Improvements in nuclear medicine management: case study in Guatemala

Mejoras en la gestión de medicina nuclear: Caso de estudio en Guatemala

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Abstract

Nuclear medicine is one of the most effective tools for diagnosis and treatment in cancer patients; however, the radionuclides used can reach sewage systems through various channels, contaminate wastewater and affect the population's health. Proposals for proper radioisotope management are scarce and incomplete. In the present work, the analysis of various hospitals that use nuclear medicine and the quality of water they discharge, the protocols used in the handling of these substances, the factors involved in these procedures, as well as the rules, laws, and regulations that protect citizens from these dangerous elements were carried out. As a result, a management system is proposed, including protocols from radioisotopes' entry to the hospital, to the wastewater containing radioactive waste from hospitalized patients with nuclear medicine treatments. Furthermore, some modifications to Government Agreement 236-2006 of the Republic of Guatemala (AG 236-200) are proposed to reduce the possible effects on the population's health.

Radioisotopes, AG 236-2006, Treatment, Management, Residual water, Radioactive activity, Radioactive, Nuclear medicine

Resumen

La medicina nuclear es una de las herramientas más efectivas tanto para el diagnóstico como para el tratamiento en pacientes con cáncer; sin embargo, los radionucleidos utilizados pueden alcanzar los sistemas de alcantarillado por medio de diversos canales, contaminar las aguas residuales y afectar la salud de la población. Las propuestas para la gestión adecuada de radioisótopos en hospitales son escasas e incompletas. En el presente trabajo, se realizó el análisis de diversos hospitales que emplean medicina nuclear y la calidad de agua que descargan, los protocolos utilizados en el manejo de estas sustancias, los factores involucrados en estos procedimientos, así como las normas, leyes y reglamentos que protegen a la ciudadanía de estos elementos peligrosos. Se proponer un sistema de gestión, que incluye desde la entrada en el hospital de los radioisótopos, hasta su descarga de aguas residuales que contienen desechos de pacientes hospitalizados con tratamientos de medicina nuclear, así como modificaciones al Acuerdo Gubernativo 236-2006 de la República de Guatemala que permitan disminuir las posibles afectaciones a la salud de la población

Radioisótopos, AG 236-2006, Tratamiento, Gestión, Agua residual, Actividad radiactiva, Radiactivos, Medicina nuclear

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Introduction

Several activities produce radioactive waste, such as nuclear plants, industries, agriculture, or nuclear medicine. (Ambashta & Sillanpää, 2012). For example, the primary purpose of nuclear medicine is to detect cancer, monitor its evolution, respond to treatment, detect metastases, and treat for it. Recently, it was shown to be very accurate for diagnosing Alzheimer's disease, which previously could be accurately diagnosed only after the patient's death.(Camacho et al., 2018; Ge et al., 2020).

Unfortunately, there are legitimate concerns about the possible induction of cancer, even from low levels of radiation exposure.(AbuAlRoos et al., 2019; Gardin et al., 1999; Vrijheid et al., 2007), Nevertheless, it is accepted that the risk is relatively small compared to the expected benefit of applying nuclear medicine (NIBIB, 2019).

The medical community has been joined worldwide by growing concern about the final fate of these radioactive radiotracers and isotopes used in nuclear medicine. (DECC, 2009; Grisales et al., 2012; IAEA, 2009; Penagos et al., 2012; Tellaetxe & González, 2021; UNSCEAR, 2010).

More than 40 million nuclear medicine procedures are performed each year, and the demand for radioisotopes is increasing by up to 5% annually. (World Nuclear Association, 2021).

Nuclear medicine uses countless radioisotopes, including technetium-99, short-period gamma emitters such as thallium-201 for cardiac studies, gallium-67 for tumor detection, indium-111 for inflammatory processes, iodine-131 and 123 for thyroid and kidney studies, xenon-133 for lung studies. Other PET studies mostly use fluorine-18 and radio immune-analysis iodine-125. Treatments are based on iodine-131 (Foro Nuclear, 2020).

If ingested in the concentrations and doses medically recommended according to the diagnosis and involvement, they fulfill the medical purpose and period of disintegration, being excreted by the kidneys of 35-75% in 24 hours (Baró Casanovas et al., 2000).

Unfortunately, it is known that exposure to even small doses of radioactive waste increases the risk of contracting different types of cancers and even cardiovascular disease.(Chan et al., 2015; Cox et al., 2014; Gardin et al., 1999).

