Journal of NUCLEAR SCIENCE and TECHNOLOGY, Supplement 4, p. 299–302 (March 2004)

Analysis of Design Characteristics of Cylindrical Ion Chamber Made by KAERI : A Comparison between EGSnrc, MCNP, and Experiment

Jae Cheon KIM[1,*], Jong Kyung KIM[1], Yong Kyun KIM[2] and Se Hwan PARK[2]

[1] *Hanyang University, Haengdang-dong, Seongdong-gu, Seoul, Korea*
[2] *Korea Atomic Energy Research Institute, Deokjin-dong, Yuseong-gu, Daejeon, Korea*

In this study, the absorbed dose of inner gas of cylindrical ion chambers designed and fabricated by cooperation with KAERI (Korea Atomic Energy Research Institute) was calculated and measured to review the design characteristics. Using Monte Carlo codes such as EGSnrc (DOSRZnrc) and MCNP4C, a series of calculations were performed to evaluate whether the electric current linearly increase with incident gamma energy or not. Some calculations and measurements were performed to investigate the current variation of the ionization chamber as the incident angle of gamma-rays changed from 0° to 90°. To improve the angular dependency, the ionization chambers with a round-type window (KAERI-SR and KAERI-LR) were considered. The short round-type (KAERI-SR) was found to be less dependent upon incident source angle compared with the other two types. The maximum current reduction of KAERI-F, KAERI-SR, and KAERI-LR is 6%, 22%, and 10%, respectively. The absorbed dose of inner gas was calculated in order to review the influence caused by length variations of collecting electrode for the flat-type ionization chamber. The length was changed from 10mm to 20mm by 2.5mm. Although the current efficiency of the ionization chamber was maximized at 12.5mm, the current difference between the length variations is within 1%, negligible.

KEY WORDS: Ionization Chamber, Design Characteristics, Radiation Detector, EGSnrc, MCNP4C

I. Introduction

Although a lot of methods for measuring radiation dose have been developed, ionization dosimetry still retains its position as the most widely used, most convenient and most accurate method of measuring either exposure or absorbed dose. In recent years, much attention has been paid to radiation detector technology in Korea as the industry needs radiation technology more and more.

The air-filled ionization chamber is required to satisfy some standards for measuring the absorbed dose of inner gas, which is transformed to the electric current by difference of voltage between cathode and collecting electrode.

The newly designed ionization chamber is necessary to be reviewed whether the electric current linearly increases with incident radiation energy or not and whether it is dependent upon the incident source angle or not. Hence, the above two were analyzed intensively in this study.

The absorbed dose of the ionization chambers, that can be directly transformed to the electric current in this work, was calculated to review the design characteristics and to find more efficient and optimized chamber using EGSnrc[1)], and MCNP4C[2)]. EGSnrc and MCNP4C were individually upgraded from EGS4 (SLAC) to EGSnrc (NRCC) and from MCNP4B to MCNP4C (Los Alamos) in 2000. These are well known and widely used for photon/electron transport.

DOSRZnrc[3)], that is the one among NRC user codes, is included in EGSnrc. In this work DOSRZnrc was used for simulation of EGSnrc. Based on the calculations of EGSnrc and MCNP4C, newly designed three ionization chambers were fabricated and experimental measurements were performed.

* Corresponding author, Tel. +82-2-2299-1732, Fax. +82-2-2294-4800, E-Mail; macpie@nural.hanyang.ac.kr

II. Design and Fabrication

Three types of the ionization chambers were designed and fabricated as shown in **Fig.1**. These are based on the Exradin A12 Farmer type ionization chamber. The Exradin A12 chamber is a farmer-type thimble chamber and is made of air-equivalent plastic C552. The chamber is particularly suited for calibration of therapy beams in terms of absorbed dose in water in accordance with established protocols such as that published by the American Association of Physicists in Medicine.

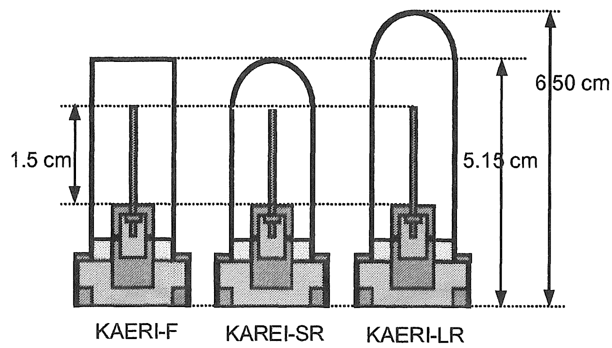

Fig. 1 The cross-sectional view of the ionization chamber with various window type designed and simulated.

