Other electronic devices

Canada, EU, and other stakeholders (IPEN)

1. **Mercury slip rings**
2. **Reference electrodes for calibration of pH measuring devices**
3. **Infrared detectors**
4. **Melt pressure transducers, transmitters and sensors using a capillary system**
5. **Mercury vacuum pump (note that this includes non-elecreic device)**
6. **Radiation light detectors**

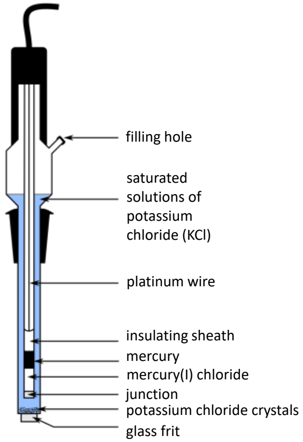
1. Category of mercury-added product	**Switches, relays and other electric devices**
2. Further description of the product (if any)	**1. Mercury slip rings**
3. Information on the use of the product	A device that provides 360-degree rotations to transmit signal and power between stator (stationary) side and rotor side of different industrial equipment. This product uses mercury as a conductor to transfer current and signal as a liquid at normal temperatures.
4. Information on the availability of mercury-free (or less-mercury) alternatives	**Canada** There are many manufacturers of mercury-free slip rings, which are widely available in all shapes and sizes. • Conductive block slip rings: used mainly for lower technology applications involving transmitting power or simple signals. These use carbon or metal alloy brushes to transmit signals. • Fiber brush slip rings: suited for a wide variety of applications and come in many sizes. Brushes made of different metal fibers transmit power and signals from a rotating ring. Metal fiber brushes ensure a high contact quality and low wear due to their flexibility. Alloys of steel and other common metals are common for power transmission, whereas gold alloys are used for signal transmission since gold does not oxidize and therefore maintains quality over time. • Wireless slip rings: use the principle of capacitive or inductive coupling for power and signal transmission. • Fiber optic slip rings (fiber optic rotary joints): the optical equivalent of a wireless slip ring. Light waves are synchronized between two ends using optic fibers. • Liquid metal slip rings using a gallium alloy instead of mercury are also available.

	IPEN Alternatives are readily available for mercury slip rings for signal transmission between rotos and stators on industrial equipment.
5.(i) Information on the technical feasibility of alternatives	**Canada** • Compared to mercury slip rings, conductive block slip rings have greater weight and volume for the same circuits, greater capacitance and crosstalk, are louder, do not last as long and require regular maintenance. Sparking may also occur if dust is present. Conductive block slip rings are low cost and are easily customized for mechanical assemblies in house since brushes and rings are available separately.[1] • Fiber brush slip rings have a large flexibility in use and can be used in a wide range of applications, from high power transmission to high frequency signal transmission. Fiber brush slip rings have an excellent volume to current ratio and are relatively maintenance free.[1] They also have a high frequency electric signal transmission and do not make a lot of noise. These are more costly than conductive block type slip rings but have comparable costs to mercury slip rings. • Wireless slip rings lack standard mechanical parts meaning they are more resilient in harsh operating environments and require less upkeep and maintenance. However, the amount of power that can be transmitted between coils is somewhat limited compared to mechanical-type slip rings. Wireless slip rings are generally less efficient than other slip rings and the loss of efficiency is proportional to the distance between the two components. One benefit of wireless slip rings is that there are many possible configurations for their placement. They are well suited for applications that need high rotational speeds and where there is poor access for maintenance.[1] Wireless slip rings are more costly than mechanical types of slip rings; however, slip ring manufacturers are investing most in developing and refining wireless slip ring technologies.[2] As this technology grows, costs will likely decline. • Fiber optic rotary joints enable continuous rotation of one or more optic fibres without affecting the signals transmitted along them. These are most beneficial for applications where a twist-free cable is needed. Single channel rotary joints are relatively simple and can be very compact while permitting high rotational speeds, good reliability, and little loss of performance over time. Multi-channel rotary joints can be very complex and need to be manually aligned when very high performance is required.[1] Often fiber optic joints are incorporated into other rotary components as the centre of the rotary assembly. These are quite costly, and costs are related to the overall size of the complete rotary joint assembly. • Mercury slip rings are limited by temperature since mercury solidifies as -40 C. The other types of slip rings do not have this limitation.

	Japan Analytical Instruments Manufacturers' Association (JAIMA) The Hg based ERC(Electric Rotating Connector=slip ring) component within ACIST IVUS could not be replaced with a RoHS compliant component at present. This falls under RoHS exemption 42 (Mercury in electric rotating connectors used in intravascular ultrasound imaging systems capable of high operating frequency (＞50MHz) modes of operation.) (ref3). Some other slip rings are also using mercury for special purposes.
5.(ii) Information on the economic feasibility of alternatives	NA
6. Information on environmental and health risks and benefits of alternatives	NA
7. If any, additional information being submitted on mercury-added products pursuant to Article 4.4 of the Convention not addressed above (e.g. manufacture, general trade information, etc.)	NA
8. Other relevant information pursuant to Decision MC-3/1	NA
9. References	1. Servotechnica. (2017) What is a slip ring. 2. Research and Markets. (2019). Global slip rings market 2019-2023. JAIMA Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment (RoHS Directive) Final Report – Pack P108 https://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_16/Excerpt_Oeko-Institut_report_2014_AnnexIV_Ex_42.pdf

