# Exemption Renewal Request Form

Date of submission:

1. **Name and contact details**

**Name of applicant:**

**SPECTARIS**

**with support of:**

**AFOP - Le Syndicat Professionnel Optique Photonique**

**Communication and Information Network Association of Japan**

**DIGITALEUROPE**

**European Aluminium Association**

**European Copper Institute**

**European Passive Components Industry Association**

**European Semiconductor Industry Association**

**European Special Glass Association**

**Gesamtverband der Aluminiumindustrie**

**InformationTechology Industry Council**

**IPC – Association Connecting Electronics Industries**

**Japan Business Council in Europe**

**Japan Business Machine and Information System Industries Association**

**Japan Electronics and Information Technology Industries Association**

**LIGHTINGEUROPE**

**TechAmerica Europe**

**The Japan Electrical Manufacturers´ Association**

**Wirtschaftsvereinigung Metalle**

**Contact details of applicant:**

| | | |
|---|---|---|
| Company: | **Spectaris e.V.** | Tel.: +49 30 41 40 21 25 |
| Name: | Dr. Wenko Süptitz | E-Mail: sueptitz@spectaris.de |
| Function: | Head of Photonics Division | |
| Address: | Werderscher Markt 15, 10117 Berlin, Germany | |


**2. Reason for application:**

Please indicate where relevant:

- Request for new exemption in:
- Request for amendment of existing exemption in
- Request for extension of existing exemption 13b in Annex III
- Request for deletion of existing exemption in:
- Provision of information referring to an existing specific exemption in:
    - Annex III
    - Annex IV
- No. of exemption in Annex III or IV where applicable: 13b
- Proposed or existing wording: Cadmium and lead in filter glasses and glasses used for reflectance standards
- Duration where applicable: **No expiry date**
- Other: This renewal request does not include or describe reflectance standards as these are different to optical filters in terms of applications, materials and function. Justification for renewal of this exemption for reflectance standards should be provided by reflectance standard manufacturers.

**3. Summary of the exemption request renewal request**

This exemption renewal request is for the use of cadmium and lead in optical filter glasses that are used in electrical and electronic equipment. There are many types of optical filter glasses that contain cadmium but only a few that contain lead. These types of optical filters are used in a very wide variety of optical applications and in many different types of equipment. These materials are used because of their unique optical properties, such as ñsharp cut-offò in the visible spectrum that is unaffected by viewing angle. They are also very stable in harsh environments. Most of the alternatives to glass containing cadmium and /or lead do not exhibit such sharp wavelength ñcut-offsò Interference filters do have sharp cut offs but the wavelength at which this occurs is viewing angle dependent and so these are unsuitable for many applications. Most of the apparent alternatives are detrimentally affected by harsh environmental conditions such as heat, moisture, UV light, etc. which makes them unsuitable for many applications.

**4. Technical description of the exemption request / revocation request**

**(A) Description of the concerned application:**

1. To which EEE is the exemption request/information relevant?

Name of applications or products:

Optical glass containing lead and cadmium is used as a light filter where a well-defined slope in the absorption spectrum is required, such as a sharp cut-off within a narrow wavelength range. Both Pb and Cd are needed to ensure that there is a high percentage of light transmission at wavelengths above the ñcut offò and close to zero transmission below the cut off wavelength. These filters are used in many types of EEE (as well as non-electrical applications) and a selection of illustrative example applications is listed below. Most of the following examples of optical filter glass contain cadmium and one example contains lead but not cadmium:

- Security and surveillance applications, e.g. infrared illumination with filters that suppress visible light (category 3 or 9).
- Airport runway lamps that indicate the runway location (category 5 or 9) ï bright specific coloured light visible from all directions which should not change in colour with direction which would occur with coated filters.
- Laser eye protection goggles / glasses (most types have no electrical function but any designs with an electrical function would be in category 9).
- Traffic monitoring - cameras to take pictures of drivers surpassing the speed limit and toll monitoring systems (category 9).
- Environmental monitoring equipment, e.g. used to monitor environmental pollutants, waste sorting, waste water analysis, exhaust gas analysis, airborne (from airplanes, satellites) environmental diagnosis photography, etc. (category 9).
- Colour channel separation for colour television (category 4).
- Spectral filters for photographic cameras (category 3).
- Attenuation or separation of undesired wavelengths in telecommunication by separation of undesired wavelengths transmitted by coated filters (category 3).
- Light barriers for motion control in electrical machinery (category 6).
- Bar code readers (category 6).
- Logistics automation equipment such as letter and parcel sorting machines (category 6 or 9).
- Industrial measurement as part of, or used with machines used for manufacturing ï many different applications (category 6 or 9).
- Industrial displays (category 6).
- Fluorescence microscope (categories 8 and 9); more details below.
- Spectrometers; for example, as stray light filters for UV and for near-IR spectrometers, requires high % transmission in the desired wavelength range and a steep cut-off with no transmission outside of the desired range.
- Gas chromatograph detectors ï use filters containing lead to detect the spectra of sulphur and phosphorous compounds (category 9).
- Flame photometric detectors used for process gas chromatography. The filters are needed to separate light of 394nm from other wavelengths which is used to measure intensity and calculate the concentration of sulphur compounds in the process gas. Blue filters containing lead are used for this application (category 9).
- Infrared cameras ï category 9.
- Radiation thermometer ï category 9, uses filters containing cadmium to detect light of specific wavelengths without interference from other wavelengths. These determine temperature by measuring the light intensity at a specific wavelength so other wavelengths must be blocked. Cadmium provides the steep edge of the transmission limit wavelength.
- Imaging luminance colorimeter ï light measurement to simulate the human eyeõs light responses. The colour response is simulated by 4 different ñstacksò for the so called Xr, Xb, Y and Z response of the "standard observer" as defined by the "International commission of illumination, CIE". The filters are sequentially introduced into the beam path of a camera system. Calibrations and evaluation of the data result in a precise image of luminance and colour. The closest match can only be achieved with filters containing cadmium (category 9).
- Spectroradiometer: This type of device has a very high fidelity of colour measurements. The light of different colours (plus infrared and ultraviolet) is dispersed by an optical grating and then analysed by a CCD sensor. However, optical gratings diffract the so called 'higher orders' of light as well as the

required wavelengths. This means that light with half the wavelength will follow the same beam path (e.g. 360nm will appear as signal at 720nm). To eliminate these higher order wavelengths, optical filter glasses are used. Optical filters containing cadmium have to be used in these measurement devices for light measurement (category 9).

- Ingredient meters and thickness meters ï use filters containing both cadmium and lead. These devices function by measuring the amount of an ingredient in the test sample to determine either its concentration or if this is known, it can be used to measure the sampleõs thickness by making use of the Lambert-Beers law. This is achieved by accurate measurement of transmitted light at a specific wavelength and filters are needed to remove other wavelengths.
- Infrared sensors ï these filters contain an evaporated layer of lead oxide which transmits light of wavelengths between 8 and 15µm and has a high refractive index. This combination of properties cannot be achieved by any other materials or designs.
- Light meter for specific wavelength ranges (category 9).
- Industrial image processing for quality assurance as part of electrical machines (category 6).
- Detection of faked paintings, filters are used in controlled wavelength light sources (category 9).
- High quality scanners used to digitise colour images (category 3).
- High performance cameras, such as television broadcasting, cinematography, medical applications, etc. (category 4).
- Light filters for astronomy research (category 9).
- Short Wavelength Automated Perimetery (SWAP) using a Humphrey field analyser (HFA) is a medical technique used to detect eye conditions such as Glaucoma and optic neuritis (category 8, more details below).
- IVD analysers (category 8); IVD analysers automatically analyse a variety of materials and some tests use colour to measure concentrations (using optical absorption spectroscopy). The required colours are selected by blocking other wavelengths using optical filters including some that contain cadmium. These must have sharp-edges to the transmitted spectrum and be stable with no colour change or fading during the life of the equipment for accuracy to be maintained.
- All types of Ultra-short pulsed lasers, with fundamental wavelength in Near-Infrared (NIR) (1064nm / 1030nm), optical filters containing cadmium are in use (RG1000 filters). These filters are used to separate the fundamental NIR radiation from other wavelengths like pump sources with 808nm /880nm / 888nm and harmonics such as 523nm / 355nm /266nm. The filtered NIR is used for determination of power values for diagnostic reasons, but mainly for power level settings and attenuation by end users of the tool. Ultra-short pulsed laser sources are used in a growing market segment like e.g. micromachining of glass, in the semiconductor industry and used to produce photovoltaics and display technologies.
- Lead containing green filter glass such as VG9 has many minor uses. It separates the different colour channels for colour TV cameras (category 4) and is used for medical colposcopes (more details below).
- Optical filters are used with optical microscopes to remove unwanted wavelengths.
- Cadmium and lead filter glasses may also be used in many other types of equipment, such as lighting applications, toys and leisure products and automatic dispensers.)

