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

Current wording of the exemption:

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

Requested validity period: Maximum (5 years and 7 years (cat. 8 and 9) respectively)

ACRONYMS AND DEFINITIONS

UV	Ultra Violet
LED	Light-Emitting-Diode
Hg	Mercury
LEU	LightingEurope

1. INTRODUCTION

1.1. 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 and Lighting Europe submitted requests[2] for the renewal of the above-mentioned exemption. The request has been subject to a first completeness and plausibility check. The applicant has been requested to answer additional questions and to provide additional information, available on the request webpage of the stakeholder consultation[3].

The stakeholder consultation is part of the review process for the request at hand. The objective of this consultation and the review process is to collect and to evaluate information and evidence according to the criteria listed in Art. 5(1)(a) of Directive 2011/65/EU.[4]

To contribute to this stakeholder consultation, please answer the below questions until the 27th of May 2021.

[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] Exemption request available at [RoHS Annex III exemption evaluation - Stakeholder consultation (biois.eu)]

[3] Clarification questionnaire available at [RoHS Annex III exemption evaluation - Stakeholder consultation (biois.eu)]

[4] Directive 2011/65/EU (RoHS) available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32011L0065:EN:NOT

1.2. Summary of the Exemption Request

According to VDMA: "*The application for prolongation of the existing exemption refers to mercury-containing UV discharge lamps which are used for curing (e.g. of layers of inks and coatings, adhesives and sealants), for disinfection (e.g. of water, surfaces and air) and for other industrial applications (surface modification, surface activation) The application includes the following lamp types:*

- ***UV medium-pressure discharge lamps (MPL) for curing, disinfection and other industrial applications** (internal operating pressure > 100 mbar). The UV medium-pressure lamps can be doped with iron, gallium or lead in addition to the mercury they contain.*
- ***UV low-pressure discharge lamps for special purposes** in the high power range. […]*

Typical applications to be covered by this application include curing, e.g. of inks and coatings, disinfection of water etc., and other industrial applications like surface activation and cleaning.

It is technically not possible to replace mercury in special UV lamps with other materials/chemicals in order to achieve the same widespread radiation distribution. LED-based technologies are increasingly being used, which in certain applications (e.g. curing) also offer many advantages over mercury-containing UV lamps. Nevertheless, LED technologies cannot be used as an equivalent replacement in many applications. "

According to LightingEurope, *"[…]* The renewal application concerns lamps and UV light sources defined as:

- High Pressure Sodium (vapour) lamps (HPS) for horticulture lighting,
- Medium and high-pressure UV lamps for curing, disinfection of water and surfaces, day simulation for zoo animals, etc…
- Short-arc Hg lamps for projection, studio, stage lighting, microlithography for semiconductor production, etc…

Replacement of mercury and mercury containing lamps is impracticable:

- *The lamps covered by exemption 4(f) must remain available on the EU market:*
  - *For new equipment for certain applications where no functionally suitable alternatives are available*
  - *As spare parts for in-use equipment as replacing end-of-life lamps avoids having equipment become electronic waste before due time"*

2. QUESTIONS

1. VDMA and LightingEurope[2] requested the renewal of the above exemption for the maximum validity periods with the same scope and wording for all EEE of cat. 3 and 5 (VDMA) and cat. 1-10 (LEU).

   a. Please let us know whether you support or disagree with the wording, scope and requested duration of the exemption. To support your views, please provide detailed technical argumentation / evidence in line with the criteria4 in Art. 5(1)(a).

In recognition of the breadth and importance of UV-C emitter applications, and that the current state-of-the-art in solid state emitters does not facilitate economically and technologically equivalent solutions, we support the application for continued exemption. At present, device performance limits the substitution of UV-C LEDs for 4(f)-type UV lamps in most, but not all, applications.

However, we disagree with the specifics of the applications on numerous points, including the technical accuracy of the data presented in the initial submissions and the Clarification Questionnaire provided by VDMA. What is deeply troubling, is the presentation of an outdated view of the UV-C LED technology and market.

UV-C LED technology is advancing rapidly, exceeding analogous development of solid-state visible lighting (see Haitz's Law). As such, a request for exemption at the maximum validity term (5 years) is out of alignment with the reality of this development (~10x increase in single-chip output power 2015 – 2020) and will result in a delayed transition to mercury-free alternatives.

b. If applicable, please suggest an alternative wording and duration and explain your proposal.

