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## Systematization and classification of e-waste and its harmful effects on health

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### ABSTRACT

Today, the waste of electrical and electronic equipment has created a number of global problems, and their solution is as urgent as other environmental problems. The article explores the issues related to the potential danger of e-waste to human health. For this, the data from a number of international normative documents and authoritative journals is collected, systematized and classified. The feasibility of classifying the waste according to the criterion "hazardous-safe" is substantiated. The main goal of the study is to identify the cause-effect relationship between hazardous waste and their harm. The elements and connections of electronic waste, the harmful environment they create, the relationship of pathological conditions related to human health.

## 1. Introduction

Due to the lack of definition of "Waste Electrical and Electronic equipment" (WEEE) (Electronic waste -EW) in the Azerbaijani legislation, the article uses the terms defined by the European Union (EU) Directives 2012/19 / EU [1] and 2008/98 / EC [2], which have been adopted as the international standards in the field of EW regulation. In this case, it is expedient to mention the explanation of several key terms related to the object of research:

- **Electrical and electronic** equipment (EEE) are the devices designed to use electric current up to 1500 volts or dependent on the electromagnetic field, as well as generating, transmitting and measuring current and electromagnetic field.

- Electronic waste (EW) is EEE used by the owner or intended for disposal or at the time of disposal, including all parts, junctions, exhaust materials contained in the equipment.

- Hazardous waste refers to the waste containing substances that can cause damage and disease detectable by modern methods, whether in

the process of work, or in further life or in future generations, in contact with the human body.

Any EW contains many hazardous and safe substances (chemical elements and compounds, materials) that are harmful to human health. In case of improper compliance with the operating rules provided in the project documents, as well as in case of improper disposal after loss of consumer properties and conversion into waste, EEE becomes a serious threat to human health and the environment. In this article, distinguishing three main cases, we summarize the information from a large number of sources and consider it practical to give separate explanations under the phrase "if not properly processed":

1. EW is thrown out in landfills as solid domestic or industrial waste and remains in the open air. In this case, equipment wears out as a result of natural influences such as sunlight, rain, wind, etc. The substances and materials in the constituent parts creates harmful compounds in the form of gases, liquids and solids with the impact of atmospheric air, precipitation, etc., by interacting

with each other, polluting the atmosphere and soil. On the lower surface of the waste mass, i.e., on the soil, the filtrate in the form of a solid liquid mass and containing toxic substance such as hydrogen sulfide, indole, skitol, etc., spread to the environment as a result of heavy precipitation and contaminate the soil, surface water, and drinking water basins through the groundwater. When these water resources are not properly handled (neutralized) and used for drinking, irrigation and other purposes, they can pose a threat to human health. Moreover, groundwater can leak into the drinking water supply network. Animal products that use leftovers from the landfill and the surrounding greenery can also be hazardous. In the conditions of positive temperature inside the waste mass, fertile conditions are created for the intensive growth of many microorganisms, and they can spread around and cause a number of infectious diseases. Correspondingly, the generated toxic gases are released into the atmosphere by the wind and pollute the atmosphere.

2. Incinerates with other wastes. In this case, spontaneous combustion or incineration of waste in the open air (it is regularly incinerated to reduce the mass of the waste and the area it occupies) can also lead to harmful consequences. Toxic gases produced during combustion, such as polyvinyl chloride (PVC) in the insulation layer of wires and cables, carcinogenic dioxins and furans with extremely high levels of danger are formed and pollute the environment. Due to the tightness of the equipment, hazardous substances are removed, which leads to some of the above.

3. Neutralized by burial. In this case, even when used as a method of disposal without burial, the waste is sooner or later eroded, and toxic substances formed in the same way, pollute the atmosphere, soil and water flows by penetrating from the soil layer into the atmosphere and groundwater.

In addition to these features, EW is an important resource for the production of a new product (as well as a fuel and energy resource), as the group of waste that contains the most material/raw materials.

This article analyzes the issues related to the potential threat to human health posed by hazardous substances and materials contained in EW.

## 2. Classification of electrical and electronic equipment and their waste

Currently, the electronics industry is considered to be the fastest growing manufacturing sector. This

is primarily due to the rapid development of advanced technologies of the EEE, their moral deterioration in a shorter period of time and the growing demand for this equipment. As a result, the volume of EW is growing dramatically year by year.

