FABAD J. Pharm. Sci., 45, 1, 91-103, 2020

REVIEW ARTICLES

Waste Disposal and Management in Radiopharmaceuticals

Asuman TAŞ[*], Asuman Yekta ÖZER[°**]

Waste Disposal and Management in Radiopharmaceuticals

SUMMARY

Radioactive wastes are produced by numerous sources, especially hospitals. Nuclear medicine uses radiopharmaceuticals for the diagnosis and treatment of diseases. Radioactive wastes, which are generated as a result of these intended uses, need to be disposed by appropriate methods. The disposal of wastes generated from the use of radiopharmaceuticals differs in certain aspects from the disposal of other radioactive wastes. The method of disposal of radiopharmaceutical wastes are altered in accordance with their classification. The classification is based on the physical and radiological properties of radiopharmaceuticals. This review article analyzes radiopharmaceutical wastes, its classification, and its method of disposal.

Key Words: *Radiopharmaceutical wastes, Waste Disposal, Classification, Nuclear Medicine, Hospital, Disposal.*

Radyofarmasötiklerde Atık Yönetimi

ÖZ

Radyoaktif atıklar, hastaneler başta olmak üzere birçok alanda oluşmaktadır. Radyofarmasötiklerin Nükleer Tıp'ta başlıca kullanım alanları tanı ve tedavidir. Hastanelerde bu kullanım amaçları sonucunda oluşan atıkların uygun yöntemlerle bertarafı gerekmektedir. Radyofarmasötiklerin kullanılması ile oluşan atıkların bertarafı, diğer radyoaktif atıkların bertarafından bazı yönlerden farklılık gösterir. Radyofarmasötik atıkların, sınıflandırılmasına göre bertaraf edilme yöntemleri değişmektedir. Bu sınıflandırılma radyofarmasötiklerin fiziksel ve radyolojik özelliklerine göre yapılmaktadır. Bu derlemede, radyofarmasötik atıkların ne olduğu, nasıl sınıflandırıldığı ve nasıl bertaraf edildiği incelenmiştir.

Anahtar kelimeler: *Radyofarmasötik Atık, Atık Bertarafı, Sınıflandırma, Nükler Tıp, Hastane, Bertaraf etmek.*

Received: 29.08.2019
Revised: 22.11.2019
Accepted: 25.12.2019

[*] ORCID:0000-0001-9831-4638, Hacettepe University, Faculty of Pharmacy, Department of Radiopharmacy, Ankara 06100, Turkey.
** ORCID:0000-0001-6707-247X, Hacettepe University, Faculty of Pharmacy, Department of Radiopharmacy, Ankara 06100, Turkey.

[°] Corresponding Author: Prof. Dr. Asuman Yekta ÖZER,
Phone : +(90) 312 305 21 96
Fax : +(90) 312 311 47 77
E-mail: ayozer@hacettepe.edu.tr

INTRODUCTION

Radioactive materials are used worldwide in medical applications, nuclear power plants, and consumer products, such as televisions, smoke detectors, phosphorous clocks and lightning rods (http://www.taek.gov.tr/ogrenci/r06.htm). Thus, radioactivity is used in many areas and radioactive waste is formed by the use of these substances. In the early 1800s, the English chemist John Dalton introduced the atomic theory. Later, the field of radiopharmaceuticals emerged when the German scientist Wilhelm Konrad Roentgen discovered X-rays in 1895, which is used in the field of nuclear medicine to diagnose and treat diseases (http://eczacilik.ege.edu.tr/index.php/radyofarmasi-anabilim-dali/)(http://www.tsnm.org/halkimiza-yonelik/nukleer-tip-nedir-).

The use of radiopharmaceuticals for both diagnostic and therapeutic purposes is increasing rapidly in the health field, which is leading to an increase in the amount of radiopharmaceutical wastes. It is necessary to properly classify and dispose of these generated wastes as they damage the environment and the living system. For this purpose, the International Atomic Energy Agency (IAEA) was established in 1957 to manage the use of radiation for peaceful purposes and to prevent damage to humans and the environment. Atomic Energy Agencies have been established in many member countries, including Turkey, which have established rules and taken precautionary measures. The radioactive waste disposal procedure has been prepared under the guidance of the IAEA. For radiopharmaceutical wastes, disposal methods have been determined under the guidance of the IAEA. According to the IAEA guidelines, the resulting wastes must first be classified and then followed by a proper disposal method.

The main purpose of waste management is to protect radiopharmasists, radiation workers, health personnel, patients, people and the environment from excessive radiation exposure. To achieve this, in addition to the rules of the IAEA, good radiopharmaceutical practices (GRP), good manufacturing practices (GRP) and radiation safety must be observed.

Radiopharmaceutical wastes are classified according to many criteria, such as radiological properties and physical properties and they are properly disposed of based on these classifications. Radiopharmaceutical wastes are divided into six classes based on their radioactive properties, that is exempt waste, very short-lived waste, very low-level waste, low-level waste, medium-level waste and high-level waste. According to their physical properties, radiopharmaceutical wastes are classified into solid waste, liquid waste, and gaseous waste (Classification of Radioactive Waste, 2009) (Policies and Strategies for Radioactive Waste Management, 2009) (Radyoaktif Atık Yönetimi Yönetmeliği No: 28582, 2013) (Silindir-Gunay et al., 2019).

Radiopharmaceutical wastes are transported in packages by highway, railway, airway, and sea. Labels, such as I – White, II – Yellow, III – Yellow, and III – Yellow and Special Condition are pasted on the packages according to the Transport Index value (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).

