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Calibration of Neutron Personnel Dosimeters in a D_2O Moderated ^{252}Cf Neutron Field

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Abstract

The calibration of Harshaw 8806 type, and Panasonic UD-802A and UD-809P type neutron personnel dosimeters have been made in a D_2O moderated ^{252}Cf neutron field in Korean Atomic Energy Research Institute. From the readings of dosimeters exposed in the calibration neutron field, calibration factors, linearities and the effect of phantom size were analyzed. Calibration factors for Harshaw 8806 type dosimeters calculated from a fit response function showed good agreement within 18% difference with the measured values in the calibration neutron field. Fitted calibration factors from the linear relationship between TLD readings and personal dose equivalents also showed no substantial difference from the measured values. Two types of phantoms of $30\times30\times15$ cm^3 and $40\times40\times15$ cm^3 were used, and no significant difference was found. The results showed that the calibration in a D_2O moderated ^{252}Cf neutron field can be used as a useful measure to assure the performance of neutron personnel dosimeters used in nuclear power plants by checking any significant change in the calibration factors obtained in the calibration neutron field.

1. Introduction

In 1980, a D_2O moderated ^{252}Cf neutron source was first recommended by Schwartz and Eisenhauer as a preferred neutron source for testing albedo neutron dosimeters used for the monitoring of nuclear power plant personnel.[1] They have reported that the leakage spectrum from neutron irradiation assembly is much closer to the neutron spectrum inside the containment of typical American nuclear power reactors. Since then, this irradiation facilities have come into use at a number of laboratories for the calibration of personnel neutron dosimeters and have been proposed as one of four calibration standards by the International Organization for Standardization (ISO).[2]

This project has implemented with four objectives: (1) to correct old calibration factor of

TLD neutron personnel dosimeters used in Korean nuclear power plants by applying new radiation weighting factor recommended by ICRP Publication 60[3]; (2) to examine the appropriateness of in-situ calibration methods; (3) to test the variation of TL responses; and (4) to examine the effect of phantom size. The calibration factors and linearities for three types of TLD neutron personnel dosimeters were investigated in a D_2O moderated ^{252}Cf calibration neutron field at Korean Atomic Energy Research Institute (KAERI). Three types of TLDs were mounted respectively on an ISO water phantom of 30×30×15 cm[4] and a water phantom of 40×40×15 cm^3 used for in-situ calibration in a nuclear power plant, and exposed in the KAERI neutron irradiation facility.

2. Experimental Method

2.1 Neutron source spectrum

The irradiation assembly at KAERI consists of a 30 cm diameter D_2O sphere having a ^{252}Cf neutron source at its center. The outer sphere is covered with a cadmium shell to absorb thermal neutrons. The calibration source is in the concrete walled neutron room of 8.1×5.7×6.1 m^3 with a hight of 2.5 m for irradiation. The calibration distance from the center of sphere to the effective center of TLD neutron personnel dosimeters mounted on a water slab phantom was taken to 50 cm. For the linearity calibration of TLDs, the exposed time at the same distance was controlled in order to obtain desired neutron fluences. Table 1 shows the neutron spectrum of a D_2O moderated ^{252}Cf source of KAERI which was measured on October 10th, 1995 with a Bonner multisphere spectrometer.[5] This neutron spectrum has been already corrected for air scattering and room return. The column 3 in Table 1 shows neutron fluences with the exposed time of 3178 seconds corrected for the decay of ^{252}Cf neutron source from October 10th, 1995 to May 21st, 1998.

2.2 Conversion factor

Conversion factors of personal dose equivalent per unit neutron fluence were taken from ICRP report 74.[6] From the neutron spectrum given in Table 1, the average-weighted conversion factor was evaluated. The average neutron energy for the spectrum, total fluence, average conversion factor and personal dose equivalent are given in Table 2.

2.3 Water phantoms

Since the phantom used for in-situ calibrations differs from the phantom used for the calibration of neutron personnel dosimeter at KAERI, the effect of phantom size on the calibration factors was examined in the calibration field of 7.05 mSv. The phantom used for the calibration at KAERI is an ISO water phantom of 30×30×15 cm^3.[3,5] However, a water phantom of 40×40×15 cm^3 recommended by American National Standard ANSI N13.11 1993 version[7] was made and used for the in-situ calibration in the nuclear power plant.

