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Institut für angewandte Ökologie
Institute for Applied Ecology

ROHS Annex II Dossier for Beryllium and its compounds. Restriction proposal for substances in electrical and electronic equipment under RoHS

Report No. 5
Substance Name: Beryllium and its compounds

Version 2
25/09/2019

EC Numbers: Beryllium metal: 231-150-7
Beryllium oxide (BeO): 215-133-1
and other Beryllium compounds

CAS Numbers: Beryllium metal: 7440-41-7
Beryllium oxide (BeO): 1304-56-9
and other beryllium compounds

Head Office Freiburg
P.O. Box 17 71
79017 Freiburg
Street address
Merzhauser Strasse 173
79100 Freiburg
Tel. +49 761 45295-0

Office Berlin
Schicklerstrasse 5-7
10179 Berlin
Tel. +49 30 405085-0

Office Darmstadt
Rheinstrasse 95
64295 Darmstadt
Tel. +49 6151 8191-0

info@oeko.de
www.oeko.de

Table of Contents

List of Tables

Abbreviations

BeCu	Beryllium copper alloy
BeS	Beryllium sensitisation
Be	Beryllium
BeO	Beryllium oxide
CAS number	A CAS Registry Number, also referred to as CASRN or CAS Number, is a unique numerical identifier assigned by Chemical Abstracts Service (CAS) to every chemical substance described in the open scientific literature
CBD	Chronic beryllium disease
ChemSec	The International Chemical Secretariat
CLP	Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (REACH)
CMR	Carcinogenic, Mutagenic, or Toxic for Reproduction
CORAP	Community Rolling Action Plan
CRM	Critical Raw Materials
EC number	The European Community number (EC Number) is a unique seven-digit identifier that was assigned to substances for regulatory purposes within the European Union by the European Commission.
EEE	Electrical and electronic equipment
EMC	Electromagnetic compatibility
MSDS	Material safety data sheet
n.d.	Not defined
OEL	Occupational Exposure Limits
OEM	Original Equipment Manufacturer
ppm	Parts per million
RMOA	Risk Management Option analysis
SCOEL	Scientific Committee on Occupational Exposure Limits
tpa	(metric) tonnes per annum
TWA	Time weighted average
WEEE	Waste electrical and electronic equipment

CONTEXT and SCOPE of the Substance Assessment

The substance assessment of beryllium and its compounds is being performed as part of the "Study on the review of the list of restricted substances and to assess a new exemption request under RoHS 2 – Pack 15". With contract No. 07.0201/2017/772070/ENV.B.3 implementing Framework Contract No. ENV.A.2/FRA/2015/0008, a consortium led by Oeko-Institut for Applied Ecology, has been assigned by DG Environment of the European Commission to provide technical and scientific support for the review of the list of restricted substances and to assess a new exemption request under RoHS 2. This study includes an assessment of seven substances / group of substances[1] with a view to the review and amendment of the RoHS Annex II list of restricted substances. The seven substances have been pre-determined by the Commission for this task. The detailed assessment is being carried out for each of the seven substances in line with a uniform methodology which was developed as a part of this study[2].

In the course of the substance assessment a 1st stakeholder consultation was held from 20 April 2018 to 15 June 2018 to collect information and data for the seven substances under assessment. Information on this consultation can be found at the Oeko-Institut's project webpage at: http://rohs.exemptions.oeko.info/index.php?id=289.

For beryllium and its compounds, a total of 18 contributions were submitted by different stakeholders. An overview of the contributions submitted during this consultation is provided in Appendix I. The contributions can be viewed at http://rohs.exemptions.oeko.info/index.php?id=294.

Based on stakeholder input and publicly available information and stakeholder input, the current dossier has been prepared, which is now subject to a 2nd stakeholder consultation. The aim of the 2nd consultation is to receive further information, data and comments:

- To provide clarity as to aspects on which data gaps still exist;
- to provide specific data for basing estimations where these are currently based on assumptions in lack of data;
- to provide sector specific data where current information does not allow making relevant distinction as to the differing use of the assessed substances by various EEE sectors;
- to comment on the general interpretations made as to the current base of knowledge.

After the revision of the dossiers and their completion, a final stakeholder meeting shall be held to allow stakeholders to comment on the dossiers and particularly on conclusions and recommendations.

[1] For the sake of better readability hereafter the term substance will be used for single substances as well as for group of substances.

[2] This methodology includes a dossier template for substance assessment which had been prepared by the Austrian Umweltbundesamt GmbH in the course of a previous study. The methodology for substance assessment has been revised based on various proposals from and discussions with stakeholders. Among others, revisions have been made to clarify when the Article 6(1) criteria are considered to be fulfilled and how the precautionary principle is to be applied. The methodology has also been updated in relation to coherence to REACH and other legislation and publicly available sources of relevance for the collection of information on substances have been updated and added. The methodology is available at https://rohs.exemptions.oeko.info/index.php?id=341

1. IDENTIFICATION, CLASSIFICATION AND LABELLING, LEGAL STATUS AND USE RESTRICTIONS

In past processes for identifying substances of relevance for possible restriction under RoHS, only beryllium metal and beryllium oxide were considered. The current assessment covers a broader scope of substances, namely elemental beryllium and its compounds and alloys.

1.1. Identification

The 'ECHA C&L inventory database' lists 13 beryllium compounds. Among them, only elemental beryllium and beryllium oxide are registered under REACH as of August 2019.[3]
The following table shows further beryllium compounds, including salts and silicates that are identifiable by a CAS code. The compilation is extracted from the recommendation from the Scientific Committee on Occupational Exposure Limits (SCOEL) that gave a recommendation on "beryllium and inorganic beryllium compounds".[4] In the following this term will be used.

Table 1-1: Overview on beryllium and its inorganic compounds

Chemical name	CAS	Formula
Beryllium	7440-41-7	Be
Beryllium acetylide	506-66-1	CBe_2
Beryllium carbonate (Basic beryllium carbonate (mixed salt)	66104-24-3	$Be_2CO_3(OH)_2$
Beryllium carbonate	13106-47-3	$BeCO_3$
Beryllium chloride	7787-47-5	$BeCl_2$
Beryllium diammonium tetrafluoride	14874-86-3	$BeF_4N_2H_8$
Beryllium diboride	12228-40-9	B_2Be
Beryllium diboride	12536-51-5	BBe_2
Beryllium dibromide	7787-46-4	$BeBr_2$
Beryllium diiodide	7787-53-3	BeI_2
Beryllium fluoride	7787-49-7	BeF_2
Beryllium hexaboride	12429-94-6	BeB_6
Beryllium hydroxide	13327-32-7	$Be(OH)_2$
Beryllium nitrate (anhydrous)	13597-99-4	Be(NO3)2
Beryllium nitrate tetrahydrate	13510-48-0	$Be(NO_3)_2 \times 4\ H_2O$
Beryllium orthosilicate	15191-85-2	Be_2SiO_4
Beryllium silicate (phenakite)	13598-00-0	Be_2SiO_4
Beryllium oxide	1304-56-9	BeO
Beryllium phosphate	13598-26-0	$Be_3(PO_4)_2$
Beryllium phosphide	58127-61-0	Be_3P_2
Beryllium selenide	12232-25-6	BeSe

3 ECHA Registered Substance Database: Entry for Beryllium (2018); https://echa.europa.eu/de/registration-dossier/-/registered-dossier/14917/1, last viewed 16.08.2019

4 Scientific Committee on Occupational Exposure Limits SCOEL (2017): SCOEL/REC/175, Beryllium and Inorganic Beryllium Compounds, Recommendation from the Scientific Committee on Occupational Exposure Limits, Adopted 8th of February 2017; https://publications.europa.eu/en/publication-detail/-/publication/732b94b7-0a1b-11e7-8a35-01aa75ed71a1, last viewed 10.08.2019

Beryllium sulphate (anhydrous)	13510-49-1	$BeSO_4$
Beryllium sulphate (dihydrate)	14215-00-0	$BeSO_4 \times 2\ H_2O$
Beryllium sulphate (tetrahydrate)	7787-56-6	$BeSO_4 \times 4\ H_2O$
Beryllium sulphide	13598-22-6	BeS
Beryllium telluride	12232-27-8	BeTe
Beryllium zinc silicate	25638-88-4	$BexH_4O_4Si.xZn$
Phosphoric acid, beryllium salt	35089-00-0	$BexH_3O_4P$
Silicic acid, beryllium salt	58500-38-2	$BeSiO_3$
Tetraberyllium boride	12536-52-6	BBe_4
Triberyllium nitride	1304-54-7	Be_3N_2
Bertrandite	12161-82-9	$4\ BeO \times 2\ SiO_2 \times H_2O$
Beryl	1302-52-9	$3\ BeO \times Al_2O_3 \times 6\ SiO_2$

Source: Scientific Committee on Occupational Exposure Limits SCOEL (2017)

1.1.1. Name, other identifiers, and composition of the substance

As elemental beryllium and beryllium oxide are so far the only beryllium compounds that are registered under REACH, detailed data on their properties can be compiled.[5] For further beryllium compounds listed in Table 1-1, detailed data are not available at the ECHA databases.

Table 1-2: Substance identity and composition of beryllium metal and beryllium oxide

Chemical name	beryllium metal	beryllium oxide
EC number	231-150-7	215-133-1
CAS number	7440-41-7	1304-56-9
IUPAC name	beryllium	oxoberyllium
Index number in Annex VI of the CLP Regulation	004-001-00-7	004-003-00-8
Molecular formula	Be	BeO
Molecular weight (range)	9.01 g/mol	25.01 g/mol
Synonyms	beryllium	beryllium oxide
Structural formula	Be	Be=O
Degree of purity	No data	No data

Source: European Chemicals Agency ECHA, Brief Profile: Entries for beryllium and beryllium oxide (2018), https://echa.europa.eu

5 ECHA Brief Profile: Entry for Beryllium (2019); https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.318, last viewed 19.07.2019; ECHA Brief Profile: Entry for Beryllium oxide (2019); https://echa.europa.eu/de/brief-profile/-/briefprofile/100.013.758, last viewed 19.07.2019.

1.1.2. Physico-chemical properties

The physico-chemical properties of elemental beryllium and beryllium oxide are summarised in Table 1-3 below.[6]

Table 1-3: Overview of physico-chemical properties of beryllium metal and beryllium oxide

Property	beryllium metal	beryllium oxide
Physical state at 20°C and 101.3 kPa	100% (solid metal)	100% (solid white powder)
Melting/freezing point	1,278°C	2,428 – 2,431°C
Boiling point	2,471°C	3,900°C [7]
Vapour pressure	13,332 hPa at 1 860°C	No data
Water solubility	500 ng/l at 20 °C and pH 6.11	1.39 - 200 µg/l at 18 - 23°C and pH 7
Partition coefficient n-octanol/ water (log KOW)	Not relevant	Not relevant
Dissociation constant	Not relevant	Not relevant
Relative density	1.848 - 1.850 at 20°C	3 g/cm³ at 20°C
Specific gravity	No data	No data

Source: European Chemicals Agency ECHA, Brief Profile: Entries for beryllium and beryllium oxide, https://echa.europa.eu

Information on physico-chemical properties for various inorganic beryllium compounds is shown in (Figure 1-1), based on data compiled by SCOEL[8]

[6] Opt. cit. ECHA Brief Profile: Entry for Beryllium and Beryllium oxide (2018)

[7] GESTIS-Stoffdatenbank. http://gestis.itrust.de/nxt/gateway.dll/gestis_de/000000.xml?f=templates&fn=default.htm&vid=gestisdeu:sdbdeu , last viewed 19.07.2019

[8] Opt. cit. Scientific Committee on Occupational Exposure Limits SCOEL (2017)

Figure 1-1: Physico-chemical data for inorganic beryllium compounds

Substance	CAS No.	EC No.	Molecular Formula	MW (g/mol)	Solubility in water (mg/l)	Melting point (°C)	Boiling point (°C)	Vapour pressure	Density (g/cm³)
Beryllium —	7440-41-7	231-150-7	Be	9.01	< 0.00005 (20°C) (insoluble)	1 287–1 292	2 970 (at 5 mm Hg)	1 mm Hg (1 520 °C); 10 mm Hg (1 860 °C)	1.846 (20 °C)
Beryllium acetylide	506-66-1	208-050-7	CBe_2	30.03					
Beryllium carbonate [a c]	66104-24-3	--	$Be_2CO_3(OH)_2$	112.05	Insoluble in cold water; decomposes in hot water ?	-	-	-	-
Beryllium carbonate	13106-47-3	236-030-8	$BeCO_3$	69.02	Insoluble in cold water; decomposes in hot water ?				
Beryllium chloride	7787-47-5	232-116-4	$BeCl_2$	79.92	71.5; Very soluble, Readily soluble	399.2; 405; 415	482.3; 520	1.291 mm Hg	1.899 (25 °C)
Beryllium diammonium tetrafluoride	14874-86-3	238-948-4	$BeF_4N_2H_8$	121.08					
Beryllium diboride	12228-40-9	235-443-0	B_2Be	30.63					
Beryllium diboride [b]	12536-51-5	235-694-6	BBe_2	28.82					
Beryllium dibromide	7787-46-4	232-115-9	$BeBr_2$	168.82					
Beryllium diiodide	7787-53-3	232-119-0	BeI_2	262.82					
Beryllium fluoride	7787-49-7	232-118-5	BeF_2	47.01	Extremely soluble, readily soluble	555	1 175	-	1.986 (25 °C)
Beryllium hexaboride	12429-94-6	235-657-4	BeB_6	73.87					
Beryllium hydroxide	13327-32-7	236-368-6	$Be(OH)_2$	43.03	3.44 (insoluble to slightly soluble)	Decomposes when heated	-	-	1.92 (20 °C)
Beryllium nitrate (anhydrous)	13597-99-4	237-062-5	$Be(NO_3)_2$	133.02	Very soluble	60	142	-	1.557
Beryllium dinitrate tetrahydrate	13510-48-0	--	$Be(NO_3)_2 \times 4\ H_2O$	205.08	1.66 x 10^6 (readily soluble at 20 °C); 0.2 (30 °C)	2 530 ± 30	3 900	-	3.01
Beryllium orthosilicate	15191-85-2	239-251-8	Be_2SiO_4	110.11					
Beryllium silicate (phenakite) [c]	13598-00-0	--	Be_2SiO_4	110.107					
Beryllium oxide	1304-56-9	215-133-1	BeO	25.01	0.2; 0.00005 (barely soluble [d]	2 508–2 547	3 787	-	3.016 (20 °C)
Beryllium phosphate [c]	13598-26-0	--	$Be_3(PO_4)_2$	216.98			-	-	-
Beryllium phosphide	58127-61-0	261-137-1	Be_3P_2	88.98					
Beryllium selenide	12232-25-6	235-450-9	BeSe	87.98					
Beryllium sulphate (anhydrous)	13510-49-1	236-842-2	$BeSO_4$	105.07	Insoluble in cold water; converted to tetrahydrate in hot water	550–600 (decomposes)	-	-	2.44; 2.443 (20 °C)
Beryllium sulphate (dihydrate) [c]	14215-00-0	--	$BeSO_4 \times 2\ H_2O$	141.12					
Beryllium sulphate (tetrahydrate) [c]	7787-56-6	--	$BeSO_4 \times 4\ H_2O$	177.13	3.91 x 10^5 mg/l (readily soluble at 20°C)	100 (loses 2 H_2O)	400 (loses 4 H_2O)	-	1.713 (10.5 °C)
Beryllium sulphide	13598-22-6	237-064-6	BeS	41.08					
Beryllium telluride	12232-27-8	235-451-4	BeTe	136.61					
Beryllium zinc silicate	25638-88-4	247-151-0	$Be.xH_4O_4Si.xZn$						
Phosphoric acid, beryllium salt	35089-00-0	252-356-3	$Be.xH_3O_4P$						
Silicic acid, beryllium salt	58500-38-2	261-293-0							
Tetraberyllium boride	12536-52-6	235-695-1	BBe_4						
Triberyllium nitride	1304-54-7	215-132-6	Be_3N_2						
Bertrandite	12161-82-9	235-299-9	$4\ BeO \times 2\ SiO_2 \times H_2O$	238.24	-	-	-	-	-
Beryl	1302-52-9	215-101-7	$3\ BeO \times Al_2O_3 \times 6\ SiO_2$	537.5	-	-	-	-	-

[a] Basic beryllium carbonate (mixed salt).
[b] Name is not in line with molecular formula. Name should probably be "Diberyllium boride"
[c] Not in ECHA inventory (ECHA 2017)
[d] The solubility depends on the temperature: beryllium oxide heated to 500 °C is more soluble than if heated to 1 000 °C (no other details) (US EPA 1998).