Radiation protection specialists, health physicists, or nuclear pharmacists (radio pharmacists) are responsible for the storage, disposal, and control of radiopharmaceutical wastes in hospitals (Özer, 2016). The IAEA has determined the standard procedures for the disposal of radiopharmaceutical wastes and countries have to dispose radiopharmaceutical waste according to these procedures. United States Nuclear Regulatory Commission (U.S. NRC) in the United States, Euratom in European countries, Canadian Nuclear Safety Commission (CNSC) in Canada, and Japan Atom Energy Agency (JAEA) in Japan are responsible for radiopharmaceutical waste management. The Turkish Atomic Energy Authority (TAEK) is responsible for radiopharmaceutical waste management in Turkey (Radyoaktif Atık Yönetimi Halkı Bilgilendirme Broşürleri, 2008) (Step-By-Step: Lıfe Cycle Radıoactıve Waste Management, 2014)(2013 Inventory summary report, 2015)(http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/review_en/2006/9_1.html)_(https://www.nrc.gov/waste.html)(http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx)

BODY

What is a Radiopharmaceutical Waste?

According to the TAEK Radioactive Waste Management Regulation, radioactive waste refers to structures, systems, components, and materials that contain radioactivity as well as radioactively contaminated nuclear materials and radioactive materials with an activity concentration above the standard limits, which renders it unusable. The wastes that result from the use of radiopharmaceuticals in nuclear medicine are called radiopharmaceutical wastes (Radyoaktif Atık Yönetimi Yönetmeliği Resmi Gazete No: 28582, 2013).

Classification of radiopharmaceutical waste

Classification of radiopharmaceuticals has gained importance in radioactive waste management. Radiopharmaceutical wastes are classified according to

many criteria, such as sources of radioactive waste, waste forms, and half-lives.

Classification by radioactive properties

Radioactive wastes are classified into very short-lived, very low-level, low-level, medium-level, and high-level radioactive waste according to the half-lives and radioactivity levels of the radionuclides that they contain (Radyoaktif Atık Yönetimi Yönetmeliği Resmi Gazete No: 28582, 2013).

Exempt Waste (EW):

Exempt waste is a waste with low radioactivity content that does not require the control of the legal authority. Substance residues after radioactivity are cleared by a legal authority and are not counted as radioactive waste (Classification of Radioactive Waste, 2009). This waste contains radioactive material at a level that is not harmful to humans or the environment around them (http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx)

Very Short-Lived Waste (VSLW):

Wastes that have radioactivity above the exemption limit and after storing it for a few years, the radioactivity of these wastes falls below the liberation limit called VSLWs (Radyoaktif Atık Yönetimi Yönetmeliği No: 28582, 2013). Such radioactive wastes usually arise from radionuclide applications for research and medical purposes (Policies and Strategies for Radioactive Waste Management, 2009).

Very Low-Level Waste (VLLW):

Radioactive wastes with radioactivity above the exemption limit, not within the VSLW class, and with an activity concentration of approximately 1 / 100 in the liberation limits fall into the VLLW category. (Radyoaktif Atık Yönetimi Yönetmeliği Resmi Gazete No: 28582, 2013). Mostly, the wastes come from the operation, decommission, and evacuation phase of a nuclear plant. (Policies and Strategies for Radioactive Waste Management, 2009).

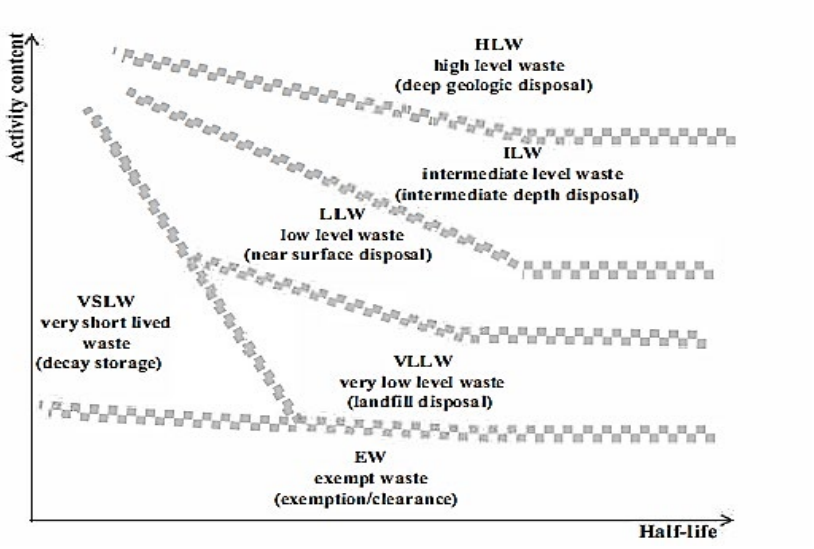

Figure 1. Classification of radioactive wastes
(Policies and Strategies for Radioactive Waste Management, 2009)

Low Level Waste (LLW):

LLW contains items that become contaminated with radioactive material or have become radioactive by exposure to neutron radiation. Contaminated protective clothing, swaps, injectors, laboratory animal carcasses, equipment, and tools contain a large amount of this type of waste. It is disposed at surface disposal facilities (Classification of Radioactive Waste, 2009)(http://www.ensreg.eu/safe-management-spent-fuel-and-radioactive-waste/categorisation-radioactive-waste)(https://www.nrc.gov/waste/low-level-waste.html).

Intermediate Level Waste (ILW):

These wastes are exposed to alpha radiation or long-lived radionuclides at concentrations that require isolation and storage of these wastes for hundreds of years. This waste group contain ion-exchange resins, certain radioactive sources used in radiation therapy, and contaminants from the disposal of reactors (http://nuclearsafety.gc.ca/eng/waste/low-and-inter-

mediate-waste/index.cfm) (http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx).

Definition of LLW and ILW waste according to TAEK: radioactivity levels of wastes that are greater than the activity concentration of VLLW but are not enough to be grouped into the HLW class are classified as LLW and ILW (Radyoaktif Atık Yönetimi Yönetmeliği Resmi Gazete No: 28582, 2013).

High Level Waste (HLW):

According to the TAEK Radioactive Waste Management Regulation HLW, "radioactive wastes that are generated as a result of reprocessing, which may contain fission products and actinides, and other radioactive wastes having activities near their activities are classified as HLW" (Radyoaktif Atık Yönetimi Yönetmeliği Resmi Gazete No: 28582, 2013).

HLWs are radioactive substances that emerge as a by-product of reactions, which take place within nuclear reactors (https://www.nrc.gov/waste/high-level-waste.html).

