molybdenum is adjusted to this zinc borat glass. Only this kind of glass fulfils all of the technical/physical requirements.

Furthermore, the applicant argues that "According to all experiments and investigations with external institutes, it is not possible to avoid the contamination of galvanic fluid. During the galvanic process, the zinc borat glass body will be dissolved and the dissolved lead gather the plating material's pure tin." And: "To change the Glass material to a resist material against galvanic fluid is not possible. Electrically loading of Glass is a key factor, to keep the electrical parameter and performance."

Upon request, the applicant confirmed that theoretically the carryover of lead could be avoided if there was no contact of the galvanic fluid with the glass body. According to the applicant, several alternative techniques were discussed but none of them were very promising or led to unacceptable short life-time of the galvanic fluid.

5.9.3 Critical Review and final recommendation

A critical review of the documents made available by the applicant led to the following observations and conclusions:

- The requested exemption strongly relates to an existing exemption for lead in glass of …, electronic components and…"[9]. The arguments behind this existing exemption are comprehensible and valid.
- Theoretically there are two different approaches to avoid lead in the plating layer of these diodes:
  - Change the glass type being used.
  - Development of alternative techniques, which avoid the contact of the glass with the galvanic fluid.
- The applicant was able to substantiate that both approaches are technically not feasible or promising.

Against this background, we recommend to grant this request for exemption. In his written documents, the applicant did not provide a wording for this exemption. After consultation with the applicant, the wording was reconciled as follows:

Lead in the plating layer of high voltage diodes on the basis of a zinc borat glass body.

[9] Entry of RoHs Annex no. 5: "Lead in glass of cathode ray tubes, electronic components and fluorescent tubes."

6 List of External Experts

During the evaluation work, the consultants contacted a certain amount of external experts where this appeared to be necessary. However, most of the time applicants and stakeholders themselves are the experts in the field of an application for which an exemption is requested. Therefore, the external experts contacted often came from:

- competing companies;
- suppliers advertising RoHS compliant components;
- applicant's or stakeholder's suppliers.

In addition, experts belonging to neutral institutions were also contacted. They came from the following areas:

- universities (e.g. research on glass, minerals);
- governmental bodies and research institutes;
- NGOs;
- internal resources (both Öko-Institut and Fraunhofer IZM can rely on a broad base of in-house experts not directly working within the RoHS exemption evaluation work but having extensive knowledge in fields like lead-free soldering and "green electronics" in general, toxicology, hazardous substances in the waste stream, chemistry, eco-design, home appliances, consumer electronic and lighting).

Experts are not listed here with their name and function as well as their institution / organisation, since the information provided has often been a short-term oral communication, which does not have the weight of a written piece of evidence. Therefore, experts want to be kept anonymous. This again reflects the fact that access to publicly available information is very difficult (cf. conclusions below in section 7) and that information can often only be obtained on a semi-confidential basis making its use within the evaluation work difficult. This is why the contractor has mostly refrained from citing oral information given by external experts.

Nevertheless, much information has also been gathered via extensive e-mail exchange which does indeed deliver a certain reliability of the written statements. However, due to practicability this correspondence with the mentioned contacts is not documented in detail in the context of this final report.

A general overview on the experts contacted during the evaluation process of set 6 and 7 (excluding contacts with the applicant and stakeholders that had submitted comments) is given here:

- Five manufacturers and users of high voltage power transformers;
- one thickfilm material supplier for trimmer potentiometer manufacturing;

- one manufacturer of professional loudspeaker systems;
- two manufacturers of electric overblankets;
- one manufacturer of household appliances;
- one manufacturer of fibre optic communication systems.

7 Overall Conclusions

In this chapter, the contractor would like to summarise a few points that have occurred during the evaluation work.

7.1 General procedural observations

In the course of the evaluation of request for exemption, the following points were observed as being crucial or problematic concerning the process in itself. Possibilities for improvement are also mentioned.

- Applicants are often not aware of the “right” or the “best” way to bring forward an exemption request. The crucial questions for the evaluation such as a detailed technical description of the function of the substance as well as of the component in which the substance is used are often not answered. Other important points like providing evidence on R&D efforts made towards RoHS compliance, information on involvement of suppliers or reasons why RoHS compliant components of competitors cannot be used in a specific application are also often not mentioned.
- A possibility for improvement would be a better communication of what exactly makes a successful exemption request and what exactly the formal needs are that applicants have to fulfil. This appears particularly important, as many applicants did not seem to understand the difference between bringing forward an exemption request and submitting a stakeholder comment.
- It seems that the public stakeholder consultations are not well enough known among relevant actors since in many cases competitors producing RoHS compliant alternatives have not brought forward comments in that sense. This, however, is crucial for a sound evaluation. The market itself best knows where alternatives are feasible and where not. In many cases, the consultants themselves initiated further investigations. Competitors in several cases confirmed that a RoHS compliant solution was available on the market.
- In the future publicity and enhanced communication of the possibility to comment on exemption requests should be used in order to gather more valuable information. This could be done e.g. through conferences held in Member States at industry associations or at municipalities. Both associations (industry, NGOs, scientific community) and Member States have Brussels-based representatives following activities with regard to

online consultations and should take the responsibility to spread the information. The Commission could set up a RoHS helpdesk with the mandate to explain in deep detail what has to be done and the way the procedure on exemption requests and evaluation works. Last, funding could be given to consultancies in order to support stakeholders at local level.

