Position Paper

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To:	European Commission, DG ENV
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From:	Typhon Treatment Systems Ltd.
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RE: Position paper on the necessity to amend Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp"

i. Introduction

This position paper aims at explaining why the wording of the exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp):" (a) 15 mg per lamp" should be amended as the criteria according to which this RoHS 2 exemption was granted are no longer fulfilled.

There are currently products such as those designed by Typhon Treatment Systems Ltd. ("Typhon Treatment Systems") that are scientifically and technically practicable and reliable substitutes for certain mercury-based products currently covered by Exemption 4(a).

Therefore, the second column of the Exemption 4(a) to RoHS II "mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp" (Scope and dates of applicability) should amended to include the following wording: "Except for the use of low pressure discharge lamps for disinfection and advanced oxidation treatment with UV light emitting equipment".

This request to amend Exemption 4(a) to RoHS II has the support of the following companies which are manufacturers of UV LED components:

Executive summary

- RoHS II Exemptions can be deleted if the conditions set forth in Article 5(1) of ROHS II are no longer fulfilled.
- The products such as those designed by Typhon Treatment Systems are practicable and reliable substitutes for certain mercury-based products currently covered by Exemption 4(a). In fact, the LED technology has outperformed mercury-based products.
- The current EU legal framework aims at substantially reducing and eventually phasing out the use of mercury in products and industrial processes.
- Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp" should be only restricted to those situations in which there is no practicable and reliable substitute.
- The scope of the exemption should be therefore amended.

ii. **Current legal framework for RoHS II Exemptions**

Directive 2011/65/EU (RoHS II)[1] prohibits the use of the following hazardous substances ("RoHS II Substances") in certain electrical and electronic equipment at the manufacturing stage (start-of-pipe stage).

- Heavy metals: lead, mercury, cadmium and hexavalent chromium;
- Flame retardants: polybrominated biphenyls (PBB) and polybrominated diphenyl ether (PBDE);
- Phthalates: Bis(2-ethylhexyl) phthalate (DEHP), (vii) Butyl benzyl phthalate (BBP), (viii) Dibutyl phthalate P) and (ix) Diisobutyl phthalate (DIBP).

The maximum concentration value weight by weight for homogenous material in the relevant equipment is 0.1% for all these substances, with the exception of cadmium for which the restriction is 0.01%.

The uses of the RoHS II Substances which are included in Annex III and Annex IV of RoHS II are exempted from these maximum concentration limits ("RoHS II Exemptions"). One of the RoHS II Exemptions listed in Annex III is Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp".

In principle, the RoHS II Exemptions listed in those Annexes fulfil the following conditions set forth in Article 5(1) (a) of RoHS II:

1) The exemption does not weaken the environmental and health protection afforded by REACH; and

2) Any of the following Technical and Environmental conditions apply:

   i. Substitution is scientifically and technically impracticable.
   ii. The reliability of substitutes is not ensured.

[1] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment Text with EEA relevance, OJ L 174, 1.7.2011, p. 88–110, available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011L0065.

iii. The total negative environmental, health and consumer safety impacts caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits of the substitution.

Additional parameters might apply in order to assess whether a RoHS II exemption is justified: (i) the socio-economic impacts of substitution; and/or (ii) the availability of the substitute; and/or (iii) the life Cycle assessment on impacts of exemption; (iv) impacts on innovation.

Annex III and Annex IV are dynamic lists to which new RoHS II exemptions can be added or current exemptions can be renewed. In addition to that, an exemption could be deleted or its wording amended if the conditions according to which the RoHS II exemption was granted are no longer fulfilled pursuant to Article 5(1) (b) of the RoHS II.

iii. Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp"

In 2015, NARVA Lichtquellen GmbH + Co. KG (NARVA) and Lighting Europe (LEU) submitted requests for the renewal of the exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp". Both applicants requested the maximum duration to be provided for the exemption.

In order to support their renewal request, LEU argued that there is no current practicable and reliable substitute for the mercury based products covered by this exemption because (i) LED technology cannot produce light in the 185-254nm range of the UVC spectrum (the action spectrum) and therefore this technology would not perform the same germicidal function as the lamps covered by the exemption 4(a); and (ii) the efficiency of the LED technology that generates UV light is not very low (the so-called "wall-plug-efficiency").