In general, the most common physical, chemical, and microbiological wastewater parameters from hospitals using nuclear medicine are fats and oils, BOD, suspended solids, N_t, P_t, pH, fecal coliforms, As, Cd, C, N_t, Cu, Cr^{+6}, Hg, Ni, Pb, Zn, Color, DQO, ^{131}In, ^{18}F, ^{223}Ra, ^{226}Ra, ^{3}H, ^{57}Co, ^{90}Sr, ^{111}In, ^{123}I, ^{125}I, ^{201}Ta, ^{89}Sr, ^{99}mTc, ^{99}Mo and ^{131}I.

Researchers such as (Lennemann 1985; Mora-Barrantes et al., 2014; Petrucci & Traino, 2015) have expressed concern about managing radioactive polluting substances lack and their discharge as part of hospital wastewater. As a result, they have proposed some individual actions to reduce their potentially harmful consequences, such as the use of membranes for wastewater treatment (Bolisetty et al., 2020; Buckley L, Bushart S, Efremenkov V, Karlin Y, Kohout R, Pabby A, 2004; Zhang et al., 2016), as well as proposals to regulate the discharge of these compounds into the drainage system (Perkins, 1997).

However, very few works propose integrated actions that include the regulatory, technical, and management aspects, from the moment the medicine arrives at the hospital until the different channels to discard these substances.

This paper proposes a management system in hospitals with nuclear medicine, reducing the affectations' possibility of people and the environment due to radioactive radioisotopes from the use of nuclear medicine in hospitals mainly to contaminated water discharges or during the journey of the drug in the hospital, as well as proposals for modification to the regulations.

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This problem is analyzed in the Republic of Guatemala as a study case. The AG 236-2006 (Congreso de la República de Guatemala, 2006) contains the regulations for the discharge and reuse of wastewater and disposal of sludge. It is proposed to update this document with elements that allow the treatment of discharge waters of hospital patients linked to cancer treatment, which unfortunately is increasing without discriminating sex, age group, or race.

Methodology

The methodology to propose a management system in hospitals with nuclear medicine procedures consisted of five basic steps: literature review, the grouping of results of physical, chemical, and microbiological parameters to compare and systematize, to propose the updating and improvement of AG 236-2006, design the internal processes for the system and simulate its operation.

Literature review

For parameters updating:

a) Grouping of results of the physical, chemical and microbiological parameters of wastewater to be analyzed

b) Comparison of results of physical, chemical and microbiological parameters grouped with permissible limits, according to local-national regulations.

c) Statistical systematization (mono-data, mean or average value, minimum value, and range) of parameters and permissible limits in order to identify those that become relevant for incorporation into Guatemalan mechanisms.

d) Definition of technically feasible parameters and permissible limits for Guatemala, according to the current structure of AG 236-2006.

For concepts harmonization:

a) Systematize existing definitions according to references consulted.

b) Define, homologate or propose relevant concepts that do not exist.

c) Develop conceptual glossary according to the current structure of GA 236-2006.

The analysis of data for the characterization of wastewater was carried out. The tolerance limits of water content and tolerance limits for human exposure were extracted, analyzed, and applied to constitute the wastewater management system of various legislatures and standards (División de alcantarillado de El Salvador, 2004; Manrique et al., 2015; MINAM, 2018; Petrucci & Traino, 2015; Ramos-Alvariño, 2016; Rodriguez-Mozaz, Sara, Chamorro, et al., 2016), in addition to the analysis of wastewater generated in the hospitals, was analyzed. The information sources were:

– The standard for regulating the quality of Special Type wastewater discharged into the sanitary sewer

– Technical standards for discharges of wastewater to receiving bodies and sanitary sewerage

– Quantification of iodine-131 in wastewater discharges from nuclear medicine laboratories in Mexico, Spain, Germany, and the United States of America

– Wastewater from a hospital in Buenos Aires, Argentina: chemical, biological and toxicological characteristics

– Focus on the legislative approach to short half-life radioactive hospital waste releasing

– Supreme Decree No. 003-2010-MINAM, Peru

– Draft amendment of the Official Mexican Standard NOM-001-SEMARNAT-1996

– Wastewater Discharge and Reuse Regulation No. 33601

– Radioactive Waste Management Regulations

– Law 10/1993 on industrial liquid discharges to the integral sanitation system, Madrid

