Toxicity of Chemicals Contained in Everyday Electronic Devices: A European Perspective

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I. Introduction

WHY does toxicity in everyday electronics matter? Everyday electronic devices contain a wide range of chemical substances embedded in electronic components, wiring, and plastic housings. While many of these substances are chemically inert, others are potentially hazardous to human health. In Europe, strict user-safety standards—most notably EN 62368—impose demanding requirements for fire prevention and ignition resistance in electrical and electronic equipment. Compliance with these safety standards has historically driven the widespread use of flame-retardant materials and other functional additives in electronic devices [1]. As a result, substances with known toxicological profiles remain present in everyday electronics, despite parallel European policies aimed at limiting their concentration and associated health risks. This review focuses on toxic substances currently regulated under European legislation in the context of everyday use of electronic and electrical equipment. While numerous additional additives and emerging chemicals may be present in electronic devices, these are beyond the primary scope of this work.

Electronic devices can be toxic in multiple ways, and we encounter them in our daily lives. This state of the art report will only treat about the toxicity of the chemicals contained in the devices. It is important to know that not only the electronic components themselves contain toxic compounds but also the metal or plastic casing, the wiring, the solder and other mechanical or electrical items that could be included in most of the electronic devices.

II. Toxic Substances in Everyday Electronics

The most common and well-known toxic chemicals are listed in Table I. Brominated Flame Retardants (BFR) are a big concern since they are widely used in electronic devices to meet fire safety requirements [2]. The BFRs are extremely present in our lives and are able to bioaccumulate. They are dangerous for most of the living beings as they are endocrine disruptors and carcinogenic [3] [4]. They are present in printed circuit boards and incorporated in polymers which are used for casing. This means humans are almost constantly in contact with BFRs [5]. The two most common BFRs are Polybrominated Biphenyls (PBB) and Polybrominated Diphenyl Ethers (PBDE).

Another important heavy metal is Lead (Pb). It was widely used in old solders and is still present in some batteries and electronic components. Lead is extremely toxic for humans and can lead to neurological disorders, especially for children [6], reproductive system, immune system, nervous system and kidneys disorders [7] [8]. It is also restricted by the EU regulations [9].

TABLE I
Common Toxic Chemicals in Electronics and EU Limits

Substance	Max (%)	Main Uses
Lead (Pb)	0.1	Solders, batteries
Mercury (Hg)	0.1	Switches, sensors
Cadmium (Cd)	0.01	Ni-Cd batteries
Hexavalent Cr	0.1	Metal plating
PBB	0.1	Flame retardants
PBDE	0.1	Flame retardants
DEHP	0.1	Cable plasticizers
BBP/DBP/DIBP	0.1	Plasticizers

Note: PBB = Polybrominated Biphenyls; PBDE = Polybrominated Diphenyl Ethers; DEHP = Di(2-ethylhexyl) phthalate; BBP = Benzyl butyl phthalate; DBP = Dibutyl phthalate; DIBP = Diisobutyl phthalate. Limits from EU RoHS Directive [9].

Phthalates are also widely used in electronic devices as plasticizers. They are used to increase the flexibility of polymers. We find them in cable insulation, plastic parts and housings and many other plastic components not directly linked to electronics. Phthalates exist under multiple forms. Only some phthalates (DEHP, DBP, BBP) are confirmed endocrine disruptors. [10].

Cadmium (Cd) is a heavy metal used in nickel–cadmium (Ni-Cd) batteries, electroplating, and various protective coatings [11]. It is also present in certain semiconductor materials. Modern consumer exposure to cadmium during normal use is considered minimal [11] [12]. The exposure to cadmium can cause disorder in the immune system, reproductive system and nervous system [12].

Mercury (Hg) is another heavy metal used in some switches, sensors, lamps, and batteries. Although its use in electronic equipment has been significantly reduced in recent decades, certain legacy products and specific components may still contain mercury. Consequently, direct exposure during normal use is generally uncommon, but accidental breakage or improper disposal can still lead to inhalation of mercury vapour, which is highly toxic and can affect the nervous, digestive, and immune systems [13].

Hexavalent chromium (Cr VI) is used for corrosion-resistant coatings and metal plating. We find this toxic chemical on printed circuit board to protect the copper traces. Hexavalent chromium is known to be carcinogenic and can cause respiratory problems. It can also affect the skin and cause allergic reactions. The two main exposure pathways are inhalation and dermal contact. [14]

Other toxic chemicals can be found in electronic devices

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TABLE II
EXPOSURE PATHWAYS FOR TOXIC CHEMICALS IN ELECTRONICS

Substance	**Exposure Routes**
Lead (Pb)	Inhalation, ingestion, skin contact
Mercury (Hg)	Inhalation (fatal), skin contact
Cadmium (Cd)	Inhalation, ingestion
Hexavalent Cr	Inhalation, skin contact
PBB/PBDE	Skin contact, ingestion
Phthalates	Skin contact, ingestion, inhalation

Note: Abbreviations defined in Table I. Exposure pathways from [3], [10], [15].

but are less common. The discussed chemicals are the most widespread and the ones regulated by the European RoHS directive.

