Radiation Dose Rates from Patients Administrated Radiopharmaceuticals Used for Brain Blood Flow Investigation

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Abstract

To estimate effective dose of a person who is attending ^{123}I-IMP or ^{99m}Tc-ECD patients, radiation exposure rates around 60 adult patients (^{123}I-IMP:30 and ^{99m}Tc-ECD:30) were measured with three ionization survey meters which were adjusted to the first cervical vertebrae (Level Ⅰ), xiphoid process (Level Ⅱ) and anterior superior iliac spine (Level Ⅲ) of the patients, respectively. The radiation exposure rates were recorded at 1.0 (^{123}I-IMP) or 0.67 (^{99m}Tc-ECD), 3.0, 6.0, 24.0 h after the administrations of ^{123}I-IMP or ^{99m}Tc-ECD solutions. These radiation exposure rates were converted into equivalent dose H_{1cm} rates of 1cm in depth using a factor of 15.2 μSv/mR. Effective doses E were calculated by using an equation of $E=0.06H_{1cm,I} + 0.28H_{1cm,II} + 0.61H_{1cm,III} + 0.05.H_{1cm,MAX}$. In the ^{123}I-IMP study, the maximum equivalent dose rate of 98.4 μSv/h per 222 MBq was recorded in Level Ⅱ and posterior projection of the patients, and in the ^{99m}Tc-ECD study, the maximum equivalent dose rate of 215.0 μSv/h per 600 MBq was recorded in Level Ⅲ and anterior projection of the patients. In all records, the anterior rates were similar to the posterior rates. However, the R- and L-lateral rates were obviously reduced to about one-second of those rates. The total effective doses around the ^{123}I-IMP patients were 810, 175, 69 and 37 μSv per 222 MBq at 0.05, 0.5, 1.0 and 1.5 m from the patients, respectively. And the total effective doses around ^{99m}Tc-ECD patients were 604, 115, 45 and 24 μSv per 600 MBq at distances of 0.05, 0.5, 1.0 and 1.5 m , respectively. Although the initial exposure rates around the ^{99m}Tc-ECD patients were higher than those from the ^{123}I-IMP patients, the total effective doses from ^{99m}Tc-ECD patients were lower than those from ^{123}I-IMP patients. Radiation doses around ^{123}I-IMP and ^{99m}Tc-ECD patients were assessed to be relatively low. So, it was thought that these patients might provide only small risk to their nursing persons, but on the ARARA spirit, it might be necessary to avoid a long contact with them at short distances for one (in a case of ^{99m}Tc-ECD) or two (in a case of ^{123}I-IMP) days after the injections of the radiopharmaceuticals.

Introduction

In 1990, ICRP widened the definition of medical exposure [1]. When a patient is administered radiopharmaceuticals for his or her diagnosis or treatment, radiation exposure to the family attending the radioactive patient is regarded as medical exposure. Although definite dose limit to the medical exposure was not recommended by ICRP, the exposure should be kept as low as reasonably achievable (ALARA). Therefore it might be necessary to set a dose constraint in nuclear medicine. So, it is important to assess the magnitude of radiation exposure to them. Since 1990 we have started some experimental and clinical studies on this subject. In the first stage of these studies, measurements of the radiation exposure around radioactive patients were carried out. In this paper, we made a report on the radiation dose assessment around N-Isopropyl-p-[I-123] Iodoamphetamine (^{123}I-IMP) and [N,N'-ethylenedi-L-cysteine(3-)]oxotechnetium(^{99m}Tc) (^{99m}Tc-ECD) patients.

Materials and Methods

Patients and radiopharmaceuticals

In sixty adult patients administered a radiopharmaceutical of ^{123}I-IMP or ^{99m}Tc-ECD for their brain blood flow imaging, radiation dose rates $\dot{X}$ (mR/h) around them were measured. The population of this investigation was shown in Table1.

