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BRIEF REPORT

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Evaluation of X-ray protective goggles in mitigating eye lens radiation exposure during radiopharmaceutical handling and patient care in nuclear medicine

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Abstract: The aim of this study is to estimate eye lens exposure dose when handling radiopharmaceuticals and interacting with patients receiving radiopharmaceuticals, and to verify the usefulness of X-ray protective goggles in mitigating such radiation exposure using phantoms. To evaluate radiation exposure during the handling of radiopharmaceuticals, we employed a fluorescent glass dosimeter to measure the radiation doses associated with ^{99m}Tc, ^{123}I, ^{131}I, ^{111}In, and ^{18}F at distances of 30 cm and 60 cm, followed by calculation of the 3 mm dose equivalent rate (3DER). We then estimated the dose reduction rates for various scenarios, including the use of syringe shields and X-ray protective goggles with lead equivalences of 0.07, 0.15, 0.75, and 0.88 mmPb, as well as their combined application. X-ray protective goggles with lead equivalence of 0.75 mmPb outperformed those with 0.07 mmPb and 0.15 mmPb, for all radionuclides and at both source distances. X-ray protective goggles with 0.88 mmPb outperformed those with 0.75 mmPb during handling of ^{131}I and ^{111}In at a distance of 30 cm. In the remaining scenarios, X-ray protective goggles with 0.88 mmPb resulted in marginal reductions or no discernible additional effects. The overall shielding effect of X-ray protective goggles was less pronounced for ^{131}I and ^{18}F, but the combined use of a syringe shield with X-ray protective goggles with 0.75 or 0.88 mmPb improved the dose reduction rate for all scenarios. In simulating patient care, X-ray protective goggles with 0.88 mmPb demonstrated a dose reduction effect of approximately 50% or more. X-ray protective goggles could reduce the 3DER for the eye lens, and were more effective when combined with a syringe shield. It is valid to use a lead equivalence of 0.88 mmPb to fully harness the protective capabilities of X-ray shielding goggles when dealing with all five types of nuclides in clinical settings.

***Keywords*:** X-ray protective goggles, eye lens protection, radiation shielding, single photon emission computed tomography (SPECT), positron emission tomography (PET)

Introduction

Prior to 2011, the accepted threshold dose for radiation induced cataracts was set as 1.5 Gy, but several studies have suggested that cataracts could develop with radiation exposure of less than this (*1-5*). In response to this evidence, the International Commission on Radiological Protection (ICRP) issued a statement on tissue reactions to radiation exposure (Seoul Statement) in April 2011, lowering the threshold radiation dose for potential cataracts to 0.5 Gy. Furthermore, the limit of the equivalent dose to the eye lens of radiation workers was changed to "20 mSv on average for five years and not to exceed 50 mSv in any one year" from that previously set as "not to exceed 150 mSv per year" (*6,7*). The Ordinance on Prevention of Ionizing Radiation Hazards in Japan was revised to align with the threshold set by the ICRP, which was effective from April 1, 2021.

Regarding X-ray examinations, X-ray protective glasses have been recommended for cardiac interventional radiology (IVR) based on reports that 0.07 mmPb X-ray protective glasses enable a reduction in eye lens exposure of approximately 60% (*8,9*). In nuclear medicine examinations, the use of syringe shields, lead-containing protective plates, and X-ray protective glasses have been shown to reduce radiation exposure of eye lens (*10-12*). Matsutomo *et al*. reported that the use of 0.75 mmPb X-ray protective goggles when handling radiopharmaceuticals resulted in a significant radiation dose reduction of 68.8% for ^{99m}Tc, 60.6% for ^{111}In, and 68.1% for ^{123}I (*12*). However, there have been no reports examining the usefulness of X-ray protective goggles when it is necessary to be near a patient lying in bed during a nuclear medicine examination, such as when the patient's condition requires assistance.

