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## A Review on the Management of Strontium-90 Waste in Medical Facilities

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### ABSTRACT

Healthcare facilities generate a large amount of waste, which is considered potentially dangerous. Hospitals are increasingly using radioactive isotopes for diagnostic and therapeutic applications. Isotopes are utilized in different applications of life purposes such as nuclear medicine, radiotherapy, and in industry. Radioactive waste is any material that contains or is mixed with a radionuclide that poses a radiation level that exceeds the IAEA recommended level or that of a national regulatory body. Today, the problem of radioactive waste is one of the biggest threats to human beings, as its effects extend to the environment, natural resources, animals, plants, and soil. Strontium-90 is one of the radioisotopes used in hospitals. Most of the hospital's radioactive waste is generated in the Nuclear Medicine department. Strontium-90 is a radioactive isotope that is considered one of the most hazardous radioactive isotopes. This study focuses on the use of strontium-90 in medical facilities and how the wastes generated are sustainably managed for human safety and the environment. The applications, waste generation, tests, effects on human health and the environment, and the treatment processes of strontium-90 waste have been studied. The treatment processes, such as forward osmosis membrane, crystalline inorganic ion exchanges, etc. of strontium-90 waste in a hospital are detailed in this review.

### INTRODUCTION

Different types of radionuclides are utilized in the field of medicine for diagnostic, therapeutic, and research purposes. Hazardous radiological wastes alongside biological and chemical wastes are formed as a result of the production of radioactive wastes from the utilization of medical radioisotopes. Many of the radionuclides in nuclear medicine departments are short-lived and in low or medium concentrations. Hospitals administering large quantities of <sup>131</sup>I for treatment of thyroid of carcinoma or using frequently Iodine for radioimmunoassay aqueous solution or Tc-99m in diagnosis (Ohiduzzaman *et al.*, 2019; Tsai *et al.*, 2016), should consider the provision of decay tanks for storage and safe disposal of radioactive waste resulting from patients excretion or laboratory waste. Radioactive waste refers to any material containing or mixed with a radioactive nuclei that poses a radiation level which exceed that level recommended by the IAEA or a national regulatory authority (Darda *et al.*, 2021; Derib, 2017). The radioactive waste problem can be regarded as the biggest threat facing human beings today, as its effects extend to the environment, natural resources, animals, plants, and soil. Healthcare institutions generate an enormous amount of waste, which is considered potentially hazardous given the inherent potential for dissemination of infection (Cook *et al.*, 2023; Rokka & Khanal, 2023). The objective of waste management is to provide protection of workers, patients, and the environment by minimizing the hazards in an effective

way over the whole life cycle of the considered product. It has been reported that Hospitals generate, on average, between 0.5 and two kilograms of waste per bed per day (Mol *et al.*, 2022). It is estimated that approximately 85% of the waste generated is not harmful, about 10% is infectious, and 5% is not infectious but harmful (Maqsood, 2023).

Radiopharmaceuticals are used in medicine for diagnostic and therapeutic purposes. The commonly used radiopharmaceuticals in medicine are <sup>99m</sup>Tc, <sup>131</sup>I, <sup>131</sup>I, <sup>123</sup>I, <sup>18</sup>F, H-3, and <sup>14</sup>C. Much of the radioactive waste in health facilities is aggregated in the Nuclear Medicine department. A greater part of the radioactive waste is in the form of a liquid, and a smaller amount in the form of solid, and the minimum in gaseous form of the radioactive waste is liquid, with a lesser amount of solid and minimal in gaseous form (Rahman *et al.*, 2011). The solid waste has traces of radioactivity in the form of syringes, needles, cotton, swabs, vials, contaminated gloves, and absorbent materials. High doses of radioisotopes like <sup>131</sup>I are found in the clothing and utensils of patients. The contaminated objects and the unused radioactive material require safe disposal to ensure that the radiation exposure to the public, radiation workers, and environment does not exceed the prescribed safe limits (Das *et al.*, 2021; Menon & Kumar LS, 2019). The short-term and long-term effects of ionizing radiation on humans are reduced by maintaining the levels of exposure within the required limits, in addition to reducing its negative impacts on

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the environment. Regular dose rate monitoring of radiological workers in the hospitals, area monitoring of hospital environment, and quality control of the radiation instruments are mandatory to assess the quality of existing radiation safety standards. Every hospital is required to have a designated Radiation Safety Officer (RSO) who oversees all aspects of radiation safety, including radioactive waste management. The RSO coordinates such measures in accordance with guidelines prescribed by the International Commission on Radiation Protection and the national regulatory body.