1. Category of mercury-added product	**Switches, relays and other electric devices**
2. Further description of the product	**2. Reference electrodes for potentiometric measurement including pH**
3. Information on the use of the product	

	An electrode with a stable and known electric potential that is used in electrochemical measurements. The reference electrode allows control of the potential of a working electrode or the measurement of an indicator electrode[1] Mercury-containing reference electrodes include calomel (Hg/Hg_2Cl_2), mercurous sulphate (Hg/Hg_2SO_4) and mercuric oxide (Hg/HgO) electrodes. The calomel electrode was widely used for pH measurements, while mercurous sulphate is used for other potentiometric measurements e.g. for silver, halides and chemical oxygen demand titrations.[2] **Comments from experts** A reference electrode maintains a virtually invariant potential under the conditions prevailing in an electrochemical measurement, and that serves to permit the observation, measurement, or control of the potential of the indicator (or test) or working electrode (definition by IUPAC[14]). They are typically used in combination with pH electrodes to measure the acidity of a fluid such as an aqueous solution, in a laboratory, in industrial processes, or in the field. Often, a reference electrode and a pH electrode are combined in one device. Other applications for reference electrodes include potentiometric determination of the oxidation potential (or redox potential) and specific ion concentrations (e.g. chloride). Several types of reference electrodes exist. The most important is the standard hydrogen electrode (SHE), whose potential is zero by definition. The potentials of all other electrodes are determined in relation to the SHE. The SHE itself is difficult to handle in practice due to the use of gaseous hydrogen. Much more common is the silver/ silver chloride reference electrode. There are at least three types of mercury-based reference electrodes commercially available: • The (saturated) calomel electrode (SCE) (includes mercury(I)chloride or Hg_2Cl_2), also referred to as low chloride mercury chloride electrode. • The mercury oxide electrode (HgO) • The mercury (I) sulphate electrode (Hg_2SO_4, also referred to as mercury-mercurous sulphate electrode) Historically, the calomel electrode was the most widely used reference electrode until it was replaced more and more by other types[15]

	 **Figure 1: Principal components of a calomel electrode (source: Wikipedia.org)**
4. Information on the availability of mercury-free (or less-mercury) alternatives	**Canada** The mercury-free alternatives are made of glass and contain potassium chloride (KCl) with silver/silver chloride (Ag/AgCl2). 3, 4, 5. 4, 5, 6 Uses of mercury-containing electrodes appear to have been largely phased out in Canada due to a movement away from this type of electrode, likely due to the human health risks, extra handling precautions, and disposal costs associated with mercury. Mercury-free electrodes are available from all major scientific equipment suppliers in Canada and some no longer have mercury-containing electrodes available. **Japan Analytical Instruments Manufacturers' Association (JAIMA)** Silver/silver chloride electrodes have replaced mercury chloride electrodes in most applications but cannot replace low chloride, mercury sulphate or mercury oxide. (ref5). It falls under RoHS exemption 1d (Mercury in reference electrodes: low chloride mercury chloride, mercury sulphate and mercury oxide.)
5.(i) Information on the technical feasibility of alternatives	**Canada** Mercury-containing electrodes show the most stable potential in the presence of potassium chloride; however, the reliable temperature range of mercury chloride is narrow. Above 60^{o}C, it begins to degrade.

	Mercury-free electrodes can work in a wide range of temperatures (up to 140^{o}C) and are therefore able to be heat-sterilized.[7] Electrodes made of silver/silver chloride can be affected by sulphides and cannot directly be used as a reference electrode for chemical analysis of chloride or silver concentrations. However, a barrier can be put in place and allow the silver/silver chloride electrodes to be used in sulphide environments and environments with other metal ions. Mercury-free alternatives are generally marginally more expensive than mercury containing electrodes but come in a variety of body styles (where mercury-containing electrodes are limited) and are refillable.[8] A newer iodine/iodide system has also been developed and is much less sensitive to temperature fluctuations.[7, 12] The iodine/iodide system is free of silver and other heavy metals, which is useful when measuring Tris buffers and protein solutions, since reference electrodes using silver/silver chloride would require the use of barriers.[7, 11] This system is considerably more expensive than other alternatives, but is one of the only options suitable for analyses with chloride ions and is more accurate and precise than silver/silver chloride reference electrodes.[12] **Comments from experts:** At least for the vast majority of fluids to be measured (pH 1-14, aqueous and non-aqueous, presence or absence of chloride), alternative reference electrodes allow reliable and traceable measurements of pH as well as other solution properties. The replacement of the calomel electrode by the silver chloride electrode is also recommended by the United States Pharmacopeial Convention (2017)[16]. Many leading electrode manufacturers no longer have mercury-containing electrodes in their program and recommend the use of silver chloride or proprietary reference electrode systems[15]. Mercury-containing reference electrodes may be needed for specific research activities where specific thermodynamic solution properties are investigated. The mercury oxide electrode is still advertised for the characterization of solutions with extreme pH (>14), such as in concentrated solutions of potassium hydroxide or sodium hydroxide in some battery electrolytes. According to industry information, monitoring of the concentration of extremely alkaline etching solutions (such as KOH) can also be measured by conductivity, densitometry, or refractometry thus eliminating the need for potentiometric measurements. It needs to be verified if these mercury-free devices fully cover the application range of mercury oxide electrodes. The mercury (I) sulphate electrode (Hg/Hg_2SO_4, mercury-mercurous sulphate electrode was indicated in cases where contamination with chloride from the reference cell was not desirable. Since chloride-free reference electrodes (e.g. iodine/iodide) are now available and double junction electrodes may be sufficient to block the

