CONTRIBUTION OF THE EUROPEAN OPTICAL STAKEHOLDERS

TO THE

STAKEHOLDER CONSULTATION ON ADAPTATION TO SCIENTIFIC AND TECHNICAL PROGRESS UNDER DIRECTIVE 2002/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL ON THE RESTRICTION OF THE USE OF CERTAIN HAZARDOUS SUBSTANCES IN ELECTRICAL AND ELECTRONIC EQUIPMENT FOR THE PURPOSE OF A POSSIBLE AMENDMENT OF THE ANNEX.

Exemption 13: "Lead and cadmium in optical and filter glass"

Supported by

SPECTARIS
Deutscher Industrieverband
für optische, medizinische und
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General questionnaireaire

1.1 For which substance(s) or compound(s) should the requested exemption be valid?

The requested exemption shall be valid for lead and cadmium and its compounds which are used within the glass matrix of optical glass and filter glass. We would like also to refer to the study of ERA Technology Ltd. from 2004 covering this subject [1].
The elements Pb and Cd are bound firmly within the glass matrix in form of i.e. lead oxides in optical glass and lead oxides, cadmium oxides, cadmium sulfides and cadmium selenides in filter glass. Under normal conditions these elements and their compounds are not leachable out of the glass matrix [2].

1.2 What is the application in which the substance/compound is used for and what is its specific technical function?

Examples of applications of classical optical glasses, coloured filter glasses and special optical glass types [3]

1. In digital projection (beamers, rear projection TV) SF57, a highly lead containing glass type, is unique for its property, not to convert thermo-mechanical stresses into birefringence. There are no other glass types with this property to the extent of SF57. In the last years some movement away from SF57 has been observed due to the down-turn of rear projection TV, which has lost market share to the LCD and Plasma flat screen TVs and due to the usage of cheaper glass types like SF1, SF2 and SF6, where a compromise between image quality and costs has been strived for. These glass types are still high lead containing glass types. Especially for this application in the years 2000 – 2005 intensive R&D effort has been undertaken by all glass manufacturers, since it would have been a great marketing advantage to provide a lead-free glass type with similar properties like SF57 (stress-optical constant equal to zero, refractive index > 1.8, good workability and low price). However nobody found a replacement solution, which fulfilled the requirements. (WEEE category 4)
2. Lead containing glasses are important for optical investigations and diagnosis in the near UV-region (bio-fluorescence, gene analyses, print-scanner) because of their high transmission in that range. (WEEE category 8)
3. Temperature compensated high end optical imaging systems for medical and printing applications need the specific behaviour of lead glasses in changing its index of refraction and dispersion with temperature changes. (WEEE category 8 and 6)
4. Some endoscopes use flint glasses (lead containing) with high requirements on the transmittance in the blue-violet region. Objective is to help surgeons with assessing human tissue with colour neutral images. The ban of lead glass would endanger the achievements of the minimum invasive surgery. High quality technical endoscopes are widely used for industrial inspections e.g. for the inspection of aircraft jet safety. (WEEE category 8)
5. Medical x-ray diagnosis equipment needs image intensifiers with the CCDs shielded against the x-rays. This can only be achieved by using lead containing flat and optical glass in combination. The same holds for electron microscopes. (WEEE category 8)
6. Interchangeable lenses for photographic applications, whether containing Pb or not, are no electrical or electronic equipment as such when the function of the lens is not dependent on electric current or electromagnetic fields. Therefore interchangeable lenses are in principle not covered by the WEEE. However, if the lenses are part of the photo camera at the time of discarding in a few special cases, we would then propose to treat these interchangeable lenses as if they are falling under WEEE-category 3, even though we are aware that they do not have an electrical function at all."
7. Surgical microscopes (an electro-medical product) with Pb-containing lens elements are used by surgeons, neurosurgeons and dentists in order to control operations of humans and possibly also animals. They are devices which fall under WEEE-category 8. In using such a surgical microscope the surgeon gets a magnified view of the operation field which allows for a better control of the operation and also a better separation of sound and damaged tissue. (WEEE category 8)

8. Microscopes for life, bio and material science as well as medical applications are widely used in hospitals, research laboratories and industry. They fall under WEEE-category 8 and 9, depending on the special application. (WEEE category 8 & 9)
9. Lead containing fibres enable high quality illumination units for operation microscopes used for microsurgery. (WEEE category 8)
10. With optical systems designed for telecom applications in the near infrared (1000 – 1500 nm) the eco versions of the lead containing glasses are no equivalent substitutes since here the optical properties differ significantly from the predecessor types. The eco versions have been developed only for the visible region. (WEEE category 3)
12. Classical optical clear and colored filter glass types are used in numerous facility safety and national security applications (WEEE category 9)
13. The cadmium containing yellow to deep red filter glasses GG, OG and RG are used in a variety of applications.
    - Airport runway safety illumination (well defined signal color independent from viewing angle, long term resistance against environmental influences (weather) and severe temperature changes due to lamp switching. Therefore such filters need to be toughened by prestressing, which is only possible with glass filters. (WEEE category 5)
    - Safety equipment e.g. laser protection eye glasses especially according to European and German standards prescribing the assurance of long-term safety function. Plastic filters may suffer from holes burnt in and long-term filter effect degradation. (WEEE category 9)
    - Traffic monitoring (cameras to take pictures of drivers surpassing the speed limit), toll monitoring systems (WEEE category 9)
    - Facility safety surveillance (infrared illumination suppressing visible light). (WEEE category 5)
    - Environmental surveillance: Waste sorting facilities, waste water analysis, exhaust gas analysis, airborne (airplanes, satellites) environmental diagnosis photography. (WEEE category 9)
    - Colour channel separation (Colour-TV). (WEEE category 4)
    - Photographic colour filters. (WEEE category 3)
    - Telecommunication: Attenuation or separation of undesired wavelengths transmitted by coated filters (side bands) (WEEE category 3)
    - Light barriers for motion control (busses, elevators,…) (WEEE category 6)
    - Bar code readers (WEEE category 6)
    - Logistics automation equipment
      (automatic reading units, letter sorters, parcel sorters ...) (WEEE category 6)
    - Industrial measurements: Well blocked band pass filters are made with thin film interference coatings, which provide the band pass characteristics, whereas additional glass filters effectively suppress the undesired transmission regions outside the bandpass, which is typical with multiple wavelength interference.
      In industrial measurement frequently blocking ratios outside the bandpass are necessary, which only Cd-containing filter glasses can provide. (WEEE category 6 or 9)
    - Industrial displays: contrast enhancement, signal effect, improved resolution, better reading. (WEEE category 6)
    - Industrial image processing for quality assurance
      e.g. for steel sheets to be used in safety relevant motor car applications (WEEE category 6)
    - Detection of faked paintings. (WEEE category 9)
    - General research (filter wheels, filter monochromators, astronomy filter sets for different observation wavelength bands). (WEEE category 9)

