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The Use and Disposal of Medical Radioisotopes

Ahmed Alharbi

Department of Physics, Qassim University, Qassim 51452, Kingdom of Saudi Arabia
qu.c@hotmail.com

Abstract: Radioactive radionuclides have been employed in medical applications since the early 1900s following the discovery of the artificial ^{226}Ra. Although ^{226}Ra source was used in cancer treatment for more than five decades in the previous century, it was eventually replaced by radioisotopes with low half-lives. This is because such isotope has a long half-life ($t_{1/2}$=1600 *y*) and can cause a second cancer resulting from long-term cell damage. These cancers include breast cancer and thyroid cancer appearing in a period between 10 to 40 years after initial treatment. Currently, most of radionuclides used in health care institutions have relatively low half-lives with the dominant source being ^{99m}Tc which is utilized in more than 80% of worldwide hospitals procedures. However, such dominant isotope has faced a shortage in supply as the prime reactors' suppliers have been shut down and therefore some approaches have proposed using accelerators to produce ^{99m}Tc. However, the radioactive waste from nuclear medicine procedures could affect the surrounding environments as well as pose a threat to human health. Hence, different waste management techniques involving dilute and disperse, delay and decay, concentration and containment as well as the use of delay tanks, have been adopted in hospitals to prevent the release of hazardous radioactive nuclides.
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1. Introduction

The use of radioactive isotopes has been extensively employed in medicine since the early 1900s and has increased over the past decades. Such isotopes have been utilized for diagnosis and even therapy purposes such as cancer treatments. These radionuclides are produced artificially either in accelerators or in reactors as some radioisotopes cannot be effectively produced in the accelerators. Following this, they are supplied to hospitals in a liquid form of radioactive material, having a various gamma rays and half-lives which are eventually injected into the patients [1]. However, concerns have been expressed regarding the impact of such radiopharmaceuticals on not only the patients but also on the surrounding environment. This could be because some of them are both radioactive and radiotoxic, since they emit alpha particles as well as having a relatively high half-life [2,3]. Moreover, some concerns have been raised regarding the sustainability of supplying such radioactive elements to healthcare intuitions [4]. This paper aims to discuss the use of radioisotopes in the field of medicine and the associated risks stemming from their use, as well as the waste management approaches used to dispose of them.

2. Radiotherapy in the Previous Century

In the early 1900s, radiation therapy began with utilizing 226 radium as a treatment method for cancer following the suggestion of the scientist Pierre Curie. Pier Curie recognized that ^{226}R could be used to damage cancerous tissues, as he had observed it damaging healthy tissue [5,6].The ^{226}Ra is a relatively the long lived isotope of Ra ,having a half-life of 1600 years and decaying into radon gas that emit alpha radiation[7].This isotope significantly reduces the absolute risks associated with several forms of cancer in patients of a wide range of ages and therefore its use became widespread use in medicine for decades. However, it has been found to cause a second cancer in patients after decades of treatment and has even led to a considerable number of deaths [8]. The treatment with radium (^{226}Ra) of 4153 women between 1925 and 1965 for bleeding disorders led to 2763 deaths due to cancer that approximately appeared 10 years after treatment [9]. Cancer mortality also increased as a result of the side effects of radium therapy on children suffering from skin hemangioma between 1920 and 1959. This was observed as different type of cancers including breast cancer and thyroid cancer, as well as bone tumors [10]. This highlighted the long-term risks stemming from using such radioactive nuclide in treatment which can cause second primary cancers that can result in the patients' death [11]. However, with the developments of artificial radioisotopes production during the second half of the past century,^{226}Ra has been gradually replaced by short half-lived radioactive sources. Although ^{226}Ra sources in 1970 were

completely replaced, currently some of its isotopes such as ^{223}Ra are used to efficiently treat cancer, due to their low half-live (11.4 days) [12] [13].

3. Current Radioisotopes in Medicine

Radiotherapy and nuclear medicine in hospitals continues to improve, since it utilizes a considerable number of shorter-lived radionuclides. These radioisotopes include Iodine, Technetium and Cobalt, as shown in Table 1, which are relatively energetic gamma emitters and can be provided in liquid form [4,5].

Table 1. Radioactive isotopes used in nuclear medicine and their half-lives [14].