The aim of this study was to estimate the 3 mm dose equivalent rate (3DER) for the eye lens and the usefulness of X-ray protective goggles when handling radiopharmaceuticals with five nuclides, ^{99m}Tc, ^{123}I, ^{131}I, ^{111}In, and ^{18}F. In addition, for the two major nuclides ^{18}F and ^{99m}Tc, we estimated the 3DER when interacting with patients receiving radiopharmaceuticals, and assessed the utility of X-ray protective goggles for mitigating exposure of eye lens to radiation.

The standard method for managing the equivalent dose to the eye lens is to use 1cm dose equivalent, 3 mm dose equivalent, and 70 µm dose equivalent, depending on the type and energy of radiation. However, because a glass dosimeter was used in this study, the 3 mm dose equivalent rate was calculated by measuring air kerma. This verification was conducted using phantoms.

Materials and Methods

Dose measurements were performed using a fluorescent glass dosimeter/small element system (Dose Ace FGD-1000; ACG TECHNO GLASS Co., Ltd. Shizuoka, Japan). Dosimetry was performed using a radiophotoluminescent glass dosimeter (RPLD) attached to the eyeball of a CT head phantom. Types of RPLD were GD-352M for the assessment of ^{99m}Tc, and GD-302M for the assessment of ^{18}F, ^{131}I, ^{111}In, and 123I. We read an initial value of air kerma for each fluorescent glass dosimeter. After irradiation (measurement) while in the holder, preheating was performed at 70 oC for 30 minutes, and the measured values were read after being left at room temperature until the temperature dropped to below 30 oC (13). Regarding syringe shields, a UG-WS-25 shield (UNIVERSAL GIKEN, Kanagawa, Japan) was used for SPECT preparations and a UG-FWS-TR50 tungsten shield (UNIVERSAL GIKEN) was used for 18F preparations. We used a NEMA IEC body phantom to verify measurements when interacting with patients. Four types of X-ray protective goggles were used: 0.07 mmPb Panorama Shield (TORAY MEDICAL, Tokyo, Japan), 0.15 mmPb EC-10 XRAY (ERICA OPTICAL, Fukui, Japan), 0.75 mmPb X-Guard Click Monarch (SHOWA OPT, Osaka, Japan), and 0.88 mmPb Dr. B-Go (Dr. Japan, Tokyo, Japan) (Figure 1).

Verification of radiation dose

The nuclides assessed in this study were selected based on the results of a survey that included the frequency of use of nuclides in nuclear medicine in Japan, which appear to be generally consistent with those in use worldwide (*14*). Radiation measurements were conducted for sealed syringes containing 260 MBq of ^{99m}Tc, 50 MBq of ^{111}In, 158 MBq of ^{123}I, 36.5 MBq of ^{131}I, and 240 MBq of ^{18}F, and these doses were set to simulate their use in a clinical scenario.

In the assessment of simulated patient care during a nuclear medicine examination, the background concentrations of the phantom were 18.0 kBq/ml for ^{99m}Tc and 2.65 kBq/ml for ^{18}F, following accepted guidelines for phantom testing (*15,16*).

Estimation of 3 mm dose equivalent

In this study, air kerma read were taken five times and the average value was used. To estimate the

Index	Panorama Shield (TORAY MEDICAL)	EC-10 XRAY (ERICA OPTICAL)	X-Guard Click Monarch (SHOWA OPT)	Dr.B-Go (Dr.Japan)
Lead equivalent (mmPb)	0.07	0.15	0.75	0.88
Weight (g)	65	69	85	100
Combined use with vision correction glasses	○	○	X	X

Figure 1. Characteristics of X-ray protective goggles.

exposure of eye lens to radiation when handling radiopharmaceuticals and simulated patient care, we calculated the 3DER by the formula (A) as follows:

$$E = \frac{k}{0.9} \times D \times \frac{\frac{\lambda}{1-e^{-\lambda \cdot t}}}{B} \quad \cdots\cdots \text{(A)}$$

E: 3 mm dose equivalent rate per radioactivity (μSv/min/GBq)
D: air kerma (μGy)
λ: decay constant (/min)
B: radioactivity amount at start of measurement (GBq)
t: measurement time (min)
k: conversion factor from air kerma to 3 mm dose equivalent (Sv/Gy)

The mutual response value of RPLD to the energy of the radionuclide was fixed to 0.9 (*12,13*). The conversion coefficient from air kerma to 3 mm dose equivalent (*k*) was 1.449 for ^{99m}Tc and ^{123}I, 1.286 for ^{131}I, 1.372 for ^{111}In, and 1.210 for ^{18}F (*12,17*).

