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Evaluation of occupational radiation dose due to ^{99m}Tc and ^{131}I based examinations

Turan Şahmaran

Department of Medical Services and Techniques/Opticianry Programme, Kırıkhan Vocational School, Hatay Mustafa Kemal University, Hatay, Turkiye

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ABSTRACT

Aims: This study investigates the individual organ doses and the impact on effective dose of radiation emitted from radioactive sources.

Methods: In the conducted research, the standing ICRP adult male phantom defined as the phantom material in the Visual Monte Carlo dose calculation program (VMC) was used. Subsequently, doses incurred were calculated by defining different doses, distances, and durations for ^{99m}Tc and ^{131}I radioactive sources.

Results: Simulation durations (exposure durations) were set at 1 minute and 5 minutes for comparison. The results indicated that both in 1-minute and 5-minute exposures, the doses remained below the ICRP's recommended annual dose limit of 50 mSv/year for occupational exposure.

Conclusion: It was observed that the organ dose and effective dose vary with the source strength and exposure duration. Regardless of how low the doses may be, individuals working in radiation fields must make greater efforts to reduce radiation doses by adhering to the ALARA principles.

Keywords: Effective dose, Monte Carlo, VMC program, ICRP Phantom

INTRODUCTION

Nuclear medicine emerges as a crucial medical discipline where radioactive substances are utilized in diagnostic and therapeutic processes.[1] However, professionals working in this field, known as radiation workers, face the risk of radiation exposure. The radiation doses of personnel working in nuclear medicine units are of critical importance both for the health of healthcare workers and the quality of patient care. Determining the radiation doses to which personnel in nuclear medicine departments are exposed is essential for radiation safety, including understanding the effects of these doses and implementing necessary precautions. Healthcare professionals working in this field are at risk of exposure to radiation due to their occupational activities. Radioactive substances such as Technetium-^{99m} (^{99m}Tc) and iodine-131 (^{131}I) are frequently used for diagnostic and therapeutic purposes in the field of nuclear medicine. During the administration of ^{99m}Tc and ^{131}I, the radiation doses incurred by personnel during patient imaging or admission to the treatment room must be meticulously monitored.[2] Compounds labeled with ^{99m}Tc are commonly employed to diagnose various diseases, including cardiac, endocrine, orthopedic, inflammatory, urological, and other pathologies.[3-5] The use of radioactive iodine is the most frequently employed method in the treatment of thyroid diseases. Following the administration of ^{131}I, it is absorbed in thyroid tissues, and clearance mainly occurs through the intestines, resulting in a whole-body dose in addition to uptake in the glandular tissues of the thyroid.[6] In patients with thyroid cancer treated with ^{131}I, the clearance of the administered activity is faster due to the surgical removal of thyroid tissues, allowing for the administration of higher doses of ^{131}I (1850-7400 MBq) in treatments.[7] With the increasing use of radiation for diagnostic and therapeutic purposes in medicine, the doses incurred by radiation workers in this field have gained significance. Personal radiation doses resulting from low-level exposure may lead to potential somatic health effects such as heart disease and cataracts.[8] Chodick et al.[9], conducted a prospective study on American technicians, reporting an increased risk of cataracts with cumulative doses of 10 mGy. Therefore, it is crucial to maintain radiation doses at acceptable levels to prevent the likelihood of stochastic effects, thus enhancing local practices and improving the implementation of radiation protection principles.[10-14]

Corresponding Author: Turan ŞAHMARAN, tsahmaran@gmail.com

Diagnostic and therapeutic procedures in nuclear medicine are rapidly expanding, and an increase in the use of new imaging agents is anticipated. Additionally, the nuclear medicine department holds particular significance as it represents one of the most crucial radiobiological models where response probability is associated with radiation dose.[14] The aim of this study is to investigate the individual organ doses and the impact on effective dose of radiation emitted from ^{99m}Tc and ^{131}I radioactive sources at different doses (10 mCi, 24 mCi, 100 mCi), durations (1 and 5 minute), and distances (50 cm, 100 cm, and 200 cm) using.

