Original Article

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Determination of TRS-398 Quality Factors for Cs-137 Gamma Rays in Reference Dosimetry

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The Cs–137 irradiator is widely used to irradiate biological samples for radiobiological research. To obtain the accurate outcomes, correct measurements of the delivered absorbed dose to a sample is important. The IAEA protocols such as TRS–277 and TRS–398 were recommended for the Cs–137 reference dosimetry. However in TRS–398 protocol, currently known as the most practical dosimetry protocol, the quality factor (k_{Q,Q_0}) for Cs–137 gamma rays is not suggested. Therefore, the use of TRS–398 protocol is currently unavailable for the Cs–137 dosimetry directly. The calculation method previously introduced for high energy photon beams in radiotherapy was used for deriving the Cs–137 beam qualities (k_{Q,Q_0}) for the 15 commercially available farmer type ionization chambers in this study. In conclusion, k_{Q,Q_0} values were ranged from 0.998 to 1.002 for Cs–137 gamma rays. These results can be used as the reference and dosimeter calibrations for Cs–137 gamma rays in the future radiobiological researches.

Key Words: Cs–137 gamma rays, TRS–398 protocol, Quality factor

Introduction

The Cs-137 irradiator is widely used to irradiate biological samples for radiobiological research. Several researches were conducted to determine the absorbed dose to the samples.[1-3] The glass dosimeter is often inserted directly to the samples to determine the absorbed dose to the target.[4] However, the calibration of the solid dosimeters such as glass dosimeter and thermo luminance dosimters is required before utilize them. The reference dosimetry can be performed in a water phantom using a calibrated ionization chamber for the given beam qualities from the International Atomic Energy Agency (IAEA) dosimetry protocols such as TRS-277 and TRS-398. In the previous study, the TRS-277 dosimetry protocol has been introduced in Cs-137 beam dosimetry for the calibration of glass dosimeters.[5] However, applying the TRS-277 protocol for Cs-137 dosimetry is limited because the air kerma based chamber calibration factor is not usually practiced nowadays and is complicated process to determine the individual factors for calibration.[6] In addition to that, the effect of waterproof sleeve for wall correction and central electrode correction was not considered in TRS-277.[6] Therefore, the TRS-398 protocol is more suitable for this purpose since the dose at the reference depth in water can be directly determined using the chamber calibration factor in terms of absorbed dose to water. However, because the quality factor (k_{Q,Q_0}) for Cs-137 gamma rays has not been mentioned in the protocol, the application of TRS-398 protocol is currently not available. Generally, the quality factors of the ionization chambers were suggested in TRS-398 protocol based on the photon beam quality ($TPR_{20,10}$). In this study, the quality factors for Cs-137 gamma rays were calculated by the calculation method previously introduced for high energy photons and electrons used in radiotherapy.[6] The k_{Q,Q_0} values for 15 commercially avaliable farmer type ionization chambers were calculated. Because the

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Cs-137 irradiators were widely used in radiobiological research, establishment of dose calibration and verification system is important to improve the accuracy of the experimental results.

Materials and Methods

1. Ionization chambers

The 15 farmer type ionization chambers were selected in this study. The listed chambers and physical characteristics used for calculating the quality factors were shown in Table 1.[7] The cavity radius was used for calculating the displacement effect and wall material, wall thickness, and the type of central electrode were used for calculating the overall correction factors including the perturbation by chamber wall (wall corrections).

2. Beam quality of Cs-137

The water to air stopping power ratio ($s_{w,air}$) can be determined by the relationship given by Andereo[7,12)]

$$s_{w,air} = 1.3614 - 1.2963\,TPR_{20,10} + 2.5302\,TPR_{20,10}^2 + 1.6896\,TPR_{20,10}^3, \qquad (1)$$

where $TPR_{20,10}$ is the tissue-phantom ratio in water at depths of 20 and 10 g/cm^2, with the field size of 10 cm×10 cm at a source to chamber distance of 100 cm. The $TPR_{20,10}$ is used as the beam quality index for high energy photon beams. According to the TRS-277 protocol, the stopping power ratio ($s_{w,air}$) for Cs-137 gamma rays is 1.136.[6] In equation (1), the $TPR_{20,10}$ calculated from the $s_{w,air}$ of 1.136 was 0.46. Therefore, $TPR_{20,10}$=0.46 was taken for a beam quality of Cs-137 gamma rays in this study. Andereo has reported $TPR_{20,10}$=0.476～0.488 using a direct Monte Carlo calculation and other methods for Cs-137 photon beams[12] but the values were not applied in this study. Further study should be done with these values in future.