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– Presence of artificial radionuclides in samples from potable water and wastewater treatment plants

– Concentrations of iodine-131 released from a hospital into a municipal sewer

– Establishing appropriate limits for the control of radionuclide discharges into the environment

– Decree 609 Emission standard for the regulation of pollutants associated with the discharge of liquid industrial waste into sewage systems, Chile

– Regulation establishing the provisions for the discharge of wastewater, Nicaragua

– Salvadoran Technical Regulation RTS 13.05.01:18

– Government Agreement No. 12-2011 Regulation on Wastewater Discharges in the Lake Atitlan Basin

– Wastewater generated in hospitals of José de San Martín Clinic, San Luis Potosi (Mexico), Havana, Southeast France, Community Association and Iran.

Update and improvement to GA 236-2006, including limits, parameters, and definitions in the sections where applicable.

Internal flow of nuclear medicine

A proposal for a general internal flow of nuclear medicine that may cause unwanted emissions or transmissions of radioactive isotopes was made. For this purpose, plant engineering tools such as distribution plans and redesign of distribution were used, taking into account the route of the drugs within the hospital. (Cuatrecasas, 2017; Estrella Lara O. & Luis, 2013).

Additionally, a proposal based on these analyses is the necessary training for all personnel responsible for these potentially dangerous drugs. It is essential to know their proper handling, distribution, or disposal and part of the activities proposed in the management system.

On the other hand, definitions analysis and systematization would allow homologating and proposing non-existent relevant concepts. Hence, a conceptual glossary, according to the current structure of the AG 236-2006, and a proposal for amendments to that document (Congreso de la República de Guatemala, 2006).

Wastewater treatment.

According to the analysis, the wastewater treatment process was designed and proposed as the last step in the management system. 1

Simulation of the operation

Finally, an operation simulation and approximate theoretical results of the management system are carried out.

Results

It was found 121 parameters (physical, chemical, and microbiological) in the literature review on wastewater quality and the conditions considered suitable globally for each parameter. The differences in the requirements in terms of quality between the different countries are since these values. The permissible limits respond to a national reality and technical need. Consequently, these limits were adapted to the Guatemalan instrument after data analysis. They can be updated, together with the treatment of solid waste (internally in the health center) and liquids (excreted or disposed of) in such a way that they are conditioned after a general treatment.

For each parameter in equivalent dimensions, the following models were used:

Monodate, cases in which, in the literature review, only a substantive value was reflected in a document.

Arithmetic average, points in which two values were available.

Minimum cases in which three or more values were available, focusing on the lowest value (hence the most restrictive).

Range: maximum and minimum values were presented for a single case (Hydrogen potential).

Definition of technically feasible permissible parameters and limits for Guatemala, according to the current structure of the AG 236-2006

For this study, emphasis is placed on the need for and importance of establishing maximum permissible limits of radioisotopes in wastewater from medical institutions with procedures related to nuclear medicine. In addition, adjusted and reasonable suggestions are made to parameters already identified in the AG 236-2006 to obtain the following (Table 1):

Parameter, unit	Maximum permissible value
Fats and oils, mg/L	0
DBO, mg/L	50
Suspended Solids, mg/L	30
N_t, mg/L	24
Pt, mg/L	5
pH	6 a 9
Fecal coliforms, NMP/100mL	1.00E+04
As, mg/L	0.1
Cd, mg/L	0.1
CN_t, mg/L	1
Cu, mg/L	3
Cr^{+6}, mg/L	0.1
Hg, mg/L	0.01
Ni, mg/L	0.1
Pb, mg/L	0.1
Zn, mg/L	2
Colour, UPC	300
DQO, mg/L	60
^{131}In, Bq/a	1E+07
^{18}F, Bq/kg	10000
^{223}Ra, Bq/kg	100000
^{226}Ra, Bq/a	1E+06
^{3}H, Bq/a	1E+12
^{57}Co, Bq/kg	1E+09
^{90}Sr, Bq/a	1E+10
^{111}In, Bq/kg	6E+07
^{123}I, Bq/kg	2E+09
^{125}I, Bq/kg	2E+09
^{201}Ta, Bq/kg	1E+07
^{89}Sr, Bq/kg	2E+09
^{99m}Tc, Bq/kg	4E+08
^{99}Mo, Bq/kg	5E+07
^{131}I, Bq/m^3	1.00E+05

Table 1 Systematization of parameters and maximum permissible limits

Hydrogen Power Units (6 a 9), Arsenic, Cadmium, Hexavalent Chromium (0.1 mg/L), Mercury (0.01 mg/L); would be maintained as established by current regulations. However, for fecal coliforms, the results yielded higher values than the current ones; therefore, it has been recommended for this parameter to remain in 1E4 NMP/100mL.

