Chapter 1

Introductory Chapter: Introduction to Hazardous Waste Management

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1. Introduction

Waste was associated with human society from prehistory to today and no doubt will continue for the future. People have to manage the produced waste. Disposal of waste into the surrounding locality has to date been the usual practice with little concern for the environment. Waste has to be managed properly to preserve the planet for the coming generations.

Waste generally generated accordingly with life continuity and related proportionally with the human activities such as agricultural, industrial, residential, institutional, municipal, commercial, mining, recreational, and others. This issue is strongly increasing and becomes a potential trouble in the community. The main focus of this study is on hazardous and radioactive wastes accompanying with their Different technologies developed for management.

Rapid trend of industry and high-technological progress are the main sources of the accumulation of hazardous materials. Nuclear applications have been rapidly developed recently, and several nuclear power plants have been started to work throughout the world. The potential impact of released radioactive contaminants into the environment has received growing attention due to nuclear accidents, which pose serious problems to biological systems.

Hazardous wastes are those that may contain toxic substances generated from industrial, hospital, some types of household wastes. These wastes could be corrosive, inflammable, explosive, or react when exposed to other materials. Some hazardous wastes are highly toxic to environment including humans, animals, and plants.

Radioactive waste was generated from use of radioactivity, in many but not all cases. Scientific society has approached the management of radioactive waste differently from the management of other waste types. Radioactive waste is defined as the material that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels as established by regulatory authorities. The higher the concentration of radionuclides above the established levels, the greater the hazard the waste possesses. The hazard of radioactive waste also depends on the nature of the radionuclides, and, at the same concentration, different radionuclides have different levels of hazard.

The management of extremely increasing volumes of these wastes became a very important accordingly. Inadequate management of waste led to contamination of environment: water, soil, and atmosphere and to a serious impact on public health. Direct health impacts of mismanagement of waste are well known and can be observed obviously in developing countries.

Saving of the environment and human health from the detrimental effects of hazardous and radioactive wastes is achieved by the effective improvement of waste management programs.

In the scope of this study, the development in waste management planning and implementation of hazardous and radioactive wastes was presented.

2. Hazardous wastes

With increasing manufacturing processes, solid, liquid, and/or gaseous emissions generate as by-products. Some of these wastes are potentially harmful to human health and environment and thus need special techniques of management.

Wastes are classified as hazardous if they exhibit one or more of ignitability, corrosivity, reactivity, or toxicity. According to Resource Conservation and Recovery Act (RCRA), hazardous wastes are defined as any waste or combination of wastes which pose a substantial present or potential hazard to human health or living organisms because such wastes are non-degradable or persistent in nature or because they can be biologically magnified, or because they can be lethal, or because they may otherwise cause or tend to cause detrimental cumulative effects [1].

The management of hazardous wastes has become a specialized discipline because of the complex nature of the problem and the solutions available to humanity. The mismanagement examples of hazardous wastes causing disastrous human and environmental consequences are numerous. The management process is based on the definition and classification of the different wastes, and their toxic effects on human and taking in consideration the application of risk management to control human health and environmental impacts of hazardous waste. Hazardous waste management, therefore, deals with minimizing harmful effects on humans and environment by applying special techniques of handling, storage, transportation, treatment, and disposal of hazardous wastes.

3. Hazardous characteristics

A useful listing of hazardous characteristics is that provided by the United Nations [2] as part of recommendations relating to the transport of dangerous goods as illustrated in **Table 1**.

UN class number	Hazardous characteristic
1	Explosive
3, 4	Flammable
5	Oxidizing
6	Poisonous/infectious
7	Radioactive
8	Corrosive
9	Toxic (delayed or chronic)/ecotoxic

Table 1. Hazardous characteristics: extracted from UN listing [2].

3.1. Industrial wastes

Waste generated from industrial sources can have non-hazardous and hazardous components, with non-hazardous waste usually representing the greater part of the volume. The hazardous component of this waste is relatively small in volume [3].

This type of waste was identified as hazardous waste when proceeds toxicity test, corrosively test, ignitability test, and some special character test. As a hazardous pollutant, it may impose serious impacts on surrounding environment and such impacts should be quantitatively examined to assess the influence on human health [4].