More details of some uses of cadmium optical filters are described below.

**Colour image recording**: Several of the above examples which record colour images (colour TV) require steep edge filters to split the visible spectrum into several colour channels each of which are recorded separately. This requires that the filters have the steepest edge possible and that they are not affected by viewing angle. This combination of properties is achievable only by optical glass filters based on cadmium and lead.

**Fluorescence spectroscopy** is an analytical technique that is used for analysis of some types of organic substances, molecular biology (e.g. cell and tissue analysis), medical research, cancer detection and other medical diagnostic procedures and industrial applications such as semiconductor analysis. All fluorescence techniques require optical glass with high percentage transmission at short wavelengths and fluorescence microscopes require many high quality lenses that contain lead as well as optical filters that are independent of viewing angle. Fluorescence spectroscopy operates by exposing the sample to light of a preselected wavelength which can be ultraviolet or visible light. Some materials absorb this light and then emit light of a longer wavelength by fluorescence in all directions. The emitted fluorescence is detected for quantitative analysis, imaging or mapping, depending on the type of instrument used. Medical diagnostics, for example often use near UV or blue/violet light to cause fluorescence and so a high percentage of light transmission at short wavelengths is essential. This technique is used to create images with **fluorescence microscopes** in which light is scattered by the object and so the optical filters must have a steep edge and this needs to be independent of viewing angle.

Images are often made by staining materials with fluorescent dyes. The wavelength of light used to illuminate samples will have a different wavelength to the fluorescent light emitted by the dyes, but these two wavelengths are usually similar. If a white light source is used, steep-edge cut off filters are needed to remove light of wavelengths that are not required for inducing fluorescence and filters are also used to remove the input excitation light from the output fluorescent light. Examples of tests carried out with fluorescent dyes shows the small differences in wavelengths that need to be separated, for example, an orange-red dye is excited at 553nm to fluoresce at 569nm . Only filters containing cadmium have sufficiently steep edge filter properties at all viewing angles to separate these wavelengths.

Some fluorescence spectrometers use diffraction monochromaters to select the wavelengths required to induce fluorescence and to separate out fluorescent wavelengths from other light. Diffraction gratings always however emit 2nd, 3rd, 4th etc. order diffracted wavelengths and these must be separated from the 1st order light that is required and this is achieved by steep-edge filters. Thin film diffraction filters are ñsteep-edgeò but transmit side-bands of undesirable wavelengths so are not suitable without the addition of optical glass filters. Thin film filters also suffer from other disadvantages, as described below in answer to Q6A. Diffraction grating and interference filters are unsuitable for imaging due to their dependency on incident and viewing angle and so on steep edge filters can be used.

**Humphrey field analyser (HFA) SWAP**: The patientôs retina is illuminated with light of specific wavelengths to determine their response to coloured light.  This technique uses two types of optical glass filters that contains cadmium (Schott OG530 and RG850). The OG530 is a yellow filter that provides yellow background illumination. The HFA uses normative databases that are used to compare patientôs visual field test results to an age-matched population. In order to use these databases, the optical spectrum from the optical filters must not change. The figure below shows how the yellow filter is used.

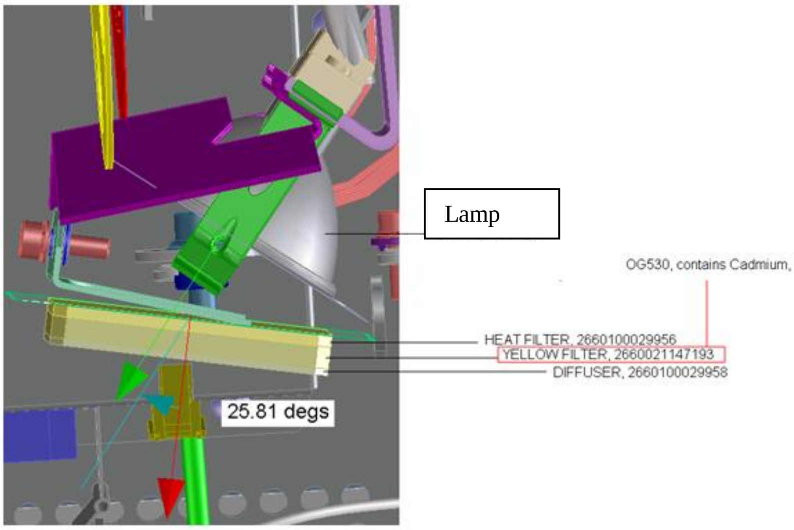



**Figure 1.** Position of lamp and yellow filter in Humphrey Field Analyser

A cadmium-based optical filter is used so that the spectrum is the same irrespective of angle between the lamp and the patientôs eye.

The RG850 optical glass filter is used to pass near infrared light from an 880nm light emitting diode (LED) and to block visible light. The purpose of the LED is to generate a reflex from the cornea and to illuminate the pupil in order to track the gaze of the patient. This filter is critical because it blocks the emission from the LED in the red part of the spectrum that would be visible to the patient and possibly could be mistaken for a stimulus. Cadmium-free dichroic filters cannot be used to reject visible light by reflection, because it would appear as a bright spot in the bowl instead of a dark spot, which could also confuse the patient into thinking a stimulus was presented, when it was not.

**Colposcopes** are used to examine inside the cervix to look for abnormalities. The instrument is essentially a low power binocular microscope but the illumination light is filtered to use in particular a green colour. This enables blood vessels and any abnormalities to be visualised. Lead glass filters need to be used to ensure that the transmitted green light wavelengths are stable. Lead has a dual function of providing the required optical properties and also lowering the glass melting point so that the added green pigments are stable.

**Light filter domes for solar radiation measurement**: An example is shown below:

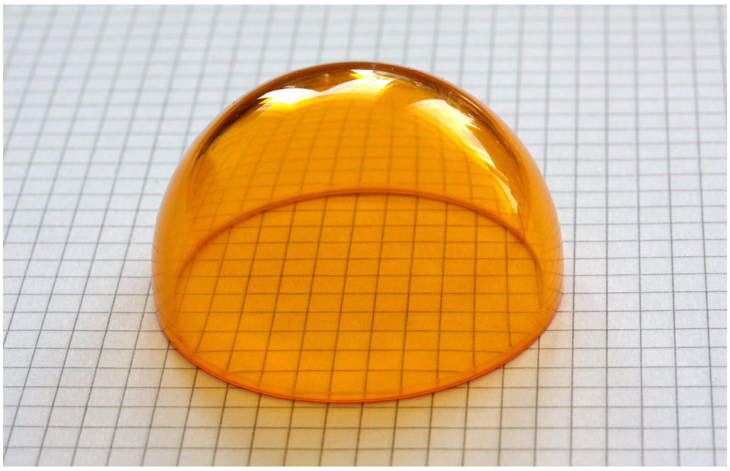


**Figure 2.** Light filter dome

The light detector of the measuring device is located in the centre of the sphere, and all sunlight rays that reach the detector, hit the filter surfaces with normal incidence and all rays have the same path-length through the filter material as shown below:

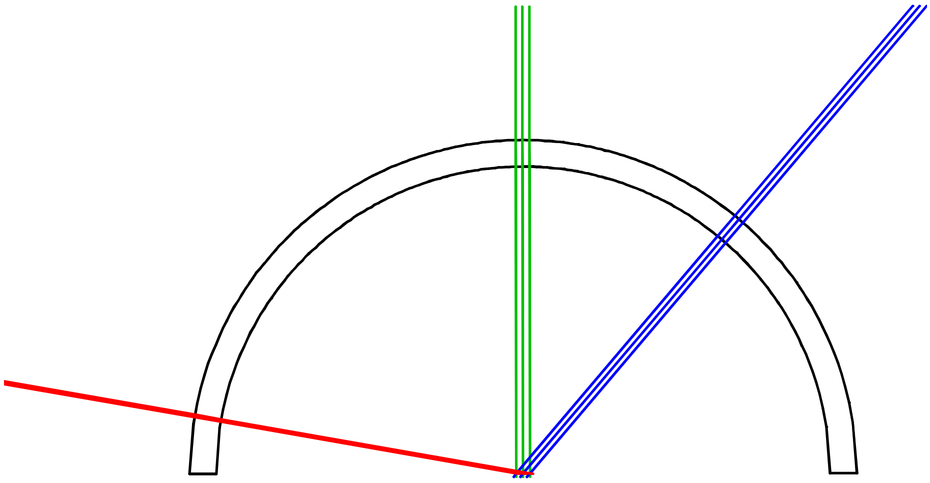


**Figure 3.** Measurement principle in a light filter dome

The filter characteristics must be independent of the direction of the detected rays and so cannot be replaced by planar dielectric filters as their optical properties are dependent on angle of incidence. If a planar substrate were used, the incident angle varies with the light ray's direction and the incident angle changes the dielectric filter's characteristic. If a curved substrate is used to avoid this effect, then the dielectric filter layers change their thickness due to the changing inclination angle during the filter production, which also shifts the spectral properties of the filter.

