EVALUATION OF SYRINGE SHIELD EFFECTIVENESS IN HANDLING RADIOPHARMACEUTICALS

by

Yong-In CHO [1], ***Chang-Soo KIM*** [2], ***and Jung-Hoon KIM*** [2*]

[1] Department of Nuclear Medicine, Dongnam Institute of Radiological & Medical Science, Pusan, Korea
[2] Department of Radiological Science, College of Health Sciences, Catholic University of Pusan, Pusan, Korea

Technical paper
DOI: 10.2298/NTRP1502158C

The purpose of this study was to evaluate the effectiveness of the radiation shield of radionuclide syringes and the personal dose equivalent by performing a simulation of radionuclides used in nuclear medicine diagnosis. In order to evaluate the dose depending on the distance between the radiation source and the ICRU sphere against the thickness of the shielding device, the distance at which a nuclear medicine worker may inadvertently come into contact with radiation from the radiation source was set at 0 cm to 30 cm according to the thickness of the shield, thus fixing the ICRU sphere. For a dose evaluation, Hp(10), Hp(3), and Hp(0.07) measurable in specific depth of the ICRU were evaluated. It was found that a dose measured on skin surface of nuclear medicine workers was relatively higher, that the dose varied in relation to the thickness of the radiation shield, and that the shielding effect decreased for some radiation sources such as ^{67}Ga and ^{111}In. It proved necessary to increase thickness of shielding device to the radiation sources such as ^{67}Ga and ^{111}In. It is also considered that a study of proper shielding thickness will be needed in future.

Key words: ICRU sphere, syringe shield, personal dose equivalent, radionuclide

INTRODUCTION

Nuclear medicine workers are commonly exposed to radiation from radioisotopes and radiopharmaceuticals due to the nature of their job which includes the compounding, distribution, and injection of radiopharmaceuticals [1]. For these reasons, studies on reducing the amount of radiation to which nuclear medicine workers are exposed have been conducted continuously. The most popular radionuclide used for diagnosis in the field of nuclear medicine is ^{99m}Tc but various others including ^{18}F, ^{131}I, ^{123}I, ^{201}Tl, ^{67}Ga and ^{111}In are used as well [2]. Each radionuclide has its own unique combination of energy emission and half-life, so the exposure dose that a nuclear medicine worker may receive differs according to the different physical characteristics of each radionuclide being handled [3]. Accordingly, it is necessary to use proper shielding devices with regard to the gamma-ray energy being emitted from the radionuclide used. Various types of syringe shields used to reduce the exposure dose to hands when transferring and injecting radiopharmaceuticals have been developed and are currently used commercially [4].

In some studies, it was reported that many nuclear medicine workers of medical institutes actually did not use any radiation shields because of discomfiture or inconvenience, or they felt that using them hampered their work efficiency, so they often performed their tasks overlooking radiation exposure to their hands. Although the personal exposure dose of nuclear medicine workers is measured quarterly with a calibrated personal dosimeter, doing so is restricted to measuring exposure of the whole body rather than any specific extremities [5, 6]. In addition, the personal exposure dose is different corresponding to the work environment of each institute, skill of workers, and how the shielding devices are used, which makes it difficult to be confident in the dosimeter for evaluating the personal exposure dose by energy and direction dependency [7].

This study is intended to simulate the personal dose equivalent depending on the thickness of a typical syringe shield used in a typical nuclear medicine institute and a dose in accordance with distance when injecting radiopharmaceuticals, thus providing basic data about the effectiveness of shielding devices and radiation protection of nuclear medicine workers.

MATERIALS AND METHODS

Monte Carlo simulation

The Monte Carlo simulation is a method of simulating the behavior of neutrons, photons, and elec-

* Corresponding author; e-mail: donald@cup.ac.kr

trons in various 3-D structures of materials to solve statistical problems by random sampling [8]. In this study, the simulation was performed using MCNPX (Ver.2.5.0) developed by the Los Alamos National Laboratory (N. Mex., USA).