With specific reference to the application by VDMA:

- The comment on page 6 that "*emitted wavelengths do not exactly match the absorption spectrum of UV-reactive chemistry*" is not well founded. UV-LEDs offer a more targeted spectral emission than mercury-based lamps and can therefore be used to *increase* the reaction efficiency of a process by selective emission at photochemical maxima (see analogous application of red/blue LED combinations in indoor horticulture). The broadband emission of medium pressure Hg lamps (in particular) can result in 'wasted' radiation outside of the spectral target,
- The claim of 'short service life' as a limiting factor for UV-C LEDs is factually inaccurate. Many UV-LED devices have been shown to achieve operating lifetimes (L70) in excess of 10,000 hours under real-world operating conditions. Further, the functional lifetime of these devices is substantially longer and replacement intervals are often extended, since:
  - LEDs display an instant-on-at-full-power characteristic, and thus it is possible operate the LED only when needed instead. This is contrasted against a 4 switches-per-day limit as is common with mercury lamps in order to maintain electrode health,
  - Catastrophic failure of UV-C LEDs is rare; instead, these devices exhibit a predictable and gradual decay in output power, allowing for 'smart' operation.
- The current market for UV-C LEDs and UV-C LED systems for water disinfection applications is misrepresented as 'early stage' and 'limited'. It has been more than a decade since the first UV-C LED water disinfection system was launched, and production in 2021 will exceed 1 Million UV-C LED systems (equating to tens of millions of UV-C LED devices), most of which are used in mass production consumer and commercial applications that demand high levels of reliability and competitive pricing.

With specific reference to the application by Lighting Europe:

- In the discussion of "Lamps for UV disinfection applications", page 56, the application describes UV-C LEDs in the germicidal range as "R&D prototypes"—this is a gross misrepresentation of the current state of the market as noted above.
- In the same section, the application simplifies the discussion to a singular question of electrical efficiency, and whereas this is an important consideration it does not represent a complete analysis of the viability of UV-C LEDs as alternatives to mercury-based lamps.

- An exemplary illustration of the lack of awareness of UV-C LED capabilities in this application is the sentiment "*UVC LED technology might suit small consumer applications like toothbrush disinfection containers, their efficiency/performance to milli Watt ratio is far too low to provide the high-power and high turnover demanded by the professional market*", which may be contrasted against the work of companies such as Typhon Treatment Systems Ltd. (UK), who recently presented a validation of their system to the US EPA UVDGM performance standard for municipal water treatment. MetaWater (Japan) have also demonstrated full-scale municipal treatment, and AquiSense Technologies LLC (USA) have planned installations of multiple municipal drinking water systems for legionella control.
- The reference provided for the views in this section is of a 2018 industry meeting, based on data collected in 2017; as such, the application does not give a contemporary perspective of germicidal UV-C LED state-of-the-art. A more recent publication provides a better reference: https://doi.org/10.1088/1361-6463/aba64c
- With regards to the "*Applications with alternative technology*" section of page 60, the sentiment that UV-C LEDs are developing more slowly than analogous visible technology is demonstrably false.
- The application makes a vague statement on 10+ years to market maturity that cannot be directly challenged due to a lack of a sufficient metric. The reality is that many major European companies within the beverage, pharmaceutical, and transportation markets are well advanced on the launch of UV-C LED products that displace mercury lamp technology.

With specific reference to the Clarification Questionnaire provided by VDMA:

- On numerous counts, the tables of Question 4 misrepresent the current state-of-the-art in UV-C LEDs. A probable cause is that these data were collected from an outdated review of this fast-moving technology, instead representing the technology as it was ~2015 or earlier,
- As noted in the open letter provided in Section 5 of this response, discussion of the viability in terms of wall-plug efficiency is not a reasonable approach. Consider the example of a cylindrical mercury-containing lamp which emits radiation radially from its axis—in the case of surface disinfection, at least 50% of the light is naturally directed away from the target and must be recovered by reflectors. However, a UV-C LED source has high directionality and can be arranged such that near 100% of its emission would impact a disinfection target without the need for reflectors or beam shaping optics,
- The statements on pages 7 and 8 regarding operational lifetimes are outdated and incorrect. Commercially available UV-C LEDs (individual manufacturer volumes 100,000 - 10,000,000 pa) routinely expect lifetimes in excess of 10,000 hours when operated according to recommended conditions. A distinction must also be drawn between lifetime as 'time to replacement' and 'operating lifetime', since unlike Hg-lamps LEDs may be power cycled without causing excess wear. This means that LEDs need only be powered when the process is operational, resulting in potential energy savings and elongated replacement intervals,
- The \$60 - \$120 pricing of UV-C LED is possibly taken from single-unit pricing available online, and is not representative of volume production pricing as would be employed by any industrial system manufacturer. Volume manufacturing pricing of UV-C LED devices in the range of \$0.75 to \$25 depending on the LED device specification,
- Commercial UV-C LED systems have been demonstrated to achieve 'disinfection efficiencies' in excess of 99.99%, comparable to conventional Hg-lamp systems.
- With regards to the response to Question 5, the specific limitations highlighted apply to the German standard, but are not representative of developments made worldwide to adapt validation methods to accommodate new technologies such as UV-C LEDs.

- In the response to Question 6, no justification is made for the statement "*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 simple fact that millions of UV-C LED based treatment systems have been deployed into a variety of applications is evidence that this statement is false. The signatories of this response contest the analysis presented by VDMA in their response.

Based on the above citation of inaccurate data on both the current state-of-the-art and the pace of development of UV-C LED technology, we recommend that the exemption extension period be 3 years, rather than the maximum 5 years of the present application. This reduction would allow for timely review of the expected developments in coming years, and stakeholder preparation for the coming transition from mercury-based UV lamps.

2. Please provide information concerning possible substitutes or elimination possibilities at present or in the future so that the requested exemption could be restricted or revoked.

   a. Please explain substitution and elimination possibilities and for which part of the applications in the scope of the requested exemption they are relevant.

   b. Please provide information as to research to find alternatives that do not rely on the exemption under review (substitution or elimination), and which may cover part or all of the applications in the scope of the exemption request.

   c. Please provide a roadmap of such on-going substitution/elimination and research (phases that are to be carried out), detailing the current status as well as the estimated time needed for further stages.

See Amano *et al.* (2020) *The 2020 UV emitter roadmap* (**https://iopscience.iop.org/article/10.1088/1361-6463/aba64c**) for detailed discussion on the technological challenges and strategies by which they may be overcome.

3. Do you know of other manufacturers producing devices of comparable features and performance like the ones in the scope of this exemption request that do not depend on RoHS-restricted substances, or use smaller amounts of these substances compared to the applications in the scope of this exemption?

The joint authors of this statement engage in both the active research and the manufacture of various components of, and whole systems, that may offer viable alternatives to the articles of the present application for exemption that do not depend on RoHS-restricted substances. Whereas the devices available today are not sufficient to cover all applications of the mercury-containing UV lamps, devices for some such applications are already in production.

4. As part of the evaluation, socio-economic impacts shall also be compiled and evaluated. For this purpose, if you have information on socioeconomic aspects, please provide details in respect of the following:

   a. What are the volumes of EEE in the scope of the requested exemptions which are placed on the market per year?

b. What are the volumes of additional waste to be generated should the requested exemption not be renewed or not be renewed for the requested duration?

c. What are estimated impacts on employment in total, in the EU and outside the EU, should the requested exemption not be renewed or be renewed for less than the re-quested time period? Please detail the main sectors in which possible impacts are expected – manufacturers of equipment in the scope of the exemption, suppliers, re-tail, users of MRI devices, etc.

d. Please estimate additional costs associated should the requested exemption not be renewed, and how this is divided between various sectors (e.g. private, public, industry: manufacturers, suppliers, retailers).

5. Any additional information which you would like to provide?

The signatories wish to promote the open and factual discussion of mercury-containing and mercury-free UV lamps, and are willing to contribute their knowledge of the state-of-the-art in UV-C LED technologies and their applications to inform evidence-led policy decisions.

Open letter:

UV-C LED and UV-C LED System Manufacturers' Perspective on Exemptions for Mercury-Containing UV Lamps

Due to its many health and environmental effects, the control of use and emission of mercury requires global coordination across public and private sectors. Several initiatives exist to reduce mercury emissions, including the restriction of its use except for important applications where no viable alternative exists; such restrictions and exemptions must be applied in a responsible manner based on state-of-the-art knowledge. Ultraviolet-C (UV-C) emitters (lamps) are one such important application of mercury where exemptions are currently granted; UV-C emitters are covered by exemptions 4(a) and 4(f) within the EU RoHS Directive 2011/65/EU.

