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Verification of Reaching the Regulatory Limit for the Release of Radioactive Liquid Waste in Nuclear Medicines

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ABSTRACT

The research was conducted at one of Iraq's nuclear medical facilities in Baghdad, which uses radioactive iodine (I-131) to treat thyroid patients, the major purpose of this research was to meet the national legal limit for the release of radioactive liquid waste into the environment, a high purity germanium reagent radiation detector was used to evaluate nine iodine I-131 samples. From 2021 and 2023, the concentration of waste prior to storage and disposal was between 24498 Bq/L and 5.7 Bq/L. Short-lived radionuclides, such as I-131 with an 8.04-day half-life, may be released into the sewage system in line with Iraq's Nationally Approved Limits and Austria's International Atomic Energy Agency (IAEA). Moreover, it is stored for 10 times the half-life, or four months, until the choice to release it into the environment is made.

Keywords Radioactive iodine I-131, liquid waste, storage and decay system, nuclear medicine, authorization limits.

INTRODUCTION

The waste is stored under well-controlled conditions until the radioactivity is lowered to an acceptable level, allowing it to be categorized as non-radioactive or meet exemption limitations. Using radioactive iodine to treat thyroid cancer creates a substantial quantity of radioactive waste. After receiving a dose of radioactive iodine with an activity of up to 7.55 GBq (0.22 Ci) [1], patients are often hospitalized for two to three days. During this time at least 80 percent of the radioactive iodine is excreted. The most common source of liquid radioactive waste is urine. The most practical way for the patient to dispose of this waste is to wash and flush in the bathroom. The radioactive liquid waste is disposed of through the municipal sewage system. The amount of radioactivity that may be disposed of in this manner depends on whether the plant's total water output can dilute the radioactivity to an acceptable level. The radioactive waste release limit through the public sewage system is 10^5 Bq/L [2] to reduce the dosage limit at the point of discharge, Typically, this waste is stored for the physical decomposition of iodine. Each patient's urine is drained through sewage networks and stored in suitable containers for a predetermined period of time prior to disposal [3].

For the storage of dissolving liquid radioactive waste, numerous aspects, including administrative and technical arrangements, facility design, safety evaluation, and quality assurance program, must be considered. Even though all types of waste containing a wide variety of radionuclides can be stored for disintegration, it is ideal for radionuclides having half-lives of fewer than 100 days. The produced effluent volume may range from a few millimeters to several cubic meters; consequently, the storage of disintegrated effluent must be organized and facility-specific. The objective of storage systems for both regular and irregular effluent discharges [4] should be to protect personnel, the general public, and the environment from radiation exposure.

Disposal of radioactive waste that is legal in several different countries

In Turkey, the discharge limitations for the sewage system were 24.8 GBq [5], Canada 370-200 Bq/L (0.37 MBq/m^3)[1], Spain 1.133 MBq/kg to 407 Bq/L [6] 370 Bq/L in the United States [7][8], compared to 7 Bq/L in France [9] (French Nuclear Safety Authority) defines, among other things, the technical rules for the disposal of radioactive effluents from hospitals and clinics. This decision mandates that the nuclide concentration in sewage must be less than 10 Bq/L, or 100 Bq/L for effluents from I-131 treated patient rooms [10].

Low-level liquid waste in Japan (10^{-5} Ci/mL) equals 370 Bq/L annually [11]. The limit for the sultanate of Oman was 22.2 MBq/m^3 [12], 100 MBq in Finland there are 22109 MBq in Portugal, and 50 GBq in London. The daily limit in Greece is 18.5 MBq [9].