The International Commission on Radiation Units and Measurement (ICRU) has suggested operational quantities for the purpose of measuring or monitoring the effective dose. Among them, the personal dose equivalent Hp (d), used for the purpose of personal monitoring is defined as a dose equivalent to the depth dose Hp(10), lens dose Hp(3), and skin surface dose Hp(0.07) at 10 mm, 3 mm, and 0.07 mm depths from the outer surface of the ICRU sphere [9]. The sphere is 30 cm in diameter; it has 1 g/cm^3 of inner density and comprises tissue-equivalent materials including oxygen 76.2 %, carbon 11.1 %, hydrogen 10.1 %, and nitrogen 2.6 %. In this study, the existing sphere suggested by the ICRU was simulated as shown in fig. 1.

A commercially available syringe shield that is popularly used when injecting radionuclides for general diagnosis of nuclear medicine uses a tungsten (W) plate that is 1~2 mm thick, has an atomic number of 74 and a density of 19.25 g/cm^3. In order to evaluate the actual effectiveness of such a shield, the syringe shield used in this study was formed from a tungsten cylinder as shown in fig. 2 and simplified to place a uniformly sized radiation source inside.

Dose assessment

The radionuclides used in this study included ^{99m}Tc, ^{123}I, ^{201}Tl, ^{67}Ga, and ^{111}In, with the energy and occurrence rate of each radionuclide selected using radiation source information as shown in tab. 1 [10].

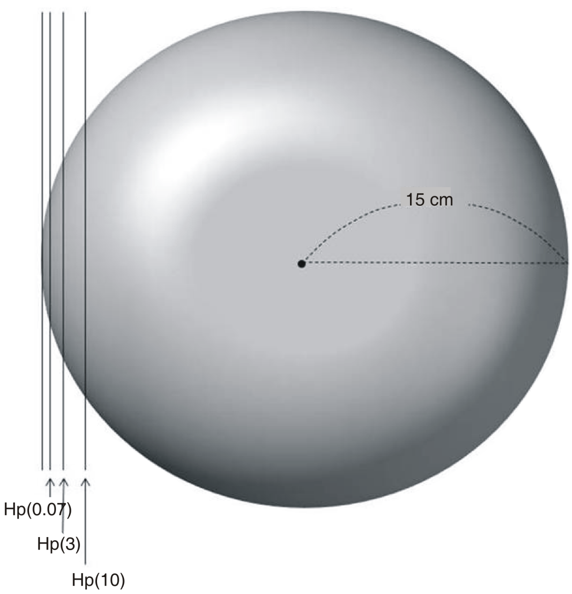

Figure 1. Simulated diagram of the ICRU sphere

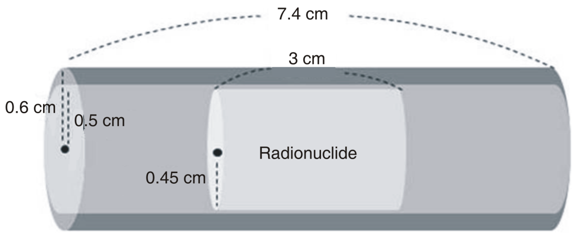

Figure 2. Simulation of radionuclide and syringe shield

Table 1. Radionuclides data

	^{99m}Tc	^{123}I	^{201}Tl	^{67}Ga	^{111}In
γ energy (yield) [keV]	140.5(0.89)	159.0(0.83)	68.9(0.27)	93.3(0.37)	274.0(0.94)
	18.4(0.04)	27.5(0.46)	11.8(0.11)	184.6(0.20)	173.0(0.08)
	18.3(0.02)	27.2(0.25)	80.3(0.11)	300.2(0.16)	
		31.0(0.09)	167.4(0.10)	393.5(0.05)	
		31.7(0.03)	79.8(0.05)	91.3(0.03)	
		529.0(0.01)	82.6(0.04)	209.0(0.02)	
			11.9(0.04)		
			135.3(0.03)		
			13.8(0.02)		
			12.0(0.02)		
			11.6(0.01)		
Half life	6.01 h	13.2 h	2.8 d	3.261 d	2.8 d

First, in order to evaluate how the dose changes in relation to the thickness of the shielding device, three thicknesses were chosen (non, 1 mm, and 2 mm) and the distance between each radiation source and the ICRU sphere fixed at 10 cm, which was defined as the surface radiation dose in compliance with Korea Atomic Energy regulations. Next, in order to evaluate the dose depending on the distance between the radiation source and the ICRU sphere against the thickness of the shielding device, the distance at which a nuclear medicine worker may inadvertently come into contact with radiation from the radiation source was set at 0 cm, the surface area, to 30 cm according to the thickness of the shield, thus fixing the ICRU sphere. For evaluating the dose, the dose of depth Hp(10), lens Hp(3), and skin surface Hp(0.07) measurable to specific depths of the ICRU were evaluated. For Tally specification cards, the absorbed energy per unit mass [MeVg^{-1}] was obtained by using the F6 Tally and converted to the personal dose equivalent when working for one hour, considering 37 MBq (1 mCi) of radiation activity for the same dose evaluation to each radionuclide. In order to reduce the statistical error of calculation below 3 %, the simulation was repeated $1\ 10^8$ times.

