Calibration of personal albedo neutron dosemeter for mixed gamma-neutrons fields

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The Dosimetry Lab use personal albedo dosemeter in order to measure the neutron dose equivalent. Measurement of the personal dose equivalent for neutrons is a difficult task because personal albedo neutron dosemeter is energy-dependent, becoming less sensitive as the energy of the neutrons is increased. To obtain a realistic characterization of the dosemeter, a set of irradiations have recently been carried out at the Czech Metrology Institute – Inspectorate for Ionizing Radiation at ^{241}Am-Be and ^{252}Cf sources. The obtained values are then compared with the neutron dose calculated using a dose calculation algorithm.

(Received June 8, 2011; accepted July 25, 2011)

Keywords: Albedo dosemeters, Radiation protection, Dose assessment, Thermoluminescence dosemeter, Neutron dose

1. Introduction

Albedo dosimetry is based on the detection of low energy neutrons (albedo neutrons) which emerge from the body of a person exposed to neutrons of various energies. By making appropriate measurements of these albedo neutrons, using a dosimeter worn close to the surface of the body, it is possible to estimate the dose equivalent in the body due to the original incident neutrons.

This process is called albedo neutron dosimetry.

In this study we used albedo dosemeters consist of thermoluminescent detectors - ^{6}LiF:Mg, Ti – ^{7}LiF:Mg, Ti pairs detectors. In a mixed neutron-photon radiation field, ^{6}LiF:Mg, Ti detectors are sensitive both to thermal neutrons and photons but ^{7}LiF:Mg, Ti detectors are only photon sensitive.

TLD albedo neutron dosemeters rely on the principle of using one detector for albedo neutrons reflected from the body of a worker, while another detector in the dosemeter is used to measure the all slow neutrons that are present in the workplace. Since the detectors are mounted in a dosemeter that is worn on the body of a worker, the dosemeter will be exposed to slow neutrons from a source in the workplace as well as albedo neutrons reflected from the body. The differentiation between slow neutrons from the source and albedo neutrons is carried out using cadmium loaded plastic filters to absorb low energy neutrons.

The neutron response depends on the neutron spectrum [1,2,3]. Albedo dosimeters have a high and nearly constant response for neutrons in the energy range from thermal to 10 keV and decreases rapidly above 10 keV. The response of the albedo dosemeter shows a strong dependence to neutron energy with an over-response to thermal neutrons and a low response to fast neutrons. In stray neutron fields, the relative energy response of an albedo detector has been found to vary by a factor of as much as 20 [4].

2. Experimental part

2.1. Materials and methods

Our laboratory use a Harshaw dosemeter (8806 badge and 6776 TL card) as albedo dosemeter for monitoring approximately 300 people who are working at workplaces with radionuclide sources.

Albedo dosemeter measures the thermal neutrons that are generated by higher energy neutrons incident onto the body and then reflected back into the dosemeter. The dosemeter is composed of two parts: a TLD card (6776 type) and a holder (8806 type). The TLD card consists of four LiF: Mg,Ti chips (^{6}LiF:Mg, Ti – ^{7}LiF:Mg, Ti pairs detectors).

Lithium, in its natural form, is approximately 92%^{7}Li and 8% ^{6}Li.When is enriched with the ^{7}Li isotope or the ^{6}Li isotope, it is referred to as TLD-700 (^{6}Li=0,007% and ^{7}Li=99,993%) or TLD-600 (^{6}Li=95,62% and^{7}Li=4,38%) respectively. These elements respond identically to gamma and beta radiation, but respond differently to neutron radiation. The ^{7}Li isotope has almost no cross-section for neutrons while the ^{6}Li isotope has a high thermal neutron cross-section.

The Cd filter absorbs all the thermal neutrons below 0.5eV. The albedo dosemeter has entrance windows made of ABS at the front size for the direct neutron signal and at the back side for the albedo neutron signal.

The specific TL materials and the filters that cover each TL element are described in Table 1.

Table 1. Description of the dosimeter used.

Element position	Material	Filtration
i	^{6}LiF: Mg, Ti (TLD 600)	465 mg/cm^2 (0.7 mm ABS + 0.5 mm Cd)
ii	^{7}LiF: Mg, Ti (TLD 700)	465 mg/cm^2 (0.7 mm ABS + 0.5 mm Cd)
iii	^{7}LiF: Mg, Ti (TLD 700)	300 mg/cm^2 (3.0 mm ABS)
iv	^{6}LiF: Mg, Ti (TLD 600)	300 mg/cm^2 (3.0 mm ABS)

For dose evaluation, a Harshaw TLD reader 4500 is used with a special Time – Temperature – Profile (TTP): Preheat: 175 ^{0}C, 10 s, Acquire 15 ^{0}C/s, 300 ^{0}C max., 10 s; Anneal: 300 ^{0}C, 10 s.