7.2 Request submission form

The contractors observed that the quality of the exemption requests was higher and the information more complete if the applicants had used or based their request on the TAC checklist. Obviously it is a good guide for the applicants and applicants should therefore be recommended to use it.

For the contractors carrying out the evaluation procedure, it is easier to process the information if it is provided in this kind of standard format. For the review process, it would be useful to add two items to the checklist:

- The contact person for the exemption request with name, phone number and e-mail;
- a clear wording for the requested exemption.

These two pieces of information were not always clearly and unequivocally linked to the exemption requests. The applicants should be recommended to use this exemption checklist.

However, the contractor would like to recommend reviewing and revising the checklist in general with regard to the observations made in this section and taking applicant and stakeholder comments with regard to comprehensibility and practicability into account.

7.3 Contractor's mandate

It has again appeared that the evaluation process itself is very lengthy and demanding: stakeholders and applicants need to be contacted and addressed with need for clarification. Sometimes it is even necessary to organise meetings between all stakeholders since the questions looked at are of so specific nature that they can only be answered by the practical experts themselves.

Initially, the Commission intended the review and evaluation work to be carried out only on the basis of the documentation available from the applicant as well as from documents made available by stakeholders during the public stakeholder consultations (this is the mandate which the contractor has been given). This is not realistic and it has appeared to be impossible if a sound recommendation shall be given.

In several cases it would have resulted in positive recommendations for exemption requests, where RoHS-compliant solutions are available. In other cases, there was a suspect or even hints that RoHS-compliant solutions are available, but the time and budget restrictions of the contractor did not allow further investigations. These additional investigations can be burdensome and lengthy, as it may take time and effort to find the right information or the right contact persons, and then to clarify whether the obtained information really is adequate and refers to the same or to a comparable application as the one for which an exemption is asked for. The contractor's mandate does not provide for the resources for such follow-ups. The result in such cases was that recommendations could not be given or had to be given with reserve.

The consultants' experiences thus show that a proper review of the exemption requests in most cases requires own investigations beyond the information provided in the stakeholder consultations (if there is any additional information that was provided at all).

It is therefore highly recommended to review the evaluation process with a view to integrate the need for massive additional efforts needed for research and gathering of additional information. If recommendations are to be given on the basis of the available information this may lead to significant misinterpretations and unqualified assessments due to a lack of information. The questions looked at are of such specific technical nature that a general assessment can not be done without prior analysis of the market situation, technical details as well as detailed inquiries of the applicant's situation regarding efforts made towards RoHS compliance.

7.4 Aspects beyond criteria Art. 5 (1) (b)

Technical feasibility of substitution and environmental impact of substances are criteria listed in Article 5 (1) (b). Even if these criteria appear to be sensible in view of the assessment of exemption requests, they leave a lot of room for interpretation.

Furthermore, they do not take into account that general environmental policy goals sometimes go beyond such narrowly defined criteria.

For example, questions relating to a phase-out period of a substance in a certain application cannot be assessed when applying these criteria. Alternatives might be available on the market but not for an application that is itself running out of business life. Or the supply chain might not be willing to work towards RoHS compliance in close cooperation with the manufacturers.

Another aspect beyond the criteria of Article 5 (1) (b) is the question of economic impact for small and medium enterprises (SMEs). SMEs are particularly struggling with the requirements of the RoHS Directive. Especially in the field of highly specialised products sold in small amounts and with long design cycles, a re-design may signify bankruptcy for a SME. This is especially the case for requests belonging to the LTB category.

Furthermore, it has to be mentioned that in view of a better regulation at Community level, exemption criteria of the RoHS Directive should be harmonised with criteria of the ELV Directive since the applications covered by these two Directives are often very similar or closely related.

7.5 Commission's information policy

The contractor noticed a considerable uncertainty among industry concerning information on the status of exemption requests. After an applicant has submitted an exemption request, which has been subject to a stakeholder consultation and to a subsequent review by a contractor, he does not receive any feedback on the status of his exemption request: he is neither informed about the Commission's decision on whether it will be included into the formal adoption procedure or not, nor is he proactively informed about a successful adoption procedure of his request and thus inclusion into a Commission Decision amending the Annex. If the Commission decides not to pursue the formal adoption procedure for an exemption, the applicant does not receive feedback either.

For example, the current situation is that the last amendments of the RoHS Directive with some additional exemptions came into force in October 2006 and that since then, looking from outside, people's perception is that there seems to be no further activities. The contractor received phone calls from industry where stakeholders expressed their concern and insecurity about the status and further proceeding of the exemption requests in the Commission ("nothing happens", "time is running out for industry as important decisions need to be taken", and so on).

The only hint an applicant is given is that whenever a new amendment of the Annex is published in the Official Journal, he can see whether or not his exemption is included and thus became a valid exemption (however, it does not necessarily mean that his exemption request will for sure never become part of the Annex). This can be between 6 and 18 months (or sometimes even longer) after the exemption was handed in to the Commission.

Hence, in case an applicant e.g. needs to plan production, (new) substitution efforts or actions to withdraw products from market, he has no information on which he can base his decisions on. Furthermore, he does not know where in the process his exemption request currently is (evaluation by contractor, formal adoption procedure TAC etc.).