RESULTS

Dose according to the thickness of the shielding device

As a result of measuring the dose at a fixed distance of 10 cm between the radiation source and the

Table 2. Dose according to thickness of syringe shield in injecting each radionuclide (unit: [Svh^{-1}])

	Hp(10)			Hp(3)			Hp(0.07)		
RN[a]	NS[b]	1 mm W	2 mm W	NS	1 mm W	2 mm W	NS	1 mm W	2 mm W
^{99m}Tc	8.688	0.191	0.005	9.543	0.196	0.006	10.06	0.200	0.006
^{123}I	8.696	0.587	0.239	9.950	0.611	0.250	10.59	0.625	0.256
^{201}Tl	5.341	0.134	0.011	9.498	0.139	0.012	15.42	0.143	0.014
^{67}Ga	11.83	3.965	2.124	12.41	4.156	2.220	12.68	4.247	2.266
^{111}In	18.51	8.532	3.992	19.50	8.946	4.166	19.95	9.142	4.252

[a] RN (Radionuclides), and [b] NS (Non syringe shield)

ICRU sphere to evaluate the dose according to the thickness of the shielding device when injecting each radionuclide, it was found that the depth dose Hp(10) was 8.688 Sv/h for ^{99m}Tc, 8.696 Sv/h for ^{123}I, 5.341 Sv/h for ^{201}Tl, 11.828 Sv/h for ^{67}Ga, and 18.509 Sv/h for ^{111}In when using no syringe shield. When using 1 mm tungsten (typical of a commercially available syringe shield), it was found that the depth dose Hp(10) was 0.191 Sv/h for ^{99m}Tc, 0.587 Sv/h for ^{123}I, 0.134 Sv/h for ^{201}Tl, 3.965 Sv/h for ^{67}Ga, and 8.532 Sv/h for ^{111}In, and the effectiveness of the shielding according to radiation sources was in order of ^{99m}Tc, ^{201}Tl, ^{123}I, ^{67}Ga, and ^{111}In. For the lens dose Hp(3) and skin surface dose Hp(0.07), it was found (as shown in tab. 2) that the effectiveness of a 1 mm tungsten shield was in the same identical order of ^{99m}Tc, ^{201}Tl, ^{123}I, ^{67}Ga, and ^{111}In. It was also shown that the shielding effect of a 2 mm tungsten shield for the depth dose Hp(10), lens dose Hp(3), and skin surface dose Hp(0.07) showed a similar tendency as can be seen in tab. 2.

Dose to distance between the radiation source and the ICRU sphere

As a result of measuring the dose according to the distance between the ICRU sphere and the radiation source, it was found (as shown in fig. 3) that at the 0 cm point at which the distance from the ICRU sphere was the surface, the depth dose was 34.939 Sv/h for ^{99m}Tc, 34.894 Sv/h for ^{123}I, 20.944 Sv/h for ^{201}Tl, 48.161 Sv/h for ^{67}Ga, and 75.830 Sv/h for ^{111}In. On the contrary, as the depth dose 30 cm from the ICRU sphere was measured as 2.526 Sv/h for ^{99m}Tc, 2.529 Sv/h for ^{123}I, 1.549 Sv/h for ^{201}Tl, 3.431 Sv/h for ^{67}Ga, and 5.359 Sv/h for ^{111}In, it was suggested that when the distance increased, the dose decreased, and the lens and skin surface doses showed an equivalent tendency to the above results.