Visual Monte Carlo (VMC) dose program. Furthermore, this study aims to contribute to the establishment of safe working environments in nuclear medicine units. Thus, the dose values obtained as a result of these exposures can serve as a guide for implementing safety measures.

METHODS

Since the conducted research is not related to either human or animal use, there is no need for an ethics committee approval.

VMC Dose Calculation Program

The VMC dose calculation program is designed for the calculation of tissue and effective doses. In this simulation program, ICRP voxel phantoms of male and female human bodies are provided. Results obtained from comparisons and validations indicate that doses calculated with VMC can be accepted within the range of ±5% of actual doses. The size and shape differences between the exposed real person and mathematical phantoms constitute the main source of uncertainty.[15] In this study, the standing ICRP adult male phantom was used as the phantom material within the VMC dose calculation program.

Some Radiopharmaceuticals used in the Study

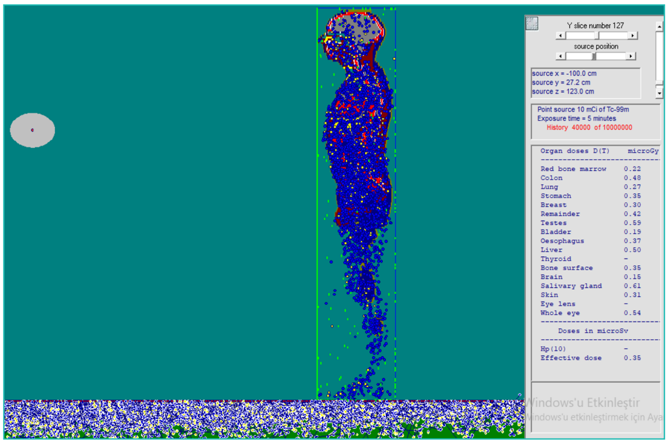
^{99m}Tc is used in various nuclear medicine imaging procedures, including myocardial perfusion scintigraphy using MIBI (methoxyisobutyl isonitrile), bone scans using MDP (methylene diphosphonate), dynamic kidney scintigraphy using DTPA (diethylene triamine penta-acetate), and many other nuclear medicine imaging procedures. In nuclear medicine imaging procedures (thyroid, kidney, bone, and heart scintigraphy), ^{99m}Tc-labeled radiopharmaceuticals are utilized, and doses vary between 1 and 40 mCi depending on the patient's age and weight. Patients may spend between 20 minutes to 4 hours in the nuclear medicine department based on the imaging procedure. In the simulation program, a 10 mCi source (representing the average imaging procedure dose) and a 24 mCi source (representing the average stress protocol for myocardial perfusion scintigraphy) of ^{99m}Tc were defined at distances of 50 cm, 100 cm, and 200 cm from the ICRP adult male phantom. Thus, the doses incurred under different doses and different radioactive sources were examined. ^{131}I ablation is a common procedure used in patients with differentiated thyroid cancer to eliminate functional residual tissues following the initial thyroid surgery.[16] Before administering ^{131}I therapy, patients are informed about all the necessary steps and requirements. Nuclear medicine departments are equipped with specially designed isolation rooms and communication systems that reduce close contact between patients and staff. Since each patient may not have the same characteristics, radioactive iodine treatment is administered in different doses. Some patients may require 20 mCi, some 50 mCi, or others 100 mCi. In this study, a simulation program defined a 100 mCi ^{131}I radioactive source from the ICRP adult male phantom at distances of 50 cm, 100 cm, and 200 cm. Table 1 shows the input parameters used in the simulation.