Classification of radioactive wastes by their physical properties

a) Solid Wastes:

According to the TAEK Radioactive Waste Management Regulation, the radiopharmaceuticals used in the radiopharmacy laboratory include empty containers after use, injectors containing unused patient doses, materials used in patient application (such as injector and vials), materials such as cotton, sponge, bandage used during application, solid material contaminants, and solid materials used in decontamination process (Gülhane Askeri Tıp Akademisi Radyoaktif Atıkların Kontrolü ve İmhası Talimatı [GATA], 2016).

b) Liquid Wastes:

These wastes are generated when patients' are given radionuclides to consume. Moreover, this group includes liquid scintillation solutions (Nükleer Tıpta Atıkların Güvenliği TAEK Kurs Sunumları, 2016).

c) Gaseous Wastes:

Gas wastes such as iodine-123,125,131 and Xenon-133 are often released to the atmosphere through an exhaust system. It is ensured that the released gases do not enter the building again through open windows or ventilation systems (Management of Radioactive Waste From The Use of Radionuclides in Medicine, 2000).

Safe Transport of Radiopharmaceutical Wastes

Rules that must be followed during the transport of radiopharmaceutical wastes are specified in the "Regulation on Safe Transport of Radiopharmaceuticals" by TAEK, which includes the stages of loading, transporting, unloading, temporary storage, delivery to the buyer for the transport of the radioactive material package by road, rail, air and sea, including design, and manufacturing stages (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005). In order to talk about the disposal and management of radioactive materials, it is also necessary to mention their packaging, labeling, and transport (Değer et al., 2004).

Packaging Used in Radioactive Material Handling

- **Excepted Packages:** Substances with very low radioactivity are carried in these packages (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).
- **Industrial Packages:** Low Specific Activity Material (LSA) is a radioactive substance with low specific radioactivity by nature. On the other hand, a Surface Contaminated Object (SCO) radioactive on its own, but is a solid substance that is contaminated with surface radioactive material (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).
- **Type A package:** Transport of specially prepared radioactive substances and radioactive substances containing more than one known radioisotope is carried out using this package (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).
- **Type B package:** It is designed and manufactured to be resistant to severe accidents (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).
- **Type C package:** It is a package designed and manufactured to carry highly active radioactive materials, so that it is resistant to the high impact of aircrafts in which it is transported (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).

Standard Procedures for Handling Radioactive Material

Transport Index (TI) and surface radiation values determine the class that the radioactive substance needs to be put in, and if the radioactive material fall in different classes; the transported item is included in an upper class. Each packet contains the United Nations (UN) abbreviation as well as UN numbers with

receiver/sender information on all, but the excepted package. The selected labels are determined for each package based on their class and the labels are affixed on both sides of the pack and sleeve and to all four sides of the commercial transport container. Information on the label include:

a) Content: The names and symbols of radioisotopes are written in the table of contents.

b) Activity: The maximum radioactivity of the radioactive material in the package is specified in terms of Bq.

c) Transport Documents: For carrying containers containing items containing radioisotopes of the same type, **See the Transport Documents** on the labels of containers for substances with different radioisotopes.

d) Transport Index: The activity measured at a 1 m distance from the outer surface of the containg is called TI. It is not necessary to write TI in transport vehicles containing **I-WHITE** class.

Four signs are put outside, on the surfaces of large transport containers carrying radioactive packets, except the excepted package. The shipper informs the carrier of the route information and emergency plans in the transport document. Packages **II-YELLOW** and **III-YELLOW** are carried in a vehicle by a trained driver via a road (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005). The driver must pay attention to the following: carriers must use transportation means to place packages in the car, transportation should be done using the shortest route during times with the least amount of traffic, and the driver must have a radioactive substance transportation document (http://www.taek.gov.tr/radyasyon-guvenligi/e-tasima-islemleri.html).

Table 1. Classification of Radioactive Substance Packages by Transport lndex and Package Signs (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Official Gazette No: 25869, 2005)

Conditions		Category
Transport İndex (TI)	The highest radiation level at any point on the surface (mSv. sa^{-1})	
0	≤ 0.005	I – WHITE
0-1	0.005 -0.5	II – YELLOW
1-10	0.5 -2	III – YELLOW
>10	2 -10	III – YELLOW and Special Condition

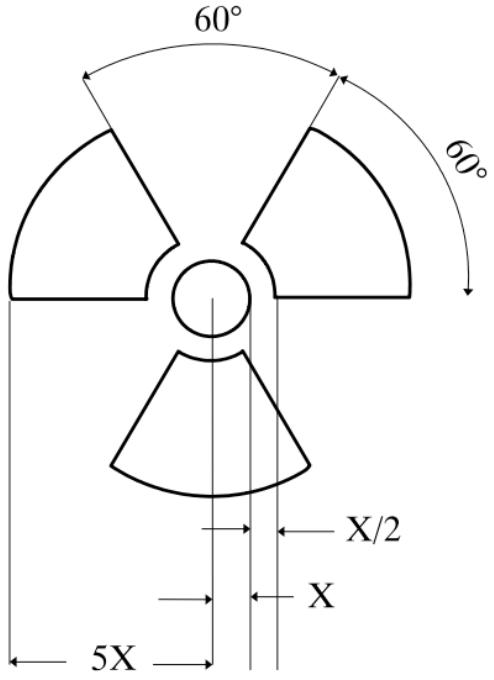

Figure 2. Radiation Symbol (The smallest value for X is 4 mm)
(Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005)

Label Types

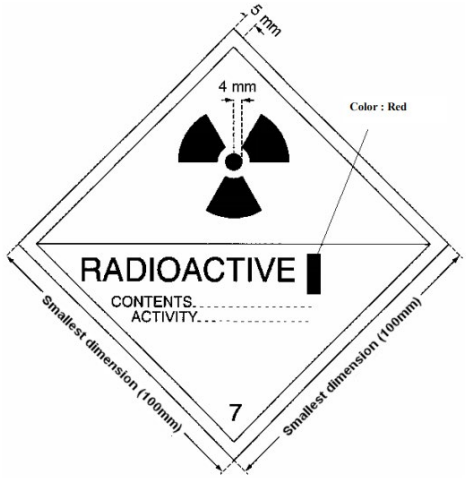

Figure 3.a. Class I- WHITE Label (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).