Cadmium must be used to obtain the sharp cut-off required and plastic filters with organic pigments will degrade when exposed to sunlight by photochemically induced decomposition processes.

a. List of relevant categories: (mark more than one where applicable)

| | | | |
|---|---|---|---|
| 1 | Yes | 7 | Yes |
| 2 | Yes | 8 | Yes |
| 3 | Yes | 9 | Yes |
| 4 | Yes | 10 | Yes |
| 5 | Yes | 11 | Yes |
| 6 | Yes | | |

b. Please specify if application is in use in other categories to which the exemption request does not refer: Not applicable.

c. Please specify for equipment of category 8 and 9:
The requested exemption will be applied in

- monitoring and control instruments in industry YES
- in-vitro diagnostics Yes
- other medical devices or other monitoring and control instruments than those in industry YES, for both

2. Which of the six substances is in use in the application/product?
(Indicate more than one where applicable)
**Lead (Pb) and cadmium (Cd)**

3. Function of the substance:
Optical filter glasses are clear transparent non-crystalline materials with a variety of compositions. Traditionally ñglassò has been understood to consist of complex inorganic silicates based on a variety of ingredients such as sodium, barium, calcium, potassium, boron, arsenic, antimony and lead but there are many diverse compositions of materials that meet the definition of ñglassò. The essential characteristics that cadmium and lead give to glass optical filters are as follows:
**Cadmium** ï the function of cadmium in optical glass is to absorb light at wavelengths shorter than a specified value and to allow all light of longer wavelengths to be transmitted through the filter. By adjusting the quantities of other constituents (S, Se and Te), red, orange and yellow filter glasses are produced from cadmium which are used to absorb wavelengths from ca. 400nm. A red filter allows only red light to pass whereas an orange filter allows red and orange light to pass. An important characteristic of cadmium-based optical filters is the difference in optical filtering above and below the cut-off wavelength. Cadmium filters can be designed to absorb almost 100% of light having wavelengths shorter than the cut-off value and transmit better than 95% of light with longer wavelengths. Furthermore, the range of wavelengths between 95 % transmission and <1% transmission can be designed to be relatively small, so that these filters are classified as ñsteep-edgeò filters. Spectra obtained from optical filters that contain cadmium, manufactured by Schott (Germany) are shown below.

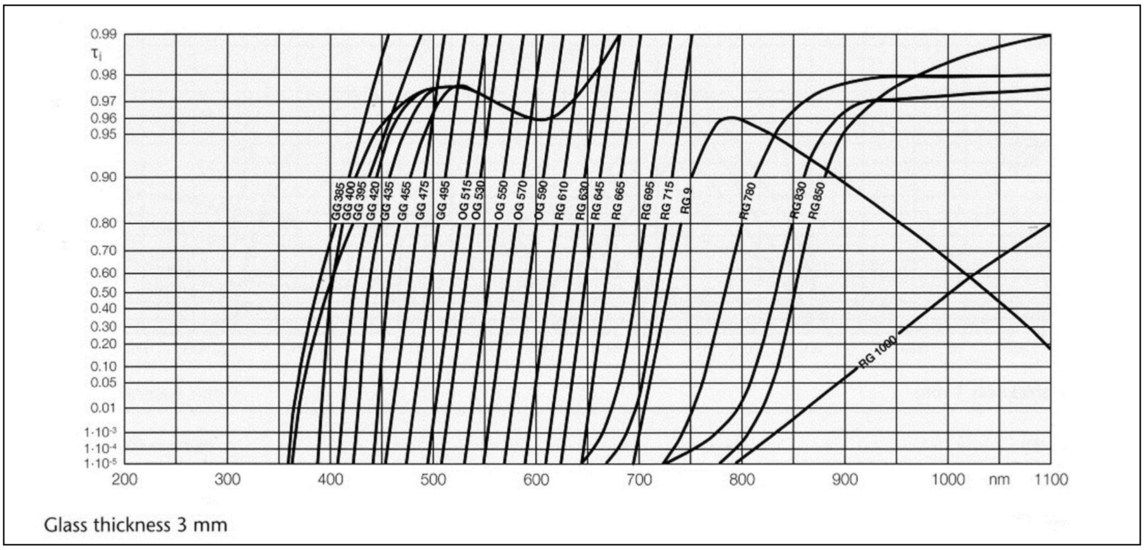



**Figure 4.** Optical transmission spectra of cadmium-based glass filters

Optical filters containing cadmium can be designed to have sharp cut-offs at most wavelength values by control of the cadmium compound composition and the heat treatment conditions of the glass. A few of the curves above have different shapes to achieve specific absorption profiles which are achieved by adjusting the ingredients in the filter glass.

As will be explained in answer to Q6, coloured filter glass is obtained by a variety of metallic additives but a steep cut-off as shown in 4 can be obtained only by cadmium compounds. These types of optical filter are also called "striking" glass and are made by adding the cadmium compounds to molten glass based on $K_2O$, ZnO and $SiO_2$[1]. The cadmium compound initially appears to disperse to give a colourless clear glass. This is then heated to nucleate and crystallise very small (sub-micron), coloured cadmium chalcogenide particles that are dispersed in a colourless matrix. The heat treatment temperature, time and cooling rate all are used to control the particle size which in turn affects the cut off wavelength and the steepness of the cut off. Research has shown that some zinc is present in the cadmium chalcogenide particles and some cadmium remains in the glass matrix, the amounts depending on the cooling rate.

Striking glasses with cadmium are not colloidal dispersions and so the colour of the individual particles is important for the optical characteristics. A steep edge cannot be obtained by colloidal dispersions that are red in appearance and research has shown that the steepness of the absorption edge increases during heat treatment and the steepness is a characteristic of the cadmium chalcogenide particles. Alternative sulphides such as antimony, lead, copper, etc. can give ruby red glass but these all form dispersions of colloidal particles and the glass does not exhibit the steep edge obtained only by cadmium compounds. 3d metals such as Fe, Mn, Ni, etc., when added to glass dissolve in the glass to form ionic complexes within the matrix. The colour depending on both the metal ion and the structure to which it is bonded. These all however have shallow absorption edges unlike cadmium filters.

As well as giving a steep edge, cadmium compounds give very low transmission at wavelengths shorter than the steep edge and very high % transmission at longer wavelengths. This is important for many applications as this prevents image distortion effects such as ñflareò(stray light) and ñghostingò(a second feint image).

[1] W. Vogel, ñGlass Chemistryò, Springer-Verlag,2nd edition 1994. ISBN 3-540-57572-3

**Lead** ï The classical way to colour glass is by adding colouring ions to a glass matrix. These are usually metal ions such as iron, copper, nickel, cobalt and chromium. The colour achieved depends on the valence of the metal ion and on its surrounding glass matrix ions. So there is not much freedom for choice of a metal ion / glass matrix combination for best performing glass filters. The green glass filter VG9 is the last remaining type of a family of VG glasses coloured with chromium III and copper II ions in a lead silicate glass matrix. The lead content of VG9 is 15 % lead oxide. It is the only green filter glass type in a portfolio of 58 glass types. Its usage is with about 250 kg / year very low. Chromium III and copper II ions added to a lead-free glass matrices do not give the same light filtering properties so are not suitable replacements. One application of lead-based optical filters is in fluorescence microscopes to transmit only the desired wavelengths. This needs to be independent of viewing angle. Other examples of uses are listed above in answer to Q4.