Source: Scientific Committee on Occupational Exposure Limits SCOEL (2017)

1.2. Classification and labelling status

The European regulation No 1272/2008 on Classification, Labelling and Packaging (CLP)[9] provides a framework for the communication of hazards of chemicals. Annex VI of the CLP Regulation lists substances where a harmonised classification exists, for instance in regard to

9 Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (REACH).

human health concerns. However, suppliers often use different classification schemes for a substance, which is then referred to as ‘self-classification’ in the terminology of CLP.

Classification in Annex VI Regulation No 1272/2008

Elemental beryllium (metal) and beryllium oxide (BeO) are classified under the CLP regulation (Regulation (EC) No 1272/2008 on Classification, Labelling and Packaging). The harmonised classification according to Annex VI Regulation No 1272/2008 according to Table 3.1 of Annex VI is presented in Table 1-4.

Table 1-4: Classification according to part 3 of Annex VI, Table 3.1 (list of harmonised classification and labelling of hazardous substances) of Regulation (EC) No 1272/2008

Index No.	International Chemical ID	EC No.	CAS No.	Classification		Labelling			Spec. Conc. Limits, M-factors
				Hazard Class and Category Code(s)	Hazard statement code(s)	Pictogram, Signal Word Code(s)	Hazard statement code(s)	Suppl. Hazard statement code(s)	
004-001-00-7	beryllium	231-150-7	7440-41-7	Carc. 1B Acute Tox. 2 Acute Tox. 3 STOT SE 3 STOT RE 1 Skin Irrit. 2 Eye Irrit. 2 Skin Sens. 1	H350i H330 H301 H335 H372 H315 H319 H317	GHS06 GHS08 Dgr	H350i H330 H301 H372 H319 H335 H315 H317	-	-
004-003-00-8	beryllium oxide	215-133-1	1304-56-9	Carc. 1B Acute Tox. 2 Acute Tox. 3 STOT SE 3 STOT RE 1 Skin Irrit. 2 Eye Irrit. 2 Skin Sens. 1	H350i H330 H301 H335 H372 H315 H319 H317	GHS06 GHS08 Dgr	H350i H330 H301 H372 H319 H335 H315 H317	-	-
004-002-00-2	beryllium compounds with the exception of aluminium beryllium silicates, and with those specified elsewhere in this Annex	-	-	Carc. 1B Acute Tox. 2 Acute Tox. 3 STOT SE 3 STOT RE 1 Skin Irrit. 2 Eye Irrit. 2 Skin Sens. 1 Aquatic Chronic 2	H350i H330 H301 H335 H372 H315 H319 H317 H411	GHS06 GHS08 GHS09 Dgr	H350i H330 H301 H372 H319 H335 H315 H317 H411	-	-

Source: Annex VI Regulation No 1272/2008; https://echa.europa.eu/de/information-on-chemicals/annex-vi-to-clp, last viewed 19.04.2019

Moreover, one group entry exists for “beryllium compounds with the exception of aluminium beryllium silicates and with those specified elsewhere in this Annex” with the following entries:[10]

- Carc. 1B (Carcinogenicity) - H350i (May cause cancer by inhalation)
- Acute Tox. 2 (Acute toxicity, inhalation) - H330 (Fatal if inhaled)
- Acute Tox. 3 (Acute toxicity, oral) - H301 (Toxic if swallowed)
- STOT RE 1 (Specific Target Organ Toxicity Repeated Exposure) - H372 (Causes damage to organs through prolonged or repeated exposure).
- Eye Irrit. 2 (Serious eye damage/eye irritation)- H319 (Causes serious eye damage)
- STOT SE 3 (Specific target organ toxicity, single exposure; Respiratory tract irritation - H335 (May cause respiratory irritation
- Skin Irrit. 2 (Skin corrosion/irritation) - H315 (Causes skin irritation)
- Skin Sens. 1 (Sensitisation, skin) - H317 (May cause an allergic skin reaction)

The above mentioned group entry additionally carries a harmonised classification for aquatic toxicity (H411 - ‘Toxic to aquatic life with long lasting effects).

Self-classification(s)

Manufacturers, importers or downstream users have to (self-)classify and label hazardous substances and mixtures to ensure a high level of protection of human health and the environment. If a harmonised classification is available, it should be applied by all manufacturers, importers or downstream users of such substances and of mixtures containing such substances.

However, mostly, suppliers decide independently as to the classification of a substance or mixture, which is then referred to as self-classification. Therefore, self-classification might indicate an e.g. additional hazard which is so far not reflected by the harmonised classification. The following assessment of the self-classification therefore emphasises cases where self-classifications differ and where additional hazards were notified in the self-classification.

According to ECHA`s C&L inventory, which contains classification and labelling information on notified and registered substances received from manufacturers and importers, the total number of notifiers is as follows:

- 267 C&L notifications submitted to ECHA for beryllium metal[11]
- 31 C&L notifications submitted to ECHA for beryllium oxide[12]

As for **beryllium metal**, most notifiers follow the harmonised classification (253 of 267 notifications: 95%). Out of these, four notifiers did not list the Hazard Class STOT SE 3 but only provided the respective Hazard Statement (H 335 – May cause respiratory irritation). Four notifiers classified beryllium additionally to the harmonised classification for the physical hazard Flam Sol. 1 (H228 – Flammable solid) and the environmental hazard Aquatic Acute 1 (H400 – Very toxic to aquatic life). A small part of the notifiers (11 notifiers) lacks classification such as e.g. the carcinogenic properties (7 notifiers) or provide only hazard statements.

As for **beryllium oxide**, most notifies follow the harmonised classification (29 out of 31 notifications: 94%). Out of these, two notifiers did not list the Hazard Class STOT SE 3 but only provided the respective Hazard Statement H 335 – May cause respiratory irritation. Two notifiers, among them a lead dossier of a REACH registration joint submission, do not classify for Skin Irritation 2, Skin Sensitation 1 and Acute Toxicity 3.

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[10] ECHA (2019) Table of harmonised entries in Annex VI to CLP. https://echa.europa.eu/de/information-on-chemicals/annex-vi-to-clp, last viewed 19.04.2019

[11] ECHA CL Inventory: Entry for Beryllium (2018), https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/47502, last viewed 11.06.2019

[12] ECHA CL Inventory: Entry for Beryllium oxide (2018), https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/70014, last viewed 11.06.2019

To summarize the various self-classifications, basically the same types of hazards are addressed as by the harmonised classification. Though in some cases the level of hazard may differ or certain hazard types have been omitted and given that the harmonised classification is assumed to have a higher scrutiny the differences in the self-classification compared to the harmonised classification are not further considered.

1.3. Legal status and use restrictions

1.3.1. Regulation of the substance under REACH

- **Elemental beryllium metal** was taken up in the Community Rolling Action Plan (CoRAP) upon the demand of the German Federal Institute for Occupational Safety and Health (BAUA) in 2013. The inclusion was motivated with regard to the concern that occupational respiratory exposure of workers to airborne beryllium dust might cause health risks, particularly beryllium sensitisation (BeS) and chronic beryllium disease (CBD) or berylliosis due to long term exposure. With view at its classification as Carcinogen 1B, according to Annex VI of the CLP regulation, beryllium has been suspected to fulfil the Article 57(a) criteria for identification as a substance of very high concern (SVHC) and authorisation was recommended as the best way to regulate this hazard. Setting and enforcing an EU-wide binding occupational exposure limit was also regarded as an important step to enhance worker protection throughout the EU, next to the authorisation.
- For **beryllium oxide**, a risk management option analysis (RMOA) is under development since 03.10.2017 because of concerns about the carcinogenic properties of BeO.[13] The RMOA is carried out by the Netherland's National Institute for Public Health and the Environment and has not yet provided any suggestion on regulatory measures to be taken.
- In light of their classification as carcinogens, **entry 28 of REACH Annex XVII** applies to beryllium metal and beryllium oxide. The regulation prohibits the supply to the general public as a substance, as a mixture or as a constituent of other mixtures.

1.3.2. Occupational Exposure Limits (OEL)

The SCOEL recommended in 2017[14] to tighten occupational exposure limits for beryllium and proposed a value of 20 ng/m³ for the setting of the (B)OEL. Meanwhile, the Directive **2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work** has recently been amended by Directive (EU) 2019/983, stipulating OEL for beryllium and its inorganic compounds as shown in Table 1-5. The regulation grants the industry a transition period of seven years for implementing occupational exposure controls for beryllium. Directive (EU) 2019/983 entered into force on 10 July 2019 and is due to be applicable in national law by 11 July 2021. As for beryllium and inorganic beryllium compounds, the Directive (EU) 2019/983 stipulates the following OEL:

[13] https://echa.europa.eu/fr/rmoa/-/dislist/details/0b0236e1821a6f8c, last viewed 19.08.2019

[14] Opt. cit. Scientific Committee on Occupational Exposure Limits SCOEL (2017)

Table 1-5: Occupational exposure limits for beryllium and its inorganic compounds

	SCOEL (2017)	Directive (EU) 2019/983 of 10 July 2019
8-hour TWA (Time weighted averages)	0.02 µg/m³ beryllium (inhalable fraction)	- 0.2 µg/m³ - A limit value of 0.6 µg/m³ applies during a transitional period of 7 years until June 2026
15 min STEL (Short term exposure limit)	0.2 µg/m³ beryllium (inhalable fraction)	No entry
Additional categorisation	Carcinogenicity group C (genotoxic carcinogen with a mode-of action based threshold)	No entry
Notations	- Dermal and respiratory sensitisation - No notation on skin sensitisation	- dermal and respiratory sensitisation - carcinogenic properties mentioned

Source: Scientific Committee on Occupational Exposure Limits SCOEL (2017); Official Journal of the European Union L 164/23[15]

The DNEL value corresponds to the REACH registration dossier for beryllium (Table 1-6).[16]

Table 1-6: Guidance values for occupational exposure to beryllium

Population	Local / systemic effect	Effects	DNEL beryllium
Workers	Inhalation Exposure	Systemic long term effects	0.2 µg/m³

Source: ECHA Registered Substance Database: Entry for beryllium (2018)

1.3.3. Other legislative measures

Beryllium is listed on the 2017 catalogue of **Critical Raw Materials (CRM)** for the EU (COM(2017) 490 final).[17] Materials appearing on this list have been identified as critical for the EU due to a risk of supply shortage (scarcity) and their high importance for the economy. For beryllium, the supply risk scores at 2.4 and the economic importance scores at 3.9. These scores indicate that beryllium has a medium criticality as compared to other raw materials. Additional aspects (e.g. environmental, social) are not mentioned in the communication in this regard.

1.3.4. Non-governmental initiatives

Beryllium metal and beryllium oxide are both listed in the SIN list because they are classified CMR according to Annex VI of the CLP Regulation.[18]

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15 DIRECTIVE (EU) 2019/983 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 amending Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work, Official Journal of the European Union L 164/23

16 Opt. cit. ECHA Registered Substance Database: Entry for Beryllium (2018)

17 EU COM (2017): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the 2017 list of Critical Raw Materials for the EU, Brussels, 13.9.2017, COM(2017) 490 final, available under: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2017:0490:FIN, last viewed 19.04.2018

18 http://sinlist.chemsec.org/search/search?query=beryllium, last viewed 24.07.2019

Furthermore, beryllium metal and beryllium oxide are listed on several other policies or codes of conducts about substance restriction, i.e. the Global Automotive Declarable Substance List (GADSL).

2. USE IN ELECTRICAL AND ELECTRONIC EQUIPMENT

2.1. Function of the substance

Beryllium is one of the most lightweight metals and at the same time very rigid with a good strength-to-weight ratio. Due to its unique combination of properties, beryllium is an essential material in the manufacture of various products and specific applications where lightweight structures are required which are resistant to deformation under high stresses or high temperatures. Thus, beryllium is considered a strategic material for many industry sectors. The important properties are summarised as follows, based on a variety of sources:[19]

- excellent electrical and thermal conductivity;
- good elastic modulus and exceptional stiffness (Young's modulus);
- good corrosion and oxidation resistance;
- hardening agent in alloys with metals, especially copper, which produces a high strength alloy;
- about 50% greater rigidity than that of steel, while its density (1.84 g/cm³) about 30% lower than that of aluminium;
- remains stable at high temperatures (melting point 1,284ºC) and it has good resistance to deformation at elevated temperatures;
- X-ray transparency and non-magnetic properties;
- Excellent formability, machinability and joinability due to isotropic structures;
- Non-magnetic and non-sparking properties combined with high strength provide protection against fires and explosions.

Technical uses of beryllium and its compounds encompass the following technical forms:

- Metallic beryllium and alloys containing >30% beryllium;
- Copper beryllium alloys containing 0.10 – 2.0% beryllium;
- Al, Cu and Ni master/casting alloys containing 1 – 15% beryllium;
- Beryllium oxide (BeO) is mainly used in form of ceramics.

Because of the unique combinations of these individual properties of lightweight, strength, ductility, formability, machinability, electrical and thermal conductivity, fatigue resistance, resistance to loss of strength with long term exposure to heat, non-magnetic, non-sparking etc, BeSt[Fehler! Textmarke nicht definiert.] indicates that no other material can offer the same combinations of these properties like beryllium and beryllium alloys.