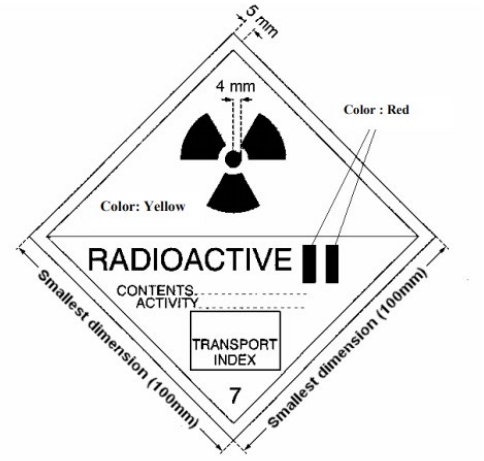

Figure 3.b. Class II- YELLOW Label (Radyoaktif MaddeninGüvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).

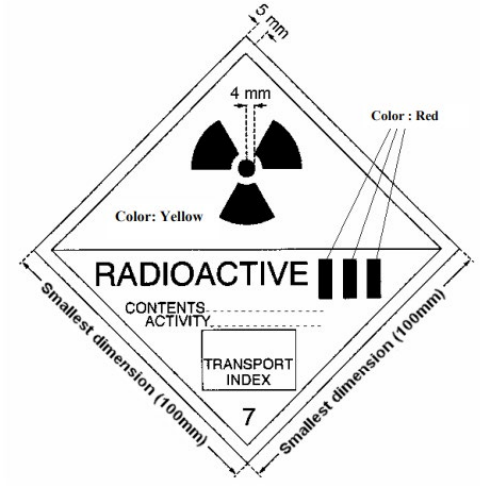

Figure 3.c. Class III- YELLOW Label (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).

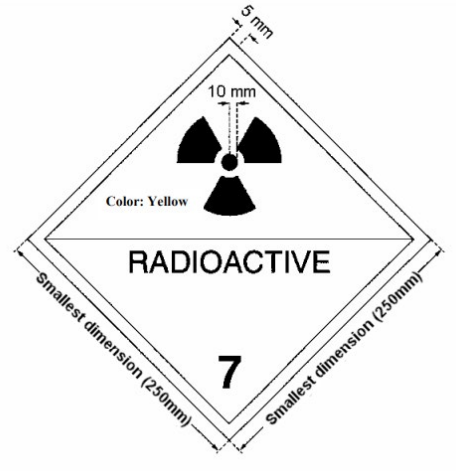

Figure 3.d. Plate (Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869, 2005).

Radiopharmaceutical Waste Management and Disposal

Applications of radiopharmaceuticals in various countries of the world are mentioned as follows.

Radiopharmaceutical Waste Management and Disposal in the United States

Radioactive waste is the result of radioactive materials used in electricity generation, medicine, agriculture, research, and industry. Radiopharmaceutical wastes should be destroyed when their radioactivity is above a certain level. The disposal of wastes is carried out according to the procedures established by the IAEA. Everything from the formation, disposal, transportation, and storage of the radiopharmaceutical to the disposal of the resulting waste is determined by these procedures. "Radiopharmaceutical Waste Management" deals with the implementation of these

procedures. Radiopharmaceutical waste management has reduced the risk to the environment and humans. The procedures to be followed for the disposal of the waste have been determined according to the physical, chemical, and radioactive properties of the waste. Procedures followed by the IAEA are determined and implemented by the United States Nuclear Regulatory Commission (USNRC) (Step-By-Step: Lıfe Cycle Radıoactıve Waste Management, 2014)(https://www.nrc.gov/waste.html).

The Radiation Safety Office of the U.S. NRC routinely collects radioactive wastes from hospital radiopharmacy laboratories every week on designated days. Prior to the laboratory's collection work, a Radiation Safety Officer needs to produce the required forms and labels for solid and liquid waste packages in the laboratory (Radıatıon Safety for Radıatıon Workers, 1996).

Liquid Radioactive Waste

The hospital's Radioactive Waste Disposal Directive is reviewed. A solid carton box that is large enough to contain waste bottles and additional packaging material is used. The cap must be secured tightly on the bottle. The "Radioactive Liquid Waste" label is prepared and adhered to the bottle. The box containing the bottle is placed upright. Moreover, the box is taped and a Radioactive Waste label containing the details is affixed to the box (Radıatıon Safety for Radıatıon Workers, 1996).

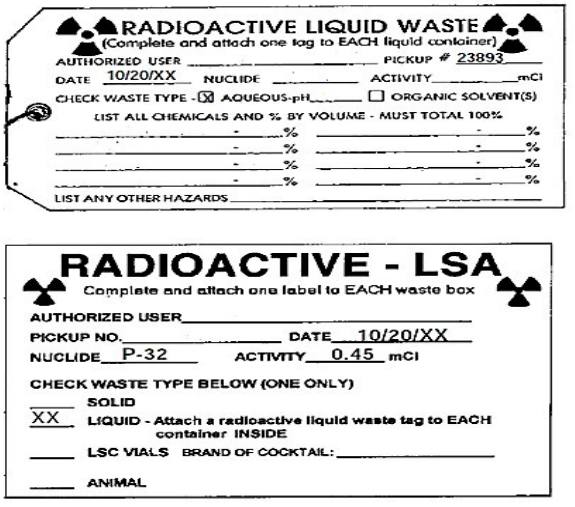

Figure 4. Radioactive Liquid Waste Label (upper) and Radioactive Waste Label (Radiation Safety for Radiation Workers, 1996)

Solid Radioactive Waste

Once laboratory procedures are in place, all materials are collected and discarded (paper, gloves, etc. are disposed of if not contaminated). Absorbent paper, disposable pipette tips (placed in a smaller cardboard box to prevent puncture injuries), paper towels, disposable gloves, among others are placed inside a solid waste box and covered with a yellow plastic bag. First, the yellow plastic bag is secured and the box is taped. Furthermore, the radioactive waste label is filled-in and pasted on the box (Radiation Safety for Radiation Workers, 1996).

