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Research Article

Handling of Radioactive Waste from the Use of Radionuclides in Hospitals

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Abstract:

The waste that is generated during the different applications of radionuclides in medicine is considered as biomedical radioactive waste. This waste includes contaminated materials and syringes generated from Nuclear Medicine procedures, unused radioactive seeds from implants in Radiation Oncology as well as sealed sources used for calibration purposes, which are no longer useful. The overall goal of biomedical radioactive waste handling is to minimize the hazards posed by the waste prior to discharge or disposal. In order to plan the treatment of radionuclides in medical facilities, it is important to design an effective system for the overall management of radioactive biomedical waste. In this scientific paper I make a general assessment of the planning methods used in the handling of radioactive waste in medical facilities, including the collection, separation and packaging of radioactive biomedical waste.

1. Introduction

Nuclear medicine procedures help detect and treat diseases by using a small amount of radioactive material, called a radiopharmaceutical. Some radiopharmaceuticals are used with imaging equipment to detect diseases. Radiopharmaceuticals can also be placed inside the body near a cancerous tumor to shrink or destroy it. Hospitals across the country that provide radiation or nuclear services will often have an Office of Radiation Safety, which is responsible for maintaining and administering high-level safety protocols. They are also responsible for the maintenance and collection of data related to waste, compliance, audits and permits along with the possible transport and safe transport of radioactive materials. Even low levels of radioactive waste from hospitals must be packaged and transported according to federal regulations. Labels, container markings and packaging must clearly identify the contents, codes and symbols. The main properties of biomedical waste are their short half-life and low radiotoxicity. Biomedical wastes usually contain low-energy Beta and Gamma emitters and are generally of low total and specific activity. Importance is given to the volume of these wastes and other hazardous properties associated with the wastes, such as biological and chemical hazards [1]. The handling of radioactive waste in Nuclear Medicine at the University Clinical Center of Kosovo requires a complete preliminary assessment to ensure that the primary focus is on waste prevention and minimization, guaranteeing protection from all risks associated with this waste. This assessment will include an analysis of the total radionuclide inventory and use pattern, types and amounts of waste generated, and potential disposal routes. Then, when all uses of radionuclides have been evaluated, it can be determined which biomedical radioactive waste minimization practices should be implemented and how the treatment of this waste can be best organized. In some cases, modification of the radioactive storage room, or organizational arrangements for its use, will be necessary before it is appropriate to change the retention period of the waste on the premises to allow for radioactive decay [2]. Although these improvements may have cost implications, they can often be offset by the savings to be made from decaying short-half-life radionuclides (T2 < 100 days) so that they can be disposed of at cleanup levels. An effective program for the management of radioactive biomedical waste is based on the principles of prevention and minimization of waste,

while providing for the protection of personnel and the environment, in accordance with the requirements of the regulatory authority [3]. Such management should integrate all the associated risks found in the waste. As part of the evaluation of a waste treatment program, it is necessary to collect information specific to each facility. These data will provide the basis for determining possible opportunities for further optimization of waste management. The data must be recorded in a data handling system and must include [4]:

- Data on waste generated and radionuclides used within the facility;

- Reference for authorizations and details of authorized waste disposal routes;

- Reference to the procedures that are currently in use for the treatment of radioactive waste;

2. Material and Methods

Radioactive medical waste includes waste generated by nuclear medicine, radiation oncology and PET. Waste from hospitals is also harmful and should be properly managed so that there are no side effects from waste toxins being dumped into various water bodies, land spillage areas, etc. Special care should be taken with drugs of the cytotoxic and antineoplastic class. Which has the ability to ensure patient care as well as the ability to take life if not properly treated before disposal [6]. Radioactive waste is considered as hazardous pharmaceutical waste. The Environmental Protection Agency (EPA) provides information about radioactive waste that includes not only radioactive waste produced by health care technologies and procedures, but also other industries. In general scenarios, radioactive waste coming from hospitals or medical research facilities is usually defined as low-level waste. According to the EPA, a low-level or low-activity radioactive waste usually contains "very small" concentrations of radionuclides. A number of guidelines for the treatment and disposal of radioactive waste used in hospitals can also vary slightly from state to state and department such as nuclear medicine, radiology processes using PET scans, or even radiation oncology specialties.