Table 1. The study population

Radiopharmaceutical	^{123}I-IMP	^{99m}Tc-ECD
Gender (male／female)	15 ／ 15	15 ／ 15
Age (yr)	53.0 ± 15.7	34.1 ± 12.8
Weight (kg)	59.6 ± 9.4	54.9 ± 11.1
Height (cm)	161.0 ± 8.4	161.7 ± 7.3
Administration dose (MBq)	265.2 ± 24.6	922.5 ± 107.8

Dosimetry and measurements

Radiation dose rates around ^{123}I-IMP and ^{99m}Tc-ECD patients were measured with three ionization survey meters (Aloka Model ICS-301). These survey meters were arranged vertically as shown in Figure 1.The radiation dose measurements were carried out at 1.0 (^{123}I-IMP) or 0.67 (^{99m}Tc-ECD), 3.0, 6.0 and 24 h after the injections of ^{123}I-IMP or ^{99m}Tc-ECD solutions. The radiation dose rates were recorded in the four directions (anterior, posterior, R-lateral and L-lateral) of the patients. The distances from the effective center of these survey-meters to the patient body surface were 0.05, 0.5, 1.0 and 1.5 m. The measured radiation dose rates with these survey-meters were normalized by the maximum standard activity of 222 MBq of ^{123}I-IMP or 600 MBq of ^{99m}Tc-ECD, respectively. These corrected radiation dose rates were converted into equivalent dose rates $\dot{H}_{1cm}$ (μ Sv/h) of 1cm in depth using a factor of 15.2 (μ Sv/mR). The 15.2 is the maximum value of the conversion function H_{1cm}/X (μ Sv/mR) curve.

The effective half-life T_{eff} of ^{123}I-IMP or ^{99m}Tc-ECD was determined from the biological half-life T_b and the physical half-life T_p by a next equation:

$$T_{eff} = (T_b \cdot T_p)/(T_b + T_p) \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Total (or potential) equivalent doses H_{1cm} (μ Sv) around the patients were calculated from the effective decay constant λ (s^{-1}) and the initial equivalent dose rates A_0 (μ Sv/h) by a next equation:

$$H_{1cm} = A_0 (1-\exp(-\lambda \cdot t)) \lambda^{-1} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

Where, the "t" is a passing time from the injections of the radiopharmaceuticals.

In Figure 1, the broken line person was assumed to be a person exposed to the radiation from the ^{123}I-IMP or ^{99m}Tc-ECD patients. To estimate effective doses E of the person attending the ^{123}I-IMP or ^{99m}Tc-ECD patients, the effective dose of this broken line person was calculated by a next equation:

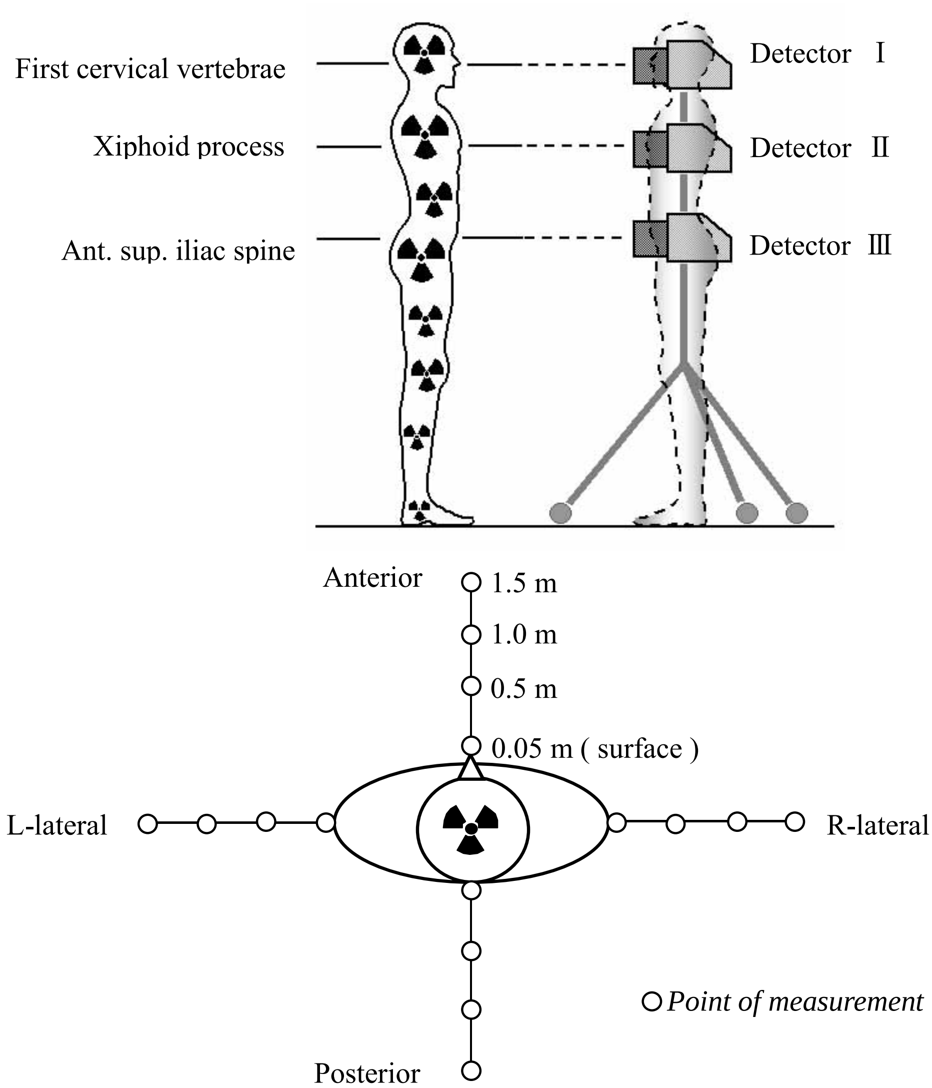

Figure 1. Detector arrangements for the radiation measurement around a radioactive patient

$$E = 0.06H_a + 0.28H_b + 0.61H_c + 0.05H_{MAX} \quad \cdots\cdots (3)$$

Where, the "H_a, H_b and H_c" were corresponding to the H_{1cm} calculated from the $\dot{X}$ of the detector 1, 2 and 3, respectively. H_{MAX} was defined as the maximum dose of H_a, H_b and H_c. The coefficients of 0.06, 0.28, 0.61 and 0.05 were obtained as the partial sums of tissue weighting factors, as shown in Table 2.

Table 2. Distributions of tissue weighting factors in recommendations -1990 of ICRP

	Detector Ⅰ (Head and Neck)		Detector Ⅱ (Thorax and Brachium)		Detector Ⅲ (Abdomen and Femur)		Max. of the three (Other tissue)	
	0.05	(thyroid)	0.12	(lung)	0.20	(gonads)	0.05	(remainder)
			0.05	(breast)	0.12	(stomach)		
			0.05	(esophagus)	0.05	(liver)		
					0.05	(bladder)		
					0.12	(colon)		
	0.012	(bone marrow)	0.048	(bone marrow)	0.06	(bone marrow)		
	0.002	(bone surface)	0.004	(bone surface)	0.004	(bone surface)		
	0.002	(skin)	0.004	(skin)	0.004	(skin)	0.001	(skin)
Total	0.066	(~0.06)	0.276	(~0.28)	0.608	(~0.61)	0.051	(~0.05)

Results

^{123}*I-IMP* study

Equivalent dose rates in the first measurements around ^{123}I-IMP patients were shown in Table 3. The maximum dose rate of 98.4 μ Sv/h per 222 MBq was recorded in the Level Ⅱ and the posterior projection of ^{123}I-IMP patients. In all records, equivalent dose rates from the posterior patients were similar to those from the anterior patients. However, the dose rates from right and left lateral patients were obviously lower than those from anterior and posterior patients. The ratio was about one-second. In all the Level, equivalent dose rates at 0.5, 1.0, and 1.5 m from the patients were reduced to about one-fifth, one-tenth and one-twentieth of the equivalent dose rates at 0.05 m, respectively. These dose reduction was milder than theoretical that based on the inverse square law.