Table 1. Input parameters

Radionuclide	**^{99m}Tc**	**^{131}I**
Parameter	Value chosen	Value chosen
Source	External Source	External Source
Radionuclide activity	10 mCi and 24 mCi	100 mCi
Phantom	ICRP adult male	ICRP adult male
Geometry	Point source	Point source
Exposure time	1 and 5 minute	1 and 5 minute
History	10×10^6	10×10^6

RESULTS

Figure 1 displays the simulation image created for different radioactive sources and distances. At a distance of 50 cm, the radiation dose received at different doses and durations is shown in Figure 2. Tables 2, 3, and 4 present the estimated radiation dose values received by organs and effective doses at different sources, distances, and durations.



```
source x = -100.0 cm
source y = 27.2 cm
source z = 123.0 cm

Point source 10 mCi of Tc-99m
Exposure time = 5 minutes
   History  40000  of 10000000

Organ doses D(T)    microGy
---------------------------
Red bone marrow     0.22
Colon               0.48
Lung                0.27
Stomach             0.35
Breast              0.30
Remainder           0.42
Testes              0.59
Bladder             0.19
Oesophagus          0.37
Liver               0.50
Thyroid             -
Bone surface        0.35
Brain               0.15
Salivary gland      0.61
Skin                0.31
Eye lens            -
Whole eye           0.54
---------------------------
    Doses in microSv
---------------------------
Hp(10)              -
Effective dose      0.35
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Figure 1. The simulation image created for different radioactive sources and distances.

Table 2. Radiation dose exposure at different durations and distances for ^{99m}Tc- 10 mCi

	5-minute μGy			**1-minute μGy**		
Organ doses D(T)	50 cm	100 cm	200 cm	50 cm	100 cm	200 cm
Red bone marrow	0.81	0.30	0.10	0.16	0.06	0.02
Colon	1.29	0.44	0.14	0.26	0.09	0.03
Lung	1.09	0.38	0.12	0.22	0.08	0.02
Stomach	1.43	0.48	0.15	0.30	0.10	0.03
Breast	1.99	0.68	0.16	0.40	0.14	0.04
Remainder	1.01	0.36	0.12	0.20	0.07	0.02
Testes	1.03	0.45	0.16	0.21	0.09	0.03
Bladder	1.18	0.46	0.15	0.24	0.09	0.03
Oesophagus	0.97	0.38	0.11	0.19	0.08	0.02
Liver	1.21	0.39	0.12	0.24	0.08	0.02
Thyroid	1.50	0.61	0.20	0.29	0.12	0.04
Bone surface	0.74	0.34	0.12	0.15	0.07	0.02
Brain	0.43	0.20	0.07	0.09	0.04	0.01
Salivary gland	1.02	0.37	0.12	0.20	0.07	0.02
Skin	0.82	0.34	0.12	0.16	0.07	0.02
Adrenals	0.54	0.22	0.06	0.11	0.04	0.01
Extrathor airways	1.04	0.40	0.13	0.21	0.08	0.03
Gall bladder	1.20	0.36	0.17	0.24	0.07	0.02
Heart	1.28	0.43	0.14	0.26	0.09	0.03
Kidneys	0.65	0.23	0.07	0.13	0.05	0.02
Lymphatic nodes	1.17	0.45	0.13	0.23	0.09	0.03
Muscle	0.75	0.32	0.11	0.15	0.06	0.02
Oral mucosa	1.05	0.37	0.11	0.21	0.07	0.02
Pancreas	1.25	0.40	0.14	0.25	0.08	0.03
Prostate	0.76	0.32	0.11	0.15	0.06	0.02
Small intestine	1.32	0.46	0.15	0.26	0.09	0.03
Spleen	0.66	0.23	0.08	0.13	0.05	0.02
Thymus	1.43	0.50	0.16	0.29	0.10	0.03
Eye lens	0.68	0.40	0.15	0.14	0.15	0.03
Whole eye	1.27	0.52	0.14	0.25	0.10	0.03
Hp(10) (μSv)	2.39	0.73	0.36	0.28	0.14	0.03
Effective dose (μSv)	1.23	0.44	0.14	0.25	0.08	0.02