- Types and examples of radioactive waste can range from contaminated syringes and materials to unused radioactive seeds commonly found in implant or pellet procedures.

- Segregation of radioactive waste is essential. Such waste must be placed in a clearly marked container. Any sharps and needles should also be placed in a separate container for disposal.

- Specifications on how to determine and verify the content and activity of radionuclides of individual waste packages;

- Data on dose rate and contamination;

- Types of packaging used for each type of radioactive medical waste;

- Verification of measurements made.

Information on the general requirements for designing a quality assurance program can be found in ISO 9000 or other relevant national and international standards. It is recommended that Member States prepare their standards for the management of radioactive biomedical waste based on the principles contained in these documents, taking into account all relevant regulations [5].

- Never dispose of any potentially contaminated items or radioactive material in a "regular" bin.

- No household staff should throw away radioactive waste! Rather, radioactive waste must be secured against the potential for unauthorized removal and must always be labeled in a manner that restricts removal except by authorized personnel.

- In hospitals where radioactive materials are used, a radiation safety office or similar personnel are responsible for the collection and disposal of this waste in a designated location.

- In some cases, such as a facility that routinely provides PET scans, radioactive waste can be allowed to decay naturally on site (as most have a relatively short half-life) and must be accompanied by compliant and accurate records.

2.1 Treatment of medical radioactive liquid waste using Forward Osmosis (FO) membrane process

The use of forward osmosis (FO) for concentrating radioactive liquid waste from radiation therapy rooms in hospitals was systematically investigated in this study. The removal of natural and radioactive iodine using FO was first investigated with varying pHs and draw solutions (DSs) to identify the optimal conditions for FO concentration. Results showed that FO had a successful rejection rate for both natural and radioactive iodine (^{125}I) of up to 99.3%. This high rejection rate was achieved at a high pH, mainly due to electric repulsion between iodine and membrane. Higher iodine removal by FO was also attained with a DS that exhibits a reverse salt flux (RSF) adequate to hinder iodine transport. Following this, actual radioactive medical liquid waste was

collected and concentrated using FO under these optimal conditions. The radionuclides in the medical waste (^{131}I) were removed effectively, but the water recovery rate was limited due to severe membrane fouling. To enhance the recovery rate, hydraulic washing was applied, but this had only limited success due to combined organic-inorganic fouling of the FO membrane. Finally, the effect of FO concentration on the reduction of septic tank volume was simulated as a function of recovery rate (Fig.1). To our knowledge, this study is the first attempt to explore the potential of FO technology for treating radioactive waste, and thus could be expanded to the dewatering of the radioactive liquid wastes from a variety of sources, such as nuclear power plants [7].

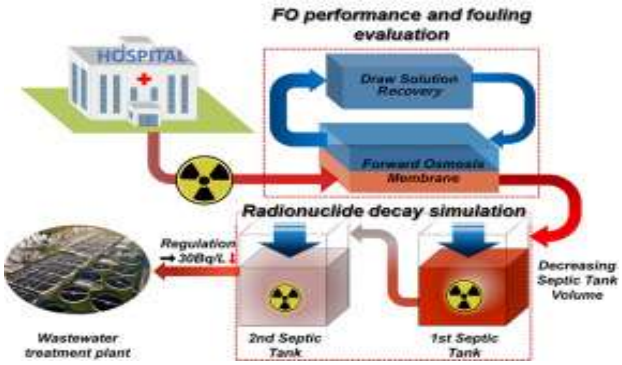

Figure 1. *Treatment of medical radioactive liquid waste [7]*

Radioactive materials, also known as radionuclides or radioisotopes, are routinely used in beneficial applications such as electricity generation, genetic modification, non-destructive inspection, and radiation medical therapy [8]. Radioactive material consists of various radioisotopes emitting α, β and γ radiation, which has a seriously negative impact on humans, animals, and plants [9], [10]. For these reasons, the leakage of radioactive material is a critical risk for human health and the environment. Radioactive liquid waste is also generated from the use of radioactive material, and this should be treated to prevent or mitigate harmful impacts, using treatments such as ion exchange [11], membrane distillation [12], reverse osmosis, and solvent extraction [13].