14. Lead containing green filter glasses serve to separate the different colour channels for colour TV cameras (WEEE category 4)

1.3 What is the specific (technical) function of the substance/compound in this application ?

1.3.1 Lead Containing Glasses

Lead containing glasses for optical systems are needed for the following reasons [4 – 10]:

1.3.1-a) Colour correction
If an optical system needs a good colour correction, it is necessary to use special combinations of different materials to ensure a good quality over a broad spectral range. From the viewpoint of optics, there are two different effects, if the colour correction is not performed well:

1. Different lateral magnifications cause colour fringes in the image
2. Axial differences cause a sharp image only for one colour. Usually green is made good, the red and the blue images are blurred and badly resolved.

When lead glasses are no longer available for optical system design a larger number of components is necessary to get the required performance. In many applications (examples are listed below) visible colour fringes due to a bad aberration correction are not acceptable. Typically a 10% to 20% larger number of lenses is needed for lead-free systems.

The dense flint glasses with lead have the comfortable properties of high index, small dispersion, high transmission and special partial dispersion. These materials are preferred to get high performance systems. Especially the KZFS-glasses are extremely important to get high-quality systems.
The general trend to achieve compact and small systems with a small number of lenses contradicts to this reduced possibility

1.3.1-b) Transmission in the Ultraviolet (UV) spectral region
Lead-free glasses and optical systems made from such Pb-free glasses have a strongly reduced transmission from 410 ...365 nm and about no transmission below 365 nm. These functionalities are essential for many very important applications.

In the following part, we will give some examples for the need to use Pb-containing glasses for colour correction:

1.3.1.1 Microscopy and Medical Systems
Microscopic objective lenses need a high performance colour correction. Otherwise, the critical applications of biological research, medical diagnostics, drug discovery etc. are not possible [9], [10].

The quality of imaging colour for medical applications have to be extremely good to recognize cancer tissue in surgery. A bad reproduction of colour in the image forming instrument is not acceptable, since cancer tissue is recognized primarily by small colour differences.

Minimal invasive endoscopic instruments for medical applications are critical. Due to the large number of relay lenses in a long transmission system, the colour aberrations are accumulated. The reasons are similar to the medical applications.

Applications with ultra short pulses as a light source:
Short pulses have a broad spectral range and need a system with a corrected group velocity dispersion.

Modern material processing in technical and medical applications use these types of light sources for the following applications:
- Cornea keratectomy
- Laser surgery and micro-dissection
- All technical and medical applications, which use optical coherence tomography (OCT)

In modern microscopy applications special imaging modes are growing up, which need a broad spectral transmission from the ultraviolet to the near infrared spectral region. Typically, nonlinear processes are used to make biological effects visible with the help of marker substances. These materials typically have a quite low density and only few light can be observed as a signal. Therefore a high transmission is necessary to perform these applications.

Some very import examples are:

- Raman microscopy for biological research
- Fluorescence Microscopy for biological and medical research
  A low radiation loading of the samples is necessary to prevent damage and bleaching
  Applications: - cancer and AIDS research
  - drug discovery
  - Clinical diagnostics, pathology
- Light guiding fibers to transport the light from the source to a minimal invasive location of application in medical surgery
- Radiation shielding properties which are required in xray-diagnostic instruments. The visualization of the fluorescence screen must be performed with an additional optical system in the visible range to magnify and enhance the image. This part of the system is quite near to the xray tube and therefore to prevent the observer from a high dosis, the optical system has to block these spectral components. Furthermore the detectors degrade due to the high energy radiation components and a fast aging of the system performance takes place, if the shielding effect of the system is low.

Photon gain from fluorescence and Raman effects is very low due to the fundamental physics of these processes. So it is of utmost importance to have an optical system within the microscope to reduce optical losses to the absolute minimum. This will result in lower energy consumption, since the power of the illumination system can be reduced. Increasing the power of illumination systems in order to compensate for transmission losses in the optical system is no option due to inherent increasing temperatures of the overall optical system with subsequent thermal instablilities and because many samples, especially from life and bio sciences, have to be observed under strictly controlled and moderate temperature conditions; otherwise they will be altered or worst-case destroyed during the observation.

A typical microscopic lens design for broad spectral applications with Pb-containing glasses results in an overall transmission of 94% at a wavelength of 365 nm (UV-region); if there would be a switch to Pb-free glasses, the transmission will fall down to an unacceptable level of only 40%. This is far too low for these microscopic applications to be performed with reasonable throughput and quality.

1.3.1.2 Photography

Photographic systems and movie cameras for professional applications need a good colour correction to guarantee good results. Especially wide-angle systems are critical to correct and need lead-containing glasses to reach the performance goals.
Pb-free glasses have different refractive indices in the red and the blue part of the spectrum und thus a very high dispersion. As a consequence Pb-free glasses have different chromatic aberrations on the optical axis as well as in the field view. This results in an overall lower optical performance and lower contrast and there are visible colour fringes in the photographic images.

Interchangeable lenses for photographic applications need Pb-containing glasses also due to the fact, that theses glasses have a better transmission in the blue and near ultraviolet spectral region. This allows for a better colour balance and correction (compensation for yellow artefacts). A brilliant colour reproduction is one of the major performance goals of camera lenses.
In principle optical designs of interchangeable photocamera lenses would be theoretically possible with Pb-free glasses; however this will have the following consequences:

- The overall number of individual lens elements made of Pb-free glasses in a typical design will be up to 20% higher than in an optical design with Pb-containing glasses in order to achieve the same optical performance of correction.
- This results in higher consumption of ressources (raw materials, grinding and polishing media, cooling lubricants, cleaning agents…) and energy (approx. +20%) for production and processing of these additional lens elements, the lens element mountings and subsequent assembling steps. There will be also 20% more waste due to higher amounts of production residues.
- Furthermore these interchangeable lenses made totally from Pb-free glasses will be bigger in size which is always critical from a handling point of view.

