Questionnaire 1 (Clarification) Exemption No. 4(f) of RoHS Annex III

Current wording of the requested exemption:

Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex

Requested validity period: 5 years

Acronyms and Definitions

UV	Ultra Violet
UV Hg	Ultraviolet radiation spectrum of UV Hg medium-pressure or low-pressure gas discharge lamps; for differentiation in the text, as the spectra between gas discharge lamps and LEDs differ fundamentally, UV Hg provides a broadband spectrum with several peaks or in case of UV Hg medium pressure lamps a significant Peak at 254 nm
UVx LED	Ultraviolet radiation spectrum of UV LEDs, to distinguish them from UV Hg, as the spectra have completely different characteristics (quasi monochrome and narrowband) to those of gas discharge lamps. (x stands for: A, B or C)
LED	Light-emitting diode
Hg	Mercury
DVGW	Deutscher Verein des Gas- und Wasserfaches e. V. – technisch-wissenschaftlicher Verein; German Technical and Scientific Association for Gas and Water (DVGW)

1. Background

Bio Innovation Service, UNITAR and Fraunhofer IZM have been appointed [1]by the European Commission through for the evaluation of applications for the review of requests for new exemptions and the renewal of exemptions currently listed in Annexes III and IV of the RoHS Directive 2011/65/EU.

VDMA e.V. submitted a request for the renewal of the above-mentioned exemption, which has been subject to a first review. As a result we have identified that there is some information missing. Against this background, the questions below are intended to clarify aspects concerning the request at hand.

We ask you to kindly answer the below questions until 9 February 2021 latest.

[1] It is implemented through the specific contract 070201/2020/832829/ENV.B.3 under the Framework contract ENV.B.3/FRA/2019/0017

2. Questions

1. Could you state the assumptions used to make the rough estimate of the quantity of mercury placed on the EU market for disinfection purposes?

In our application, we estimated the amount used annually for UV Hg gas discharge lamps for disinfection at less than 100 kg. This is based on the following assumptions:

We have taken basic data from the market study "UV LEDs - Technology, Manufacturing and Application Trends 2016 Report by Yole Developpement":

Forecast market volume mercury-containing UV Hg lamps 2021:	915.3 million US$
Market share disinfection:	27%
Share of UV Hg medium pressure lamps in disinfection:	63.5%.
Market share Europe:	21%

Further assumptions:

average price of a UV Hg medium pressure lamp:	275 US$
average content of mercury in UV Hg medium pressure lamps:	0.5 g

This results in a calculated market volume of approx. US$ 33 million for UV Hg medium pressure lamps in the disinfection sector in Europe. Based on the average price, one can infer an approximate quantity of 120,000 UV Hg medium pressure lamps that are marketed annually for disinfection applications in Europe. With an average of 0.5 g per lamp, this results in a total of 60 kg mercury for UV Hg medium pressure lamps in the disinfection sector. No calculation could be made for UV Hg low pressure lamps. The amount of mercury in these lamps is lower and it was therefore concluded on the basis of the lamp manufacturers' estimates that the amount of mercury for the disinfection sector is less than 100 kg.

From your application, information about the use of UV disinfection in German drinking water production facilities seems available, what share of the German drinking water production does it represent?

UV Hg disinfection systems have been in use in public drinking water supply since the end of the 1990s. According to a DVGW survey on the water regulations from 2008[2] , in which the basic data on water production and treatment were collected, around 50 % of 954 water supply companies surveyed disinfect the drinking water to be supplied. Disinfection with UV Hg light is the most frequently used method for disinfecting drinking water (42 %) compared to disinfection with chlorine dioxide, chlorine/hypochlorite or ozone. Especially smaller drinking water suppliers with a turnover volume of up to 3 million m^3/a prefer disinfection with UV Hg light.

[2] Niehues, B., DVGW survey Regelwerk Wasser - Ergebnisse der Umfrage aus 2008. DVGW energie I wasser-praxis 3/2009.

Only UV Hg medium-pressure or low-pressure lamps are used. UVC LEDs cannot be used due to the very poor radiation yield and the large amounts of water and cannot be approved due to the lack of test specifications (see answer to question 5).

In recent years, the share of UV Hg disinfection in the disinfection processes used has increased significantly, so that it can be assumed that this share is now well over 50 % of the drinking water to be continuously disinfected at the waterworks outlet.