When using a 1 mm tungsten shield (as with a typical commercially available syringe shield), the depth dose at the point of 0 cm of which the distance from the ICRU sphere was the surface, was measured as 0.527 Sv/h for ^{99m}Tc, 1.963 Sv/h for ^{123}I, 0.389 Sv/h for ^{201}Tl, 14.137 Sv/h for ^{67}Ga, and 29.794 Sv/h for ^{111}In. On the contrary, it was shown that as the depth dose at 30 cm from the ICRU sphere was measured as 0.063 Sv/h for ^{99m}Tc, 0.181 Sv/h for ^{123}I, 0.043 Sv/h for

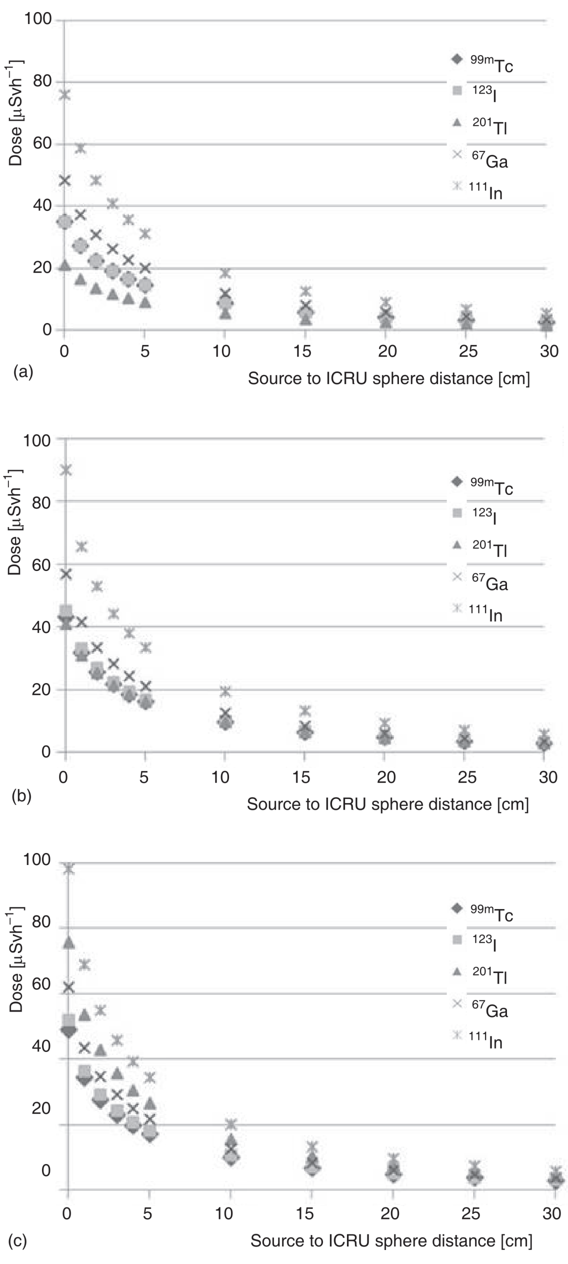

Figure 3. Dose according to distance between the ICRU sphere and the radiation source in using no syringe shield: (a) Hp(10, (b) Hp(3), and (c) Hp(0.07)

^{201}Tl, 1.184 Sv/h for ^{67}Ga, and 2.556 Sv/h for ^{111}In radiation source, the dose equivalent decreased according to the increase of the distance despite the presence of the shielding device. It was also found that the lens and the skin surface doses showed a similar tendency to the previous results, and the reduced dose ratio among the radiation sources was higher by as much as 1~1.5 times for ^{67}Ga and ^{111}In (fig. 4).

Despite using an increased thickness, 2 mm tungsten, it was found also (as shown in fig. 5) that when the distance increased, the dose decreased, and the reduced dose ratio was higher by as much as 1~1.5 times for ^{123}I (fig. 5). In addition, it was suggested that the reduced dose effect was higher in order of skin surface, lens and depth dose regardless of thickness of the shielding device.