III. Exposure Pathways

How are we exposed to these toxic chemicals when handling electronic devices? The main exposure pathways are inhalation, ingestion and dermal contact [15]. Table II summarizes the main exposure pathways for each common toxic chemical. The inhalation of dust particles is a common way to be exposed to toxic chemicals. Dust particles can originate from handling electronic devices, from material degradation over time, or from chemical migration from new devices during initial use [16]. The ingestion of toxic chemicals can happen when we eat or drink without washing our hands after handling electronic devices. The dermal contact is also a common way to be exposed to toxic chemicals. We are in contact with electronic devices all day long.

The respective effect on health of each chemicals depends on the exposure pathway. The age and the health condition of the person exposed are also important factors and children tend to be more vulnerable to toxic chemicals [6] as their organs are still developing.

IV. EU Regulatory Framework

Since the toxic chemicals used in electronic devices are harmful for humans and the environment, we could expect strong regulations to limit their use and exposure. As the use of these toxic chemicals is widespread and confer important specific properties to electronic devices, it is difficult to completely ban them. However, the European Union has implemented regulations to limit their use.

The most important regulation is the Restriction of Hazardous Substances Directive (RoHS) [9]. It restricts the use of certain hazardous substances in electrical and electronic equipment. The maximum concentration limits for the most common toxic chemicals in electronics are listed in Table I. The RoHS directive represents an important step toward reducing exposure to toxic chemicals in electronic devices but it doesn't totally ban them. However, this could raise the question of whether the regulations are sufficient to protect us since the regulation only limits the concentration of toxic chemicals. Moreover, as explained in RoHS directive, exemptions are possible, for instance certain device categories purchased before 2019 do not have to comply with the directive.

Another important point is the enforcement of the regulation. According to an impact assessment report from the European Commission from 2017 [19], 23-28% of the electronic devices placed on the EU market were non-compliant with RoHS directive. This can be explained by the complexity of the supply chain and the lack of control which makes it difficult for the authorities to control the compliance of every EEE. The enforcement of the regulation is uneven across the EU member states as well. As each member state is responsible for the enforcement of the regulation within its territory with its own means [15]. Authorities must write reports about non-compliant devices found and they are mainly about electronic devices imported from China [15]. This raises the questions of the transparency again as supply chains are complex and not always fully disclosed in foreign countries. On the other hand an exemption system exists in RoHS. According to the evaluation report from 2023 [15] the system seems too unclear and difficult to enforce as well. This also creates vulnerabilities in the regulation as it allows the use for toxic chemicals in a way.

The RoHS directive is not only about the toxicity for humans but also for the environment. But the main EU regulation dealing with the environmental aspect is the Waste Electrical and Electronic Equipment Directive (WEEE) [17]. It aims to reduce the amount of e-waste and to promote the recycling and reuse of electronic devices. The recycling of electronic devices and the correct management of e-waste is an important aspect to consider as well. It is important to regulate the use of toxic chemicals in electronic devices but also to ensure that the devices are recycled properly to avoid environmental contamination. The protection of the environment is an indirect protection for humans as well. Most of the sources consulted for this review deal with ingestion of toxic chemicals via contaminated food or water as well.

Other EU regulations deal with the toxicity of chemicals in general such as REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation [18]. It also regulates chemicals in the EU market but is not specific to electronic devices. REACH also covers the exposure to chemicals during manufacturing, recycling and handling. The regulation leads to mandatory communication about chemicals from companies, supply chain transparency and pressure to find substitute chemicals to the dangerous one. Many chemicals regulated by RoHS were firstly classified as dangerous by REACH regulation. The REACH regulation suffers from the same enforcement issues as RoHS directive though. As lots of electronic devices are imported from non-EU countries, where supply chain transparency is not always guaranteed.

It should be noted that European regulations such as RoHS and REACH primarily address hazardous substances on an individual basis. In real-life conditions, however, users are exposed to complex mixtures of chemicals originating from electronic devices, including regulated substances as well as additional additives and degradation products. Current regulatory risk assessment frameworks only rarely account for such combined exposures, despite growing evidence that mixture effects may be additive or synergistic, particularly for substances with endocrine-disrupting properties [20]. This represents an important limitation of existing regulatory approaches and a significant knowledge gap in the assessment of health risks associated with everyday electronic devices.

V. Conclusion

This review has highlighted the presence of toxic chemicals despite regulations in everyday electronic devices and their potential health risks. The question of whether current regulations are sufficient to protect us from these toxic chemicals is legitimate. Even if those chemicals are toxic, they are still widely used in electronic devices due to their specific properties. It is important to continue researching and monitoring the presence of these toxic chemicals in electronic devices. Such studies may inform new regulations and promote the development of safer alternatives. On the question of the toxicity of mixtures of chemicals, is EU able to tackle this issue in the future regulations? Further research is needed to better understand the combined effects of multiple chemicals present in electronic devices but ongoing studies suggest that mixture effects may be significant and should be considered in future regulatory frameworks. It remains unclear whether the EU RoHS and REACH regulations are sufficient to address the widespread non-compliance of electronic devices, highlighting the need for stronger enforcement and improved supply chain transparency. Stronger enforcement mechanisms and increased transparency in supply chains may be necessary to ensure better compliance and protection but what would be the consequences on the EU market?

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