This generates additional insecurity and expenses, as some requests – for which the Commission has already decided not to pursue formal adoption procedure – are handed in several times again (as the example of the Last Time Buy issues shows, which occurred again and again in several stakeholder rounds).

It could be useful to publish the contractor's monthly reports so that applicants have insight into the recommendations and the reasoning behind and can thus get a hint on what the tendency is concerning a possible inclusion into the Annex (however still not informing about the further procedure following up on the recommendation). Further, a regular publication of exemption requests that will not be part of the formal adoption procedure as well as on the procedural status of the not yet further proceeded exemption requests would give guidance to applicants and stakeholders and reduce their insecurities.

7.6 Future prospects

It is inherent to legislation like the RoHS Directive that not all special cases can be taken into account when drafting the legislation. Nevertheless, the field of electrical and electronic equipment is characterised through complex products in a huge variety of applications. All aspects that occur on the way to more efficient and less harmful products cannot be covered by the provision given in Article 5 (1) (b).

Should the RoHS Directive be reviewed it is thus recommended to adapt the criteria that should be applied to exemption requests. Otherwise, the legislator should at least consider a practical procedure on how to implement the criteria of Article 5 (1) (b) in practice for the future evaluation work.

For example, the question on relevance of a hazardous substance with regard to its environmental impact can at the moment not be taken into account: on the one hand, the Commission Decision on maximum concentration values contains some priority setting with regard to substance content. However, it does not refer to absolute amounts of hazardous substances. On the other hand, in the context of the evaluation procedure, this can e.g. lead to situations where a product using lead in an amount just below the maximum concentration value but put on the market in large amounts is considered RoHS compliant; but the total amount of lead is very important and thus has a high environmental impact. Whereas e.g. a remaining number of lead-containing ICs with an amount of lead above the maximum concentration value would not be considered RoHS compliant, although the overall environmental impact might be far lower than in the first case.

In the contractor’s perspective, this point should at least be considered when reviewing the Directive in order to avoid disproportional decisions.

Annex I: Monthly reports 1-9

See attached zip file

Annex II: Stakeholder documents requests no. 22 set 6, no. 23 set 6 and no. 4 set 7

See attached zip files

Annex III: Testing of Macron optocouplers for RoHS compliance and test results

Similar to the situation in the 4th stakeholder consultation, a manufacturer of photoresistors and optocouplers, Macron, opposes the exemption of cadmium use in photoresistors. Macron claims to have a RoHS-compliant photoresistor solution that can fully replace the photoresistors in optocouplers, which are not RoHS-compliant.

Macron's photoresistors also contain cadmium, but, according to Macron, the concentration of cadmium in the homogeneous material remains below 0.01 % of weight, which is the maximum allowed cadmium level for RoHS-compliance.

Macron claims RoHS-compliance for the following models of photoresistors:

- MI1210CL-R
- MI65CL-R
- MI0202CL-R

According to Macron, the MI1210CL-R is the most popular out of the three models. The number "1210" refers to the dimension of the optocoupler, the area measurement of the model is 12mm * 10mm. The "65" in the MI65 model means 6mm * 5mm of area, and so on. The height of the optocoupler is a standard of ~10mm and therefore is not indicated in the model name.

Within each model, Macron explains, English letters differentiate the characteristics of each series of optocoupler. The MI1210CLA-R is the A series of the MI1210CL-R model, MI1210CLB-R the B series, and MI1210CLH-R stands for the H series of this model. The A series is most sensitive to light. The more sensitive the photocell, the more cadmium it needs to produce the high sensitiveness to light.

Series A of each of the three models therefore has the highest content of cadmium among the three models for which Macron claims RoHS-compliance.

The supporters of the exemption request oppose the Macron statements. They challenge Macron's claim that its photoresistors and optocouplers are RoHS-compliant. Both the supporters of the exemption request and Macron have submitted test reports dealing with the RoHS compliance of the Macron devices. The Macron test reports confirm RoHS-compliance; the opponents' test reports the opposite.

Macron test reports from stakeholder consultation 6

During the 6th stakeholder consultation, Macron had submitted certificates from laboratories confirming the RoHS-compliance of the assessed Macron photoresistors (see in reference documents 1, 2, 3, 4, 5 and 6 in section 5.3.6). The documents 1 and 2 are reports stating the RoHS-compliance of the assessed Macron photoresistors, documents 3 and 4 that of Macron optocouplers. The tests were conducted by the SGS laboratory, and the test reports specify the silvery pins of the photoresistor as a homogeneous material and the rest of the photoresistor as another homogeneous material, both in the photoresistor and the optocoupler tests (see photos of photoresistors in the figure below).

Testing documents 5 and 6 separate the photoresistors into three homogeneous materials instead of only two. Document 6 is a test report certifying the RoHS compliance of the entire optocoupler, comprising the LEDs, the black case and the photoresistors. Document no. 5 is a test report of photoresistors only. In both reports, the sampling and the analysis of the photoresistors are identical.

As the discussion of RoHS compliance is about the cadmium in the photoresistors only, the photoresistor tests are the important ones. In both cases, the testing laboratory RWTT states the RoHS compliance of the photoresistors.