	release of chloride from the Ag/AgCl reference electrodes, the continued need for Hg/Hg_2SO_4 electrodes appears to be doubtful.
5.(ii) Information on the economic feasibility of alternatives	NA
6. Information on environmental and health risks and benefits of alternatives	**Canada** Handling and disposal are less of an issue with silver/silver chloride systems since silver is non-toxic to humans. For example, the safety data sheet for mercury chloride electrodes list them as having acute toxicity due to inhalation risks, reproductive toxicity, and repeated exposure toxicity.[9] Whereas silver/silver chloride solutions used in electrodes are listed only as causing skin and eye irritation.[10] Iodine/iodide systems would not be subject to strict handling or disposal procedures since iodine/iodide solution is not toxic to humans but could cause skin or respiratory tract irritation.[13] **Comments from experts** The use of mercury-containing reference electrode includes the following risks: • Mercury spillage/contamination in case of damage to the product (inside or outside the human body) • Contamination of the measuring solution by slow diffusion of mercury-contaminated filling solution into the fluid that is being measured • Mercury spillage/contamination in case of inappropriate disposal of waste product/ contaminated filling solutions
7. If any, additional information being submitted on mercury-added products pursuant to Article 4.4 of the Convention not addressed above (e.g. manufacture, general trade information, etc.)	NA
8. Other relevant information pursuant to Decision MC-3/1	NA

9. References

1. Kahlert, H. (2005). Reference electrodes. In: Scholz F. (eds) Electroanalytical Methods. Springer, Berlin, Heidelberg. Available from: https://link.springer.com/chapter/10.1007/978-3-662-04757-6_14

2. COWI (2008). Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society. Final report for the European Commission prepared by Lassen, C., Holt Andersen, B., Maag, J & Maxson, P.

3. Fisher scientific. (2020). Fisherbrand accumet glass body Ag/AgCl reference electrodes – mercury-free. Available from: https://www.fishersci.com/shop/products/fisher-scientific-accumet-glass-body-ag-agcl-reference-electrodes-mercury-free-4/p-2903565
4. Sensorex. (2012). Product specification sheet: Sensorex new 'calomel free' epoxy and glass body pH and reference electrodes. Available from: https://www.sensorex.com/docs/specs/SpecsCalomelFree.pdf
5. Autolab electrochemical instruments. (N.D.) Autolab application note: reference electrodes and their usage. Available from: http://www.autolabj.com/appl.files/appl%20note/Appl038.pdf
6. Fisher scientific. (2020). Fisherbrand accumet epoxy body mercury-free reference electrode. Available from: https://www.fishersci.com/shop/products/fisher-scientific-accumet-epoxy-body-mercury-free-reference-electrode/p-4950075#?keyword=mercury+sulphate+reference+electrode
7. YSI (2019). Anatomy of pH electrodes. Available from: https://www.ysi.com/ysi-blog/water-blogged-blog/2019/02/anatomy-of-ph-electrodes
8. ThermoFisher Scientific. (N.D.) Essentials of pH measurement. Available from: http://www.ohiowea.org/docs/1500_pH_Seminar_Meirose.pdf
9. Koslow Scientific. (2015). Kit product number: Saturated calomel electrode (SCE), Safety data sheet. Available fromhttps://www.ameteksi.com/-/media/ameteksi/download_links/documentations/supportcenter/princetonappliedresearch/safety_data_sheets/g0115_saturated_calomel_electrode.pdf?la=en
10. ThermoFisher Scientific. (2014). Safety data sheet, Filling solution: 4M KCL saturated with Ag Cl. Available from: https://www.fishersci.com/shop/msdsproxy?productName=SP135500&productDescription=POTASSIUM+CHLORID+SOL+4M+500ML&catNo=SP135-500&vendorId=VN00033897&storeId=10652
11. Engineer Live. (2013). Innovative pH electrodes with iodine/iodide reference system. Available from: https://www.engineerlive.com/content/innovative-ph-electrodes-iodineiodide-reference-system
12. Fisher scientific. (2020). Sartorius GoldLINE electrodes. Available from: https://www.fishersci.ca/shop/products/goldline-electrodes/p-5295538
13. Home science Tools. (2018). Safety data sheet: iodine-potassium iodide solution. https://www.homesciencetools.com/content/reference/CH-IODINE.pdf

14. International Union of Pure and Applied Chemistry (IUPAC) (2014) Gold book. https://goldbook.iupac.org/terms/view/R05229

15. Metrohm (2011) Reference Electrodes and Their Usage. Autolab Application Note EC02. https://www.metrohm-autolab.com/download/Applicationnotes/Autolab_Application_Note_EC02.pdf