Table 1. Neutron spectrum of a D_2O moderated ^{252}Cf source at KAERI at the distance of 50 cm from the center of the source

Energy (Max) (MeV)	Neutron Fluence Rate (95.10.10) (n/cm^2-s)	Neutron Fluence (98.05.21) (n/cm^2)
4.140E-07	5.404E+01	9.1022E+04
6.826E-07	1.625E+02	2.7371E+05
1.445E-06	3.111E+02	5.2400E+05
3.059E-06	4.138E+02	6.9698E+05
6.476E-06	5.458E+02	9.1931E+06
1.371E-05	7.096E+02	1.1952E+06
2.902E-05	8.969E+02	1.5107E+06
6.144E-05	1.087E+03	1.8309E+06
1.301E-04	1.248E+03	2.1021E+06
2.754E-04	1.347E+03	2.2688E+06
5.929E-04	1.410E+03	2.3749E+06
1.234E-03	1.327E+03	2.2351E+06
2.613E-03	1.283E+03	2.1610E+06
5.531E-03	1.181E+03	1.9892E+06
1.171E-02	1.066E+03	1.7955E+06
2.479E-02	9.551E+02	1.6087E+06
5.247E-02	8.634E+02	1.4543E+06
1.111E-01	8.287E+02	1.3958E+06
2.237E-01	8.922E+03	1.5028E+06
4.508E-01	1.451E+03	2.4440E+06
9.072E-01	3.025E+03	5.0951E+06
1.872E+00	3.892E+03	6.5555E+06
3.679E+00	1.281E+03	2.1576E+06
7.408E+00	7.369E+01	1.2412E+05
1.492E+01	4.737E-01	7.9787E+02
2.581E+01	3.310E-03	5.5752E+00
Total	2.630E+04	4.4307E+07

Table 2. Characteristics of a D_2O moderated ^{252}Cf neutron field of KAERI

Average Energy (keV)	Total Fluence (n/cm^2)	Conversion Factor (mSv cm^2)[a]	Personal dose equivalent (mSv)[b]
465	4.431E+07	159.12E-09	7.05

a. Conversion factor was calculated from the neutron spectrum shown in column 3 of Table 1 and personal dose equivalent per unit neutron fluence given in ICRP 74.

b. Personal dose equivalent was obtained by multiplying the conversion factor and total fluence of the neutron spectrum

2.4 Neutron personnel dosimeters

Three types of neutron personnel dosimeters used in the nuclear power plants were calibrated. One is Harshaw 8806 type albedo neutron personnel dosimeter. Another two are Panasonic UD-809P type albedo neutron personnel dosimeter and UD-802A type photon and neutron personnel dosimeter. Their detail descriptions can be found in otherwhere[8-10].

3. Calibration Results

3.1 TL readings

The calibration has been made for three types of TLDs mounted on a water phantom of 40 ×40×15 cm^3. For the linearity calibration, various exposed time was applied to give personal dose equivalents of 1.41, 4.23, 7.05, and 9.87 mSv, respectively. The comparison between two phantoms was made only for the irradiation field of 7.05 mSv. For each type of TLDs, three TLDs were irradiated to four different dose equivalents. Table 3, 4 and 5 show the results of TL readings for each type of TLDs.

3.2 Effect of phantom size

Because the phantom size used for the in-situ calibration differs from ISO phantom used for the routine calibration at KAERI, the effect of phantom size was examined by comparing TL readings from TLDs mounted on two kinds of phantoms. Table 6 shows the comparison between the readings of three types of TLDs on two kinds of phantoms. The results shown in Table 6 imply that there is no significant difference in the TL readings although the tendency of slight increase in the readings of TLDs mounted on 40×40×15 cm^3. Therefore, a 30×30×15 cm^3 water phantom can be used interchangeably with a 40×40×15 cm^3 water phantom for the irradiation of personnel neutron dosimeters for the neutron source and irradiation conditions studied in this work.

3.3 Linearity

The linearities of the neutron personnel dosimeters were investigated in the D_2O moderated ^{252}Cf neutron field, and the results are shown in figure 1, 2 and 3. The mean readings were

Table 3. The result of readings for Harshaw 8806 type TLD

Hp(10) (mSv)	L1 (mR)	L2 (mR)	L3 (mR)	L4 (mR)
1.41	517.05±2.23%	15.92±5.03%	13.44±1.44%	716.43±3.54%
4.23	1706.05±4.61%	48.16±0.38%	41.26±1.42%	2196.39±5.35%
7.05	2884.32±1.57%	88.42±10.4%	69.06±1.79%	3627.37±5.74%
7.05*	2699.91±4.38%	81.55±1.11%	69.14±1.45%	3448.93±2.05%
9.87	3808.73±5.03%	111.94±3.32%	96.00±0.58%	5041.52±3.24%

* The readings measured on 30×30×15 cm^3 water phantom.