3.2. Household waste

Households generate small quantities of hazardous wastes such as oil-based paints, paint thinners, wood preservatives, pesticides, insecticides, household cleaners, used motor oil, antifreeze, and batteries. It has been estimated that household hazardous waste in industrialized countries such as the United States accounts for a total of about 0.5% (by weight) of all waste generated at home, while in most developing countries, the percentage probably is even lower [3].

3.3. Biomedical waste [5]

There are some of hazardous medical and dental wastes that, when disposed improperly, could cause harm to the environment. It also presents an occupational health hazards to the health-care personnel who handle these wastes at the point of generation and those involved with their management, that is, segregation, storage, transport, treatment, and disposal.

Healthcare waste that is capable of producing injury or disease including many sorts of hazardous wastes such as:

- Infectious waste: Which contain pathogens namely bacteria, viruses, fungi, or parasites in concentrations sufficient to cause disease in susceptible hosts. Cultures and stocks of infectious agents from laboratory work; tissues and dressing generated from autopsies, surgeries, and treatment of infected patients and animals; materials or equipment in contact with blood and infected body fluids.

- Pathological waste: Including tissue, organs, body parts, human fetuses, and animal carcasses, blood and body fluids.
- Sharps: It comprise syringes, needles, scalpels, saws, infusion sets, knives, blades, broken glass, or other items that can cause cut or puncture wounds.
- Pharmaceutical waste: It covers expired, unused, spilt, and contaminated pharmaceutical products, drugs, vaccines, and sera that are no longer required and need to be disposed of in appropriate manner.
- Genotoxic waste: This type combines cytostatic drugs, vomit, urine, or feces from the patients treated with cytotoxic drugs, chemicals, and radioactive materials. Genotoxic waste has mutagenic, teratogenic, and carcinogenic properties.
- Chemical waste: Discarded solid, liquid, or gaseous chemicals should be considered as hazardous if it is toxic, corrosive, inflammable, or reactive.
- Waste with high content of heavy metals: Mercury (thermometers, blood pressure gauges, amalgam), cadmium (discarded batteries), and lead (reinforced wood panels for radiation proofing in radiology department) generated from hospitals could be represented as a subcategory of hazardous chemical waste.
- Radioactive waste: The use of radioisotopes in vitro analysis of body tissues and fluids, in vivo organ imaging, tumor localization, and treatment and various clinical studies involving certain radionuclides need to be specially managed in a centralized treatment facility for radioactive wastes.

3.4. Radioactive waste

Nuclear applications have been rapidly developed recently, and several nuclear power plants started to work throughout the world. The potential impact of released radioactive contaminants into the environment has received growing attention due to nuclear accidents. Contamination of soil and water by radionuclides due to natural processes, global fallout from nuclear weapon testing, discharges from nuclear installations, disposal of nuclear waste, and occasional nuclear accidents (i.e., Chernobyl in 1986 and Fukushima in 2011) poses serious problems to biological systems. Radioactive waste includes a variety of radionuclides and occurs in a variety of physical and chemical forms. It can be generally classified as low-/intermediate-level radioactive waste and high-level radioactive waste [6].

Radioactive waste, arising from civilian nuclear activities as well as from weapon activities, poses a potential problem for handling and saving the environment for coming generations.

Radioactive waste includes a variety of radionuclides and occurs in a variety of physical and chemical forms. It can be generally classified as low-/intermediate-level radioactive waste and high-level radioactive waste. Nuclear research establishments include, for example, waste containing different organic components, toxic or chemically aggressive constitu-

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ents, radionuclides with specific properties (high mobility, high chemical activity, volatile elements, etc.), waste difficult for treatment and not appropriate for direct immobilization (e.g., spent organic ion exchange resins and spent liquid scintillation cocktails). For such waste, application of conventional treatment and conditioning options may not be efficient and appropriate in terms of economy, safety, and performance characteristics. In many cases, such wastes are stored awaiting an appropriate treatment and conditioning solution [7].

The primary sources of radioactive wastes in a country without nuclear fuel cycle activities are nuclear research, production of radioisotopes, application of radioisotopes, and decontamination and decommission of nuclear installations.

4. Hazardous and radioactive wastes management

Waste management is an important component of environmental policy all over the world. Priority of hazardous solid waste for environmental protection is formulated on source reduction and reuse, recycling, treatment, and landfilling [8].