Table 3. Equivalent dose rates around ^{123}I-IMP patients at 1.0 h after the administrations

	Patient position	Dose rates μSv / hr / 222 MBq at 1 h (n = 30) Distance from ^{123}I-IMP patient 0.05 m	0.5 m	1.0 m	1.5 m
Detector Ⅰ (Level Ⅰ)	Anterior	46.6 ± 10.1	12.2 ± 1.6	5.0 ± 0.5	2.7 ± 0.3
	R-lateral	25.5 ± 3.6	7.3 ± 1.0	3.2 ± 0.3	1.8 ± 0.2
	Posterior	46.7 ± 9.1	10.0 ± 1.2	4.2 ± 0.5	2.4 ± 0.3
	L-lateral	24.5 ± 3.6	6.6 ± 0.7	3.0 ± 0.3	1.7 ± 0.2
	Average	35.8 ± 13.0	9.0 ± 2.5	3.8 ± 0.9	2.1 ± 0.5
Detector Ⅱ (Level Ⅱ)	Anterior	85.6 ± 21.3	15.2 ± 2.1	5.6 ± 0.6	2.9 ± 0.3
	R-lateral	40.0 ± 6.8	9.2 ± 1.5	3.7 ± 0.3	2.1 ± 0.2
	Posterior	98.4 ± 17.7	13.5 ± 2.4	4.7 ± 0.8	2.5 ± 0.4
	L-lateral	37.1 ± 6.7	8.2 ± 1.2	3.4 ± 0.4	1.9 ± 0.3
	Average	65.3 ± 30.8	11.5 ± 3.4	4.3 ± 1.0	2.3 ± 0.5
Detector Ⅲ (Level Ⅲ)	Anterior	55.5 ± 15.7	12.6 ± 3.1	5.0 ± 0.6	2.7 ± 0.3
	R-lateral	27.5 ± 6.9	7.7 ± 1.4	3.3 ± 0.4	1.8 ± 0.2
	Posterior	54.3 ± 10.3	12.7 ± 2.0	4.8 ± 0.5	2.6 ± 0.2
	L-lateral	25.2 ± 6.0	7.0 ± 1.2	3.0 ± 0.3	1.7 ± 0.2
	Average	40.6 ± 17.7	10.0 ± 3.3	4.0 ± 1.0	2.2 ± 0.5

At various distances, total equivalent doses and total effective doses of the person attending a ^{123}I-IMP patient were calculated by equation (2) and (3) using an effective half-life of 11.0 h, determined by the time dependence of ^{123}I-IMP activities in the patient's body, as shown in Table 4. The maximum total equivalent dose of the attendant was 1090 μ Sv per 222 MBq in his thorax and brachium at 0.05 m from the patient, and the total effective dose of him was 810 μ Sv per 222 MBq at 0.05 m from the patient body surface.

^{99m}Tc-ECD study

Table 4. Total equivalent dose and effective dose around ^{123}I-IMP patients

Dose evaluation tissue	μ Sv / ∞ h / 222 MBq (n = 30) Distance from ^{123}I-IMP patient 0.05 m	0.5 m	1.0 m	1.5 m
Head and neck (Ha)	599	151	64	36
Thorax and brachium (Hb)	1090	193	72	39
Abdomen and femur (Hc)	679	167	67	37
Effective dose (E)	810	175	69	37

$E = 0.06H\text{a} + 0.28H\text{b} + 0.61H\text{c} + 0.05H_{\text{MAX}}$

Equivalent dose rates in the first measurements around ^{99m}Tc-ECD patients were shown in Table 5 The maximum dose rate of 215.0 μ Sv/h per 600 MBq was recorded in the Level Ⅲ and the anterior patients. In all records, the equivalent dose rates in posterior projection were similar to those in anterior projection. However, the dose rates from right and left lateral patients were obviously lower than those from anterior and posterior patients. The ratio was about one-second. In all the Level, equivalent dose rates at 0.5, 1.0, and 1.5 m from the patients were reduced to about one-fifth, one-tenth and one-twentieth of the equivalent dose rates at 0.05 m, respectively. These dose reduction was milder than theoretical that based on the inverse square law.