The discharge limitations of radioactive effluents in an Indian institute in the year 2020 were examined. (Nuclear Regulatory Commission) during the experiment, 38 participants were treated with 129.4-42 mCi of radioactive iodine (range 40–200). During the course of the inquiry, reservoirs were emptied twice. The washer diluted the (6 million liters). Discharge radioactivity was 1.6 and 1.5 MBq/m^3 at the place of release [13]. In India, the recommended limit is 22.2 GBq, before water addition [14], liquid radioactive effluents in the republic of Korea is 37 Bq/L [15] and in Malaysia [15], one discharge-channel to the South China Sea has somewhat elevated activity levels compared to the background. There are no particular precautions in place to cater for this [16].

Liquid effluents from nuclear facilities have been examined due to their disposal in urban areas, which raises environmental problems. Analysis of the ^{131}I activity levels in the wastewater samples collected from a university hospital's nuclear medicine facility in Brazil was conducted. The findings of the gamma spectrometry measurements and analyses conducted on the collected sewage samples revealed that the estimated values (EV) for activity concentrations obtained for ^{131}I in July were significantly lower than those obtained in July (8.78×10^3 Bq/m^3), September 2016 (9.80×10^3 Bq/m^3), and February 2017 (1.14×10^4 Bq/m^3) were all below the exemption level (EL = 1.90×10^4 Bq/m^3) [17].

In Slovenia, the yearly and quarterly limits for liquid radioactive releases are 200 and 80 GBq, respectively [18].

Low-level liquid waste classified as waste with activity contents of less than (4×10^6 Bq/L) in China [19]. Moreover, in Germany, certain radioactive elements are monitored, including noble gases, iodine, aerosols, and some nuclides from nuclear plants. Gamma spectrometric studies have a sensitivity of 1 Bq/kg, while beta-emitting radionuclides have a sensitivity of 0.1 Bq/kg [15].

Governmental requirements for the design of storage and decay systems

The design of the tank system must comply with the following general specifications – it should be made from appropriate materials, such as stainless steel, concrete, or high-density polyethylene, and be of sufficient quality to prevent leaks or flooding for the lifetime of the disintegration tank system. In contrast, steel has grown in popularity due to its superior strength, rigidity, ductility, and ease of production [20].

The application of exemption and liquidation principles

By storing waste until its decomposition, regulatory oversight can be avoided. The authorized disposal levels must be established by the national regulatory agency. Once all traces of radioactivity have been eliminated, the waste can be treated as any other similar waste at the hospital, keeping biological and chemical hazards in mind. This is a common method of radioactive waste management in nuclear medicine. Sources and practices involving exposure of people to ionizing radiation are controlled by a notification and authorization system as described in BSS [21]. Before using radioactive materials, the operator is frequently required to review his plans and acquire authorization in the form of a registration or license. According to the ALARA [22] concept, it is possible to reach an acceptable limit for the controlled and appropriate dosage.

These authorizations frequently impose limits on the total amount and/or concentration of activity as conditions for the disposal of various types of waste. A permit for the discharge of effluent and gaseous waste may contain discharge limitations such as total activity and concentration limits and release restrictions (release rate). The site of discharge is under control, and the surrounding environment is being monitored [23].

MATERIALS AND METHODS

Patients receiving treatment

Individual restrooms with delay and decay tanks after dilution and release are recommended over waste disposal straight into the sewage system, according to varied legislation in different nations. The governing authority should choose the criteria with environmental considerations in mind. The rate of radiation activity per patient during therapy with radioactive iodine (I-131) in liquid or capsule form is 150 mCi. Urine and feces are extremely radioactive, containing an estimated 80% of the 150 mCi. A disintegration and delay mechanism are required for the safe discharge of waste into the main sewers. The discharge pipe to the environment following the end of the permissible storage time is seen in Figure 1.

Figure 1. Discharging and transition pipe on top of the storage and decay system

Radiation exposure of patients

Environmental practices, external exposure, and internal exposure from pollutants. External exposure is the key factor influencing dosages for adult patients. After receiving radioactive iodine treatment, contamination of children and pregnant women should be avoided, since it can result in significant dosages of the radioactive isotope being stored in the child's thyroid gland.