According to a joint study by the United Nations University (UNU), the Geneva National Institute for Teaching and Research and the World Telecommunication Union, 36 million tons of EW was generated worldwide in 2014 and 53.6 million tons in 2019. According to their predictions, this figure is estimated to reach 74.5 million tons in 2030, the mass of EW is anticipated to double in 16 years [3, 4]. The EW group varies from other waste groups (medical, military, agricultural waste, etc.) by the diversity of substances and compounds it contains. According to estimations, more than 70 elements and many materials from the Mendeleev table are used in the preparation of the EEE. Due to a number of similar physicochemical features, these substances are often grouped into metals (Fe, Cu, Al, etc.), precious metals (Au, Ag, Pt group elements, etc.), heavy metals (As, Ba, Cd, Co, Cr, Cu, Hg, Mn, Pb, Sn, Zn, etc.), rare earth metals (Eu, Y, Pm, Ti, etc.), polybromide 1.2 phenyl, PVC, cadmium, beryllium and their compounds. On the other hand, as mentioned above, when the mass of EW is burned outdoors or in special equipment, but not following the exploitation rules, new substances and compounds are formed between themselves and chemical reactions with air, many of which (dioxins and furans, aromatic carbohydrates, groups of phthalates, etc.) are highly toxic and pose a serious threat to human health [3, 5].

In order to classify EW according to the hazardous effects on human health, it is beneficial to first classify EEE. There are various approaches to this issue in the technical literature. Generally, depending on the field of use, EEE are grouped into: household, industrial, medical, military, agricultural equipment, etc. However, the classification by groups does not provide a clear idea about the structural parts of the waste, the electrical and electronic parts applied in its manufacture, and the substances and materials. Because, the same electrical and electronic parts can be applied in any of the above waste groups, however, it is suitable for assessing the features of wastes that are characteristic for these areas.

Stating from the field interests of the refinery she represents, M.A Ivanova in her article [5] classifies the EEE according to its material/raw material resources, and refers the equipment containing gold, silver and platinum group more to the first group.

Other groups of authors propose that the classification of these technologies should be based on the fact that the technologies used to extract and recycle the material/raw material resources contained in the EW are decisive. Given that the main component of EW consists of ferrous metals, they consider the separation, pyrometallurgy and hydrometallurgy methods as the main group [6].

In a review of the results of extensive research conducted by a group of scientists from India, taking into account the vital importance of the health factor, EEE and waste elements and substances are classified according to pathological conditions (effects) that may arise from potential hazards to the human body: equipment with central nervous and cardiovascular diseases and their wastes are classified in the same groups [7].

A broader classification of medical equipment is presented in [8]. Here, equipment is classified into groups such as radio waves, electromagnetic waves, infrared, ultraviolet, ionizing radiation, acoustic noise generators, lighting systems, etc., as well as, according to the similarity of the hazard characteristics of the elements and compounds.

In the annual summaries of EW statistics collected and produced annually around the world and countries, a group of UNU experts provided a comparative analysis of the classification options adopted in the international documents of the Directive 2012/19/EU on EEE and EW and the Basel Convention and compared the pros and cons of each, proposed by their organization -STEP UNU - Solving the E- Waste Problems. It is indicated that each country can use the option of the National Legislative documents appropriate to these classifications [9].

It should be noted that each of the classification approaches specified has pros and cons. The authors believe that, based on the general approach of EEE's identification indicators (field of consumption), the classification of Directive 2012/19/EU is more practical for use. According to the classification of this directive adopted as an international standard in the regulation of issues related to the EW, the following is the waste of 600 EEE, which is mentioned in the following and 10 groups:

1. large-size household appliances.
2. Small-sized household appliances
3. Information and telecommunication equipment
4. Household appliances and photoelectric (photovoltaic) solar panels.
5. Light devices.
6. Electrical and electronic tools (excluding large stationary industrial machines).

7. Equipment for toys, sports goods and recreation.

8. Medical devices (excluding implantation and infected products).

9. Control and monitoring tools.

10. Vending machines.

EU member states use this classification of EEE in national legislative documents.