The following figure and table show the analysed samples and the essential results.

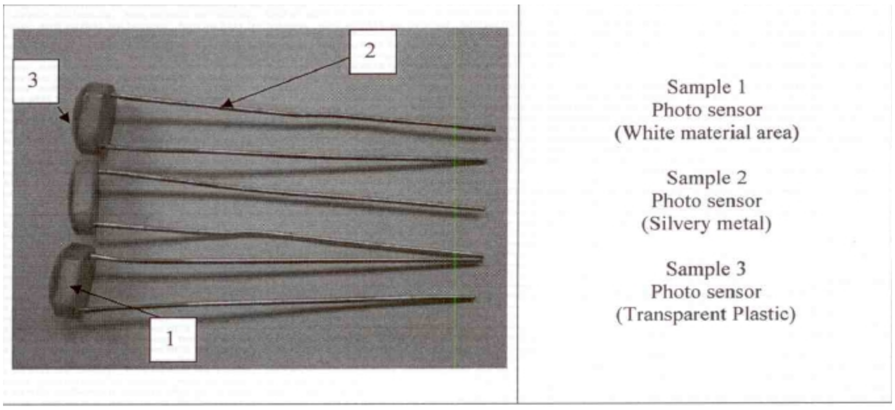


Figure 11: Homogeneous materials (samples) according to RWTT test report (source: RWTT test report in stakeholder document no. 5 in references, section 5.3.6)

Sample 1 is the crucial sample. It consists of

- the ceramic body,
- the photosensitive, cadmium-containing material,
- a thin metallization.

The testing laboratory considered this sample 1 as a whole as homogeneous material. The transparent plastic on top (sample 3) had been removed and was treated as an own homogeneous material.

Table 10 shows the results of the analyses for the three samples. The crucial result is the cadmium content of sample 1. The RoHS Directive allows a maximum content of 0.01 % (100 ppm) of weight in the homogeneous material. The analysis of sample 1 indicates a cadmium content of 0.0052 % (52 ppm), measured by ICP (inductive coupled plasma).

Table 10: Results of RoHS-compliance test (source: RWTT, see test report in stakeholder document no. 5, section 5.3.6)

Testing Item	**Result (ppm)**		
	Sample ID		
	1	2	3
Cadmium	52	N.D.	N.D.
Lead	N.D.	N.D.	N.D.
Mercury	N.D.	N.D.	N.D.
Chromium VI	N.D.	N.D.	N.D.

The stakeholder, Macron, says that these results prove that the cadmium content of its photoresistors are below the maximum allowed threshold limits and therefore claims these photoresistors to be RoHS-compliant. For details of the tests please refer to the stakeholder document no. 5 section 5.3.6. The crucial point is that sample 1 comprising the ceramic body, the photosensitive, cadmium-containing material and the thin metallization are considered as homogeneous material.

Both test reports in documents no. 5 and 6 only indicate that photoresistors and optocouplers had been tested. No producer or article numbers or other specifications of the tested products are indicated.

ERA test reports from stakeholder consultation 7 and from the review process

In the 7th stakeholder consultation, Casco Silonex had submitted a test report by ERA stating that the Macron photoresistors are not RoHS-compliant (see section 5.3.6, document no. 7). However, it was not indicated in the report, which Macron model of photoresistor had been assessed. Macron stated that it produces both RoHS-compliant and non-RoHS-compliant photoresistors and optocouplers, and that the photoresistor tested by ERA was not from its RoHS-compliance models.

Another test reports was submitted during the review process (document no. 11, section 5.3.6). This test report is from ERA by the order of Casco Silonex as well and negates the RoHS compliance of the assessed Macron products. In opposite to the first ERA report, ERA this time specifies the tested Macron devices:

- MI 1210CLA-R (type “A”)
- MI 1210CLB-R (type “B”)
- MI 1210CLH-R (type “C”)

ERA states that Macron claims these three photoresistors to be RoHS compliant. This statement of ERA in principle is congruent with Macron’s information that the three versions of its MI1210CL-R model is one of its three RoHS-compliant photoresistor models. The “C”-denomination of the last of the three series, the MI1210CLH-R, is not congruent with Macron’s information. According to Macron, this is the “H”-series, and there is no information from Macron whether a “C”-series actually exists. In the ERA test report, the MI 1210CLH-R model is sometimes addressed as “C”-type, sometimes as “H”-type (e.g. in Table 9).

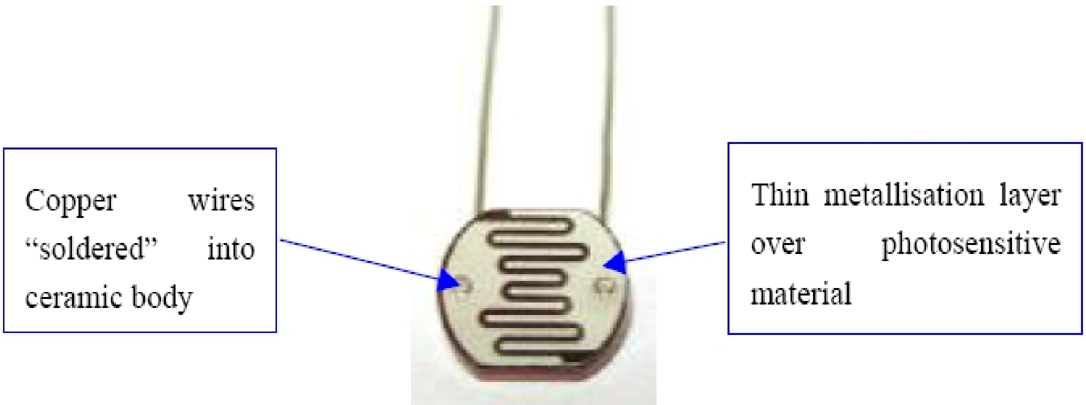


Figure 12: Image of Macron photocell (source: ERA, see document 7 in references, section 5.3.6)