Whether to retain the patient in the hospital or discharge them should be decided individually. This is dependent on the activity of any residual radioactive material in the patient, as well as other important considerations. The public and loved ones will be less exposed if the patient is kept in the hospital, but hospital workers would be more exposed. Hospitalization frequently entails a considerable psychological burden in addition to financial and other costs that need to be justified. If the trip is only a few hours long, the patients who have recently undergone radioactive iodine therapy rarely pose a threat to other travelers.

Environmental or other radiation detectors are able to detect the patients treated with radioactive iodine for several weeks after treatment. Operators of these devices must be specially trained to determine the handling of nuclear medicine patients. The hospital should create thorough records of the radiation therapy and give the patient written instructions. Special safety measures must be performed if a patient dies after receiving open radionuclide therapy in the months just before [24].

Design and storage duration of Decay System

The system consists of four basins for storing liquid radioactive waste, where the four storage basins were established in order to postpone the release of radioactive material into the environment, because one of the characteristics of radioactive material is dissolution and disintegration, and each radioactive material has a specific half-life. The storage system has four tanks, which are as follows: Tank No. 1 Initially: This is the tank for receiving, collecting, and disintegrating (dissolving) waste for a whole month (30 days) in order to carry out the decomposition process.

Tanks No. 2, 3 and 4: constructed for the same function and length of stay as the first tank No. 1, with the waste remaining in each tank for a full month (30 days) to facilitate the decomposition process until the total storage period reaches 120 days. Diagrams No. 1 and 2 show the system of storage and delay at Al-Amal National Hospital [25].

Up to the discharge limit, I-131 and other short-lived radionuclides with a half-life of 8.04 days can be disposed of in the sewage system. The subject of the investigation was radioactive liquid medical waste created by the patients who received radioactive iodine for the treatment of thyroid cancer.

The waste was kept in the storage system for 120 days to reach the permitted level and complete the decomposition process. Figure 2 shows a system for liquid radioactive waste storage and decay or delay.

Multiple samples were collected, and the results indicated that sewage was discharged within the control limits specified by the International Atomic Energy Agency (IAEA) and the Iraqi radioactive sources regulatory Authority (IRSRA). As the authorized regulatory authority to implement regulatory control. The radiation dose per patient for radioactive iodine (I-131) therapy in liquid capsules is between 150 mCi and 200 mCi.

Estimates were made about how much radioactive iodine was in the liquid waste of 25 patients per month.

Remaining activity:

$$A = A_{\circ} e^{-\lambda t} \tag{1}$$

where: A – activity in time ($t = 0$), t – elapsed time, λ – decay constant equal to $\lambda = \frac{\ln 2}{t_{1/2}}$, $t_{1/2}$ – half-life of I-131 equel to 8.04 day.

The data for calculations was shown in Table 1.