Verification when handling radiopharmaceuticals

The distance between the eye lens and the radioactive material was set at 60 cm based on the average length of the arm in Japanese individuals. A setting of 30 cm was also used, to allow for bending of the elbows during work (*12*). Radiation measurements were conducted continuously for 1 hour for the following four situations: *i*) with no protection, *ii*) using only the syringe shield, *iii*) using only the X-ray protective goggles, and *iv*) using both the syringe shield and the protective goggles.

Simulated patient care

In the simulation of patient care during a nuclear medicine examination, measurements were obtained at distances of 30 and 60 cm, and the height of the bed was set at 95 cm. Measurements were made with the eyeball of the brain phantom set at heights of either 150 and 165 cm from the floor, consistent with the average heights of Japanese women and men, respectively (Figure 2). Radiation dose measurements were conducted continuously for 30 minutes, and the 3DER was calculated for these specific conditions.

Results and Discussion

In this study, we estimated the 3DER for the eye lens and the usefulness of X-ray protective goggles when handling radiopharmaceuticals prepared with each of five nuclides (^{99m}Tc, ^{123}I, ^{131}I, ^{111}In, ^{18}F). For the two major nuclides, ^{18}F and ^{99m}Tc, we also estimated 3DER when interacting with patients receiving radiopharmaceuticals and assessed the utility of X-ray protective goggles.

Shielding effect of syringe shield when handling radiopharmaceuticals

Table 1 summarizes the shielding effect of the syringe shield for each radionuclide at radioactive source distances of 30 and 60 cm. The syringe shield reduced the 3DER of ^{99m}Tc, ^{123}I, ^{111}In, and ^{18}F by more than 70%, and reduced the 3DER of ^{131}I by about 30%. Except for ^{18}F, the reduction in 3DER was more pronounced at a distance of 60 cm than at 30 cm.

In simulation of bone scintigraphy (^{99m}Tc, 950 MBq) and PET examination (^{18}F, 240 MBq), if radiopharmaceuticals are handled for 5 minutes a day at a distance of 30 cm and without radiation protection, the annual eye lens equivalent dose (240 days) is estimated as 5.94 mSv/year for ^{99m}Tc and 8.63 mSv/year for ^{18}F, based on the results of the 3DER.

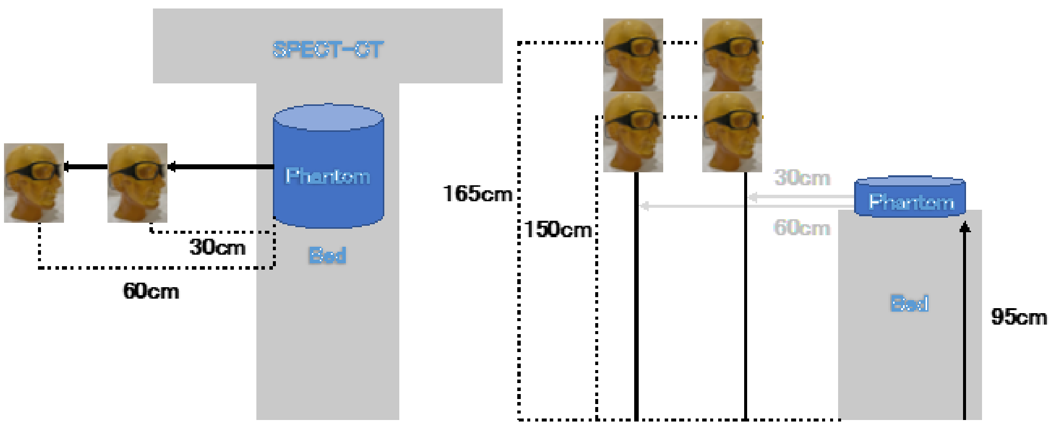

Figure 2. Phantom installation diagram (Horizontal/vertical direction).