In Table 2, when a 10 mCi radioactive source of ^{99m}Tc was used at 50 cm, the highest doses within a 5-minute duration were received by the breast (1.99 μGy), thyroid (1.50 μGy), and stomach (1.43 μGy), respectively. When this duration was reduced to 1 minute at the same distance, the highest received doses decreased to 0.40 μGy, 0.29 μGy, and 0.30 μGy for the breast, thyroid, and stomach, respectively. In Table 2, when a 10 mCi radioactive source of ^{99m}Tc was used at a distance of 100 cm, the highest doses within a 5-minute duration were received by the breast (0.68 μGy), thyroid (0.61 μGy), and stomach (0.48 μGy). When this duration was reduced to 1 minute at the same distance, the highest received doses decreased to 0.14 μGy, 0.12 μGy, and 0.10 μGy for the breast, thyroid, and stomach, respectively. In Table 2, when a 10 mCi radioactive source of ^{99m}Tc was used at a distance of 200 cm, the highest doses within a 5-minute duration were received by the thyroid (0.20 μGy), breast (0.16 μGy), and gall bladder (0.17 μGy), respectively. When this time was reduced to 1 minute at the same distance, the highest dose received was 0.04 μGy for breast, thyroid, while the doses received by other organs ranged between 0.03 μGy and 0.02 μGy. When a 10 mCi radioactive source of ^{99m}Tc was used, the effective doses obtained within a 5-minute duration at distances of 50 cm, 100 cm, and 200 cm were found to be 1.23 μSv, 0.44 μSv, and 0.14 μSv, respectively. When the duration was reduced to 1 minute at the same activity and distances, the effective doses were found to be 0.25 μSv, 0.08 μSv, and 0.02 μSv, respectively. As seen from Table 2, the radiation dose is inversely proportional to the distance. The intensity of radiation decreases as the square of the distance, i.e., radiation intensity diminishes proportionally with the square of the distance from the radiation source.[17] As the distance increases, the effect of the radiation dose decreases. Therefore, personnel working in the radiation field should operate as far away as possible from the radiation source.

In Table 3, when a 24 mCi radioactive source of ^{99m}Tc was used at a distance of 50 cm, the highest doses within a 5-minute duration were received by the breast (4.78 μGy), stomach (3.59 μGy), and thyroid (3.42 μGy), respectively. When this duration was reduced to 1 minute at the same distance, the highest received doses decreased to 0.96 μGy, 0.69 μGy, and 0.72 μGy for the breast, thyroid, and stomach, respectively. In Table 3, when a 24 mCi radioactive source of ^{99m}Tc was used at a distance of 100 cm, the highest doses within a 5-minute duration were received by the breast (1.58 μGy), thyroid (1.19 μGy), and stomach (1.13 μGy), respectively. When this duration was reduced to 1 minute at the same distance, the highest received doses decreased to 0.33 μGy, 0.29 μGy, and 0.23 μGy for the breast, thyroid, and stomach, respectively. In Table 3, when a 24 mCi radioactive source of ^{99m}Tc was used at a distance of 200 cm, the highest doses within a 5-minute duration were received by the thyroid (0.46 μGy), breast (0.42 μGy), and Thymus (0.40 μGy), respectively. When this time was reduced to 1 minute at the same distance, the highest dose received was 0.09 μGy and 0.08 μGy for thyroid and breast, respectively, while the doses received by other organs ranged between 0.04 μGy and 0.08 μGy. For a 24 mCi radioactive source of ^{99m}Tc, the effective doses obtained within a 5-minute duration at distances of 50 cm, 100 cm, and 200 cm were found to be 2.94 μSv, 1.03 μSv, and 0.32 μSv, respectively. When the duration was reduced to 1 minute at the same activity and distances, the effective doses were found to be 0.59 μSv, 0.21 μSv, and 0.06 μSv, respectively. In nuclear medicine departments, myocardial perfusion scintigraphy rest and stress imaging procedures are often performed on the same day (same-day protocol), but they can also be done on different days.