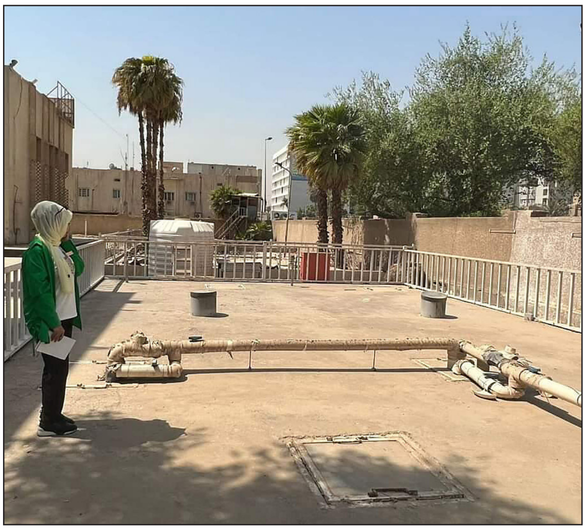

Figure 2. Storage and decay system

Table 1. Data using in calculations

Weekly number of patients	25
The period of each patient's hospital stays	3 days
Average dose given to a patient – activity expressed in millicuries	150 mCi
Excreting ave from 150 mCi	80%
Residual effective dose released to sewage (storage and decay system)	25×150×0.8 = 3000 mCi
Patient consumes of waters for washing and flashing each day	176.2 L
Patient consumes of waters for washing and flashing each week	176.2×3 = 528.6 L
Patient consumes of waters for washing and flashing in month	528.6×25×4 = 52860 L
Total of the storage period	4 weeks
Stages of storage in each tank	30 days
The volume = 71.68 m^3 equals	71680 L
The capacity of the tank is 80% of the total volume	71680×0.8 = 57344 L

Concentration of liquid waste

Concentration is obtained by calculating the remaining radioactivity of the patient's excrement at the end of the first month in the for a number of (25 patients per week, Table 2) and dividing it by the tank capacity in units L) which is equal to (1,936,544.91 Bq/L) to (10,847.43 Bq/L) and is compared with the disposal release limit, then stored for a third month in the third tank, then transmitted to tank the last tank, and by comparison with the permissible limit, it is found to be suitable for releasing waste into the sewerage system, as shown in Table 3.

RESULTS

The samples were taken from the subtraction site, the measurement was carried out using HPGE Germanium Reagent calibrated and measured gamma systems with driver software (Genie2000) and a multi-energy standard source, the calibration locates the energies and generates an efficiency curve that encompasses the observed spectrum's energy bands and its clear the remaining activity (A) in mCi and the concentration of waste in Bq/L, as previously shown

Table 2. Remaining radioactivity (A) after administe-ring a dose of 150 mCi of I-131 to a thyroid patient

Pa. No./w		25	Activity before decay $A_o = 25 \times 150 \times 0.8 = 3000$				
Adm. dose (mCi)		150					
Excreting ave.		80%					
			$A = A_o e^{-\lambda t}$	$A = A_o e^{-\lambda t}$	$A = A_o e^{-\lambda t}$	$A = A_o e^{-\lambda t}$	
t(d)	A_o(mCi)	$e^{-\lambda t}$	(A) 1st week (mCi)	(A) 2nd week (mCi)	(A) 3rd week (mCi)	(A) 4th week (mCi)	
0	3000	1	3000.00				
1	3000	0.917216068	2751.648203				
2	3000	0.841285315	2523.855945				
3	3000	0.771640408	2314.921225	8 days (decay period of I-131)			
4	3000	0.707760981	2123.282943				
5	3000	0.649169744	1947.509232				
6	3000	0.59542892	1786.286759				
7	3000	0.546136972	1638.410917	3000.00			
8	3000	0.500925606	1502.776819	2751.648203			
9	3000	0.459457015	1378.371044	2523.855945			
10	3000	0.421421356	1264.264069	2314.921225	8 days (decay period of I-131)		
11	3000	0.386534439	1159.603318	2123.282943			
12	3000	0.354535598	1063.606795	1947.509232			
13	3000	0.325185748	975.5572425	1786.286759			
14	3000	0.298265593	894.7967778	1638.410917	3000.00		
15	3000	0.273573994	820.7219819	1502.776819	2751.648203		
16	3000	0.250926463	752.779389	1378.371044	2523.855945		
17	3000	0.230153784	690.461351	1264.264069	2314.921225	8 days (decay period of I-131)	
18	3000	0.211100748	633.3022453	1159.603318	2123.282943		
19	3000	0.193624998	580.8749951	1063.606795	1947.509232		
20	3000	0.17759596	532.7878788	975.5572425	1786.286759		
21	3000	0.162893868	488.6816031	894.7967778	1638.410917	3000.00	
22	3000	0.149408873	448.2266184	820.7219819	1502.776819	2751.648203	
23	3000	0.137040219	411.1206564	752.779389	1378.371044	2523.855945	
24	3000	0.125695491	377.0864718	690.461351	1264.264069	2314.921225	
25	3000	0.115289924	345.8697708	633.3022453	1159.603318	2123.282943	8 days (decay period of I-131)
26	3000	0.10574577	317.2373111	580.8749951	1063.606795	1947.509232	
27	3000	0.09699172	290.9751591	532.7878788	975.5572425	1786.286759	
28	3000	0.088962364	266.8870912	488.6816031	894.7967778	1638.410917	
29	3000	0.081597709	244.7931283	448.2266184	820.7219819	1502.776819	
30	3000	0.07484273	224.5281905	411.1206564	752.779389	1378.371044	2766.80
60	3000	0.005601434	–	–	–	–	15.50
90	3000	0.000419227	–	–	–	–	1.16
120	3000	0.000031376	–	–	–	–	0.09