Radiopharmaceutical Waste Management and Disposal in European States

The rules set by the IAEA in the management of radioactive waste, has been adapted to European Union by Euratom Regulations (http://ec.europa.eu/research/energy/euratom/index_en.cfm?pg=fission&section=disposal).

To minimize storage requirements, non-radioactive wastes are separated from radioactive wastes and disposed of as normal hospital waste. Protected bins are covered with plastic bags that are easily removable once full. Long-lived wastes are also stored. Radioactive wastes, such as syringes, pharmaceutical tubing, needles, and swaps are produced daily in the Radiopharmaceutical Laboratory. Wastes generated from the preparation and distribution of radiopharmaceuticals are first disposed of in waste containers that are placed at the work-station. The waste container at the work-station should not be allowed to overflow and should be emptied at regular intervals. For long-term storage of wastes, wastes must be removed from the shielded area, the contents of which must be written on the label in detail and stored as a designated depot radioactive waste. After their use, the syringes and needles that are cutting and drilling edges are thrown into the waste box. Overfilling of reservoirs should not be allowed. Cutting and drilling tool waste boxes must be closed. All radioactive wastes should be safely stored and regularly monitored. Wastes should be checked using an appropriate equipment and disposed of after they decay to background activity levels. Any item above the background activity level should be kept in the depot for the duration of the decay (The Radiopharmacy a Technologist's Guide, 2016).

Radiopharmaceutical Waste Management and Disposal in Canada

The CNSC is responsible for the management of radioactive waste in Canada (2013 Inventory summary report, 2015). Radioactive waste has developed a system allowing it to decay by hiding (physical half-life) until its activity reaches a level that can be ignored. After reaching this level, the waste is treated as non-radioactive normal waste (medical waste). Wastes containing and not containing Tc-99m are kept

till the completion of decay in certain compartments until a negligible amount (0.5 mR. sa^{-1}) is reached. The choice of radiopharmaceutical to be discarded depends on the physical half-life of the radionuclide. Short half-life radiopharmaceuticals are put in Bin A. All wastes in boxes A, B and C are allowed to degrade for approximately 9 half-lives till the background activity level is less than 0.5 mRem. sa^{-1}. When the box is full, it is closed and dated, as is allowed to decay for 9 half-lives. Two smaller containers, specially allocated for Tc-99m waste, are placed next to Bin A, B and C. These are named as Bin 1 and 2 and have lead protection. Bin 1 is filled on the first day and Bin 2 is filled on the second day. On the third day, Tc-99m is drained to Bin 1, Bin A with a degradation of about 9 half-lives. This cycle is repeated for Bin 2 the next day (Guidelines to Radiopharmacy, 1982).

Tablo 2. Radionuclides that can be put into trash can (Guidelines to Radiopharmacy, 1982)

BIN A ($t_{1/2}$ less than 10 hours)	BIN B ($t_{1/2}$ less than 9 days)	BIN C ($t_{1/2}$ greater than 9 days)
All ^{99m}Tc products	K-42	Co-57
^{81m}Kr generator cores	Fe-52	Cr-51
	Ga-67	I-125 (sealed source)
	In-111	Se-75
	^{99}Mo generator cores	Yb-169
	I-123	
	I-131	
	Xe-133	
	Hg-197	
	Au-198	
	Tl-201	

Radioiode products should only be placed in boxes when they are in a non-volatile form (in capsule form). In radioactive waste containers, if the surface reading on each side of the box is less than 0.5 mRem. sa^{-1}, it is disposed of as normal waste. All radioactive symbols and notices must be removed from the outer surfaces of these containers after they have been disposed of. The disposal of the radioactive waste is recorded in the "Radioactive Waste Records" (Guidelines to Radiopharmacy, 1982).

Radiopharmaceutical Waste Management and Disposal in Japan

The JAEA undertakes radioactive waste management in Japan (http://jolisfukyu.tokai-sc.jaea.go.jp/fukyu/review_en/2006/9_1.html). Radioactive wastes from nuclear medicine operations are either disposed by the disposal of low-activity wastes into the sewerage system, if permitted by local regulatory authorities or by safely storing the radioactive decay activity until the activity is safe. Long half-life or high-activity wastes require long-term storage in a convenient storage area. The waste materials resulting from the preparation of patient injections are divided into two groups as long half-life and short half-life. Usually, Tc-99m waste needs to be stored in a plastic bag in an shielded container for 48 h. The label should be placed on the container with the radionuclide and date written. Gallium-67, Iodine-131 and other longer-live radionuclides should be placed in the container in a plastic bag with separate label mentioning the date, and should be stored safely. Sharp objects, such as needles should be separated and placed in a protective plastic box for safety. When disposing of wastes, care should be taken to dispose of a waste in any waste carton if the surface dose rate is less than 5 mGy. s^{-1}, to wear disposable gloves while handling sharp objects, and to place two bags inside the waste to minimize the risk of spillage (Nuclear Medicine Resources Manual, 2016).

Radiopharmaceuticals Waste Management and Disposal in Turkey

In Turkey, TAEK undertakes the responsibility of the radioactive waste management. The aim of TAEK and other such institutions in the world is to control radioactive waste generation, and ensure the protection of human health, the environment, and future generations. (Radyoaktif Atık Yönetimi Halkı Bilgilendirme Broşürleri, 2008). In hospitals, radioactive wastes usually occur in their Nuclear Medicine units, Radiology units, and Radiopharmacy laboratories.

