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Examination of ^{99m}Tc-mdp radioactivity after ınjection according to time and distance

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Abstract

In nuclear medicine, the imaging process used to diagnose diseases and to examine the functions of organs is carried out with radiopharmaceuticals containing radioisotope. In this study, the amount of external radiation emitted from bone scintigraphy patients who were given ^{99m}Tc-MDP kit was examined. The measurements have been performed using FLUKE Victoreen ASM 990 portable detector at Nuclear Medicine Department Medicine Faculty in Tokat Gaziosmanpasa University. The external dose rate values have been measured at 0.50 m, 1.0 m, 2.0 m and 3.0 m away from the patient considered as the source of radiation. All measurements have been taken within approximately one hour and 10 minutes at 10 minutes intervals after injection of the pharmaceutical. In this study, the highest external dose rate value is measured 13.81 µSv h^{-1} from 0.50 m distance after 30 minutes from the radiopharmaceutical injection and the lowest external dose rate value 1.53 µSv h^{-1} is obtained from 3.0 m distance after 60 minutes. Then, dose rate values per unit activity were calculated and the highest value was found as 20.57 µSv h^{-1} GBq^{-1} 30 minutes after injection at 0.50 m. The results obtained were compared with other studies in the literature.

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1. Introduction

Radiopharmaceuticals are medicinal drugs that contained radioactive compound. The usefulness of radiopharmaceutical, which has two components, radionuclide and pharmaceutical, is determined by the properties of these two components. When designing a radiopharmaceutical, a pharmaceutical is first selected according to its localization in a given organ or its participation in the physiological function of the organ. In nuclear medicine nearly 95% of the radiopharmaceuticals are used in nuclear imaging to evaluate organ functions and organ physiology, while the rest are used for treatment [1,2].

In nuclear medicine, the radiation-based medical imaging techniques that are made using radiopharmaceuticals are single photon emission computed tomography (SPECT) and positron emission tomography (PET). The image is created by detecting the radiation emitted by the applied radiopharmaceuticals. These radiation-based imaging techniques are provided information not only for diagnostic purposes but also for early diagnosis of cancer and organ functions. They are complementary to the conventional anatomic imaging modalities of computed tomography (CT) and magnetic resonance (MR) imaging [3,4].

Besides the fundamental differences in the design and properties of SPECT and PET, the most important difference between the two imaging systems is based on the properties of the radioisotopes used. For SPECT, single photon emitting radionuclides are used, while in the PET are used radionuclides that make β^+decay realized with a positron release. SPECT radiopharmaceuticals are medium to long half-life radionuclide containing agents that allow biological processes to be observed longer than PET radiopharmaceuticals. Generally, in SPECT

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applications are used Technetium-99m (half-life, 6 hours), Samarium-153 (half-life, 1.9 days), Indium-111 (half-life, 2.8 days), Iodine-123 (half-life 13.3 hours), Iodine-131 (half-life, 8 days), Thallium-201 (half-life, 73 hours) and Gallium-67 (half-life 78 hours). For PET applications, Fluorine-18 (half-life, 110 minute), Carbon-11 (half-life, 20 minute), Nitrogen-13 (half-life, 10 minute), Oxygen-15 (half-life, 2 minute) and Gallium-68 (half-life,68 minute) are used [5].

Some of these radionuclides are produced in particle accelerators, such as cyclotrons, where the target material is bombarded with charged particles, while others are produced by radionuclide generator systems. In radionuclide generator systems, radionuclides of short half-life are produced from long half-life radionuclides by chemical or physical separation methods [1]. Technetium-99m, which has a wide range of uses such as thyroid, liver, bone, kidney imaging and myocardial perfusion is supplied from molybdenum-99 (half-life, 66 hours) generator and emits gamma radiation with an energy of 140 keV [3].

Technetium-99m methylene diphosphonate (^{99m}Tc-MDP) introduced by Subramanian et al. [6] is an excellent bone imaging agent used to detect bone metastasis associated with many forms of cancer. The most important feature of ^{99m}Tc-MDP is that it contains phosphate. Thus, it can be attached to the bone tissue. Thus, it allows us to detect bone tissue abnormalities. Tc-99m MDP injection is done intravenously. The dose given in adult patients varies between 20-30 mCi, while the dose given in children is 2 mCi. The image is taken approximately two to three hours after the injection since it is cleared of soft tissues and peaked in bone tissue approximately two to three hours after the radiopharmaceutical injection. Also another important feature of ^{99m}Tc-MDP is that it is excreted from the kidney. In this way, it gives additional contribution related to urinary system pathologies from time to time. Kidney function affects both bone and organ involvement in Bone Scintigraphy (BS) [7,8].