One of the major concerns is the separation of Sr-90 (a B-emitter with a half-life of 28.8 days), which is due to its large concentration resulting from a high fission reaction product and specific activity (Parus & Mikolajczak, 2012; Moore, 2018). The chemical properties of the  $^{90}\text{Sr}$  radioisotope make it possible to be utilized in the treatment of cancer (Herrero Álvarez *et al.*, 2021; Semenishchev & Voronina, 2020; Yeong *et al.*, 2014). It is important to note that strontium ninety is known to be the most hazardous isotope of strontium (Burger & Lichtscheidl, 2019; Holt *et al.*, 2021; Pathak & Gupta, 2020; Semenishchev & Voronina, 2020). Thus, much interest is attached to the separation of strontium ninety. The selective separation of  $^{90}\text{Sr}$  from a solution of radioactive waste for it to be suitably utilized or disposed of is a significant field of research. This review, therefore, focuses on the management of radiological medical waste from the utilization of strontium ninety in hospitals.

## LITERATURE REVIEW

Strontium ninety is purely a  $\beta$ -decay radionuclide having a 28.9 years half-life. It is exposed to the environment by various means, such as nuclear weapon testing, nuclear power plant accidents, the nuclear fuel reprocessing industry, etc. Following the Chernobyl and Fukushima nuclear accidents in 1986 and 2011, respectively, great attention has been paid to monitoring the presence of  $^{90}\text{Sr}$  in food and the environment within the vicinity of nuclear facilities. The elements strontium and calcium are homologous and therefore share similar chemical and physical properties (Kołodziejska *et al.*, 2021; Nedobukh & Semenishchev, 2019). Strontium ninety ( $^{90}\text{Sr}$ ) and its daughter radionuclide yttrium ninety ( $^{90}\text{Y}$ ) are distributed in bones and teeth as a result of accumulation during long-term exposure (Glasco *et al.*, 2024; Tolstykh *et al.*, 2000). The radionuclide subsequently enters the circulatory system of the human body together with calcium and induces bone cancer and leukemia. The long half-life and high fission yield of strontium ninety renders among the most radiological hazards for humans and the environment. It is a fission product of  $^{235}\text{U}$  and  $^{239}\text{Pu}$ .  $^{90}\text{Sr}$  emits beta particles with a maximum energy of 546 keV, and its decay product is short-lived  $^{90}\text{Y}$  (half-life=64 hrs) (Semenishchev & Voronina, 2019). Yttrium ninety decays to a stable nuclide  $^{90}\text{Zr}$ , resulting in the emission of  $\beta$ -particles.

The growth of the nuclear power industry in the world

and the widespread utilization of nuclear technology (Kessides, 2012; Zhan *et al.*, 2021), are the basis for the high demand in radiation protection and radiological risk assessment during routine operation and nuclear emergencies. It is therefore very important to provide analytical methods that are more effective in determining toxic radionuclides like Sr-90. The separation and purification of Y-90 from Sr-90 can be done by utilizing a number of methods such as precipitation, solvent extraction, ion exchange, and extraction chromatography (Lee *et al.*, 2022; Muchtaridi *et al.*, 2017; Pichestapong *et al.*, 2016). The extraction chromatography using solvent-impregnated resins has been applied widely for trace metal separation and recovery (Cortina & Warshawsky, 2021).