2. You state that the "*recovery rate of mercury in used lamps is high*"

   a. How high is it when lamps are indeed collected?

   b. What is the overall recycling rate of mercury when considering uncollected lamps?

This question can only be answered qualitatively as there are no data collected specifically for lamps falling in exemption 4(f).

The term "recovery" in case of mercury is probably not adequate. Because mercury is a hazardous substance, there is a clear political will to reduce the available amount and not necessarily to recycle it in the sense of a circular economy. Therefore, the correct disposal of mercury containing fractions after collection of lamps and recycling of the other lamp materials is one way of collection and treatment. Another way of some recyclers is to distil mercury from waste fractions, usually fractions of different nature, not only lamps. In this case mercury is made available again for other uses as far as allowed in the EU.

UV Hg lamps falling under exemption 4(f) are used by commercial or public legal entities but not by private households. They are legally obliged to dispose of the lamps separately from household waste. Due to the WEEE legislation, the take back and recycling of lamps is free of charge in the EU for the users, illegal disposal by them would lead to high financial and non-financial risks for the user but not create any benefit. This is the basis of our assumption that UV Hg low-pressure and medium-pressure gas discharge lamps from the industrial and public sectors are collected and transferred to recycling companies to a very large extent.

Joint collection systems have been set up in European countries for end-of-life lamps e.g. in Germany organized by Lightcycle (www.lightcycle.de). Many of these systems are organized in Eucolight (https://www.eucolight.org/our-members), the European association of collection and recycling organisations for WEEE lamps and lighting. These systems established in all EU Member States ensure that UV Hg lamps like other discharge lamps are taken back and collected correctly and afterwards treated and recycled by qualified and certified recycling companies. Eucolight has recently announced that they have taken back and recycled 2 billion lamps.[3]

In practice, it is possible to extract almost 100% of the mercury from UV Hg low-pressure and medium-pressure gas discharge lamps by using established treatment processes and to make it available again for new products with a high degree of purity or to dispose it of in a long-term and secure way.

---

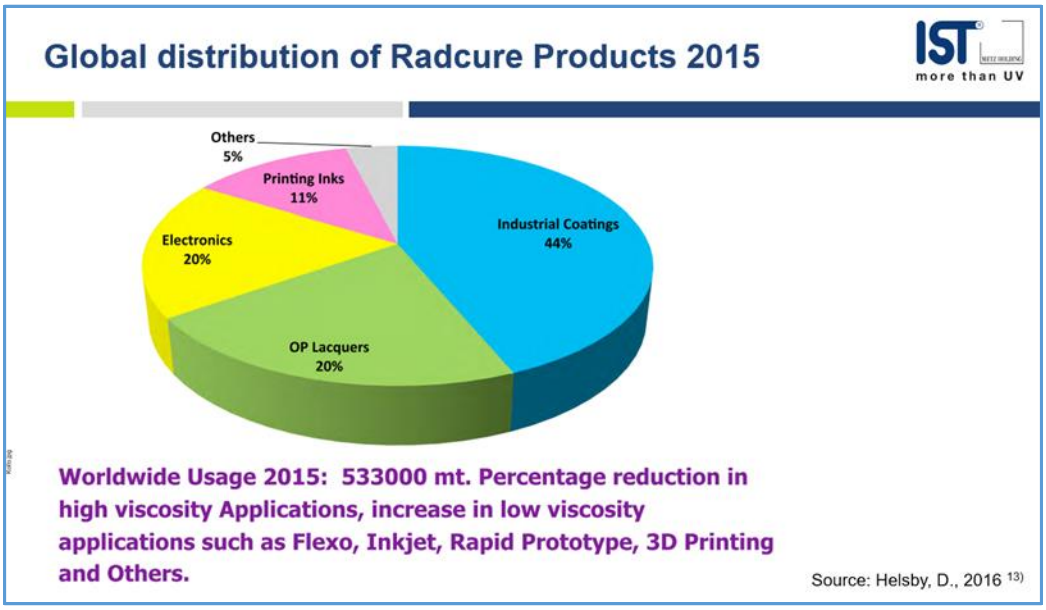
[3] https://www.eucolight.org/webinar-2-billion-lamps-recycled

3. From our understanding of your statements concerning the printing sector, there are applications for UVA LEDs which means that for that specific application, there is no need for medium pressure Hg lamps.

   a. What are the benefits of using UVC curing inks compared to that of the UVA ones, and why can UVC curing inks not be substituted with UVA ones?

