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Medical Waste Management: Technologies ANS Innovations

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Abstract*: *The problem of medical waste management is an issue that concerns not only experts since the amount of waste has a stable tendency to intensive growth.

The research aims to study the status of medical waste management and analyze the approaches to its classification, taking into account the specific features of its formation and possible disposal.

The article defines theoretical approaches to the analysis of the "medical waste" category and identifies the main directions of research in the field of medical waste management. Based on the analysis of scientific literature and an expert survey, the authors analyze the problems associated with the disposal of medical waste and the possible approaches to their solution. The authors propose a classification of medical waste and operations performed with it in health care centers.

Keywords*: *medical waste, waste management, disposal, pharmaceutical waste, health care center.

I. INTRODUCTION

At present, the volumes of waste accumulation, as well as the numbers of dumping sites and landfills for waste disposal, are increasing in Russia, which leads to a deterioration of the ecological state of the environment and the sanitary condition of settlements [1]. Waste is considered hazardous if it exhibits properties that can be characterized as flammable, reactive, explosive, corrosive, radioactive, infectious, irritating, sensitizing or bioaccumulating [2]. When studying the problem of the treatment of medical waste (MW), it should be noted that this category is complex, as it belongs to the field of regulation of environmental, economic and medical law, although in slightly different aspects. Thus, in the framework of economic or medical law, MW can be defined as an object, in respect of which contracts for removal or disposal are concluded, while in the framework of environmental law, one can consider its essential and quantitative indicators characterizing the harmfulness or absence thereof, etc. Besides, since waste management activities are subject to licensing, the administrative aspect of this category should also be kept in mind. The situation with MW is complicated by the fact that its number is growing rapidly. Up to 1 million tons per year of MW forms annually in Russia, which, in the absence of an effective system for managing it, can become the main source of dangerous infections. Moreover, MW pollutes the atmosphere, soil and air, which significantly affects the health of the population and leads to the appearance of cardiovascular and oncological diseases, dystrophic changes, allergies, hormonal dysfunction, changes in the immune and endocrine systems, reduced life expectancy and birth of children with a variety of congenital abnormalities. MW is a source of parenteral infections, which is confirmed by cases of hepatitis B infection and HIV infection by both medical personnel and ordinary citizens [3]. In ecologically polluted areas, the level of allergic diseases and neuropsychiatric abnormalities also increases. The population living in these areas has an increase in the number of diseases of the respiratory system (by 12%), nervous system (by 29%), hematopoiesis system (by 37%), tuberculosis (by 45%) and hypertension (by 67%). A significant part of these diseases (approximately 40%) is associated with environmental impact [4].

In this regard, the disposal of MW is necessary not only for vaccines and precursors but also for ordinary unused or expired tablets in blisters and syrups, used syringes, dressing materials contaminated with patients' biological fluids, bandages, cotton wool, etc., which are no less hazardous.

MW is generated not only in health care centers (HC) of the humanitarian and veterinary types but also in objects of the household sector (HS). The situation is complicated by the fact that today the majority of the population of Russia does not separate hazardous waste and municipal solid waste (MSW). Although, if 1 g of MSW contains from 0.1 to 1 billion microorganisms, in MW, this number increases to 200-300 billion, with more pathogenic microorganisms. Besides, vast majority of MW contains biologically active synthetic compounds, analogs of which are not found in nature, which complicates the process of their safe natural disposal. All this is removed to HSW disposal sites or landfills, where, together with the filtrate that forms in the body of the landfill, it seeps into the soil and aquifers and, as a result, creates a serious ecological hazard to the environment and human health.

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As a result, we can observe an uncontrolled entry of hazardous MW into the environment, including antibiotics, antiseptics, cytostatic agents, drugs with hormone-modulated, psychotropic and narcotic effects and other physiologically active substances, which, getting into the environment, can significantly disrupt the ecological balance and lead to unpredictable consequences.

II. LITERATURE REVIEW

According to research, MW, its managing and disposal are important epidemiological and environmental components of the safety of the population of Russia, since the accumulation of MW in landfills leads to unpredictable physical, chemical and biochemical processes, the products of which are numerous toxic chemical compounds in liquid, solid and gaseous state [5].