For the major part, beryllium is used as a component of alloys, especially in copper alloys. Only a few products contain pure beryllium metal or high beryllium containing composite parts. Beryllium metal is mainly used in form of alloys as it provides for long product service life, reliability and consistent electrical performance in moving/mating parts over the extended lifetime of RoHS category 9 industrial equipment (TMC 2018).[20]

As an alloying component in combination with copper, aluminium, or other metals, beryllium increases the alloys' rigidity, modulus of elasticity. Moreover, these alloys have a low density and better corrosion resistance in comparison with other light metals. For instance, high beryllium copper alloy (BeCu), containing 0.10 – 2.0% beryllium,[21] offer the best possible known combination

[19] http://beryllium.eu/about-beryllium/properties-of-pure-beryllium/; BeST (2018); ThermoFisher (2018), ZWEI (2018)

[20] Test and Measurement Coalition TMC (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_TMC_7_Substances_response_20180615_fin.pdf

[21] BeST - Beryllium Science & Technology Association BeST (2018): Contribution endorsed by ESIA submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of

of mechanical strength, the electrical and thermal conductivity resistance to corrosion and a high modulus of elasticity combined with a low density. Moreover the alloy's properties enhance product performance, increase reliability, extend life products and facilitate miniaturisation of components and products in EEE.

Other alloys, e.g. aluminium beryllium alloys, are mainly used in the aerospace and space industries, however these application areas are outside of the scope of RoHS (AEM 2018).[22] Nickel beryllium alloys are used for springs that require need to retail high elastic modulus at elevated temperatures for a long product lifetime, such as thermostats and electric connectors (e.g. in plugs, sockets, and electromechanical switches etc.). According to the Association of Equipment Manufacturers AEM (2018),[23] nickel beryllium alloys are less common in the EEE sector than copper beryllium alloys.

Beryllium ceramics or powder, containing BeO in concentrations of 20% to 37% beryllium (BeST 2014)[24] has high heat conductivity and is therefore used for heat sinks in electronic appliances as well as an electrical insulator and thermal conductor for high-temperature equipment or in high technology ceramics. The Beryllium Science & Technology Association (BesT) asserts that beryllium oxide is typically applied to high-end products and rarely to consumer EEE. Beryllium oxide is one of the most expensive raw materials used in ceramics. The expense is linked in part to the precautions to avoid the toxic effects of the powder when handling during fabrication.[25] Beryllium ceramics is used in high power devices or high density electronic circuits for high speed computers (ibid). Moreover, since BeO is transparent to microwaves, the material may be used as windows and antennas in microwave communication systems and microwave ovens (ibid).

Some power semiconductor devices have used beryllium oxide ceramic between the silicon chip and the metal mounting base of the package in order to achieve a lower value of thermal resistance than for a similar construction made with alumina. It is also used as a structural ceramic for high-performance microwave devices, vacuum tubes, magnetrons, and gas lasers.[26]

2.2. Types of applications / types of materials

Beryllium is used across various industrial sectors as shown in figure Figure 2-1. EEE Applications that are within the scope of RoHS account for roughly 40% of the beryllium consumption.

the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_BeST_ESIA_Beryllium_RoHS-Pack15_20180615.pdf

22 Association of Equipment Manufacturers AEM (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_AEM_Beryllium_20180615_RoHS.PDF

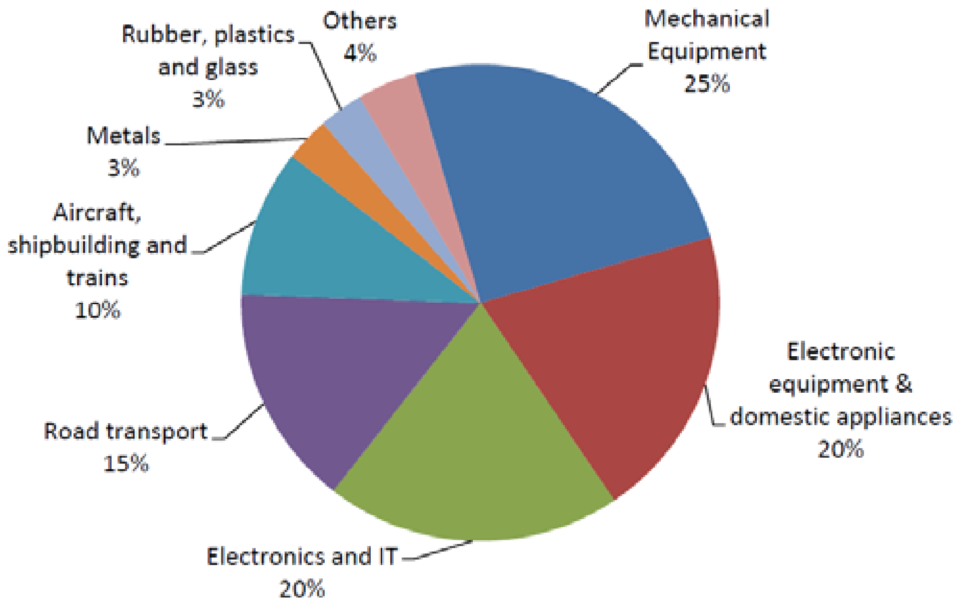
23 Opt. cit. AEM (2018)

24 Beryllium Science & Technology Association BeST (2014): Contributions submitted during stakeholder consultation on 04.04.2014; documents to be retrieved at: http://rohs.exemptions.oeko.info/index.php?id=213

25 AZoM (2001) Beryllium Oxide – Beryllia. https://www.azom.com/article.aspx?ArticleID=263 last viewed 26.08.2019

26 Stanford Advanced Materials (SAM) https://www.samaterials.com/beryllia-/968-beryllium-oxide-beo-ceramic-heat-sinks.html last viewed 26.08.2019

Figure 2-1: End-use of beryllium in Europe in 2012 (by weight)



Source: BeST (2013) quoted by European Commission (2015)[27]

Table 2-1 shows relevant applications of beryllium as compiled by the German Federal Institute for Occupational Safety and Health (BAUA 2014) during its CORAP substance evaluation.[28]

Table 2-1: Overview of relevant application areas of beryllium and beryllium oxide

Sector	Applications examples
Aerospace (not under RoHS)	• Engines and rockets • Brakes and landing gear • Satellites and gyroscopes • Precision tools • Altimeters • Mirrors
Energy and industrial equipment (not under RoHS)	• Heat exchanger tubes and heat sinks (BeO ceramics) • Electric motor brushes • Relays and Switches • Microelectronics and Microwave devices • Nuclear reactor components (Thermonuclear Experimental Reactor) • Oil field drilling devices
Telecommunications and ICT (RoHS categories 3, 4)	• Undersea repeater housings • Mobile phones; personal computers • RF-cable assemblies, • Transistor mountings on printed circuit boards • Substrate for integrated circuits, structural ceramics for ICs etc.

[27] European Commission (2015) Report on critical raw materials for the EU - Critical raw materials

[28] The German Federal Institute for Occupational Safety and Health (BAUA) (2014) Substance evaluation report Beryllium; ZWEI (2018); AEM (2018); BeTS (2018); ESIA (2018); MedTech Europe (2018)

Sector	Applications examples
	• Electrical connectors, contacts, switches and springs • Lightweight housings and electromagnetic shielding
Components used in generic electrical and electronic equipment (EEE)[29] (including all RoHS categories except cat. 5)	• Electrical connectors and contacts, e.g. headers and wire housing; board-to-board connectors; RF-connectors; IC-sockets etc. • Thermal management components: dielectric heat sinks, thermal conductive paste, thermal grease (premium products may contain BeO based precision ceramic parts), • Circuit protection: fuse clips, • Test leads and test sockets, • Electromechanical DIP/SIP-switches, • Electric motors with sliding contact brushes • EMC (Electromagnetic Compatibility) gaskets, Fingerstock shields, • Different types of springs (spring clip, battery springs, contact springs); battery contacts and connectors
(Bio-)Medical and industrial devices (RoHS categories 8, 9)	• XRF/XRD spectrophotometric equipment: X-ray tube windows (Be-foil with typical size of 12x12 mm x 12.5 µm) • Magnetic Resonance Imaging, Scanning electron microscopes, • Medical & industrial laser and plasma generators • Elements of connectors; components in switches and attenuators; probe tips and contacts, HRF connectors, • BeO ceramic encapsulation of high-power semiconductors • Dental prostheses (not under RoHS)
Defence (not under RoHS)	• Tank mirrors • Springs on submarine hatches • Mast mounted sights • Missile guidance • Nuclear triggers
Fire prevention	• Non-sparking tools • Sprinkler systems
Automotive (not under RoHS)	• Air-bag triggers • Anti-lock braking systems • Steering wheel connectors
Miscellaneous (non EEE applications - not under RoHS)	• Plastic moulds • Bellows • Jewellery (aquamarine and emerald mineral) • Golf clubs • Bicycle frames • Camera shutters • Fishing rods • Pen clips

[29] https://eu.mouser.com/_/?Keyword=beryllium

Sector	Applications examples
	• Scrap metal recovery and recycling • Precision ceramics

Source: BAUA (2014) complement with data from various stakeholders to the consultation conducted from 20 April 2018 to 15 June 2018

Beryllium alloys are used in many specialised electronics applications, as they can be used to design miniaturised components (Foley et al. 2017). This is especially desirable for mobile consumer electronics such as smartphones with slim design. For a robust and reliable design (also for electromagnetic shielding), small gaps in the devices are sealed by a flexible mesh, so called finger stock. That mesh is often made of BeCu alloy because it is the strongest copper alloy. It retains about 22% to 28% of the conductivity of pure copper, and it has excellent shielding performance. The alloy contains 1.8% to 2.0% of beryllium and a minimum of 0.2% of nickel and cobalt but no more than 0.6% of nickel and cobalt and iron.[30]

Semiconductor devices that use beryllium oxide ceramics instead of aluminium oxide between the silicon chip and the metal mounting base tend to last longer because the beryllium oxide ceramics provide more heat resistance, efficient thermal management and effective heat dissipation (Foley et al. 2017). Beryllium oxide is specifically used in the ceramic encapsulation of high-power semiconductors to provide the best possible combination of thermal conductivity and dielectric property.

Table 2-2: Identified uses of beryllium and Be-compounds in electrical and electronic equipment

Beryllium and its compounds	Functions of Be	Examples on the component level	Examples of the EEE-relevant Applications	Concentration estimated
Beryllium-copper alloys	A hardening agent in metal, high strength, electromagnetic shielding	Springs and connectors	Used in telecommunication applications and high-conductivity alloys in automotive	High strength alloys contain typically 1.6%-2% Be [31]
		EMC (Electromagnetic compatibility) gaskets[32]	EEE devices, that need to be sealed against EMI (and dust), depending on their design	
	High conductivity	- SMD (Surface mounted devices) contact springs; - Golden Brick contact - Wire clampers for PCB - Grounding contact - Conductive connectors, used to make contacts and	- Antenna contacts (used in the smartphone)[33] - Battery contacts and electric clamps, used in almost all EEE devices, such as washing machines, clothes dryers, dish washers, microwaves, air conditioners, printed circuits	High conductivity alloys containing 0.2%-0.6% Be

[30] https://www.evaluationengineering.com/home/article/13014317/emc-gaskets-sealing-against-emi-and-the-environment

[31] http://www.ngk-alloys.com/NGK_Berylco_Design_Guide_En.pdf; http://beryllium.eu/wp-content/uploads/2016/07/Beryllium-Production-and-Outlook-Roskill-Mineral-Sevices.pdf

[32] https://www.evaluationengineering.com/home/article/13014317/emc-gaskets-sealing-against-emi-and-the-environment

[33] https://www.ajato.com.tw/product/spring-contact/#Spring-contact-application

Beryllium and its compounds	Functions of Be	Examples on the component level	Examples of the EEE-relevant Applications	Concentration estimated
		connectors, relays, switches and shielding	boards, televisions, computers, etc.[34]	
Beryllium-nickel alloys	high strength and high temperature stability	mechanically and thermally highly stressed springs, contacts, and connectors.	- "Test & Burn-in"[35] sockets for stress testing electronic devices (i.e. chips); - high temperature commercial lighting fixtures (e.g. halogen lamps)[36]	Commoditised NiBe alloys contain Be in the range of 2 wt%. e.g. "Alloy 360" contains 1.85%-2.05% Be in weight[37]
Beryllium oxide ceramics	Effective heat dissipation for small sized thermal manage-ment for EEE components,[38] e.g. high-power semiconductors	Beryllium oxide (BeO) ceramic heat sinks		Up to 99.9% beryllium oxide
Beryllium oxide ceramics	(Be-bearing ceramic encapsulation provides an insulating material with excellent thermal conductivity).	Radio Frequency (RF) power transistors; valve bases, some resistors[39]	-Power amplifiers are used in aerospace & Hi-reliability communications, avionics & radar, Industrial & medical equipment.[40]	containing 20% to 37% beryllium oxide (BeST 2014)[41]
		other semiconductor components as a heat sink material,[42] e.g. transistor heat sinks[43]	Generic EEE equipment	

34 (Foley et al. 2017)

35 Test sockets and burn-in sockets are considered part of the electronic connector market, while wafer probes are designed to test bare die and wafers in the semiconductor equipment market. https://www.bce.it/wp-content/uploads/2013/10/BCE-Test-and-burn-in-sockets-_10-13_.pdf

36 https://www.mill-max.com/products/new/high-temperature-beryllium-nickel-contacts

37 https://materion.com/-/media/files/alloy/datasheets/other-alloy-products/ad0005_0615-alloy-360-nickel-beryllium-strip.pdf

38 Coherent (2018); TMC (2018)

39 Greening of Electronics. Danish Ministry of the Environment, Environmental Project No. 1416, 2012, https://www2.mst.dk/Udgiv/publications/2012/07/978-87-92779-99-1.pdf

40 ESIA (2018): ESIA submission Stakeholder Consultation on Be and its compounds - RoHS Substances Study Contribution, submitted on 15.06.2018

41 Beryllium Science & Technology Association BeST (2014): Contributions submitted during stakeholder consultation on 04.04.2014; documents to be retrieved at: http://rohs.exemptions.oeko.info/index.php?id=213, last viewed 11.06.2018

42 https://materion.com/-/media/files/beryllium/engineering-design/beryllium-as-a-heat-sink_materion.pdf

43 http://www.delbertblinn.com/page_2frame.htm

Not all applications listed above are used for consumer EEE. Some specific uses of beryllium in industrial EEE, identified during the stakeholder consultation, include:

- Beryllium metal related to the use in X-Ray devices such as tubes and detectors[44], as its physical properties allow for maximum X-Ray transmission, excellent vacuum and thermal performance, and mechanical toughness;
- Beryllium metal or BeCu for use electron microscopes, spectrophotometers such as mass spectrometers, XRF/XRD equipment, surface analysis and micro analysis tooling;[45]
- Beryllium copper alloy (BeCu) alloys are essential in the connectors of electrical cars, autonomous, vehicles, and solar panels;
- BeCu alloys in electrical contacts[46] (springs, contact springs, terminals connector) of industrial equipment;
- BeCu for use in electrical connectors [47] and components in switches and attenuators; probe tips and contacts, HRF connectors, and springs and gaskets;
- BeO used as expansion matched submounts for the horizontal arrays;[48]
- BeO is specifically used in the ceramic encapsulation of high-power semiconductors to provide efficient thermal management and effective heat dissipation;[49]
- BeO use in high frequency high power integrated circuit packages. These are mainly used by the telecoms sector;[50]

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[44] OLYMPUS OSSA (2018): Contribution submitted on 05.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/OlympusOSSA_Submission-for-beryllium-and-its-compounds.pdf

[45] Thermo Fisher (2018): Contribution submitted on 13.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_ThermoFischerScientific_Beryllium_RoHS_Consulation_public.pdf

[46] EDAX Inc. (2018): Contribution submitted on 11.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_EDAX_Inc_Beryllium_2ss180608.pdf

[47] MedTech Europe (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_MedTech_Europe_7_substance_contribution20180613_FINAL.PDF

[48] Coherent (2018b): Contribution submitted on 12.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_2_Coherent_Beryllium_Usage_Survey_at_Coherent_BUs_Ron_M_6-12-18_20180613.pdf

[49] Test and Measurement Coalition TMC (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_TMC_7_Substances_response_20180615_fin.pdf

[50] European Semiconductor Industry Association ESIA (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/Contribution_ESIA_BeO_Final_15062018.pdf

- BeO, is an insulating material used in the construction of Radio Frequency (RF) Power transistors in power amplifiers.