The application submitted by LEU reads as follows:

> "*Unlike general lighting lamps, **there is no available LED that can produce light in the 185-254nm range of the UVC spectrum** or other lighting technology that may use less mercury, or can be used as a substitute for these lamps at this time or foreseeable in the next five to ten years. **There are UVC producing LEDS made by companies such as Nichia which are in the early stages of development and use at the higher wavelengths of the UVC spectrum i.e. 365-405nm, however these would not perform the same germicidal function as the lamps covered under this request**. It is estimated by the LED manufacturers that deep **UVC LEDs will not be available for five to ten years due to the high power and long life requirements that are available with low pressure gas discharge lamps.*** (…)
>
> ***There are other materials available from which LEDS can be made that generate UV light** (like AlGaN), **however the efficiency** (radiated power out/electrical power in) **of LEDs with those materials is still very low**. In the UVC (100-280nm) and UVB (280-315nm), the WPE (wall plug efficiency of LEDs are below 1%), where the wall plug efficiency of low pressure gas discharge UVC lamps are 30-40% or even higher.* (….)
>
> ***Conclusion: No comparable WPE for LEDs below 380 nm: making LED not suitable soon as a practical alternative for: Disinfection/purification of air/water/surfaces"*** (emphasis added)

The Oeko-Institut, the appointed institute that prepares RoHS II exemption assessments, agreed with the arguments put forward by LEU and concluded that there was no alternative for the products covered by Exemption 4(a) because (i) the spectral output of available LEDs radiating in the UV spectrum is only with the longer wavelength range (365-404-nm); and (ii) current LEDs alternatives does not provide sufficient wall-plug-efficiency and would result in higher energy consumption.

"*It can be followed that* ***alternatives are currently not available for applications with specific characteristics covered by Ex. 4(a), as the spectral output of available LEDs radiating in the UV spectrum is only in the UV spectrum with longer wavelength range (365-404nm):*** *Such a spectral output would not provide for the function of lamps covered by this exemption, for which the main spectral output needs to be in the shorter wavelength UVC range of 185-254nm. Furthermore,* ***current LED alternatives do not provide sufficient wall-plug-efficiency and would thus result in higher energy consumption should alternatives be in the relevant spectral output range***".

Accordingly, the Oeko-Institut recommended renewing the exemption until 21 July 2021.

iv. **Substitution: LED products**

Typhon Treatment Systems is a UV water treatment technology company which has designed a reactor with optimised geometrical configuration of Light Emitting Diodes (LEDs) for use in high flow-rate biological (UV disinfection) and chemical (Advanced Oxidation Process) water treatment. This technology could be used to treat and disinfect water by removing a broad range of micropollutants and microbiological organisms from reclaimed water.

This technology is now a **practicable and reliable substitute to the use of mercury vapour lamp UV technologies which are currently covered by the exemption 4(a)**.

In other words, the technology developed by Typhon Treatment Systems rebuts the assertion made by LEU in its renewal application for the Exemption 4(a) that there is not currently a practicable and reliable substitute for mercury based lamps due to (i) the limited action spectrum; and (ii) the lack of efficiency of LEDs versus mercury lamps.

More importantly, the LED technology currently outperforms mercury lamps technology for the following reasons:

a) **No lamp fouling.** With both drinking water and wastewater mercury UV treatment, fouling is an inherent, inevitable and expensive problem. No fouling has been observed in Typhon Treatment Systems' products;

b) **No quartz solarisation.** Mercury lamp solarisation is caused primarily by heat and mercury vapour reacting with the quartz. This leads to decline of output and frequent lamp replacement. Contrary to that, the quartz in Typhon's reactor stays cool, and is not exposed to mercury. With Typhon Treatment System's UV LED technology, more than 18 months of continuous testing has not resulted in any observed discoloration or decline in UV transmittance; and

c) **Rapid and continuous increase in UV LED power and a rapid and continuous decrease in costs**. All major UV led suppliers are forecasting continuing significant performance improvement for years, while its costs are rapidly and continuously decreasing.