However, the population is not informed about the dangers posed by the improper managing of MW and does not have information on possible methods of neutralizing low-quality and expired drugs at home. Most importantly, there are no conditions for collection of MW from the population with a view to its further transmission to relevant facilities that have licenses for operations in the field of hazardous waste management [6].

According to [7], MW can be divided into five hazard classes, depending on the degree of its epidemiological, toxicological and radiation hazards, as well as its negative impact on the environment: Class A – epidemiologically safe waste close in composition to MSW; class B – epidemiologically hazardous waste; class C – extremely epidemiologically hazardous waste; class D – toxicologically hazardous waste of hazard classes 1-4; class E – radioactive waste.

To solve the problems of defining the concept of MW and its correlation with other categories of waste, one should turn not only to Russian but also to foreign experience.

Thus, the International Committee of the Red Cross indicates that MW includes all waste generated during medical and diagnostic work. Waste similar to household waste can be assigned to the same collection and recycling procedure as municipal waste. Others are the hazardous types of MW that pose a threat to health [8]. It is stipulated that in determining this category, there is no emphasis on the origin of such waste from health care institutions, however, its origin is consistent with the work carried out by such institutions, whether medical or diagnostic. It is also provided that in the context of resolving the issue of the need to determine the place of activity of health care institutions, as a result of which the MW is formed, the following rule can be indicated: the waste is generated as a result of the economic activity of the health care institution and on the territory of the health care institution, however, in some cases, when medical or diagnostic work is provided at the patient's location (for example, if a patient with a serious illness calls an ambulance to the place of their residence), the waste of their activity is also should be recognized as medical.

The World Health Organization (WHO) uses the term "health care waste" and indicates that health care waste includes all waste generated by health care institutions, research institutions and laboratories. This includes the waste that is generated from "insignificant" or "scattered" sources, such as the waste produced during medical work carried out at home (dialysis, insulin injections, etc.) [9]. Thus, the WHO uses a wider definition than the Russian legislator regarding the inclusion of wastes from medical devices and drugs to medical ones.

The experience of the United States is interesting since it was one of the first countries that began to develop and adopt specialized legislation on waste management. The US Medical Waste Tracking Act (MWTA, 1988), the first MW management act, was passed after the arising of life-threatening events related to the lack of proper MW disposal systems. According to the MWTA, MW includes "any solid waste generated in the diagnosis, treatment or immunization of humans or animals, in the study, production or testing of biological substances" [10].

Thus, in the study of MW, we should note such its characteristic as connection with economic medical activities. Although, it should be noted that this does not necessarily mean that such waste can be generated exclusively at the location of the health care institution.

The hypothesis of the study: the most relevant for the medical industry is the distinction between the treatment of MW according to the hazard class, which is associated with restrictions on its processing imposed by hazard class characteristics.

III. PROPOSED METHODOLOGY

A. General description

The methodological basis of the work includes critical analysis of current provisions on the principles of MW classification and the principles of management and treatment of MW streams. For this study, we used the published data of Russian authors (including regulatory documents), as well as research materials on the problems of management and disposal of some components, including specific ones, of MW.

In the study, we also used the expert survey method to determine methods and approaches to solving the medical and environmental problems of MW management.

Twenty-two experts participated in the survey in online mode, including 14 employees of HC and 8 employees of hazardous waste utilization enterprises.

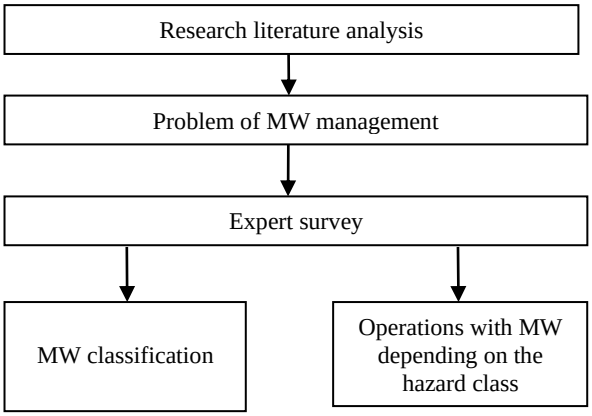
The experts were asked several questions regarding the problems of MW management and disposal.