In hospitals, radionuclides (e.g., ^{90}Y, ^{125}I, ^{131}I, ^{89}Sr, ^{192}Ir, ^{60}Co, and ^{137}Cs) are utilized to examine and treat cancer patients by shrinking tumors and killing cancer cells [14], [15]. Radiation therapy rooms should be isolated to protect people from undesired radiation exposure. However, because wastewater containing radioactive substances (e.g., urine, feces, and detergent) is produced within radiation therapy rooms, it must be stored in separate septic tanks so that the radioactive material can decay to meet discharge regulations; this requirement limits the number of radiation therapy rooms that can be in operation [16].

Because the use of radionuclides can generate a significant amount of radioactive liquid waste, which requires large storage tanks, concentrating this waste can be beneficial in that it will reduce management costs. Only a limited number of studies have been carried out on the treatment of medical radioactive liquid waste arising from radioimmunoassays (RIAs), which are an in vitro assay technique used to measure the concentration of antigens [17]. RIA waste is composed of various kinds of proteins because they are generated from analysis reagents and samples [18]. Membrane technologies, such as the ultrafiltration–reverse osmosis (UF-RO) hybrid system, have been considered for the treatment of RIA waste containing ^{125}I. An UF-RO pilot study demonstrated that radioactive liquid waste could be made 15 times more concentrated and the final permeate successfully discharged after further treatment [19].

The objective of this study is to evaluate the feasibility of FO for the treatment of the medical radioactive liquid waste produced by radiation therapy in a hospital. First, the transport mechanism of radioactive iodine in FO was analyzed by comparing it with that of natural iodine to determine the optimal FO operating conditions (i.e., pH and the characteristics of the draw solution). After this, actual radioactive liquid waste was collected and concentrated using FO under these operating conditions. Finally, the management of radioactive liquid waste (i.e., the volume of storage tanks) was simulated based on theoretical models derived from mass balance. This study has potential implications for the concentration of radioactive liquid waste produced from other sources (e.g., nuclear power plants, legacy wastes, industries, and naturally occurring radioactive materials) [4].

2.2. A revolutionary solution for waste treatment: MagnetGas treatment system

A cutting-edge revolutionary treats all types of medical waste and eliminates the emission problem of dioxin and furan in traditional medical waste incineration or pyrolyzing. The MagnetGas Treatment System turns all organic wastes into white ashes, is compliance with strictest the emission standards, and reaching the goals of zero waste and carbon reduction (Fig.2).

Figure 2. *MagnetGas treatment System*

The latest revolutionary MagnetGas Treatment System is jointly developed in Canada, USA and China (Fig.5). The system treats all categories of medical waste including chemical waste and pharmaceutical waste, generates almost no dioxins or furans and is compliance with worldwide strictest emission standards. The treatment capacity is from 0.5 ton to dozens of tons per day with a wide application for various demands of medical waste treatment (Fig.3).

Figure 3. *Medical waste autoclave system*

2.3. Integrated autoclave with Shredder

Dedicated designed for processing medical waste. Double-shaft shredder with specific wear-resistant blades destroy soft materials as well as hard materials in medical wastes (Fig.4).

Figure 4. *Shredder System*

Figure 5. *Automated medical waste treatment plant [20]*

3. Results and Discussions

To determine the activity of radioactive waste from medicine, and especially the waste of the radioisotope Tc-99m, the production of technetium from molybdenum-technetium generators (Mo-99/Tc-99) has been considered. These generators are of the "Gentec 2-120" type, produced by the company "Polatom" and their initial activity is 6 GBq. The above generator uses the radioisotope Mo-99, which decays to give the radioisotope Tc-99m. In this way, a sterile aqueous solution of sodium pertechnetate (NaTc99mO4) is obtained from the generator. Molybdenum radionuclides (Mo-99), which are fixed on a chromatographic column of aluminum oxide (Al2O3), decompose through beta radiation with a half-life equal to 66 hours in the radioisotope Tc-99m. The latter, being in a metastable state, undergoes an isomeric transformation with a half-life of 6 hours, transforming into the radioactive isotope Tc-99. The latter radioisotope (Tc-99) decays with a half-life of 2.13x105 years, releasing a beta particle and transforming into the stable isotope Ru-99. The breakdown scheme of the Mo-Tc generator is presented as follows:

$$\begin{array}{ccccccc} & \beta & & \gamma & & \beta & \\ \text{Mo-99} & \Rightarrow & \text{Tc-99m} & \Rightarrow & \text{Tc-99} & \Rightarrow & \text{Ru-99} \\ \text{T = 66 hour} & & \text{T = 6 hour} & & \text{T = } 2.13\text{x}10^{5}\text{ year} & & \end{array}$$

The obtained Tc-99m pertechnetate solution can be used for intravenous injection or oral administration to patients, or for radiochemical treatment together with various cooling kits (radiopharmaceuticals) used for organ diagnostics. The nominal activity of

Tc-99m (6 GBq) is taken at 12.00 on the first day of elution and is determined by the manufacturer (day zero). The maximum activities from the generator will in any case be obtained when 24 hours have passed from the time of the first elution. The period of use of a Mo-Tc generator is 14 days, after which it is necessary to import a new generator. Table 1 gives the activity values (in GBq) of the Tc-99m radioisotope for 14 consecutive (consecutive) days from the start of elution.

***Table 1**. Mo-Tc generator activity (in GBq) on 14 consecutive days*

Day	**0**	**1**	**2**	**3**	**4**	**5**
Activity	6,0	4,7	3,6	2,8	2,2	1,7
Day	**6**	**7**	**8**	**9**	**10**	**11**
Activity	1,3	1,0	0,8	0,6	0,6	0,4
Day	**12**	**13**	**14**			
Activity	0,3	0,2	0,1			

The elution of the generator can also be done in shorter time intervals than 24 hours, but in this case the activity of the eluting solution will be less than the maximum activity for the day of the corresponding elution.

***Table 2.** Correction factors for the calculation of the activity of the Tc-99m solution*

Time since last elum, hours	0	2	4	6	8	10
Reduction correction factor. Mo-99	1	0.98	0.96	0.94	0.92	0.90
Correction factor for Tc-99m increase	1	0.21	0.39	0.51	0.62	0.71
Time since last elum, hours	12	14	16	18	20	23
Correction factor for Tc-99m increase	0.88	0.86	0.84	0.83	0.81	0.8
Correction factor for Tc-99m increase	0.79	0.85	0.89	0.93	0.96	1

To make concrete the use of the values presented in the table 2, we are taking a concrete example. Let's accept that for the Mo-Tc generator with zero day activity of 6 GBq, the elution was performed on the fourth day, at 09.00 and another elution was performed on the same day but at 13.00. Calculate the activities of Tc-99m carried out in both elutions. In the first case (09.00) the activity of Tc-99m will be given by Table 3, where we find that on the fourth day the activity of the generator is 2.2 GBq, so the activity of Tc-99m, which is eluted at 09.00 is equal to 2.2 GBq, so:

$$A_1 = 2{,}2\ \text{GBq} \qquad (1)$$

In the second case (elution at 1:00 p.m.) the activity of the Tc-99 solution that will be obtained from the elution performed at 1:00 p.m., after 4 hours from the first elution, will be equal to:

$$A_2 = 2{,}2\ \text{GBq} \times 0{,}96 \times 0{,}39 = 0{,}82\ \text{GBq} \qquad (2)$$

The process starts by getting the generator, with this certificate:

***Table 3**. The physical properties*

Certificate of radioactive source	No. DP1 – 1 – 018/25/12/0001
Name:	POLGENTEC 0.5 – 15,0 GBq /ml, radionuclidic generator
Pharmaceutical form :	$Na^{99m}TcO_4$ in 0.9 % solution of NaCl
Code :	MTcG – 4
Batch No.	25/12
Registration No.	R/ 1791
Activity	^{99m}Tc 6 GBq on 15.11.2022 (12^{00} CET)
Activity	^{99}Mo 24.2 GBq on 20.11.2022
Expiration date	09.12.2022
Nature of immediate container	glass column with Al_2O_3
Container type and number	SPECIAL – 50 N_0. 25/1