Table 1. Comparison of 3mm dose equivalent rate with and without syringe shield at distance of 30 cm and 60 cm

Radionuclide	Protection	Distance of 30 cm		Distance of 60 cm	
		3 mm dose equivalent rate (μSv/min/GBq)	Reduction (%)	3 mm dose equivalent rate (μSv/min/GBq)	Reduction (%)
^{99m}Tc	None	5.21 ± 0.06	-	5.21 ± 0.06	-
	Syringe shield	0.93 ± 0.00	82.1	0.93 ± 0.00	82.1
^{123}I	None	8.94 ± 0.31	-	8.94 ± 0.31	-
	Syringe shield	2.58 ± 0.08	71.1	2.58 ± 0.08	71.1
^{131}I	None	16.70 ± 1.35	-	16.70 ± 1.35	-
	Syringe shield	11.88 ± 0.55	28.9	11.88 ± 0.55	28.9
^{111}In	None	25.71 ± 0.68	-	25.71 ± 0.68	-
	Syringe shield	8.13 ± 0.36	68.4	8.13 ± 0.36	68.4
^{18}F	None	29.97 ± 0.19	-	29.97 ± 0.19	-
	Syringe shield	4.85 ± 0.08	83.8	4.85 ± 0.08	83.8

Table 2. Reduction of 3 mm dose equivalent rate by X-ray protective goggles (distance-dependent variations)

Radionuclide	Goggle for protection	Distance of 30 cm		Distance of 60 cm	
		3 mm dose equivalent rate (μSv/min/GBq)	Reduction (%)	3 mm dose equivalent rate (μSv/min/GBq)	Reduction (%)
^{99m}Tc	None	5.21 ± 0.06	-	1.63 ± 0.05	-
	0.07 mmPb	3.62 ± 0.07	30.6	1.28 ± 0.09	21.5
	0.15 mmPb	3.39 ± 0.05	34.9	1.10 ± 0.12	32.9
	0.75 mmPb	0.83 ± 0.10	84.1	0.39 ± 0.05	76.0
	0.88 mmPb	0.89 ± 0.06	82.9	0.43 ± 0.05	73.4
^{123}I	None	8.94 ± 0.31	-	6.15 ± 0.08	-
	0.07 mmPb	5.00 ± 0.09	44.1	2.11 ± 0.37	65.8
	0.15 mmPb	4.53 ± 0.19	51.3	2.24 ± 0.14	63.5
	0.75 mmPb	2.58 ± 0.14	71.1	0.78 ± 0.09	87.3
	0.88 mmPb	2.75 ± 0.19	69.2	0.65 ± 0.08	89.5
^{131}I	None	16.70 ± 1.35	-	8.61 ± 0.29	-
	0.07 mmPb	15.53 ± 0.85	7.0	6.66 ± 0.55	22.7
	0.15 mmPb	14.35 ± 0.80	14.1	5.22 ± 0.00	39.4
	0.75 mmPb	12.27 ± 0.71	26.6	4.70 ± 0.71	45.5
	0.88 mmPb	10.31 ± 0.29	38.3	6.00 ± 1.26	30.3
^{111}In	None	25.71 ± 0.68	-	13.92 ± 0.58	-
	0.07 mmPb	13.52 ± 0.45	47.4	7.93 ± 0.28	43.1
	0.15 mmPb	13.42 ± 0.28	47.8	5.29 ± 0.28	62.0
	0.75 mmPb	10.57 ± 0.43	58.9	3.86 ± 0.28	72.3
	0.88 mmPb	7.62 ± 0.36	70.4	3.46 ± 0.43	75.2
^{18}F	None	29.97 ± 0.19	-	8.34 ± 0.11	-
	0.07 mmPb	26.96 ± 0.10	10.1	8.00 ± 0.19	4.0
	0.15 mmPb	26.62 ± 0.22	11.2	7.10 ± 0.08	14.8
	0.75 mmPb	22.82 ± 0.05	23.9	6.84 ± 0.07	18.0
	0.88 mmPb	21.90 ± 0.10	26.9	6.82 ± 0.04	18.2

Shielding effect of X-ray protective goggles when handling radiopharmaceuticals

Table 2 summarizes the shielding effect of X-ray protective goggles for each radionuclide at radioactive source distances of 30 and 60 cm.