B. Algorithm

At the first stage of the study, we performed an analysis of the research literature on the problem of MW management.

In the second stage of the study, we conducted an expert survey on the current problems of the management and disposal of MW.

C. Flow chart



IV. RESULT ANALYSIS

Based on the generalization of sources [11]-[14] and the results of the expert survey, we identified the following traditional features of MW classification:

- the hazard class (class A, B, C, D, E);
- the type of provision of services (from the provision of medical services, from the provision of veterinary services, from the provision of pharmaceutical services, from scientific research in the field of health care);
- the state of aggregation (solid, liquid, gaseous and pasty);
- the chemical resistance (explosive, self-igniting, sustainable waste and waste decomposing with the release of toxic gases);
- the origin (organic, inorganic and mixed).

Based on the analysis of previous classifications and expert interviews, we propose a classification of MW and operations with it in HC (Table 1).

Table 1: Classification of MW and operations with it in HC

No.	Class	No.	Subclass	Composition	Operations
1	Safe MW	1a	small MW	Glass, paper, linen, overalls, in the absence of contact with biological fluids of patients, carriers of infection	1. Collecting in disposable (white) bags located in reusable containers. 2. Sealing a 3/4 filled bag. 3. Attaching a label with appropriate information to the bag.
		1b	large MW	Equipment, furniture, inventory	
2	Hazardous MW	2a	biological MW	Surgery biowaste of infectious patients, laboratory waste in the presence of microorganisms of 3-4 pathogenic groups	1. Collecting in disposable (yellow) bags located in disposable, labeled containers. 2. Sealing a 3/4 filled bag. 3. Closing the container. 4. Attaching a label with appropriate information to the bag.
		2b	infected MW	Dressing material in the presence of contact with infectious patients, laboratory waste in the presence of microorganisms of 3-4 pathogenic groups, household waste contaminated with patient secretions	
		2c	food MW	Canteens of infectious departments	
		2d	vaccines	Used live vaccines, defective and expired vaccines	
		2e	piercing/cutting objects	Expired/used syringes Disposable piercing/cutting tool	
3	Extremely hazardous MW	3a	biological MW	Biowaste after operating infectious patients, laboratory waste in the presence of microorganisms of 1-2 pathogenic groups, from patients with anaerobic infection	1. Collecting in disposable (red) bags located in disposable, labeled containers. 2. Sealing a 3/4 filled bag. 3. Closing the container. 4. Attaching a label with appropriate information to the bag.
		3b	infected MW	Contaminated dressing in contact with infectious patients, laboratory waste in the presence of microorganisms of 1-2 pathogenic groups, household waste from patients with anaerobic infection	
4	Medicines	4a	pharmaceutical products (PP)	Expired preparations and reagents, waste of medicines and disinfectants	1. Collecting depending on the state of aggregation in soft/hard (blue) packaging. 2. Attaching appropriate information to the packaging.
		4b	PP packaging	Packaging of drugs, disinfectants, etc.	

		4c	industrial MW	All types of waste generated during the production of PP	
5	MW requiring special treatment	5a	MW containing mercury	Mercury-containing devices (equipment)	1. Collecting in soft/hard (black) packaging. 2. Attaching appropriate information to the packaging.
		5b	radioactive MW	Radioactive components	1. Collecting into a special package that prevents dispersion and is labeled with the type of radioisotope.

Compiled based on the expert survey.

In general, work with MW in HC involves the completion of the following tasks: collecting and sorting; marking; disinfecting; transporting to drives in the territory of the health care facility; disposing (of those types of MW that can be disposed of without an additional license); dumping (only the A category of MW).

MW is collected into separate containers at the places of their formation. Boxes or bags must be of different colors or be labeled appropriately. One must make sure there are always spare tanks in places where MW is systematically formed. Filled bags and containers (after the initial collection of waste) must immediately be sealed, marked with paper for further labeling, transferred to covered storage containers. To neutralize class A MW in a decentralized way, a special installation is installed at the institution.

If it is necessary to disinfect class B and C MW, it must be placed in bags and labeled in such a way as to indicate the MW category, date and type of disinfection, as well as the person who carried out the disinfection. The most important thing is not to mix MW of different categories.