Because of the photon sensitivity of TLDs, the neutron dose reading is given by the difference between ^{6}LiF and ^{7}LiF detector readings.

In practice, we use Harshaw Win8806, a special developed dose calculation algorithm, which divide the neutron energy range in three categories [5]:

- Moderated Cf-252
- Unmoderated Cf-252
- Unknown

When "Moderated Cf-252" or "Unmoderated Cf-252" is selected, there are built-in factors that are applied to the algorithm. When "Unknown" is selected, additional fill-in information is needed, provided from irradiation at a similar neutron source to the source of radiation expected in normal use, including geometry.

3. Results

^{137}Cs relative response

The determination of Reader Calibration Factor (RCF) and Element Correction Coefficients (ECC's) were done using a ^{137}Cs source. The Harshaw Reader System was calibrated in gU (general units).

The ^{137}Cs relative response is established for each element position after the irradiation of five the dosemeters at 5mSv, using a ^{137}Cs source. Another five dosemeters was kept as background control dosimeters.

The results of each element position (in gU) for the five irradiated cards and the results of each element position for the five background control cards are presented in Table 2 and Table 3.

The results obtained after subtraction the averages of the control background cards from the same positions of the irradiated cards at 5 mSv are shown in Table 4.

Table 2. ^{137}Cs exposed cards.

Card ID	i TLD-600	ii TLD-700	iii TLD-700	iv TLD-600
517855	744.513	730.135	807.219	802.748
517902	761.920	741.221	776.287	815.098
517936	751.821	680.999	765.245	755.967
517878	724.011	719.282	796.658	749.725
517854	744.299	688.216	725.441	740.957
Average	745.313	711.971	774.170	772.899

Table 3. ^{137}Cs background control cards.

Card ID	i TLD-600	ii TLD-700	iii TLD-700	iv TLD-600
517822	2.382	2.056	2.989	4.259
517916	2.260	5.725	2.728	5.122
517917	2.864	1.444	2.255	4.173
517587	2.123	1.865	2.812	2.893
517257	1.791	1.820	1.997	2.123
Average	2.284	2.582	2.556	3.714

Table 4. ^{137}Cs reported exposure.

Card use	i TLD-600	ii TLD-700	iii TLD-700	iv TLD-600
Exposed	745.313	711.971	774.170	772.899
Control	2.284	2.582	2.556	3.714
Difference	743.029	709.388	771.614	769.185

The Relative Response at ^{137}Cs (in gU/mSv) is presented in Table 5.

Table 5. ^{137}Cs relative response.

Exposure	i TLD-600	ii TLD-700	iii TLD-700	iv TLD-600
Reported (gU)	743,029	709,388	771,614	769,185
Actual (mSv)	5	5	5	5
Relative Response (gU/mSv)	145,202	138,628	150,788	150,313

Dose evaluation using Win8806 Algorithm

A number of 40 albedo dosemeters were irradiated at ^{241}Am-Be and ^{252}Cf sources in primary standard conditions (at the Czech Metrology Institute – Inspectorate for Ionizing Radiation).

The response for the thermoluminescent albedo dosemeter was determined on ISO water slab phantom, in terms of the operational quantity Hp(10) [6, 7, 8].

For each dose value, a number of four albedo dosemeters were irradiated and the standard deviation was estimated for each element. The personal neutron doses were calculated using the Harshaw Win8806 algorithm.

The estimates provided by these personal albedo dosemeters were compared to reference values of dose equivalent quantities derived from fluence-to-dose equivalent conversion coefficients (conventional true values reported by the irradiation lab.).

In Table 6 and Table 7 are presented the results for TL albedo dosemeter irradiated at ^{252}Cf and ^{241}Am-Be sources.

$Hp_{c.a.}$ represents the conventional true value, obtained in primary standard irradiation condition and $Hp_{meas.}$ represents the value obtained using dose calculation algorithm, with built-n factors associated with "Unmoderated Cf-252".

Table 6. Measurement of neutron dose using the Harshaw personnel albedo dosemeter related to the conventional true dose (irradiation at ^{241}Am-Be source).