X-ray protective goggles with lead equivalence of 0.75 mmPb outperformed those with 0.07 mmPb and 0.15 mmPb, for all radionuclides and at both source distances. X-ray protective goggles with 0.88 mmPb outperformed those with 0.75 mmPb during handling of ^{131}I and ^{111}In at a distance of 30 cm. However, in the remaining scenarios, X-ray protective goggles with lead equivalence of 0.88 mmPb resulted in only marginal reductions or no discernible additional effects. The overall shielding effect of X-ray protective goggles was less pronounced for ^{131}I and ^{18}F in comparison with the other radionuclides.

All of the tested X-ray protective goggles demonstrated a dose reduction effect, and the dose reduction rate tended to improve as the lead equivalence increased. In particular, by using 0.88 mmPb X-ray protective goggles, a high dose reduction effect of approximately 70% or more was obtained for ^{99m}Tc, ^{123}I, and ^{111}In, and the reduction rate was about 20% to 40% for ^{131}I and ^{18}F.

Although it has been reported that syringe shields alone are effective in reducing radiation exposure

Table 3. Reduction of 3 mm dose equivalent rate by X-ray protective goggles with syringe shield (distance-dependent variations)

Radionuclide	Goggles combined with a syringe shield	Distance of 30 cm			Distance of 60 cm		
		3 mm dose equivalent rate (μSv/min/GBq)	Reduction (%)	Reduction (%) by goggle	3 mm dose equivalent rate (μSv/min/GBq)	Reduction (%)	Reduction (%) by goggle
^{99m}Tc	Syringe shield only	0.93 ± 0.00	82.1	-	0.27 ± 0.06	83.5	-
	0.07 mmPb	0.79 ± 0.06	84.9	15.6	0.10 ± 0.00	93.7	61.5
	0.15 mmPb	0.79 ± 0.09	84.9	15.6	0.31 ± 0.07	81.0	-15.4
	0.75 mmPb	0.52 ± 0.07	90.1	44.4	0.31 ± 0.10	81.0	-15.4
	0.88 mmPb	0.31 ± 0.00	94.1	66.7	0.21 ± 0.10	87.3	87.3
^{123}I	Syringe shield only	2.58 ± 0.08	71.1	-	0.78 ± 0.09	87.3	-
	0.07 mmPb	1.19 ± 0.12	86.7	54.0	0.48 ± 0.14	92.3	52.4
	0.15 mmPb	0.68 ± 0.00	92.4	73.7	1.02 ± 0.12	83.4	28.7
	0.75 mmPb	0.71 ± 0.14	92.0	72.4	0.71 ± 0.14	88.4	33.3
	0.88 mmPb	0.95 ± 0.19	89.4	63.2	1.22 ± 0.08	80.1	19.1
^{131}I	Syringe shield only	11.88 ± 0.55	28.9	-	5.35 ± 0.71	37.9	-
	0.07 mmPb	8.87 ± 0.58	46.9	25.3	4.83 ± 0.36	43.9	9.8
	0.15 mmPb	10.96 ± 0.55	34.4	7.7	4.96 ± 0.36	42.4	7.3
	0.75 mmPb	6.52 ± 0.46	60.9	45.1	2.48 ± 1.26	71.2	53.7
	0.88 mmPb	5.74 ± 0.55	65.6	51.7	2.87 ± 0.74	66.7	46.3
^{111}In	Syringe shield only	8.13 ± 0.36	68.4	-	4.17 ± 0.56	70.1	-
	0.07 mmPb	4.07 ± 0.62	84.2	50.0	2.44 ± 0.43	82.5	41.5
	0.15 mmPb	2.95 ± 0.43	88.5	88.5	2.74 ± 0.58	80.3	34.2
	0.75 mmPb	5.49 ± 0.43	78.7	78.7	2.95 ± 0.43	78.9	29.3
	0.88 mmPb	2.34 ± 0.85	90.9	90.9	2.95 ± 0.23	78.8	29.3
^{18}F	Syringe shield only	4.85 ± 0.08	83.8	-	1.87 ± 0.07	77.5	-
	0.07 mmPb	4.66 ± 0.08	84.4	3.9	1.54 ± 0.11	81.6	18.0
	0.15 mmPb	4.61 ± 0.04	84.6	5.0	1.67 ± 0.10	80.0	11.0
	0.75 mmPb	3.03 ± 0.05	89.9	37.5	1.09 ± 0.05	87.0	42.0
	0.88 mmPb	3.45 ± 0.08	88.5	29.0	1.09 ± 0.08	87.0	42.0