There are a whole range of advantages that make the use of UVC indispensable in the curing of ink and coating layers. These include the high energy density, which enables fast and reliable curing of the layers.

The drying of (non-pigmented) varnishes is a widespread and, in terms of quantity, the most important application. Market data describe a share of 84% for UV coatings from the industrial coatings, overprint laquers and electronics sectors. The actual ink segment, and thus the potential for UV LED, accounts for only approx. 11%.



Especially with industrial coatings and overprint laquers UV Hg mercury discharge lamps, due to the UVC radiation, show clear advantages for cross-linking and the associated quality. These are.

- No to minimal yellowing of the coating layer;
- Best curing of the surface due to UVC Hg;
- Highest mechanical and chemical resistance (e.g. in industrial printing in the field of wood and floor decoration, protective films...);
- High safety for food contact materials (FCM), by reducing migration (e.g. food and cosmetic packaging);
- Possibility of UVC Hg direct cross-linking with elimination/reduction of photoinitiators.

As described in our request, UVA LED applications are especially found in commercial printing with the process colors Black, Cyan, Magenta and Yellow. In contrast, in packaging printing the use of varnishes and special inks is standard. The comprehensive requirements (see list above) for packaging production are today met by classic UV Hg inks in connection with UV Hg drying technology.

The range of UV LED inks is generally not as comprehensive and stable as with classic UV Hg inks. Due to the specialisation on only one wavelength range (UVA), not many photoinitiators can be used. The photoinitiators are very special and are not nearly as well researched as the photoinitiators for UVC. The UV Hg inks are established on the market and the ink formulations are stable. There is a much wider choice of special inks and varnishes with UV Hg curing with UV Hg discharge lamps. For this reason, UV Hg lamp technology offers the highest process variability and safety.

In the UVA area, there were and are presumably further restrictions on photoinitiators, some of which are disappearing from the market as a result of regulation (reclassification). In addition, there is a shortage of alternative UV LED curing photoinitiators.

The application of UVA LED inks also requires more technical effort, as sunlight can already cause the ink to harden (sunlight contains mainly UVA, hardly any UVB - approx. 10%, no UVC share).

A large future-oriented industrial sector is the printing of functional layers. Among other things, this involves the printing of conductive tracks and sensors. Here, high layer thicknesses of conductive pastes are transferred directly onto components and substrates that can only be cured with a high dose of UVC. Therefore, only UV Hg gas discharge lamps can be used here. Areas of application are found in the automotive sector, for example.

b. You state that multi-pass technology allows for the use of UVA curing inks and so UVA LEDs. What justifies the use of single-pass technology that requires the use of medium pressure Hg lamps?

Multi-pass and single-pass technology are two different processes in digital inkjet printing, which have different applications.

Multi-pass technology uses a traversing print head in which the UV LED dryer module is integrated. The feed of the substrate is slow (typically < 1 m/min) and discontinuous. While the print module moves sideways, several lines are printed. The print head prints all colours simultaneously. However, the UV LED lamp irradiates a larger area than the current printed area in the feed direction. This means that the area printed in the previous step is irradiated again when the following area are printed. The UV LED lamp therefore irradiates the same area several times. This increases the radiation dose, which is crucial for curing. That's why UVA LED dryer modules are sufficient. However, due to the low printing speed caused by the technology, only individual copies or small quantities can be printed with this technology. This is used, for example, in outdoor advertising or for printing single posters and small print runs. The advantage of multi-pass technology is the possibility of very large print widths, printing on rigid materials and fabrics and the technical effort (use of small print heads) is not so high.

The single-pass process works at higher speeds (typically 15 – 270 m/min, depending on the quality). The print heads are fixed, extend across the entire substrate width or they are cascaded. The individual inks are applied via print modules arranged separately one behind the other. By means of an intermediate drying process called pinning, UVA LED dryers fix the individual colours but do not dry them through. This influences also the flow behaviour of the ink droplets. Due to the high feeding speed and the amount of ink on the substrate, a high radiation dose is required for final curing. Since the irradiation time is very short, only conventional UV dryers based on Hg medium-pressure discharge lamps can be used here.