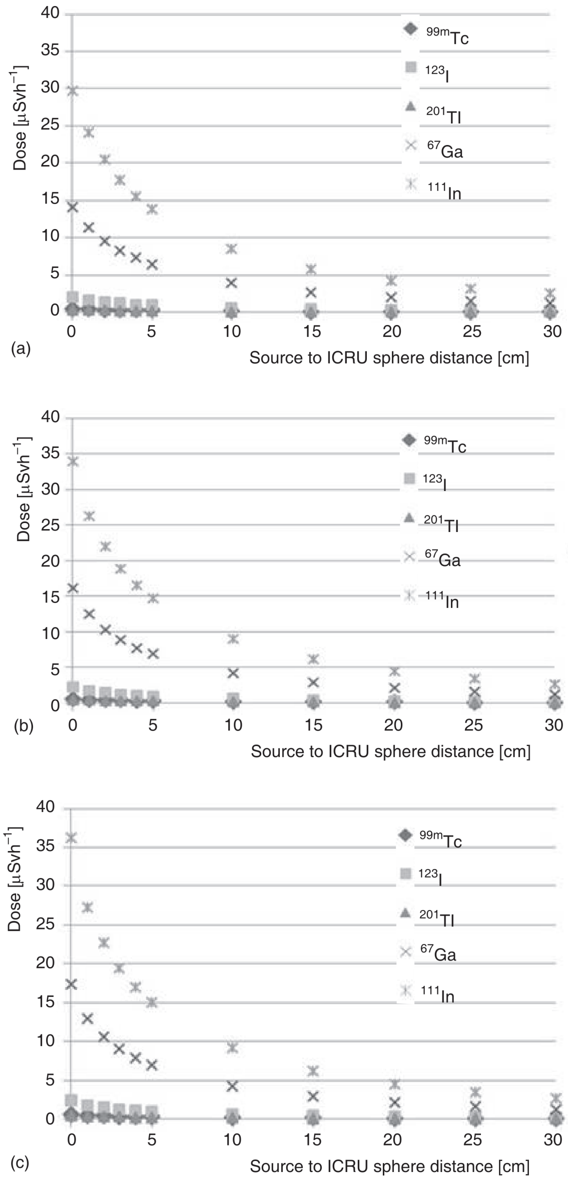

Figure 4. Dose according to distance between the ICRU sphere and the radiation source in using 1 mm tungsten shielding device: (a) Hp(10), (b) Hp(3), and (c) Hp(0.07)

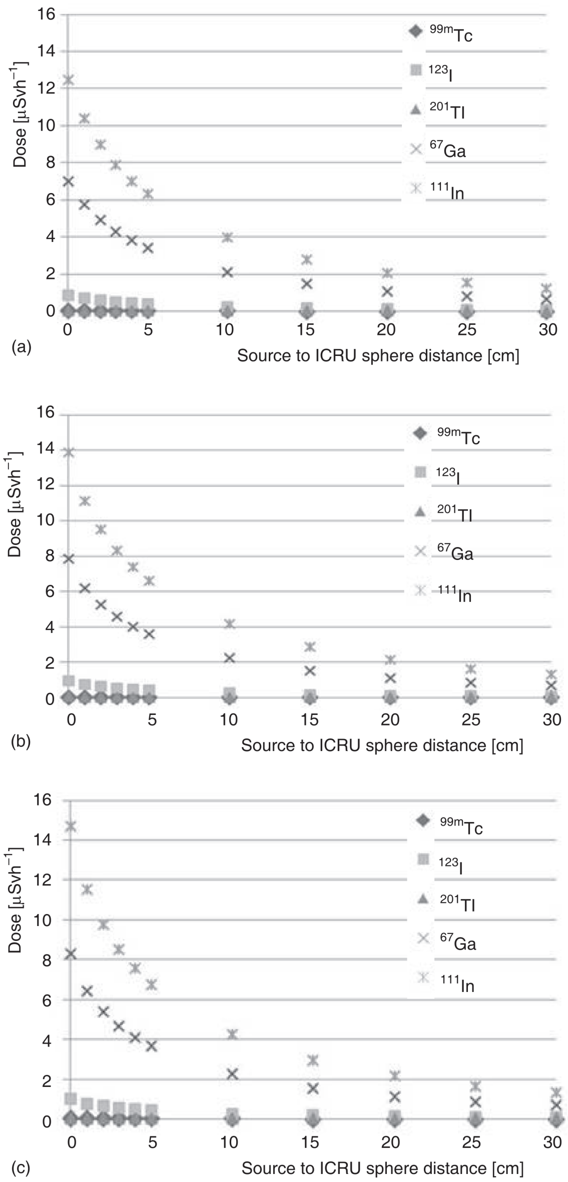

Figure 5. Dose according to distance between the ICRU sphere and the radiation source in using 2 mm tungsten shielding device: (a) Hp(10), (b) Hp(3), and (c) Hp(0.07)