Radioisotope	□-ray Energy(keV)	$\tau_{1/2}$
Technetium-99 m	140	6.01 *h*
Iodine-131	364	8.02 *d*
Iodine-125	27.5	59.49 *d*
Cobalt- 60	1330	5.27 *y*

^{131}I is paramount in nuclear medicine applications as it emits a high energy of beta particles with mean energy of 190 keV and has an 8-day half-life, making it efficient for killing cancerous cells. ^{99m}Tc (a metastable isotope of ^{99}Tc) is also utilized in roughly 80% of the global nuclear medicine procedures annually for diagnosing diseases in a considerable number of organ systems and tissue. The benefit of such radionuclide stems from having a short half- life as well as emitting energetic gamma rays (140 keV) that can be traced efficiently with various camera technology [15]. Hence, it provides patients with a relatively low dose of radiation for a number of procedures. However, exposure to the radiation of such radionuclide by operators including nurses, doctors and nuclear medicine technicians can be severely harmful to them, as it can exceeds the annual occupational dose limit. Indeed, a study conducted among more than 110 workers in nuclear medicines between 1980 and 2003 observed that approximately 10% of the operators had exceeded the annual effective dose (20 mSv/year) [16]. Furthermore, ^{99m}Tc has a half-life of 6 hours which makes transport and storage purposes less effective. As a result, radionuclide generators are used to produce ^{99m}Tc form Molybdenum-99(^{99}Mo) which is a non-medical long-lived isotope produced by either fission of Uranium 235 in a nuclear reactor (^{235}U+n→^{236}U+^{99}Mo+^{134}Sn+3n) or by neutron irradiation(activation) of ^{98}Mo (^{99}Mo+n→^{99}Mo+□) [17]. Molybdenum-99 has a half-life of 66 hours which can be easily transported into a generator through countries without significant loss of activity. This dose rate at a distance of one meter from a generator is 20-50 □□□/*h* due to beta decay which can be shielded effectively. Therefore, the ^{99m}Tc is extracted from the decay product of Mo-99 in the generator as shown in Figure 1 [18].

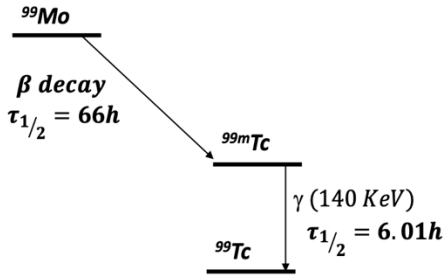

Figure 1. Mo-99 decay scheme [18].

4. Supply Shortages

The worldwide shortages of the dominant sources ^{99m}Tc used in medicine began to occur during the previous decade. This is because the two primary aging reactors (National Research Universal Reactor and Patten Nuclear reactor) have been shut down for safety issues and maintenance. These reactors have run for more than five decades and have provided approximately 66% of the world's supply of ^{99m}Tc [19]. Consequently, because of the continued disruption in the supply of ^{99m}Tc, together with the fact that demands for $^{99-m}$Tc are expected to increase, alternative approaches to generate $^{99-m}$Tc, as well as ^{99}Mo inside the accelerator have been proposed. One of the proposed techniques, involves using the p+^{100}Mo→ ^{99m}Tc+n reaction for the direct production of 99mTc which is based on targeting ^{100}Mo using proton to produce ^{99m}Tc without generating ^{99}Mo.However, such a technique requires performing this type of reaction in accelerators located in hospitals or healthcare institutions, as ^{99m}Tc cannot be transported due to its short life. Furthermore, another method involves applying the photon induce a reaction such as □ +^{100}Mo→^{99}Mo+n to produce ^{99m}Tc which can also be achieved in an accelerator [20,21].

5. Waste Management

Medical institutions and hospitals generate a significant amount of radioactive waste containing beta particles and gamma rays which is potentially hazardous and comparatively radiotoxic. Most of these radionuclides are considered to be a low-level liquid waste as they have short half-lives with different activity levels [21]. Safe disposal of the radioactive materials is a paramount objective for hospitals to ensure that patients, practitioners and the public, as well as environment, are protected and not vulnerable to the effects of radiation [22]. When various radioactive elements that have different half-lives are utilized, separate waste collection containers should be used. Therefore, the disposal of the radionuclides collected

can be accomplished using several approaches including, dilution and dispersal, delay and decay, as well as concentration and containment, depending on their half-lives [23].

5.1. Dilute and Disperse

Low activity solid forms, including tissue papers, needles, syringes and cotton swabs with a maximum limit of 1.35 microcuries can be disposed of as ordinary wastes in hospitals. Similarly, liquid diagnostic wastes as a result of using radioactive isotopes such as ^{99m}Tc that have an activity less than a microcurie are allowed to be mixed with normal waste after two days delay (8 half-lives) and can also be disposed of in the sewer system [24].

5.2. Delay and Decay

Radioactive wastes with half-lives of less than a month can be stored in a special storage room that has lead shielding with an appropriate thickness .Therefore, it is essential to store such radioactive waste for a minimum period 10 half-lives until there has been a necessary reduction in activity which is equivalent to 0.1% of the initial activity(A_o).Some therapy waste such as ^{131}I ($t_{1/2}$=8.02 *d*) can be stored in a temporary storage trolley for 2-3 months after treatment, as shown in Figure 2. Consequently, it can be disposed of in a normal bin or even discharged directly into the public sewage system [24,25].

