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■ 論 文 ■

A Study on the Angular Dependence of the PB-3 Dosimeter Using Teledyne 9150 TLD Reader System

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ABSTRACT

An angular dependence experiment was made and a performance test of the Teledyne dosimetry system was done in accordance with the ANSI N13.11-1992. The angular dependence experiment was performed with ^{137}Cs and low energy X-ray beam. Teledyne dosimetry system performed well at the 0° angle of incidence for all dosimeters in both vertical and horizontal irradiations. It would have easily passed the 0.5 tolerance limit. But the dosimetry system was not performed well at the ±60° angle of incidence for low energy X-ray beam. The accuracy for ^{137}Cs beam at all angles of incidence was within the 0.5 tolerance limit. Therefore performance of the dosimetry system could be considered acceptable in case that the dosimeter is irradiated to ^{137}Cs beam. However, it could not be acceptable for the dosimeter irradiated to low energy X-ray, especially at more than ±40°.

Key Words : Dosimetry system, angular dependence, performance test

INTRODUCTION

Thermoluminescent dosimeters (TLDs) are used for the personnel radiation monitoring at nuclear installations, especially at the nuclear power plants (NPPs). The response of TLDs to the radiation field, in fact, varies with the direction of incident radiation. Meanwhile algorithms for determination of dose equivalent are developed based on the response of TLDs to radiation incident perpendicularly on the dosimeters[1]. In actual cases, the field conditions are much more complicated. The accuracy of the evaluated dose has imposed some limitation. Two major sources of error in personnel dosimetry are the energy response and angular response of personal dosimeters[2]. Compared with energy response, the angular response problems of the dosimeters have not received much attention or studied until recently[3, 4].

In the United States, the dosimetry performance testing standard of the American National Standards Institute, N13.11(ANSI N13.11)[5], is used to test the dosimetry performance of dosimetry processors as a part of the dosimetry accreditation program of the National Voluntary Laboratory Accreditation Program(NVLAP)[6] since 1983. ANSI N13.11[5] requires that, for every dosimeter design submitted for testing, a study of processor performance with dosimeter under multidirectional irradiation should be carried out once by the testing laboratory. However, no pass-fail criterion is given for angular dependence[7]. A key reason for this is that the appropriate dose equivalent quantity, which can reasonably estimate the effective dose equivalent, H_E, in a multidirectional radiation field with reasonable conservatism, has not bean agreed upon by the US health physics community[2].

In 1992, ANSI N13.11[8] has been revised by the review committee formed for periodic review of the stnadard as specified by ANSI policy. A pass-fail criterion for angular dependence is specified in revised ANSI N13.11[8]. The TLD irradiation under multidirectional radiation incidence is thus required.

The main purpose of this study is to investigate the angular dependence of a dosimeter(PB-3) in accordance with revised ANSI N 13.11 with the Teledyne 9150 Reader System being using at NPPs in Korea and at the Korea Atomic Energy Research Institute (KAERI).

PERFORMANCE TEST

For photons, numerical values for the shallow and deep dose equivalent are assigned as [8]

$$H_s = \bar{c}_{K,s} K_a \text{ and } H_d = \bar{c}_{K,d} K_a \quad (1)$$

where K_a is the air kerma measured at the location of the center of the front face of the phantom, and $\bar{c}_{K,s}$ and $\bar{c}_{K,d}$ are conversion factors from air kerma to shallow dose equivalent and deep dose equivalent, respectively.

The air kerma is related to exposure X in roentgen by the equation[9]

$$rads = \frac{87.7}{100} \times \frac{(\mu_{en}/\rho)_m}{(\mu_{en}/\rho)_a} \times roentgens \quad (2)$$

where $(\mu_{en}/\rho)_m$ is the mass energy absorption coefficient for tissue and $(\mu_{en}/\rho)_a$ is the mass

Table 1. Dose Equivalent Conversion Factors.

Average Energy (keV)	C_K (Sv/Gy) shallow	C_K (Sv/Gy) deep
20	1.04	0.47
34	1.30	1.07
51	1.62	1.65
662(^{137}Cs)	1.21	1.21

energy absorption coefficient for air.