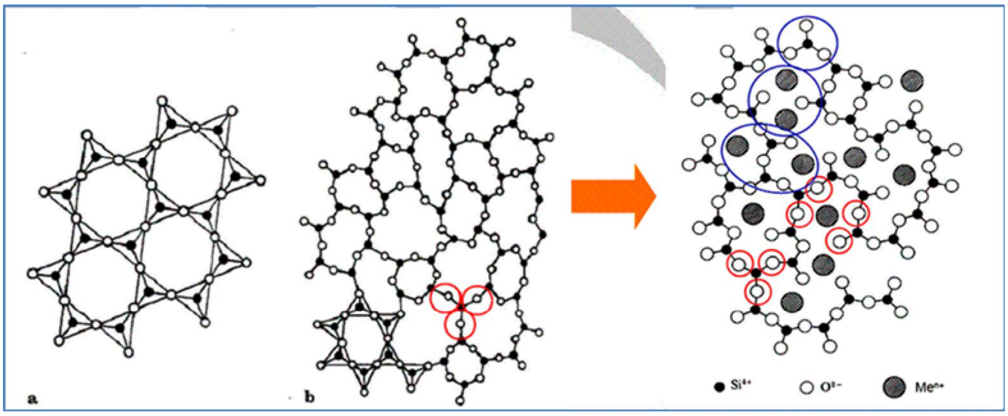
**4. Content of substance in homogeneous material (% weight):** Pb present at up to 40% Pb by weight and cadmium is present at up to 1.5% by weight

**5. Amount of substance entering the EU market annually through application for which the exemption is requested**: 172 kg of cadmium and 14kg of lead

Please supply information and calculations to support stated figure.
Cadmium/lead filter glass is made in Germany, Japan and China. Japanese + German production is estimated to be ca. 56 tonnes p.a. of glass. Chinese production is not published but we estimate is about 55 tonnes p.a. so that total global production is 111 tonnes with about 40% being used in products placed on the EU market. Not all of these are in scope of RoHS (e.g. uses in satellites, military equipment, laser safety glasses and large-scale stationary industrial tools are excluded) but most uses are in scope. Therefore the total weight of filter glass with Pb and Cd placed on the Global market is ca. 111 tonnes and ca. 40 tonnes is placed on the EU market.
The **cadmium** content of filters varies from 0.4 to 2% and on average is 0.43%
**Global consumption** of cadmium filter glass used in EEE in scope of RoHS = 473 kg Cd per year
**EU consumption** of cadmium filter glass used in EEE in scope of RoHS = **172 kg Cd** per year
The **lead** affects only one type of glass VG9 with global sales Ò250kg per year so with a lead content of 15% PbO or 14% Pb, this represents global lead consumption of 35kg per year and an EU consumption of **14kg Pb per year** assuming that the EU has 40% of this market.

**6. Name of material/component**: ñGlassò that contains cadmium, lead, silicon, sodium and other elements as a variety of complex mixed oxide compositions.

Glasses are characterized by their non-regularly ordered amorphous atomic structure




crystalline $SiO_2$ amorphous $SiO_2$ mulit-component glass

**Figure 2. Atomic structures of silica and multi-component glass**

Glass is produced from different constitutional components:

1. Glass formers form glass network
   - $SiO_2$ silicon oxide
   - $B_2O_3$ boron oxide
   - $P_2O_5$ phosphorus oxide

2. Network modifier break up the network

   alkaline oxides:
   - $L_{i2}O$ Lithium oxide
   - $Na_2O$ sodium oxide
   - $K_2O$ potassium oxide

   Alkaline earth oxides such as CaO

   Rare earths elements

   Etc.

3. Intermediate elements added as oxides may also be bound into the network

   - $Al_2O_3$ aluminum oxide
   - MgO magnesium oxide

4. Additional agents introducing special properties

   - Coloring ions
     Fe, Mn, Cr, V, Co, Cu, Cd, Se, .
   - Laser active ions
     $Nd^{3+}$, $Yb^{3+}$, $Er^{3+}$, é
   - Ionizing radiation stabilization compounds
     $CeO_2$
   - etc.

A crystalline structure with composition well defined by chemical formula e.g. silicon dioxide: quartz, is:

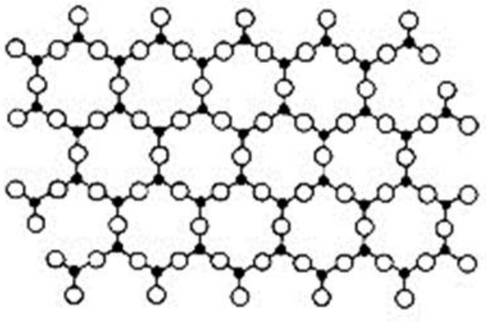


**Figure 3. Atomic structure of crystalline silica**

An amorphous structure still having a well-defined composition and precise chemical formula, e.g.: amorphous silicon dioxide: fused silica

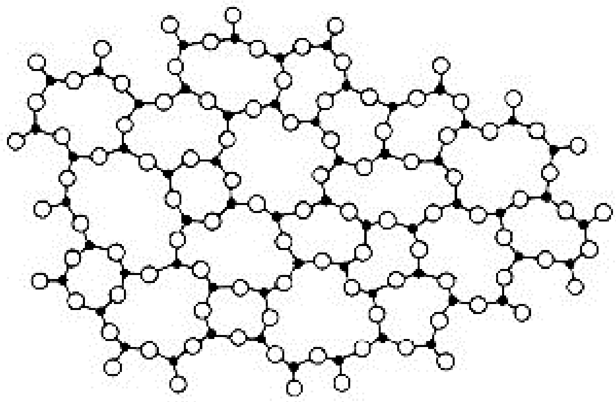


**Figure 4. Atomic structure of amorphous silica**

An amorphous structure produced on the basis of a defined recipe, but without composition that can be well defined by a chemical formula, e.g. sodium - lime glass with a broad range of possible contents of sodium and potassium. In the figure below, only sodium ions are shown for simplicity.

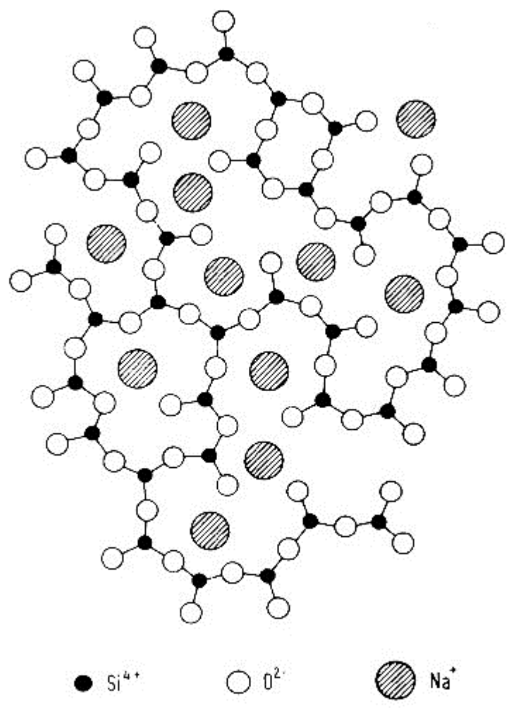



**Figure 5. Atomic structure of a soda-lime glass (showing only Si, O and Na)**

7. Environmental Assessment: This exemption is required because no substitute materials or designs are available that provide the required performance. Therefore a full LCA is not required; however the impacts of cadmium and lead in all life cycle phases is explained here.
LCA: No ï LCA not applicable to this request.

**Cadmium**:
**Mining and extraction of cadmium**: Cadmium is not mined as a primary ore. It occurs naturally with other metals such as zinc, copper and lead that are mined in very large quantities. When zinc, copper and lead are refined, impurities are removed to obtain the required purity and it is often necessary to remove cadmium, particularly from zinc as otherwise >100ppm would be present in zinc metal, which is not permitted by in some products due to EU Directives. Therefore, cadmium is recovered during the metals refining process whether there are industrial uses for cadmium or not. Refining processes carried out in the EU are regulated by the Industrial Emissionõs Directive (IED) 2010/75/EC which imposes strict emission limits on cadmium and other harmful substances. The EU publishes Best Available Technology Reference (BREF) guides that are used by Member States to impose permit requirements on operators of industrial installations. Permits allow emissions only at a level equivalent to the best technology available in the EU. Therefore, as long as IED is effectively enforced, metals refining should not pose a risk to human health or the environment

**Manufacture of cadmium-based optical filter glass**: Optical glass is usually manufactured by combining the appropriate mixture of ingredients and heating these

in a furnace to cause the ingredients to react to form a ñmeltò The melt is cast and cooled at a controlled rate to form the glass. This creates large pieces of glass that are cut and shaped by grinding to form the required optical components.
Production of molten glass potentially emits metal oxides including cadmium oxide. However, glass melting is in scope of the IED and so strict limits based on data in the ñGlass BREF Guidanceò published by the EU are imposed on hazardous emissions so that no risk occurs.
Cutting glass creates glass powder and small pieces that are disposed to landfill. Cadmium in the form of glass should not leach out in well managed landfill sites.

**Use phase**: In use, optical filter glass is very stable and inert. 100% of the cadmium content remains within the glass under all normal use conditions.

**End of life**: At end of life, optical filter glass from WEEE may be either landfilled with the WEEE (i.e. no recycling) or be passed through the WEEE recycling process with other electrical equipment. Glass is relatively heavy so after dismantling, shredding, physical separation by density, etc. the glass is likely to occur in the metals fraction. Scrap metals have a value and so are usually recycled thermally.