16. United States Pharmacopeial Convention (2017) General Chapter Prospectus: <541> Titrimetry. https://www.uspnf.com/notices/gcp-541-titrimetry

JAIMA

Review of Directive 2002/95/EC (RoHS) Categries 8 and 9 Final report P61 and P175-177
https://ec.europa.eu/environment/pdf/waste/weee/era_study_final_report.pdf

1. Category of mercury-added product	Switches, relays and other electric devices
2. Further description of the product	**3. Infrared detectors**
3. Information on the use of the product	Infrared detectors are detectors that react to infrared (IR) radiation. IR detector products can be highly specialized and have many uses in the military, scientific, security, medical, industrial and automotive areas. For example, IR detectors can be used in: rail safety, gas leak detection, flame detection, medical applications, petroleum exploration, space operations, temperature sensing, water and steel analysis, as well as motion detectors for alarm systems. There are two major types of IR detectors: thermal detectors and photon-sensitive detectors (photodiodes). Thermocouples, bolometers, thermistors, Golay cells, and pyroelectric devices such as those based on deuterated triglycine sulfate (DTGS) are examples of thermal detectors; while silicon photodiode, indium gallium arsenide (InGaAs), lead selenide (PbSe), mercury cadmium telluride (MCT), and indium antimonide (InSb) are examples of photon-sensitive semiconducting detectors. **Comments from experts:** An infrared detector is a device for the measurements of electromagnetic radiation (EMR) with wavelengths longer than those of visible light (700 nm to 1 mm). They are used in many civilian as well as military applications such as thermal efficiency analysis, remote temperature sensing, short-range wireless communication, moisture measurement, spectroscopy, astronomy, target acquisition, surveillance, night vision and many more. In principle, two measuring principles exist[4] - Thermal detectors exploit the infrared energy as a source of heat that leads to a change of electrically measurable properties. They work independent of the radiation wavelength, need no cooling but have slow response times and low sensitivity. - Quantum or photodetectors are semiconductors whose electrical resistance decreases with increasing radiation. Photodetectors have a much lower response time and a higher sensitivity than thermal detectors but often need to be cooled to suppress thermal noise. Each photodetector system is applicable only in a narrow spectral bandwidth. Infrared detectors are selected according to the specific requirements in a given application. Mercury-containing infrared detectors belong to the group of photodetectors. Among them, mercury cadmium telluride (MCT) is the commercially most important material type. It is a mixture of mercury telluride (HgTe) and cadmium telluride (CdTe). Changing the mixing ratio allows an optimization of the sensitivity at certain wavelengths. That is why MCT detectors, unlike other systems, can cover a quite broad

	spectral range (2 – 16 µm). That includes spectral ranges that are poorly covered by other semiconductor types, especially in the short wave and medium wave infrared spectrum[5].
4. Information on the availability of mercury-free (or less-mercury) alternatives	**Canada** Depending on the detector and application, several other types of IR detectors are available including (but not limited to): InGaAs (indium gallium arsenide), InAs/GaInSb (indium arsenide/gallium antimonide), InSb (indium antimonide), SiAs (silicon arsenide), PbSe (lead selenide), InSb (indium antimonide) and SiSb (silicon antimonide), and SiGe (silicon germanium).[1] Detectors may also use a combination of the different types of technologies. New high-performance IR detectors are also using emerging technologies based on nanomaterials including graphene.[2] The alternative most suitable for the reported IR detector products will depend on the exact product type and the nature of the mercury-containing component. The 2018 report by ToxEcology indicated that although some MCT-based detectors were imported into Canada in 2016, other companies are using mercury-free alternatives. [1] This indicates that in Canada, mercury-free alternatives are available. **Comments from experts** • The European regulation, namely Restriction of Hazardous Substances Directive (RoHS), has exemption system for infrared detectors. Mercury or cadmium in the infrared detectors is exempted under RoHS, but the EU Commission is currently investigating for which applications the exemption needs to be renewed. It is possible to look at the investigation results when they are available. The homepage of EU RoHS exemption renewal can be accessed at https://rohs.biois.eu/requests.html. • An expert, in response to a query, responded that he was not certain about the actual content of mercury in the infrared detectors, but assumed that the absolute mercury content could be rather low, because only a small layer of mercury compound is needed to achieve the functioning of the infrared detectors. In addition, infrared detectors are typically a part of some sophisticated device used by the professionals in specialized circumstances. In other words, infrared detectors are less likely to end up as a general household waste, unless disposed improperly. On the other hand, it is worth noting that alternatives to mercury cadmium telluride (MCT) are other materials that also contain heavy metals. It is, therefore, necessary to fully assess the health and environmental risks and benefits of these alternatives. • Japan Analytical Instruments Manufacturers' Association (JAIMA)