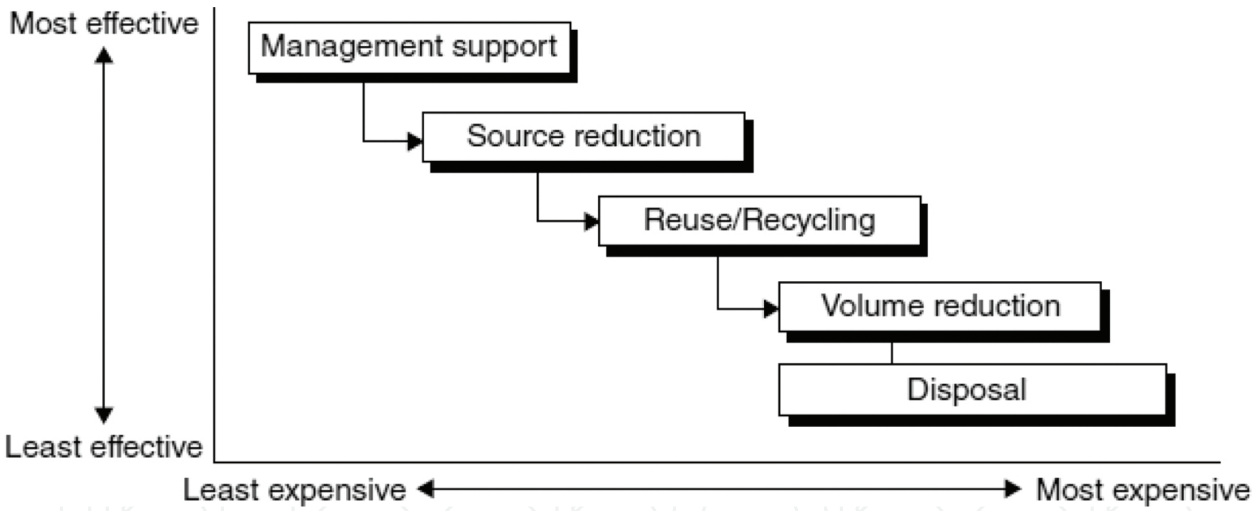

Figure 1. Minimization program for low- and intermediate-level radioactive wastes [11].

The objective of radioactive waste management is to deal with those wastes that in a manner that protects human health and the environment now and in the future without imposing undue burden on future generations [9]. Radioactive waste management involves many steps keeping the position of radioactivity clean. As nuclear power and arsenal grow, continuous monitoring and immobilization of waste over several decades and centuries and deposition in safe repositories assume great relevance and importance. The overall waste management generally includes the following steps: segregation and sorting of the radioactive wastes, treatment, conditioning, storage, transport, and final disposal. To achieve a satisfactory overall waste management strategy, component steps must be complementary and compatible with each other [10]. Consequently, for every nuclear activity, there should be a waste minimization program that aims to reduce the amount of generated wastes. Such programs should cover the organizational, technological, and economic aspects of the performed waste minimization processes. The key considerations of the minimization program for low- and intermediate-level radioactive wastes are illustrated in **Figure 1**, based on the effectiveness and cost of processing [11].

4.1. Waste minimization

Waste minimization is a process aimed to reduce the amount and activity of waste to a level as low as reasonably achievable. This process is now applied at all stages of nuclear processing from power plant design through operation to decommissioning. It consists of reducing waste generation as well as recycling, reuse, and treatment, with due consideration for both primary wastes from the original nuclear cycle and secondary wastes generated by reprocessing and clean-up operations [12].

Some wastes may require treatment for safety, handling, or stability for interim storage reasons. Treatment methods can be generally classified as chemical, physical, and/or biological. For new wastes, there is an opportunity to influence the process design so that wastes generated will require little or no treatment. If treatment is required, it is usually easier to obtain most of the characterization, while the waste is in raw form and characterization requirements may be directed toward treatment process control. For historic wastes, many situations are possible. Wastes may have already undergone some degree of treatment with little or no precharacterization. In such a case, further characterization will be required both before and during treatment to obtain a sufficient degree of detailed information. Waste streams may have been inadvertently combined, leading to a much larger volume of material that must be checked for certain properties. Previously treated wastes need to be examined to determine the compatibility of the prior treatment process with the waste acceptance criteria for the conditioning and disposal phases [13].