For irradiation at normal incidence the values for the conversion factors from air kerma at specified depth, d, $C_K(d)$, are taken from Table 1. For irradiation with photons at various incident angles, α, the values for the conversion factors from air kerma at specified depth, d, $C_K(d, \alpha)$, are calculated by the following equation,

$$C_K(d, \alpha) = C_K(d) \times ARF(d, \alpha) \quad (3)$$

where $ARF(d, \alpha)$ is angular response factor taken from Table 2 for the particular angle used for the irradiation. Conversion factors and Angular response factors were calculated by interpolation method.

Performance in a test category shall be considered acceptable if, for the deep and shallow dose equivalents,

$$|B| + S - E \leq L \quad (4)$$

where B is the bias, S is the estimate of the standard deviation of the performance quotient, E is the testing laboratory's estimate of the uncertainty in the delivered dose equivalent and L is the tolerance level. The values of E shall not exceed 0.05. In the case of varied angles of incidence, the tolerance levels of deep dose equivalent and shallow dose equivalent are 0.5.

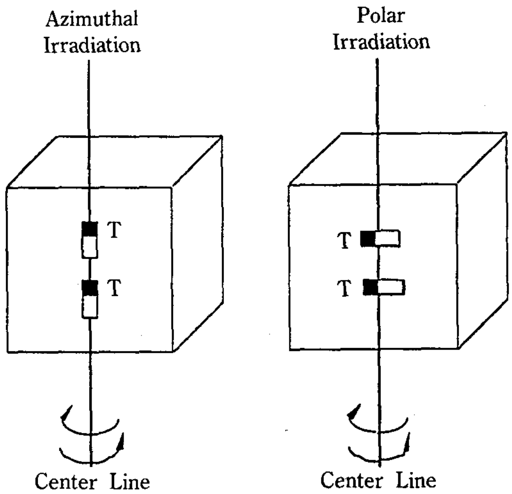

Fig. 1. Irradiation Setup for the Angular Dependence Experiment.
Clockwise : Positive Angle
Counterclockwise : Negative Angle
Dark Area is the open window section of PB-3 badge.

Table 2. Angular Response Factors(ARF) Based on the Dose Equivalent.

Average Energy (keV)	Angle of ±40°		Angle of ±60°	
	shallow	deep	shallow	deep
20	0.995	0.885	0.981	0.660
34	0.970	0.928	0.902	0.760
51	0.970	0.929	0.905	0.783
662(^{137}Cs)	1.000	0.989	1.000	0.949

ANGULAR DEPENDENCE EXPERIMENT

The irradiation setup for the angular dependence study is shown in Figure 1. The number of dosimeters used in this experiment was 180 for $CaSO_4 : Dy$ Radi-Guard dosimeters. Two dosimeters as a group were irradiated on the vertical center line of a polymethyl methacrylate (PMMA) slab phantom ($30 \times 30 \times 15\ cm^3$) at a certain front incident angle. For experiments of azimuthal angle dependency, the open window of the dosimeter was toward the top of phantom. For experiments of polar angle dependency, the open window of the dosimeter was toward the left side of phantom. Clockwise rotaion of

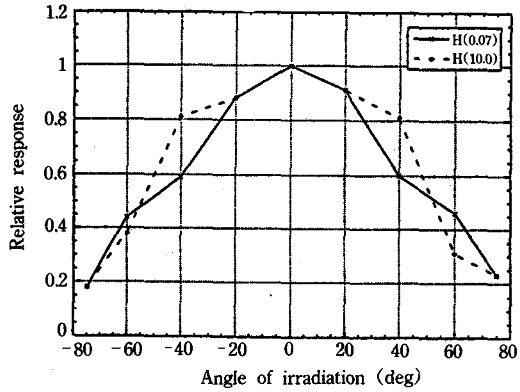

Fig 2. Angular Response of $CaSO_4 : Dy$ Dosimeters to 36 keV X-ray in the Azimuthal Irradiation.

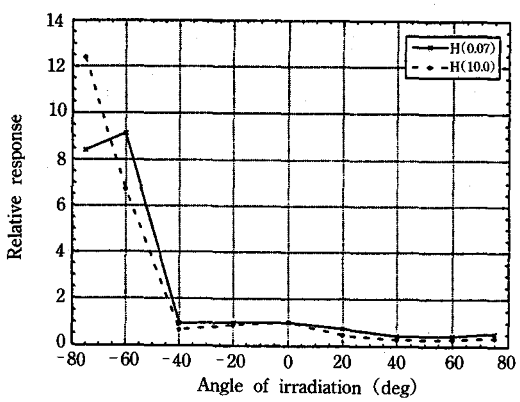

Fig 3. Angular Response of $CaSO_4 : Dy$ Dosimeters to 27 keV X-ray in the Polar Irradiation.