Although in other printing processes (e.g.: web and sheetfed offset printing) in combination with UV Hg drying it is theoretically also a single-pass process, this term is only used in relation to digital printing. The use of a multi-pass process is technically not possible in other printing processes due to the high printing speeds (typically speeds: Sheetfed offset: 1,5 .. 3,6 m/s, flexo press/ web offset: 6 .. 15 m/s).

c. If single-pass technology is an older technology than multi-pass, what is its market size compared to that of multi-pass and what is its life expectancy?

As already described above, both processes exist side by side and are also used in completely different applications due to the extremely different feeding speed. In this respect, it is not possible to determine a market share. The statistics also do not differentiate between the two processes in digital printing. However, the total area printed per year in single-pass processes is many times larger than in the multi-pass processes because the printing speeds are higher and the applications are more numerous.

4. Could you compare UVC LEDs, medium pressure Hg lamps and flash lamps in terms of Wall Plug Efficiency, Power output, life expectancy, cost and efficiency for their specific applications (disinfection efficiency for flash lamps and medium pressure Hg lamps, curing efficiency for UVC LEDs and medium pressure Hg lamps)?

Comparison of data for UV curing

The comparison must also take into account the desired properties of the end product, process-related requirements and the limitations of materials. When considering the substitution of mercury, the necessary and more reactive chemistry of UV LED inks should also be taken into account. A disposal problem certainly also arises from the use of LEDs.

	Hg Low Pressure		Hg Medium Pressure		UVC LED	
	From	To	From	To	From	To
UVC Wall Plug Efficiency / %	30	35	5	17	1	5
Output Power per UVC source / W	40	1000	1000	35000	0,01	0,4
Life Expectancy at full power / h	12000	16000	2000	10000	2500	5000
Cost per source / $	5	100	50	250	0,5	15
Cost per W UVC / $/W	$0,417	$0,286	$1,000	$0,042	$5.000,00	$750,00
Cost per µJ UVC / $/µJ	$0,010	$0,005	$0,139	$0,001	$555,556	$41,667

<u>Comparison of data for disinfection (wave range 240-280 nm)</u>

Both flash lamps and UV Hg gas discharge lamps have their use cases in the disinfection sector. Flash lamps have advantages, for example, in the sterilisation of cups for the food industry. UV LEDs are only used in a niche application (very low throughput) for disinfection and cannot be used industrially. The radiant efficacy of UVC LEDs is about 1-6% (see table). In comparison, low-pressure mercury lamps have an optical yield of over 30%-40%. To achieve a comparable optical yield with UV LEDs, the material effort would increase significantly and the electrical power requirement would rise fivefold due to the approx. 80% lower optical yield. From an ecological point of view, the current use of UVC LEDs on an industrial scale is therefore not sustainable and leads to increased energy and material consumption.

NOTE: The optical yield indicates how much electrical power is converted into radiant power at the desired wavelength. For disinfection the characteristic wavelength for or Hg low-pressure lamps is 253.4 nm. With an electrical lamp power of 370 W, Hg low-pressure lamps have an optical yield > 30% and thus approx. 120 W radiant power.

In addition, the service life of UVC LEDs for disinfection is much shorter than that of LEDs that emit in the visible range and is usually less than 5000 hours.

Especially from the Covid-19 point of view, the further availability of UV Hg medium-pressure and low-pressure lamps for air and surface disinfection is essential because of their high efficiency. This development of Covid-19 was not foreseeable at the time of the preparation of the elongation request.

	UVC LEDs	low pressure Hg lamps	medium pressure Hg lamps	flash lamps
Wall Plug Efficiency for UVC / %	1-6	30-40	10-20 (undoped)	2-4
Electrical power / W	0,1-10	4-1000	150-36.000	100 – 3000
Power output / W	0,001-0,3[c]	1,2-400	15-7.200	2 - 120
Life expectancy / h	< 5000	8000-16000	4000-8000	5 - 10 million flashes[d]
Cost (only lamp, chip)/ $	60 – 120 per Chip[a]	5 - 100	50 - 250	180[b]
Disinfection efficiency	not applicable[f]	99,99 % log 4[e]	99,99 % log 4[e]	99,9999% log 6[e]

a System costs for a 1000 W UV power system are estimated to be 40 times higher compared to a state-of-the-art system with UV Hg low pressure lamps

b Costs for Flash Systems are more than 5 times higher than systems with low pressure lamps

c LED package

d (corresponds to 1400 - 2800 hours at 1 Hz), 2-3 times shorter than low pressure lamps

e Factor of the germ reduction, log 4 means reduction from 100,000,000 to 10,000 microorganisms, at log 6 to 100

f not effective enough and economical for industrial use

5. You claim that the sensor technology used for monitoring the irradiance of UV lamps for disinfection "cannot be simply transferred to UV LED systems". Could you provide some clarification as to the reason why?