Table 3. The concentration of waste in Bq/L

Days no.	Excreting ave for 4 week/L	Concentration = [radioactive waste activity/ excreting ave for month] mCi /L	Concentration in uCi/L	Concentration in Bq/L
30	52863	0.052339052	52.33905151	1936544.90
60	–	0.000293174	0.293173756	10847.428
90	–	2.19419E-05	0.021941924	811.85120
120	–	1.64219E-06	0.001642194	60.761160

Figure 3. HPGE Germanium Reagent

Figure 4. The system of measurements

in Table 2. Figure 3 shows pure geranium radiation detector and Figure 4 shows the system of measurements:

Table 4 shows the concentrations of the samples that were collected, and it turns out that the concentrations were lower than the required limit for release.

By comparing the results with the regulatory limits of many countries, it was found that they are close and achieve the limits imposed by the regulatory authorities. The characteristics of radionuclides utilized in medicine are very varied. As an introduction to the appropriate management of radioactive medical waste, the sources must be fully explained in terms of their radiological, chemical, biological, and physical characteristics, as well as their diagnostic, therapeutic, and research uses.

Table 4. Samples of wastewater contains radioactive iodine waste in discharge manhole

Year / seasons	I-131 concentration – toilets patients, Bq/L	I-131 concentration – final release, Bq/L
2021 summer	135296	48.14
	259820	27.26
2021 winter	2982	10.6
	3536	5.7
2022 summer	1275160	161.2
	1152740	2.8
2022 winter	332622	24493
2022–2023	11912.9	4672
	3128	163.2

The major emphasis of the waste management program should be on proper waste management, waste avoidance, and waste reduction. In addition to the radiation health protection measures for radioactive medical waste, further precautions must be taken. The majority of radionuclides used in medicine, particularly those employed for diagnostic reasons, have a very brief half-life (typically less than 10 days but can be up to 100 days). Therefore, full use of on-site disintegration procedures should be considered so that waste may be disposed of at the levels approved by the relevant regulatory authority based on risk assessment. It is preferable to minimize radioactive elements by disintegration prior to on-site or off-site treatment as biologically contaminated waste after taking the necessary measurements.

The multi-tank system accommodates a large number of patients and resolves the majority of issues associated with the single-tank system. To ease system design and operation, large capacity tanks are used. Thus, the usage of large tanks decreases radiation exposure and is advantageous from a radiation safety standpoint.

CONCLUSIONS

From observing the readings of the results, it turns out that the readings are below the regulatory limit followed for the purpose of releasing radioactive liquid waste into the sewage, This means that the safety requirements are practically met, as the readings show the decomposition that occurs within 4 months (it is evident from the observation of a decrease in reading), which is the period between patients entering the halls and the end of the 120-day storage period that is currently used and included in the study in the first scenario in a meal, entering 25 patients per week with a 120-day storage period 30 days for each tank.

After the period approved by the regulatory authorities has ended, the legal release limit 10^5 Bq/L was reached and may be safely discharged to the sewage system.

According to the study, using a dilution mechanism and diligent monitoring might significantly minimize radiation exposure and overall radioactive output from the site.

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