- Landfill ï The behaviour of cadmium in landfill is very complex as it (and other metals) can react with other constituents to form various compounds. A report by the European Environment Agency[2] states that measurements of leachate from EU landfill sites has found that cadmium (and other metals including lead) areé ñnot generally present at significant concentrations in leachates from municipal landfills. Mean and median values for all metals were well below concentrations routinely determined in household sewage that is typically flushed from a domestic propertyò This result may either be because cadmium becomes immobilised by clays and other materials in landfills to form insoluble metal complexes or that the amount of cadmium in waste present is so small that any cadmium in leachate is undetectable. Cadmium compounds are not volatile so air emissions will not occur. Only 40 tonnes of cadmium optical glass is placed on the EU market annually whereas 100 million tonnes of municipal waste is disposed of to landfill[3]. If all cadmium optical glass is disposed to landfill, the concentration is only 0.4ppm and this glass being large pieces is relatively inert.
- Thermal treatment ï scrap metals may simply be heated to melt them or are heated with reducing agents such as carbon to convert oxides to metals. Simply heating will melt the glass which will mix with other non-metallic and non-volatile materials to form a ñslagòthat is inert and sent to landfill. Cadmium will not leach out of this material as explained above. Under reducing conditions such as in a smelter used to recover copper from printed circuit boards, some cadmium compounds may be reduced to cadmium metal which is volatile at the process temperature, the vapour then oxidises and has to be collected. This material is a hazardous waste. Cadmium will be present in the feed-stocks used for smelting processes such as those used for WEEE recycling from many materials other than optical glass filters. In WEEE it will occur as electric contacts which are exempt from RoHS but smelters also treat ores and refinery by-products as a mixture with WEEE to achieve maximum yields and efficiencies and these materials will also contain

[2] ñDangerous substances in wasteò Jürgen Schmid et al, February 2000, European Environment Agency http://edz.bib.uni-mannheim.de/daten/edz-bn/eua/00/tech38.pdf
[3] 500kg of waste per capita in 2009 of which 200kg per capita is landfilled from http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Municipal_waste_statistics EU population is 500 million.

cadmium. Therefore cadmium collection and disposal would occur whether there is cadmium present in optical filter glass or not.

**Lead**:
Only about 100kg of optical filter glass containing 14kg of lead is placed on the EU market annually. This amount of lead will not have a significant harmful effect as it represents only 0.03 ppb of EU municipal waste.
**Mining and extraction of lead**: The US Geological Survey publishes global primary lead production and this was 5.2 million tonnes in 2012, a level figure that has been increasing since 1990. In addition, there are significant amounts from secondary sources so in 2008, 8.5 million tonnes of lead was used increasing to 10.5 million in 2012 (International Lead Association). Most lead is used in batteries and in rolled and extruded products; lead in electrical equipment is a relatively minor use and in optical glass it is an extremely minor use. Therefore restrictions on the use of lead in optical glass will have no impact on this life cycle phase.

**Manufacture of lead-based optical glass**: Optical glass is usually manufactured by combining the appropriate mixture of ingredients and heating these in a furnace to cause the ingredients to react to form a melt. The melt is cast and cooled at a controlled rate. This creates large pieces of glass that are cut and shaped by grinding to form the required optical components.
Production of glass potentially emits metal oxides including lead oxide. However, glass melting is in scope of the IED and so strict limits are imposed on hazardous emissions so that no risk occurs.
Grinding glass creates glass powder and small pieces that are disposed to landfill. Lead in the form of glass should not leach out in well managed landfill sites.

**Use phase**: In use, optical filter glass is very stable and inert. 100% of the lead content remains within the glass under all normal use conditions of electrical equipment.

**End of life**: At end of life, optical filter glass from WEEE may be either landfilled with the WEEE (i.e. no recycling) or be passed through the WEEE recycling process with other electrical equipment. Glass is relatively heavy so after dismantling, shredding, physical separation by density, etc. the glass is likely to occur in the metals fraction. Scrap metals have a value and so are usually recycled thermally.

- Landfill ï The behaviour of lead in landfill is very complex as it (and other metals) can react with other constituents to form various compounds. A report by the European Environment Agency[4] states that measurements of leachate from EU landfill sites has found that lead isé ñnot generally present at significant concentrations in leachates from municipal landfills. Mean and median values for all metals were well below concentrations routinely determined in household sewage that is typically flushed from a domestic propertyò. This may be because lead becomes immobilised by clays and other materials in landfills that form insoluble metal complexes. Lead compounds are not volatile so air emissions will not occur.
- Thermal treatment ï scrap metals may simply be heated to melt them or are heated with reducing agents such as carbon to convert oxides to metals. Simply heating will melt the glass which will mix with other non-metallic and non-volatile materials to form a ñslagò that is inert and sent to landfill. Lead will not leach out of this material as explained above. Under reducing conditions such as in a smelter used to recover copper from printed circuit boards, some

[4] ñDangerous substances in wasteò Jürgen Schmid et al, February 2000, European Environment Agency

lead compounds may be reduced to lead metal which is volatile at the process temperature, the vapour then oxidises and has to be collected. This material is a hazardous waste. Lead will be present in the feed-stocks used for smelting processes such as those used for WEEE recycling from many materials other than optical glass filters. In WEEE it will occur in a variety of RoHS exempt forms (e.g. high melting points solders), but smelters also treat ores and refinery by-products as a mixture with WEEE to achieve maximum yields and efficiencies and these materials will also contain lead[5]. Therefore lead is collected and depending on the design of process, is either recovered for reuse or is waste for disposal. Disposal of lead waste will occur whether there is lead present in optical filter glass or not.

**(B) In which material and/or component is the RoHS-regulated substance used, for which you request the exemption or its revocation? What is the function of this material or component?**
See answer to Q 4.A3

**(C) What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?**
See answer to Q 4.A3

**5. Information on Possible preparation for reuse or recycling of waste from EEE and on provisions for appropriate treatment of waste**
**1) Please indicate if a closed loop system exist for EEE waste of application exists and provide information of its characteristics (method of collection to ensure closed loop, method of treatment, etc.)**

.
WEEE from used EEE devices is collected and treated according to WEEE regulation. Business WEEE usually has a high metals content and so is sold for recycling in the EU by the last user and this complies with EU laws on waste recycling. Consumer WEEE is usually collected as mixed types of WEEE at municipal waste sites or even as separated WEEE from other municipal waste depending on the maturity of the collection and treatment techniques available in the EU member states for WEEE . Electrical equipment sold primarily to consumers contains very little optical filter glass that contains cadmium or lead as these materials are used primarily in business-to-business type (b2b) products, although there are some exceptions listed in the answer to Q4.

Closed loop systems do not exist due the very large variety of applications for optical glass. Optical glass is used as small components of electrical equipment which follows a variety of routes at end of life. Some is refurbished and then sold to second users, some will be recycled although glass parts are usually not removed before metal recovery processes. A small proportion is landfilled

**2) Please indicate where relevant:**

- Article is collected and sent without dismantling for recycling ï this is usually what happens to most WEEE

[5] Hoboken site visit 2012, download from http://www.umicore.com/investorrelations/en/newsPublications/presentations/

- Article is collected and completely refurbished for reuse – some professional WEEE is refurbished including some types of medical devices[6] and some other types of equipment but no quantitative data is available.
- Article is collected and dismantled:
  - The following parts are refurbished for use as spare parts:
  - The following parts are subsequently recycled:
- Article cannot be recycled and is therefore:
  - Sent for energy return
  - Landfilled

Electrical equipment containing optical glass is not collected or recycled separately from other types of electrical equipment and so is recycled using the same procedures as other WEEE. The equipment is often re-sold to second (or third, etc.) users both within the EU and outside of the EU but no data is available on quantities.

**3) Please provide information concerning the amount (weight) of RoHS substance present in EEE waste accumulates per annum:** No data available

- In articles which are refurbished
- In articles which are recycled
- In articles which are sent for energy return
- In articles which are landfilled

EU industry complies with all applicable waste legislation. Refurbishes were this is practical, recycles materials where possible and uses landfill only as a last resort. No data available on the quantities of optical glass that is refurbished, recycled or landfilled. Energy recovery from glass is not applicable.