1.3.1.3 Optical Systems for technical applications

Lead containing glasses for optical systems for technical applications are needed for the following reasons:

- High quality of colour reproduction for printing objective lenses
- Resolution of spectroscopic applications is reduced, if the colour correction of the relay optic is bad.
- Other important systems types, which need a high performance colour correction are scanner and industrial camera systems.
- Radiation shielding properties which are required for imaging optics in electron microscopes
- Minimized thermo-mechanical stress generation (i.e. glass type SF57). This material is used in digital projection optics (beamer) for beam splitters to separate illumination and signal beams at a high energy density with a corresponding high thermal loading
- Faraday rotator components with high Verdet constant in a broad spectral range without considerable absorption are only deliverable with heavy flint glasses. These materials are used in polarimetric instruments.
- Glasses with and without lead show a significant difference in the thermal dependence of the refractive index. This is used in practice to compensate for temperature effects in high-performance systems. This is especially important for medical applications and optical imaging systems for printing devices.
- Gradient index lenses are one option for innovative concepts with small scale systems in telecommunication, minimal invasive endoscopic medical instruments, smart sensors and other technical applications. Gradient index materials usually have a basic substrate glass material with special inclusions of dopants to change the refractive index as a function of the space coordinate [14], [15]. These components offer additional degrees of freedom to generate concepts primarily for the above applications with critical boundary conditions for the overall size of the system. This is one of the promising options for building small micro systems.
- Special manufacturing properties [3]: Pb-containing glasses (i.e. glass type F2) allow for a special glass forming process with high precision, the so-called “blanc-pressing”. In addition to the precision lens moulding process used in consumer optics another direct pressing process is applied in industrial optics. Starting from about 1 m long 3 cm diameter rods out of lead containing glasses lenses are made avoiding following grinding and polishing processes. Since both processes, the direct press process and the conventional way to produce glass lenses, need a reheating of the glass to the temperature range where it becomes soft again, there is probably no substantial energy saving from this point of view. However the direct press process saves material and also the energy needed to produce it and avoids grinding sludge. Generally grinding sludge is, no respect if lead is inside or not, not suited to be disposed with normal household waste.

1.3.2 Cadmium Containing Glasses

The Cadmium-containing filter glass series (i.e. GG, OG, RG) are used because of the following technical properties:

1.3.2.1 Steep-Slope Long-pass Filter and Colorimetric Properties [3]

- They provide a set of steep-slope long pass filters covering a wide range of wavelengths. The position of the absorption edge may vary from 395 nm up to 850 nm, that is the total visible range and part of the near infrared. This enables short wavelengths blocking at the desired cut-off wavelength in a very flexible, convenient and efficient way.
- The blocking ratios in the absorption range better than 10^{-5} are unequalled by any other bulk filter solutions. This is required especially in laser safety applications and sensitive measurement methods relying on high signal to noise ratios.
- They maintain their colorimetric properties even under harsh conditions (temperature shocks from lamp switching, direct weather exposition) over long time periods and independent of viewing angles. This is required by air traffic safety regulations (runway illumination). There are no alternative solutions.
- They maintain their filter characteristic over long time periods without any bleaching, from which all plastic filter products suffer.
- They can endure significantly higher temperatures than plastic filters, which are limited to about 150°C. With illumination applications such temperatures will easily be reached.
- They maintain their filter characteristics almost independent from the angle of light incidence, which may be a significant advantage over filters made with interference coatings, which exhibit a significant angular dependence of their spectral characteristics. This is especially important if the filter is located at a position where light beams are strongly convergent or divergent.
- Interference coatings and cd-containing long pass filters together provide optical filter solutions, which combine the specific advantages of the individual components (effective absorption of color glass filters and the reflection properties of taylor-made interference coatings).

1.3.2.2 Microscopic and Medical Systems

- Cd-containing glass filters are used as blocking filters for very hard UV-radiation from the illumination system. This is necessary to separate the light from the illumination system, which contains a rather high amount of hard UV-radiation from the signal light which is needed in the imaging system itself. Without such filters, the hard UV-radiation cannot be kept away from sensitive samples like biological probes, living cells, human tissue and in-vivo investigations.
- Provision of a sharp cut-off edge of parts of the spectrum is necessary for many applications. A smooth spectral transition which could be made in principle with Cd-free filters is not possible microscopic applications.

1.3.2.3 Photography

Professional photography uses filter glasses for special imaging techniques and colour effects, for example the blocking of certain parts of the visible sunlight spectrum when recording natural scenes.

1.3.2.4 Optical Systems for technical applications

- Performance of applications requiring a necessary high signal-to-noise ratio (SNR) in a special range of the wavelength.
- Generation of sharp edged filter curves for many spectroscopic applications, insensitive to temperature and incidence angle and a high separation ratio
- Robust airport and traffic illuminations, low environmental sensitivity
- Laser protection eye glasses
- Traffic observation and monitoring systems
- Facility safety surveillance
- Environmental surveillance, satellite photography and multispectral mapping of water constituents in lakes
- Colour channel separation in TV and general color visualization and display systems
- Industrial and technical inline and motion measurement, camera and control systems
- In general scientific systems with critical spectroscopic detection principles

1.4 Please justify why this application falls under the scope of the RoHS Directive (e.g. is it a finished product ? Is it a fixed installation ? What category of the WEEE directice does it belong to ?)

Lead and cadmium containing optical and filter glasses are present in a large variety of finished products as key functional optical elements as well as in fixed installation and in mobile devices. The WEEE categories covered by their applications are 3, 4, 5, 6, 8 and 9 as given for the examples listed above and in the table under 2.1.

1.5 What is the amount (in absolute number and in percentage by weight) of the substance/compound in: (i) the homogeneous material, (ii) the application and (iii) total EU annually for RoHS relevant applications ?

Pb-containing glasses may contain up to 75 weight-% in form of Pb-oxides in the homogeneous material.

Cd-containing glasses may contain max. 0,5 weight-% of Cd in form of oxides, sulfides or selenides in the homogeneous material.

The glass content within the overall optical devices is between 1 and 5 weigth-% or 2,5% of Pb-containing compounds within the glass matrices itself. Since not every single lens element within an optical system is made of Pb-containing glass, the amount of Pb-containing glasses will be even lower.