Table 4. The result of readings for Panasonic UD-809P type TLD

Hp(10) (mSv)	L1 (mR)	L2 (mR)	L3 (mR)	L4 (mR)
1.41	20.42±2.99%	113.12±5.80%	104.58±9.12%	262.90±5.40%
4.23	68.72±5.97%	331.79±5.05%	352.91±7.68%	755.57±9.32%
7.05	105.46±11.6%	609.79±3.51%	514.58±1.66%	1161.24±11.5%
7.05*	111.32±11.6%	588.45±4.64%	533.58±5.72%	1184.57±3.68%
9.87	138.19±5.92%	819.12±6.84%	756.91±6.11%	1724.57±2.53%

* The readings measured on 30×30×15 cm^3 water phantom.

Table 5. The result of readings for Panasonic UD-802A type TLD

Hp(10) (mSv)	L1 (mR)	L2 (mR)	L3 (mR)	L4 (mR)
1.41	135.27±1.48%	137.72±4.25%	2.94±13.8%	6.22±25.6%
4.23	413.60±3.52%	447.72±10.7%	27.59±9.26%	27.22±12.3%
7.05	653.27±8.09%	768.39±4.78%	51.83±1.83%	48.68±3.29%
7.05*	630.27±3.53%	687.39±9.19%	47.69±3.69%	47.55±1.59%
9.87	978.27±1.48%	1034.72±4.77%	71.27±3.54%	74.92±3.27%

* The readings measured on 30×30×15 cm^3 water phantom.

Table 6. The effect of phantom size on the TL readings for each type of TLDs

Phantom Size (cm^3)	L1 (mR)	L2 (mR)	L3 (mR)	L4 (mR)
For Harshaw 8806 TLD				
40×40×15 (A)	2884.32±1.57%	88.42±10.4%	69.06±1.79%	3627.37±5.74%
30×30×15 (B)	2699.91±4.38%	81.55±1.11%	69.14±1.45%	3448.93±2.05%
(B-A)/B	-6.83%	-8.42%	0.12%	-5.17%
For Panasonic UD-809 TLD				
40×40×15 (A)	105.46±5.55%	609.79±3.51%	514.58±1.66%	1161.24±11.5%
30×30×15 (B)	111.32±11.6%	588.45±4.64%	533.58±5.72%	1184.57±3.68%
(B-A)/B	5.56%	-3.50%	-3.69%	2.01%
For Panasonic UD-802 TLD				
40×40×15 (A)	653.27±8.09%	768.39±4.78%	51.83±1.83%	48.68±3.29%
30×30×15 (B)	630.27±3.53%	687.39±9.19%	47.69±3.69%	47.55±1.59%
(B-A)/B	-3.52%	-10.54%	-7.99%	-2.32%

plotted against the neutron dose equivalent which varied from 1.41 mSv to 9.87 mSv. From a least squares linear fit, r^2 (square of correlation coefficient) values and slopes (calibration factors) were obtained. The fit equation, slope and r^2 for each type of TLDs are given in Table 7.

Table 7. Linearity calibration results of TLDs (fit equation, slope and r^2)

TLD Type	Fit Equation	Slope (Calibration Factor) (mR/mSv)	r^2
Harshaw 8806	TL(A) = a + b×Hp	380.3	0.997
	TL(T) = a + b×Hp	501.1	0.999
Panasonic UD-809P	TL = a + b×Hp	148.8	0.987
Panasonic UD-802A	TL = a + b×Hp	99.4	0.999

Note) TL(A)=E1-E2; TL(T)=E4-E3

3.4 Calibration factors

For a known neutron spectrum, it is possible to calculate personal dose equivalent from personal dose equivalent per unit fluence given in ICRP 74.[8] The net neutron response for TL element can be also evaluated if the energy response of a TLD is available. Then, calibration factor for the TLD can be calculated from the personal dose equivalent and the net neutron response. The energy response value (the element response value corresponded to an incident neutron energy) of Harshaw type 8806 TLD albedo dosimeter were taken from Ref. 10 in order to calculate net neutron response. From the calculated net neutron response and personal dose equivalent, calibration factors for Harshaw 8806 type albedo neutron personnel dosimeter were obtained.

Table 8 shows the calculated, measured and fitted calibration factors. The maximum difference between the fitted calibration factors and the measured mean calibration factors is only 4.84%. And the calculated values shows good agreement with the fitted calibration factors within 18% difference. For Panasonic UD-809P type albedo neutron TLD, the calibration factor for thermal neutron component hasn't been evaluated because the D_2O moderated ^{252}Cf source covered cadmium shell has no thermal neutron leakage spectrum.