KAERI-F is the ionization chamber with flat-type window. KAERI-SR and KAERI-LR have a round-type window. The former is short and the latter is long. The ionization chambers with round-type window (KAERI-SR and KAERI-LR) were introduced to improve the angular dependency in this work. All of the chambers have the cavity diameter of 12mm and the cavity length of about 28mm. The wall thickness is 1mm. The length and the diameter of the collecting electrode were 15 mm and 1mm, respectively.

Most part of the ionization chamber such as wall, window, and collecting electrode consist of PVDF (Polyvinylidene fluoride) known for air-equivalent plastic. Teflon is used as insulation material of guard region between electrode and wall. The detector was filled with the typical air gas. **Fig. 2** shows the picture of the ionization chamber with flat-type window.

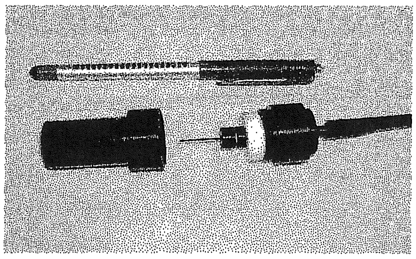

Fig. 2 The flat-type ionization chamber fabricated.

III. Simulations and Measurements

The present investigation focused on the angular dependency, the energy linearity of the ionization chamber, and the influence on length variations of collecting electrode. ^{241}Am and ^{137}Cs were used as the source for simulation and experiment. The distance to source from the rotation point of the ionization chamber is 7cm. The rotation point is 1.77cm under the surface of window of flat-type ionization chamber.

The *dose and stoppers* was used for tally option (IFULL) of DOSRZnrc. The maximum fractional energy loss per step (ESTEPE) and photon/electron energy cut-off was 0.25 and 1keV, respectively. For MCNP4C, F8* tally, which estimates the energy deposited in the cell, was used for dose calculation. The energy cut-off for photon was 1keV, which was the same as in DOSRZnrc. DOSRZnrc has a difficulty in modeling the ionization chamber with the round-type window because the code only supports RZ-geometry. Therefore, the approximation was used for simulating round-type window in DOSRZnrc as shown in **Fig. 3**.

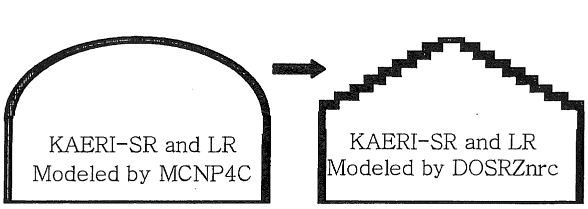

Fig. 3 The approximation used for reproducing the round-type window in DOSRZnrc

Monte Carlo codes cannot directly simulate the electric current. But the absorbed dose of inner gas of ionization chamber can be easily calculated. In this context, this study introduced a conversion factor of W-value, which was defined as the average energy needed for producing one ion-pair as the radiation goes through any specific gas. Finally, the electric current of the ionization chamber can be easily obtained by the calculated absorbed dose and W-value, as follows:

$$\text{Electric current} = \frac{\text{Absorbed dose}}{\text{W-value}} . \qquad (1)$$

1. Monte Carlo calculation

The electric current of the designed ionization chamber was computed to review the energy linearity with the incident gamma-ray energy. The gamma-ray energy changed from 40keV to 1MeV, and current variations are shown in **Fig. 4**.

The results of simulation show that the electric current of KAERI-F and KAERI-SR linearly increases with the incident gamma-ray energy. The solid and the dotted line linearly fit the results of the MCNP4C and EGSnrc for the flat-type window, respectively.

The electric current calculated by MCNP4C tends to be greater than that by DOSRZnrc. The current of MCNP4C was greater than that of EGSnrc in KAERI-F, about 7.2% and in KAERI-SR, about 31.7%. Most statistical error was within 5%. However, the error reached 15% in the calculation of the electric current of the ionization chamber with round-type window. It is attributed to the fact that the inner gas was modeled by the air-filled and very small cell in DOSRZnrc calculation for the ionization chamber with round-type window.

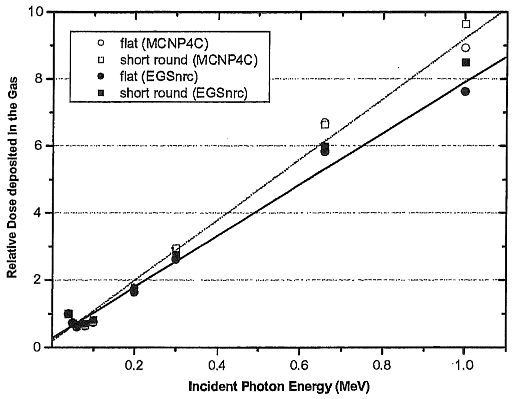

Fig. 4 The current variations of the ionization chamber by changing incident gamma-ray energy from 40keV to 1MeV calculated by EGSnrc, MCNP4C