In its response to the stakeholder consultation, the Beryllium Science & Technology Association (BeST 2018)[51] states that the EEE manufacturers use beryllium only as a metal, mainly as alloying element in copper and as beryllium oxide ceramic. Beryllium salts or soluble compounds are not used in EEE. AEM (2018) states that *"Only beryllium metal, its alloys and beryllium oxide occur in electrical and electronic equipment (EEE). Other beryllium compounds such as the sulphate, chloride, nitrate, etc. have no known uses in EEE".*[52] This statement is endorsed by BeST (2018), which confirms that the scope of the current substance evaluation, namely "beryllium metal and beryllium oxide" represents the only scope significant for the RoHS Directive. It is to be mentioned that the overview above omits possible applications of beryllium as intermediary material used in production processes in the course of EEE supply chains.

2.3. Quantities of the substance used

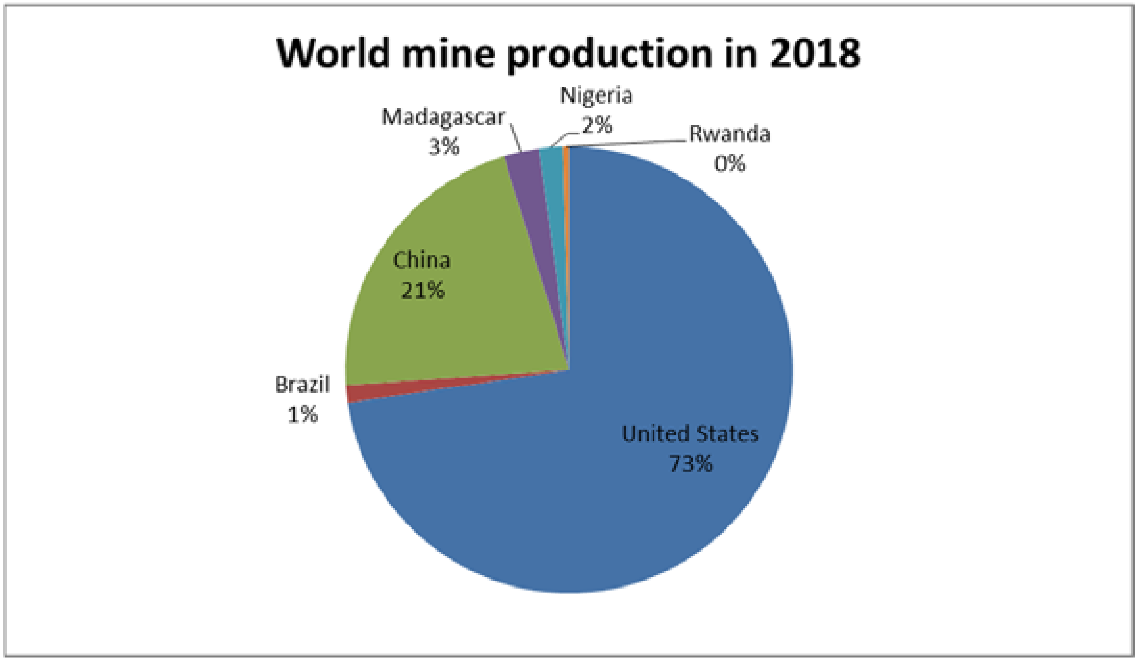
The annual worldwide production of beryllium in 2014 was estimated as 300 metric tonnes, according to BeST (2016).[53] USGS (2019) reports a global production volume for beryllium metal of 230 metric tonnes as of 2018. However, literature data from different sources on production and consumption of beryllium is contradictory to some degree. Knudson & Wilkins (2014) report that the worldwide beryllium consumption was about 400 metric tonnes per year and SCOEL (2017) quote (JRC 2012), that the future world consumption is expected to grow to 350 metric tonnes by 2020 and 425 metric tonnes by 2030, due to the application for fusion reactor power generator construction. The United States dominate the world`s mine production of beryllium raw material. As illustrated by Figure 2-2, 73% of the world's primary beryllium supply is supplied to the world market by the United States, followed by China with 22%.

[51] Opt. cit. BeST (2018)

[52] Association of Equipment Manufacturers AEM (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15);

[53] http://beryllium.eu/about-beryllium/facts-and-figures/

Figure 2-2: Country shares of primary beryllium production in 2018



Source: USGS (2019)

The most comprehensive consumption figures for beryllium commodities are available from the U.S. governmental organisation USGS. Table 2-3, recited from the USGS report (2016), shows the beryllium flows in percent from mining to the end use stage. According to these figures, based on value-added sales revenues, 75% of the global beryllium production was used to make alloys, while the use of pure beryllium metal accounts for 20%. The remaining 5 percent of beryllium consumption are attributable to Be-bearing ceramics (USGS 2016[54]). The USGS report specifies that beryllium alloy strip and bulk products (the most common forms of processed beryllium) were used across all application areas mentioned. The majority of unalloyed beryllium metal and beryllium composite products were used in defence and scientific applications. Consumer electronics and telecommunications infrastructure, which are both included in the scope of RoHS, account for 26% of the total global beryllium consumption. In the EU, approximately 40% of beryllium commodities were used in telecommunications, electronics, automotive electronics (16%), aerospace components and general EEE (10%) and other (non EEE) end-use markets (□ 34%) according to BeST (2018).

Table 2-3: Beryllium flows from mining to end use stage (source: USGS 2016[54])

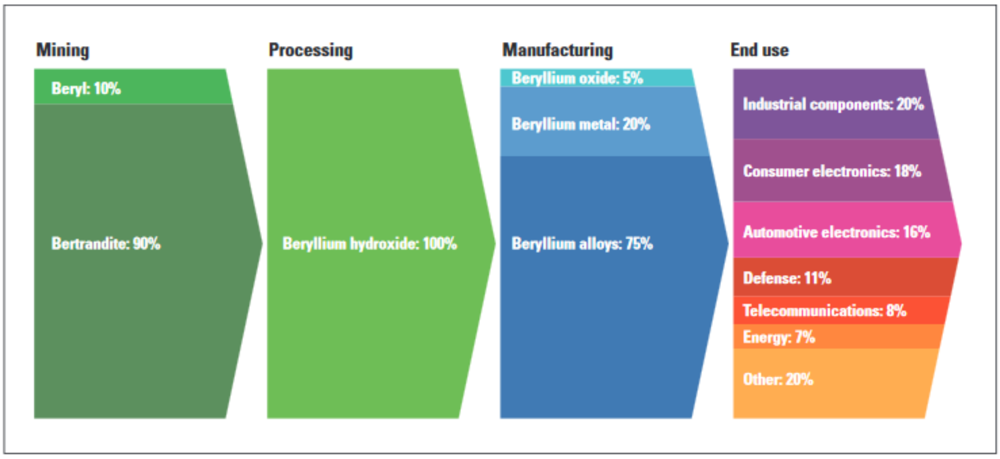
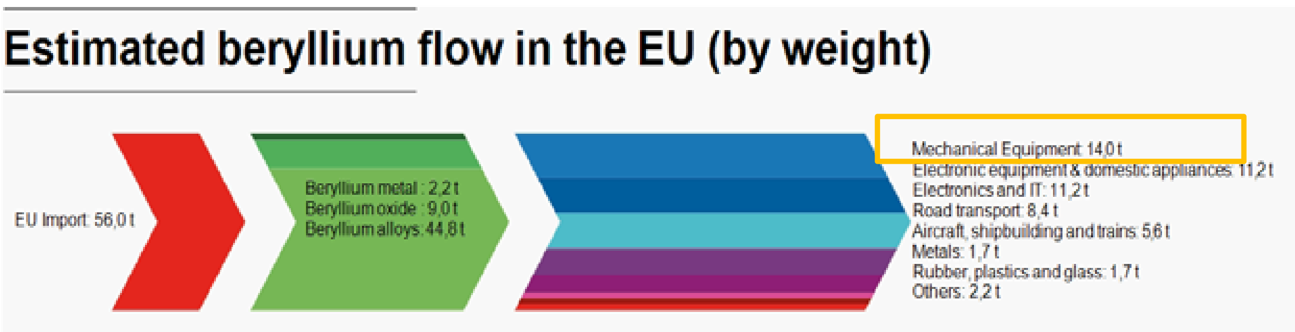


Figure 2. Simplified flow diagram of the beryllium industry. Percentages are relative to the total beryllium flow at each stage; flows between stages do not account for losses, changes in stocks, or recycling. End use category labelled "Other" includes 2 percent used in medical applications (Materion Corporation, 2016).

Source: USGS (2019)

The EU is a net importer of beryllium. Table 2-4 demonstrates the simplified beryllium flow by weight in the EU. According to BeST (2018), the beryllium consumption in the EU is approximately 50 tonnes per year (about 14% of the worldwide consumption). 80% of the beryllium used in the EU goes into the production of beryllium alloys. Pure beryllium metal accounts for 16% of beryllium consumption in the EU, whereas beryllium oxide accounts for 4% approximately (extrapolated from the proxy estimation of the percentage distribution in the United States). In the EU, about 40% of beryllium is used in EEE and telecommunication equipment, which is included in the scope of the RoHS Directive (AEM 2018).[55] That amount equals about 23 tonnes per annum. However, a substantial amount of beryllium imports in the EU may be unaccounted for in raw material trade figures, as the substance is also contained in imported semi-finished products or finished consumer and industrial products. The quantities of beryllium used in other sectors are calculated based on the percentage distribution published by the 2015 report on critical raw materials for the EU.[56]

Table 2-4: Simplified beryllium flows in the EU to end use stage



Source: USGS (2019)

[54] USGS (2016) Beryllium—A Critical Mineral Commodity— Resources, Production, and Supply Chain https://pubs.usgs.gov/fs/2016/3081/fs20163081.pdf, last viewed 28.08.2019

[56] European Commission (2015) Report on critical raw materials for the EU - Critical raw materials profiles. http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations, last viewed 18.07.2019

More detailed specification of the amounts of beryllium on the level of distinct products is not possible as numbers on beryllium contents in applications are not publicly available. Table 2-5 exemplary shows the extrapolated amount of beryllium used in EEE-products based on the available information. Knudson and Wilkins (2014) state that, among EEE applications that use beryllium-containing alloys, some models of cellular phones contain the highest amount of beryllium among WEEE items, reaching 40 ppm (parts per million). Strip-down analyses of electrical and electronic devices show that a typical smart phone such as an Apple I-Phone 5 contains 15.6 ppm beryllium.

Table 2-5: Estimation of the amount of beryllium used in exemplary EEE-products

Product types	Assumed beryllium concentration in products	Weight of reference products	Extrapolated amount of beryllium per product
Mobile phone	0.1% in weight[57]	Weight of an Apple iPhone 5: 112 g [58]	112 mg / Smartphone (=112g*0.1%*1,000)
Personal computer	0.0157% in weight[59]	Weight of a desktop PC[60]: 11.7 kg	1.84 g (=11.7 kg*0.0157%*1,000)
Computer Display	Alloy Cu-0.7Be: 0.3% in mass (HP, 2019[61])	Weight of a 27" HP display: 4.86 kg[62]	102 mg / Display (=4.86 kg*0.3%*0.7%*10^6)

Source: own calculation

3. HUMAN HEALTH HAZARD PROFILE

The following recites the harmonised hazard statements for human health hazards the CLP regulation that apply for beryllium metal, beryllium oxide (BeO) and beryllium compounds with the exception of aluminium beryllium silicates:

- Carc. 1B (Carcinogenicity) - H350i (May cause cancer by inhalation)
- Acute Tox. 2 (Acute toxicity, inhalation) - H330 (Fatal if inhaled)
- Acute Tox. 3 (Acute toxicity, oral) - H301 (Toxic if swallowed)
- STOT RE 1 (Specific Target Organ Toxicity Repeated Exposure) - H372 (Causes damage to organs through prolonged or repeated exposure).
- Eye Irrit. 2 (Serious eye damage/eye irritation)- H319 (Causes serious eye damage)
- STOT SE 3 (Specific target organ toxicity, single exposure; Respiratory tract irritation - H335 (May cause respiratory irritation)
- Skin Irrit. 2 (Skin corrosion/irritation) - H315 (Causes skin irritation)
- Skin Sens. 1 (Sensitisation, skin) - H317 (May cause an allergic skin reaction)

3.1. Critical endpoint

According to SCOEL (2017),[63] it is assumed that the toxicity of beryllium is attributable to particulate beryllium dust or fumes. Taylor et al (2003) recapitulate that "*exposure to certain*

[57] Greening of Electronics. Danish Ministry of the Environment, Environmental Project No. 1416, 2012, https://www2.mst.dk/Udgiv/publications/2012/07/978-87-92779-99-1.pdf

[58] https://support.apple.com/kb/SP655?viewlocale=en_US&locale=de_DE

[59] http://web.mit.edu/ieee/sanjay/11.122/ewaste.htm

[60] https://www.eup-network.de/fileadmin/user_upload/Produktgruppen/Lots/Final_Documents/EuP_Lot3_PC_FinalReport.pdf; average weight of home desktops

[61] http://h20195.www2.hp.com/V2/getpdf.aspx/c05117791.pdf

[62] https://store.hp.com/GermanyStore/Merch/Product.aspx?id=4HZ38AA&opt=ABB&sel=MTO