DISCUSSION

In this study, it was intended to evaluate the personal dose according to the thickness of the commercial syringe shields currently used in departments of nuclear medicine and the dose according to the distance when injecting a radionuclide. The results showed that there were some differences in the doses according to the thickness of the syringe shield and these results showed that the emitted gamma ray was reduced due to the shielding effect of the tungsten shielding material. It was suggested that in the radiation sources with energy distribution of gamma rays over 200 keV such as ^{67}Ga and ^{111}In, the probability of photon interaction was lower than that of a radiation source in a low energy area, so the shielding effect was reduced more relatively. For the skin surface dose, it was considered that as the dose was measured at a shallow point of 0.07 mm depth into the ICRU sphere and the number of photons absorbed and scattered inside of the sphere was less than that of the lens and depth doses, it was measured higher. As a result of measuring doses according to distance between the ICRU sphere and the radiation source, there was a tendency that as the distance increased, the dose decreased, and it was found that the reduced dose ratio according to shield thickness and by radiation sources was different, respectively. Namely, it is considered that as the distance from the radiation source increases, the dose decreases from the inverse square of the distance. In several previous radiation studies on nuclear medicine workers, it was reported that the effect of shielding was different due to differences in work environments and as for radiation evaluation, various errors such as underestimation or overestimation of doses might occur depending on the wearing sites and types of dosimeter [11,12]. As a method to complement these errors, a simulation performed in computer virtual space, an ideal condition, has been evaluated as one of the useful tools able to reduce various errors [13,14]. In the simulation of Working Package 4 under the ORAMED Project and other studies, it was mentioned that the thickness of any shielding device handling ^{99m}Tc should be at least 2 mm of tungsten [15-17]. In this study, similar results were shown and additionally, the effect of the shielding device was compared considering physical characteristics by radionuclides. As a result, it seems that in case of other radionuclides such as ^{67}Ga and ^{111}In, an increased application of the shielding device is necessary by their physical characteristics in spite of the lower application frequency. This study is significant in that it identifies the effectiveness of syringe shields and personal dose tendency through simulation testing for radionuclides currently used in general diagnosis of nuclear medicine and provides basic data concerning radiation protection of nuclear medicine workers.

CONCLUSION

As the results of the test on syringe shields through a Monte Carlo simulation, it was identified that the skin surface dose of nuclear medicine workers was relatively higher and there were differentiated dose reduction effects by radionuclides according to the thickness of syringe shield used. Accordingly, on the basis of these results, it is recommended that nuclear medicine workers do not overlook application of the syringe shield and radiation to protect their hands and it is also necessary to increase the thickness of the shielding device to protect against radiation sources such as ^{67}Ga and ^{111}In. It is considered also that a study for proper shielding thickness should be done in the future. In addition, it is considered that workers should shorten the time required in handling the shielding device through simulation training and skills improvement and always be mindful of taking all necessary precautions to protect against personal radiation exposure through obligatory application of shielding devices and wearing of proper protective gear.

AUTHOR CONTRIBUTIONS

MCNPX simulations and data processing were done by Y.-I. Cho under the supervision of J.-H. Kim. Discussions regarding this paper were held with J.-H. Kim and C.-S. Kim. The writing of the manuscript, including figures and tables, were done by Y.-I. Cho.

REFERENCES

[1] Vanhavere, F., *et al*., An Overview on Extremity Dosimetry in Medical Applications, *Radiation Protection Dosimetry, 129* (2008), 1-3, pp. 350-355

[2] ***, Korea Radioisotope Association, Statistics on the Radiation Practices in Korea, Korea Association Radiation Application, 2013

[3] Chiesa, C., *et al*., Radiation Dose to Technicians per Nuclear Medicine Procedure: Comparison between Technetium-99m, Gallium-67, and Iodine-131 Radiotracers and Fluorine-18 Fluorodeoxyglucose, *European Journal of Nuclear Medicine and Molecular Imaging, 24* (1997), 11, pp. 1380-1389

[4] Hae-Jun, S., Radiation Shielding Analysis according to the Material Making up the Transport Container of ^{99m}Tc Injectors Using GEANT4, M. Sc. thesis, Majoring in Radiation, Graduate School of Chonbuk National University, 2008

[5] Jun-Chul, P., Sung-Jae, P., Study of External Radiation Expose Dose on Hands of Nuclear Medicine Workers, *Korean Society of Radiological Science, 35* (2012), 2, pp. 141-149