	Mercury cadmium telluride(MCT) was first developed in the 1970's as an infra-red detector and no substitute has yet been found that has equal sensitivity and speed over the same wavelength range. Detectors are very small containing from 10 to 500 mg of MCT. MCT is the only semiconductor that is sensitive to wavelength between 6 (the upper limit for InSb) and 20µm. Semiconductor detectors are very sensitive and also very fast which is particularly essential for Fourier transform infra-red(FTIR) spectrometers which are the most accurate and sensitive type of spectrometer on the market.(ref 5). It falls under RoHS exemption 1C (Lead, cadmium and mercury in infra-red light detectors)  **Figure 1: Example of a cooled infrared detector (source: Wikipedia.org)**
5.(i) Information on the technical feasibility of alternatives	**Canada** The non-mercury alternatives can provide comparable performance to MCT-based detectors for all applications and are used by major IR detector manufacturers.[3, 4]
5.(ii) Information on the economic feasibility of alternatives	**Comments from experts:** According to available information, the global volume of the infrared detector market is in the order of 500 Mio. USD with a strong tendency for growth[6]. The share of MCT detectors is unknown
6. Information on environmental and health risks and benefits of alternatives	**Canada** Substitution of mercury with lead compounds would not be recommended from a human health or environmental perspective. Further investigation on the appropriateness of substituting mercury compounds with arsenic compounds may be needed to fully assess the health and environmental risks and benefits of these alternatives.

	Comments from experts: Several other IR detectors are available such as - Thermal detectors - photo detectors: indium gallium arsenide InGaAs, lead sulphide PbSe, lead selenide PbSe, indium arsenide InAs, indium antimonide InSb - They may replace MCT detectors in some but due to different characteristics not in all applications
7. If any, additional information being submitted on mercury-added products pursuant to Article 4.4 of the Convention not addressed above (e.g. manufacture, general trade information, etc.)	NA
8. Other relevant information pursuant to Decision MC-3/1	NA

9. References

1. ToxEcology Environmental Consulting Ltd. (2018). Technical background study on products containing mercury in Canada with reference to the recently ratified Minamata Convention on Mercury.

2. Tan, C.L & Mohseni, H. (2017). Emerging technologies for high performance infrared detectors. Nanophotonics, 7(1): 169-197: Available from : https://www.degruyter.com/downloadpdf/j/nanoph.2018.7.issue-1/nanoph-2017-0061/nanoph-2017-0061.xml

3. Rogalski, A. (2012). History of Infrared detectors. Opto-Electron. Rev. 20, no.3. 279-308: DOI: 10.2478/s11772–012–0037–7 (e.g. see Table 3) https://doi.org/10.1088/0034-4885/68/10/R01;

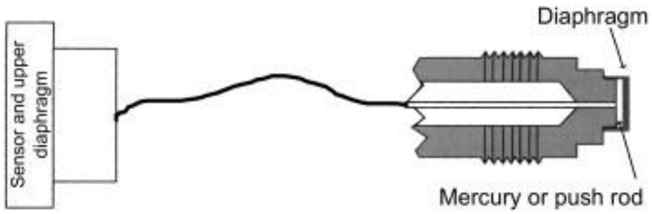
4. Hamamatsu Photonics. (2011). Infrared Detectors – Technical Information. Available from: https://www.hamamatsu.com/resources/pdf/ssd/infrared_kird9001e.pdf

5. Lynred (2020) Understanding and using infrared technology. https://lynred.com/sites/default/files/2020-05/Livre%20Blanc-Sensibilisation_EN_compressed.pdf

6. Markets and Markets (2020) Infrared Detector Market worth $683 million by 2025 https://www.marketsandmarkets.com/PressReleases/ir-detector.asp

JAIMA

Review of Directive 2002/95/EC (RoHS) Categries 8 and 9 Final report P169-170
https://ec.europa.eu/environment/pdf/waste/weee/era_study_final_report.pdf

1. Category of mercury-added product	**Switches, relays and other electric devices**
2. Further description of the product	**4. Melt pressure transducers, transmitters and sensors using a capillary system**
3. Information on the use of the product	Melt pressure transducers, transmitters and sensors enable accurate pressure measurements to be made, enhancing product quality and limiting damage to equipment (Dynisco, 2016). In melt pressure transducers, pressure transmission occurs in a closed capillary system filled with a transmission medium (i.e. mercury). The system is designed to transfer the pressure exerted on the diaphragm, pictured in Figure 1, to the transduction feature (i.e. upper diaphragm with the strain gauge). The strain gauge then converts the physical pressure into an electric signal (Gefran, 2017). In cases of excess pressure during extrusion, this process enables transducers to ensure safety, by switching off extruder driving systems when defined pressure limits have been exceeded (Bagsik, 2019). In melt pressure transducers, mercury was traditionally used as the transmission medium, due to its capacity to transmit pressure readings at high temperatures. However, there is potential risk of mercury leakage during the manufacturing process. The EU through Directive 2011/65/EC (RoHS Directive) has required the use of inert mercury-free alternatives, such as silicon oil and sodium potassium alloy (NaK) (Industry Search, 2019). Despite the absence of regulation in other countries, many countries outside the EU also manufacture mercury-free alternatives, appealing to international customers. **Figure 1 – Melt pressure transducer cross-section (Wagner, et al., 2014)**  The mercury content in melt pressure transducers varies depending on the model. Dynisco states that their pressure transducer 420/460 model contains 7mm^3 of mercury as the transmission medium. However, models released by other companies display a mercury filling volume of 30mm^3 – 40mm^3 (Gefran, 2014). In addition,