### **3. Classification of electronic waste in terms of danger of human health**

Many of the chemical elements, their compounds and structural materials used in the preparation of EEE are toxic, radioactive, irritating, carcinogenic, infectious, teratogenic, mutagenic, etc. due to their action mechanisms. When the EEE transferred to the waste category is dumped in landfills without proper recycling, the above-mentioned cases occur and are considered hazardous waste as they become a source of various levels of harmful effects on human health. Generally, the degree of hazardous effects of EW depends on the hazard class (degree) of the substances contained in this equipment, the mass and type of waste, disposal methods, the distance from landfills to habitats, water basins and surface to groundwater, geographical conditions (temperature, amount of precipitation, strength and direction of characteristic winds, etc.), health status, age, gender, etc. of the affected people. However, the characteristics of the destructive effect are mainly determined by the hazard classes of the elements and compounds they contain. Therefore, it is important to classify these components into hazard classes. According to the recommendations of a number of international organizations involved in EW management, the classification should be carried out in such a way that the EEE of the same category is not included in different classification groups not to complicate the process of collecting and analyzing statistical data by countries and regions [10]. Based on these recommendations, the number of classification groups should not be too large or too small, and the classification should be based on specific factors that reflect key features. In this regard, it is recommended to take health/environmental hazards, equipment operating functions, substances/materials in them, similarity of weights and, in addition, service life, typical causes of failure, etc. as a classification factor.

Below, a brief review of few articles and regulations classifying EWs according to the analytical factor in accordance with the goal of the study is presented.

In the article on the result of many years of joint

research by several Indian research centers [7], the effects of some hazardous elements in EW on human health: mercury, chromium and 6-valent chromium, cadmium, beryllium, arsenic, lead and tin, as well as of nickel, copper, iron and aluminum compounds are studied. Observations are made on children and pregnant women as the object of research and pathological cases are identified.

In another article, a group of researchers from several European countries studied the impact of a number of substances belonging to the family of dioxin and furan compounds (brominated flame retardants, polybromide diphenyl esters, biphenyls, dibenzodioxins and dibenzofurans, (polyaromatic) polycyclic aromatic carbohydrates, etc.), which are highly dangerous for the last 32 years, on a) human health; b) mental state; c) education; d) propensity to commit criminal acts. To this end, they reviewed 2,274 published articles in this field. The research articles study the impact of waste on the landfills in the Chinese cities of Gui, Taizhou and Lui on the health of: a) those engaged in informal waste disposal (“black disposal”); b) employees of official processing enterprises; c) residents living near the landfill [11].

Another article studies the results of the analysis of X-ray spectroscopy, optical emission spectroscopy and other methods of hazardous substances formed during the incineration of the remaining mass after informal handling of metal parts (Fe, Al, Cu, etc.) of modern mobile phones and their accessories thrown in landfills and their impact on employee’s health [12].

The degree of hazard of substances harmful to human health in the territory of the Commonwealth of Independent States (CIS) is determined by the standard GOST 12.1.007-76\* and is grouped into 5 hazard classes [13]:

- extremely hazardous substances;
- high-hazardous substances
- moderate-hazardous substances;
- less-hazardous substances;
- safe substances.

There is no list of hazardous substances in each class, however, the following basic norms and indicators defining their class are displayed:

- permissible concentration in the air of the work area;
- average lethal dose when ingested;
- average lethal dose in case of skin contact;
- lethal concentration in the air.

The definition of these norms and indicators is regulated by the sanitary rules SP2.1.7.1386-03, found by one of the computational or experimental

methods. In the first case, the final hazard class is calculated by the formula, taking into account the mass ratio and hazard class of each hazardous substance in the waste, in the second case, the effect of the components on experimental animals and the development of certain plants is examined. The document states that the waste producers are responsible for the determination of hazard classes by these rules. Although the requirements of the standard are obligatory, this process is so complex and tedious that it is almost never applied in practice [14].