Strontium readily dissolves in water, making it easier to be distributed in the environment (Mukherjee & Mishra, 2021). The transportation of Sr-90 from the environment to the food chain and finally into the human body can be done in different pathways. Strontium and calcium are group IIA elements with similar chemical properties and therefore have similar biological processes in the human body. Calcium is known to belong to the typical bone-seeking nuclides. Strontium ninety follows the uptake of Ca when it enters the human body and readily accumulates on the surface layer of bone as  $\text{Sr}_3(\text{PO}_4)_2$  salts layers (Genter, 2012; Sharma, 2019a). Strontium ninety is involved in the formation of bone salts and enters the inorganic salts of the bone crystals, becoming immobile in the bone during the physiological osteogenesis process.  $^{90}\text{Y}$  produces high-energy beta particles, which severely damage the human bone and hematopoietic tissues of the bone marrow, resulting in bone cancer and leukemia. Several studies have been conducted on the treatment of strontium ninety in water, which is associated with the synthetic radioactive isotope Sr-90 and have similar physical properties to stable strontium (Gupta *et al.*, 2017; Semenishchev & Voronina, 2019; Sharma, 2019a).

The utilization of radiopharmaceuticals in radiation therapy has been existing for decades and offers enormous benefits to cancer patients, particularly to those suffering from thyroid cancer (Chinweike-Umeh *et al.*; Lepareur *et al.*, 2023; Salih *et al.*, 2022; Sgouros *et al.*, 2020). Several clinical trials using radiopharmaceuticals to treat other types of cancer are ongoing and their success will increase the demand for therapeutic radiation pharmaceuticals in the future. Radionuclides with very short half-lives have challenges such as transportation and the need for frequent shipments. Short-lived radioisotopes are globally made available for efficient therapeutic purposes by the use of radionuclide generators.

Imaging equipment are utilized alongside some radiopharmaceuticals to detect diseases (Payolla *et al.*, 2019). A cancerous tumor can be destroyed or shrunk by placing a radiopharmaceutical inside the body. Hospitals that provide radiation or nuclear services 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, as well as the possible transport and safe handling of radioactive materials. Even low levels of radioactive waste from hospitals must be packaged and transported according to regulatory requirements (Ali *et al.*, 2017; CENA & HASI, 2024; Ravichandran *et al.*, 2011). Labels, container markings, and packaging must identify the contents, codes, and symbols. Short half-lives and low radio-toxicity are the primary properties of biomedical waste, and contains low-energy Beta and Gamma emitters with a low total and specific activity (CENA & HASI, 2024; Hooshmand *et al.*, 2020).

## MATERIALS AND METHODS

About 104 articles were explored from various publishing houses and online research platforms such as Elsevier, Wiley, MDPI, Research Gate, etc, with data related to the topic “A Review of Managing Strontium-90 Waste in Medical Facilities”. The articles were systematically reviewed by employing the Preferred Reporting Items for Systematic Reviews (PRISM) guidelines. The research question was structurally formulated based on previous work reported by various researchers on the Management of Radioactive Wastes in Medical Facilities.

### The Hospital’s Use of Strontium-90 and Its Waste Management

#### Utilization of Strontium Ninety Isotope In A Medical Facility

<sup>90</sup>Sr is a significant radioisotope utilized in medicine over the years. The applications of <sup>90</sup>Sr in nuclear medicine have been reported by many researchers. Strontium is deposited in bones for a pain relief signal that communicates to the brain (Cristofaro, 2017; Genter, 2012; Ru *et al.*, 2024; Semenishchev & Voronina, 2020). Eye disorders and radiotherapy cancer cells can be also be treated using strontium ninety (Banerjee *et al.*, 2022; Burov, 2023; Liberal *et al.*, 2016). In medicine, strontium ninety compound is used to treat hepatocellular carcinoma (HCC) and other liver cancers (Chakravarty & Dash, 2012; Gao *et al.*, 2021; Mukherjee & Mishra, 2021). According to IAEA 1998, it is reported that strontium-90 in medical facilities is utilized as manual brachytherapy and further highlighted its use as a radioactive tracer. Findings show that strontium ninety is used to treat skin and eye diseases (Neal *et al.*, 1991; Qin *et al.*, 2012).