[18,19] In stress protocols, patients are typically administered doses in the range of 555 MBq–1.11 GBq. Standard exercise protocols involve injecting the radiopharmaceutical at the peak of exercise.[20] During the injection of the radiopharmaceutical, there are doctors, technicians, and nurses in the room. Radiation workers in the room are exposed to radiation during the injection of the radiopharmaceutical. In the study, the ^{99m}Tc radiation source was additionally selected at 24 mCi to estimate the doses incurred by radiation workers. As the radiation dose increases, exposure and the effects of radiation on the body also increase. However, the farther the radiation source is from the body, the lower the dose that will be incurred. As shown in Table 3, there is a significant difference in dose between the results obtained at distances of 50 cm and 200 cm.

Table 3. Radiation dose exposure at different durations and distances for ^{99m}Tc- 24 mCi

	5-minute µGy			1-minute µGy		
Organ doses D(T)	50 cm	100 cm	200 cm	50 cm	100 cm	200 cm
Red bone marrow	1.94	0.73	0.24	0.39	0.15	0.05
Colon	3.11	1.02	0.32	0.62	0.21	0.06
Lung	2.62	0.93	0.30	0.52	0.18	0.06
Stomach	3.59	1.13	0.34	0.72	0.23	0.07
Breast	4.78	1.58	0.42	0.96	0.33	0.08
Remainder	2.42	0.87	0.28	0.48	0.17	0.06
Testes	2.47	1.10	0.37	0.49	0.21	0.07
Bladder	2.82	1.13	0.37	0.56	0.22	0.07
Oesophagus	2.33	0.80	0.29	0.47	0.18	0.06
Liver	2.90	0.96	0.29	0.58	0.19	0.06
Thyroid	3.42	1.19	0.46	0.69	0.29	0.09
Bone surface	1.78	0.81	0.30	0.36	0.16	0.06
Brain	1.03	0.49	0.18	0.21	0.09	0.04
Salivary gland	2.44	0.86	0.28	0.49	0.18	0.06
Skin	1.96	0.82	0.29	0.39	0.17	0.06
Adrenals	1.31	0.46	0.17	0.26	0.10	0.03
Extrathor airways	2.50	1.08	0.37	0.50	0.19	0.07
Gall bladder	2.88	0.84	0.23	0.58	0.17	0.05
Heart	3.08	1.06	0.31	0.62	0.21	0.06
Kidneys	1.55	0.56	0.19	0.31	0.11	0.04
Lymphatic nodes	2.82	0.95	0.31	0.56	0.22	0.06
Muscle	1.79	0.77	0.27	0.36	0.15	0.05
Oral mucosa	2.53	0.99	0.29	0.51	0.18	0.06
Pancreas	3.01	0.98	0.32	0.60	0.19	0.06
Prostate	1.83	0.67	0.28	0.37	0.15	0.06
Small intestine	3.16	1.07	0.33	0.63	0.22	0.07
Spleen	1.58	0.56	0.20	0.32	0.11	0.04
Thymus	3.43	1.29	0.40	0.68	0.24	0.08
Eye lens	1.63	2.29	0.33	0.33	0.37	0.07
Whole eye	3.04	1.20	0.34	0.61	0.25	0.07
Hp(10) (µSv)	5.74	1.22	0.38	1.15	0.35	0.07
Effective dose (µSv)	2.94	1.03	0.32	0.59	0.21	0.06

In Table 4, when a 100 mCi radioactive source of ^{131}I was used at a distance of 50 cm, the highest doses within a 5-minute duration were received by the breast (55.66 µGy), stomach (45.65 µGy), and thyroid (42.93 µGy), respectively. When this duration was reduced to 1 minute at the same distance, the highest received doses decreased to 11.13 µGy, 9.13 µGy, and 8.59 µGy for the breast, stomach, and thyroid, respectively. In Table 4, when a 100 mCi radioactive source of ^{131}I was used at a distance of 100 cm, the highest doses within a 1-minute duration were received by the breast (18.44 µGy), stomach (15.21 µGy), and thyroid (12.90 µGy), respectively. When this duration was reduced to 1 minute at the same distance, the highest received doses decreased to 3.69 µGy, 3.04 µGy, and 2.58 µGy for the breast, stomach, and thyroid, respectively. In Table 