The above image is from the first ERA report submitted during the stakeholder consultation. It is not clear which photoresistor this image shows, as the report does not specify this. It is shown here nevertheless as it helps understanding the sampling and the results of ERA in the second report. As only the second ERA report (document no. 11 in references) allows a clear attribution of the test results to clearly specified products, the following results were taken from this second report.

ERA challenges the homogeneous material definition of the RWTT test reports. The sample 1 in the Macron test report no. 5 can be mechanically disjointed into two homogeneous materials:

- the ceramic base
- photosensitive layer containing cadmium and the metallisation (cannot be mechanically disjointed from cadmium layer)

ERA describes the preparation of the homogeneous material and the testing as follows (document no. 11, section 5.3.6):

"Each device was cut into two parts using a diamond saw. This separates the LEDs from the light dependent resistors [the Macron devices obviously are optocouplers, not single photoresistors; the contractors]. The light dependent resistors have coatings of a transparent gel over a thin metal mask that defines the resistor path which is made of the photosensitive material."

Figure 13: Light dependent resistors from Macron optocoupler type "A", type "B" and type "C" (left to right) (source: ERA, see reference document no. 11, section 5.3.6)

"It was possible to use a surgical scalpel to scrape off the transparent gel. The metal layer was very thin and could not be separated from the photosensitive layer and so these are removed together with the scalpel as one material which was transferred to an adhesive stub."

ERA says that they scraped the photosensitive layer with metal mask off the substrate from between the metal pins, which are visible as the two silvery circles in each type of photoresistor in the above and below figures. According to ERA, the pins are soldered into position and the solder contains tin but no tin was detected in the analysis sample and this shows that it was possible to avoid the pins.

Figure 14: Light dependent resistors from Macron opto-coupler type “A”, “B” “C” (left to right) after the gel and photosensitive material coatings had been removed (source: ERA, document no. 11, section 5.3.6)

“The stubs are designed for insertion into a Scanning Electron Microscope (SEM) and materials are analysed using energy dispersive X-ray (EDX) analysis.

This analysis technique was chosen, as it is able to analyse very small quantities of material. If many optocouplers had been available, it would be possible to scrape off sufficient photosensitive layer for analysis by other techniques such as Inductively Coupled Plasma (ICP) Spectroscopy but ERA had only two of each type available. “

Table 11: SEM/EDX analysis of photosensitive coating from Macron optocouplers

	Results (weight percent)	**Comments**
“A“	Cadmium 60,6 %, sulphur 15,5%, selenium 5,5 %	This material is cadmium sulphide/selenide
“B“	Cadmium 70 %, sulphur 18,4 %, selenium 4,1 %	This material is cadmium sulphide/selenide
“H“	Cadmium 58,2 %, sulphur 15,1 % selenium 2,3 %	This material is cadmium sulphide/selenide

(Source: ERA, document no. 11, section 5.3.6)

ERA explains that the figures in the table for the cadmium-containing elements do not add up to 100% because small amounts of impurities from the gel coating (carbon and oxygen) and the alumina substrate (aluminium and oxygen) have not been included.

According to the test results in Table 11, the cadmium content in the analyzed Macron photoresistors would be clearly above 0.01 %. The optocouplers would thus not be RoHS-compliant. For details, refer to document no. 11 in references, section 5.3.6.

Additional Macron Test Report

Macron, as a reaction on the ERA test report submitted during the seventh stakeholder consultation (document 7, section 5.3.6), insisted on the RoHS compliance of its photoresistors and submitted a new test report during the exemption review process (document no. 12 in references, section 5.3.6).

The report contains an explication about Macron's technology:

"Traditional photocells usually contain a layer of CdS/CdSe which act as a photosensitive layer. However, Macron has developed a new technology where much lesser cadmium is required to obtain the same function. The innovative manufacturing method from Macron is a new process that mixes cadmium into the ceramic base, which allows the ceramic base to have photosensitive function. For this reason, Macron's photocell can only be separate into three homogeneous materials (transparent plastic, white ceramic and silvery metal).

Macron uses the innovative technology of photosensitive ceramic instead of using an additional photosensitive CdS/CdSe layer. According to the definition of the EU Commission, this ceramic base cannot be "mechanically disjointed" from the white ceramic part. Therefore, the ceramic base -cadmium mixture should be counted as the same homogeneous material with the white ceramic part."