Finally, this technology has not only been certified for use but it is a reality in some countries. Typhon Treatment System's products have been tested in accordance with U.S. Environmental Protection Agency's validation protocol which has certified it for its use worldwide. This technology is currently under validation in Germany.

In 2018, Typhon Treatment System entered into an eight-year supply agreement with one of the largest water companies in Europe, United Utilities[2]. United Utilities is the water and wastewater service provider for Liverpool, Manchester and millions of other residential and industrial customers in England.

[2] "North West firm wins contract thanks to pioneering tech", BusinessCloud, 5 December 2018. Link: https://www.businesscloud.co.uk/news/north-west-firm-wins-contract-thanks-to-pioneering-tech

Typhon Treatment System is not the only UV LED water treatment equipment manufacturer that produces LED products which are practicable and reliable substitute to the use of mercury vapour lamps UV technologies covered by the exemption 4(a). Other companies such as Metawater[3], AquiSense[4], Acuva Tech and Watersprint also manufacture water treatment equipment that uses UV LEDs (for small and big scale uses), while an EU-based company, Osram, currently develops a project to market UV LEDs for industrial disinfection processes[5].

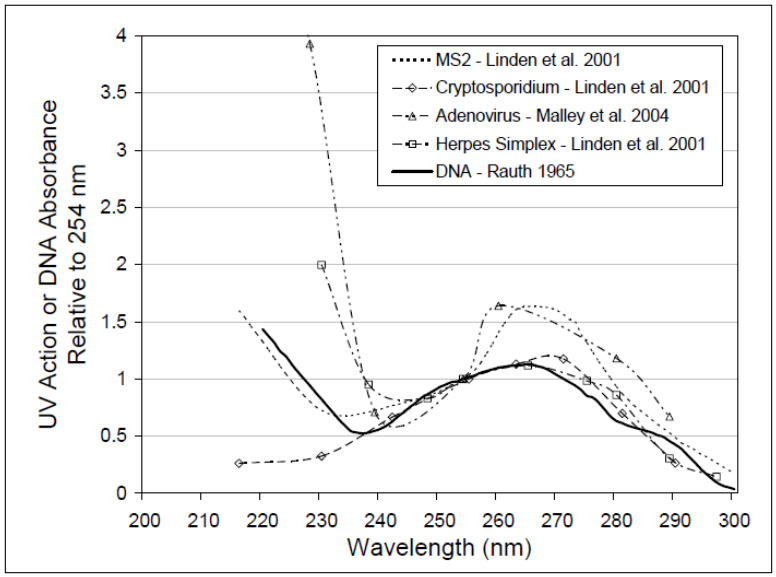
v. The action spectrum and the efficiency of LED versus mercury lamps

As mentioned before, the technology developed by Typhon Treatment Systems rebuts the assertions made by LEU in its renewal application for the Exemption about (i) the limited action spectrum; and (ii) the lack of efficiency of LEDs versus mercury lamps.

a) The action spectrum

As mentioned before, LEU argued that the LED technology cannot produce light in the 185-254nm range of the UVC spectrum, and therefore the LED technology would not perform the same germicidal function as the low pressure mercury lamps covered by the exemption 4(a).

Typhon Treatment Systems disagrees with this conclusion. UV treatment is an established technology for disinfection and has been applied at full scale since 1910 when it was discovered that DNA could be damaged by UV light. For most microorganisms, the UV damage peaks between 260-270 nm, meaning that UV light at 260-270 nm is the most effective at inactivating microorganisms. Nevertheless, the wavelength of 254nm has become the standard for UV disinfection because (i) the range between 256-270nm is not an efficient way to produce UV light; and (ii) mercury can produce UV light at 254nm.



Source: Adapted from Rauth (1965), Linden et al. (2001), and Malley et al. (2004)

Fig. 1: Action spectrum of various microorganisms as a function of the irradiation wavelength.