Literature review for conceptual harmonization

Next, relevant concepts (not yet existent) are listed and described to correspond to the best understanding by adding parameters in the Agreement.

From the Governmental Agreement Number 176-2015 Radioactive Waste Management Regulations:

Radionuclides (Radioisotopes): Natural or artificial elements, whose nucleus have the property of disintegrating, spontaneously emitting ionizing radiation, characterized by the number of protons and neutrons that make up its nucleus, as well as its nuclear energy state.

Half-life: (For a radionuclide) time required for its activity to be halved due to the process of radioactive decay.

Characterization of radioactive waste: Determination of the physical, chemical, and radiological properties of radioactive wastes to substantiate the need for further adjustment, treatment, conditioning, or its suitability for additional handling, processing, storage, and final disposal.

Radioactive waste management: All administrative and operational activities necessary for the handling, pre-treatment, treatment, conditioning, transportation, storage, and final disposal of radioactive waste from a radioactive facility.

Radioactivity: It is the property of certain chemical elements (radioactive elements) to decompose spontaneously, releasing energy continuously from nuclear radiation: alpha, beta, gamma (from the standard to regulate the quality of wastewater of a particular type discharged to the sanitary sewer).

Proposal to update and improve the AG 236-2006

Table 2 summarizes the suggested changes (by article) incorporated into the AG 236-2006.

Article	Suggested changes	Foundation
4	Incorporate the following definitions: Radionuclides (radioisotopes): Natural or artificial elements, whose nucleus have the property of disintegrating, spontaneously emitting ionizing radiation, characterized by the number of protons and neutrons forming its nucleus, and its nuclear energy state. Half-life: (For a radionuclide) time required for its activity to be halved due to the process of radioactive decay. Characterization of radioactive wastes: Determination of the physical, chemical, and radiological properties of radioactive wastes to substantiate the need for a new adjustment, treatment, conditioning, or its suitability for subsequent handling, processing, storage, and final disposal. Radioactive Waste Management: All administrative and operational activities necessary for the handling, pre-treatment, treatment, conditioning, transportation, storage, and final disposal of radioactive waste from a radioactive facility. Radioactivity: It is the property of certain chemical elements (radioactive elements) to decompose spontaneously, releasing energy continuously from nuclear radiation: alpha, beta, gamma).	Definitions are already set in AG176-2015
5	The endorsement of the technical study (for medical institutions with radioactive applications) is through the Ministry of Energy and Mines.	Ministry is responsible for the matter.
6	Current status and projection of radiological specifications (qualitative and quantitative) used. II.b), hospital units where a particular type of wastewater is used, administered, or discharged (nuclear medicine).	Information will allow the patient to know the approximate quantity and quality of discharge, diagnosis, and treatment.
16	Include parameters: ^{131}Indium, ^{18}Fluorine, ^{223}Radio, ^{226}Radio, ^{3}Hydrogeno (tritium), ^{57}Cobalt, ^{90}Strontium, ^{111}Indio, ^{123}Iodine, ^{125}Iodine, ^{201}Thallium, ^{89}Strontium, ^{99m}Technetium, ^{99}Molybdenum, ^{131}Iodine.	Most common radioisotopes in medical applications, in search of cancer treatment.
1i7	Maximum date of compliance with DBO to the year 2024 (only term available in its actual modification), a modification to the maximum parameter of 60 mg/L, instead of 200 mg/L.	According to theoretical results obtained in this study.
27	Maximum date of compliance with DQO to the year 2024 (only term available in its actual modification), a modification by setting the maximum parameter of 50 mg/L.	
30	Changes to the following values: Temperature, 35°C Fats and oils, 10 mg/L DBO, 50 mg/L DQO, 60mg/L SS, 30 mg/L N_t, 24 mg/L P_t, 5 mg/L Ni y Pb, 0.1 mg/L Zn, 2 mg/L Colour, 300 UC Add the following parameters (in Bq/a): ^{131}In, 1E+07 ^{226}Ra, 1E+06 ^{3}H, 1E+012 ^{90}Sr, 1E+010 Add the following parameters (in Bq/kg) ^{18}F, 1E+04 ^{223}Ra, 1E+05 ^{57}Co, 1E+09 ^{111}In, 6E+07 ^{123}I-^{125}I-^{89}Sr, 2E+09 ^{201}Ta, 1E+07 ^{99m}Tc, 4E+08 ^{99}Mo, 5E+07 Add the following parameters (in Bq/m^3) ^{131}I, 1E+05	
45	The collection, treatment, conditioning, and storage (by confinement) as an appropriate form for sludge -a by-product of wastewater-, equipment, inputs used and unused for practical life, as well as decomposed matter (human and animal), must be moved and disposed of according to the regulations of the Ministry of Energy and Mines, through the National Center for Radioactive Waste (CENDRA), for example.	Functions and attributions according to AG176-2015.