Syringes, injection vials, needles, blood and blood products, body fluids, body tissues, gloves, urine, and stools of the patient are the radiopharmaceutical and radioactive wastes commonly found in these units. In addition, wastes found in hospitals, which are used in diagnosis, medical treatment, and radiopharmaceutical drugs, are collected and processed in these units. Nuclear pharmacists are responsible for the preparation of radiopharmaceuticals in hospitals. Radiation protection specialists, health physicists, and nuclear pharmacists are responsible for the storage, disposal, and control of radiopharmaceutical wastes (Günalp & Dönmez, oral interview / GATA, November 2016). The regulations stipulated by TAEK are essential for the establishment of these units in hospitals. The storage and disposal of wastes generated in these units are carried out according to the "Regulation on Wastes from Radioactive Substance Use" and "Radioactive Waste Management Regulation" of TAEK. Radiopharmaceutical wastes generated in hospitals are collected in separate cups. These wastes are not immediately released as in-house wastes and they have special disposal conditions.

Disposal of Radiopharmaceutical Wastes in Hospitals

Radiopharmaceutical wastes that are generated from hospitals are disposed of by providing appropriate conditions without harming people and the environment. Hospitals, in general, produce dry and solid radioactive waste, liquid waste, biological and sharp wastes, and airborne wastes (Gülhane Askeri **Tıp** Akademisi Radyoaktif Atık Bertaraf Prosedürü [GATA], 2016).

a) Solid Radioactive Wastes

Empty containers of radiopharmaceuticals used in the radiopharmacy laboratory, like bottles, injectors, inhalation apparatus, the Positron Emission Tomography (PET) end-resultant wastes, gloves used during injection are included in this group of wastes. Radioactive wastes are collected separately in waste collecting containers and not with the other wastes. These containers are opened and closed with the help of foot pedals. According to the radiation type and energy of the radioactive material, the inside of these containers, their covers and their bases are shielded with appropriate material. An international radiation mark is placed on the outside of the container. A red colored plastic waste bag, with a thickness of 150 microns, is placed in this waste collection box so that the top of the container can be reached easily (GATA Radyoaktif Atık Bertaraf Prosedürü [GATA], 2016).

Figure 5.a) I-131's Lead Sheet Covered Container, Cutter, and Drill I-131,

Waste Storage Containers for Medical Waste, b) Medical Waste and

Domestic Waste (Gülhane Askeri **Tıp** Akademisi [GATA], November 2016)

For sharp-tipped wastes such as needles, a separate container should be used instead of a plastic bag. If a plastic bag is used, it may tear. This container should also have the international radiation sign. No waste other than radioactive wastes should be disposed of in these collecting containers (Günalp & Dönmez, oral interview / GATA, November 2016).

The end of the accumulation containers is filled with the label of the end of the plastic bags by connecting the mouth. In order to facilitate the disposal of the wastes, it is important to mention on the label the type of waste present in the container or from which room it is taken. The same process is followed for the collecting containers of injectors (GATA Radyoaktif Atık Bertaraf Prosedürü, 2016).

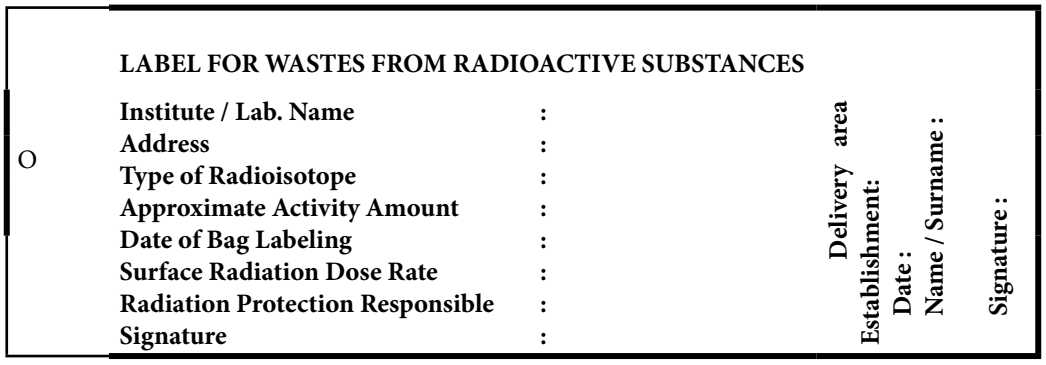

Figure 6. Radioactive Wastes Generating from RRD Studies Waste Label (GATA, November 2016).

These containers are then collected in a separate place and the radiation dose rate is measured by a health physicist with the aid of a Geiger Müller (GM) detector. If the measured value is 1 μSv. sa^{-1} or less than this value, the waste is considered to be a normal medical waste and is disposed directly. If the measured value is above this value, the accumulation container is kept in the lead shielded storage. The waiting time varies according to the half-life of the radionuclide present in the waste. The radionuclide is allowed to stand for ten times longer than the physical half-life, and then the radiation dose rate is measured again with the GM instrument. If the value is less than 1 μSv. sa^{-1}, the waste is disposed as normal medical waste. Solid radioactive wastes are checked once a week by the GM detector. For example, the physical half-life of Fluorine-18 (F-18) is 110 min. Wastes from the PET chambers are F-18 radionuclide wastes. Therefore, these wastes are stored for approximately 24 h, that is approximately 10 times their half-lives. After 24 h, it is measured by the GM device and discarded as medical waste according to the value or kept waiting for longer time (Günalp & Dönmez, oral interview / GATA, November 2016).

b) Liquid Radioactive Wastes

The scintillation fluids used in the laboratory and urine and stools of patients containing radionuclides, and having physically long half-lives, such as I-131 are in this type of waste class. Hospitals do not have sinks in the rooms where patients are given radiopharmaceuticals, and their shower and handwashing systems are not provided with direct sewerage. These rooms have a separate sewerage system. Hospitals have two 9 m^3 tanks for toilet wastes. First, the wastes are collected in tank 1 and are held in it ten times longer than the physical half-life of the radionuclide used. Then, the waste is moved to waste tank 2. The waiting period of the waste tank 2 is the same as waste tank 1. At the end of the waiting period, the waste is transferred to normal sewerage. Liquid wastes, which are generated by a patient's handwashing and showering, are kept in a third tank, which is located away from these two tanks. The size of this tank is also 9 m^3. The radionuclide is held in this tank till the time the physical half-life of the radionuclide is 10 times, and is given to the sewerage at the end of this period (Günalp & Dönmez, oral interview / GATA, November 2016).