After scintigraphy application, the patient emits radiation to the environment. The effect of the emitted radiation decreases depending on time and distance. Following the radionuclide application, all the hospital staff, as well as the radiation worker, will be at risk from the radiation released from the patient. At the same time, family members and street people will be exposed to radiation, as the patient will emit rays even after leaving the hospital. Therefore, informing patients and their relatives about radiation exposure is essential. The current system of radiation protection that is internationally accepted provides no dose limits for patients. However, dose limits are prescribed for staff and members of the public. Furthermore, there are dose constraints for carers, and some countries also provide dose constraints for staff [9-11]. According to TAEK data, the dose taken at a distance of 1.0 m from the patient should not be discharged until 30 μSv h^{-1} [12,13].

The first aim of this current study is to determine the external dose rates with respect to distance from patient for radiation security. Another purpose of this study is to examine how the external radiation dose rate changes over time, taking into account the radiopharmaceutical clearance effect due to physical decay of Tc-99 MDP. For this, the measurements were taken on a patient and the distance at which the measurement was taken and the time after injection were recorded.

2. Materials and Methods

In this study, the external dose rate measurements have been performed at Nuclear Medicine Department, Medicine Faculty in Tokat Gaziosmanpasa University by taking the patient as the source of radiation. The measurements were made with FLUKE Victoreen ASM 990 portable detector which had been calibrated using a Cs-137 source. The ASM-990 series are designed to be detected alpha, beta, gamma, neutron, or x-ray radiation within a range of 1 μR h^{-1} to 1 R h^{-1}, depending on the selected probe, such as Geiger-Muller, neutron, proportional counter, scintillation. These detectors are used as a general survey meter with the proper probe combination. The ASM-990 is a portable, battery operated general-purpose survey meter for use with all Victoreen Geiger-Mueller (GM) and scintillation probes, proportional counting probes and neutron probes. The ASM-992 is identical to the ASM-990 with the addition of a second, internal GM tube and supporting circuitry. The ASM-993 contains both an internal GM tube, as well as an internal pancake probe. The measurements taken before and after the mechanical shocks will not be in variance by more than +/- 15% [14].

In this study firstly, the background measurement was made in the room where the measurement will be made. The measurements were taken as cps (count per second) and then were converted to μSv h^{-1} in such a way that 5 cps equals 1 μSv h^{-1} [15]. The background dose rate value was measured as 0.09 μSv h^{-1}. The

patient who was given 18.15 mCi (671.55 MBq) ^{99m}Tc-MDP for bone scintigraphy was taken to the room where the measurement will be made four minutes after the injection. Dose rates were measured at 0.50 m, 1.0 m, 2.0 m and 3.0 m perpendicular to the middle of the trunk with the patient in the sitting position 10 minutes after injection. The other measurements were made 10 minutes after the first measurement and with an interval of 10 minutes. The correct distance has been determined by making markings on the floor. All measurements taken at each distance were determined by taking the average of ten data taken every 10 seconds.

3. Results and Discussion

In our study, measurements were taken as cps and values were converted to μSv h^{-1}. All measurements are performed 10 minutes after injection, 10 minutes apart, within 1 hour and 10 minutes. The measured of the dose rates values at distance of 0.50, 1.0, 2.0 and 3.0 m are presented in Table 1.

Table 1. Dose rate (μSv h^{-1}) depending on distance and time.

	Distance (meter)			
Time	0.50 m	1.0 m	2.0 m	3.0 m
10.min	11.72	7.81	3.49	2.36
20.min	13.31	9.17	4.31	2.91
30.min.	13.81	9.82	3.89	2.46
40.min	12.70	9.49	3.81	2.02
50.min	11.42	7.71	3.70	1.96
60.min.	8.08	5.88	2.82	1.53
70.min	8.15	6.04	2.84	1.66

As seen in Table 1, the highest external dose rate value is measured as 13.81 μSv h^{-1} at a distance of 0.50 meter 30 minutes after the radiopharmaceutical injection, and the lowest dose rate value is measured as 1.53 μSv h^{-1} from 3.0 meter distance 60 minutes after injection. The measured dose rate values per unit activity for each distance and time after administration are listed in Table 2. As can be seen in Table 2, the greatest value is found as 20. 57 μSv h^{-1} GBq^{-1} at 0.50 m in 30 minutes after administration.