Table 5. Equivalent dose rates around ^{99m}Tc-ECD patients at 0.67 h after the administrations

	Patient position	Dose rates μSv / hr / 600 MBq at 0.67 h (n = 30)			
		Distance from ^{99m}Tc-ECD patient			
		0.05 m	0.5 m	1.0 m	1.5 m
Detector Ⅰ (Level Ⅰ)	Anterior	46.1 ± 8.7	16.6 ± 4.4	7.9 ± 1.4	4.5 ± 0.5
	R-lateral	26.4 ± 4.8	10.1 ± 2.5	4.9 ± 1.1	2.9 ± 0.3
	Posterior	49.1 ± 15.3	13.8 ± 2.8	6.3 ± 1.0	3.5 ± 0.5
	L-lateral	25.7 ± 5.6	9.0 ± 1.7	4.6 ± 0.6	2.7 ± 0.3
	Average	36.8 ± 14.4	12.4 ± 4.2	5.9 ± 1.7	3.4 ± 0.8
Detector Ⅱ (Level Ⅱ)	Anterior	83.2 ± 17.9	23.4 ± 4.8	9.9 ± 1.5	5.2 ± 0.6
	R-lateral	43.1 ± 8.4	13.0 ± 1.9	5.5 ± 0.9	3.2 ± 0.4
	Posterior	87.3 ± 30.6	19.8 ± 3.0	7.9 ± 1.0	4.1 ± 0.5
	L-lateral	38.9 ± 8.4	11.9 ± 2.1	5.2 ± 0.8	2.9 ± 0.4
	Average	63.1 ± 28.9	17.0 ± 5.7	7.1 ± 2.2	3.8 ± 1.0
Detector Ⅲ (Level Ⅲ)	Anterior	214.9 ± 84.9	29.2 ± 6.2	10.8 ± 1.6	5.4 ± 0.6
	R-lateral	60.3 ± 17.4	14.1 ± 2.1	5.5 ± 0.7	3.1 ± 0.3
	Posterior	138.0 ± 26.2	23.3 ± 4.8	8.5 ± 1.3	4.3 ± 0.5
	L-lateral	60.0 ± 18.1	13.0 ± 2.1	5.2 ± 0.7	2.9 ± 0.3
	Average	118.3 ± 79.0	19.9 ± 7.9	7.5 ± 2.6	3.9 ± 1.1

At various distances, total equivalent doses and total effective doses of the person attending a ^{99m}Tc-ECD patient were calculated by using equation (2) and (3) as shown in Table 6, then the effective half-life of 4.0 h determined by the time dependence of ^{99m}Tc-ECD activities in the patient. The maximum total equivalent dose of the attendant was 730 μ Sv per 600 MBq in his abdomen and femur at 0.05 m from the patient, and the total effective dose of him was 604 μ Sv per 600 MBq at 0.05 m from the patient.

Table 6. Total equivalent dose and effective dose around ^{99m}Tc-ECD patients

Dose evaluation tissue	μ Sv / ∞ h / 600 MBq (n = 30)			
	Distance from ^{99m}Tc-ECD patient			
	0.05 m	0.5 m	1.0 m	1.5 m
Head and neck (Ha)	227	76	37	21
Thorax and brachium (Hb)	390	105	44	24
Abdomen and femur (Hc)	730	123	46	24
Effective dose (E)	604	115	45	24

$E = 0.06H_a + 0.28H_b + 0.61H_c + 0.05H_{MAX}$

Discussion

Dosimetry and measurements

In this investigation, we considered that the radiation dose rates around ^{123}I-IMP or ^{99m}Tc-ECD patients were not uniform. Therefore, to estimate the equivalent dose or effective dose of the attendant for them, we adopted the detector arrangement for the measurements as shown in Figure 1, and it was assumed that the attendant illustrated with a broken line was standing in the non-uniform radiation area around the ^{123}I-IMP or

^{99m}Tc-ECD patients. For the sake of convenience, we divided the attendant into the four body parts, which were head and neck, thorax and brachium, abdomen and femur, and remainder. Equivalent dose of each part of the body was calculated from the readings of each survey meter using the equation (2). The justice of this method was attested from the different readings of the three survey meters arranged to each part of the broken line person in Figure 1. In Japan, this partition technique was generally accepted to evaluate the radiation dose of a human in a case of staying in a non-uniform radiation area. Since 1989, in Japan, usage of this technique was put under an obligation.