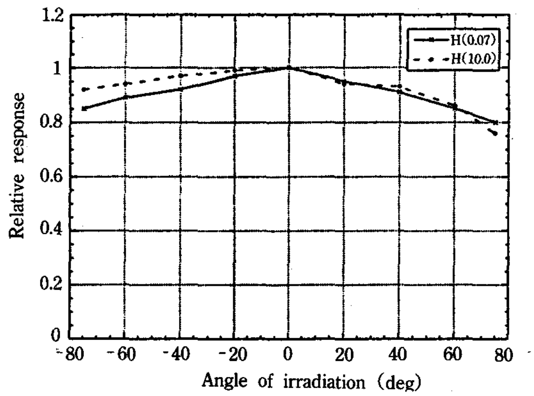

Fig 4. Angular Response of $CaSO_4 : Dy$ Dosimeters to ^{137}Cs in the Azimuthal Irradiation.

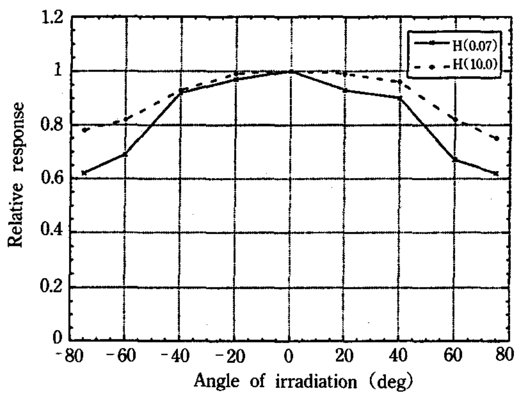

Fig 5. Angular Response of $CaSO_4 : Dy$ Dosimeters to ^{137}Cs in the Polar Irradiation.

the phantom about the rotational axis is denoted as positive angle of incidence and counterclockwise rotation as negative angles. Therefore, the terms azimuthal-positive, azimuthal-negative, polar-positive, and polar-negative irradiations indicate that the radiations incident upon the TLD are from the right, left, top, and bottom side of the TLD, respectively. The angles of incidence was $-75°$, $-60°$, $-40°$, $-20°$, $0°$, $20°$, $40°$, $60°$, and $75°$. The distance of source to vertical centerline of the phantom surface was 100 cm for all irradiation.

The photon beams used for this experiment were produced with a X-ray generator (Model MG-320 : Philips Co.) and ^{137}Cs. Transmission chamber(IQ-4, PTW-FREIBURG) was used tomaintain good X-ray beam quality from X-ray generator. Because of mechanical problem, effective energies of X-ray were determined only at low energy. Effective energies of X-ray which were determined in the Secondary Standard Radiation Laboratory (SSRL) at KAERI were different from those of ANSI N13.11. But this procedure will be applied to the energies of ANSI N13.11. $CaSO_4$: Dy dosimeters were exposed to 500 mR and stored at 17°C in dark room for 2 days after X-ray and ^{137}Cs irradiation.

RESULTS AND DISCUSSION

A reported dose equivalent was determined for the shallow and deep depths for each dosimeter. Some typical results of angular dependence experiment were shown in Figure 2 through 5. The dose equivalent was recalculated using fading correction factor for each dosimeter and ECFs for each element of each dosimeter.

For low X-ray in the azimuthal irradiation, the angular dependence of the exposed dosimeter was higher than for ^{137}Cs irradiation. The minimum relative responses of $CaSO_4$: Dy in azimuthal irradiation were 0.22, 0.18, 0.20, and 0.41 in the case of shallow dose equivalent and 0.29, 0.18, 0.16, and 0.34 in the case of deep dose equivalent at energies of 27 keV, 36 keV, 46 keV, and 51 keV, respectively. This decrease was caused by increase of effective attenuation in filters as irradiation angles were increased. But as the energy increased, the angular dependence was decreased. The relative responses of polar irradiation of X-ray were sharply increased at $-40°$. This increase in polar irradiation was caused mainly by the asymmetry of PB-3 badge case. When X-ray penetrates the PB-3 badge from open window region (A1), X-ray is streaming through the gap between filters and dosimeter due to low energy. So the raw data of A4 which is main region for dose assessment will be much higher than other regions. The high raw data for A4 cause this problem.