[3] "Completion of development of ultraviolet treatment equipment for water treatment facilities using ultraviolet light emitting diodes (UV-LED)", Metawater, Press release 16 February 2017. Link: http://www.metawater.co.jp/eng/news/detail/20170307zVu.html

[4] Link: https://www.aquisense.com/water-treatment

[5] UNIQUE project for developing mass market UV LEDs for disinfection, OSRAM Trade Press, 11 June 2017. Link: https://www.osram.com/os/press/press-releases/unique_project_for_developing_mass_market_uv_leds_for_disinfection.jsp

LEDs have the versatility of emitting at any desired wavelength, the UV disinfection is no longer restricted to 254nm. This is important because whilst 260-270nm has the highest germicidal power (Fig. 1), other parameters need to be considered when selecting the optimal wavelength for UV disinfection.

UV absorbance/transmittance is an important parameter used to describe the behaviour of UV light. UVT at 254nm is affected by all organics and inorganics present in water, in particular to natural organic matter which absorbs strongly UV light. A low UVT results in a higher UV dose required to inactivate a microorganism to the desired level as more photons are absorbed or scattered by the background organic matter present in water. Fig. 2 represents the UV absorbance of a typical UK water source over the UV spectrum, and demonstrates a strong influence of wavelength on the UV absorbance. For instance, by shifting the wavelength from 254nm to 280nm the UVT is greatly improved (reduction of UV absorbance by over 40%). This means that a significantly higher percentage of longer wavelength UV reaches the target in the reactor.

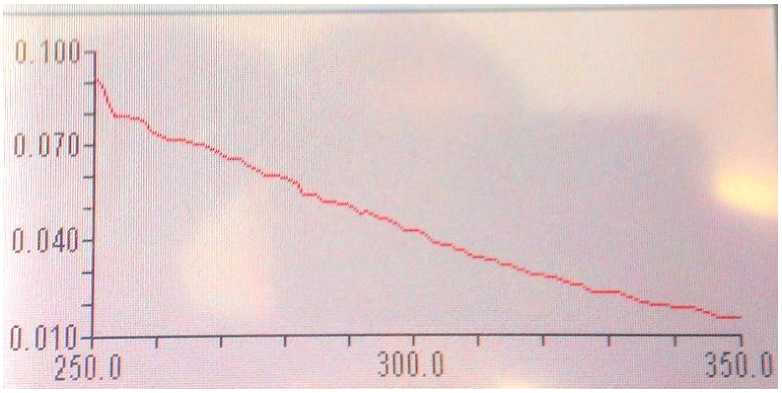


Fig. 2: UV absorbance of a typical UK water source as a function of the wavelength in the UV range.

For this reason, Typhon Treatment Systems has selected a wavelength of 275nm for their UV disinfection. The advantages of this wavelength outweigh the results that could be achieved with mercury based lamps, whose wavelength is restricted to 254nm:

i. Higher germicidal power at 275nm over 254nm (Fig. 1);
ii. Less energy required to procedure the same number of photons at 275nm than at 254nm (and 260nm);
iii. Higher LED wall plug efficiency at 275nm over 254nm (and 260nm); and
iv. Higher UV transmittance at 275nm than at 254nm (Fig. 2).

b) The photonic efficiency

The photonic efficiency is the most important factor in photochemical processes. It represents the ratio between the output power of the lamp and the number of effective photons that will react with organisms in the reaction chamber. The quantification of the photonic efficiency can be dissociated into two parts: the wall-plug-efficiency and the photon delivery efficiency. While wall-plug-efficiency of UV has improved substantially and it is expected to outperform mercury lamps in a few years, Typhon Treatment Systems' technology is six times more efficient than conventional mercury lamp technologies at delivering photons to the target organism or molecules in the reactor.

i. Wall-plug-efficiency

The wall-plug-efficiency (WPE) represents the fraction of electrons generated (output power) converted into photons emitting at the appropriate wavelength. The WPE of mercury UV lamps hasn't improved over the years and is stabilised at about 30-35 percent for low pressure lamps and 10-15 percent for medium pressure lamps (the rest of the energy being wasted as heat). The current wall plug efficiency of UV LEDs has reached 2.7% in 2017, up from less than 0.5% in 2012.