Table 2 Elements of updating and improvement to GA 236-2006 emphasize nuclear medicine waste

The general internal flow of emission and application of nuclear medicine that may emit unintended radiation.

The following main points can be considered for a secure internal transfer of inputs and reagents (Figures 1).

Reception and delivery area. Preferably at times of lower influx of outpatient patients. The inventory record will allow the order, information, and guarantee of complying with the minimum projected supply without exceeding excessive quantities in the warehouse. Suppliers and reception managers must wear personal protective radiation equipment in good condition at all times. One of the guarantees of protection is the automation of processes, using machinery for reception, which will be taken in subsequent steps (without direct contact). In addition, it must have an immediate response team and notify the authorities in an emergency. Underground or isolated transfer to and from the reception and delivery area. It is appropriate to consider the transfer tunnel by unintentional radiation in new buildings. Appropriate adaptations in existing buildings for isolation of halls and authorized sites in non-structural measures of armor should be made. Its use should be restricted to transporting components (inputs and waste). It must activate emergency alarms in case of leakage or spill, warnings to immediate evacuation medical personal for specialized attention. A technical data sheet/safety sheet in Spanish will be provided as the essential information for the action.

It is proposed that products, supplies, and new reagents for use and application, properly labeled and separated (to avoid unintentional chemical reactions), should be stored separately with concrete shielding.

Equally, the products, supplies, and reagents used should be separated and labeled on restricted rooms to avoid the human risk of confusion of reagents with waste, in addition to unexpected physics and chemistry.

Diagnostic units and treatment application / administration (clinics/bedding).

The solid waste is transferred to separate storage to be delivered to private or public services CENDRA for final disposal summarized in confinement and incineration.

Liquid waste is channeled to the treatment of specific wastewater (PTAR^{+R}).

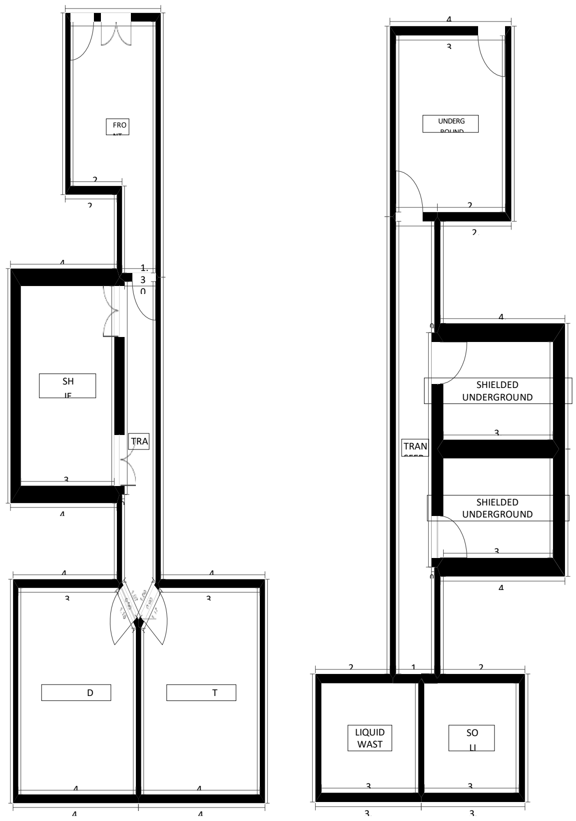

Figure 1 Flow a) internal -income and b) internal discharge to avoid unintentional emissions in the internal transfer of radioactive reagents

Table 3 lists the proposed elements that should be considered to manage radioactive isotopes in the hospitals that operate them properly. Again, emphasis is placed on the training that personnel who internally handle these potentially hazardous substances and their recurrent medical check-up should have to avoid complications after accidental exposure.