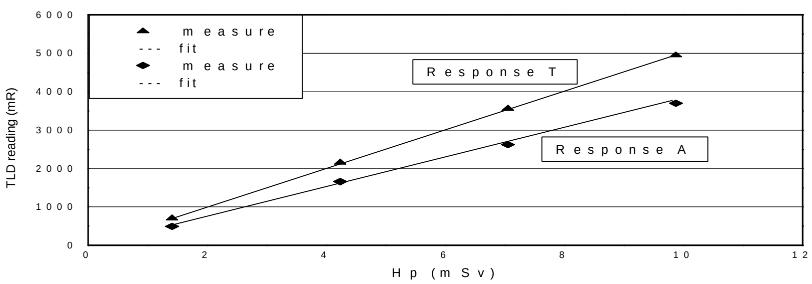

Fig. 1 Hp vs TL readings of Harshaw 8806 type TLD

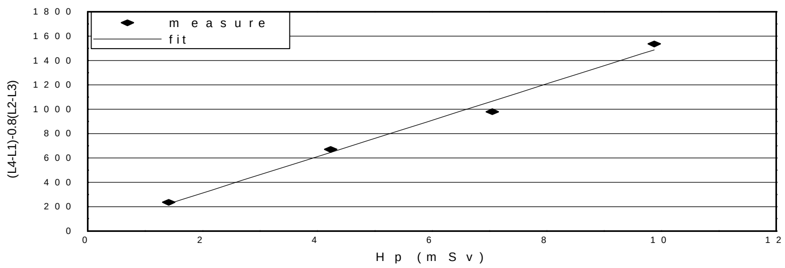

Fig. 2 Hp vs TL readings of Panasonic UD-809P type TLD

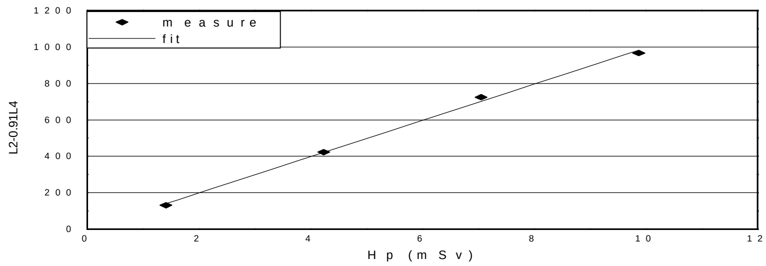

Fig. 3 Hp vs TL readings of Panasonic UD-802A type TLD

Table 8. Comparison of the calculated, fitted and measured mean calibration factors

TLD Type	Calculated (C) (mR/mSv)	Fitted (F) (mR/mSv)	Measured (M) (mR/mSv)	$\frac{F-C}{F} \times 100$	$\frac{F-M}{F} \times 100$
Harshaw 8806 (A)	330.4	380.3	379.4	13.12 %	0.02 %
Harshaw 8806 (T)	414.9	501.1	503.5	17.20 %	0.48 %
Panasonic UD809P	-	148.8	156.0	-	4.84 %
Panasonic UD802A	-	99.4	99.1	-	0.30 %

4. Conclusion

Neutron personnel dosimeters used in Korean nuclear power plants were calibrated with a D_2O moderated ^{252}Cf neutron source of KAERI. Neutron fluences and the delivered personal dose equivalent were evaluated based on the neutron spectrum provided by KAERI. In the concrete-walled neutron source room of 8.1×5.7×61 m^3, three types of TLDs mounted on water phantoms of 30×30×15 cm^3 and 40×40×15 cm^3 were exposed to the neutron source at the distance of 50 cm from the source center and the hight of 2.5 m. Delivered personal dose equivalents were 1.41, 4.23, 7.05, and 9.87 mSv.

Based on TL readings for each type of TLDs, the effect of phantom size on the readings and response linearity were investigated. As shown in Table 6, there was no significant difference in the TL readings depending on the phantom size. The differences in the TL readings were less than 1σ values of the mean readings. Linearity fitting of the results gave a good correlation between the delivered personal dose equivalent and the TL readings with r^2 more than 0.987. Calibration factors were obtained from calculated, measured, and fitted responses. For Harshaw 8806 type albedo neutron personnel dosimeter, the difference between the calculated and the fitted calibration factors were less than 18%. The fitted calibration factors can be used as a basis for the quality assurance control of routine personnel dosimeter calibration.

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