In our devices (Zeiss is one customer of Pb- and Cd-containing glasses among many others) we use approximately 5 tons of Pb-containing glasses/year which results in the use of approx. 2,5 tons of Pb-oxides/yr. within the glass matrices of the various applications.
The usage of Cd-containing filters is approx. 200 kg/yr; this results in a Cd-amount of approx. 2 kg/yr.
The amounts of lead containing glasses sold by Schott in the last three fiscal years are 293 (2005), 119 (2006) and 159 tons (2007) [3].
Assuming an average glass yield factor of 0.67 the produced amounts are about 440 (2005), 180 (2006) and 240 tons (2007). Taking into account the individual amounts sold per glass type and year and the lead content of each glass type this corresponds to a content of elementary lead of 270 (2005), 100 (2006) and 140 tons (2007) (with 0.928 Pb in PbO).
The glass yield factor consists mainly of production yield and geometrical yield. The raw glass item geometry being mostly rectangular has to be converted to near net shape optical element geometry. Strip glass will be processed and repressed to round lens blanks. Cutting prisms out of rectangular block glass e.g. may lead to significant cut away losses.

Several effects influence the development of the production amounts with time as given above:
- The general cycling of economy
- In the years 2004 – 2005 one major glass company ceased production of lead containing glasses. So Schott probably got some orders in addition.
- Rear projection TV using lead glass prisms declined due to the success of flat screen TV
- Changes of optical systems designed by optical companies without lead containing glasses become effective 2 – 3 years later in glass purchasing because of changes necessary in the production processes and market launch lead times. So a further reduction in production amount can be expected.

Schott is now the only producer for lead containing glasses outside China. The other glass melting companies, mainly in Japan, have stopped the production of these glass types. This is mainly due to the fact, that they serve the consumer optics market, whereas Schott is strong in the industrial optics market, where glasses with special properties and outstanding quality are required. So the produced amounts quoted above can been seen as representative for the total world wide market supply at least in the last two years except for Chinese glass. There is a possibility that cheap Chinese binoculars may contain lead glasses, since the cheapest way to produce a moderately colour corrected optical system is an achromate consisting of a boron-crown and a lead-flint glass lens pair. Digital cameras and mobile phones will not contain lead glasses, since the producers have committed themselves not to use lead glasses.

The amount of cadmium containing glass types produced in 2007 is 37 tons. There is only one significant competitor in the world, who produces glasses of the same kind, the Japanese company

Hoya. Schott claims to have an at least 2/3 market share, so that one can derive as the total world wide amount 56 tons. The content of cadmium-oxide equivalent in these glasses is less than 0.5 %, which results in a total amount of 245 kg cadmium (with 0.875 Cd in CdO).
The quoted amounts do not only go to the market segments regulated by the WEEE. There is a significant part used for military equipment, which cannot be quantified since there are many different paths glass items can go and which cannot be monitored without tremendous effort.

For all glass types there are economically critical amounts. If the request falls below these limits this will lead to production stop. All glass types can be molten in small pots and hence could be produced in small amounts in principle. However, in order to achieve the quality level required by industrial optics, larger melting tanks are necessary. With small devices the homogeneity and inclusion quality characteristic for optical glass is not possible. With requested amounts further reduced as may be expected, more and more glass types will be eliminated from the glass program range.

1.6 Please check and justify why the application you request an exemption for does not overlap with already existing exemptions respectively does not overlap with exemption requests covered by previous consultations.

The other exemptions from the RoHS-directive dealing with the use of lead and cadmium in glasses are not applicable with respect to exemption #13. The reasons are as follows:

- Exemption #5 (lead in glass of cathode ray tubes, electronic components and fluorescent tubes) was granted to the best of our knowledge for applications using Pb-containing glasses for the purpose of radiation shielding. Radiation shielding is by far not the only focus of exemption #13.
- Exemption #20 (lead oxide in glass used for bonding front and rear substrates of flat fluorescent lamps used for liquid crystal displays) is not applicable for us, since this exemption does not refer to the optical properties of Pb-containing glass.
- Exemption #21 (lead and cadmium in printing inks for the application of enamel on borosilicate glass) is not applicable for us, since this exemption is obviously needed to fix a printing ink on the surface of a certain glass, because otherwise there might be an adhesion problem of this printing ink when applying enamel on the glass. This has however nothing to do with the unique optical properties of a Pb- or Cd-containing glass, where Pb and Cd are constituents of the glass matrix within the homogeneous material and not on the surface of a glass piece.
- Exemption #21 (lead as impurity in RIG (rare earth ion garnet) Faraday rotators used for fibre optic communication system) is also not applicable, since exemption #21 deals with Pb-impurities in a crystal matrix (rare earth garnets are single crystals to the best of our knowledge). A glass however has no crystalline properties.
- Exemption #25 (lead oxide in plasma display panels (PDP) and surface conduction electron emitter displays (SED) used in structural elements; notably in the front and rear glass dielectric layer, the bus electrode, the black stripe, the address electrode, the barrier ribs, the seal frit and frit ring as well as in print pastes) seems to be an exemption for a very specialized application, which has no overlap with exemption #13.
- Exemption #26 (lead oxide in the glass envelope of Black Light Blue (BLB) lamps) seems to have been granted for radiation shielding properties of such glasses for BLB-lamp applications. Again, there is no match to our exemption #13.
- Exemption #29 (lead firmly bound in crystal glass according to appendix I (crystal glasses 1, 2, 3 and 4) of directive 69/493/EEC of the council) is not applicable for us, since Pb-containing crystal glass, which is used for decorative purposes, does not have such an overall good homogeneity which is necessary for glass which is used in optical applications.

1.7 Please provide an unambigious wording for the (requested) exemption

We stick to the original formulation for exemption #13 in the RoHS-directive which is: “Lead and cadmium in optical and filter glass”.

2. Answers to the specific questionnaire concerning Exemption #13 “Lead and cadmium in optical and filter glass”

2.1 Please specify these small number of applications (differentiate between applications using optical glass and those using filter glass): which applications currently fall under the scope of the RoHS directive ? Please provide a comprehensive list with allocation to WEEE categories. Which applications falls under category 8 & 9 of the WEEE directive ? Which applications are covered by exemption 5 (lead in glass of cathode ray tubes, electronic components and fluorescent tubes) ?