Macron was asked whether the ceramic base and the white ceramic part are two different materials. Macron explained, "The ceramic base and the white ceramic part refer to the same ceramic part. It must be a typo. In this sentence "According to the definition of the EU Commission, this ceramic base cannot be "mechanically disjointed" from the white ceramic part.", "ceramic base" should really mean "cadmium". In our manufacturing process, cadmium was mixed into the ceramic before it cools; there is only 1 ceramic part in the photocell unit." (Source: Macron, received via e-mail 31 August 2007).

"White ceramic" is also used in other sections of the test report, e.g. in the following figure as well as in the description of the samplings and the analyses in Table 8 in section 5.3.4.1.

This denomination is consistent throughout the test report no. 12 in section 5.3.6. The testing laboratory considers the white ceramic part as homogeneous material, as the following figure underpins.

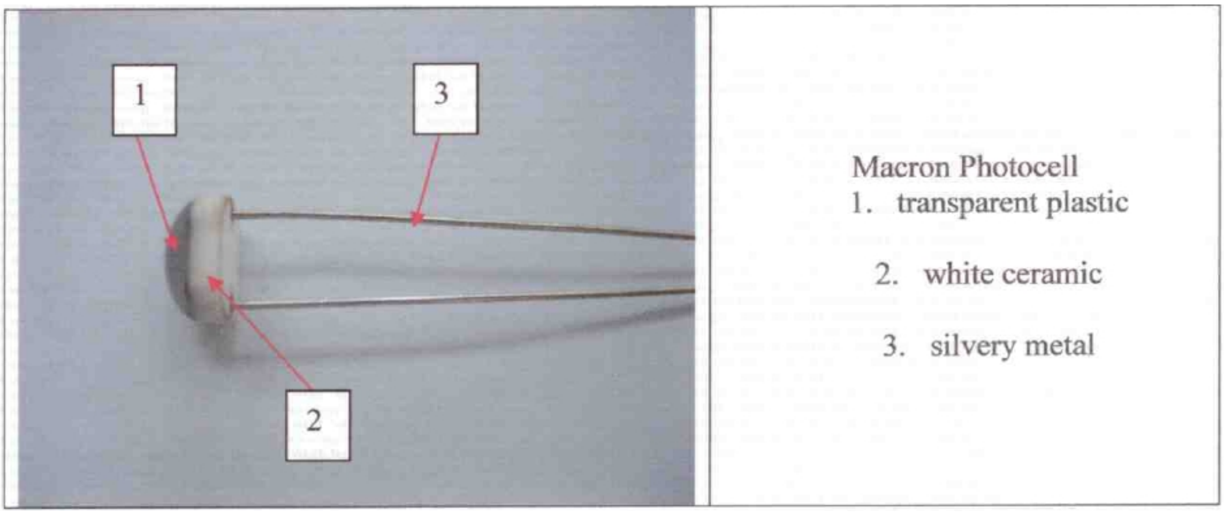
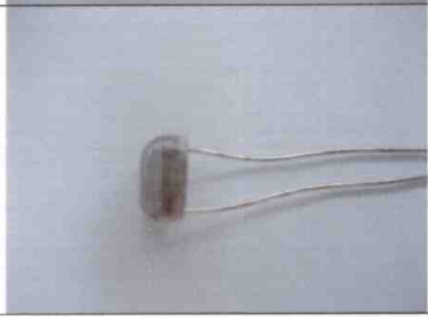


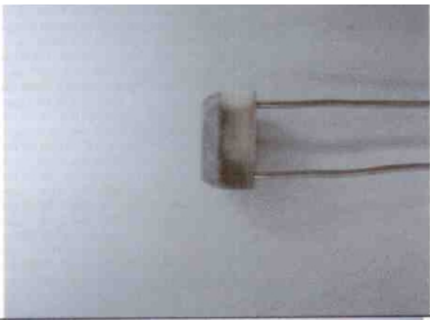
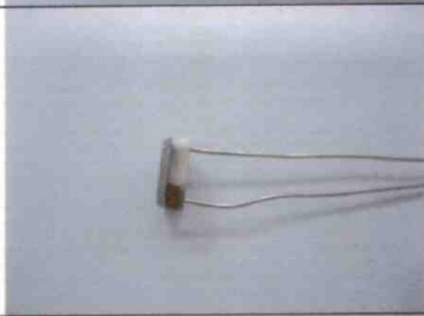
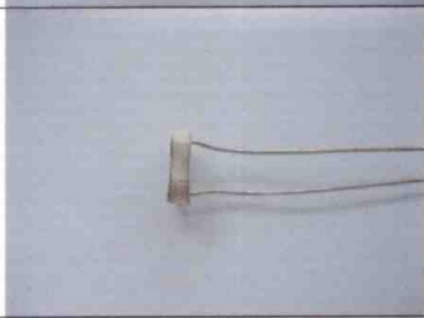
Figure 15: Physical appearance and homogeneous materials in Macron photoresistors (source: RWTT test report, document no. 12 in references in section 5.3.6)

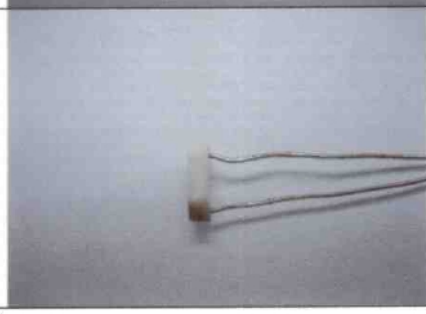
The report specifies the tested product as Macron's MI 1210CLA-R (A-type), which according to Macron has the highest content of cadmium to achieve a high photosensitivity.