For the analysis of angular dependency of the ionization chamber, the source angle was changed from zero degree to 90 degree. The source in the reference case was located vertically above the window of the ionization chamber in **Fig. 5**. The electric current was normalized to the value in the reference case of zero degree. Therefore, the normalized electric current is obtained by

$$\text{Normalized electric current} = \frac{\text{The current at a certain angle}}{\text{The current at the reference angle}} \quad . \quad (2)$$

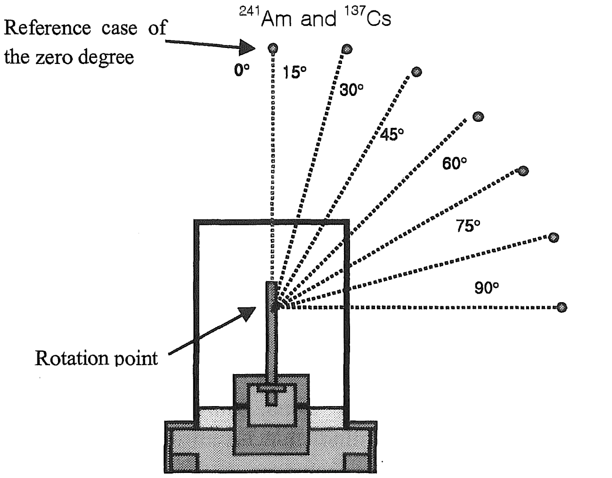

Fig. 5 The variation of the source angle incident on the ionization chamber

When ^{241}Am was used as the source, the current reduction calculated by DOSRZnrc and MCNP4C was within 13% and 22% in KAERI-LR ionization chamber, respectively. The current reduction was within 7% in DOSRZnrc and within 10% in MCNP4C for KAERI-F, respectively.

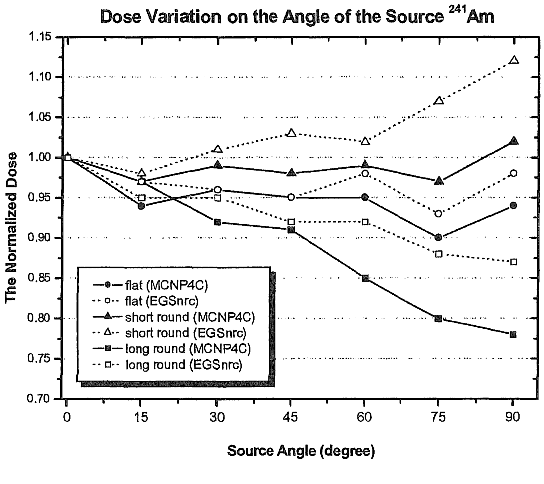

Fig. 6 The comparison of the doses of KAERI-F, KAERI-SR, and KAERI-LR produced by ^{241}Am

When ^{137}Cs was used, the difference between the dose of the zero degree and those of any other degrees was shown in **Fig. 7**. As a whole, the variation of the electric current by changing source angle tends to increase with the incident source energy. DOSRZnrc calculations using approximate window surface, i.e. KAERI-SR and LR, have a tendency not to agree with[3] MCNP4C results whereas those calculations for the ionization chamber with the flat-type window were in well agreement with MCNP4C results. The statistical error was similar to that by the calculation for energy linearity of the ionization chamber.

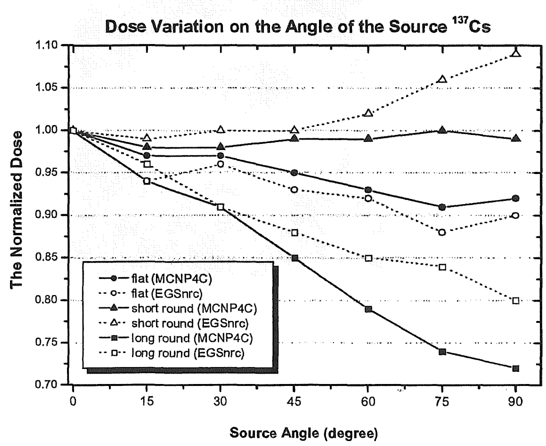

Fig. 7 The comparison of the doses of KAERI-F, KAERI-SR, and KAERI-LR produced by ^{137}Cs

Through DOSRZnrc calculations, the influence on length variations of collecting electrode was investigated on the KAERI-F. The designed original length of collecting electrode of KAERI-F is 15mm. The length was changed from 10mm to 20mm by 2.5mm. In this work, two methods were used to estimate the efficiency of the ionization chamber. First, the total volume of air gas producing current was fixed and the inner wall diameter was changed. Second, the volume was changed and the inner diameter was fixed with the length variations.