The following comprehensive list contains the applications as listed already in section 1.2:

Application	Usage of Optical Glass	Usage of Filter Glass	WEEE-category
Interchangeable lenses for photographys	Yes	Yes	3
Medical Optical Products	Yes	Yes	8
Microscopes for life, bio and material sciences	Yes	Yes	8 and 9
Digital projection (beamers, rear projection TV)	Yes	No	4
Optical applications and diagnosis in the near UV-region (bio-fluorescence, gene analyses, print-scanner)	Yes	Yes	8
Temperature compensated high end optical imaging systems for medical and printing applications	Yes	Yes	8 and 6
Endoscopes	Yes	No	8 and 9
Fibres for high quality illumination units for operation microscopes in microsurgery	Yes	No	8
Optical systems designed for telecom applications in the near IR spectral range (1000 – 1500 nm)	Yes	No	3
Facility safety and national security applications	Yes	Yes	9
Airport runway safety illumination	No	Yes	5
Safety equipment, e.g. laser protection eye glasses	No	Yes	9
Traffic and toll monitoring systems	No	Yes	9
Facility safety surveillance	No	Yes	5
Environmental surveillance	No	Yes	9
Colour channel separation (colour TV)	No	Yes	4
Photographic colour filters	No	Yes	3
Attenuation or separation of undesired wavelengths in telecommunication	No	Yes	3

Application	Usage of Optical Glass	Usage of Filter Glass	WEEE-category
Light barriers for motion control	No	Yes	6
Bar code readers	No	Yes	6
Logistics automation equipment	No	Yes	6
Industrial measurement applications	No	Yes	6 or 9
Industrial displays	No	Yes	6
Industrial image processing for quality assurance	No	Yes	6
Detection of faked paintings	No	Yes	9
General research	No	Yes	9

None of the mentioned applications falls under RoHS-exemption #5, because to the best of our knowledge this exemption was granted for Pb-containing glasses in applications where radiation shielding is required. Radiation shielding is not the primary focus with exemption #13. For this reason exemption #5 does not cover exemption #13.

2.2 Which of the applications covered by exemption 13 are available as RoHS compliant products (i.e. without Pb and Cd) on the EU market ? Which applications are currently not available as RoHS compliant products ?

There are Pb-free glasses on the market which are mainly used for consumer products. However with these glasses the desired optical performance of certain optical applications cannot be achieved. See details in sections 1.3 and 2.4.

To the best of our knowledge there are no Cd-free glass filters on the EU market which fulfil required optical properties, like a steep and discrete absorption edge in the spectrum, to achieve the best performance within the applications.

2.3 Are there different technical characteristics between optical and filter glass ? If so, what are the different technical functionalities of Pb and Cd in these types of glasses ?

Optical glass is used to pass and form light trough a number of various lens elements or more complicated components (i.e. either flat, concave or convex shaped lens elements) in order to achieve an optical image with the best optical resolution which is needed for the relevant application. There are also non-imaging applications, where it is necessary to guide signal light or to transport the energy of a light beam with the corresponding beam shaping capabilities according to the actual needs form the source to the detector.

Pb-containing optical glasses are needed due to the fact, that theses glasses have a better transmission in the blue and near ultraviolet spectral region. This allows for a better colour correction.

Filter glass is needed to cut-off a certain part of the light spectrum which would otherwise distort the optical image itself.

Filter glasses contain Cd-compounds (oxides, sulfides and selenides) with a Cd-content of max. 0,5 weight-%. This small Cd-content allows to achieve steep and very discrete absorption edges in a spectrum, for instance to cut-off the infrared part of the spectrum. To cut off the IR radiation is necessary to allow for an optimal thermal control of an optical system. If this could not be made there will be major problems and disadvantages, for instance thermal drift and instabilities, because the heat caused by IR-radiation of the spectrum of a light source cannot be compensated for.

Please refer also to section 1.3 and 2.4 for more details.

2.4 Which are the technical characteristics related to the use of Pb and Cd that are essential for the technical functionality of applications/products related to exemption 13 ? List those applications named under point 1 for which substitution is technically not feasible and justify.

This question has been already answered under section 1.3, so there will be here only a repetition of the answers given already in 1.3.

2.4.1 Lead Containing Glasses

Lead containing glasses for optical systems are needed for the following reasons [4 – 10]:

2.4.1-a) Colour correction
If an optical system needs a good colour correction, it is necessary to use special combinations of different materials to ensure a good quality over a broad spectral range. From the viewpoint of optics, there are two different effects, if the colour correction is not performed well:

1. Different lateral magnifications cause colour fringes in the image
2. Axial differences cause a sharp image only for one colour. Usually green is made good, the red and the blue images are blurred and badly resolved.

When lead glasses are no longer available for optical system design a larger number of components is necessary to get the required performance. In many applications (examples are listed below) visible colour fringes due to a bad aberration correction are not acceptable. Typically a 10% to 20% larger number of lenses is needed for leadfree systems.

The dense flint glasses with lead have the comfortable properties of high index, small dispersion, high transmission and special partial dispersion. These materials are preferred to get high performance systems. Especially the KZFS-glasses are extremely important to get high-quality systems.
The general trend to achieve compact and small systems with a small number of lenses contradicts to this reduced possibility

2.4.1-b) Transmission in the Ultraviolet (UV) spectral region
Lead-free glasses and optical systems made from such Pb-free glasses have a strongly reduced transmission from 410 ...365 nm and about no transmission below 365 nm. These functionalities are essential for many very important applications.

In the following part, we will give some examples for the need to use Pb-containing glasses for colour correction:

2.4.1.1 Microscopic and Medical Systems
Microscopic objective lenses need a high performance colour correction. Otherwise, the critical applications of biological research, medial diagnostics, drug discovery etc. are not possible [9], [10].

The quality of imaging colour for medical applications have to be extremely good to recognize cancer tissue in surgery. A bad reproduction of colour in the image forming instrument is not acceptable, since cancer tissue is recognized primarily by small colour differences.

Minimal invasive endoscopic instruments for medical applications are critical. Due to the large number of relay lenses in a long transmission system, the colour aberrations are accumulated. The reasons are similar to the medical applications.

Applications with ultra short pulses as a light source:
Short pulses have a broad spectral range and need a system with a corrected group velocity dispersion.

Modern material processing in technical and medical applications use these types of light sources for the following applications:
- Cornea keratectomy
- Laser surgery and micro-dissection
- All technical and medical applications, which use optical coherence tomography (OCT)

In modern microscopy applications special imaging modes are growing up, which need a broad spectral transmission from the ultraviolet to the near infrared spectral region. Typically, nonlinear processes are used to make biological effects visible with the help of marker substances. These materials typically have a quite low density and only few light can be observed as a signal. Therefore a high transmission is necessary to perform these applications.