**6. Analysis of possible alternative substances**

**(A) Please provide information if possible alternative applications or alternatives for use of RoHS substances in application exist. Please elaborate analysis on a life-cycle basis, including where available information about independent research, peer-review studies development activities undertaken**

**Potential cadmium substitutes**.

There are three types of potential alternative optical filters that are used for some applications, although these cannot replace cadmium-based optical filter glass where this is used due to its essential characteristics. These are (i) alternative additives in glass, (ii) coatings on glass and (iii) coloured "plastic" filters:

i. **Alternative additives to the glass** – Cadmium plus sulphur, selenium and tellurium are added to glass to make a material that contains microparticles of cadmium as mixed sulphide, selenide and telluride (as $CdS_xSe_yTe_z$ where x, y and z range from 0 to 1 and x+y+z =1) in the glass matrix and the cut off wavelength (colour) is regulated by the ratio of these elements as well as the heat treatment conditions. The exact form of the cadmium compound is unclear but can be seen as small particles in a colourless matrix so it is not colloidal. In order to obtain the same optical properties, alternative inorganic compounds would be needed that are thermally stable at the melting temperature of the types of glass used (therefore all organic pigments cannot be used) and gives the same optical spectrum with the same steep edge. Research has been carried out for many decades to look for alternatives to cadmium, but with no success. The range of elements and their combinations that are suitable is limited as explained here:
   - Industry is limited to the naturally occurring non-radioactive elements of the periodic table. The additive must be a compound with two or

[6] SCRIP Insights "The Market Outlook for Refurbished Medical Devices to 2016", K. Bhattarcharjee, Reference BI00043-007, November 2011.

more elements which must be at least one metal and to match the performance of cadmium, also one non-metal.

- The compound must be coloured which eliminates many metallic elements. Many of the transition metals and rare earth metals will colour glass but none give the same optical characteristics.
- Non-metals could be O, N, S, Se, Te, P, As or Sb. Halides are unsuitable as they are either water soluble or too unstable and so cannot be combined with molten silicate glass.
- The compounds that are suitable must disperse in molten glass without causing crystallisation of the glass (this would destroy the optical properties) and form clear transparent glassy materials. (the coloured phase must be so that the glass is clear and transparent).
- Research has found that a few compounds can be used as coloured glass additives which are either combinations of group II metals with group VI non-metals (i.e. II-VI compounds such as CdS) or group III metals with group V non-metals (i.e. III-V compounds such as GaAs). However, very few of these compounds are yellow, orange or bright red with sharp wavelength cut-offs.
- Most coloured compounds that can be added to glass give different colours to cadmium. For example, nickel compounds are green, cobalt compounds are blue, iron are dull red or brown, mercury (as sulphide) is pink, etc. Compounds with three or more elements have also been evaluated such as CuInSe (a II-III-VI compound), but these also do not give the required steep edge cut-off, as shown below in 5.

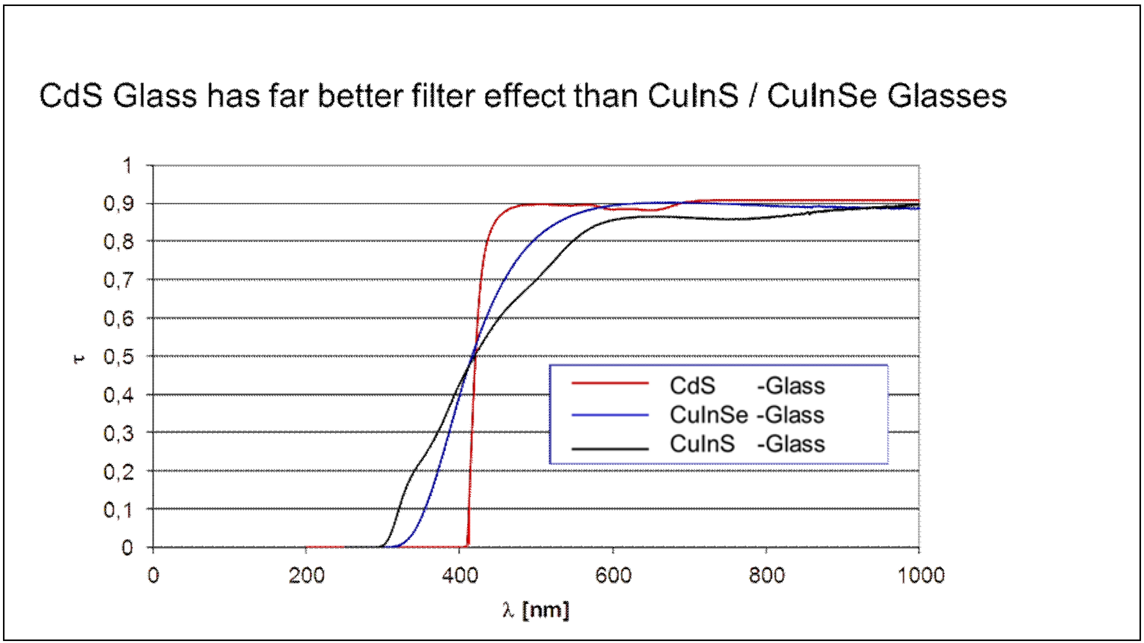



**Figure 5.** Optical transmission spectra of coloured filter glasses (25 mm thickness) comparing slope shapes of CdS with CuInS and CuInSe.

The version of fig. 5 shown above is reproduced below to show the difference in wavelength range between 10% and 90% transmission.

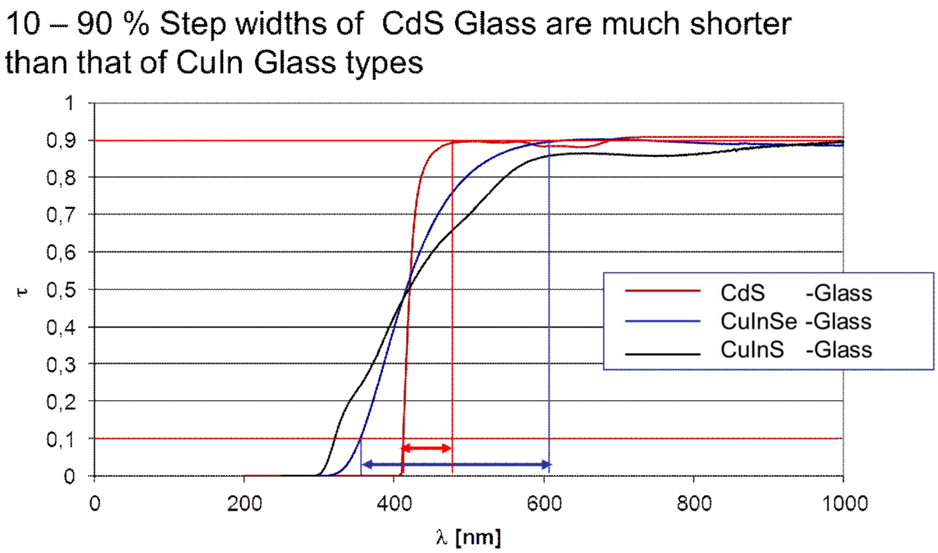



**Figure 6.** Comparison of cadmium glass filters with cadmium-free substitutes to show difference in slope

**Metal ion coloured glass** ï This another alternative type of coloured glass filter where metal ions (usually transition metals) are inserted into the glass matrix to colour the glass. In the typical example shown below, $Cu^{+}$ and $Cr^{3+}$ ions are added to the glass, but the spectra are very different to those of cadmium steep edge filters:

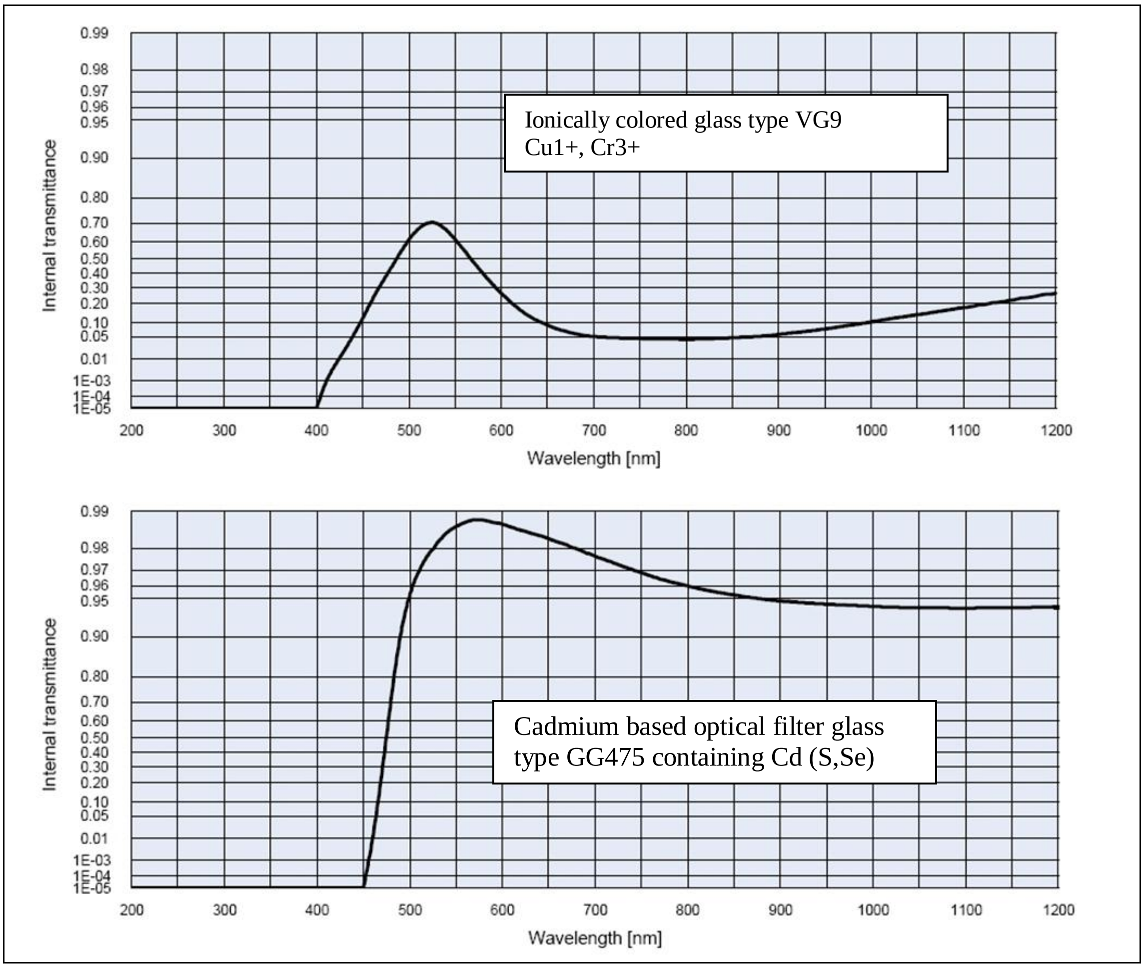



**Figure 7.** Spectra of ionically coloured glass (above) compared with cadmium glass (below)

Figure 7 shows that ionically coloured glasses have different shaped spectra to cadmium based glass with lower % light transmission at longer wavelengths and the slope of the curve of the metal ion coloured glass is shallower than the steeper slope of the cadmium filter.

**Colloidal dispersions:** Coloured glass including ruby red colours can be obtained by adding substances to glass which form colloidal dispersions. The colloid's particle size controls the colour by diffraction of light but colloids do not however give sharp cut-offs, so are not suitable alternatives to cadmium compounds. Colloids are produced by several metal sulphides such as Pb, Sb, Cu, etc. and also be metals such as gold and silver.

ii. **Thin film coatings on transparent substrates**:

**A. Interference filters** - Interference, or dichroic filters are quite widely used for certain applications but their properties are very different to glass filters based on cadmium compounds. Their main characteristic is that they absorb light within a specific but fairly narrow wavelength range with sharp cut-offs at both ends of this wavelength range. Spectra of light that has passed through this type of filter are quite different to spectra obtained with cadmium glass filters as shown below.

Spectra of interference coated filters

Spectra of coloured glass filters, the two at the right contain cadmium (RG9 and RG850)

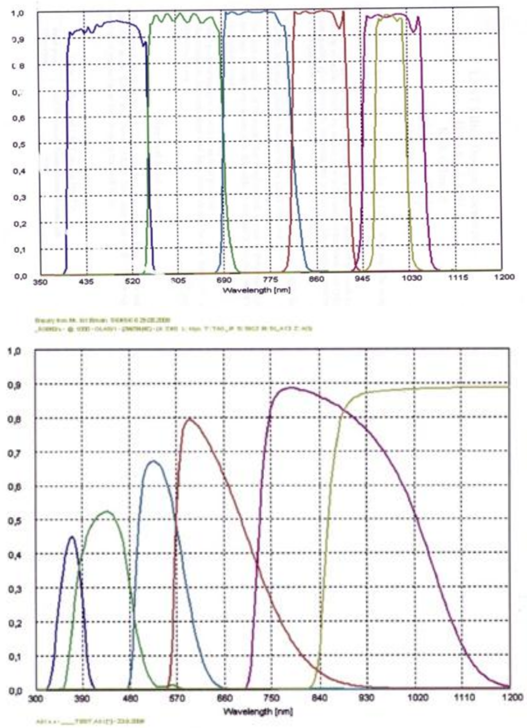



**Figure 8.** Spectra of interference coated filters with coloured glass filters

Interference filters are also viewing angle dependent and can give ȗghostòimages. The images below show how viewing angle affects the transmission spectra from glass filters and interference coated filters.

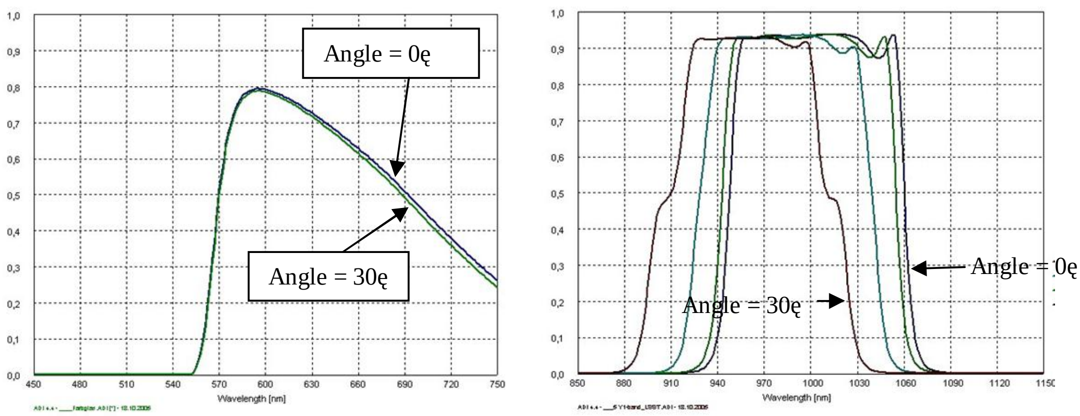



**Figure 9.** Spectra of light from coloured glass filter (left) and interference coated filter (right)

Interference filters may transmit light in one main band but also in unwanted side-bands at lower intensity.
One example that illustrates why dichroic filters cannot always replace optical filters containing cadmium is discussed in the answer to Q4.1 where HFA SWAP is described. This technique uses two types of cadmium based filters. Dichroic filters cannot be used instead of the yellow filter because changes in viewing angle affect the transmitted spectrum and any change means that the normative databases cannot be used to determine if the patient is suffering from early stages of glaucoma or other conditions. The light source used is a halogen lamp which gives light with a range of incident angles, i.e.

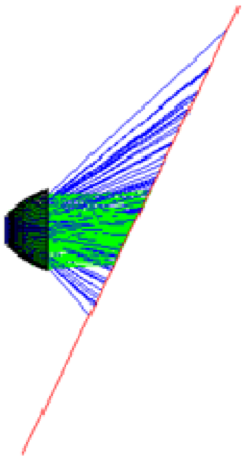


**Figure 10.** Range of incident angles from the lighting source in a HFA SWAP

The light spectrum transmitted through a cadmium-based optical filter will always be the same, whereas spectra of light transmitted through dichroic filters varies with angle of incidence. This will be same if the filter is placed parallel with the lampôs face as the angle of incidence will span 20ę. Dichroic filters cannot be used as alternatives to the RG850 filter to reject visible light by reflection because it would appear to the patient as a bright spot instead of a dark spot, which could confuse the patient into thinking a stimulus was presented when it was not and give erroneous results.

**B. Coloured coatings** - For inorganic compounds, unless the coatings are based on cadmium compounds, the steep edge properties described above cannot be achieved. Organic pigment coatings are inferior because these fade when exposed to ultraviolet light and are easily scratched.

iii. **Transparent plastics with organic pigments** are used as optical filters and have advantages and disadvantages, but these disadvantages make them unsuitable for many applications. The addition of organic dyes and organic pigments to molten glass is impossible as all are thermally unstable at glass melting temperatures. Only heat stable inorganic compounds such as the cadmium chalcogenides (e.g. CdS/Se) can be used.
Coloured organic compounds can, however, be added to a few types of transparent non-crystalline plastics such as acrylics, to give clear coloured transparent plastics without decomposition of the coloured substance. Achieving optical clarity is however not possible for all combinations of coloured compounds and polymers. Most polymers are available only as opaque materials and most pigments will not dissolve so give opaque dispersions. Optical transparency requires that the pigment either dissolves in the polymer, so is present as discrete molecules, or that the particle size is sub-micron and smaller than the wavelength of visible light, so that they are not visible to the human eye. Coloured transparent plastics are however used for low-end optics (e.g. childrenôs toys) where high performance is not required. The main disadvantages are:

- Plastics are easily scratched.
- They are affected by humidity as all plastics absorb water from humid air.
- They are affected by high temperatures (distort, degrade, change colour). Optical filters are used with lamps that can become very hot as well as with laser light sources that heat the filter. Apart from heat transmitted by

the lamps, most filters function by adsorbing light of certain wavelengths and transferring the absorbed energy into heat.