Containers with safe MW must be kept on a specially designated fenced asphalt site at a distance of at least 25 m from medical buildings, canteens and catering units.

Category B MW is potentially infected MW. This category includes all MW that came into contact with biological fluids and must be disinfected by physical methods, except for food waste from the infectious departments (where the chemical method is applied).

Class C MW is collected in labeled indoor containers and stored in separate rooms. Cytostatics and genotoxic drugs cannot be collected or stored without deactivation. Such MW also cannot be disposed of by institutions without an appropriate license.

V. DISCUSSION

According to the experts, the majority of MW (75-80% of the total volume) does not pose any particular risk to human health or the environment (glass, paper, packaging material, metal, food and other waste similar to MSW), but the remaining 20-25% of it is environmentally hazardous (infectious, anatomical, pathological, chemical, pharmaceutical and radioactive waste, sharp objects).

The experts note that the treatment of extremely hazardous MW should involve its careful separation and destruction. To neutralize such MW, it is advisable to use incinerators. At the same time, the experts emphasize that, given the harmful effects of toxic substances and ash emissions on public health, incineration cannot be considered an absolutely environmentally safe method for the destruction of hazardous MW; therefore, it should be used only as a temporary method if there are no other possible options not related to incineration. The remaining MW, after appropriate treatment or without it, can be transferred to the state of secondary material resources.

According to the experts, the use of autoclaves is an environmentally sound method for the treatment of infectious MW, which requires relatively small investments and operating costs. Infected MW (waste materials or equipment contaminated with blood and other biological fluids) in sealed bags should be placed in special containers at HC with subsequent waste neutralization. Needles (after separation from the plastic syringe), blades and other sharp objects must be placed in plastic or metal containers.

The experts note that the waste chemicals that are produced during disinfection procedures or cleaning processes, as well as pharmaceutical waste (consisting of expired, unused or contaminated PP, drugs, vaccines, etc.), include preparations ranging from pharmaceutical substances and cleaning products that do not pose any risk to human health and the environment and ending with disinfectants containing heavy metals and certain drugs, which include a number of dangerous substances. They must be disposed of at an appropriate waste disposal facility, depending on the risk that they pose. If possible, the experts emphasize that it is better to return old pharmaceuticals and chemicals to the manufacturer for disposal of active ingredients or appropriate disposal.

A fairly large part of MW, according to the experts, consists of polymeric materials used as packaging for medicinal products, injection syringes, droppers, etc. The main direction of their managing should be thermal destruction, however, as the experts specify, the incineration of polymer MW produces dioxins and other dangerous chemical compounds. Also, polymeric MW can be used as secondary raw materials after disinfection. For example, wax, styrene, methyl methacrylate, carbon and the like are obtained from pyrolysis from polymer MW. Recycling of polymer MW, according to the experts, can save money by abandoning dumping, irradiation and thermal destruction of MW and, taking into account the gain of raw materials (in case of industrial use),

become a quickly recouped and commercially attractive way of their disposal.

The experts emphasize that part of the MW is mixed with waste from the HS and MSW disposed of in landfills (dumping sites) and, therefore, the MW management system should fit into the general scheme of differentiation of MSW streams. Hazardous MW should be separated from the MSW stream and connected with the links of the HC waste management system. Otherwise, in the absence of sorting of MSW in the places of its formation, it is unlikely that it will be possible to neutralize or destroy the MW that falls into the MSW containers [15].

Unfortunately, the experts say that today, there are no uniform rules for the disposal of MW since the rules differ for each type of waste. Since the general goal of waste management is to prevent environmental hazards from MW products, the emphasis should be placed on the management aspect of the process. However, as the experts emphasize, often the treatment of MW is limited only to chemical and physical disinfection at the place of its formation, dumping of MW in HSW landfills, washing it into the sewers and using high-temperature combustion. However, not enough attention has been paid to ensuring environmental safety.

According to one expert (Mikhail D.), "due to the lack of special equipment for disinfecting or neutralizing class B and C waste, it is disinfected with traditional calcium hypochlorite, bleach and chloramine, which, due to their instability, do not provide complete disinfection. Besides, chlorine, reacting with organic compounds, which are available in sufficient quantities at MSW disposal siteы, forms compounds hazardous to human health, such as dioxins".