Table 2. Dose rate per unit activity (μSv h^{-1} GBq^{-1}) for each distance and time after administration.

	Distance (meter)			
Time (min.)	0.50 m	1.0 m	2.0 m	3.0 m
10. min.	17.45	11.63	5.20	3.51
20. min.	19.82	13.65	6.43	4.33
30. min	20.57	14.62	5.79	3.66
40. min	18,91	14.14	5.68	3.00
50. min	17.00	11.47	5.52	2.92
60. min.	12.04	8.75	4.20	2.28
70. min	12.14	8.99	4.23	2.47

The change of measured dose rate values over time at certain distances is given in figures 1-4. In figures 1 and 2, it is observed that the external dose rate values are taken from the patient at 0.50 m and 1.0 m distances increase within 30 minutes and decrease within the next 30 minutes. Figures 3 and 4 show that external dose rate values measured at 2.0 m and 3.0 m from the patient peak within 20 minutes and decrease over time. From figures 1-4, it is seen that the external dose rate values increase a little at the 60th and 70th minutes

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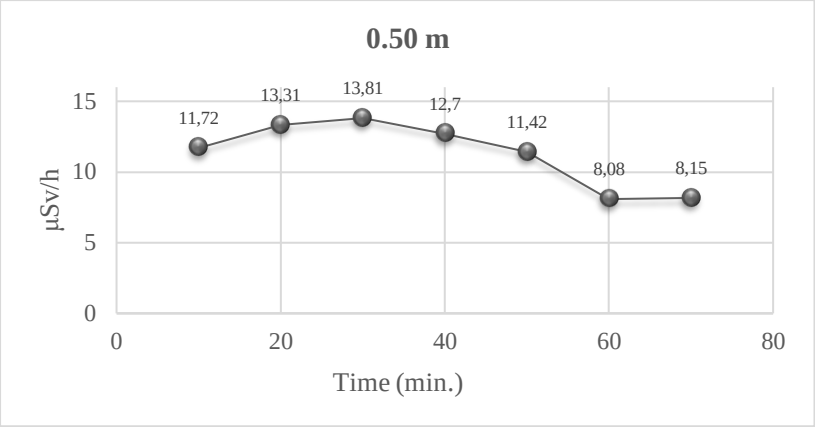

Figure 1. Change of dose rates in time at 0.50 m after the pharmaceutical injection.

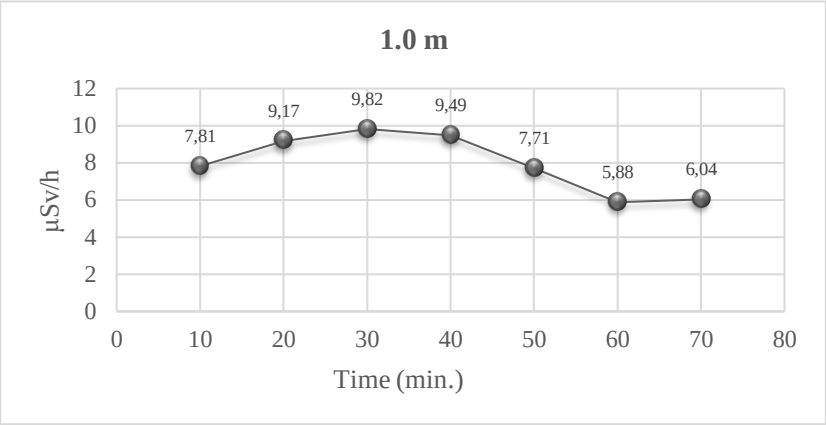

Figure 2. Change of dose rates in time at 1.0 m after the pharmaceutical injection.