^{123}I-IMP study

The potential effective dose of 810 μ Sv at 0.05 m from the ^{123}I-IMP patient should be used to estimate a contact dose caused to his family. For example, if the ^{123}I-IMP patient contacts his spouse or children for 8 h per day, their maximum effective dose will reach 270 μ Sv. Although this effective dose will not be able to exceed their dose limit as 1 mSv per year, their doses will be substantial to annual limit. On the other hand, the potential effective dose of 175 μ Sv at 0.5 m gives a dose estimation of a nursing staff or an attendant. It is already known that the nursing care time contacting with a patient per day was 3 to 6 h [2]. If one ^{123}I-IMP patient requires a nursing care of 6 h , their effective doses will be reach to 44 μ Sv per patient. Provisionally, occupational dose limit of 20 mSv per year is applied to the nursing staff; they can attend over four hundred patients in a year. It is considered that this patient number was enough to attend ^{123}I-IMP patients for the nursing staff. Effective doses of other patients staying in the same nursing room with a ^{123}I-IMP patient should be calculated from the potential effective dose of 37 μ Sv at 1.5 m. Temporarily, ^{123}I-IMP patients spend all his time on his bed nearby other patients. The effective doses of other patients equal to the potential effective dose of 37 μ Sv. This effective dose allows the presence of many ^{123}I-IMP patients in this nursing room. It was considered that the family dose received from the ^{123}I-IMP patient was substantial; however, the nursing staff and other patients doses received from the^{123}I-IMP patient were not significant.

^{99m}Tc-ECD study

The potential effective dose of 640 μ Sv at 0.05 m from the ^{99m}Tc-ECD patient should be used to estimate a contact dose of his family. The 8 h contact with a ^{99m}Tc-ECD patient per day will expose 213 μ Sv to his spouse or children. Although this effective dose will not be able to exceed their dose limit as 1 mSv per year, their doses will be substantial to the annual limit of public members. The effective dose of 29 μ Sv of a nursing staff or an attendant was estimated by multiplying the potential effective dose of 115 μ Sv at 0.5 m by 0.25 (=6h/24h). This dose was sufficiently low to the occupational dose limit of 20 mSv per year. Effective doses of other patients staying in the same nursing room with a ^{99m}Tc-ECD patient was calculated from the potential effective dose of 24 μ Sv at 1.5 m. When the ^{99m}Tc-ECD patient spent all his time on his bed, the effective doses of other patients in the same room with him equal to the potential effective dose of 24 μ Sv. When a family exposed to a ^{99m}Tc-ECD patient; the family dose would reach 213 μ Sv. We considered that the effective dose of the family would be substantial. On the other hand, the effective doses of the nursing staff and other patients were very lower than the family dose, so the doses from a ^{99m}Tc-ECD patient were not significant.

Comparison between ^{123}I-IMP and ^{99m}Tc-ECD studies

As shown Table 3 and 5, in the Level Ⅰ and Ⅱ, initial equivalent dose rates around the ^{99m}Tc-ECD patients were approximately equal to those around ^{123}I-IMP patients, however in the Level Ⅲ, the doses of ^{99m}Tc-ECD were larger than those of ^{123}I-IMP. These radiopharmaceuticals used for brain blood flow study are distributed to not only brain but also several organs and tissue. For example, ^{123}I-IMP is mainly distributed to lung and liver, ^{99m}Tc-ECD especially accumulates to liver, small intestine and kidney. In this way, the internal distribution of ^{123}I-IMP is slightly different from that of ^{99m}Tc-ECD. So, it is considered that the cause of the lager equivalent doses in Level Ⅲaround the ^{99m}Tc-ECD patients will be accumulations of ^{99m}Tc-ECD to their abdomen tissue like small intestine.

Equivalent dose accumulations around ^{123}I-IMP or ^{99m}Tc-ECD patients were shown in Figure 2. In the early time after the injections of the radiopharmaceuticals, the dose accumulations around the ^{99m}Tc-ECD patients has markedly increased than those around the ^{123}I-IMP patients. However, it was not long before the dose accumulation around the ^{123}I-IMP patients exceeded those around the ^{99m}Tc-ECD patients. It is considered that the difference of effective half-lives of 11.0 h (^{123}I-IMP) and 4.0h (^{99m}Tc-ECD) led to the cause of this phenomenon.