### The Accumulation of Strontium Ninety In Medical Waste

The waste produced from the use of strontium ninety is dangerous to people and the environment. In order to solve this problem, it is significant to understand how these wastes are generated. It has been reported that strontium ninety waste is aggregated from the waste waters produced in radiation therapy rooms through urine, faeces, and detergents (Luhar *et al.*, 2021; Maddheshiya

*et al.*, 2025; Pant, 2021). The liquid of strontium ninety wastes can also be generated from radioimmunoassays (RIAs) utilized to measure the concentration in patients in vitro assay technique. Radioimmunoassay waste comprises proteins generated from reagents and samples during analysis. Much work has not been done on the liquid waste of strontium ninety from radiation therapy rooms. Liquid wastes such as of urine, feces, detergent and radionuclides from radioactive therapy differs from RIA waste (CENA & HASI, 2024; Lee *et al.*, 2018; Ravichandran, 2017; Sancho *et al.*, 2013) where all of the liquid waste aggregated from the examination, radiation, and the patients themselves (Chitnis *et al.*, 2005; Lee *et al.*, 2018; Padmanabhan & Barik, 2019; Rahman *et al.*, 2011; Zikhathile *et al.*, 2022), while RIA wastes are only obtained from the analysis of reagents and samples, and especially when its radioactivity is far lower than wastes accrued from radiation therapy room (Ahmed, 2001; CENA & HASI, 2024; Puspita *et al.*, 2023; Sancho *et al.*, 2013).

### Determination of Strontium Ninety

A number of environmental materials, such as air filters, swipes, biota, water, soil, etc., are utilized to test for strontium. Strontium-90 can be quantified by employing a variety of chemical methods (Ppoletiko *et al.*, 1994; Tayeb *et al.*, 2016; Vajda & Kim, 2010), like spectrophotometry, atomic absorption spectroscopy, x-ray fluorescence spectrometry, inductively coupled plasma spectroscopy-atomic emission and mass spectrometry applications (i.e., ICP-AES and ICP-MS), etc. Proportional in vitro gas flow, scintillation, and Cherenkov counting are the technologies used to detect the quantity of strontium-90 in the environment (Domenech, 2017; Hou & Roos, 2008; Tayeb, 2015). Radiostrontium in water and urine is determined using the EPA analytical standard procedure. Strontium-90 is precipitated as insoluble carbonates by adding a stable strontium carrier to water. The sample then undergoes preliminary counting that represents the total strontium activity (<sup>90</sup>Sr). Bioassay technique urinalysis can be tested for strontium-90 (Dai *et al.*, 2013; Sadi *et al.*, 2010; Shiraishi *et al.*, 2007; Wang *et al.*, 2004). The estimated internal dose due to exposure to radiostrontium is provided by strontium ninety utilizing ion chromatography internal dose due to exposure to radiostrontium (Semenishchev & Voronina, 2020; Tomita & Takeuchi, 2019; Vajda & Kim, 2010). Strontium-90 can be detected in water and urine samples using the Fast Column Separation method and liquid scintillation counting. A high-capacity iminodiacetate chelating resin buffered to a pH of 5 was utilized to extract strontium ninety. The transition metals, lanthanides, etc, were extracted by the resin at a pH of 5 and transferred to a column separator and subsequently released as weak acids.

### Human Health and Environmental Effects of Strontium Ninety

Strontium-90 wastes in medical facilities are harmful to people and the environment. Food and water which

are major exposure pathways for the population are contaminated by strontium ninety when disposed to the environment (Sharma, 2019b; Wang *et al.*, 2023). Exposure to strontium-90 can lead to a number of health issues such as bone disorders, bone cancer, etc. (Marx *et al.*, 2020; Ru *et al.*, 2024). It has been reported that strontium-90 was found in the teeth children following a global nuclear testing in the atmosphere (Froidevaux *et al.*, 2006; Gould *et al.*, 2000) which resulted to harmful effects like leukemia or skeletal cancer caused by damage in DNA cells. Strontium-90 has a long half-life of 28.8 years, and its presence in the body can lead to long term irradiation of skeletal bone structure which may lead to damage in bone marrow, leukemia, and other bone cancers (Gupta *et al.*, 2018).