UV-C LEDs generate UV photons via the electroluminescence of a semiconductor crystal; these semiconductors crystals are most commonly formed of AlGaN compounds, grown on sapphire or AlN substrates. These solid-state devices have no mercury content and do not depend on other substances subject to environmental restrictions; as such, they may offer an alternative to conventional mercury-containing UV lamps. The signatories of this response are an *ad hoc* group of UV-C LED and UV-C LED system manufacturers; we are keen to see accurate representation of the current state-of-the-art in this technology, particularly in the application of evidence-led policy decisions.

Several technical and economic considerations mean that UV-C LEDs cannot replace UV lamps in all use cases. Due to the importance of UV technology in applications such as water disinfection, chemical production, and curing, exemptions for mercury containing lamps should continue where UV-C LEDs cannot reasonably be applied. However, it should be noted that certain applications have already seen open-market competitiveness of UV-C LED systems due to numerous other considerations beyond mercury content, even in consideration of the relatively lower electrical efficiency of current devices. The rapid pace of advancement in UV-C LED technology, along with strong market pressures for their use, provide a driver for the regular review of the necessity for such exemptions; we believe that a broad 5-year extension of current exemptions is not justifiable.

The development of UV-C LED emitters is played out openly within the industry, with a blend of academic publications and press releases from device manufacturers; however, the rapid pace of development and the conflict between terminology of these two stakeholder groups can lead to some confusion about the current state-of-the-art. Even highly regarded publications such as *The 2020 UV emitter roadmap* (https://doi.org/10.1088/1361-6463/aba64c) cannot capture the full complexity of what is available on the market today. This complexity leads to a misunderstanding of the technology readiness of UV-C LEDs, and a persistence that the idea that most applications are in research and prototype stages. This is not a true representation.

Alongside confusion over the current state of UV-C LEDs is the misrepresentation of integration considerations, and the misapplication of design performance metrics. The common argument runs that UV-C LEDs cannot operate at the output power and electrical efficiency required for practical applications. Whereas it is true that UV-C LEDs will not compete on electrical efficiency for some years, such an argument misses the point of how a fundamentally different technology may be applied differently to the incumbent. For instance, the output power of UV-C LEDs is currently within the 10 – 200 mW range (per device); however, as low-voltage DC-powered units they may be easily arrayed in series and parallel to form high power-density structures, meeting or exceeding equivalent mercury-based lamp outputs. The argument of electrical efficiency (W UV power out per W electrical power in) disregards the fate of UV photons after generation, assuming the same design efficiency of an LED-based system as the conventional Hg-based equivalent. The discrete nature of UV-C LEDs as a radiation source means that they can be arrayed into numerous form factors to maximise the delivery of photons to the target; though the efficiency of photon generation may be lower, the efficiency of photon use may be higher. As such, the comparison of these two technologies cannot be trivialised to a single discussion of electrical efficiency (commonly termed wall-plug efficiency).

Numerous other factors such as power conversion, non-continuous operation, wavelength selectivity, and thermal management also affect the relative viability of this technology alternative.

It is the belief of this group that UV-C LED emitters offer a technologically and commercially viable alternative to mercury-containing UV lamps for drinking water disinfection applications within the <8 lpm range—this is evidenced by the range of validated solutions available on the market today. Shipped volumes of such systems exceeds 1 Million units at the time of writing. In these applications, mercury-containing lamps do not represent an 'essential' technology as reasonable alternatives exist.

Arrays of UV-C LEDs have been demonstrated in numerous large-scale systems, including water disinfection applications in the 5,000 m3/day range. Whereas these systems do not meet the cost-competitiveness targets of their lower-flow counterparts, known developments in emitter technology means that installation of 4(f)-equivalent UV-C LED systems is expected well within the proposed 5-year exemption extension period.

We support the extension of exemption for 4(f)-type mercury-containing lamps, though wish to set the record straight on the current state-of-the-art for alternative UV-C LED technologies and make the case a reduction in the exception extension period to 3 years.

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Please note that answers to these questions can be published in the stakeholder consultation, which is 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.

Please do not forget to provide your contact details (Name, Organisation, e-mail and phone number) so that the project team can contact you in case there are questions concerning your contribution.