Some very import examples are:

- Raman microscopy for biological research
- Fluorescence Microscopy for biological and medical research
  A low radiation loading of the samples is necessary to prevent damage and bleaching
  Applications: - cancer and AIDS research
  - drug discovery
  - Clinical diagnostics, pathology
- Light guiding fibers to transport the light from the source to a minimal invasive location of application in medical surgery
- Radiation shielding properties which are required in xray-diagnostic instruments. The visualization of the fluorescence screen must be performed with an additional optical system in the visible range to magnify and enhance the image. This part of the system is quite near to the xray tube and therefore to prevent the observer from a high dosis, the optical system has to block these spectral components. Furthermore the detectors degrade due to the high energy radiation components and a fast aging of the system performance takes place, if the shielding effect of the system is low.

Photon gain from fluorescence and Raman effects is very low due to the fundamental physics of these processes. So it is of utmost importance to have an optical system within the microscope to reduce optical losses to the absolute minimum. This will result in lower energy consumption, since the power of the illumination system can be reduced. Increasing the power of illumination systems in order to compensate for transmission losses in the optical system is no option due to inherent increasing temperatures of the overall optical system with subsequent thermal instablilities and because many samples, especially from life and bio sciences, have to be observed under strictly controlled and moderate temperature conditions; otherwise they will be altered or worst-case destroyed during the observation.

A typical microscopic lens design for broad spectral applications with Pb-containing glasses results in an overall transmission of 94% at a wavelength of 365 nm (UV-region); if there would be a switch to Pb-free glasses, the transmission will fall down to an unacceptable level of only 40%. This is far too low for these microscopic applications to be performed with reasonable throughput and quality.

2.4.1.2 Photography

Photographic systems and movie cameras for professional applications need a good colour correction to guarantee good results. Especially wide-angle systems are critical to correct and need lead-containing glasses to reach the performance goals.
Pb-free glasses have different refractive indices in the red and the blue part of the spectrum und thus a very high dispersion. As a consequence Pb-free glasses have different chromatic aberrations on the optical axis as well as in the field view. This results in an overall lower optical performance and lower contrast and there are visible colour fringes in the photographic images.

Interchangeable lenses for photographic applications need Pb-containing glasses also due to the fact, that theses glasses have a better transmission in the blue and near ultraviolet spectral region. This allows for a better colour balance and correction (compensation for yellow artefacts). A brilliant colour reproduction is one of the major performance goals of camera lenses.

In principle optical designs of interchangeable photocamera lenses would be theoretically possible with Pb-free glasses; however this will have the following consequences:

- The overall number of individual lens elements made of Pb-free glasses in a typical design will be up to 20% higher than in an optical design with Pb-containing glasses in order to achieve the same optical performance of correction.

- This results in higher consumption of ressources (raw materials, grinding and polishing media, cooling lubricants, cleaning agents…) and energy (approx. +20%) for production and processing of these additional lens elements, the lens element mountings and subsequent assembling steps. There will be also 20% more waste due to higher amounts of production residues.
- Furthermore these interchangeable lenses made totally from Pb-free glasses will be bigger in size which is always critical from a handling point of view.

2.4.1.3 Optical Systems for technical applications

Lead containing glasses for optical systems for technical applications are needed for the following reasons

- High quality of colour reproduction for printing objective lenses
- Resolution of spectroscopic applications is reduced, if the colour correction of the relay optic is bad.
- Other important systems types, which need a high performance colour correction are scanner and industrial camera systems.
- Radiation shielding properties which are required for xray-diagnostics and imaging optics in electron microscopes
- Minimized thermo-mechanical stress generation (i.e. glass type SF57). This material is used in digital projection optics (beamer) for beam splitters to separate illumination and signal beams at a high energy density with a corresponding high thermal loading
- Faraday rotator components with high Verdet constant in a broad spectral range without considerable absorption are only deliverable with heavy flint glasses. These materials are used in polarimetric instruments.
- Glasses with and without lead show a significant difference in the thermal dependence of the refractive index. This is used in practice to compensate for temperature effects in high-performance systems. This is especially important for medical applications and optical imaging systems for printing devices.
- Gradient index lenses are one option for innovative concepts with small scale systems in telecommunication, minimal invasive endoscopic medical instruments, smart sensors and other technical applications. Gradient index materials usually have a basic substrate glass material with special inclusions of dopants to change the refractive index as a function of the space coordinate [14], [15]. These components offer additional degrees of freedom to generate concepts primarily for the above applications with critical boundary conditions for the overall size of the system. This is one of the promising options for building small micro systems.
- Special manufacturing properties [3]: Pb-containing glasses (i.e. glass type F2) allow for a special glass forming process with high precision, the so-called “blanc-pressing”. In addition to the precision lens moulding process used in consumer optics another direct pressing process is applied in industrial optics. Starting from about 1 m long 3 cm diameter rods out of lead containing glasses lenses are made avoiding following grinding and polishing processes. Since both processes, the direct press process and the conventional way to produce glass lenses, need a reheating of the glass to the temperature range where it becomes soft again, there is probably no substantial energy saving from this point of view. However the direct press process saves material and also the energy needed to produce it and avoids grinding sludge. Generally grinding sludge is, no respect if lead is inside or not, not suited to be disposed with normal household waste.

2.4.2 Cadmium Containing Glasses

The Cadmium-containing filter glass series (i.e. GG, OG, RG) are used because of the following technical properties:

2.4.2.1 Steep-Slope Long-pass Filter and Colorimetric Properties [3]

- They provide a set of steep-slope long pass filters covering a wide range of wavelengths. The position of the absorption edge may vary from 395 nm up to 850 nm, that is the total visible range and part of the near infrared. This enables short wavelengths blocking at the desired cut-off wavelength in a very flexible, convenient and efficient way.
- The blocking ratios in the absorption range better than 10^{-5} are unequalled by any other bulk filter solutions. This is required especially in laser safety applications and sensitive measurement methods relying on high signal to noise ratios.
- They maintain their colorimetric properties even under harsh conditions (temperature shocks from lamp switching, direct weather exposition) over long time periods and independent of viewing angles. This is required by air traffic safety regulations (runway illumination). There are no alternative solutions.
- They maintain their filter characteristic over long time periods without any bleaching, from which all plastic filter products suffer.
- They can endure significantly higher temperatures than plastic filters, which are limited to about 150°C. With illumination applications such temperatures will easily be reached.
- They maintain their filter characteristics almost independent from the angle of light incidence, which may be a significant advantage over filters made with interference coatings, which exhibit a significant angular dependence of their spectral characteristics. This is especially important if the filter is located at a position where light beams are strongly convergent or divergent.
- Interference coatings and cd-containing long pass filters together provide optical filter solutions, which combine the specific advantages of the individual components (effective absorption of color glass filters and the reflection properties of taylor-made interference coatings).