The harmful effects of strontium-90 are reasons for its monitoring in the environment, particularly in groundwater surrounding nuclear facilities (Freed, 2002; Semenishchev & Voronina, 2020). Chlorophyll formation in plants is decreased when contaminated by strontium-90 (Chatterjee *et al.*, 2020; Dresler *et al.*, 2018; Moyen & Roblin, 2010). Plants absorbed radioisotopes from the environment enters the food chain which affects human health and the environment. Agricultural plants cultivated in areas contaminated by Sr-90 also pose health risks to humans or animals when eaten and ingested (Burger & Lichtscheidl, 2019; Gupta *et al.*, 2018; Sharma, 2019b).

#### **Treatment Methods for Strontium-90 Medical Wastes The Pretreatment of <sup>90</sup>Sr Using Forward Osmosis (FO) Membrane Technique**

The Forward Osmosis (FO) membrane process used for the pretreatment of strontium-90 liquid waste have been highlighted by many researchers (Kadadou *et al.*, 2023; Pabby *et al.*, 2022). This application has two radionuclide decay system of two main septic tanks for the collection of liquid waste and the decay of radionuclides, respectively (Azman *et al.*, 2024; Kadadou *et al.*, 2023; Rao *et al.*, 2022). The first tank is used to store the collected liquid waste to allow the radionuclides to decay and then subsequently pumped to the second tank where the radionuclide will further decay and discharged after the radioactivity or quality of the final water reached regulatory requirements. A very large area is required to carry out the pretreatment method and therefore requires improved management of radiation therapy facilities.

A highly concentrated draw solution (DS) is utilized as the main driving force to extract pure water from the feed solution (FS) based on the difference in osmotic pressure between DS and FS (Blandin *et al.*, 2020; Chekli *et al.*, 2012). FO consumes low energy, has high fouling reversibility, and high rates of recovery. Medical radioactive wastewater having high fouling potential can be suitably treated using FO due to the low working pressure of FO, leading to high fouling reversibility. FO is used to remove heavy metals and arsenic due to the high rejection rate.

#### **Ion Exchange Inorganic Crystals**

Crystalline inorganic ion exchangers for Sr-90 are employed in the treatment of Sr-90 nuclear waste due to their high radiation, thermal, and chemical stability (Figueiredo *et al.*, 2018; İnan, 2022; Li & Chen, 2024; Marinin & Brown, 2000) and ion selectivity. They can easily be transformed into alternate ceramics compatible with the metrics immobilization. Inorganic ionic crystal exchangers are mostly selected for specific ions due to their crystallochemical properties such as ionic radii, charge, and polarizabilities, etc. Inorganic materials such as phosphates, molybdates, titanates, silicates, etc., are therefore utilized to separate <sup>90</sup>Sr from radioactive waste (İnan, 2022; Savva, 2016; Yudinsev, 2021). Titanates and silicotitanates are employed for their increased stability in conditions of radioactive wastes (Popa & Pavel, 2012; Stefanovsky & Yudinsev, 2016; Zhang *et al.*, 2022), but are however ineffective for the separation of <sup>90</sup>Sr in acidic solutions because they strongly inhibits protons. Various authors have conducted research on different hydrous oxides to selectively separate the cations of radioactive elements from aqueous solutions using inexpensive methods. The behaviors of amorphous MnO<sub>2</sub> and birnessite were compared and the result shows faster sorption kinetics, higher adsorption capacities and stabilities observed in birnessite than amorphous manganese oxide. Birnessite crystals are extensively stable in acidic media and have a higher sorption capacity than the amorphous nature due to structural properties. Strontium ninety is separated by ion exchange using inorganic monosodium titanate (MST) (Hobbs *et al.*, 2005; Peters *et al.*, 2006). MST exhibits a very good performance with a little strontium desorption during washing.