In ^{137}Cs irradiation, the minimum relative responses of $CaSO_4:Dy$ in azimuthal irradiation is 0.80 in the case of shallow dose equivalent and 0.76 in the case of deep dose equivalent. In polar irradiation the minimum relative responses of $CaSO_4:Dy$ is 0.62 in the case of shallow dose equivalent and 0.75 in the case of deep dose equivalent. In ^{137}Cs irradiation, the effect of angular dependence for both azimuthal and polar irradiation was smaller than the case of X-ray irradiation. Because ^{137}Cs is a high energy gamma source (0.66 MeV), attenuation of photons in the filters is not significant so the angular dependence becomes smaller than the case of X-ray irradiation. In polar irradiation, gamma ray is not streaming through the gap due to higher energy. So the sharp increase in the case of X-ray irradiation was not shown up.

As mentioned earlier, the main purpose of this study is to examine the angular dependence of Teledyne (PB-3) dosimeter. A performance test for angular dependence of the dosimeter was performed in accordance with the revised ANSI N13.11. As shown in Figure 1, each set attached on phantom for this angular dependence study involved two dosimeters. Selected angles for testing were 0°, ±40°, and ±60° as specified in the revised ANSI N13.11. The dosimeters were processed using the ECFs for each dosimeter. The dosimetry performance results for sets of two dosimeters irradiated at fixed angles to a given radiation beam in polar and azimuthal irradiation are listed in Tables 3 and 4.

Teledyne dosimetry system performed well at the 0° angle of incidence for all dosimeters in both azimuthal and polar irradiations as shown in Tables 3 and 4. It would have easily passed the 0.5 tolerance limit of Eq. (4). It was clear that as the angle of incidence increased, the dosimetry performance result($|B|+S-E$) of the dosimetry system dec-

Table 3. Dosimetry Performance Results($|B|+S-E$) for Sets of Two $CaSO_4:Dy$ Dosimeters for Azimuthal Angle Dependency.

Angle	Depth	27 keV	36 keV	46 keV	51 keV	^{137}Cs
−60	shallow	0.37	0.35	0.32	0.48	0.23
	deep	0.55	0.66	0.49	0.66	0.06
−40	shallow	0.22	0.37	0.19	0.38	0.32
	deep	0.42	0.28	0.38	0.48	0.10
0	shallow	0.08	0.16	0.01	0.23	0.35
	deep	0.20	0.38	0.36	0.43	0.08
40	shallow	0.27	0.20	0.32	0.41	0.30
	deep	0.43	0.47	0.48	0.47	0.03
60	shallow	0.35	0.33	0.33	0.51	0.18
	deep	0.49	0.72	0.48	0.67	0.01

Table 4. Dosimetry Performance Results(| B | +S—E) for Sets of Two $CaSO_4$: Dy Dosimeters for Polar Angle Dependency.

Angle	Depth	27 keV	36 keV	46 keV	51 keV	^{137}Cs
−60	shallow	8.42	8.56	6.00	5.07	0.08
	deep	8.56	5.60	2.99	2.65	0.01
−40	shallow	0.05	0.17	0.45	0.41	0.27
	deep	0.03	0.46	0.48	0.49	0.02
0	shallow	0.01	0.04	0.19	0.28	0.35
	deep	0.03	.26	0.39	0.50	0.05
40	shallow	0.38	0.50	0.46	0.42	0.22
	deep	0.34	0.45	0.48	0.50	0.04
60	shallow	0.56	0.38	0.39	0.40	0.01
	deep	0.61	0.63	0.66	0.58	0.01

lined. But the dosimetry system did not perform well at the ±60° angle of incidence for low energy X-ray beam. Especially for low energy X-rays, the dosimetry system could not pass generally the 0.5 tolerance limit at more than ±40°. The dosimetry performance result for ^{137}Cs beam at all angles of incidence was within the 0.5 tolerance limit. Therefore, performance of the dosimetry system could be considered acceptable in case that the dosimeter is irradiated to ^{137}Cs beam. However, it could not be acceptable for the dosimeter irradiated to low energy X-ray, especially at more than ±40°. Though the revised ANSI N13.11 requires to use at least five dosimeters for calculating an accuracy in a test category, only two dosimeters at each angle of incidence in this study were used calculating the accuracy. It might increase uncertainty of data. More work with more number of dosimeters is needed to reduce the uncertainty of data in the future.