As already described in our request, UV Hg gas discharge lamps and UV LEDs have very different radiation spectra. UV Hg gas discharge lamps for disinfection produce a continuous spectrum (distribution over the entire spectrum from VUV to UVC) with several peaks in the range of 200 to 280 nm or emit - in case of UV Hg low-pressure lamps - a quasi-monochromatic line at 254 nm. UV LEDs, on the other hand, only radiate in quasi monochromatic narrow bands of the UV range. The peak wavelengths of the UVC LEDs available today are in the range of 260 to 280 nm.

The sensor technology for the UV Hg gas discharge lamps works with filters that filter the area of interest for disinfection accordingly. However, the sensor technology is not developed for the characteristics of the UV LEDs and corresponding wavelength ranges would not be detected correctly.

Drinking water disinfection systems are subject to approval by the authorities. In Germany, the approved treatment substances and disinfection processes are specified in § 11 of the Drinking Water Ordinance 2001. Currently, only UV systems based on UV Hg medium and low-pressure lamps are approved and must be certified. The requirements are laid down in the technical rule DVGW W 294[4], or in DIN 19294-1[5] , the requirements for measuring systems in DIN 19294-3[6] .

There is still no standard or technical rule that describes the requirements for UV LED systems for water disinfection and their measurement technology. Since UV LED modules consist of several individual chips, it is also unclear whether it is sufficient to monitor a assembly of several UV LEDs or whether each individual chip must be monitored. Since there is still no test specification for UV LED disinfection systems in Germany and other EU countries, this cannot be anchored in the ordinances like the Drinking Water Act and therefore the UV LED systems cannot be approved. A DVGW working group that has been commissioned with the topic of UV LED water disinfection has just been founded.

6. In your previous application, you also state that: "Shorter LED wavelengths are technically available in R+D, but are expensive and not powerful enough for the applications covered by this request." Have there been no improvements of LED technology over the last five years?

Due to the promising application possibilities, research is being conducted worldwide in various research clusters on the further development of UV LEDs with shorter wavelengths (especially in UVC range). The main driver here is the disinfection area. Researchers also refer to this as the Deep UV range (DUV)[7].

Progress has also been made in recent years with regard to efficiency and service life. Five years ago there were only prototypes, today UVC LEDs are available in small quantities. However, they are still not suitable for industrial use. Reasons are the significantly higher costs (see table in the answer of question 4), as well as the lower stability and service life, the latter also in connection with the total costs of an entire UV LED system.

A system for water disinfection today would cost 100 to 1000 times as much as a system based on UV Hg gas discharge lamps. The situation is similar for many applications in the UV curing sector. In addition, UVC LEDs are not commercially available in the wavelength range up to 250 nm.

We had also sought discussions with developers on the topic of developing deep UV LEDs at the end of 2019. The development of UVC LEDs is very challenging and there are physical limits. On the one hand, this concerns the semiconductor materials themselves,

---

[4] https://www.dvgw.de/medien/dvgw/wasser/aufbereitung/dvgw-information-uv-desinfektion.pdf

[5] DIN 19294-1:2020-08: Devices for the disinfection of water using ultraviolet radiation - Part 1: Devices equipped with UV low pressure lamps - Requirements and testing

[6] DIN 19294-3:2020-08: Devices for the disinfection of water using ultraviolet radiation - Part 3: Reference radiometers for devices equipped with UV low pressure lamps - Requirements and testing

[7] https://compoundsemiconductor.net/article/112266/The_Evolution_Of_The_Deep-UV_LED/feature

and on the other, the optics combined with them, which become blind over time due to the UVC light.