3. Quality factor calculation

According to the IAEA TRS-398 protocol, the quality factor (k_{Q,Q_0}) for a given radiation quality can be expressed,[7]

$$k_{Q,Q_0} \simeq \frac{[s_{w,air}\ P_Q]_Q}{[s_{w,air}\ P_Q]_{Q_0}} \qquad (1)$$

where, $s_{w,air}$ is the average stopping power ratio between water and air for electrons liberated from the radiation and P_Q is the overall perturbation factor including all the departures from the behaviour of an ideal cavity in Bragg-Gray theory. The P_Q is expressed as $P_Q = [p_{cav}\, p_{dis}\, p_{wall}\, p_{cel}]_Q$, where p_{cav}, p_{dis}, p_{wall}, p_{cel} are the correction factors for cavity perturba-

Table 1. Farmer type ionization chambers and its physical data used in this study.

Manufacturer	Model	Cavity volume (cm^3)	Cavity radius (cm)	Wall material	Wall thickness (g/cm^2)	Central electrode
Capintec	PR06C/G Farmer	0.65	0.32	C-552	0.050	C-552
Exradin	A12 Farmer	0.65	0.31	C-552	0.088	C-552
Nuclear Assoc.	30-751 Farmer	0.69	0.31	Delrin	0.056	Al
Nuclear Assoc.	30-752 Farmer	0.69	0.31	Graphite	0.072	Al
NE	2571 Farmer	0.6	0.32	Graphite	0.065	Al
NE	2581 Farmer	0.6	0.32	A-150	0.041	A-150
PTW	23333 Farmer	0.6	0.31	PMMA	0.053	Al
PTW	30001/30010 Farmer	0.6	0.31	PMMA	0.045	Al
PTW	30002/30011 Farmer	0.6	0.31	Graphite	0.079	Al
PTW	30004/30012 Farmer	0.6	0.31	Graphite	0.079	Al
PTW	30006/30013 Farmer	0.6	0.31	PMMA	0.057	Al
SNC	10073 Farmer	0.6	0.35	PMMA	0.060	Al
SNC	10074 Farmer	0.6	0.35	Graphite	0.085	Al
Sctronix-Wellhofer	69(FC65P) Farmer	0.67	0.31	Delrin	0.068	Al
Sctronix-Wellhofer	70(FC65G) Farmer	0.67	0.31	Graphite	0.068	Al

tion, displacement of the measuring point, perturbation by chamber wall, and central electrode effect respectively. The cavity correction factor accounts for the perturbation of the electron fluences due to the difference in scattering between the air cavity and the medium. The displacement correction factor accounts for the effective point of measurement. The wall correction factor accounts for the differences in the photon mass energy absorption coefficients and electron stopping powers of the different chamber wall materials and the reference media.[10] The central electrode correction factor accounts for the lack of air equivalence of the central electrode.[11]

The wall correction factor (p_{wall}) for Cs-137 gamma rays was calculated using the given stopping power ratio ($s_{wall,air}$) for wall and sleeve materials and the mass energy absorption coefficient ratio ($(\overline{\mu_{en}}/\rho)_{w,wall}$) for wall and sleeve materials in TRS-277. The k_{Q,Q_0} value was directly derived from equation (1) with the given individual factors. In P_Q calculation, $p_{cav}=1$ as mentioned in TRS-398 protocol, and p_{dis} and p_{wall} values for Cs-137 gamma rays were calculated with the formulas described in TRS-398 protocol. The calculation process for high energy photon beams to produce the quality factors was introduced by Ref. 8 and 9 in detail.[8,9]

Results

The quality factors (k_{Q,Q_0}) for PTW-30013 farmer type ionization chamber as a function of beam quality ($TPR_{20,10}$) were shown in Fig. 1. The calculated quality factors between $TPR_{20,10}$=0.50 and 0.85 were in good agreement with the values in TRS-398 protocol. In Fig. 1, the line was from the values in TRS-398 protocol and the value below $TPR_{20,10}$=0.50 was extrapolated using sigmoid fit function for the comparison with the calculated Cs-137 gamma rays quality factors. The individual physical quantities used in the calculation was shown in Table 2. The k_{Q,Q_0} values given in TRS-398 protocol were also shown in Table 2. The k_{Q,Q_0} values derived from the two

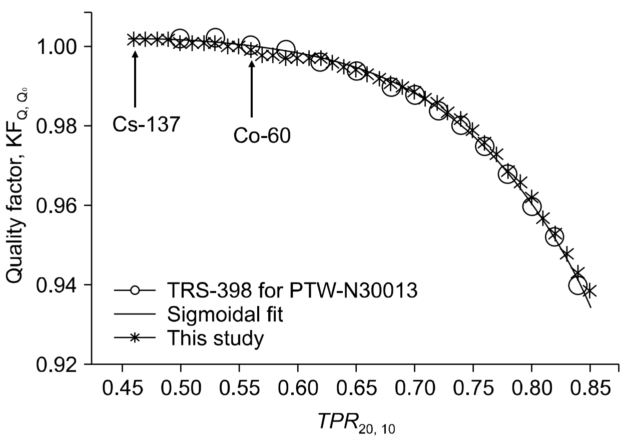

Fig. 1. Quality factors including Cs-137 gamma rays determined in this study. The quality factor for Cs-137 is slightly higher than that of Co-60 gamma rays.