	Dynisco have provided another estimate of the mercury fill being approximately 0.003 cubic inches per transducer (~50mm^3) (Dynisco, 2016).
4. Information on the availability of mercury-free (or less-mercury) alternatives	**EU** **<u>Main alternatives</u>: sodium-potassium alloy, silicon oil** Although mercury devices are still on the market, a number of alternative transmission mediums exist. It is essential that alternatives meet certain requirements to ensure that they are suitable for extrusion processes. For example, products must be capable of withstanding high temperatures (up to 700°F) and high pressures (up to 30,000 psi), as well as being able to function in potentially corrosive settings (Dynisco, 2016). In addition, it is essential that the substances replacing mercury are capable of transferring pressure in a similar fashion. The two key alternatives to the use of mercury as a transmission medium are silicon oil and sodium-potassium alloy (NaK). The latter is capable of transferring pressure with comparable quality to mercury (Gräff, 2015). However, Gräff (2015) states that silicon oil is not always an appropriate alternative to mercury, due to the disparity in its capacity to transfer pressure in a comparable manner to mercury. However, the silicon oil substitute is commonly used in food and medical applications, where lower temperatures are required. Some companies have also developed sensors which do not require a transmission fluid. Instead, pressure is transferred to a silicon element through a diaphragm (Gefran, 2017). **IPEN** Hg free alternatives are available for melt pressure transducers, transmitters and sensors using mercury in a capillary system.
5.(i) Information on the technical feasibility of alternatives	**EU** Mercury-free alternatives are technically feasible and already commercially available. Through the use of advanced production processes, melt pressure products can be produced without the mercury filling and still provide an accurate reading (Müller, 2019). Sodium-potassium alloy is an alternative used by multiple manufacturers, due to its ability to mimic the characteristics of mercury. Sodium-potassium alloy alternatives can withstand temperatures of 400°C and according to Gräff (2015, p. 4), their mercury-free alterative is '100% market-compatible with all common manufacturers'. Due to its capacity to function under high temperatures, NaK is an ideal alternative for the plastics manufacturing industry (Industry Search, 2019). In addition, the majority of manufacturers also produce melt pressure transducers which use silicon oil as an alternative transmission medium. Although these products have limits on the temperature which they can withstand, their use is ideal in food, medical and pharmaceutical applications.

5.(ii) Information on the economic feasibility of alternatives	**EU** Due to increasing pressure from the US Food and Drug Administration (FDA) and the EU Restriction of Hazardous Substances (RoHS) Directive, several manufacturers already produce mercury-free alternatives (Gräff, 2015). As these alternatives are readily available on the market, manufacturers will not face the additional cost of having to invest in research and development to create mercury-free alternatives (Gefran, 2010). All European manufacturers comply with the RoHS Directive and manufacturers based in China already produce mercury-free alternatives.
6. Information on environmental and health risks and benefits of alternatives	**EU** The primary risk of mercury transducers, transmitters and sensors is the exposure to mercury during manufacturing processes. In addition, the use of mercury is particularly concerning in processes concerning food packaging, due to the direct link to human consumption (Dynisco, 2016). The silicon oil and NaK alternatives are considered safe by the US FDA, with neither of these alternatives containing hazardous substances. However, NaK is known to react strongly with water to produce highly-flammable hydrogen. NaK also reacts with CO_2 to produce methane (Chemwatch, 2009). However, the significance of this reactivity depends on the volume of NaK present. With the relatively low volume of transmission medium fill (7mm^3-50mm^3) for melt pressure transducers, the effect is likely to be minimal.
7. If any, additional information being submitted on mercury-added products pursuant to Article 4.4 of the Convention not addressed above (e.g. manufacture, general trade information, etc.)	NA
8. Other relevant information pursuant to Decision MC-3/1	NA

9. References

AZO Materials, 2019. What are Mercury Fill Sensors?. Available at: https://www.azom.com/article.aspx?ArticleID=17470.

Bagsik, 2019. Pressure Measurement. Available at: http://www.bagsik.net/download.php?module=download&file=ZmlsZXMvZG93bmxvYWQvMTQ3Njk2MjAzMzE3NTNfZW5fcHJlc3N1cmUtbWVhc3VyZW1lbnQucGRm.

Chemwatch, 2009. Sodium-potassium alloy. Available at: http://datasheets.scbt.com/sc-281150.pdf [Accessed 25/06/2019].

Dynisco, 2016. Melt Pressure Measurement: Environmental Effects. Available at: https://www.dynisco.com/userfiles/files/Datasheets/melt_pressure_measurement_environmental_effects.pdf.

Gefran, 2010. Melt pressure transducers and transmitters. Available at: https://gefran-online.com/products/pdf/1323.pdf.

Gefran, 2014. Pressure Sensors for High Temperature. Available at: http://www.thermalsolutionsoftexas.com/pdfs/components/user-manuals/nak-fill.pdf.

Gefran, 2017. Melt Pressure Sensors. Available at: https://www.gefran.com/en/download/3367/attachment/en.

Government of Canada, 2017. Terms and conditions for the approval of pressure transducers. Available: https://www.ic.gc.ca/eic/site/mc-mc.nsf/eng/lm00123.html.

Gräff, 2015. Melt Pressure Sensors. Available at: http://www.graeff-gmbh.com/pdf/MASSEDRUCK_EN_eigen.pdf.