2.4.2.2 Microscopic and Medical Systems

- Cd-containing glass filters are used as blocking filters for very hard UV-radiation from the illumination system. This is necessary to separate the light from the illumination system, which contains a rather high amount of hard UV-radiation from the signal light which is needed in the imaging system itself. Without such filters, the hard UV-radiation cannot be kept away from sensitive samples like biological probes, living cells, human tissue and in-vivo investigations.
- Provision of a sharp cut-off edge of parts of the spectrum is necessary for many applications. A smooth spectral transition which could be made in principle with Cd-free filters is not possible microscopic applications.

2.4.2.3 Photography

Professional photography uses filter glasses for special imaging techniques and colour effects, for example the blocking of certain parts of the visible sunlight spectrum when recording natural scenes.

2.4.2.4 Optical Systems for technical applications

- Performance of applications requiring a necessary high signal-to-noise ratio (SNR)
- Generation of sharp edged filter curves for many spectroscopic applications, insensitive to temperature and incidence angle and a high separation ratio
- Robust airport and traffic illuminations, low environmental sensitivity
- Laser protection eye glasses
- Traffic monitoring systems
- Facility safety surveillance
- Environmental surveillance, satellite photography and multispectral mapping of water constituents in lakes
- Colour channel separation in TV and general color visualization and display systems
- Industrial and technical inline and motion measurement, camera and control systems
- In general scientific systems with critical spectroscopic detection principles

2.5 What has changed since the last evaluation in 2004 ? What is the current status of R&D efforts towards substitution of Pb and Cd in the different applications ?

Comprehensive efforts have been made in the last few years to solve the problems associated with the use of lead-free glass materials in all applications of optics. The following list shows some examples in optical research and development in order to avoid Pb- and Cd-containing glasses:

- Development of diffractive components to correct for colour aberrations
- Special coatings for substitution of filter glasses (there are still many fundamental physical problems to be solved, e.g. for a broad range of the incidence angle, polarization effects, high sensitivity of the parameters)
- Basic research on nanocomposite materials in polymer matrices to achieve the desired optical parameters without making any compromises in optical performance of such systems
- Modified design strategies and algorithms to optimize optical systems to achieve the same optical performance as with Pb- and Cd-containing glasses. This however means a mathematical solution for the optical problem with fewer degrees of freedom on the optical material side which is not always straightforward in its use and possible at all. One example for this strategy is a photographic interchangeable lens made totally Pb-free. The unavoidable consequence however is the use of more lens elements in the design, see 1.3.1.2 or 2.4.1.2. These additional degrees of freedom (more lens elements) are necessary to compensate for the smaller number of optical materials available.

There are still many fundamental optical problems which could not be solved with Pb- and Cd-freee glasses until now; details have been presented in the previous sections.

Additionally we have to take into account, that the frame conditions have changed significantly in the last years. The relevance of near UV applications and broad spectral applications (biomedical research and technical applications) have grown and are still growing significantly.

We are aware of the fact, that devices/applications under WEEE-categories 8 & 9 do not have to be RoHS-compliant until now. However since there is a current review of RoHS-directive to extend the scope of the RoHS-directive also to these two WEEE-categories (possibly already from 2012 on, as can be derived from the ongoing discussions on this issue), we have to take this development into account with respect to a prolongation of exemption #13, [11], [12].

New developments are made under the constraint to achieve full RoHS-compliance, when there are no fundamental technical and/or scientific reasons, which request the usage of non RoHS-compliant materials or compounds. For these applications, exemption request have been already made (exemption #13) or have been addressed to ERA Technology Ltd. for their report during the stakeholder consultation process [11].

RoHS-compliance is – as described already in detail – not possible for many applications using Pb- and Cd-containing optical glasses and filter glasses. There are some fundamental technical and scientific reasons which require that theses types of glasses are available in the future. This was also already investigated in [1] where it is stated that there are certain specific applications, where a combination of properties are required which can be achieved only with Pb- and Cd-containing optical glasses and filter glasses.

2.6 Are manufacturers still investigation alternatives ? (a) If yes, please provide a roadmap or similiar evidence showing until when they intend to replace lead in glass in the applications mentioned above. (b) If no, please explain and justify why no further research has been undertaken against the background that the RoHS annex is subject to regular revisions.

The main research and development activities to replace lead in optical glass took place in the 1990s [3]. Due to the market requirements most glass manufacturers developed lead and arsenic free glass types as alternatives or in parallel to the lead and arsenic containing glass types. This development was driven by large optical companies in consumer optics business, who wanted to obtain a marketing advantage by declaring their products to be environmentally friendly. They wanted to have lead-free glass types since at that time lead-free fuel for motor cars had become a synonym for environmental friendliness. This being true for motor car fuel, where lead had been present as a toxic lead-organic compound set free to the environment with each car drive and hence was easily bio-available, in glass the situation is much different. Here lead is bound inorganically mainly as lead oxide, which is much less toxic and bound firmly in the glass matrix. So is hardly bio-available at all. However in consumer markets such distinctions will not become popular especially when alternatives exist. The first company who changed to lead free optical glass in total was Hoya, Japan. Ohara and Schott changed their programs some years later. The other European glass melting companies Corning and Pilkington did not change their programs significantly and finally went out of business, Pilkington in 2006. The new Schott glass program was launched in 1999 introducing 66 lead and arsenic free glass types after 3 years of intense and costly developments. Since 2000 all new optical glass types have been developed by all remaining glass melting companies (out of China) to be lead and arsenic free, with one exception at Schott, the very special and expensive short flint glass type KZFS12, which is used only in small amounts (< 1 ton / year) in order to achieve outstanding optical system performance.

Optical glass development goes on. Each year new glass types are introduced to the market mainly driven by the request for smaller camera modules in mobile phones, thinner pocket digital cameras, better image quality, better transmittance and better support of low price mass production. The latter are the so-called low Tg glass types for precision moulding which allow direct pressing of finished lenses avoiding costly and time consuming reheat pressing, grinding and polishing. This process allows also to produce cost-effective aspherical lenses, one of them saving two or more of classically produced spherical lenses in optical systems. Since more than 12 years all major glass companies have intensely researched to find alternatives for lead glass types with optical properties as close to those of these glasses as possible. For consumer optics with its moderate performance requirements compared to those of industrial optics, the reduction of lead arsenic containing glass types has reached a level of more than 90% (estimated). For industrial optics also exchanges have been done if ever possible if only because of logistics and material management reasons. For the remaining lead arsenic glass types it is not worthwhile to invest in high research and development efforts from the glass melting companies point of view. Due to the small amount expected to be sold in the future there would be no prospects for pay-back.