[63] Opt. cit. Scientific Committee on Occupational Exposure Limits SCOEL (2017)

beryllium compounds, particularly less soluble forms such as beryllium metal and oxides, appears to be correlated with a higher incidence of disease." Such particulate matter can emerge from thermal and dry mechanical metal crafting processes. The toxicity hazard profile of such dust correlates with their respective beryllium content. For alloys, this refers to the content of elemental beryllium metal. SCOEL summarizes that "*The lung is the main target organ at inhalation exposure to beryllium and beryllium compounds. At relevant exposure concentrations, critical health effects comprise carcinogenicity, beryllium sensitisation (BeS) and chronic beryllium disease (CBD)." "Inhaled beryllium is deposited in the lung tissue, particularly in pulmonary lymph nodes. It is distributed from the lungs to the skeleton, after being very slowly absorbed into the blood. The skeleton is the ultimate site of beryllium storage. Trace amounts are distributed throughout the body. Less than 1% of orally administered beryllium is absorbed via the gastrointestinal tract."*

The Substance Evaluation Conclusion Document, submitted by BAUA (2014),[64] explained that beryllium is classified as a non-threshold carcinogen known to provoke "Beryllium Sensitisation" (BeS) as an early health effect of respiratory exposure to beryllium that can result in Chronic Beryllium Disease (CBD) in case of long term exposure. Maier (2010)[65] reports "*that BeS precedes CBD and develops after as little as 9 weeks of beryllium exposure. CBD occurs within 3 months and up to 30 years after initial beryllium exposure*". According to Wambach and Laul (2008), are "*acute health effects, primarily chemical pneumonitis caused by the more soluble forms of Be*" whereas "*CBD is caused by the immune system's continuing reaction to the less soluble forms of beryllium retained in the body*".[66] Up to 4% of people that are exposed to beryllium bearing dust develop CBD (ibid). However, CBS and CBD seem to be related to an individual disposition of humans to immune-system response against beryllium exposure rather than general health hazards of beryllium. The authors assert, that existing data from the U.S. authority DOE did not exhibit a correlation of CDB cases to the length of employment of a worker in a beryllium facility (ibid). SCOEL (2017) provides an extensive review of existing toxicological studies (human and animal as well as in vitro studies) on the development mechanisms of CBS and CBD. In summary, SCOEL explains that "*In humans, the primary target of beryllium toxicity following inhalation exposure is the respiratory tract, leading to BeS, acute and chronic beryllium disease and lung cancer as the principal effects. Regarding acute beryllium disease, high levels of exposure can result in inflammation of the upper and lower respiratory tract and airways, bronchiolitis, pulmonary edema, and chemical pneumonitis. Repeated inhalation exposure to low concentrations of beryllium or beryllium compounds can cause chronic beryllium disease (CBD) in humans. CBD is a cell-mediated immunological reaction of delayed type and is generally observed after a long latent period. BeS precedes chronic beryllium disease (CBD), but the progression from sensitisation to disease is not fully understood. The prevailing view is that most individuals must first be sensitised before beryllium in the lungs can cause the lung damage of CBD, based on studies showing that almost all individuals with CBD with positive BeLPT are also sensitised*." In the case of beryllium, it appears to be extremely difficult to establish exposure dose – response relationship. Long term exposure to beryllium, even at low doses, seems to be able to inflict CBD in persons that have already been sensitisised and have an individual genetic susceptibility.

Beryllium compounds have been shown to be skin sensitisers in animal experiments. Following skin contact, beryllium and beryllium compounds can cause allergic contact dermatitis or a granulomatous skin reaction in humans. It is suspected, that working clothes, shoes, and the workers' vehicles contaminated with beryllium bearing dust can affect (cause skin sensitisation) not only their owners but their family members if carried home and cleaned in private households (Taylor et al, 2003).

Single inhalation exposures to high beryllium concentrations (> 100 µg/m³) can cause acute beryllium disease (ABD) in humans. Signs and symptoms of ABD range from mild inflammation of

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[64] German Federal Institute for Occupational Safety and Health BAUA (2014): Substance Evaluation Conclusion Document, https://echa.europa.eu/documents/10162/f76365ec-ce93-4422-bdf6-519517cc68be, last viewed 19.04.2018

[65] Maier, L.A. (2010) Beryllium Health Effects in the Era of the Beryllium Lymphocyte Proliferation Test. Journal of Applied Occupational and Environmental Hygiene)16(5):514-520.

[66] Wambach, P.F. and Laul, J.C. (2008) Beryllium health effects, exposure limits and regulatory requirements. Journal of Chemical Health and Safety. 15(4):5-12.

the upper respiratory tract to tracheo-bronchitis and severe pneumonitis. As for systemic effects, after repeated inhalation, cardiovascular, renal, hepatic and haematological effects, and weight loss were observed in humans, which may be a consequence of functional respiratory restrictions.
As for carcinogenicity and genotoxicity, SCOEL concludes that even though the mechanism of action of the carcinogenicity of beryllium is not yet elucidated, it appears to involve indirect genotoxicity and cell transformation rather than direct genotoxicity. Therefore, beryllium and its inorganic compounds must be considered as human carcinogens and are categorised in SCOEL carcinogen group C (genotoxic carcinogen for which a practical threshold may exist). As for reproductive toxicity after respiratory exposure, no data could be found because human studies or animal studies were not available.

3.2. Existing Guidance values (DNELs, OELs)

In the EU, 65,000 workers are potentially exposed to beryllium. About 1250 of them are employed in foundry or similar processes, most of them in Italy, France, Germany, the United Kingdom, Switzerland and Hungary. These workplaces are of particular concern as the highest exposure levels exceed 2 µg/m^3. Because of the trend to move foundry work to China, the number of workers in this sector in the EU may decrease in the future (IOM 2011).
The Scientific Committee on Occupational Exposure Limits SCOEL (2017)[67] provides an overview of existing OELs for beryllium and beryllium compounds (Table 3-1 and Table 3-2).

Table 3-1: Overview of existing OELs for beryllium and beryllium compounds in EU countries

EU	TWA (8 hrs)		STEL (15 min)		Remarks	References
	ppm	mg/m³	ppm	mg/m³		
Austria		0.002		0.008	TRK	AT GKV (2011)
Belgium		0.002		0.01	8 hrs TGG (TWA)	BE KB (2014)
Denmark		0.001				DK BEK (2011)
Germany (DFG)					*BGV (BAR): 0.05 µg/l beryllium/L urine*	Drexler and Hartwig (2012)
Finland		0.0001		0.0004	STEL = 15 min. average	FI MSAH (2012)
France (INRS)		0.002			VME = TWA 8 hrs	FR INRS (2012)
France (ANSES)		0.00001			Skin notation	FR ANSES (2010)
Ireland		0.0002				IE HSA (2011)
Sweden		0.002			Total dust	SE SWEA (2015)
UK		0.002			TWA	GB HSE (2011)

- BAR [Biologischer Arbeitsstoff Referenzwert] = biological reference value
- TWA = Time-Weighted Average (usually 8 hours average).
- STEL = Short Term Exposure Limit (usually 15 minutes average).
- TGG [TijdGewogen Gemiddelde] = TWA.
- TRK [Technische RichtKonzentration] = indicative concentration.
- REL = Recommended Exposure Limit (NIOSH)
- TWAEV = Time-Weighted Average Exposure Value = TWA
- PEL = Permissible Exposure Level (OSHA)
- VME [Valeur Moyenne d'Exposition] = TWA.

[67] Opt. cit. Scientific Committee on Occupational Exposure Limits SCOEL (2017)

Source: Scientific Committee on Occupational Exposure Limits SCOEL (2017); COM(2018) 171 final

Table 3-2: Overview of existing OELs for beryllium and beryllium compounds in non-EU countries (expressed as Be)

EU	TWA (8 hrs)		STEL (15 min)		Remarks	References
	ppm	mg/m³	ppm	mg/m³		
Australia		0.002			TWAEV	AU SWA (2011)
CA (Ontario)		0.002		0.01	TWA	CA OML (2013)
CA (Québec)		0.002				Canada (2016)
Japan		0.002				JA JSOH (2015)
New Zealand		0.002				NZ HS (2013)
Norway		0.001				NO NLIA (2011)
Switzerland		0.002			inhalable aerosol	CH SUVA (2015)
USA (OSHA)		0.002		0.005	PEL	US OSHA (2006)
USA (NIOSH)		0.0005		0.0005	REL	US NIOSH (2016)
USA (ACGIH)		0.00005			TLV-TWA	US ACGIH (2012)

Source: Scientific Committee on Occupational Exposure Limits SCOEL (2017); COM(2018) 171 final

Wambach and Laul (2008) report on the regulatory status quo in the U.S: "*The current ACGIH and OSHA adopted occupational exposure limit for workers is 2.0 µg/m^3, based as an 8-hour time weighted average (TWA). An occupational exposure limit of 0.2 µ/m^3 (8-Hr TWA) has been adopted by California as a regulatory limit and is being used by others as well. To protect the public from CBD, there is a long-standing EPA beryllium ambient air limit set of 0.01 µg/m^3 as a 30-day TWA.*"[68]

4. ENVIRONMENTAL HAZARD PROFILE

Very few environmental assessments studies for beryllium or beryllium compounds could be found in the body of publicly available literature, nor were such studies mentioned by stakeholders during the consultation. BAUA (2014) did not assess environmental hazards during the CORAP substance evaluation for beryllium. The entries in the ECHA database on registered substances for beryllium and beryllium oxide do not contain eco-toxicological information.

Taylor et al (2003) report the results of a review study of beryllium in the environment. The authors state that "*Beryllium contamination of soils, surface water, groundwater, and air in close proximity to facilities where beryllium has been manufactured, machined, and tested is not well documented*" (neither in the U.S. nor outside the U.S.).

Geologic background concentrations of beryllium in water bodies vary depending on the occurrence of geochemically mobilised beryllium minerals. Acidic, organic-rich continental river waters exhibit a higher level of beryllium than ocean water and the beryllium concentration in groundwater tends to be higher than in surface waters. "*The beryllium content of ocean waters (10^4 to 10^1 mg/l for the Pacific Ocean) is approximately three orders-of-magnitude less than that of river waters*" (ibid). In soil, "*Natural beryllium concentrations range from a mean of 0.1 mg/kg to 40 mg/kg at locations around the world*" (ibid). Coal contains beryllium typically range from 1.46 to 1.52 mg/kg (data for the U.S.). The combustion of coal in power plants contributes to widespread environmental beryllium pollution if emission controls are insufficient. Taylor et al (2003) state that

68 Wambach, P.F. and Laul, J.C. (2008) Beryllium health effects, exposure limits and regulatory requirements. Journal of Chemical Health and Safety. 15(4):5-12.

in the U.S. "*an estimated 80% of all beryllium emissions in the US originate from coal-fired vessels.*"

Data on the impacts of beryllium on biota is lacking. However, the substance may have effects on organisms in the aquatic environment. There are a few notifiers that classify beryllium for being hazardous to the aquatic environment (Aquatic Acute 1 - H400, Very toxic to aquatic life).

4.1. Endpoints of concern, NOAECs, acute, chronic

There are no data available.

4.2. Potential for secondary poisoning and bioaccumulation

There are no data available.

4.3. Guidance values (PNECs)

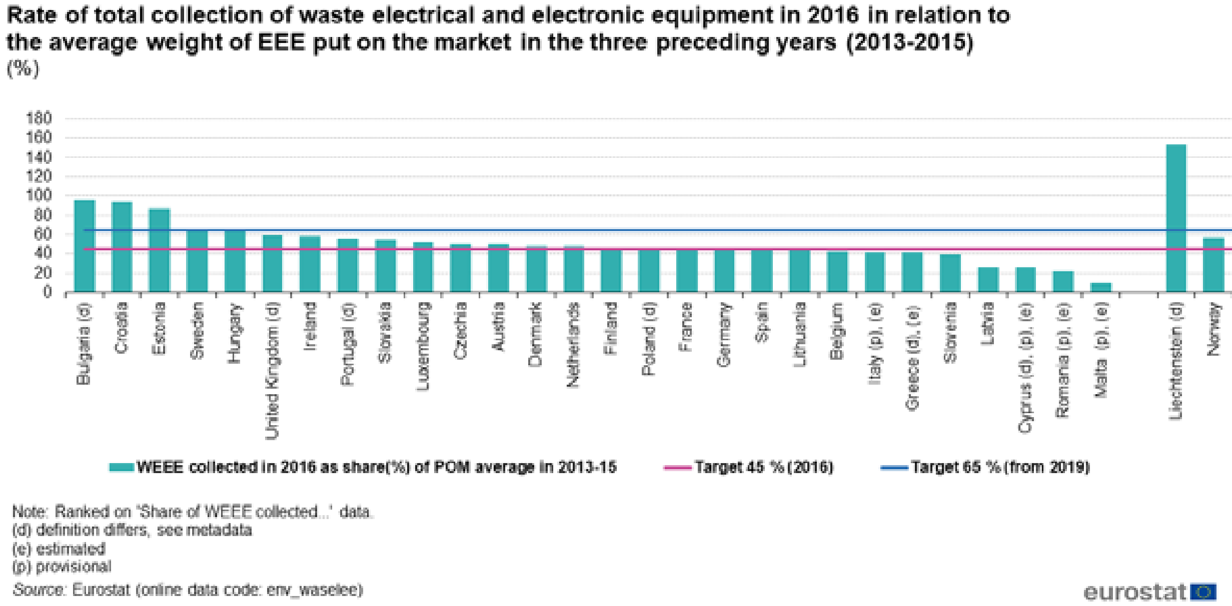
There are no data available.

5. WASTE MANAGEMENT OF ELECTRICAL AND ELECTRONIC EQUIPMENT

5.1. Description of waste streams

Waste electrical and electronic equipment (WEEE) is recycled or disposed of as solid waste. A certain amount of end of life EEE products are likely to be shipped outside the boundaries of the EU as second hand goods. Between 2015 and 2016, the amount of EEE put on the EU market increased by 2.9% from 9.8 million tonnes to 10.1 million tonnes. The amount of collected WEEE varies across EU Member States. In 2016, eighteen EU Member States achieved or surpassed the 44.9% collection target for WEEE. Large household appliances accounted for 55.6% of the total collected WEEE. IT and telecommunications equipment (14.8%) and consumer equipment and photovoltaic panels (13.5%) are the second and third largest categories for WEEE collection in the EU, accounting for 669 thousand tonnes and 610 thousand tonnes respectively. Small household appliances contributed with 408 thousand tonnes, accounting for 9.0% to WEEE collection. The remaining seven categories together totalled about 325 thousand tonnes, or 7.2% of WEEE collected in the EU in 2016.[69]

Figure 5-1: Rates of WEEE collected per EU country in 2016



Source: Eurostat (2019)

69 Eurostat (2019) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics_-_electrical_and_electronic_equipment&oldid=445263#EEE_put_on_the_market_and_WEEE_collected_in_the_EU

Hence, roughly 40% of the beryllium contained in the WEEE can be expected to enter a WEEE recycling process whereas the remaining 60% are disposed of together with WEEE as part of (municipal) solid waste. An unknown amount of beryllium is probably exported as second-hand EEE to non-EU countries. If disposed of as part of municipal solid waste, treatment in waste incineration plants (MSW) is the most likely disposal channel, whose endpoints are bottom ash and fly ashes from waste gas treatment. Beryllium and BeO that is liberated from WEEE during incineration may end up in both fractions. Some metal alloy parts (e.g. CuBe and NiBe) will likely pass the incineration process and could be recovered from the bottom ash. Fly ashes from MSWs are normally to be disposed of as hazardous waste and this is a likely endpoint for the bulk of beryllium co-incinerated in MSW incinerators.