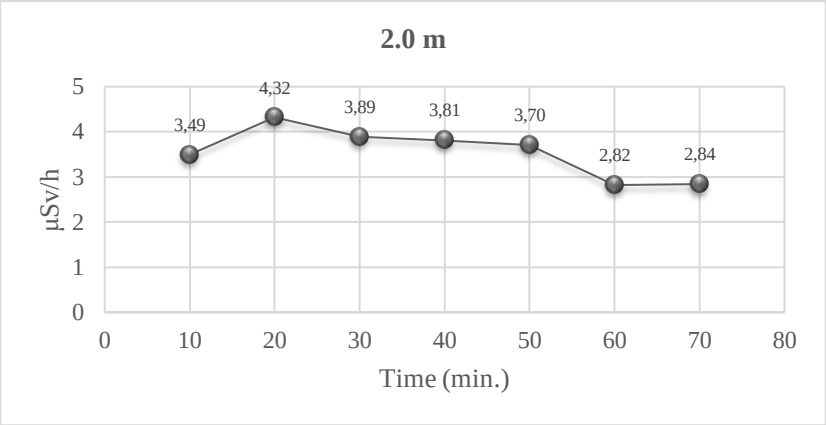

Figure 3. Change of dose rates in time at 2.0 m after the pharmaceutical injection.

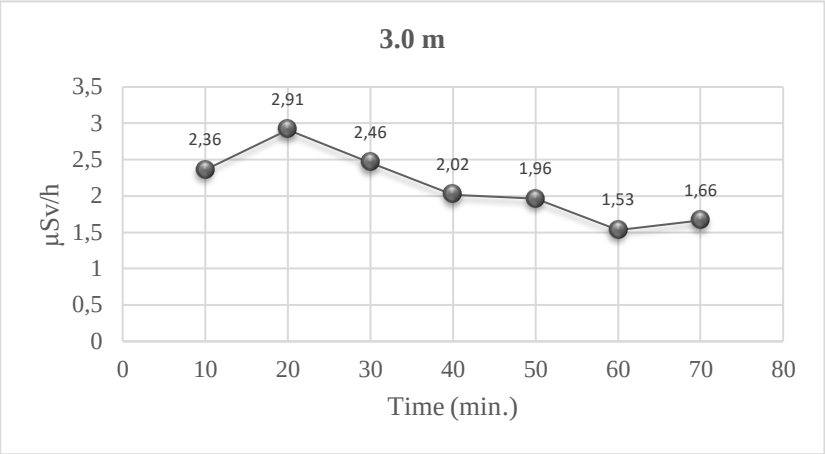

Figure 4. Change of dose rates in time at 3.0 m after the pharmaceutical injection.

The main uptake of radiopharmaceuticals containing phosphates such as pyrophosphate and polyphosphate used for bone scintigraphy happens in the bones, with a very small proportion in the kidneys, and the excretion is via the renal system. The rate of the biological process, such as uptake, metabolism, and excretion, is usually given as the half-life of the corresponding exponential function [16]. Biological clearance for each radiopharmaceutical is specified as the fraction of administered activity assigned to each half-life. In this context, it is reported that a fraction of 0.3 of the administered activity for ^{99m}Tc-MDP is taken up by bone with a half-time of 30 min, and retained there with halftimes of 2 h (0.3) and 72 h (0.4) [16,17]. In addition, the dose rate varies depending on the varying distribution of radiopharmaceuticals within the body and the amount of accumulation in certain organs in the body. For Tc-99 bone scans, the activity is more uniformly distributed throughout the skeleton [18].

This situation is clearly seen from Table 1 and Figures 1-2. it was predicted that the increase in the external dose rate values obtained within the first 30 minutes and the decrease within the next 30 minutes may be due to the biological clearance effect. Considering the time intervals of approximately 10 seconds for each distance, it was thought that the external dose rate values taken at 2 m and 3 m were taken within 25-30 minutes. In this context, it was forecasted in Figures 2 and 3 that the decrease in external dose values after 20 minutes may be originated due to biological clearance effect.