Table 2. Individual physical quantities used for the calculation of quality factor for PTW-30012 ionization chamber for Cs-137 and Co-60 gamma rays. The expected quality factor extrapolated from the sigmoidal fit function with the TRS-398 data was slightly higher than the calculated value as shown in the table.

Physical quantity		Cs-137	Co-60
$s_{w,air}$		1.136	1.133
p_{cav}		1.000	1.000
p_{dis}		0.988	0.988
p_{wall}		1.002	1.001
p_{cel}		0.991	0.993
P_Q		0.981	0.982
$s_{w,air}\,P_Q$		1.114	1.113
k_{Q,Q_0}	This study	1.002	
	TRS-398 (Sigmoidal fit)	1.003	

Table 3. Quality factors for a Cs-137 gamma rays for 15 farmer type ionization chambers.

Manufacturer	Model	Cavity volume (cm^3)	k_{Q,Q_0} (Cs-137)
Capintec	PR06C/G Farmer	0.65	0.998
Exradin	A12 Farmer	0.65	1.000
Nuclear Assoc.	30-751 Farmer	0.69	1.000
Nuclear Assoc.	30-752 Farmer	0.69	1.001
NE	2571 Farmer	0.6	1.001
NE	2581 Farmer	0.6	1.010
PTW	23333 Farmer	0.6	1.002
PTW	30001/30010 Farmer	0.6	1.002
PTW	30002/30011 Farmer	0.6	1.001
PTW	30004/30012 Farmer	0.6	1.001
PTW	30006/30013 Farmer	0.6	1.002
SNC	10073 Farmer	0.6	1.002
SNC	10074 Farmer	0.6	1.001
Sctronix-Wellhofer	69 (FC65P) Farmer	0.67	1.001
Sctronix-Wellhofer	70 (FC65G) Farmer	0.67	1.001

independent methods were overlapped each other. In this manner, the calculated k_{Q,Q_0} of Cs-137 gamma rays for 15 ionization chambers were shown in Table 3. The quality factors were slightly higher than that of Co-60 gamma rays ($k_{Q,Q_0}=1$).

Discussion and Conclusions

The quality factors for Cs-137 gamma rays were determined by applying the TRS-398 dosimetry protocol for radiobiological researches. As a result, reference dosimetry using a ionization chamber calibrated in terms of water can be performed to determine the irradiation condition or to calibrate the dosimeters used for verifying dose delivery in biological experiments. Since the irradiators equipped with Cs-137 source are widely used in radiobiological research, the results are expected to improve the accuracy of the experimental outcomes.

In determination of quality index ($TPR_{20,10}$) for Cs-137 beam quality, the published formula was used only in this study, but direct measurement of $TPR_{20,10}$ was also considered. However the measurements should have been performed for 10 cm×10 cm field size at the reference SSD or SCD from the definition of $TPR_{20,10}$. Because of fixed collimator system of the irradiator, an additional collimator was required to configure the recommended conditions. Further studies on the idea should be conducted.

As mentioned before, because of lack of k_{Q,Q_0} factors below $TPR_{20,10}$=0.50 in TRS-398 protocol, the interaction data such as $s_{wall,air}$ and $(\overline{\mu_{en}}/\rho)_{w,wall}$ below $TPR_{20,10}$=0.50 including Cs-137 gamma rays should be studied to determine the quality factors precisely. These approaches are important to improve the photon beam dosimetry techniques.

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Cs-137 감마선의 선량측정을 위한 TRS-398 선질인자 결정에 관한 연구

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Cs-137 방사선 조사기는 방사선생물 연구 분야에서 시료에 방사선 조사장치로 널리 사용되고 있다. 이러한 방사선 조사기 사용에 있어 시료에 조사되는 흡수선량의 평가는 향상된 연구 결과를 얻기 위하여 중요하다. 국제원자력기구의 TRS-277 또는 TRS-398 같은 선량측정 프로토콜은 이러한 목적에 적합하다. 그러나 현재 가장 실용적인 선량측정 프로토콜로 알려진 TRS-398의 경우에 Cs-137 선원에 대한 선질인자가 제공되지 않는 단점이 있다. 본 연구에서는 이전에 보고된 고에너지 방사선치료용 광자선에 대한 계산방법을 이용하여 Cs-137 선원의 선질인자를 결정하였으며 15종의 파머형 전리함에 대하여 선질인자를 결정하였다. 결과로서 대상전리함에 대한 Cs-137 선원에서 선질인자는 0.998에서 1.002 범위를 보였다. 이 결과는 Cs-137 선원을 사용하는 분야에서 물흡수선량 측정과 선량계의 교정에 유용하게 사용할 수 있을 것으로 본다.

중심단어: Cs-137 감마선, TRS-398 프로토콜, 선질인자