4, when a 100 mCi radioactive source of ^{131}I was used at a distance of 200 cm, the highest doses within a 5-minute duration were received by the testes (5.67 µGy), breast (4.74 µGy), and Thymus (4.03 µGy), respectively. When this duration was reduced to 1 minute at the same distance, the highest received doses decreased to 1.13 µGy, 1.01 µGy, and 0.95 µGy for the testes, prostate, and breast, respectively. When a 100 mCi radioactive source of ^{131}I was used, the effective doses obtained within a 5-minute duration at distances of 50 cm, 100 cm, and 200 cm were found to be 36.58 µSv, 12.53 µSv, and 3.83 µSv, respectively. When the duration was reduced to 1 minute at the same activity and distances, the effective doses were found to be 7.32 µSv, 2.51 µSv, and 0.77 µSv, respectively.

Table 4. ^{131}I – Radiation dose exposure at different durations and distances for ^{131}I - 100 mCi

	5-minute µGy			1 minute µGy		
Organ doses D(T)in	50 cm	100 cm	200 cm	50 cm	100 cm	200 cm
Red bone marrow	26.11	9.64	3.00	5.22	1.93	0.60
Colon	37.58	12.55	4.00	7.52	2.51	0.80
Lung	33.81	11.77	3.64	6.76	2.35	0.73
Stomach	45.65	15.21	3.38	9.13	3.04	0.68
Breast	55.66	18.44	4.74	11.13	3.69	0.95
Remainder	31.20	11.02	3.50	6.24	2.20	0.70
Testes	27.52	11.58	5.67	5.50	2.32	1.13
Bladder	35.08	12.93	3.78	7.02	2.59	0.76
Oesophagus	31.91	11.71	3.37	6.38	2.34	0.67
Liver	36.26	11.66	3.41	7.25	2.33	0.68
Thyroid	42.93	12.90	3.97	8.59	2.58	0.79
Bone surface	20.75	9.13	3.26	4.15	1.83	0.65
Brain	16.04	7.55	2.47	3.21	1.51	0.49
Salivary gland	31.56	12.03	3.59	6.31	2.41	0.72
Skin	24.26	10.22	3.46	4.85	2.04	0.69
Adrenals	21.64	4.55	2.27	4.33	0.91	0.45
Extrathor airways	31.65	13.42	3.20	6.33	2.68	0.64
Gall bladder	39.66	12.78	3.65	7.93	2.56	0.73
Heart	38.06	12.99	3.91	7.61	2.60	0.78
Kidneys	20.67	6.95	2.35	4.13	1.39	0.47
Lymphatic nodes	34.12	11.91	3.88	6.82	2.38	0.78
Muscle	23.66	9.78	3.33	4.73	1.96	0.67
Oral mucosa	31.37	12.27	3.52	6.27	2.45	0.70
Pancreas	38.45	11.67	3.76	7.69	2.33	0.75
Prostate	24.07	12.07	5.03	4.81	2.41	1.01
Small intestine	38.22	12.89	3.87	7.64	2.58	0.77
Spleen	21.12	6.78	2.68	4.22	1.36	0.54
Thymus	42.90	15.21	4.03	8.58	3.04	0.81
Eye lens	33.38	10.66	0.51	6.68	2.13	0.10
Whole eye	39.48	13.43	3.75	7.90	2.69	0.75
Hp(10) (µSv)	62.22	16.92	5.34	12.44	3.38	1.07
Effective dose (µSv)	36.58	12.53	3.83	7.32	2.51	0.77

DISCUSSION

Radioactive pharmaceuticals such as ^{99m}Tc and ^{131}I are utilized for both diagnostic and therapeutic purposes in nuclear medicine departments. During the administration and imaging procedures of these radiopharmaceuticals, radiation workers are constantly exposed to radiation doses. Monitoring of these doses is performed through dosimeters. The International Atomic Energy Agency (IAEA) recommends an average annual dose of <5 mSv for radiation workers employed in nuclear medicine departments.[21,22] The amount of radiation dose is directly proportional to the time of exposure. The less time one is exposed to radiation, the lower the dose received. Radiation workers should plan their tasks in advance and avoid unnecessary time spent in the radiation field. In the study conducted by Kara,[17] indicating a linear dependence of effective dose on the exposure time of the human body. Similar results were obtained in this study as well, indicating that as the exposure duration increases, the radiation dose also increases accordingly. In their study, Işıkçı