The most promising semiconductor material is aluminium gallium nitride. Despite progress in development, the external quantum efficiency (EQE) under laboratory conditions is currently only 20% and the wall plug efficiency (WPE) only about 10% for the wavelength range above 250 nm. See publications on this topic. Quotation::" *AlGaN-based deep ultraviolet light-emitting diodes (DUV LEDs) offer great potential to replace mercury discharge lamps in various applications, including sterilization, water purification, medical diagnostics, phototherapy, and UV curing [1]–[3]. Currently, however, the performance of the devices is still poor…"* [8][9]

Generally, the shorter the wavelength, the greater the development challenges. In the UVB range, development is at least 5 years behind.

7. You argue that lamps covered by exemption 4(f) are required as spare parts to replace lamps in products placed and still made available on the market. RoHS Art. 4(4)(f), however, ensures that spare parts remain available even after the expiry of exemptions.

   Do you agree to our interpretation of the above-mentioned article, or do you see specific circumstances or conditions where Art. 4(4)(f) might not guarantee the availability of lamps with mercury in case exemption 4(f) would not be renewed?

As these lamps play a very specific role in the supply of our food, our drinking water and the production of many products that our society needs, and there are no alternatives for these lamps, the exemption in RoHS is needed, not only for existing but also for new equipment.

We can agree with that interpretation that these lamps are also needed as spare parts.

In our request we only wanted to emphasise once again that a supply of spare parts is necessary in the long term for UV Hg systems used in industry, as these are long-lasting assets with a very long life time. Taking them out of service before they have reached the end of their useful life is not justifiable either from an economic or an environmental point of view.

But we also want to reiterate that the applications where 4(f) lamps are used are still needed and will be required in the long-term, as alternatives are not mature or available.

8. Looking at the uses of the UV mercury lamps, we wonder whether the devices are large scale fixed installations (LSFI) or large-scale stationary industrial tools (LSI) which would be

[8] H. K. Cho et al., "Enhanced Wall Plug Efficiency of AlGaN-Based Deep-UV LEDs Using Mo/Al as p-Contact," in IEEE Photonics Technology Letters, vol. 32, no. 14, pp. 891-894, 15 July15, 2020, doi: 10.1109/LPT.2020.3003164. https://ieeexplore.ieee.org/document/9119464/metrics#metrics

[9] Kneissl, M., Seong, TY., Han, J. et al. The emergence and prospects of deep-ultraviolet light-emitting diode technologies. Nat. Photonics 13, 233-244 (2019). https://doi.org/10.1038/s41566-019-0359-9

excluded from the scope of the RoHS Directive so that exemption 4(f) might not be needed. Could you please comment?

This is true for a whole range of machines. However, UV Hg systems are not only installed in large printing machines and supplied from a single source. Existing printing machines are also retrofitted with UV Hg dryers.

There are also smaller equipment for special applications (e.g. label printing machines, equipment for decoration of promotional items) and laboratory equipment (e.g. for the development of UV-curable materials).

There are also smaller installations in the disinfection sector that are not LSFI and LSI. Examples are mobile systems for hospital disinfection and systems for air disinfection. There is also an increased need for small or mobile disinfection systems from a Covid-19 point of view. The effectiveness of UVC radiation in eliminating germs, bacteria and viruses (including coronaviruses) has been proven. Accordingly, the demand for disinfection systems for air and surface disinfection is increasing. To ensure effective disinfection, the use of medium- and low-pressure lamps is essential in this area.

Examples for smaller equipment:

UV Hg laboratory equipment for testing inks, varnishes and adhesives; weight: 170 kg, Example of size: 120 x 97 x 76 cm, Source: IST Metz

Belt dryer, continuous table-top device for rapid curing of UV Hg inks, UV coatings and UV adhesives in the small-format printing sector for testing or production on flat material and moulded parts, Example of size: (L×H×W) 105 x 40 x 50 cm, appr. 45 kg

UV Air disinfection; Dimensions (L×H×W): 998mm x 685mm x 197mm, appr. 35 kg, UVC Hg low pressure lamp; Source: Heraeus

UV Chamber for disinfecting objects (surface disinfection)., Example of size: (L × H × W) 651 mm × 437 mm × 320 mm, appr. 26 kg, contain 4 UVC Hg low pressure lamps, Source: Heraeus

Air disinfection devices; Source Dr. Hönle AG

Please note that answers to these questions will be published as part of the evaluation of this request. If your answers contain confidential information, please provide a version that can be made public along with a confidential version, in which proprietary information is clearly marked.

It would be helpful if you could kindly provide the information in formats that allow copying text, figures and tables to be included into the review report.