As shown in **Fig. 8**, the maximum current was at 12.5mm. But the difference of the current was calculated within ± 1%, which was found to be negligible.

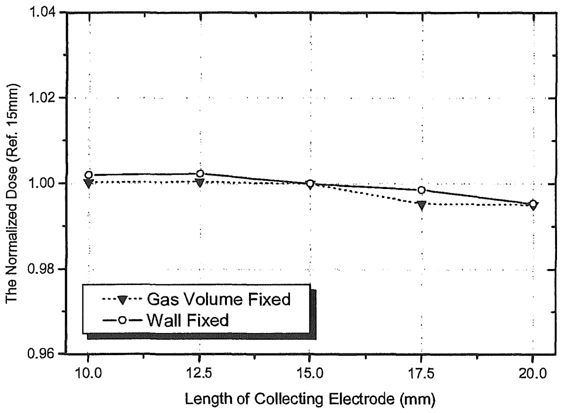

Fig. 8 The variation of the electric current according to changing the length of collecting electrode

2. Experimental measurements

Fig. 9 shows experiment to estimate the angular dependency of KAERI-SR. The experiment on the KAERI-F and KAERI-LR were also implemented in the same condition.

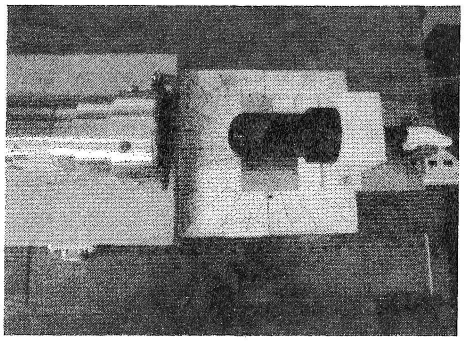

Fig. 9 The experiment for analysis of angular dependency using short round-type ionization chamber

Fig. 10 shows the experimental measurements with the variation of the incident source angle when ^{241}Am and ^{137}Cs were used. For ^{241}Am, the current reduction of KAERI-F, KAERI-SR, and KAERI-LR was within 6.5%, 2.6%, and 18.6%, respectively. For ^{137}Cs, the maximum difference of KAERI-F and KAERI-SR was within 7.4% and 5.9%, respectively. For KAERI-SR, the deviation of MCNP dose from experiment is 4.0% and 8.2% in case of ^{241}Am and ^{137}Cs, respectively. The deviation of EGSnrc from experiment is 16.5% at ^{241}Am and 20.7% at ^{137}Cs.

The experimental measurements of the round-type ionization chambers were well agreed with calculations of MCNP4C, since MCNP4C is able to accurately simulate the geometry of the ionization chambers having round-type window. Meanwhile, for the flat-type ionization chamber, KAERI-F, there is less difference compared with the KAERI-SR with round-type window.

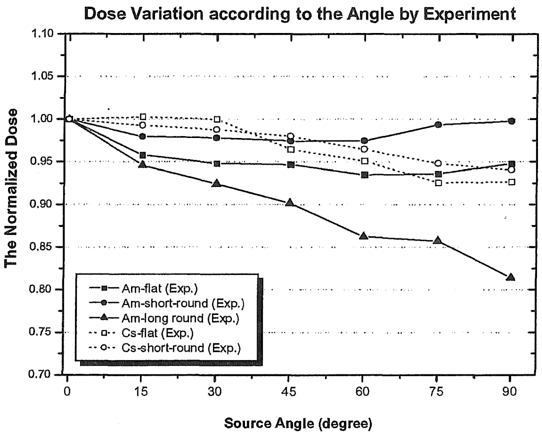

Fig. 10 The current variations measured by experiment with the incident source angle

IV. Summary

Through Monte Carlo simulation, the electric current of all the designed ionization chambers linearly increased with the incident gamma-ray energy. KAERI-SR was less dependent upon the source angle than the other types. The maximum difference was within 5.9%. It was found that the efficiency of KAERI-F was the best when the collecting electrode was 12.5mm in length but the difference was negligible, within 1%.

In the mean while, although EGSnrc uses class II Monte Carlo model for simulating photon and electron transport, MCNP4C results are better agreement with experiment compared with EGSnrc in this work because the geometric defect occurred in EGSnrc modeling.

V. Conclusions

In this work, three types of the ionization chamber, KAERI-F, KAERI-SR, and KAERI-LR, were designed and fabricated. In the results of simulation, we verified the energy linearity of the three ionization chambers. In addition, it was also found that the angular dependence of the ionization chamber decreases as the ionization chamber is short and has a round-type window.

Acknowledgement

This work has been supported financially by iTRS (innovative Technology Center for Radiation Safety) and KAERI (Korea Atomic Energy Research Institute).

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