The generator is placed in the designated place, and this is called an open source of radioactivity, which is protected with lead plates (Fig.6). For diagnostic tests in nuclear medicine, 99mTc is obtained from the radionuclide generator. After each photographing, the elution of pure Technetium is kept, which in the first days has high activity, then with the passage of time it loses its activity. Elution is done in glass vials. We put the physiological solution on one side, while the vacuum is placed on the other side. The generator consists of a glass column with aluminum oxide, where Mo-99 is absorbed, and by rinsing the column with physiological composition, it is possible to separate 99mTc from the radionuclide in the vacuum flask. Depending on the number of patients, the amount of Technetium is also eluted. HDP radiopharmaceutical labeled 99mTc, depending on the person's weight, the determination is made:

From 50 – 60 kg = 407 MBq

From 60 - 70 kg = 444 MBq

From 70 – 80 kg = 481 MBq

From 90 – 100 kg = 555 MBq

Over 100 kg = 592 MBq, while for children it is allowed 9-10 MBq/kg.

It is carried out in a 3-6 ml vial of 99mTc with a maximum activity of 200 mCi.

Figure 6. *Generator packaging*

In its early days, the generator has high activity and work is being done on scintigraphy that requires higher doses of activity, such as scintigraphy of bones, heart, liver, etc. This includes his activity in the first week of work. In the second week, the activity is less, the first 3 days work with the kidneys, the last 2 days work with the thyroid glands. When elution of the material is complete, place the measurements in the dose calibrator. The dose is prepared and labelled with various radiopharmaceuticals (Fig.7). The prepared doses are given to the patient and based on the picture, what is there, then it has to stay for a certain time. Doses are marked and based on analyses that have been kept for a certain time in ampoules. After 2 weeks of work, the generator is thrown, it is no longer active, take shelter in the lead room and stay there for a long time. Radioactive waste that remains in vials, syringes or other glass containers must be thrown into special cardboard bags, where the date of receipt is marked in each bag and when it is done, the closing date is marked again (Fig.8).

Figure 7*. Dose calibrators*

Figure 8*. Taking notes from me inside the bunker*

Removal of radioactive waste is done:

- Short-lived isotopes are thrown into special containers where they are kept for at least 8 half-lives.

- Live isotopes are stored for a long time in the bunker (hot zone), where the door of the bunker is permanently closed and only trained personnel have access.

4. Conclusions

Depending on the type of radioactive waste from nuclear medicine procedures indicate to simply store the wastes till radioactive decay reduces the activity to a safe level or possibly by disposal of low-activity waste into the sewage system to achieve sufficient dilution. According to the EPA, radioactive wastes that contain "very small" concentrations of radionuclides are typically in small enough amounts that the more stringent recommendations for handling higher activity radioactive materials are not always required. Unfortunately, guidelines regarding regulations for the disposal of radioactive waste are fairly inconsistent and depend on the origin of the waste. Medical radioactive liquid waste was treated using FO for the first time. FO successfully rejected both natural and radioactive

iodine. The rejection of FO was optimized for high pH and DS with adequate RSF. Actual radioactive liquid waste was effectively concentrated, reducing its volume. Severe fouling was observed due to the combined effect of organic and inorganic foulants. This scientific paper provides the practiced practice, applied to the radioactive biomedical waste coming from the use of radionuclides in hospitals. The correct treatment of radioactive waste coming from medicine, makes the prevention of their accumulation and minimization and should be the main focus in the framework of the management program of this waste. Characteristics of radionuclides used in medicine are extremely diverse. Sources must be fully characterized in radiological, chemical, biological and physical terms and within their diagnostic, therapeutic, and research applications as a precursor to effective biomedical waste handling. Most radionuclides used in medicine and especially those used for diagnostic purposes, have relatively short half-lives (i.e. typically less than 10 days but may be up to 100 days). Therefore, full use of on-site decay methods should be utilized so that waste can be disposed of at the clearance levels authorized by the relevant regulatory agency based on risk assessment.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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