[6] Yeong Seon, K., *et al.*, The Usefulness Evaluation of Radiation Shielding Devices in PET Scan Procedures, *Korean Society of J Nuclear Medicine Technology, 14* (2010), 2, pp. 65-76

[7] Blunck, Ch., *et al*., Radiation Protection in Inhomogeneous Beta-Gamma Fields and Modelling of Hand Phantoms with MCNPX, *Radiation Protection Dosimetry, 134* (2009), 1, pp. 13-22

[8] Yong, H. C., *et al*., Monte Carlo Simulation Codes for Nuclear Medicine Imaging, *Korean Society of J Nuclear Medicine, 42* (2008), 2, pp. 127-136

[9] Mattsson, S., Soderberg, M., Dose Quantities and Units for Radiation Protection, in: Radiation Protection in Nuclear Medicine, Springer Berlin Heidelberg, 2013, pp. 7-18

[10] Faw, R. E., Kenneth Shultis, J., Radiological Assessment: Sources and Doses, American Nuclear Society, La Grange Park, Ill., USA, 1999

[11] Sans-Merce, M., *et al.*, Recommendations to Reduce Hand Exposure for Standard Nuclear Medicine Procedures, *Radiation Measurement, 46* (2011), 11, pp. 1330-1333

[12] Carnicer A., *et al*., The Use of Different Types of Thermoluminescent Dosimeters to Measure Extremity Doses in Nuclear Medicine, *Radiation Measurement, 46* (2011), 12, pp. 1835-1838

[13] Berdeguez, M. T., Pardo, E. A., Falcon, L., Dose Rate in Contact with Plastic Syringes of 1, 2 and 5 mL for Different Beta and Gamma Emitting Radionuclides, International Radiation Protection Association, 2008, pp. 19-24

[14] Blunck, Ch., Becker, F., Urban, M., Simulation of Beta Radiator Handling Procedures in Nuclear Medicine by Means of a Movable Hand Phantom, *Radiation Protection Dosimetry, 144* (2011), 1-4, pp. 497-500

[15] Ferrari, P., Sans-Merce, M., Carnicer, A., Main Results of the Monte Carlo Studies Carried Out for Nuclear Medicine Practices within the ORAMED Project, *Radiation Measurement, 46* (2011), 11, pp. 1287-1290

[16] Mariotti, F, Gualdrini, G., Extremity Dosimetry Problems During the Handling of Radionuclides Syringes in Nuclear Medicine: A Monte Carlo Radiation Transport Simplified Approach, *Radiation Measurement, 46* (2011), 4, pp. 430-435

[17] Cho. Y.-I., *et al.*, An Evaluation of Effectiveness on Technetium-99m Syringe Shield, *Proceedings*, Symposium – Korea Contents Association, 2014, pp. 431-432

Received on April 21, 2015
Accepted on June 6, 2015

Јонг-Ин ЧО, Чанг-Су КИМ, Јунг-Хун КИМ

ПРОЦЕНА ЕФЕКТИВНОСТИ ЗАШТИТЕ ШПРИЦЕВА ПРИ РАДУ СА РАДИОФАРМАЦИМА

Циљ овог рада је процена ефективности и заштите од зрачења код шприцева са радионуклидима и процена личног дозног еквивалента симулацијом радионуклида коришћених у дијагностичкој нуклеарној медицини. Како би се проценио однос између дозе, која зависи од растојања између извора зрачења и ICRU сфере, и дебљине заштитног материјала, за растојање при коме техничар одељења нуклеарне медицине може случајно доћи у контакт са радиоактивним извором узето је растојање 0-30 cm према дебљини заштитног материјала, чиме се фиксира положај ICRU сфере. За процену дозе, мерени су Hp(10), Hp(3) и Hp(0.07) на специфичним дубинама у ICRU сфери. Уочено је да је доза на површини коже техничара висока, да се доза мења у зависности од дебљине заштитног материјала и да се заштитни ефекат смањује за неке радиоактивне изворе као што су ^{67}Ga и ^{111}In, те је за ове радиоизотопе потребно повећати дебљину заштитног материјала. Закључено је такође да је убудуће потребно извршити детаљну студију дебљина заштитних материјала.

Кључне речи: ICRU сфера, заштита од зрачења за шприцеве, лични дозни еквивалент, радионуклид