As seen, different approaches to the classification of EW according to the hazard factor are available. According to the authors of the article, the most detailed and simple classification in this regard is provided in the Basel Convention [15]. This document, which is accepted as an international standard, lists all hazardous elements and compounds contained in the EW individually or in groups. Here, the “hazardous rate” of elements and compounds is associated with one of the features (each is defined) as “poisonous”, “infectious”, “toxic” (causing long-term or chronic diseases), “corrosive”, “eco-toxic” and etc. Subsequently, other elements and compounds proven to be hazardous to human health and the environment shall be added to the list in agreement with the countries which adopted the document. The items in the document are not divided into hazard classes, a list of harmless substances (for example, in groups) is not provided. This can be referred as the perception of elements and compounds that are part of EW and are not included in this list as “harmless”. Therefore, the authors consider it more convenient to classify EW into two classes: “hazardous” and “harmless”. This classification allows making decision on the initial disposal of the components, especially after the dismantling of the equipment in the recycling process. On the other hand, a number of requirements of international standards related to the production of EEE also serve to determine the threat of EW. For example, EU Directive 2011/65/EU [16] states that the maximum mass of hazardous elements and compounds used in structural units of equipment should not exceed the following limits relative to the mass of these units (effective from 2016):

- tin - 0.1;
- mercury - 0.1;
- cadmium - 0.01;
- 6-valent chromium - 0.1;
- polybrominated biphenyls - 0.1;
- polybromide diphenyl ethers - 0.1.

Based on the above and other sources, information on hazardous elements and compounds in EW is collected and systematized, the main EEE used, the

source (means) of impact, the route of transmission from source to person and the main health effects are provided in table below.

**Table 1. Health effects of hazardous elements and compounds in EW.**

Elements and compounds	Some used electricity and electronic equipment	Source of impact (method)	Way of influence	The main impact on health
1. Persistent organic pollutants				
Brominated flame retardants, polybrominated diphenyl ethers	Wire, cable, fireproof housings and covers	Air, dust, food, water and soil	Respiratory, swallowing, intrauterine	Carcinogen, cytotoxin, cognitive impairment
Polychlorinated biphenyls	Generator, transformer, capacitor, fluorescent lamp, electric motor, electrical appliances	Air, dust, soil, water and food (especially bioaccumulation in fish and seafood)	Inhalation, ingestion, skin contact, intrauterine	Carcinogen, cytotoxin, lung diseases, including lung cancer, abortion
2. Dioxins and furans				
Polychlorinated dibenzodioxins and dibenzofurans	Generator, transformer, capacitor, fluorescent lamp, electric motor, electrical appliances	Air, food, soil, dust, water	Inhalation, skin contact, absorption, intrauterine	Immune system diseases, central nervous system diseases (CNS), liver, kidney, skin disorders
Dioxin-like polychlorinated biphenyls	Generator, transformer, capacitor, fluorescent lamp, electric motor, household appliances	Food, air, soil, dust, water (especially bioaccumulated in fish and seafood)	Absorption, inhalation, skin contact	Diabetes, hypertension, cardiovascular diseases
Polycyclic aromatic carbohydrates	Wire, cable, housing of radio electronic devices	Air, dust, soil, food	Inhalation, skin contact, absorption	Carcinogen, cytotoxin, lung cancer, abortion
3. Elements				
Tin and compounds	Printers, electronic beam tube (EBB), lamp, television, battery, mobile phone	Air, dust, water, soil	Inhalation, ingestion, skin contact	Diabetes, hypertension, cardiovascular diseases, Parkinson's disease
Hexavalent chromium	EEE coating, memory elements	Air, dust, water, soil	Inhalation, ingestion, skin contact	Carcinogen, cytotoxin, lung cancer
Cadmium and its compounds	Contact converters, connectors, printed circuit board, battery, semiconductor chip, copier, electron beam tube, mobile phone	Air, dust, soil, water, food (especially rice and fruits)	Inhalation, skin contact, absorption	Diabetes, hypertension, cardiovascular diseases, lung cancer
Mercury and compounds	Thermostat, transmitters, elements of printed circuit boards, fluorescent lamp	Air, mercury vapor, water, soil, food (especially bioaccumulated in fish)	Inhalation, skin contact, absorption	Cognitive impairment, mental health disorder, visual impairment
Zinc and compounds	ESB (electron beam tube), soldering, metal coating of radio-technical products	Air, water, land	Inhalation, ingestion, skin contact	Jaundice (Botkin's disease), malignant tumors, infertility, conjunctivitis, osteoporosis
Nickel compounds	Metal coating of batteries and accumulators, ferromagnetic, radio-technical products	Air, soil, water, plants, food	Inhalation, ingestion, skin contact, ingestion, intrauterine	Carcinogen, genotoxin, lung cancer
Lithium compounds	Batteries and accumulators, thermos-electrochemical converters	Air, soil, water, plant foods	Inhalation, skin contact, absorption	Lung cancer
Barium compounds	Batteries and accumulators, radiosopic apparatus	Air, soil, water, plant foods	Inhalation, skin contact, absorption	Structural gastrointestinal