et al.,[22] determined the radiation dose contribution of radiopharmaceuticals labeled with ^{99m}Tc, 18F, and 68Ga to technologists' annual occupational doses over a period of 6 years. The dose contribution of positron emission tomography/computed tomography was found to be the highest among diagnostic nuclear procedures. Albersberg et al.,[23] aimed to predict and subsequently measure the occupational radiation exposure of all personnel using [^{99m}Tc]Tc-PSMA-I&S, which has begun to be used for the identification of tumor-positive lymph nodes during salvage prostate cancer surgery. In the study, the effective dose for personnel working with [^{99m}Tc]Tc-PSMA-I&S was found to be comparable to other ^{99m}Tc radiopharmaceuticals, hence it was concluded to be safe for imaging and radioguided surgery. In our study, it was observed that the radiation dose exposure remained within the specified limit values and did not exceed the annual dose limit. In their study, Elshami et al.[24] investigated the temporal trends and variations in occupational radiation doses among nuclear medicine workers. The study emphasized the possibility of implementing measures to reduce occupational radiation exposure for nuclear medicine technologists, who constitute the most exposed group in the study. In their study, Fathy et al.[3] determined the radiation doses incurred by radiation workers in the nuclear medicine department. According to this study, the average doses per patient for cardiac stress and rest were found to be 20.4±5.0 and 16.0±3.8 µSv, respectively. For bone scans, 67Ga, 18F, and ^{131}I therapy, the average doses per patient were found to be 6.1±2.5, 6.0±1.4, 11.1±2.2, and 4.1±2.6 µSv, respectively. Analysis of data and measurements related to occupational radiation risks can lead to the development of different ways to reduce radiation exposures.[25] Evaluation and improvement of radiation protection measures are important. Similarly, assessing radiation protection practices can assist in developing measures against radiation exposure.[26]

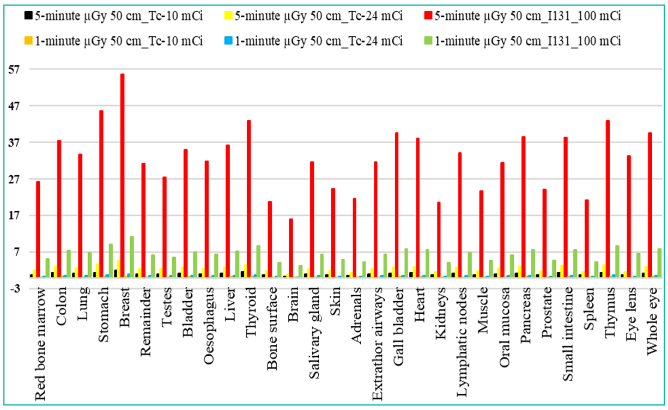

Figure 2. Radiation dose received at 50 cm distance at different doses and durations

CONCLUSION

In this study, individual organ doses and effective dose results at different distances and durations were obtained using Monte Carlo simulation for ^{99m}Tc and ^{131}I radioactive sources. It was observed that the organ dose and effective dose vary with the source strength and exposure duration. According to the ICRP 103 report, the annual effective dose for radiation workers should not exceed an average of 20 mSv over any consecutive five-year period and 50 mSv in any single year. The study demonstrates that as the distance from the radiation source increases, the recommended annual dose limit is not exceeded. Regardless of how low the doses may be, individuals working in radiation fields must make greater efforts to reduce radiation doses using the ALARA principles.

ETHICAL DECLARATIONS

Ethics Committee Approval

Since the conducted research is not related to either human or animal use, there is no need for an ethics committee approval.

Informed Consent

Informed consent is not required due to the design of the study.

Referee Evaluation Process

Externally peer reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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