(*10*), wearing X-ray protective goggles may provide an additional reduction in the exposure of eye lens to radiation, especially in cases of difficulties such as mismatches between syringe and syringe shields.

Shielding effect of combined syringe shield with X-ray protective goggles when handling radiopharmaceuticals

Table 3 shows the results of measurements performed using both a syringe shield and goggles. "Reduction [%] by goggle" in Table 3 is the percentage difference in the 3DER between using only a syringe shield and using both a syringe shield and goggles. At both distances, radiation dose tended to decrease as the lead equivalence of the X-ray protective goggles increased, particularly for ^{131}I and ^{111}In. Dose reduction depended largely on the use of a syringe shield and the source distance for ^{99m}Tc, and on the use of a syringe shield for ^{123}I. When a syringe shield and X-ray protective goggles were both used at a distance of 30 cm from the source, improvements in dose reduction rate were observed for all nuclides. Based on these results, it is considered beneficial to wear X-ray protective goggles in addition to using a syringe shield when the radiation worker should stay close to the radiation source and handle radionuclides with high energy and a long half-life.

In terms of effects on the 3DER and the reduction rate, it is imperative to use X-ray protective goggles with a minimum 0.75 mmPb to fully harness the protective capabilities of it when dealing with all five types of nuclides in clinical settings.

The dose reduction rate achieved using a syringe shield or X-ray protective goggles was lower for ^{131}I than for other nuclides. The reason for this finding appears to be that ^{131}I has an energy of 364 keV and a half-life of about 8 days, which are both higher values than for other nuclides. However, the present results indicate that combined use of a syringe shield with X-ray protective goggles would contribute to improving the dose reduction rate for ^{131}I.

When handling ^{18}F radiopharmaceuticals, the 3DER can be reduced from 8.63 mSv/year to 1.40 mSv/year by using a syringe shield, and that further reductions can be achieved by the combined use of a syringe shield with X-ray protective goggles.

Verification of shielding effect of X-ray protective goggles in simulated patient care

Table 4 shows the results of the shielding effect of X-ray protective goggles for two radionuclides (^{99m}Tc and ^{18}F) at distances of 30 and 60 cm from the NEMA phantom. At all distances and heights, the dose reduction rate improved as lead equivalence increased. The results of the NEMA phantom study indicated that X-ray protective goggles with 0.88 mmPb are

Table 4. Reduction of 3 mm dose equivalent rate by X-ray protective goggles based on NEMA phantom study (distance-dependent variations)