5.1.1. Main materials where the substance is contained

As reported in section 2.2, EEE contains metallic beryllium mostly in the form of copper-beryllium alloys, whose beryllium content is usually below 2 percent. Beryllium oxide and beryllium-bearing ceramics occur in minor amounts only. As established in section 2.3, the consumption of beryllium commodities in the EU is estimated to be approximately 50 tonnes per year. Additional amounts of beryllium are likely to be imported as part of end products but do not enter trade statistics for beryllium commodities. It can be assumed that a similar amount enters the total WEEE generated in the EU.[70] Thereof, roughly 40 percent are collected and subjected to sorting and recycling (see 5.1). A further distinction into different materials and WEEE categories is not possible due to non-existent data on many EEE applications of different generations and the WEEE that emerges thereof at the end of product life with a delay ranging from a few months to many years.

5.1.2. WEEE categories containing the substance

According to the Information provided by the stakeholders in the course of the consultation, no sufficient data on the uses of beryllium in individual EEE categories could be established. Hence, the data gap extends to the end of life of EEE products. As explained in section 2.2, beryllium may occur in manifold types of EEE devices in form of an alloy metal, beryllium oxide for ceramic parts and beryllium alloys combining beryllium with metals such as copper, nickel, or aluminium.

Table 5-1: WEEE categories susceptible containing beryllium metal, BeO, or Be-ceramics

WEEE Category	beryllium susceptible to be present in WEEE
Cat. 1. Thermal exchange equipment	x
Cat. 2. Screens, monitors and equipment containing screens	x
Cat. 3. Lamps	x
Cat. 4. Large equipment	x
Cat. 5. Small equipment	x
Cat. 6. Small IT and telecommunication equipment	x

Questions for Stakeholders participating in the stakeholder consultation:

Further data as to the amounts and concentration of beryllium and BeO incorporated in specific EEE components is sought for. In, particular, information on the occurrence of the substances in individual EEE categories should be provided and a distinction between historical EEE products and contemporary EEE products should be made.

[70] Noteworthy to consider the possibility that present day WEEE may contain very old legacy devices with higher beryllium contents than modern EEE.

5.2. Applied waste treatment processes

The generic WEEE collection and recycling chain encompasses of four general steps, illustrated in Figure 5-2

1. Collection
2. Sorting/dismantling and pre-processing, incl. mechanical treatment such as shredding
3. End-processing, incl. refining of recycled materials
4. Disposal of residues

The recycling chain for end-of-life electrical and electronic equipment can be generically differentiated in the following steps:

Figure 5-2: Generic recycling chain for end-of-life EEE

Source: own illustration

WEEE collected for recycling is pre-sorted and then processed with the aim to recover valuable secondary materials and to separate hazardous materials. WEEE, which is separately collected, are either manually dismantled or shredded. This happens typically in large-scale metal shredders which can be combined with automated material sorting or specific shredders (e.g. horizontal cross-flow shredders, plants for treatment of screens etc.) (Knudson and Wilkins, 2014).[71]

Only a small amount, if any, of beryllium is recovered directly from post-consumer WEEE. Pure beryllium metal components used in technological applications have extremely long lifetimes (up to 30a), and, therefore, return to the recycle stream very slowly. TFS (2018) confirms the "*difficulty in separating Be containing metals from Electron Microscopes and X-Ray and Electron Spectrophotometers at end-of-life*". [72] The metallic beryllium components in WEEE are thus not specifically addressed by sorting and separation processes. The reason is the usually small size of the beryllium containing components in EEE products. Additionally, not all devices of a certain type contain beryllium bearing components so that the separation of beryllium containing WEEE by device type is no feasible option.

Co-processing with generic WEEE (usually done by shredding and then mechanical/physical separation) poses a difficulty for their identification beryllium bearing component among other metallic part and their separation under profitable circumstances. The low beryllium content in the alloys (beryllium-copper alloys contain 0.2% to 2.7% beryllium) poses little economic incentive for beryllium containing components in mass volume generic WEEE from post-consumer WEEE collection. The same applies for high concentrated beryllium components (e.g. X-ray windows). Such parts are usually small in size and would necessitate manual disassembly which cause too high labour costs compared to the recoverable value of beryllium scrap metal (the identification of beryllium within WEEE would require highly skilled workforce). The recycling of scrap metals from WEEE containing beryllium-copper alloy has been focusing on the economic profitable reclamation of the copper.

[71] Knudson, T.L. and Wilkins, H. (2014) An Evaluation of Airborne Beryllium Exposures During Recycling of Waste Electrical and Electronic Equipment (WEEE). Proceeding of the 13th International Electronic Recycling Congress (IERC), Salzburg, Austria January 23, 2014

[72] Thermo Fisher Scientific TFS (2018): Contribution submitted on 13.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15)

5.2.1. Initial treatment processes applied to the WEEE containing the substance of concern

Table 5-2: Initial WEEE treatment processes applied

Initial treatment processes	Beryllium may be present in appliances belonging to:					
	Cat1	Cat2	Cat3	Cat4	Cat5	Cat6
For WEEE collected separately						
Collection and transport	x	x	x	x	x	x
Dedicated treatment processes for cooling & freezing appliances	x					
Dedicated treatment processes for screens		x				
Dedicated treatment processes for lamps			x			
Manual dismantling	x	x		x	x	x
Shredding (and automated sorting)	x			x	x	x
For WEEE not collected separately						
Landfilling (of residual waste)		x	x		x	x
Mechanical treatment (of residual waste)		x	x		x	x
Incineration		x	x		x	x
Uncontrolled treatment in third countries	x	x		x	x	x

5.2.2. Treatment processes applied to wastes derived from WEEE containing the substance of concern

Table 5-3: Treatment processes for wastes derived from WEEE

Treatment processes for wastes derived from WEEE treatment	Beryllium may be present in the following main components/materials								
	Ferrous metals	Non-ferrous metals	Plastics	Electronic components	Cables	Glass	Powders	Fluids	Others
Under current operational conditions in the EU									
Storage of secondary wastes	x	x	(x)*	x	x		x	x	
Shredding and automated sorting of secondary wastes	x	x	(x)*	x	x		x		x
Recycling of ferrous metals	x								
Recycling of NE metals		x							
Recycling of plastics			(x)*						
Recycling of glass									
Recycling as building material									
Landfilling of residues	x	x	x	x	x		x	x	x
Incineration of residues	x	x	x	x	x		x	x	x
Co-incineration of residues	x	x	x	x	x		x	x	x
Dedicated processes for hazardous residues							x	x	
Under uncontrolled conditions **									
Acid leaching		x		x	x			x	
Grilling/desoldering		x		x	x				
Uncontrolled combustion		x	(x)		x				
Uncontrolled dumping of residues			(x)	x	x		x	x	x

` Be/BeO might be present as a contaminant

** risk refers to disposal of second-hand EEE exported to developing countries

5.3. Waste treatment processes relevant for assessment under RoHS

5.4. Releases from WEEE treatment processes

Beryllium bearing alloys are assumed to enter primarily one of the metal fractions of mechanical recycling processes. These are typically ferrous metals, copper alloys, and aluminium. BeO and beryllium ceramics are likely to enter the non-metal residue, which is usually disposed of as solid waste. Transfer factors depend on process technologies applied as well as the processing regime. Knudson and Wilkins (2014) analysed beryllium in the processed WEEE and found that *“concentrations were low ranging from <0.55 to 6.1ppm. Beryllium concentrations above the limit of detection were found in only 25% of the bulk samples”.* However, mechanical-physical shredding and sorting under badly controlled operation regime could distribute traces of Be-alloys and BeO across several output fractions. This may also include fractions that are not usually expected to contain beryllium (such as separated plastics (ABS, PVC).
Beryllium contained in alloys and electrical circuits is recycled using metallurgic smelting processes. However, beryllium is usually not the primary target of metallurgic recycling due to its low concentration in alloys. AEM (2018) maintains, “*the concentration of beryllium in recovered secondary metals (mainly copper) is so low as to be undetectable”*. The alloy makes up approximately 0.15% of the copper used in electrical equipment which, during pre-processing of end-of-life equipment, is collected together with other copper in the scrap and diluted to ~ 2 ppm in the copper recycling stream (Knudson and Wilkins, 2014). Rather, beryllium is contained in secondary copper may therefore be co-processed in copper refining plants. Secondary copper usually undergoes electrometallurgical refinery where beryllium is likely to enrich in the electrolyte or be precipitated as constituent of anode sludge, depending on the pH. These residues are normally subjected to chemical processing aiming at extraction of precious metals. It could not be established whether beryllium recovery takes place in practice. Knudson and Wilkins (2014) state that recovery of beryllium from metallurgic copper slags was not economically feasible. As a result, for old scrap the recycling flow value is quite high (~75%), but the recycled content and particularly the end-of-life recycling rate material specific rate are very low. The fate of beryllium in the recycling processes of other alloys (e.g. aluminium, nickel) also remains unclear. Detailed data on the quantities of recycled beryllium in the EU are not available.

Questions for Stakeholders participating in the stakeholder consultation:

Further data as to the amounts of recycled beryllium, specifically from WEEE is sought for. This includes, beryllium recycled from metallurgical processes which use secondary metals from WEEE as a feedstock.

Beryllium oxide and beryllium-bearing ceramics occurring in WEEE are hardly accessible for recovery because industrialised recycling processes are not adjusted for the recovery of oxides or ceramics. Such components are likely to end up in solid shredding residue and dust and are eventually destined for final disposal. Beryllium contained in nuclear or medical apparatus is difficult to recycle due to a risk of scrap being contaminated with other hazardous materials.

Exposure of end-users to beryllium is presumably low for most EEE applications that contain beryllium bearing components. The CORAP substance evaluation (CORAP 2014) did not, based on the assessed data “*indicate a concern based on consumer exposure to beryllium via consumer uses*”. Most EEE products contain beryllium alloys only within a casing and a release is unlikely under normal circumstances of use. Short term skin contact cannot be ruled out. However, the risk of contact allergy is limited as it occurs mostly due to long term exposure to beryllium.

One application area of **concern is electric motors with sliding contact brushes** used for instance in vacuum cleaners and electric tooling. According to Weiland et al (2011), “*a preferably used material for the construction of wires for sliding contacts are copper-beryllium alloys, in* *particular CuBe2, which are often used because of their good elastic properties"*.[73] Such sliding contact brushes are likely to release airborne beryllium bearing dust due to abrasion during the use phase.[74] Argibay et al (2010) observe "*debris flakes forming on the fibre tips with characteristic widths in the range 10–100 µm and thickness on the order of 1 µm*". Consumer exposure to CuBe2 debris depends on the type of device (hand held) and frequency of use but might exceed Occupational Exposure Limits. Measurement data on exposure levels are not available.

Questions for Stakeholders participating in the stakeholder consultation:

Further data as to the amounts of beryllium-bearing electric motors in professional and consumer EEE products should be provided. Moreover, please provide information on the types and their market volume of household products that contain beryllium bearing sliding contact brushes.

Additional data about concentration of beryllium-bearing particulate debris in exhaust air from motors are required to support the evaluation of occupational and domestic exposure during the use of such products.

5.5. Releases from WEEE treatment processes in developing countries

Old EEE products exported outside the EU in form of second-hand goods may end up in crude recycling processes. These may include manual crushing, open burning, open acid leaching and chemical precipitation as well as uncontrolled landfilling and dumping in the environment.

Acid leaching is often applied to extract precious metals from PWB. This process could dissolve metallic beryllium and BeO and form soluble beryllium compounds such as beryllium sulphate, beryllium chloride, or beryllium nitrate. Studies on informal recycling businesses in developing countries suggest that little if any safety precautions are usually taken. Workers are hardly protected against skin contact to chemicals and residues and airborne fumes. Thus, human and environmental exposure to soluble and insoluble beryllium compounds appears likely to occur. Specific information on quantities of WEEE processed under circumstances described above is not available nor is there any data on releases of beryllium and Be-compounds. It can be assumed that beryllium, among other hazardous chemicals emerging in the course of uncontrolled open burning and chemical leaching might be only a relatively small contributor to the serious health and environmental problems related to crude WEEE recycling.

[73] Weiland et al (2011) Wire for sliding contacts and sliding contacts, Patent DE102011106518A1

[74] Argibay, Nicolas & A. Bares, Jason & H. Keith, James & Bourne, Gerald & Gregory Sawyer, W. (2010). Copper–beryllium metal fiber brushes in high current density sliding electrical contacts. Wear. 268. 1230-1236. 10.1016/j.wear.2010.01.014.

6. EXPOSURE ESTIMATION DURING WEEE TREATMENT

Beryllium is a naturally occurring element and is ubiquitous throughout the environment. The substance is found in soils, rocks, coal, wood and foodstuffs. The general population is exposed to naturally occurring beryllium from ambient air, drinking water and diet on a daily basis. Additionally, beryllium is released from various technical processes, most notably combustion of coal but also from metal working processes. Although beryllium occurs in nature, the major source of its emission into the environment is through the combustion of fossil fuels (primarily coal), which releases beryllium-bearing dust and fly ash into the atmosphere. Most exposures to beryllium that cause human health effects are related to beryllium processing. The release occurs usually in form of airborne dust which can cause occupational exposure and environmental pollution of soil and water bodies. The average concentration of beryllium in outdoor air is < 0.03–0.07 ng/m³, with higher concentration in cities up to 6.7 ng/m³, and up to 100 ng/m³ near beryllium processing plants (ATSDR 2002,[75] WHO 2001[76]). The major route of human exposure is through airborne particles of beryllium metal, alloys, oxides, and ceramics. Beryllium particles are inhaled into the lungs and upper respiratory tract. Hand-to-mouth exposures and skin contact with ultrafine particles can also occur. Humans who live near sources of beryllium emissions are likely to be exposed to higher levels than the general population.