				diseases, Central nervous system diseases, cardiovascular diseases, eye diseases, heart failure
Beryllium and compounds	Integrated circuit, components of radio-electronic equipment, power supply, computer, fluorescent lamp	Air, food, water	Respiratory, swallowing, intra-abdominal,	Carcinogen, acute and chronic pneumonitis, sarcoidosis, acute beryllium
Copper and compounds	Integrated circuit, equipment components, connectors, printing plates, wires	Air, water, food	Inhalation, ingestion	Central nervous system diseases, liver diseases, Alzheimer's disease, atherosclerosis

#### 4. Discussion and suggestions

As the table illustrates, EW contains a number of hazardous elements and compounds that, if not properly disposed of, can become a potential source of danger to human health under certain conditions. Therefore, the solution of waste problems is one of the most pressing and vital environmental problems facing every country.

This requires the establishment of an effective EW management system. It is acknowledged that a system of waste management, including hazardous EW, has been established and is being developed in a number of developed and developing countries [6]. Some implementations have been done in Azerbaijan to cope with hazardous waste. For instance, Azerbaijan signed the Basel Convention in 1996 and joined the Convention in 2001 (adopted by the UN in 1989). The Law of the Republic of Azerbaijan (AR) "On Industrial and domestic waste" (1998) was adopted [18]. (The second edition was adopted in 2007). Normative acts such as Decision of the Cabinet of Ministers of the Republic of Azerbaijan on the "Requirements on medical waste management" (2007), Resolution of the Cabinet of Ministers of the Republic of Azerbaijan on the "Rules of certification of hazardous waste" (2003), State Strategy for hazardous waste management in the Republic of Azerbaijan (2004), etc. are analogous. However, these documents do not fully meet modern requirements and some provisions contradict international norms [19]. Moreover, no special legal framework for EW management, and no relevant recycling infrastructure has been established so far. Up to now, EW generated in households, offices and enterprises is usually disposed of as mixed waste.

For instance, according to the State Statistics Committee of the Republic of Azerbaijan, in 2016, collected in the country, 2.0 tons of mercury-

containing substances, 4.1 tons of fluorescent lamps, 41.6 tons of batteries and accumulators were dumped in landfills. [20].

This practice continued in the following years (with less mass). The activities of informal groups, engaged in primitive recycling of hazardous EW collected from the population and dumped in landfills, pose a more serious threat to their own health and the health of others. Therefore, according to the authors, taking into account the national characteristics, the ecological, economic, technological, social, cultural and other aspects of our country, the formation of an effective EW management system should be one of the most pressing issues facing our state.

Hence:

- The current situation and problems in the field of EW management in our country should be deeply analyzed;

- The experience of advanced countries should be studied and the work on the establishment of a national EW management system should be launched. This system should cover the special legislative framework, organizational and management methods and mechanisms, financing, information support system, etc. and the establishment of infrastructure covering the entire life cycle (selective collection, collection, storage, reuse, primary and recycling, disposal, liquidation, transportation, etc.) from the moment of EW creation to its abolition.

#### 5. Conclusion

The article discussed the environmental problems caused by EEE waste and substantiates and the urgency of solving these problems. It showed that EW contains a number of chemical elements, compounds and materials that can become a potential source of health hazards for staff

and people living in the area if they are disposed of in landfills without proper recycling. It was found that from the moment of transition of EEE to waste category, it is subject to three conditions: mixed with other wastes and dumped in landfills, burned or buried in the ground. In all three cases, the properties of the substances and compounds formed in the air, soil and water basins were identified. EW containing hazardous elements, compounds and materials was systematized and it was proposed to classify them according to the principle of “harmful-harmless”. The main diseases and other pathological conditions caused by EW for human health were classified. The cause-and-effect relationship between the hazardous environment created by the hazardous components of EW, the route of transmission to the human body, and the health-related conditions was identified. The results of the study can be used by specialists dealing with EEE waste problems and those engaged in health safety.

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