Radionuclide	Height (cm)	Goggle for protection	Distance of 30 cm		Distance of 60 cm	
			3 mm dose equivalent rate (μSv/min/GBq)	Reduction (%)	3 mm dose equivalent rate (μSv/min/GBq)	Reduction (%)
^{99m}Tc	150	None	1.45 ± 0.20	-	1.16 ± 0.35	-
		0.07 mmPb	1.45 ± 0.35	0.0	1.13 ± 0.29	2.5
		0.15 mmPb	1.16 ± 0.20	20.0	0.87 ± 0.29	25.0
		0.75 mmPb	0.87 ± 0.20	40.0	0.58 ± 0.20	50.0
		0.88 mmPb	0.58 ± 0.35	60.0	0.46 ± 0.22	60.0
	165	None	1.04 ± 0.33	-	1.04 ± 0.30	-
		0.07 mmPb	0.87 ± 0.25	16.7	1.04 ± 0.38	0.0
		0.15 mmPb	0.69 ± 0.34	33.9	0.97 ± 0.30	6.9
		0.75 mmPb	0.52 ± 0.48	50.0	0.52 ± 0.40	50.0
		0.88 mmPb	0.52 ± 0.31	50.0	0.52 ± 0.56	50.0
^{18}F	150	None	18.09 ± 1.64	-	14.80 ± 2.01	-
		0.07 mmPb	18.09 ± 0.00	0.0	13.16 ± 2.01	11.1
		0.15 mmPb	16.44 ± 1.64	9.1	11.51 ± 1.64	22.2
		0.75 mmPb	9.87 ± 5.07	45.5	8.22 ± 1.64	44.4
		0.88 mmPb	9.87 ± 1.16	45.5	4.93 ± 2.60	66.7
	165	None	13.81 ± 3.00	-	13.32 ± 1.90	-
		0.07 mmPb	12.83 ± 6.64	7.1	13.32 ± 1.43	0.0
		0.15 mmPb	11.84 ± 1.96	14.3	10.36 ± 1.12	22.2
		0.75 mmPb	9.87 ± 3.08	28.6	7.40 ± 2.32	44.4
		0.88 mmPb	6.91 ± 1.57	50.0	5.92 ± 2.43	55.6

optimal for achieving maximum dose reduction under all circumstances. Even at a source distance of 60 cm, the present results demonstrated the efficacy of X-ray protective goggles for reducing radiation dose, and that this effect was more prominent when using X-ray protective goggles with 0.88 mmPb equivalence.

The use of X-ray protective goggles of 0.75 mmPb equivalence reduced radiation dose for various radiation sources, as found in the assessment of dose to the eyeball in a CT head phantom (Table 2). However, the 0.88 mmPb X-ray protective goggles reduced the dose by more than 50%, which was greater than that with the 0.75 mm X-ray protective goggles in the assessment performed using the NEMA phantom to simulate patient care. Considering the difference between the radiation source and the NEMA phantom, 0.88 mmPb X-ray protective goggles might be the most effective for reducing radiation coming from a wider range of sources.

With reference to background radiation dose in the phantom studies according to the Imaging Guidelines for Phantom Studies (*15,16*), in simulation of the situation of attending to each patient for 10 minutes, for 10 people per day, the estimated radiation exposure received from patients was 6.44 mSv/year for ^{99m}Tc and 11.85 mSv/year for ^{18}F. Under this condition, when exposure during handling of radiopharmaceuticals is also taken into account, the average value over a five-year period could exceed the dose limit for ^{18}F. In simulation of patient care of PET examination, the 3DER can be reduced from 11.85 mSv/year to 6.46 mSv/year by using 0.88 mmPb X-ray protective goggles. In the case of the other nuclides, using this equipment will also contribute to minimizing the 3DER.

The results showed that X-ray protective goggles could reduce the 3DER for the eye lens, and were most effective when combined with a syringe shield. However, it is imperative to use a syringe shield with a minimum equivalence of 0.88 mmPb to fully harness the protective capabilities of X-ray shielding goggles when dealing with all five types of nuclides in clinical settings. Matsutomo *et al.* reported that for X-ray protective goggles, lead equivalence of around 0.75 mmPb or higher is desirable when handling radiopharmaceuticals (*12*), in agreement with the present results. Our study additionally assessed a greater variety of nuclides and conducted a simulation of patient care. However, it is important to note that as the lead equivalence increases, the increasing weight of the goggles and narrowing of the field of view may become burdensome for the wearer, particularly when worn for a long period of time. Moreover, some protective goggles cannot be used while wearing corrective eyeglasses. In addition, lutetium oxodotreotide (^{177}Lu), which has recently been used in Japan as a nuclear medicine treatment for neuroendocrine tumors, has a very high dose of 7.4 GBq per dose, so it is expected that crystalline lens protection glasses specialized for nuclear medicine examinations will be developed in the future.

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