Regarding pyrolysis and plasma technologies, the experts note that they are quite energy-consuming and dangerous to operate and sterilization plants are ineffective.

Unfortunately, according to the experts, one of the main methods for neutralizing hazardous MW in Russia is incineration, which, due to non-compliance with environmental laws, leads to environmental pollution and negatively affects people's health.

During the discussion, the experts separately focused on the pharmaceutical waste that has its specifics. In particular, poor-quality drugs that have not been properly disposed of can have an undesirable biological effect on plants and animals, as well as enter the human body indirectly through drinking water and food products, causing allergization of the body and the formation of drug resistance.

Thus, the intake of drugs with estrogen-, progesterone- and testosterone-like effects and pesticides that mimic the effects of estrogen (lindane) with waste or groundwater in uncontrolled quantities is a significant risk to human health and the environment. According to the results of studies, these drugs, simulating the action of natural hormones, trigger physiological processes or, on the contrary, block their action, which especially negatively affects the development of the fetus during pregnancy [16]. Numerous studies have shown that under their influence, there is an increase in the number of cases of infertility, hormone-dependent malignant neoplasms and neurological disorders in children [17, 18].

Of particular danger are antibiotics, antiseptics and cytostatic agents, which, falling into the environment, can significantly disrupt the ecological balance. Hormonal drugs that enter the water and soil can adversely affect the development of animals.

In the European and global practice of developed countries, people only have to come and take such medicines to a reception point or a pharmacy that performs this function in the region [19]. Unfortunately, as the experts say, in Russia, there are no such reception points. Besides that, according to one of the experts (Anatoly K.), "pharmaceutical organizations and the population act at their discretion, without making any effort; they throw the waste into the trash or dump it into the sewer". Unlike in European countries, where the vast majority of patients receive injections during inpatient treatment, the number of people in the day-patient treatment is increasing in Russia, which results in an increase of the uncontrolled dumping of medicines and syringes from home medicine kits into garbage containers. The experts say that in Russia, the issue of collecting and neutralizing medicines that have expired or unused medicines has not been resolved.

One can identify the following main sources of pharmaceutical waste generation: pharmaceutical manufacturing companies; medical facilities (hospitals, clinics, dispensaries, health resorts, etc.); pharmacies, drugstores; population.

Large manufacturers of pharmaceuticals, as a rule, also have the appropriate licenses to independently dispose of and destroy low-quality drugs that were formed during the production process with a violation of technology or with an expired shelf life, taken back from buyers under the terms of the contract.

Medical institutions provide for the separate collection of hazardous waste in household waste into red containers with its separation at the collection or sorting stage and its subsequent transfer to specialized enterprises that have licenses for operations in the field of hazardous waste management.

Upon detection of substandard medicines, pharmaceutical organizations either return them to the supplier (if this is stipulated by the contract) or transfer substandard medicines to specialized enterprises licensed to carry out operations in the field of hazardous waste management.

At the moment, the problem of disposal of pharmaceutical waste generated by the population in Russia remains unresolved [20]. The population is not informed about the dangers posed by the improper management of pharmaceutical waste and does not have information on possible methods of neutralizing low-quality and expired drugs at home; there are no conditions for the reception of pharmaceutical waste generated by the population with a view to its further transfer to the appropriate structures that have licenses for operations in the field of hazardous waste management.

VI. CONCLUSION

Thus, the areas of activity to solve the problem of MW in Russia include the following:

1) monitoring of enterprises involved in the field of MW processing to determine environmentally safe and cost-effective methods of neutralizing MW;

2) raising public awareness and education;

3) assessment of existing and creation of environmentally friendly technologies for MW disposal;

4) ensuring the formation and increase of environmental awareness and culture of the population, its awareness of the possible dangerous consequences of inappropriate MW management.

The results of the study confirmed the hypothesis that the most relevant for the medical industry was the distinction between the treatment of MW under the hazard class, which is associated with restrictions on its processing imposed by hazard class characteristics.

Separately, attention should be paid to the uncertainty of such a category as "pharmaceutical waste", the uncertainty of the status of waste from medical devices, etc. that arise as a result of the household use of those medical devices. We think that further detailed development and research of these issues can be a promising area for future studies.

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