Fig. 3 illustrates the development of commercially available UV LEDs since 2003 and shows that their output power has increased by 200 percent over the last 5 years whilst their price per mW has decreased by 200 percent. In comparison, the development of visible light LEDs has followed for 40 years a trend known as Haitz's law which is characterised by a 20-fold increase in the total output per Watt and a 10-fold drop in the cost per lumen for every decade as shown in Fig. 4 (they have become 200 times better every 10 years).

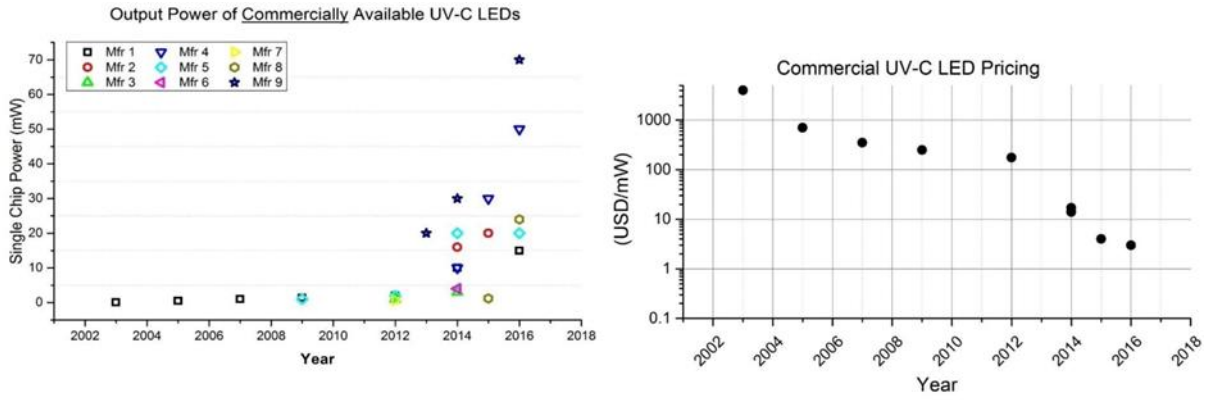


Fig. 3: The development of UV LEDs between 2003 and 2016.

If UV LEDs follow the development trend of visible LEDs (Fig.3 indicates that between 2012 and 2016, their development has been twice as fast as visible LED's development), it is only a matter of a few years before the wall-plug-efficiency of LEDs outperforms mercury lamps. It is believed that WPE of UV LEDs will exceed 50%.

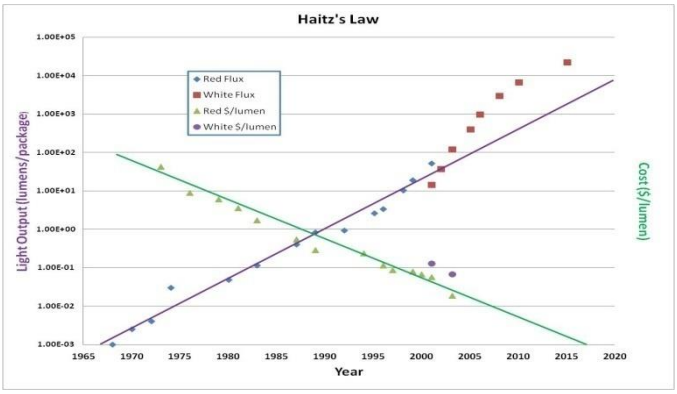


Fig. 4: Haitz's law representing the development of visible LEDs between 1967 and 2010.

ii. Photon delivery

The likelihood of UV radiation damaging a microscopic organism in any location within a flow cell is a function of the UV irradiant intensity in that location. In a flowing water pipe, organisms are uniformly distributed through the cross section of the flow cell. An ideal UV reactor would uniformly distribute UV irradiant intensity. Because of the geometry of dense arrays of radially emitting cylinders, mercury arc lamp arrays inevitably have many inefficient "overkill" zones where the irradiant intensity exceeds the lethal dose as shown in Fig. 5A (in those regions, a large proportion of available photons do not result in a photochemical reaction). To overcome this issue, Typhon Treatment Systems' reactor was designed in such a way that the irradiance was as uniform as possible in any point of the reactor.