CONCLUSIONS AND FUTURE WORKS

1. Conclusions

Two major sources of inaccuracy in personal dosimetry are the energy response and angular response of personnel dosimeters. Compared with energy response, the angular response problems of dosimeters have not received much attention or studied until recently. To investigate the angular dependence of dosimeter (PB-3) with Teledyne 9150 Reader System being used at NPPs and KAERI at present, an angular dependence experiment was made and a performance test of Teledyne dosimetry system was done in accordance with the revised ANSI N13.11. Conclusions for this study are as the followings:

(1) The angular response of the Teledyne 9150 Reader System was characterized to be bell shaped except for polar irradiation of X-ray. It was shown that dosimeters irradiated between −40° and −60° for polar irradiation of X-ray would be severely angular dependent.

(2) In azimuthal irradiation of X-ray, angular dependence of dosimeters decreased except near ±75° as the radiation energy increased.

(3) Teledyne dosimetry system performed well at the 0° angle of incidence for all dosimeters in both azimuthal and polar irradiations. It would have easily passed the 0.5 tolerance limit.

(4) Performance of the dosimetrysystem could be considered acceptable in case that the dosimeter is irradiated to 137 Cs beam. However, it could not be acceptable for dosimeters irradiated to low energy X-ray, especially at more than ±40°.

2. Future Works

To solve the problems shown in this angular dependence experiments, further studies are needed as the followings:

(1) Because the raw data for A4 region of PB-3 was much higher than other region, increase of dose dquivalent in polar irrad'ation of low energy X-ray was caused. So this problem should be studied by more experiments.

(2) Angular dependence of dosimeters in high energy X-ray irradiation should be examined

(3) More works with more numbers of dosimeters is needed for reducing the uncertainty of data.

REFERENCES

1. P. Weng *et. al., The Angular Energy Response of Personnel Thermoluminescent Dosimeters, ORNL/TM-109, Oak Ridge National Laboratory* (1989).
2. J. C. Liu *et. al.*, "Angular Response Performance Study of a New Harshaw Neutron Albedo TLD," *Radiat. Prot. Dosim.*, **30**, 161 (1990).
3. International Commission on Radiation Units and Measurements, *Determination of Dose Equivalents Resulting for External Radiation Sources, ICRU Report 39, Bethesda* (1985).
4. International Commission on Radiation Unitsand Measurements, *Determination of dose Equivalents Resulting for External Radiation Sources-Part 2, ICRU Report 43, Bethesda* (1988).
5. American National Standard Institute, *American National Standard for Dosimetry-Personnel Dosimetry Performance-Criteria for Testing, ANSI N13.11, New York* (1983).
6. National Bureau of Standards, *National Voluntary Laboratory Accreditation Program, NVLAP News, April* (1987).
7. P. Plato *et. al.*, "Two Methods for Exami-

ning Angular Response of Personnel Dosimeters," *Health Phys.* **54**, 596 (1988).

8. American National Standard Institute, *American National Standard for Dosimetry-Personnel Dosimetry Performance-Criteria for Testing, ANSI N13.11-1992, New York* (1992).

9. H. Cember, *Introduction to Health Physics,* pp. 122−143, Pergamon Press, Oxford, (1983).

열형광선량계(도시메터타입：PB-3)의 방향의존성에 관한 연구

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요 약

Teledyne 9150 판독장치에서 사용되는 PB-3 열형광선량계의 방향의존성에 관한 실험을 실시하였고 ANSI N13.11－1992에 의거하여 성능실험을 실시하였다. 조사선원은 ^{137}Cs과 X선이었다. Teledyne 9150 선량판독장치는 0°에서는 모든 경우에 방향의존성에 대한 성능시험범주를 만족하였다. 그러나 저에너지 X선의 경우, ±60°에서는 방향의존성에 대한 성능시험범주를 만족할 수 없었으며 ^{137}Cs은 모든 경우에 방향의존성에 대한 성능시험범주를 만족하였다.

Key Words：*PB-3 열형광선량계, 방향의존성, 성능시험*