The contribution of WEEE recycling processes to beryllium-related environmental pollution and human exposure is unknown. BAUA estimated up to 65,000 workers being potentially exposed throughout the EU, though data did not allow estimating the actual workers in risk. The major exposure risk is likely to exist during the primary production processes of products that contain beryllium alloys. In 2016, BAUA concluded in its Risk Management Option analysis (RMOA) that further regulatory risk management activities are required for beryllium due to its hazard profile. With view at the DNEL for beryllium in dust of 60 ng/m³, "*a risk for workers exists at a lot of metal working processes"* whereas industry has thus far committed to a *"(voluntary) exposure limit of 200 ng/m³"* only".[77]

6.1. Basis of exposure estimation

Information specific to releases of beryllium bearing dust during the processing of WEEE is not available; therefore a number of assumptions need to be made. The exposure risk to beryllium bearing debris differs between the general steps of WEEE treatment (see Figure 5-2):

1. Collection
2. Sorting/dismantling and pre-processing, incl. mechanical treatment such as shredding
3. End-processing, incl. refining of recycled materials
4. Disposal of residues

- Assumption no 1: WEEE collection and pre-sorting is unlikely to cause elevated exposure levels above OEL because no abrasive forces occur.
- Assumption no 2: mechanical treatment such as shredding is likely to cause elevated exposure levels due to the abrasive nature of the processes. The actual exposure risk depends on the feedstock materials (e.g. PWB and electric connectors), the type of processing equipment as well as safeguard measures.
- Assumption no 3: End-processing of recycled materials is likely to pose a risk of occupational exposure to beryllium. However, the risk exists not exclusively due to RoHS-relevant recycling feedstock.

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[75] ATSDR, Agency for Toxic Substances and Disease Registry (2002) Toxicological profile for beryllium. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, GA, USA. http://www.atsdr.cdc.gov/toxprofiles/tp4.pdf last viewed 19.09.2019

[76] WHO, World Health Organization (2001) Concise International Chemical Assessment Document 32: Beryllium and Beryllium compounds, WHO, Geneva, Switzerland.

[77] BAUA (2016) Risk Management Option Analysis Conclusion Document, Substance Name: Beryllium

- Assumption no 4: Disposal of residues from recycling as well as disposal of untreated WEEE in waste incinerators may lead to occupational exposure to beryllium. However, the risk exists not exclusively due to RoHS-relevant constituents of waste.
- Assumption no 5: Occupational Exposure Limits apply throughout the whole WEEE treatment processing chain but monitoring and implementation may not take places at each and every WEEE processing site. In particular, small recycling businesses may lack the instruments necessary for monitoring airborne beryllium dust. Absence of monitoring and occupational safeguard measures is to be assumed in WEEE processing sites in developing countries.

6.2. Human exposure estimation

Little has been published about the occupational exposures of workers to beryllium in the WEEE recycling industry. Therefore, estimates of the number of people exposed to beryllium at work in the WEEE recycling industry are not possible. Knudson and Wilkins (2014) investigated the airborne beryllium exposure levels of workers processing WEEE in the UK. Results showed that "*All exposure measurements for airborne beryllium were below the level of analytical detection (<0.0069 µg/sample) and therefore below the […] OELs of 0.2 µg/m^3. Statistical analysis demonstrated that exposures are anticipated to be below this level greater than 95 percent of the time.*"
Based on the assumptions stated above, some potential hot spots of occupational exposures to beryllium bearing dust can be made: Workers and operators of mechanical and thermal WEEE treatment may be at risk to face peaks of exposure that exceed given Short Term Exposure Limits (STEL) if the feedstock currently processed contains legacy WEEE, which might contain higher than usual contents of beryllium compared to modern EEE products. Moreover, the occupational exposure at final disposal sites may exceed given STEL, if such legacy WEEE enters the disposal without proper pre-treatment. Workers in developing countries bear a high risk of occupational exposures to beryllium bearing dust.

As explained in 5.4, end consumers and professional users might be exposed to an unknown concentration of beryllium bearing dust released from electric motors with sliding contact brushes.

6.3. Environmental exposure estimation

Environmental exposure data specific to WEEE recycling processes are not available.

7. IMPACT AND RISK EVALUATION

The international risk-management standard ISO 31000 defines the term ‘risk’ as “the effect of uncertainty on objectives” (ISO 2011).[78] In the context of the RoHS Directive, Article 1 states its overarching objective as follows: “*contributing to the protection of human health and the environment, including the environmentally sound recovery and disposal of waste EEE*”. Thus, a risk can be regarded as a possible deviation from the objective to keep adverse impacts away from humans and the environment. To this end, the regulatory objective is to protect these safeguarded subjects against adverse impacts of hazardous substances contained in electrical and electronic equipment (EEE). The risk is considered as a function of a substance’s hazardous properties and the exposure of safeguard subjects to this substance. The risk evaluation provided in this section determines both aspects of risk in the case of beryllium oxide (BeO).

The hazard potentials of beryllium and beryllium oxide (BeO) are a result of the substances’ properties and their interaction with biota (human body and organisms). Section 3 provides information on the known hazard potential on human health. No data could be found about berylliums hazard potential to the environment.

In summary, it can be concluded that the health hazard potential of beryllium and BeO is significant. These substances are classified acute toxic by inhalation and oral ingestion and carcinogenic as well as skin irritating by dermal contact. Respiratory exposure do airborne beryllium is known to cause serious health impacts, “Beryllium Sensitisation” (BeS) as an early health effect and Chronic Beryllium Disease (CBD) due to long term exposure. However, uncertainty prevails regarding the dose-response relationship. The likelihood of adverse health impacts seems to be influenced not only by exposure levels but also due to a genetic predisposition of humans exposed to beryllium.

The possibilities of exposure at the working place and during the use phase of beryllium bearing EEE is outlined in section 6. In summary, it can be concluded that exposure to airborne beryllium might occur during the use phase of consumer EEE that contain high power electrical motors due to wear and tear of beryllium bearing sliding brushes. The resulting exposure levels are uncertain. Occupational exposure levels during the WEEE treatment are uncertain too. Is thought that the exposure at WEEE treatment plants remains below the OELs in force of 0.2 µg/m^3. However, short term exposure peaks cannot be ruled out and depend on the processing technology and safeguard measures applied. Concern regarding occupational exposure addresses mechanical shredding and hot-metallurgic recycling processes as well as final disposal of residues from recycling and untreated WEEE.

However, given the ubiquitous presence of beryllium and BeO in EEE products, there is reason to be alert of unexpected exposure hot spots. These might exist due to treatment of WEEE in incineration plants for MSW, uncontrolled disposal of concentrated residues, and crude WEEE recycling practices in developing countries.

[78] ISO (2011). ISO 31000: Risk management - principles and guidelines.

ALTERNATIVES

7.1. Availability of substitutes / alternative technologies

Due to its unique properties it is often recited that beryllium cannot easily be replaced by other materials without functional disadvantages, such as lower mechanical strength, elasticity and long term reliability. However, industry has already undertaken to limit the use of beryllium for economic reasons (AEM 2018). Beryllium-rich materials are expensive and therefore only used when its unique and enabling properties are indispensable for the technical application purpose or product reliability. For example, pure beryllium metal and Al-Be (62% Be) alloys are only used in applications where demanding performance requirements cannot be met by beryllium free alloys. CuBe alloy is only used when high functional reliability is essential to ensure safe operation in the defence, transport or energy sector. High performance EEE products, which contain beryllium in form of alloys or ceramics, are usually designed to be lightweight and slim (e.g. electronic components on printed wiring boards, electric contacts and heat sinks). Other industrial EEE applications may be designed for heavy duty use and long term reliability. Especially safety related applications contain beryllium alloys to ensure good performance and long term reliability.

The replacement of beryllium in alloys by other metals would in most cases be technically possible but would entail a decrease of the components' functional performance. Foley et al. (2017) state that "*In some less-demanding applications, copper alloyed with Ni-Si, Sn, Ti, or Sn-P may be substituted for high-cost beryllium-copper alloys, and aluminium nitride or boron nitride may be substituted for high-cost beryllium oxide with no loss in performance. The substitution of high-strength grades of aluminium metal, pyrolytic graphite (an ultra-thin graphite film with a thermal conductivity up to four times greater than that of copper), silicon carbide, steel, or titanium metal for beryllium metal or composites, however, can result in substantially reduced performance.*" JX Nippon states that the very high strength Cu-Ti alloy NKT322 has been already commercialised as a substitute to Cu-Be C172 (Be: 1.80-2.00 weight percent). However, ZVEI (2018) states that NKT322 GIGALLOY® achieves only about half of the conductivity of CuBe.[79] AEM (2018) provides a table (s. below) comparing the spring contact properties of copper beryllium with bronze alloys and also NKT322. The comparison given in Table 0-2 shows that copper beryllium with ca. 1.9% Be is superior overall, as it has higher electrical conductivity and the ratio of yield stress versus modulus of elasticity is higher than the other alloys.

[79] ZVEI (2018): Contribution submitted on 14.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15)

Table 0-1: Copper beryllium alloys and substitutes: comparison of properties

Alloy	Yield stress N/mm2	Modulus of elasticity GPa	Ratio of Yield stress / Modulus of elasticity	Conductivity %IACS
Copper beryllium (1.8 – 2%Be)[3]	1120	127	8.82	25
NKT322[4]	800 to 1050	120	6.67 to 8.75	10 - 13
Bronze CuSn8	750	110	6.81	12
Phosphor bronze CuSn9P	800	108	7.4	12
Comments	Altered by heat treatment	Absolute value is less important than ratio	Highest values are best spring performance	Depends on heat treatment, but high conductivity is important to reduce oxidation caused by resistance heating

Source: (AEM, 2018)[80]

Most of stakeholder responses from the 1st consultation state that substitution of beryllium in EEE leads to a loss of functional performance. BeST (2018) warns that "*it is not expected that any significant volume of beryllium usage can be substituted without an unacceptable loss of performance*".[81] For instance, the T&M Coalition states that "*there are no known alternatives that meet equivalent performance specifications or can assure the reliability of substitution required for of Category 9 industrial equipment*".[82] ESIA (2018) comments, "*An example of two materials exhaustively studied to replace BeO are diamond and Aluminum Nitride. However, these and other materials have various challenges inhibiting their adoption, especially for high power RF Power semiconductor packaging*".[83]

Improper substitution of beryllium alloys, metals, or composites has resulted in higher risk of technical failure of certain components and thus reduced their product service life. Therefore, a substitution of beryllium in certain key components could entail an increase in failure rates of EEE products thus adding to the generation of WEEE.

On the other hand, the electronics industry has been assessing the availability of substitutes for Be for economic reasons. As compared to potential substitutes, beryllium is a relatively expensive raw material and necessitates the implementation of expensive measures for occupational safety and pollution reduction throughout the production chain. Many EEE manufacturers have already reduced or even banned the use of beryllium bearing components in their products in order to improve end consumer acceptance Table 0-2. The overview shows that numerous EEE manufacturers have started to implement voluntary measures for phasing out beryllium from their products. Thus, it can be inferred that the unique and enabling properties of beryllium are less indispensable for the EEE industry than explained above. While engineering details are not publicly

80 AEM (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15);

81 Beryllium Science & Technology Association BeST (2018): Contributions submitted during stakeholder consultation on 15 June.2018;

82 T&M Coalition (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15)

83 European Semiconductor Industry Association (ESIA) Coalition (2018): Contribution submitted on 15.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15)

communicated there is a reason to assume that a reduction of beryllium in certain types of consumer EEE is not impossible after all. Also windows of Low Energy X-Ray detector instruments that do not require mechanical toughness "*can be made of thin Silicon Nitride (Si3N4)* and *have been successfully used; the benefits in are significant compared to Beryllium*".[84] TFS (2018) counters that "*Currently, there are no known material substitutions for Be or BeCu alloys in Electron Microscopy or X-ray or Electron Spectrophotometers*".

Table 0-2: Overview of various EEE manufacturers and their corporate policies regarding substitution of beryllium

EEE manufacturers	Substitution policy for beryllium
Apple	Self-commitment to eliminate beryllium in products down to < 1,000 ppm. As of 2019, beryllium-copper connectors and springs are eliminated from all new product designs
ASUS	Asus has shown progress on the elimination of beryllium
Dell	Dell monitors the use of beryllium but has not set elimination targets or threshold restrictions.
Google	Google has restricted the use of beryllium
HP	HP restricts the use of beryllium with a threshold limit of 1,000 ppm with the exemption of ceramics in electronic components and electrical bonding applications of beryllium copper, such as connectors, springs, or EMI gaskets. In 2019, HP states that they will restrict all remaining uses of beryllium in PCs and Displays.[85]
Huawei	Huawei has not published commitments to eliminate the use of beryllium and beryllium compounds in consumer products but reports it has restricted its use since 2016
Lenovo	Lenovo added phase-out target for beryllium and its compounds in 2019.[86] Suppliers are required to quantify and report the beryllium content for individual parts, thresholds for Be and BeO are between 1,000 ppm (e,g. heat sinks and insulator ceramics) and 200 ppm (IC substrates and housings alloys).
LG	Phasing out beryllium from mobile phones since 2011
Olympus OSSA	Olympus OSSA does not use EEE components containing Be compounds or Be alloys.[87]
Samsung	Since 2013, beryllium compounds phased out of all products
Sony	Sony has not published a timeline for phasing out beryllium but declares that today all Xperia™ products (smartphones) are beryllium-free.[88]

84 EDAX, Inc. (2018): Contribution submitted on 06.08.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15)

85 HP (2019) General Specification for the Environment http://h20195.www2.hp.com/V2/getpdf.aspx/c05117791.pdf

86 Lenovo (2019) Lenovo Engineering Specification 41A7731, Baseline Environmental Requirements for Lenovo Products, Materials and Parts. https://www.lenovo.com/us/en/pdf/41A7731.pdf

87 OLYMPUS OSSA (2018): Contribution submitted on 05.06.2018 during the stakeholder consultation conducted from 20 April 2018 to 15 June 2018 in the course of the study to support the review of the list of restricted substances and to assess a new exemption request under RoHS 2 (Pack 15); http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_15/1st_Consultation_Contributions/OlympusOSSA_Submission-for-beryllium-and-its-compounds.pdf

88 https://blogs.sonymobile.com/about-us/sustainability/substance-control/substances-of-concern

Sources: (Greenpeace, 2017)[89], various Engineering Specifications

The following materials have been considered for substitution of beryllium and have presented the following issues Table 0-3:

Table 0-3: Possible substitute materials for beryllium in various application areas

Application Sector	Substitute materials	Issues with the substitute materials
Telecommunications electronic/automotive electronics/aerospace and defence electronics	Alloys of copper: e.g. CuZn brasses; CuSn bronzes, CuNiSi alloys etc.	Insufficient combination of strength/ formability/electrical conductivity/ stress relaxation resistance/failure to resist vibration/corrosion resistance
Aerospace/defence structural components	Titanium	Higher density / lower specific stiffness (modulus/density)
	Carbon fibre composites	Formability / high and low temperature properties / specific stiffness/ weldability / fracture toughness Impact resistance / specific heat
Aerospace/Defence industrial components	Alloys of copper: e.g. CuZn brasses; CuSn bronzes, CuNiSi alloys etc.	Insufficient combination of strength/ formability/thermal conductivity/ stress relaxation resistance/failure to resist vibration/corrosion resistance
Other: e.g. X-ray windows	Titanium / aluminium / polymers / glass	Reduced resolution of the X-ray or CT scan images leading to reduced detection of tumours and medical issues
Beryllium oxide laser bores	Aluminium oxide ceramic	Thermal conductivity
Nuclear facilities, e.g. ITER fusion reactor lining	Tungsten	Fail safe nuclear interaction of beryllium as a neutron reflector is lost, reducing safety margin in the event of loss of magnetic control of the hot gas plasma

Sources: Merchant Research & Consulting Ltd, London (2012): Beryllium Market Review. Quoted by (BeST, 2018)

7.2. Hazardous properties of substitutes

BeST (2018) states that Cu-Ti alloy (e.g. NKT322) has a risk classification for work-related cancer similar to that of CuBe. ECHA has concluded[90] that titanium dioxide (TiO_2) meets the criteria to be classified as a Category 2 carcinogen. As TiO_2 is used in the production of copper titanium alloys, there is a risk of occupational exposure although the health impacts of TiO_2 differ from those of beryllium exposure (BES and CBD). However, the mechanisms of formation of airborne TiO_2 during technical processes differ from those of beryllium bearing dust. It is unlikely that airborne TiO_2 emerges from Cu-Ti alloys during WEEE processing and recycling operations.