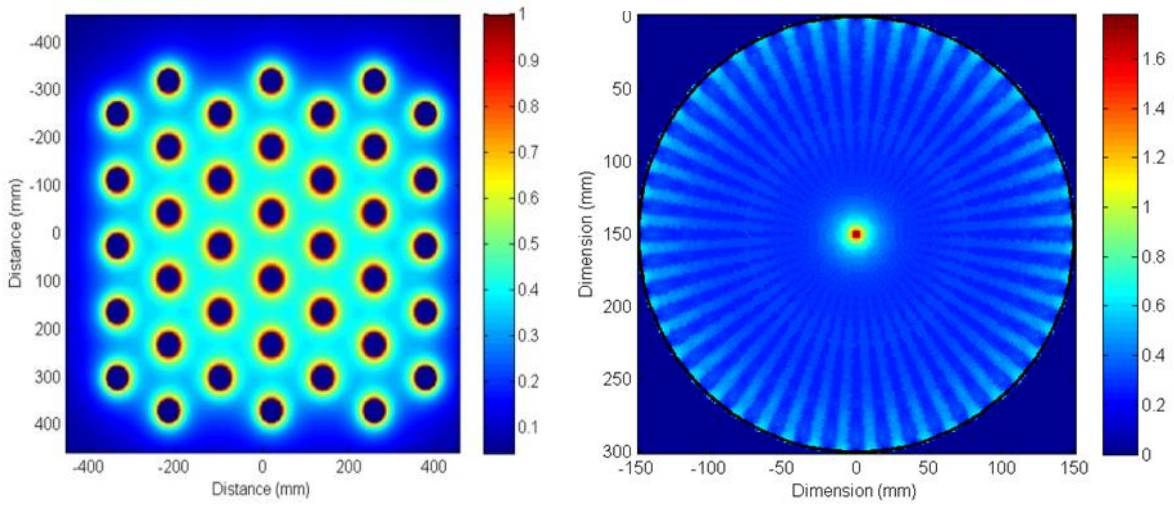


Fig. 5: Spatial average irradiance of (A) a conventional UV system and (B) Typhon's UV

The profile shows a nearly uniform photonic intensity (or irradiance) across the full 300 mm section (except in the centre). To overcome this inefficient overdosing zone, the water is swirled to create an internal vortex. This additional feature improves the performances even further and reactor modelling has demonstrated that Typhon Treatment Systems technology is six times more efficient than conventional mercury lamp technologies at delivering photons to the target organisms or molecules in the reactor.

vi. The mercury-free legislation in the European Union.

Since the publication of the Communication of 28 January 2005 from the Commission to the European Parliament and the Council entitled 'Community Strategy Concerning Mercury", the EU has implemented a number of measures to target highly toxic mercury pollution. These measures aim not only to reduce mercury exposure but also to reduce the use of this substance in products and industrial processes.

As mentioned by the European Commission, mercury is "a very toxic substance which represents a global and major threat to human health, including in the form of methylmercury in fish and seafood resources, ecosystems and wildlife"[6].

Firstly, Directive 2007/51/EC[7] banned the use of mercury-containing thermometers and other measuring devices intended for sale to the public was banned in the European Union. Secondly, Regulation 1102/2008[8] banned the exports of metallic mercury and certain mercury compounds and mixtures and the safe storage of metallic mercury.

Regulation 2017/852[9], which repealed Regulation 1102/2008, not only banned the export of these components but also introduced additional restrictions for the use and storage of and trade in mercury, mercury compounds and mixtures of mercury. Equally important, Regulation 2017/852 banned the use of mercury in dental amalgam, the largest use of mercury in the European Union and a significant source of pollution.

[6]Proposal for a Regulation of the European Parliament and the Council on mercury, and repealing Regulation (EC) No 1102/2008, COM(2016) 39 final 2016/0023(COD).

[7] Directive 2007/51/EC of the European Parliament and of the Council of 25 September 2007 amending Council Directive 76/769/EEC relating to restrictions on the marketing of certain measuring devices containing mercury, OJ L 257, 3.10.2007, p. 13–15.