Hpc.a.[a] ± u(Hp, k=2)[b] mSv	i (gU)	ii (gU)	iii (gU)	iv (gU)	Hp meas. ± SD[c] mSv	Ratio
0.200 ± 0.005	31.28 ± 1.07	15.30 ± 0.35	20.75 ± 1.05	47.49 ± 3.03	0.124 ± 0.007	0.62
0.500 ± 0.013	60.80 ± 1.53	25.46 ± 2.78	34.63 ± 0.64	97.45 ± 2.18	0.274 ± 0.032	0.55
1.008 ± 0.027	108.28 ± 12.68	36.10 ± 3.23	56.77 ± 6.26	173.43 ± 24.10	0.559 ± 0.074	0.56
2.000 ± 0.520	210.08 ± 1.74	64.93 ±1.63	103.52 ± 5.26	338.18 ± 9.74	1.124 ± 0.077	0.56
5.001 ± 0.131	491.58 ± 9.60	143.23 ± 4.50	243.70 ± 10.01	801.88 ± 45.71	2.696 ± 0.064	0.54

[a] - Hp c.a—dose conventional true value
[b]– expanded uncertainty with coverage factor k=2 (i.e. 95% confidence level approximately)
[c] – standard deviation of measurements

Table 7. Measurement of neutron dose using the Harshaw personnel albedo dosemeter related to the conventional true dose (irradiation at ^{252}Cf source).

Hpc.a.[a] ± u(Hp, k=2)[b] mSv	i (gU)	ii (gU)	iii (gU)	iv (gU)	Hp meas. ± SD[c] mSv	Ratio
0.200 ± 0.005	33.60 ± 1.47	13.15 ± 0.30	17.01 ± 0.95	53.07 ± 1.69	0.159 ± 0.012	0.79
0.500 ± 0.013	63.73 ± 5.73	16.41 ± 1.84	22.79 ± 1.73	101.87 ± 3.84	0.366 ± 0.031	0.73
1.008 ± 0.027	123.63 ± 2.21	18.73 ± 1.44	21.74 ± 0.40	192.33 ± 6.49	0.812 ± 0.013	0.81
5.011 ± 0.132	535.60 ± 24.63	52.97 ± 1.95	63.16 ± 3.59	886.53 ± 90.99	3.735 ± 0.193	0.80
10000.018 ± 0.264	1132.75±48.64	95.56±0.70	113.83 ± 1.88	1840.50 ± 87.53	8.026 ± 0.373	0.80

[a] - Hp c.a—dose conventional true value
[b]– expanded uncertainty with coverage factor k=2 (i.e. 95% confidence level approximately)
[c] – standard deviation of measurements

4. Results and discussions

Response increases linearly with increasing dose and the estimated values using the dose calculation algorithm depend on calibration source spectra [9, 10, 11, 12, 13].

The dosemeter response as a function of the irradiation energy was found to be in the (0.54 - 0.81) interval.

The actual requirements for neutron dosemeters specify that are certainly difficulties meeting 30% combined standard uncertainty for doses to the whole body from neutrons [4, 14]. Even with a relaxation of the criterion to 50%, the requirements specify that it is not possible to meet the criterion over the full range of neutron energies possibly present in the workplace. For this is very important to establish the relationship between calibration source spectrum and operational field spectra [15].

In this study, the relative neutron response, without any correction, does not vary by more than a factor of 2. Calibration curves for working areas can reduce of albedo response within ± 30% [14]. The use of a workplace field specific correction factor should enable an overall uncertainty for the assessment of annual effective dose within the limit of a factor of 1.5 to be achieved. For now, there are no EN or IEC requirements available for passive neutron dosemeters, suitable for the uncertainty calculation.

5. Conclusions

Thermoluminescent albedo dosemeters are used to measure *H*p(10) from thermal and epithermal neutrons (up to a few keV) in a simple design, with response characterization and field specific correction factors for intermediate and high energy neutrons. Harshaw personnel albedo dosemeters can be used to determine the doses received by personnel working in mixed gamma – neutron radiation field.

Using Harshaw Win8806 algorithm, with "Unmoderated Cf-252" built-in factors, the albedo dosemeters can provide a good estimation of doses received by personnel working with Am-Be and Cf-252 sources.

Furthermore, by applying field specific correction factors, determined by a "calibration" of dosemeters in the workplace field, it is possible to increase the accuracy to meet 30% combined standard uncertainty.

Acknowledgement

The authors wish to thanks to Dr. Miroslav Kralik from the Czech Metrology Institute – Inspectorate for Ionizing Radiation for his generous help in the conduct of the irradiations requested by this study.

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