Other possible substitutes, as far as applicable, do not impose hazards that differ from those of general metal working industry.

7.3. Data basis for alternatives and uncertainties

The producers of beryllium free metal alloys assert that substitute materials are on the market for various applications. However, the available alternatives are not suitable for all applications of beryllium alloys. It is understood that substitution materials exist but their inferior technical

[89] Greenpeace (2017) Guide to Greener Electronics 2017, Report Cards. https://www.greenpeace.org/usa/reports/greener-electronics-2017/

[90] https://echa.europa.eu/-/titanium-dioxide-proposed-to-be-classified-as-suspected-of-causingcancer-when-inhaled

performance limits their usefulness to almost all fields of application of beryllium. Also alternative technologies and product designs (e.g. more bulky physical design, wireless data transfer to eliminate pin contacts) can be considered, but are either characterised to suffer significantly from reduced performance data, as well as higher energy consumption or are generally considered unsuitable in a given application context. Therefore, more efforts in development of tailored beryllium free metal alloys would be necessary if beryllium was restricted in EEE.
The information specified above regarding alternatives for beryllium and BeO originates from various documents generated also in the context of the REACH and CLP regulations. Such documents are understood to have been subject to review, stakeholder consultations as well as scrutiny of academic and professional expertise. Hence, these sources have to be granted a relatively high level of confidence.

8. DESCRIPTION OF SOCIO-ECONOMIC IMPACTS

The socio economic impact analysis is inapplicable as the substance is not recommended for restriction in ANNEX II of ROHS.

9. RATIONALE FOR INCLUSION OF THE SUBSTANCE IN ANNEX II OF ROHS

There is currently little support in available data justifying a regulatory restriction of beryllium and BeO in EEE under RoHS. Industry stakeholders insist on the high technological importance of beryllium for the European EEE sector, as well as all possible end-application areas of EEE products. Since beryllium in alloys and in form of BeO in ceramics seems to be a very ubiquitous constituent of EEE, a regulatory restriction would entail massive shortcomings in functional performance of EEE products used in the EU. In particular, EEE of the RoHS categories 8 and 9 (bio-medical and industrial devices) would be affected because existing products are hard to redesign with beryllium free materials. Although some substitute materials are available, they do not match with the technical requirements in all respective application areas of beryllium. A reduction or substitution of beryllium and BeO necessitates research & innovation in alternative materials as well as product testing and certification, especially as it comes to medical and safety relevant products. Given the relatively high technical importance of the substances and based on the result of the risk evaluation that beryllium and BeO in EEE pose medium risks during WEEE treatment and disposal, the **inclusion of beryllium and BeO in ANNEX II of ROHS is currently not recommended.** This recommendation is in line with BAUA (2016), who expressed the opinion, that "*a general or even a partial ban will undoubtedly reduce risks, the societal impacts would be disproportionate*".[91] BAUA states that the health hazards of beryllium and BeO, in particular CBD and even CBS "can *be regulated through an OEL"* (occupational exposure limits). BAUA also indicates the "*high potential for risk reduction capacity and equivalent high health benefits for the workers. On the other hand additional costs for the measures for exposure reduction may incur e.g. plants with encapsulated equipment. However, taking into account the investment for the continuous improvement, the additional costs would be proportional to the benefits arising from exposure reduction.*" The recommendation not to restrict beryllium under REACH implies that European WEEE recyclers make progress in implementing exposure controls in order to meet established OELs of 0.6/0.2 µg/m^3 for airborne beryllium at mechanical and thermal treatment plants throughout the EU. The implementation of exposure controls in WEEE treatment plants is beneficial beyond the prevention of BES and CBD since the same measures can reduce the release of other pollutants (e.g. heavy metal bearing dust) at the same time. Moreover, specific risk management measures should be implemented in the WEEE collection and recycling system in Europe. Specifically, domestic WEEE collection targets should be increased and the uncontrolled movement of WEEE (or second-hand EEE) towards recipients in developing countries should be stopped.

In addition, certain measures should be taken into account to cut the likelihood of exposure to beryllium:

- A selective restriction of beryllium-coper alloys for sliding contact brushes in consumers and professional EEE such as vacuum cleaners and tools should be considered. As a first measure, the relevance of such applications in the consumer domain should be explored.
- SCOEL and DG Employment are encouraged to prioritize setting an OEL for beryllium. This implies the adoption of emission controls and exposure reduction measures in the WEEE recycling industry throughout, as suggested by BAUA (2016). The SCOEL (2017) suggested 8-hour TWA (Time weighted averages) 0.02 µg/m^3 inhalable beryllium fraction should be endorsed by EU.
- EEE manufacturers should commit to a voluntary reduction of beryllium in products. The development and implementation of a voluntary product stewardship program towards a phase out of beryllium was suggested by BAUA (2016) as a way to avoid the classification of beryllium and compounds as SVHC under REACH. A similar approach is recommended here to avoid restriction under RoHS. The beryllium content in many EEE products can be lowered to below 1,000 ppm as numerous large EEE manufacturer in the sector of consumer electronics have demonstrated (see Table 0-2). The voluntary measures should be adopted by the whole EEE sector, at least OEM and industrial EEE suppliers should reconsider possible alternatives to beryllium in the light of functional and design requirements. A case to case evaluation could reveal opportunities for reducing the beryllium concentration in various components where its presence is not essential to the function. OEM should require their

[91] BAUA (2016) Risk Management Option Analysis Conclusion Document, Substance Name: Beryllium (November 2016)

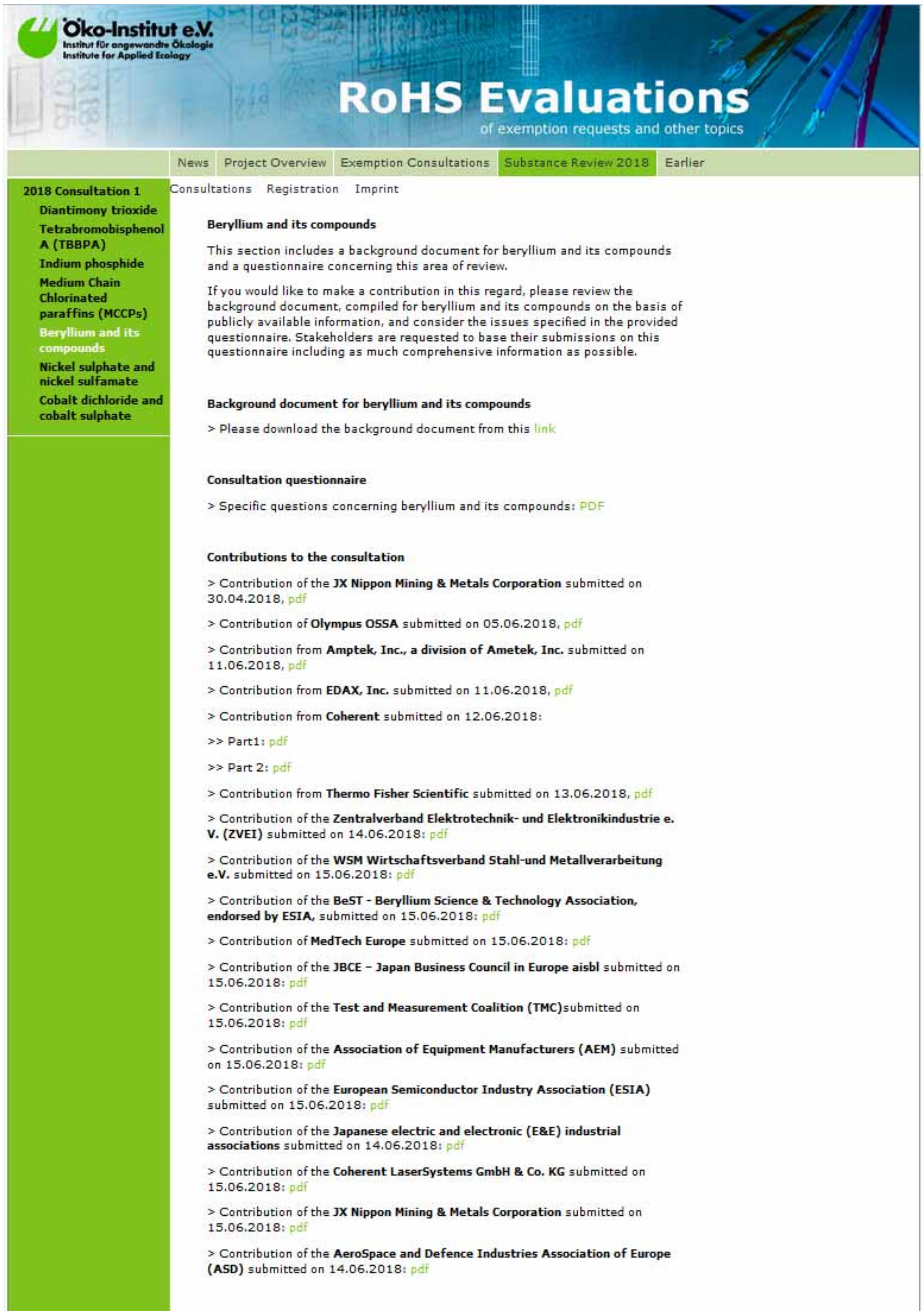
suppliers (components manufacturers) to indicate the concentrations of Be in weight of their intermediary products.

10. List of References

Baron et al (2014)	Baron, Y.; Blepp, M.; Gensch, C.-O.; Moch, K. (Oeko-Institut e.V.); in collaboration with Hogg, D. (Eunomia Research & Consulting Ltd.); Study for the review of the list of restricted substances under RoHS 2 – Analysis of impacts from a possible restriction of several new substances under RoHS 2, 2014; commissioned by the EU Commission, DG Environment; available at: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Substance_Review/20140806_Substance_Review_revised_version_final_plus_Dossier.pdf, last viewed 19.04.2018
Foley et al (2017)	Foley, N.K., Jaskula, B.W., Piatak, N.M., and Schulte, R.F., 2017, Beryllium, chap. E of Schulz, K.J., DeYoung, J.H., Jr., Seal, R.R., II, and Bradley, D.C., eds., Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological Survey Professional Paper 1802, p. E1– E32, https://doi.org/ 10.3133/pp1802E. available at: https://pubs.usgs.gov/pp/1802/e/pp1802e.pdf, last viewed 19.08.2019
Knudson & Wilkins (2014)	Knudson T.; Wilkins, H.; An evaluation of airborne beryllium exposures during recycling of waste electrical and electronic equipment (WEEE), published in the Proceeding of the 13th International Electronic Recycling Congress (IERC), Salzburg, Austria, January 23, 2014
Taylor et al (2003)	Taylor, T. P., Ding, M., Ehler, D. S., Foreman, T. M., Kaszuba, J. P., & Sauer, N. N. (2003). Beryllium in the Environment: A Review. Journal of Environmental Science and Health, Part A, 38(2), 439–469.

11. Appendix II: Contribution to stakeholder consultation hold from 20 April to 15 June 2018

Figure 11-1: Non-confidential contributions submitted regarding Beryllium and its compounds



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2018 Consultation 1
- Diantimony trioxide
- Tetrabromobisphenol A (TBBPA)
- Indium phosphide
- Medium Chain Chlorinated paraffins (MCCPs)
- Beryllium and its compounds
- Nickel sulphate and nickel sulfamate
- Cobalt dichloride and cobalt sulphate

Beryllium and its compounds

This section includes a background document for beryllium and its compounds and a questionnaire concerning this area of review.

If you would like to make a contribution in this regard, please review the background document, compiled for beryllium and its compounds on the basis of publicly available information, and consider the issues specified in the provided questionnaire. Stakeholders are requested to base their submissions on this questionnaire including as much comprehensive information as possible.

Background document for beryllium and its compounds

> Please download the background document from this link

Consultation questionnaire

> Specific questions concerning beryllium and its compounds: PDF

Contributions to the consultation

> Contribution of the **JX Nippon Mining & Metals Corporation** submitted on 30.04.2018, pdf

> Contribution of **Olympus OSSA** submitted on 05.06.2018, pdf

> Contribution from **Amptek, Inc., a division of Ametek, Inc.** submitted on 11.06.2018, pdf

> Contribution from **EDAX, Inc.** submitted on 11.06.2018, pdf

> Contribution from **Coherent** submitted on 12.06.2018:

>> Part1: pdf

>> Part 2: pdf

> Contribution from **Thermo Fisher Scientific** submitted on 13.06.2018, pdf

> Contribution of the **Zentralverband Elektrotechnik- und Elektronikindustrie e. V. (ZVEI)** submitted on 14.06.2018: pdf

> Contribution of the **WSM Wirtschaftsverband Stahl-und Metallverarbeitung e.V.** submitted on 15.06.2018: pdf

> Contribution of the **BeST - Beryllium Science & Technology Association, endorsed by ESIA,** submitted on 15.06.2018: pdf

> Contribution of **MedTech Europe** submitted on 15.06.2018: pdf

> Contribution of the **JBCE – Japan Business Council in Europe aisbl** submitted on 15.06.2018: pdf

> Contribution of the **Test and Measurement Coalition (TMC)**submitted on 15.06.2018: pdf

> Contribution of the **Association of Equipment Manufacturers (AEM)** submitted on 15.06.2018: pdf

> Contribution of the **European Semiconductor Industry Association (ESIA)** submitted on 15.06.2018: pdf

> Contribution of the **Japanese electric and electronic (E&E) industrial associations** submitted on 14.06.2018: pdf

> Contribution of the **Coherent LaserSystems GmbH & Co. KG** submitted on 15.06.2018: pdf

> Contribution of the **JX Nippon Mining & Metals Corporation** submitted on 15.06.2018: pdf

> Contribution of the **AeroSpace and Defence Industries Association of Europe (ASD)** submitted on 14.06.2018: pdf

Source: http://rohs.exemptions.oeko.info/index.php?id=294, last viewed 24.07.2018