[8] Regulation (EC) No 1102/2008 of the European Parliament and of the Council of 22 October 2008 on the banning of exports of metallic mercury and certain mercury compounds and mixtures and the safe storage of metallic mercury, OJ L 304, 14.11.2008, p. 75–79.

[9] Regulation (EU) 2017/852 of the European Parliament and of the Council of 17 May 2017 on mercury, and repealing Regulation (EC) No 1102/2008, OJ L 137, 24.5.2017, p. 1–21

The total negative environmental, health and consumer safety impacts caused by these legislative measures were clearly outweighed by the total environmental, health and consumer safety benefits of the restrictions to the use of mercury. Both the impact assessments of Directive 2007/51/EC and Regulation 2017/852 emphasized that the environmental, human and economic benefits of prohibiting or strictly regulating the use of mercury in product and industrial processes outweighed the negative effects of these measures.

As mentioned before, RoHS II prohibits the use of mercury in certain EEE at the manufacturing stage (Annex II to the RoHS II). As discussed above, it is only possible to produce EEE that contain mercury when they fall under one of the exemptions to Annex III to the RoHS II (such as Exemption 4(a)). Nevertheless, the European Commission has recognised that the mercury exemptions under RoHS II are "under regular review with a view to their phase-out"[10].

The aim of this legal framework is to ban or strictly restrict current uses of mercury in products and industry, unless significant environmental and health are demonstrated and provided that there are no mercury-free alternatives which are available in the market.

Last but not least, Directive 2012/19/EU[11] provides a selective treatment for gas discharge lamps that contain mercury in order to ensure that the mercury is properly removed.

In this context, the mercury exemptions under RoHS II, such as the **Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp", should be only restricted to those situations in which there is no practicable and reliable substitute.**

vii. The environmental, health and consumer benefits of LED alternatives

The amendment of the current wording of the exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp" will address several environmental, health and consumer issues highlighted during the consultation period launched by the Oeko-Institut on this exemption.

a) Disposal of mercury based products and mercury waste.

An appropriate treatment of mercury prior to permanent storage depends on correct separation of waste[12]. However, a recent study highlighted by the European Commission quantifying environmental impacts from the incineration of unseparated household waste products including mercury, found that mercury from lamps and batteries accounted for 96%of the toxic impacts of such misplaced waste[13].

During the consultation period launched on the Exemption 4(a), the Danish Ministry of Environment and Food and the Belgium Ministry of Health, Food Chain, Safety and Environment pointed out that not only the consumers ignore how to properly recycle mercury based lamps or disposed broken mercury lamps, but there are very few options for the re-use of mercury once it has been collected. The incorrect disposal of mercury based products poses therefore a major environmental and health problem.

b) Limited capacity for mercury waste

[10] European Commission, Science for Environmental Policy, In-Depth Report 15 Tackling mercury pollution in the EU and Worldwide, November 2017, page 26.

[11] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE), OJ L 197, 24.7.2012, p. 38–71

[12] European Commission, Science for Environmental Policy, In-Depth Report 15 Tackling mercury pollution in the EU and Worldwide, November 2017,

[13] Ibid.

In addition to that, the increase of the use of LED products versus mercury-based products will address the current problem that the EU faces regarding mercury waste.

As mentioned by the Expert group on the Implementation of the New Mercury Regulation, a limited capacity for the temporary storage and conversion of mercury waste[14]. Only two Member States (Germany and The Netherlands) have to some extent a temporary storage capacity for mercury waste.

viii. The new scope of Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp"

Based on the above, we believe that the wording of Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp" should be amended as the products designed by Typhon Treatment Systems are scientifically and technically practicable and reliable substitutes for certain mercury-based products currently covered by the Exemption 4(a).

The second column of the Exemption 4(a) "mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp" (Scope and dates of applicability) should include the following: " Except for the use of low pressure discharge lamps for disinfection and advanced oxidation treatment with UV light emitting equipment".

The amended wording of this exemption will reflect that there are currently reliable and practicable substitutes for certain mercury-based products covered by the Exemption 4(a) to RoHS II.

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[14] Document MEG-3/05 Summary of information received regarding for temporary storage and conversion of mercury waste.