The testing laboratory, RWTT, has taken a different approach for the sampling this time compared with the previous Macron reports described before. The following table shows the sampling procedure and the cadmium content for each of the obtained samples. The samples were analyzed using XRF analysis.

Table 12: Sampling and XRF analysis results of obtained samples

Removal stage	Cadmium concentration (ppm)	Other element detected	Physical Appearance
With complete resin layer	N.D.	Sn, Pb, Cu, Fe	
After 1st abrasion to remove a layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	

After 2nd abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 3rd abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 4th abrasion to remove another layer of transparent plastic	N.D.	Sn, Pb, Cu, Fe	
After 5th abrasion to remove all the transparent plastic, white ceramic and metal silvery pin has been exposed	31.1	Sn, Pb, Cu, Fe	
After 6th abrasion to remove a layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	

After 7th abrasion to remove another layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	
After 8th abrasion to remove another layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	
After 9th abrasion to remove another layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	
After 10th abrasion to remove another layer of the white ceramic base and metal silvery pin	N.D.	Sn, Pb, Cu, Fe	

* Accuracy estimated by instrument as ± 50 ppm for cadmium.

Source: Macron test report/RWTT, document no. 12, section 5.3.6

According to these test results, only the last bit of transparent layer (material of 5th abrasion) would contain 0.0031 % (31.1 ppm) of cadmium, which is below the maximum allowed level of 0.01 % for RoHS compliance. The photoresistor would thus be RoHS-compliant. For details, refer to document no. 12 in references in section 5.3.6.

Macron was asked to explain the results. The cadmium, according to the process description in the test report, is mixed into the ceramic base. The test result, however, indicates no detectable cadmium in the ceramic base, but only in the last bit of abraded transparent plastic.

Macron explained that the cadmium was detected in the 5th abrasion of the transparent layer because RWTT might have abraded parts of the white ceramic with the last bit of transparent layer. There is no cadmium in the transparent layer, according to Macron, but the cadmium concentration should be higher nearer to the photosensitive surface of the ceramic and it therefore was detected with the first abrasions of the white ceramic. Macron said it could not prove the higher cadmium surface at the surface, as it had no clear evidence. Macron stated that it did not see how the sampling was done and there is no standard of how deep the sample should be abraded before each analysis. Macron itself relativised this statement in a later e-mail saying that the detected cadmium comes from the top of the ceramic abraded with the last bit of transparent layer, and there is a gradient of cadmium content from the surface towards the inside of the ceramic body. Macron did not explain why later it was sure of the gradient of cadmium content, while before it was just expressed as an assumption.

Macron states that the process of making the photo-sensitive ceramic is one possible explanation for the cadmium content of 0.003 % analysed with the last bit of transparent layer. During the early stage of the cooling process of the photosensitive ceramic, before the ceramic hardens, a small amount of cadmium added is sedimented to the bottom of the photo-sensitive ceramic. The bottom of this photosensitive ceramic becomes the photosensitive surface, where a layer of the transparent plastic is added. This processing makes plausible that there could be a gradient of cadmium content with higher contents of cadmium in the material directly under the transparent layer. This would mean, on the other hand, that the cadmium is not really mixed INTO the liquid ceramic, as described before. Macron did not give further explanations on the processing issue.

Macron says the fact that no cadmium could be detected in the later abrasions after the 5th one may have to do with the XRF analysis. The XRF analysis deviates within ± 50 ppm (± 0.005%), as also mentioned in the ERA report. Macron states that its photosensitive ceramic contains cadmium under the surface layer, too, but, as the inside only contains trace amounts of cadmium, it cannot be detected with the XRF analysis. In another statement, Macron says that for each of its optocouplers, a total of around 80 ppm of CdS and CdSe are added into the ceramic liquid for mixing. Macron says that the 80 ppm of CdS/CdSe are already related to the weight of the solid ceramic, not the liquid ceramic.

This corresponds to a cadmium content of around 0.004 % of cadmium for CdSe and around 0.006 % for CdS. As both cadmium compounds are mixed, the calculatory average cadmium content should be somewhere in between neglecting the gradient of cadmium content from the surface towards the inner ceramic.

The contractors did not go further into details of the test results, as this would be beyond the possibilities of their mandate.

Homogeneous material definition and interpretations in the tests

The applicants and stakeholders have submitted tests which arrive at different, contrary and controversial results. While the ERA test reports by the order of Silonex shall prove that the products, which Macron specifies as RoHS-compliant, are not RoHS-compliant, the RWTT test reports by the order of Macron shall prove the opposite.

A part of the discussion is what should be considered as the homogeneous material in the assessed products. As mentioned before, the contractors will not assume a position in this discussion, but just show the different standpoints.

The Commission's frequently-asked-questions (FAQ) document (http://ec.europa.eu/environment/waste/weee/pdf/faq_weee.pdf) informs in section 2.3:

"2.3. Are maximum concentration values set in the RoHS Directive?

For the purposes of Article 5(1)(a) the Commission has adopted Decision 2005/618/EC whereby a maximum concentration value of 0.1% by weight in homogeneous materials for lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) and of 0.01% weight in homogeneous materials for cadmium shall be allowed.