The sink should be washed with plenty of water when radioactive material is poured in the sink. It should then be checked with the Survey Meter. Moreover, radioactive waste storage should be checked twice a year (GATA Radyoaktif Atık Bertaraf Prosedürü, 2016).

The amount of radioactive wastes, that an establishment can give to sewage at one time, cannot exceed 2.5 times of the ALI_{min} value (Radyoaktif Madde Kullanımından Oluşan Atıklara İlişkin Yönetmelik Resmi Gazete No: 25571, 2005).

c) Gaseous Radioactive Waste

These wastes are released into the atmosphere by the licensee within the framework of the rules set out during the design and licensing of the installation (Radyoaktif Madde Kullanımından Oluşan Atıklara İlişkin Yönetmelik Resmi Gazete No: 25571, 2005).

Rules for the release of radionuclides, such as Cobalt (Co), and the use of radioisotope generators (such as Technetium-99m / Molybdenum-99) are made by TAEK (Günalp & Dönmez, oral interview / GATA, November 2016).

World Health Organization's Radiopharmaceutical Waste Rules

The storage period for radioactive waste degradation differs from the storage period of other waste sources. The main goal is to store the wastes until they are safe to be classified as normal medical waste with a significantly low radioactivity. Wastes with a half-life of less than 90 days are kept for at least 10 half-lives of radioisotopes. Infectious radioactive wastes are disinfected before disposal. Sharp wastes such as

needles and Pasteur pipettes are placed in containers. Radioactive wastes with a half-life of more than 90 days are collected and stored in accordance with national regulations. In many countries, such wastes are transported to a national waste site by a government agency or specialized contractor. Storage sites must be adequately marked as "Radioactive Waste" and should be flameproof. The floor, tables and walls of the storage sites must be covered with suitable material that will not allow contamination, and ventilation systems and radioactive monitoring systems should be installed. Disposable injectors containing radioactive wastes are discharged at a designated site for the disposal of radioactive liquid wastes. Sewerages serving as sinks for the discharge of radioactive fluids should be identified. If excessive radioactive fluids enter the sewer by mistake, a large amount of water should be allowed to flow (dilution method) into the sewerage to facilitate to dilute it to approximately 1 $kBq.L^{-1}$. If radioactive wastes exceed the permissible amount of sewerage, it should be immediately notified to the relevant government entity to check if it has been escaped to the atmosphere or to the surrounding area. In case of therapeutic treatments involving radionuclides, if there is no separate for each patient, hospital should be checked for radioactive contamination after each use (Agarwal et al., 2014).

Other Countries

In Khartum, radioactive wastes are collected in radiotherapy centers in accordance with the Sudan Atomic Energy Agency (SAEK) laws for in-patient wastes. The radioactive wastes to be handled by SAEK are put in yellow bags (Saad, 2013).

Oman has become a new member of the IAEA. The disposal of radioactive waste in hospitals is regulated according to the conditions laid down by the IAEA. The resulting Tc-99m wastes are allowed to mix with normal wastes after 48 h of storage. All wastes, such as used syringes and gloves, are collected in plastic cups with the date of collection being recorded. Usually, Tc-99m, Ga-67, and used syringes are placed in different containers. In the Royal Hospital in Oman, there are special isolation rooms for I-131, which are treated by the Nuclear Medicine Department. Solid wastes from these rooms are labeled with the patient protocol number in yellow or black polyethylene bags and sent to Temporary Storage Trolley (TST). It is allowed to decay for two to three months before the wastes are thrown away. The flushed away wastes from the toilets of patients who are treated with I-131 in the isolation chamber are collected in delay tanks. There are two delaying tanks and one isolation room in the hospital. Sewers are connected to the concrete tanks below the ground level of the two isolation chambers. During the filling phase of one tank, the other tank which is full is degraded in approximately two months (Ravichandran, Binukumar, Sreeram & Arunkumar, 2011).

CONCLUSION

Disposal and management of radiopharmaceuticals in the US, European Union, Japan, Canada, and Turkey complies with the established rules. In Turkey, TAEK supervises the disposal of radiopharmaceutical wastes and blocks incorrect practices. Thus, wastes can be disposed without harming human beings and the environment. As a result, the basic principle for the peaceful use of radioactivity is to comply with the relevant rules and apply them. The aim of the use of radiopharmaceuticals should be to ensure maximum benefit from it, manage and dispose wastes, and ensure that rules are in place and are followed.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

REFERENCES

9 Development of Technology on Nuclear Cycle Back-end- 9-1 Nuclear Facility Decommissioning and Radioactive Waste Management, https://rdreview.jaea.go.jp/review_en/2006/9_1.html Accession date: 16 November 2016.

Agarwal, A., Bouvet, F., Chartier, Y., Drew, C., Emmanuelel, J., Krisiunas, E., ……..Zghondi, R. (2014). *Safe management of wastes from health-care activities*. 2nd edition. Switzerland, WHO Press. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0012/268779/Safe-management-of-wastes-from-health-care-activities-Eng.pdf

Canadian Nuclear Laboratories Low-Level Radioactive Waste Management Office. (2015). 2013 Inventory summary report. Ontario. Retrieved from https://www.cnl.ca/site/media/Parent/2013-CNL_LLRW-Summary-Report-Eng.pdf

Categorisation of radioactive waste, http://www.ensreg.eu/safe-management-spent-fuel-and-radioactive-waste/categorisation-radioactive-waste, Accession date: 9 November 2016.

Değer, M., Demir, M., İnce, M., Kıraç, S., Köseoğlu, K., Turan, E., …Uysal, B. (2004). Kalite Kontrol, Enstrumantasyon ve Radyasyon Güvenliği Yönergesi, *Turk J Nucl Med,* 13,151- 169.

European Association of Nuclear Medicine. (2016). The Radiopharmacy A Technologist's Guide. Retrieved from http://www.eanm.org/content-eanm/uploads/2016/11/tech_radiopharmacy.pdf

European Commission. Radioactive waste management, http://ec.europa.eu/research/energy/euratom/index_en.cfm?pg=fission&section=disposal, Accession date: 15 November 2016.