The graphic representation of the measurements within 10, 30, 50 and 60 minutes after administration respect to distance are given in Figures 5, 6, 7 and 8. From figures 5-8, the external dose rate values are seen to decrease as the distance from the patient increases. Also, it is observed that the sharpest decreasing trend is between 0.50 m and 2.0 m and the lowest decreasing trend is between 2.0 and 3.0 meters from figures 5 and 7. In figures 6 and 8, the sharpest decreasing trend is observed between 1.0 and 2.0 meters. It is calculated that the measured within 10, 20 and 50 minutes external dose rate values at 0.50 m decreased by an average factor of 0.32 µSv h^{-1} at 1.0 m. In addition, it is calculated that the measured within 30, 40, 60 and 70 minutes external dose rate values at 0.50 m decreased by an average factor of 0.27 µSv h^{-1} at 1.0 m.

The variation in the dose rate with respect to distance from an adult patient depends on the anatomical distribution of the radiopharmaceutical [19] and the reduction of the radiation intensity with the square of the distance [20]. Here, it was estimated that the decrease factor of the external dose rate values measured at different time intervals according to the distance changes depending on the anatomical distribution of the radiopharmaceutical in the body. It was also seen that the external dose rate values decreased with the distance as related to the inverse square law.

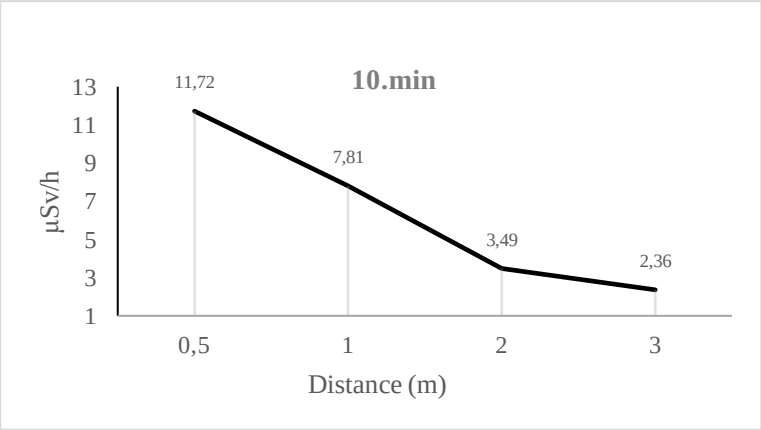

Figure 5. The change of dose rates by distance 10 minutes after the pharmaceutical injection.

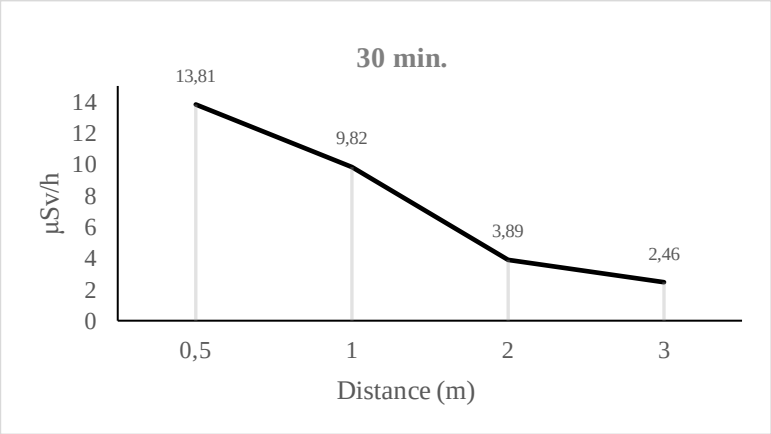

Figure 6. The change of dose rates by distance 30 minutes after the pharmaceutical injection.

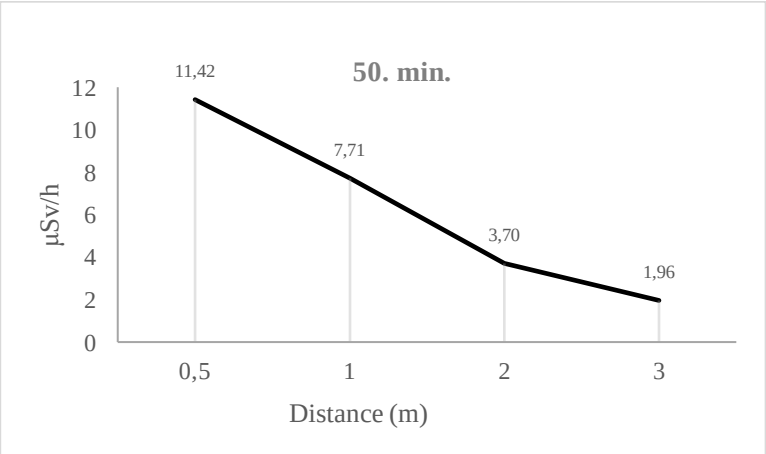

Figure 7. The change of dose rates by distance 50 minutes after the pharmaceutical injection.