Before incorporation	
Aptitude process	Personal and work history (emphasis on jobs with cytostatics, genotoxic or carcinogenic) and personal and family clinical (emphasis on chemo-radiotherapy treatments, radiological tests, malformations, cytostatic allergies), habits and their updating
	Previous exposures using products with cytostatic-like effects, personal and family medical history, habits, specific laboratory control

Confirmed aptitude, Description, and assignment of role and responsibilities	
Confirmed aptitude, Description, and assignment of role and responsibilities	Initial training:
	-Theoretical concepts
	-National and international legal framework
	-Datasheets of radioisotopes and medicines
	-Protocols of acceptance, transfer, use and discard
	-Health, safety, and malicious acts risks
	-Authorizations and access control
	-Routine evaluations
While working	
Personnel medical evaluations	In the beginning, after joining the risk job.
	Periodically during the working life in that job.
	After acute accidental exposure.
	After a prolonged absence from work.
	When leaving the manipulation job (by termination, retirement, or change of position).
	Continuous training
	-Equipment maintenance
	-Inventory
	-Non-routine evaluations
After exposure* water or prolonged absence	Immediate treatment after watery or accidental exposure

Table 3 Protocol Elements for Security Plan

Staff will work in shifts to reduce the risk of contamination and prolonged exposure in the reception, transfer/storage, administration areas. Teaching/training may include equipment (research reactors, promoted by OEIA).

Proposal for wastewater and related solid waste treatment process

Figure 2 shows the following flow: from the bedding type unit for patients receiving nuclear treatment, with toilet, sink and shower, with universal access (solids and liquids are discharged as fecal and urinary stools) and the Application/Administration Unit (solids and liquids are discarded products and by-products of the treatment, including cleaning of personnel and facilities), solids and liquids are conducted to the tri barrier settler. The purpose is to remove suspended solids by decantation or settling using the gravity force in an 8-day operation (allowing the common radioisotopes natural decay). It can be designed as a metal drum covered by protective layers that separate from the environment; these can be: lead, ant, and earth (therefore, it must be underground).

The different material: liquid and solid, is conducted in a differentiated way. A pump or gravity drives the liquid/gaseous material into the wet electrostatic precipitator, which uses electrostatic forces (reducing cost) to eliminate particulate matter emissions in the gas streams. This contributes to environmental protection and can be investigated as energy thrusters for internal operation.

The liquid continues with a pump that must supply sufficient pressure to overcome the loss of load of the filter assemblies and the osmotic pressure towards pH adjustment and gravity ultrafiltration membrane passage. The membrane is made of denatured protein and activated carbon. This membrane can suppress radioactive elements (mainly Uranium, ^{131}I, and ^{177}Lu) on 99.8% effectively. It removes radionuclides from hospital effluents and is low cost (Bolisetty et al., 2020). Denaturation implies a change in the chemical structure of the chain towards a linear shape. Thus new bonds appear that allow proteins to be more reactive chemically (Pilamontaty Mañay, 2017) that seems to work with the adsorption capacity by the porosity of activated carbon. Another type of similar technology is composite membranes (hydrophobic/hydrophilic), a two types mixture of surface modifying macromolecules from polysulfone and polyethersulfone (thermoplastics) that were tested for the treatment of low and medium level aqueous solutions of the radioactivity of salts of ^{60}Co, ^{137}Cs, ^{85}Sr (Khayet, 2013). The type of ceramic membrane (alumina) can be used for radioactive wastewater treatment (Lorente, 2017) due to the stability of its properties infiltration processes in chemically aggressive environments and at high temperatures. Using a membrane is effective (operation, energy consumption), although it requires maintenance for cleaning and secondary waste emanates from it.

An alternative unitary operation that may represent a temperature and air risk on the underground treatment area is direct contact membrane distillation. However, it can be helpful since no presence of Cs^{+}, Sr^{2+}, Co^{2+} radionuclide ions were detected in analyzed wastewater (Liu & Wang, 2013).