Guidelines to Radiopharmacy. (1982). Chapter VII, Radioactive Waste Disposal, Canada.

Gülhane Askeri Tıp Akademisi (GATA) Nükleer Tıp Ana Bilim Dalı. Radyoaktif Atık Bertaraf Prosedürü. SOP. Accession date: 2016.

Gülhane Askeri Tıp Akademisi (GATA) Nükleer Tıp Ana Bilim Dalı. Radyoaktif Atıkların Kontrolü ve İmhası Talimatı. SOP. Accession date: 2016.

Gülhane Askeri Tıp Akademisi (GATA). SOP. Accession date: 2016.

Günalp, B. & Dönmez, S. Oral interview. GATA, Accession date: November 2016

International Atomic Energy Agency. (2000). Management Of Radioactive Waste From The Use Of Radionuclides in Medicine. Vienna: International Atomic Energy Agency. Retrieved from https://www-pub.iaea.org/MTCD/publications/PDF/te_1183_prn.pdf

International Atomic Energy Agency. (2006). Nuclear Medicine Resources Manual. Vienna: International Atomic Energy Agency. Retrieved from https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1198_web.pdf

International Atomic Energy Agency. (2009). Classification of Radioactive Waste (Report No: GSG-1). Vienna: International Atomic Energy Agency. Retrieved from https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf

International Atomic Energy Agency. (2009). Policies and Strategies for Radioactive Waste Management (Report No: NW-G-1.1). Vienna: International Atomic Energy Agency. Retrieved from https://www.iaea.org/sites/default/files/policiesrwm0609.pdf

International Atomic Energy Agency. (2014). Step-By-Step: Lıfe Cycle Radıoactıve Waste Management. *International Atomic Energy Agency (IAEA) Bulletin, 55*. Retrieved from https://www.iaea.org/sites/default/files/55304630507.pdf

Michael A.G. (2005). *Measuring Mass: From Positive Rays to Proteins*. Philadelphia: Chemical Heritage Press.

Özer, A.Y. (2016) Radiopharmaceutical Waste Disposal in Turkey and the World. 76th İnternational Congress of FIP. Buenos Aires, Argentina

Radyoaktif Atık Yönetimi Yönetmeliği Resmi Gazete No: 28582. (2013, 9 March), Retrieved from http://www.resmigazete.gov.tr/eskiler/2013/03/20130309-4.htm Accession date: 15 November 2016.

Radyoaktif Madde Kullanımından Oluşan Atıklara İlişkin Yönetmelik Resmi Gazete No: 25571. (2005, 2 September), Retrieved from http://www.resmigazete.gov.tr/eskiler/2004/09/20040902.htm Accession date: 16 November 2016.

Radyoaktif Maddenin Güvenli Taşınması Yönetmeliği Resmi Gazete No: 25869. (2005, 8 July), Retrieved from http://www.resmigazete.gov.tr/eskiler/2005/07/20050708-16.htm Accession date: 16 November 2016.

Ravichandran R., Binukumar J.P., Sreeram R., & Arunkumar L.S. (2011). An overview of radioactive waste disposal procedures of a nuclear medicine department. *Journal of Medical Physics, 36*, 95-99. doi: 10.4103/0971-6203.79692

Saad, SA. (2013). Management of hospitals solid waste in Khartoum State. *Environment Monitoring Assessment, 185*(10),8567- 82. doi: 10.1007/s10661-013-3196-1

Silindir-Günay M., Özer, A.Y. (2019). The Significance of Radioactive Waste Management and Disposal for Radiopharmacy Laboratories. 4rd International Multidisciplinary Symposium on Drug Research and Development- DRD 2019. Malatya/Turkey p:129-130.

Türkiye Atom Enerjisi Kurumu Ankara Nükleer Araştırma ve Eğitim Merkezi. (2016). Nükleer Tıpta Atıkların Güvenliği. TAEK Toplantısında Sunulan Kurs Sunumları. Ankara. Retrieved from https://www.taek.gov.tr/tr/belgeler-formlar/Kurs-Sunumlar%C4%B1/NTRK/12_N%C3%9CKLEER-TIPTA-ATIKLARIN-G%C3%9CVENL%C4%B0%C4%9E%C4%B0/lang,tr-tr/

Türkiye Atom Enerjisi Kurumu. Bölüm 3 - Radyasyon "Radyasyon ve Biz", http://www.taek.gov.tr/ogrenci/r06.htm, Accession date: 15 April 2017. Retrieved from http://kurumsalarsiv.taek.gov.tr/bitstream/1/107/2/30014.pdf

Türkiye Atom Enerjisi Kurumu. E-Taşıma İşlemleri, https://www.taek.gov.tr/tr/online-islemler/e-tasima-islemleri.html Accession date: 2 November 2016.

Türkiye Atom Enerjisi Kurumu. Radyoaktif Atık Yönetimi. Halkı Bilgilendirme Broşürleri 001; 2008; Ankara. Ankara: TAEK; 2008.

Türkiye Nukleer Tıp Derneği. Nükleer Tıp Nedir?, http://www.tsnm.org/halkimiza-yonelik/nukleer-tip-nedir-, Accession date: 25 February 2017.

U.S. NRC. Low- And İntermediate-Level Radioactive Waste, http://nuclearsafety.gc.ca/eng/waste/low-and-intermediate-waste/index.cfm, Accession date: 15 November 2016.

U.S. NRC. Low-Level Waste, https://www.nrc.gov/waste/low-level-waste.html, Accession date: 9 November 2016.

U.S. NRC. High-Level Waste, https://www.nrc.gov/waste/high-level-waste.html, Accession date: 10 November 2016.

U.S. NRC. Radioactive Waste, https://www.nrc.gov/waste.html, Accession date: 9 November 2016.

UW - Madison Safety Department. (2005), *Radiation Safety for Radiation Workers*. Chapter 5 Radioactive Material Work Practices (pp. 57-68). Madison, Wisconsin: University of Wisconsin Printed.

World Nuclear Association. Radioactive Waste Management, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx, Accession date: 10 November 2016.