- Organic pigments fade when exposed to ultraviolet light and polymers are also affected causing colour changes. Brittle fracture may also occur when exposed to UV light.
- Image quality tends to be poor as the surfaces of plastic filters are easily warped, so are not optically flat.
- Some polymer filters with organic pigments have relatively poor maximum transmission percentages at wavelengths of light that should pass through the filter.
- Some polymer filters transmit light at wavelengths where light needs to be blocked.

An example of the spectra of three commercial cadmium-free plastic filters is illustrated below[7]. ).

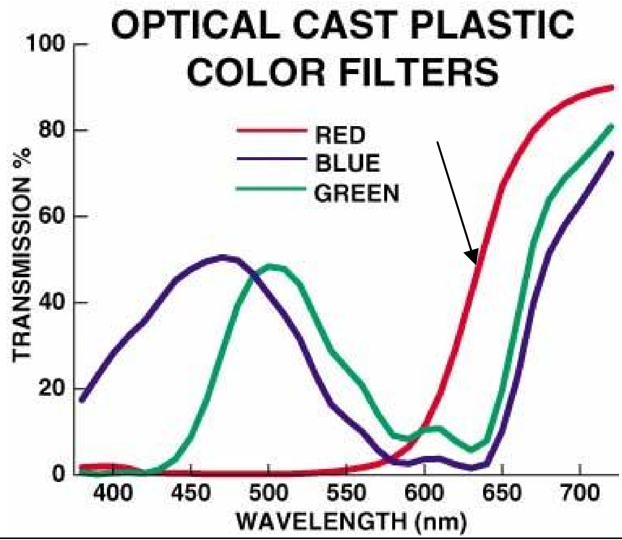



**Figure 11.** Spectra of light transmission for commercial plastic filters

In the red spectrum of figure 11, the slope is much less steep than with cadmium based optical glass filters

Several types of ñgel filtersò are used for photography and other applications. These include polyester gel filters and also the Kodak Wratten range of coloured filters. These are made of gelatine with organic dyes so will fade in sunlight, they will readily absorb moisture (and distort) at high ambient humidity and as gelatine is a protein, they will be affected by a wide variety of chemicals such as oils, fingerprints, etc. and are prone to degradation by micro-organisms. Gel filters are also heat sensitive so cannot be used with hot lamps or at high ambient temperature and being relatively soft, they are easily damaged.

The properties of optical glass and optical polymer filters are compared in the table below.

---

[7] http://www.anchoroptics.com/catalog/product.cfm?id=249

**Table 1. Comparison of glass and plastic materials for filters**

| Property | Glass filters | Plastic filters |
|---|---|---|
| Tolerance (i.e. variation in characteristics of commercial lenses) | Low (±0.0001) can be achieved, so variation is very small | Estimated at ±0.001 |
| Abbe number | Broader range (20 to >80) especially to low dispersion values | 23 ï 58 is possible |
| Transmittance of unfiltered light (through 3mm) | >99% achievable | 85 ï 91% typically |
| Density | Lead-based are ca. 5 g/cm$^3$. This offers advantages and disadvantages | 1 ï 1.2 |
| Water absorption | Zero (so moisture has no effect on performance) | All plastics absorb water causing changes to properties (as they swell) and also potentially degradation can occur. From 0.01% to 0.3% |
| Thermal expansion | CTE(-30°C;+70°C) = 5.1 - 11.9 x $10^{-6}$ /K | Range is 47 to 80 x $10^{-6}$/K. This causes optical changes with temperature and thermal degradation |
| Refractive index thermal dependence | Smaller range of - 0.7 to + 1.2 $10^{-5}$/ȩC | -8 to -14 $10^{-5}$/ȩC |
| Resistance to damage | Relatively hard so not easily damaged. | Soft so easily scratched |
| Exposure to UV light | No effect | Organic pigments fade and plastic discolours and degrades |
| Heat | Resistant to temperatures created by lamps and laser light sources | Lamps and lasers can easily cause deformation or even make holes |

**Lead**

Only one type of filter glass is currently produced that contains lead and is used because of its unique combination of properties. Research has not identified an alternative material with the same combination of essential properties.

**(B) Please provide information and data to establish reliability of possible substitutes of application and of RoHS materials in application**

Reliability is not an issue for this exemption, which is required because no alternatives provide all of the essential characteristics

**7. Proposed actions to develop possible substitutes**

**(A) Please provide information if actions have been taken to develop further possible alternatives for the application or alternatives for RoHS substances in the application.**

Research has been carried out for many decades and alternatives to cadmium and lead are already used where these are suitable. Combinations of all of the elements in the periodic table have been evaluated and only cadmium gives all of the essential characteristics for the applications where these filters are used. The only possible alternatives would be completely different designs of optical equipment but so far, alternatives have not been developed for the applications described in this renewal request and other applications. It is also not possible to envisage alternative designs so research timescales cannot be planned. Therefore, no substitutes are likely to be developed in the foreseeable future and so the maximum validity period is required for this exemption.

**(B) Please elaborate what stages are necessary for establishment of possible substitute and respective timeframe needed for completion of such stages.**
See 7 (A) above

**8. Justification according to Article 5(1)(a):**
**(A) Links to REACH: (substance + substitute)**

1) Do any of the following provisions apply to the application described under (A) and (C)?

- Authorisation **No**
- SVHC **No***
- Candidate list **No**
- Proposal inclusion Annex XIV **No**
- Annex XIV **No**
- Restriction **No**
- Annex XVII **No**
- Registry of intentions **No**
- Registration **Not applicable to articles**

* When cadmium compounds are added to optical glass to produce an optical filter, very small dispersed particles form in the glass matrix. The exact composition of the dispersed particles is uncertain as chemical analysis of these very small particles is very difficult. However, there is evidence that these contain, for example, cadmium, sulphur and other elements, such as zinc from the glass matrix[1] To achieve a ñsteep edgeò the dispersed particles are most likely to be a type of semiconductor and as such will not have an exact stoichiometric chemical formula of ñCdSò.

2) Provide REACH-relevant information received through the supply chain.
Note that REACH includes obligations on cadmium in certain types of plastics, coatings and braze alloys but there are no restrictions on its use in glass. Several cadmium compounds are SVHCs but none of these are present in optical glass filters.

**(B) Elimination/substitution:**

1. Can the substance named under 4.(A)1 be eliminated?
   - Yes. Consequences? See below
   - No. Justification: - See below
   - Performance and characteristics would be significantly inferior if cadmium-free filters were to be used. The examples explained elsewhere in this document illustrate why substitution is not possible:

2. Can the substance named under 4.(A)1 be substituted?
   Yes.
   - Design changes:
   - Other materials: See answer to Q6A
   - Other substance: See answer to Q6A

   No.

Justification: Reasons explained in answer to previous questions.

3. Give details on the reliability of substitutes (technical data + information): Not applicable

4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to

1) Environmental impacts: Airport runway lighting where colour is unaffected by environmental conditions
2) Health impacts:
3) Consumer safety impacts:

 Do impacts of substitution outweigh benefits thereof?

Not applicable as these are not reasons for needing this exemption. However, not allowing this exemption would negatively affect all three, for example:

1) Environmental impacts: Unable to analyse for environmental pollutants.

2) Health impacts: Medical research would be much more difficult or impossible without fluorescence microscopes and other instruments that use these filters.

3) Consumer safety impacts: Facility security survey at night time without dazzling observer (by use of near infrared imaging). Some types of speed enforcement cameras use these filters.

Please provide third-party verified assessment on this: Not applicable.

**(C) Availability of substitutes:** None with suitable performance are available, as explained above.

a) Describe supply sources for substitutes: None exist
b) Have you encountered problems with the availability? Describe: None exist
c) Do you consider the price of the substitute to be a problem for the availability? No
d) What conditions need to be fulfilled to ensure the availability? Not known at present

**(D) Socio-economic impact of substitution:** Not applicable for this exemption renewal request

 What kind of economic effects do you consider related to substitution?

Increase in direct production costs -
Increase in fixed costs -
Increase in overhead
Possible social impacts within the EU
Possible social impacts external to the EU
Other:

**9. Other relevant information**

**Please provide additional relevant information to further establish the necessity of your request:**

None

**10. Information that should be regarded as proprietary**

**Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:**
None