Revisions by real administration doses of the radiopharmaceuticals

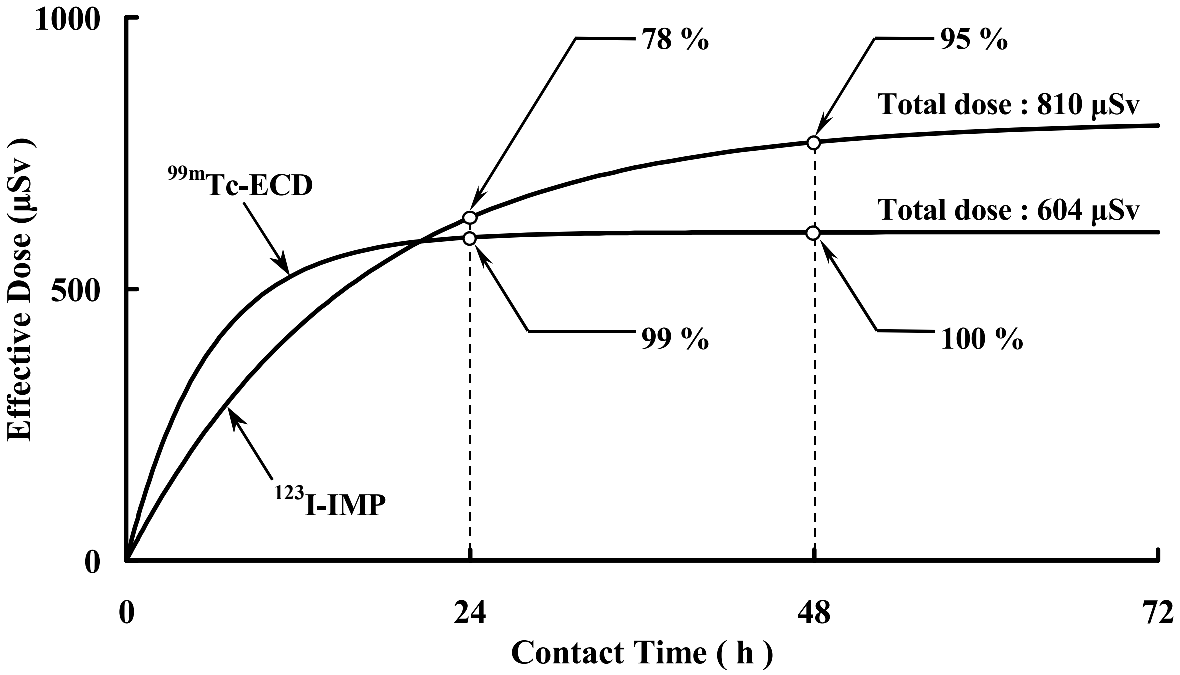

Figure 2. Equivalent dose accumulations around ^{123}I-IMP and ^{99m}Tc-ECD patients at 5 cm distance

Recently, in the Tokai area in Japan we have performed a survey for the administration dose (MBq) of radiopharmaceuticals [3]. The administration dose of ^{123}I-IMP per study was 168±79 MBq, and which was about 75% of the maximum standard dose of 222 MBq per patient. On the other hand, the administration dose of ^{99m}Tc-ECD per study is unknown presently. Consequently, our reporting data may give an over estimation of the effective doses of an attendant. If this data is adapted to dose estimations of attendants, it will be necessary to correct by a ratio of the true administration dose to the maximum standard dose.

Conclusion

As far from 0.05 to 1.5 m, radiation dose rates from the ^{123}I-IMP or ^{99m}Tc-ECD patients effectively reduced. In the close contact area to the patients, these rates from the ^{123}I-IMP or ^{99m}Tc-ECD patients were substantially maintained for about 48 or 24 h after the administrations of the radiopharmaceuticals, respectively. Accordingly, a radiation hazard around the patient is very small and low. Therefore, the ^{123}I-IMP and ^{99m}Tc-ECD patients will provide only a small risk to others around them. If it is desired to reduce the radiation dose with the small risk, a long contact with the patients should be avoided at least one or two days post administrations of the radiopharmaceuticals.

References

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