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Then it enters the radioactive deactivation reactor before entering a wastewater treatment plant of hospital origin. The macro, micro, or nanoscopic solids remain decanted towards a compactor dam with an underground transported solar energy source (reducing volume).

An alternative form to acquiring reagents is the development and production of materials to establish diagnoses and, in some cases, treat diseases for peaceful and medical purposes. The IAEA's Proposal is through research reactors (International Atomic Energy Agency, 2019) that are simpler in design, operate at lower temperatures, require much less fuel, and generate less waste.

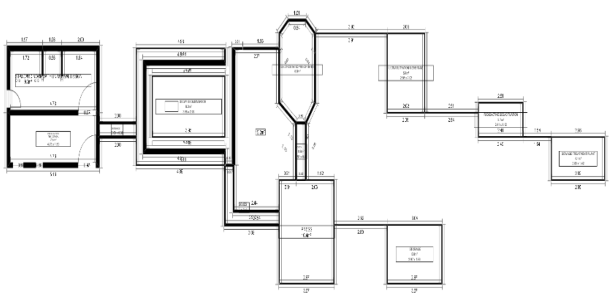

Figure 2 Proposal of the treatment process

Operation simulation and approximate theoretical results of the management system

- Calculation bases for the simulation of Radioactive Activity (Table 4):
- Treatment for ten patients per day (based on 3,500 new cases per year)).
- Flow: 0.007 L/s or 600 L/day/bed because:
- is within the range of 400 to 1,200 L/bed/day, is coincident with the value presented in the converted ATHA Manual (Almazán Gárate, 2010)
- It is assumed that it will include the flow used during the application, as estimated by the Health Services Network Design Standard (Ministerio de Salud Pública y Asistencia Social, 2015)
- Dosage of ^{131}I applied per patient: 17.5 mCi (average between 5-30 mCi).
- Absorption/person: 35%
- Remanence: 100 % - % adsorption / person: 65%
- Half-life of ^{131}I: 8,05 days (Agencia Española de medicamentos y productos sanitarios, 2020)
- Estimated effectiveness in primary treatment (sedimentation/precipitation): 30%
- Estimated effectiveness in secondary treatment (ultrafiltration): 10%
- Estimated percentage of efficacy in tertiary treatment (radioactive deactivation): 10%

S%	P %	U %	Ra %	Ira (mCi) %	Rra (mCi) %
10	10	10	10	113.75	37.5136
20	10	10	20	113.75	29.484
30	10	20	20	113.75	25.7985
20	20	30	30	113.75	22.932
20	20	35	50	113.75	11.83

Table 4 Theoretical simulation exercises, varying the effectiveness of each process

S: sedimentation, P: precipitation, U: ultrafiltration, Ra: radioactive deactivation, Ira: Initial reactive activity, Rra: Resulting reactive activity

Conclusions

Although there are significant efforts by the State, academia, and associations to manage radioactive elements, there is no systematic or normative methodology that applies, verifies, monitors validate, and encourages.

It is proposed to incorporate elements in radioisotope management: protecting human resources and training, half-life or disintegration barriers to reduce emissions and ensure reception conditions, handling, and transfer of these materials. After analyzing physical, chemical, and microbiological parameters reported in various countries and types of hospitals that handle nuclear medicine, the maximum permissible limits appropriate for the Republic of Guatemala are proposed. Additionally, it is suggested to integrate some necessary concepts to the existing regulations that allow their understanding and adequate regulation through the Ministry of Energy and Mines.

It also proposes a protocol of reagents and solid waste internally of the diagnostic or application center to avoid cross-contamination and compaction to reduce the volume subsequently transferred to the competent national institution, whose management is with trained personnel.

The proposed wastewater treatment comprises sedimentation, precipitation, membrane ultrafiltration, and radioactive deactivation. Finally, a theoretical simulation was carried out integrating the proposed elements.

Consolidated management and directed by competent governing institutions and the AG 236-2006 as a tool to guide compliance. Incorporating the management elements proposed can reduce the probability of environmental pollution and health risks due to exposure to radioactive substances used in hospitals handle them.

It is proposed to continue researching possible exposure to radioactive elements, for example, those cancer patients who are sent home and dispose of liquid and solid waste that may have radioactive traces and the treatment system.

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