#### **Physicochemical Method to Remove Sr(II) In Aqueous Solution**

Effective adsorbents for the removal of Sr (II) in aqueous solutions are eggplant hull, moss, activated carbon, sawdust modified with magnetic Fe<sub>3</sub>O<sub>4</sub> particles, pecan shell, synthetic zeolites, baker's yeast, etc (Koshy & Pathak, 2019; Liu *et al.*, 2024). Clay is a cost-effective, natural abundance adsorbent material that is suitable to remove the ions of strontium in solution (Ahmadpour *et al.*, 2010; Li *et al.*, 2022; Shahadat & Isamil, 2018). The interest in cement and clay has grown considerably in recent times. The removal of radiotoxic ions in the treatment of wastewater has been carried out using different types of clay and clay minerals. Strontium ninety is used in a batch experiment to investigate the adsorption behavior of montmorillonite and kaolinite minerals for SR (II), which reveals that adsorption occurs through ion exchange (Başçetin & Atun, 2006; İnan & Hiçsönmez, 2022; Koshy & Pathak, 2019). Bentonite was also utilized to get Cs and Sr by a rapid uptake and good sorption capacity. Sr (II) in aqueous solution was removed using powdered dolomite (Ghaemi *et al.*, 2011; Sdiri, 2018). The Langmuir isotherm was utilized to interpret the equilibrium data

and the pseudo-second order kinetic model. According to the adsorption isotherm, the maximum sorption capacity was observed to be 1.172 mg/g at 273K (Tiwari & Lee, 2015). Sr (II) was also effectively removed in aqueous solution by other types of clay minerals like clinoptillite and paligrskite. Sr (II) are attached to negatively charged mineral surfaces forming complex outer spheres (Rahnemaie *et al.*, 2006), and the extent of adsorption depends on several factors, such as ionic strength, pH, and composition.

#### The Use of Graphene Oxide Membrane (GO) Method to Remove of Sr(II) From High Liquid Waste

Many researchers have reported the separation of radioactive strontium waste using Graphene Oxide (GO) membrane method (Wei *et al.*, 2024; Xing *et al.*, 2019). This is a well-known and newly accepted carbon-based method for radiochemical separation. An investigation was carried out to determine how metallic elements permeate in high liquid waste (HLLW) using a 5µm thick ionic sieve GO membranes. It was observed that the rate at which the ions permeate through GO membranes decreases with an increase in hydrated ionic radii. Sr (II) was seen to permeate faster than lanthanide and actinide ions, which slowly infiltrate, making it possible for separation according to their difference in hydrated ionic radii. The initial concentrations of metal ions and the acidity of the solution influence the permeation of the ions passing through the GO membranes. The higher initial metal ions and the feed acid solution are suitable for the removal of strontium ninety. The suitability of the GO membranes to separate Sr (II) from HLLW is proven by the barrier separation test.

#### The Biochroma Technique

Medical radioactive waste like Sr-90 can be managed using the Biochroma technique (Semenishchev & Voronina, 2020). It is a pretreatment method that utilizes a bio-treatment system where adsorption is the final phase. Buffer tanks are used to store the waste waters from the radiotherapy wards. The tanks are fitted with specially designed pumps with a device or instrument that shredder solid particles, thus homogenizing the effluent (Banerjee & Mitra, 2013). The holding tanks are responsible for the bio-treatment phase, and they have an aeration system that prevents anaerobic processes. Before the biological treatment, the wastewater is allowed to undergo sedimentation to remove larger particles that may reduce the sludge performance in the biologically made reactor. The next stage of the process is the upstream installation of an optimized biological treatment plant for the final phase of adsorption and filtration. The plant is designed with a secondary clarification stage to filter and separate any suspended solid materials and finally reduce organic contaminants to their lowest level. The downstream adsorption filter is protected against unwanted clogs. The activated carbon filters and selective ion exchangers in the adsorption filter system are used to eliminate the dissolved

radioactive components in the wastewater before finally collected in the storage tanks. The wastewater in the storage tank is constantly monitored as it is subsequently discharged into the sewage system.

#### CONCLUSION

Strontium ninety is an important radioactive isotope in medical radiotherapy and research due to its various applications in the treatment various illnesses such as liver cancer, bone cancer, and tumors. Despite the justifiable use of this radioisotope, the waste generated must be properly managed. The inadequate management and disposal of radioactive waste to the environment contaminates agricultural plants and crops. When these radioisotope contaminated crops are eaten by humans, they accumulate in bones and teeth leading to several diseases. To maintain a healthy environment, it is essential to use good pretreatment methods such as the biochroma pretreatment method.

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