For the cadmium containing glass types there have been attempts to replace them by glasses with less toxic ingredients also since long times. This was driven by the producers because of labour safety and environmental goals. The production of these glass types has to obey strict rules and is allowed only with safety and filter equipment. Therefore since more than 10 years Schott has tried to find alternative glass compositions and production methods. In 1994 a detailed study was performed to evaluate literature and patents to find alternatives. The most recent activity was the doctorate thesis of Jochen Freund investigating the possibility of producing cadmium containing glass types via sintering and to find alternative glass types [13].

Here again it has been stated, that there are no real replacement solutions for the cadmium containing glass types. Only glass types are possible (e.g. $CuInS_2$) with inferior absorption edges with much broader slopes than the cadmium containing glass types thus making the filter effect significantly worse.

The production process via sintering was shown to work in principle, but only on a laboratory scale. To employ it as a production process would have needed additional years of development. A lot of money and time would have had to be spent without any prospects to finally solving the cadmium problem. So the development was stopped.

Cu-halogenide doped glasses have similar steep slopes, but the absorption edge positions are restricted to the blue-violet spectral region. So even if a production process for these glasses would exist, they would be only a very limited replacement possibility.

III-V-semiconductor doped glasses are reported to have long pass filter behaviour. They never reached production melting scales and have at least one toxic component. This would not make them acceptable replacements for cadmium containing glasses.

Several other exotic approaches have been checked. Like those mentioned before all of them showed little prospects to be up-scalable from laboratory test melts to production melts and many needed components which were toxic again. So even if punctual replacements would be possible in principle, time consuming and very costly production process development would be necessary with only little chance for success from the technical point of view. This makes developments so unattractive, that Schott stopped this after the PhD-work mentioned above.
The only known serious competitor with steep slope long pass filter glasses is company Hoya. They also use cadmium containing glasses. We do not know for sure but are very confident, that Hoya also tried to replace cadmium in these glasses and if they would have had success, they would have exploited this in the market.

2.7 Please state for applications name under point 1 the amount of Pb and Cd used per application, the Pb content in the homogeneous material, the annual production volume as well as the number of applications related to exemption 13 put on the EU market annually.

This question has been already answered under section 1.5, so there will be here only a repetition of the answer given already in 1.5.

Pb-containing glasses may contain up to 75 weight-% in form of Pb-oxides in the homogeneous material.

Cd-containing glasses may contain max. 0,5 weight-% of Cd in form of oxides, sulfides or selenides in the homogeneous material.

The glass content within the overall optical devices is between 1 and 5 weigth-% or 2,5% of Pb-containing compounds within the glass matrices itself. Since not every single lens element within an optical system is made of Pb-containing glass, the amount of Pb-containing glasses will be even lower.

In our devices (Zeiss is one customer of Pb- and Cd-containing glasses among many others) we use approximately 5 tons of Pb-containing glasses/year which results in the use of approx. 2,5 tons of Pb-oxides/yr. within the glass matrices of the various applications.
The usage of Cd-containing filters is approx. 200 kg/yr; this results in a Cd-amount of approx. 2 kg/yr.

The amounts of lead containing glasses sold by Schott in the last three fiscal years are 293 (2005), 119 (2006) and 159 tons (2007) [3].

Assuming an average glass yield factor of 0.67 the produced amounts are about 440 (2005), 180 (2006) and 240 tons (2007). Taking into account the individual amounts sold per glass type and year and the lead content of each glass type this corresponds to a content of elementary lead of 270 (2005), 100 (2006) and 140 tons (2007) (with 0.928 Pb in PbO).

The glass yield factor consists mainly of production yield and geometrical yield. The raw glass item geometry being mostly rectangular has to be converted to near net shape optical element geometry. Strip glass will be processed and repressed to round lens blanks. Cutting prisms out of rectangular block glass e.g. may lead to significant cut away losses.

Several effects influence the development of the production amounts with time as given above:

- The general cycling of economy
- In the years 2004 – 2005 one major glass company ceased production of lead containing glasses. So Schott probably got some orders in addition.
- Rear projection TV using lead glass prisms declined due to the success of flat screen TV
- Changes of optical systems designed by optical companies without lead containing glasses become effective 2 – 3 years later in glass purchasing because of changes necessary in the production processes and market launch lead times. So a further reduction in production amount can be expected.

Schott is now the only producer for lead containing glasses outside China. The other glass melting companies, mainly in Japan, have stopped the production of these glass types. This is mainly due to the fact, that they serve the consumer optics market, whereas Schott is strong in the industrial optics market, where glasses with special properties and outstanding quality are required. So the produced amounts quoted above can been seen as representative for the total world wide market supply at least in the last two years except for Chinese glass. There is a possibility that cheap Chinese binoculars may contain lead glasses, since the cheapest way to produce a moderately colour corrected optical system is an achromate consisting of a boron-crown and a lead-flint glass lens pair. Digital cameras and mobile phones will not contain lead glasses, since the producers have committed themselves not to use lead glasses.

The amount of cadmium containing glass types produced in 2007 is 37 tons. There is only one significant competitor in the world, who produces glasses of the same kind, the Japanese company Hoya. Schott claims to have an at least 2/3 market share, so that one can derive as the total world wide amount 56 tons. The content of cadmium-oxide equivalent in these glasses is less than 0.5 %, which results in a total amount of 245 kg cadmium (with 0.875 Cd in CdO).

The quoted amounts do not only go to the market segments regulated by the WEEE. There is a significant part used for military equipment, which cannot be quantified since there are many different paths glass items can go and which cannot be monitored without tremendous effort.

For all glass types there are economically critical amounts. If the request falls below these limits this will lead to production stop. All glass types can be molten in small pots and hence could be produced in small amounts in principle. However, in order to achieve the quality level required by industrial optics, larger melting tanks are necessary. With small devices the homogeneity and inclusion quality characteristic for optical glass is not possible. With requested amounts further reduced as may be expected, more and more glass types will be eliminated from the glass program range.

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This contribution was coordinated by SPECTARIS

Contact:
Dr. Joachim Giesekus
Fon: +49 (0)30 41 40 21 – 29
Fax: +49 (0)30 41 40 21 – 33
giesekus@spectaris.de

SPECTARIS.
German Industrial Association for Optical,
Medical and Mechatronical Technologies
Saarbrücker Straße 38, D-10405 Berlin, Germany