Figure 2. Temporary storage trolley for collecting therapy wastes [24].

5.3. Concentrate and Contain

This method involves the disposable of radioactive waste that has relatively high activity levels and half-lives longer than a month, such as ^{125}I. Because of the limited radioactive storage rooms available at hospitals, disposal of such radionuclides after a long storage period using delay and decay method seems to be impractical. In this case, radioactive waste is collected in a specific container before being buried in exclusive burial areas permitted by the authorities [26].

5.4. Special Cases of Radioactive Waste in HealthCare Institutions

5.4.1. Disposal of Patients Excreta and Urine

Excreta and releases of radioisotopes, particularly ^{131}I, from patients who undergo treatment in hospitals can be discharged directly into the public sewage systems. Therefore, it can pose an issue for those working at a sewage plant, who may become externally exposed to radioactive isotopes that have been piped into the sewage plant [3,27]. These radioisotopes can also affect the public after consuming food grown on agriculture land that has been fertilized utilizing sludge from sewage. However, one solution is for liquid waste generated from ^{131}I to be collected in delay tank systems. These tanks are then closed and isolated for about two months until their radioactive levels are within a safe limit. This is because the urine excreted from these patients consists of approximately 90 % of ^{131}I. Once the liquid has reached an optimum radioactive level, corresponding to 1.2 microcuries per liter, such waste can be discharged directly into a general public sewage (Figure 3). Health care institutions are permitted to release no more than 37GBq(1Curi) of liquid radioactive waste into public sewer systems annually [28].

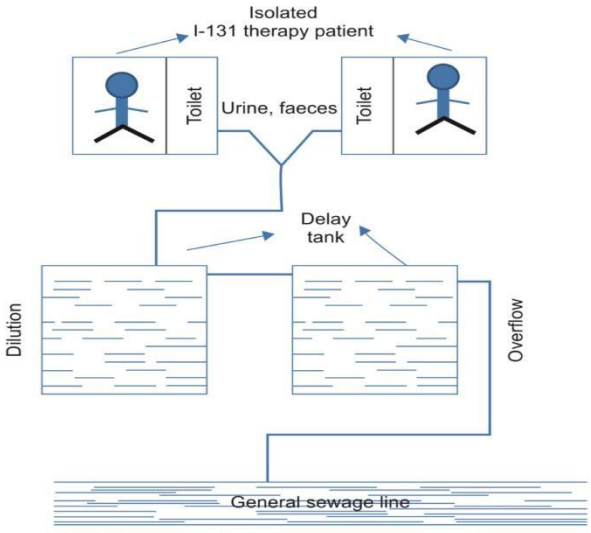

Figure 3. Delay tanks used for liquid radioactive waste disposal [27].

5.4.2. Disposal of Gaseous Waste

Iodine isotope 131 can release and emit radioactive vapor that can be digested or inhaled, as well as generates airborne radioactive waste. Therefore, hospitals workers, patients and even visitors can be vulnerable to the radiation released in a gaseous form, which can concentrate in a person's thyroid. Such gaseous radioisotopes must be treated before being released into the atmosphere by using an opened

container connecting through tube lines to a vent in the ceiling. Before the gaseous waste is dispersed and diluted into the atmosphere, a special air filter traps the vapor in porous bags, only allowing air to pass through [24,28]. As previously mentioned, this waste can have an impact on the surrounding environment and human health, so employing waste management approaches is essentially to reduce their impact.

6. Conclusion

Hospitals and clinics have used various radioisotopes for diagnostic and therapeutic purposes for more than a century. These radioisotopes could be classified as long half-life radionuclides such as ^{226}Ra and short half-lives radioisotopes including ^{131}I and ^{99m}Tc which are all commonly used in nuclear medicine. Cancer treatments using ^{226}Ra in the previous century have led to a relatively high increase in the death rate, with cases resulting from their use appearing up to 40 years after treatment. Therefore, after investigating the relationship between ^{226}Ra doses and mortality, the use of ^{226}Ra was completely stopped in 1970 and replaced by short half-life radioactive elements such as ^{99m}Tc. However, many healthcare institutions using ^{99m}Tc are confronted with a serious shortage due to the shutdown of the main reactor suppliers. Hence, alternative techniques have been proposed to generate ^{99m}Tc directly in the accelerators to meet the hospital demands. Several radioactive waste management programs to dispose of both liquid and gaseous waste have also been established to fulfill the radiation protection requirements, as well as reach safe background levels.

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