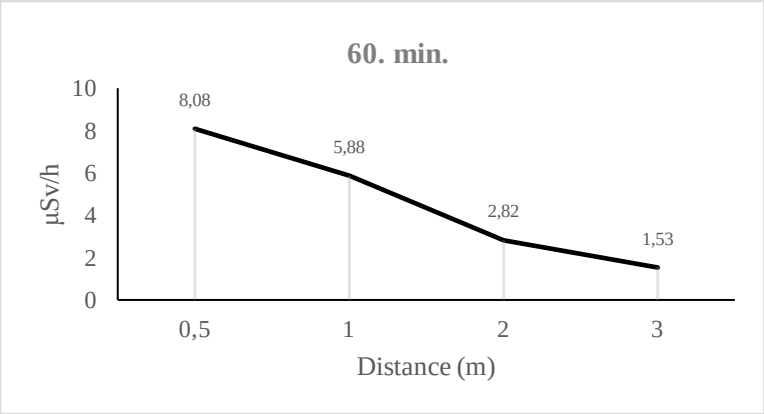

Figure 8. The change of dose rates by distance 60 minutes after the pharmaceutical injection.

The measured dose rate values and the dose rate per unit injected activity found by the other studies are presented in Table 3.

Table 3. A list of dose rates values and dose rate per unit injected activity for Tc-99m MDP in literature.

		Distance (meter)			
		Dose rate (µSv h^{-1})		Dose rate per activity (µSv h^{-1} GBq^{-1})	
References	Activity (MBq)	0.50 m	1.0 m	0.50 m	1.0 m
Harding et al.	500	12.10	3.10	24.20	6.20
Mountford et al.	550	11.30	3.50	20.55	6.36
Gomez-Palocios et al.	814	15.9	5.7	19.53	7.00
Bayram et al.	740	5.6 ± 2.0	3.3 ± 1.2	7.58± 2.70	4.46 ± 1.62
Barlett et al.	864	-	4.0	-	4.62
Stenstad et al.	-	20 ± 7	10± 3	-	-

In general, the external dose rates measured in the present study are consistent with one or the other previous studies, but not all studies. When compared with the studies of Harding et al. [18] and Mountford et al. [19], it is seen that the results obtained at 0.50 m within 40 and 50 minutes are consistent, but the values obtained at all time intervals at 1.0 m are higher. The value obtained at 1.0 m in 60 minutes is closer to the result obtained in the study conducted by Stenstad et al. [21]. However, the dose rate values per unit activity taken within 20 and 30 minutes at 0.50 m are consistent with the results obtained by Gomez-Palacios et al. [22] and Mountford et al. [19]. The dose rate value per unit activity taken within 60 minutes at 1.0 m is closer with the result obtained by Gomez-Palacios et al. [22]. In these studies, the measurement time after injection is not exactly specified. In these studies, involving multiple patients and different scan types, the average time after administration was specified.

4. Conclusion

In this study, it was concluded that the external dose rate values vary depending on the anatomical distribution of the radiopharmaceutical in the body and the time of administration. In addition, it was concluded that the increase and decrease of the external dose rate values at a certain time interval after administration may be due to the biological clearance effect of ^{99m}Tc-MDP. The obtained results show that the dose rate decreases respect to distance. It was concluded that this situation is related to the inverse square law, which shows that the radiation intensity decreases with the square of the distance. The lowest value obtained in these measurements can be taken as a safe distance to avoid exposure to high radiation from the patient, who is the radiation source. This provides healthcare staff to protect themselves better. The high amount of radiation emitted from the injected patient can pose a risk for both employees and individuals with whom the patient may be in contact or remain in the same environment. In addition, considering that all patients are waiting in the same room, the external dose rate is estimated to be higher. According to the results, close contact with the patient for a while should be

avoided in order to be protected from environmental radiation. Thus, the amount of activity will decrease according to the half-life and will not pose an environmental risk.

Conflicts of interest

The authors state that there is no conflict of interests.

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