Industry Search, 2019. Highly Durable Melt Pressure Sensor by Gefran. Available at: https://www.industrysearch.com.au/highly-durable-melt-pressure-sensor-by-gefran/p/65842.

METI, 2017. Overview of the National Implementation Plan for Preventing Environmental Pollution of Mercury. Available at: https://www.meti.go.jp/english/press/2017/pdf/1016_003a.pdf.

Minister of Justice, 2019. Products Containing Mercury Regulations. Available at: https://laws-lois.justice.gc.ca/PDF/SOR-2014-254.pdf [Accessed 13/06/2019].

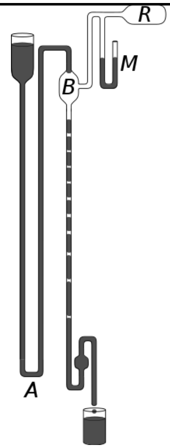
MPI Melt Pressure, 2019. Oil Fill Melt Pressure Transducers & Transmitters. Available at: https://www.mpipressure.com/melt-pressure/transmitters/oil-fill.

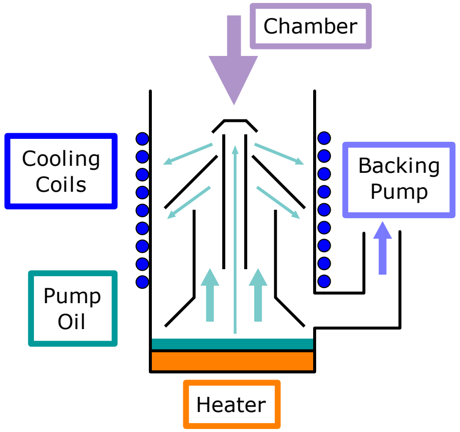
Müller, 2019. Melt pressure and melt temperature sensors. Available at: https://mueller-ie.com/en/current-news/1112-melt-pressure-and-melt-temperature-sensors.html.

Wagner, J., Mount, E. & Giles, H., 2014. Extrusion. Available at: https://www.sciencedirect.com/book/9781437734812/extrusion#book-info.

World Bank, 2019. Capacity Strengthening for Implementation of Minamata Convention on Mercury Project. Available at: http://projects.worldbank.org/P151281?lang=en.

1. Category of mercury-added product	**Switches, relays and other electric devices**
2. Further description of the product	**5. Electric and non-electric mercury vacuum pump**
3. Information on the use of the product	Two types of mercury vacuum pumps exist:

	 1. The Sprengel pump is a form of non-electric vacuum pump that uses drops of mercury falling through a small-bore capillary tube in order to trap air. Mercury is contained in the reservoir and flows into bulb B, where it forms drops which fall leaving air entrapped in bulb B. Mercury is collected and restored to the left reservoir. In this way almost all air can be removed from bulb B and by extension vessel R (Sella 2008). **Figure 2 – Mercury-containing vacuum pump (Beach & Chandler, 1914)** Range of mercury content: 3.4 kg-Hg (COWI, 2008) The same principle was used in the more efficient (electric) mercury rotation pump invented by Gaede in 1905. It contained 26 kg mercury. But both variants were soon replaced by the mercury diffusion pump (see below). 2. Mercury diffusion pumps The mercury diffusion pump was invented by Gaede in 1913 and later improved by Langmuir. It was one of the first effective sources of high vacuum. It uses the principle that a jet of heavy gas vapour directs (lighter) gas molecules in the pump throat down into the bottom of the pump and out the exhaust (Sella 2009). The heavy gas is condensed on the walls and flows back to a heater section where it is vaporized again. Initially, mercury was used as a working fluid, but until the 1980ies it was almost completely replaced by different types of oils such as polyphenyl ether (Vac Aero 2014). Unlike other vacuum pumps, diffusion pumps have no moving parts and thus are robust and very durable. Older pumps suing mercury as a working fluid may still be in use but there is no indication that mercury vacuum pumps are still produced on a commercial basis.

	 **Figure 3: Diagram of an oil diffusion pump (source: wikipedia.org, mercury diffusion pumps use the same principle)**
4. Information on the availability of mercury-free (or less-mercury) alternatives	**EU** **Main alternatives: Positive displacement pumps, momentum transfer pump** Positive displacement pumps use a mechanism to expand a cavity, causing gases to flow in from the chamber that is to be extracted, after which the chamber is sealed and gases are exhausted. This can be repeated indefinitely to create an increasing vacuum. Momentum transfer pumps (molecular pumps) use dense fluid or high speed blades to knock gas molecules out of the chamber. **IPEN** Hg free alternatives are available and are in common use for mercury vacuum pumps.
5.(i) Information on the technical feasibility of alternatives	**EU** There are technically feasible alternatives to mercury pumps available and widely used. Positive displacement pumps are most effective for the creation of low vacuums, while momentum transfer pumps are used to create high vacuums. The KALPUREX process for removing helium from exhaust gases in a planned fusion demonstration power plant (DEMO, potential successor of the ITER) employs two mercury vacuum pumps. Mercury is used as a working fluid because of its very good compatibility with radioactive tritium (Giegerich & Day, 2014). The concept was chosen as the most suitable option on the basis of a Strength, Weakness, Opportunity and Threat (SWOT) analysis (Giegerich & Day, 2014).