However, the seeking of inexpensive methods has led to develop new technologies based on the utilization of plant in biosorption of hazardous elements such as radioisotopes. Phytoremediation is the using of plants to remove hazardous contaminants from the environment. This trend is a growing application in remediation studies due to its numerous advantages, such as environmental friendliness, cost-effectiveness, and high abundance [6, 14]. Phytoremediation like other traditional treatment processes has to follow the subsequent step called immobilization process, and it could be done to solidify and stabilize the resulting secondary solid waste in an inert matrix [15]. The efficiency of contamination removal by phytoremediation can be greatly enhanced by a proper selection of the species suitable for the nature of pollutant and according to its geographic location, the microclimate, hydrological conditions, soil properties, and accumulation capacity of the plant species.

4.2. Processing and immobilization

Processing of radioactive waste includes any operation that changes its characteristics such as pretreatment, treatment, and conditioning. Solidification/stabilization (s/s) of hazardous and radioactive wastes is an attractive technology to reduce their risks and facilitate their handling prior to disposal. The long-term safe landing of the solidified hazardous waste is an important request for keeping the surrounding environment more secure for the coming generations [16, 17]. Immobilization reduces the potential for migration or dispersion of contaminants including radionuclides. The International Atomic Energy Agency (IAEA) defines immobilization as the conversion of a waste into a waste form by solidification, embedding, or encapsulation. It facilitates handling, transportation, storage, and disposal of radioactive wastes. Conditioning means those operations that produce a waste package suitable for handling, transportation, storage, and disposal. Conditioning may include the conversion of waste to a solid waste form and enclosure of waste in containers [12].

Solidification/stabilization is typically a process that involves the mixing of a waste with a binder to reduce the contaminant leachability by both physical and chemical means and to convert the hazardous waste into an environmentally acceptable waste form for land disposal. Moreover, it provides the waste form acceptable mechanical performance to withstand transport and handling. Inorganic binders such as cement are effective in immobilizing heavy metals through chemical and physical containment mechanisms, but are not as effective in immobilizing most organic contaminants. Many substances in the wastes significantly affect the setting and hardening characteristics of binders, especially cement-based cementing systems [18].

The requirements for the waste form are to provide physical, chemical, and thermal stabilities of the solidified radioactive materials. Moreover, the immobilized final waste forms resist leaching, powdering, cracking, and other modes of degradation. Portland cement is the most widely inorganic-based system used for solidification/stabilization of hazardous, low- and intermediate-level radioactive wastes [19–21].

4.3. Disposal of hazardous and radioactive wastes

Waste disposal is the final step of waste management and ideally comprises placing hazardous waste in a dedicated disposal facility, although discharging of effluents into the environment within permitted limits is also a disposal option. Concepts for radioactive waste disposal have, however, developed considerably since that time and great consideration is now given to the necessary retention times and retention capacities for different types of waste, resulting in much-improved repositories and planned disposal facilities [12].

According to IAEA, the disposal of radioactive waste is defined as the emplacement of waste in an approved specific facility that is intended to isolate the waste from human and environment and to prevent or limit a release of potentially harmful substances such that human health and the environment are protected. However, the safe disposal of radioactive wastes is one of the main concerns for those who oppose the nuclear technology. Therefore, disposal plays an important role in public acceptance of civilian applications of nuclear technology in different nations [10].

The effect of climatic conditions, for example, flooding and freezing/thaw accidents on the solidified wastes, is one of the most issues taken into consideration to evaluate the performance of this immobilized hazardous and radioactive wastes under the worst climatic conditions during the disposal process. Flooding accidents, one of the main dangerous problems that could face the solidified waste at the disposal site, should deserve special attention. Water is the primary agent of both creation and destruction of many natural materials, happens to be central of most durability problems in solidified waste materials [22, 23]. The rate of chemical deterioration is dependent on whether the chemical attack is confined on the surface of solidified waste material or also happening inside the material. The rate of deterioration is affected by the type and the concentration of ions present in water and by the chemical composition of the solid matrix.

5. Multi-barrier concept

Safety strategy for radioactive waste containment and isolation for the proposed storage and transportation focuses on two objectives: (1) to provide stabilization of the radioactive waste within the including package and (2) to limit the radiation exposure dose of the public during the transportation or other handling processes [24].

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