Homogeneous material means a material that cannot be mechanically disjointed into different materials.

Definitions:

The term "homogeneous" means "of uniform composition throughout". Examples of "homogeneous materials" are individual types of: plastics, ceramics, glass, metals, alloys, paper, board, resins and coatings.

The term "mechanically disjointed" means that the materials can, in principle, be separated by mechanical actions such as: unscrewing, cutting, crushing, grinding and abrasive processes.

Examples:

- A plastic cover is a "homogeneous material" if it consists of one type of plastic that is not coated with or has attached to it or inside it any other kinds of materials. In this case, the limit values of the Directive would apply to the plastic.
- An electric cable that consists of metal wires surrounded by non-metallic insulation materials is an example of a "non-homogeneous material" because the different materials could be separated by mechanical processes. In this case, the limit values of the Directive would apply to each of the separated materials individually.
- A semi-conductor package contains many homogeneous materials which include: plastic moulding material, tin-electroplating coatings on the lead frame, the lead frame alloy and gold-bonding wires."

(End of quotation from the Commission's FAQ-document)

Both test reports refer to the above definitions in the Commission's FAQ-document or the respective phrases in the RoHS Directive and technical guidance documents.

ERA adds that the definition of homogeneous materials is simply a definition; it is clearly not an instruction for chemical analysis. ERA explains that if one material in principal can be separated from another then these are separate materials, even if a "clean" separation is not possible or it is impossible to separate sufficient material for chemical analysis to be carried out. ERA cites a document published by the RoHS Enforcement Network (see page 13 of document no. 12 in section 5.3.6) as reference for this position.

ERA in its test report describes the photoresistors for which Macron claims RoHS compliance and draws conclusions:

"The photocell is made from a ceramic disc with a deposited layer containing cadmium. This is heated then to create the photosensitivity. Macron state that after heating, the surface layer cannot be "mechanically disjointed" from the ceramic substrate. This is a crucial point and one that needs to be tested. Note that the definition of mechanical disjointing is that the materials can, in principal, be separated by mechanical actions indicates and so implies that separation need not be perfect." (source: document no. 7, section 5.3.6)

ERA made several abrasions of the ceramic base after removal of the transparent plastic layer. The materials obtained via these abrasions are considered as homogeneous material. The cadmium content in these abraded materials is clearly above the maximum allowed threshold level of 0.01 % of cadmium. ERA concludes that the tested Macron photoresistors are not RoHS-compliant.

RWTT has tested the Macron photoresistor and describes the product as well as how it is manufactured and draws conclusions concerning the homogeneous material:

"In the traditional photocell manufacturing method, a thin layer of CdS/CdSe is sprayed onto a ceramic base. [...] However, Macron has developed a new technology where much lesser cadmium is required to obtain the same function. The innovative manufacturing method from Macron is a new process that mixes cadmium into the ceramic base, which allows the ceramic base to have photosensitive function. For this reason, Macron's photocell can only be separate into three homogeneous materials (transparent plastic, white ceramic and silvery metal). Macron uses the innovative technology of photosensitive ceramic instead of using an additional photosensitive CdS/CdSe layer. According to the definition of the EU Commission, this ceramic base cannot be "mechanically disjointed" from the white ceramic part.

Therefore, the ceramic base cadmium mixture should be counted as the same homogeneous material with the white ceramic part." (Source: document no. 12, section 5.3.6).

RWTT made several abrasions of the ceramic body including the silvery pins. Each of the different abraded materials was tested for its cadmium content.

None of these materials exceeded the 0.01 % of cadmium content. RWTT concludes that the assessed Macron photoresistor is RoHS-compliant.

ERA says that the abrasion of material was conducted in between the silvery pins. The tested material thus did not include any constituents of these silvery pins. RWTT had abraded the tested material after removal of the transparent plastic layer from the surface including the silvery pins. It is not clear whether and how far this has an influence on the test results.

Furthermore, Macron says that its A-type photoresistor has the highest contents of cadmium and therefore had this type tested. ERA, however, measured the highest cadmium contents in the B-type photoresistor. According to the ERA results, its cadmium content is around 10 % higher than in the A-type.

The RWTT and the ERA tests arrive at contrary, conflicting results. They state the RoHS-compliance and non-RoHS-compliance of the tested Macron photoresistors respectively. The differences cannot only be explained with different homogeneous material definitions. The description of the tested Macron photoresistor from ERA and from RWTT already differ considerably, as the above quotations from the test documents show, although the article numbers coincide. It could have been expected that the ERA test and the second RWTT test (document no. 12 in section 5.3.6) arrive at similar results, as in both cases the sampling is done by abrasion from the ceramic body. The inclusion of the silvery pins in the RWTT test might in parts explain the differences. Several reasons might be possible for the deviations, although, considering the huge differences between the results ranging from “not detectable” up to around 61 % of cadmium content, this might be a difficult task. The evaluation of the test procedures and the deeper investigation into the differences between the results is, however, beyond the contractors’ mandate.

The opposing parties could agree on a test procedure and a testing lab and then have the tests conducted again. In case an agreement or other solutions are not possible, both parties may file a lawsuit at the European Court of Justice.