5.(ii) Information on the economic feasibility of alternatives	**EU** There are economically feasible alternatives to mercury using vacuum pumps, evidenced by the fact that no mercury using pumps were sold in the EU since before 2008 (COWI, 2008).
6. Information on environmental and health risks and benefits of alternatives	**EU** There are no known environmental downsides to mercury free alternatives to mercury containing vacuum pumps (COWI, 2008).
7. If any, additional information being submitted on mercury-added products pursuant to Article 4.4 of the Convention not addressed above (e.g. manufacture, general trade information, etc.)	NA
8. Other relevant information pursuant to Decision MC-3/1	**EU** According to Directive 2011/65/EU, the RoHS Directive, Member States must ensure that all electrical and electronic equipment placed on the market shall not contain mercury beyond a maximum concentration of 0.1% by weight in homogenous material. There are however exemptions for medical devices and monitoring and control instruments, as well as research applications.

9. References

Atta & Hablanian, 1991. "Vacuum and Vacuum Technology". In Rita G. Lerner; George L. Trigg (eds.) Encyclopedia of Physics (Second ed.). s.l.:VCH Publishers.

Beach & Chandler, 1914. "Air Pump". The New Student's Reference Work. Chicago: F.E. Compton and Co..

COWI, 2008. Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society. [Online]

Available at: http://ec.europa.eu/environment/chemicals/mercury/pdf/EU_Mercury_Study2008.pdf

Giegerich & Day, 2014. Development of Advanced Exhaust Pumping Technology for a DT Fusion Power Plant. [Online]

Available at: https://ieeexplore.ieee.org/document/6762984

Giegerich & Day, 2014. The KALPUREX-process - A new vacuum pumping process for exhaust gases in fusion power plants. [Online]

Available at: https://inis.iaea.org/search/search.aspx?orig_q=RN:46087195

Sella 2008. Classic Kit: Sprengel pump. Available at: https://www.chemistryworld.com/opinion/classic-kit-sprengel-pump/3004941.article

Sella 2009. Classic Kit: Gaede's diffusion pump. Available at: https://www.chemistryworld.com/opinion/classic-kit-gaedes-diffusion-pump/3004912.article

Vac Aero International, 2014. Oil Diffusion Pump Controls. Available at https://vacaero.com/information-resources/vacuum-pump-technology-education-and-training/966-oil-diffusion-pump-controls.html

1. Category of mercury-added product	**Switches, relays and other electric devices**
2. Further description of the product	Radiation light detectors / detectors for ionizing radiation
3. Information on the use of the product	Detectors for ionizing radiation are employed to measure ionizing radiation, especially gamma rays. They are used in medical and industrial instruments to see inside or through the human body or technical objects. Applications include computed tomography, bone densitometry, mammography, non-destructive testing, X-ray imaging, food inspection and security purposes. Three general measuring principles are employed: - photographic film (now largely replaced by more sensitive electronic devices) - indirect detectors using scintillators that convert radiation into visible light - direct detectors using semiconductors According to information by COCIR (2020) mercury(II) iodide (mercuric iodide, HgI_2) is one of several semiconductor materials considered for such detectors.
4. Information on the availability of mercury-free (or less-mercury) alternatives	Electronic detection of ionizing radiation often requires the use of heavy metals because lighter chemical elements such as silicon have a much lower sensitivity. Using lighter elements would have to be compensated by higher radiation which is not desirable and potentially harmful. Several semiconductor materials have been developed, but the following types are the most important on the market (JBCE 2020, COCIR 2020) - silicon (Si) - selenium (α-Se) - germanium (Ge) - cadmium telluride (CdTe) - cadmium zinc telluride (CZT) - lead iodide (PbI_2)

	According to (JBCE 2020), mercury iodide (HgI_2) is still in the development phase and not commercially available, so that existing applications using ionizing radiation are already covered by at least one of the above-mentioned materials.
5.(i) Information on the technical feasibility of alternatives	Currently, two industrial groups applied for specific exemptions under the European RoHS directive regarding the use of cadmium and lead in detectors for ionizing radiation. But they did not include mercury compounds in their application. Therefore, it must be concluded that the use of mercury iodide or any other mercury compound is technically not necessary.
5.(ii) Information on the economic feasibility of alternatives	As there is currently no indication that semiconductors containing mercury iodide (HgI_2) are present on the market there seem to be no economic incentives to introduce it.
6. Information on environmental and health risks and benefits of alternatives	Many of the technical alternatives also contain heavy metals that may be harmful to human health and the environment if disposed of improperly.
7. If any, additional information being submitted on mercury-added products pursuant to Article 4.4 of the Convention not addressed above (e.g. manufacture, general trade information, etc.)	NA
8. Other relevant information pursuant to Decision MC-3/1	NA
9. References	Japanese Business Council in Europe (JBCE) (2020) Exemption Request (RoHS, on cadmium in detectors for ionising radiation) https://rohs.biois.eu/Ex_1-IV_JBCE_Renewal-Request.pdf COCIR (2020) Exemption Request (RoHS, on cadmium and lead in detectors for ionising radiation) https://rohs.biois.eu/Ex_1-IV_COCIR%20_Renewal-Request.pdf