¹Iran Nuclear Regulatory Authority, Tehran, Iran
²Radiation Application Research School, Nuclear Science and Technology Research Institute, Tehran, Iran

Evaluation of Effective Sources in Uncertainty Measurements of Personal Dosimetry by a Harshaw TLD System

Hosseini Pooya SM[1,2]*, Orouji T[1]

ABSTRACT

Background: The accurate results of the individual doses in personal dosimety which are reported by the service providers in personal dosimetry are very important. There are national / international criteria for acceptable dosimetry system performance.

Objective: In this research, the sources of uncertainties are identified, measured and calculated in a personal dosimetry system by TLD.

Method: These sources are included; inhomogeneity of TLDs sensitivity, variability of TLD readings due to limited sensitivity and background, energy dependence, directional dependence, non-linearity of the response, fading, dependent on ambient temperature / humidity and calibration errors, which may affect on the dose responses. Some parameters which influence on the above sources of uncertainty are studied for Harshaw TLD-100 cards dosimeters as well as the hot gas Harshaw 6600 TLD reader system.

Results: The individual uncertainties of each sources was measured less than 6.7% in 68% confidence level. The total uncertainty was calculated 17.5% with 95% confidence level.

Conclusion: The TLD-100 personal dosimeters as well as the Harshaw TLD-100 reader 6600 system show the total uncertainty value which is less than that of admissible value of 42% for personal dosimetry services.

Keywords

TLD, Uncertainty, Personal Dosimetry, TLD Reader, Dose, Response

Introduction

TLD is one of the most common and accurate methods for personal dosimetry which are used in the world [1] The TLDs may be used in an extended range of occupational exposures from low level in medicine, (e. g. interventional radiology) to those of high risk such as angiography, nuclear medicine and radiotherapy [2]. On the other hand, any decisions are made by regulatory bodies for the workers are based on the results of personal dosimeters in comparison with different dose limits (i. e. reporting, investigation, annual and action levels). So the accurate reports of the dose by the service providers are very important. Several national and international organizations have established criteria for acceptable dosimetry system performance, including ICRP, ISO, IEC and the IAEA. The IAEA guidance appears in "Assessment of Occupational Exposure Due to External Sources of Radiation, RS-G-1.3" [3].

In this work, some parameters that may be a source of uncertainty for

*Corresponding author:
SM Hosseini Pooya
Iran Nuclear Regulatory Authority, Tehran, Iran, P.O. Box 14155-1339
Radiation Application Research School, Nuclear Science and Technology Research Institute, Tehran, Iran
E-mail: mhosseini@aeoi.org.ir

dose measurement with TLD dosimeters and TLD reader system in personal dosimetry for medical centers were evaluated.

Material And Methods

Overall uncertainty is composed of two types of uncertainty, often referred to as random and systematic. Random, or Type A uncertainties, are those uncertainties which can, in principle, be reduced by increasing the number of measurements.

Typical source of Type A uncertainty are:
a) Inhomogeneity of detector sensitivity;
b) Variability of detector readings due to limited sensitivity and background;
c) Variability of detector readings at zero dose.

Type B uncertainties are those which cannot be reduced by repeated measurements. The following sources are usually considered to cause uncertainties of Type B:
a) Energy dependence;
b) Directional dependence;
c) Non-linearity of the response;
d) Fading, dependent on ambient temperature and humidity;
e) Effects due to exposure to light;
f) Effects due to exposure to types of ionizing radiation that are not intended to be measured by the dosimeter;
g) Effects from mechanical shock;
h) Calibration errors;
i) Variation in local Natural Background.

Type of TLD and exposures

The TLD-100 Harshaw cards as well as a TLD reader Harshaw- 6600 has been used for measurements [4]. All the dosimeters have been exposed by the 137Cs, 60Co or x-ray fields in the Secondary Standard Dosimetry Laboratory (SSDL) of Iran. The reader was adjusted to a setting included the reading rate of 13 $^\circ$C/s, maximum temperature of 300 $^\circ$C and an acquired time of 25 s.

Calculation of uncertainties

The total uncertainty, Uc is calculated via equation (1) as [3]

$$U_C = \sqrt{U_A^2 + U_B^2} \qquad (1)$$

where U_A and U_B are the type A and B uncertainties respectively. The RS-G 1.3 suggests the normal statistical distribution for type A and rectangular distribution for type B uncertainties [3]. So equation (1) is changed to equation (2) as [5]:

$$U_C = \sqrt{(U_A^2 + 1/3\sum_i a_i^2)} \qquad (2)$$

where a_i is the half range of the measured value for each types of the type B uncertainties, which is calculated versus the maximum and minimum of the quantity X by equation (3) as:

$$half-range(X) = \frac{Max(X)-Min(X)}{2} \qquad (3)$$

Type A

a) Inhomogeneity of detector sensitivity;

Inhomogeneity of TLD sensitivity depends on the production quality of its manufacturer which leads to differences in TLD responses (Pederson et al. 1995). There are two ways for calculation of Type A uncertainty, U_a, due to inhomogeneity of detector sensitivity. First, all the card dosimeters should be exposed in an identical value of dose. Then the standard deviation divided by number of TL values, n, is considered for the uncertainty [6] as:

$$U_a = (\frac{1}{n.n-1}\sum_{i=1}^{n}(TL_i - \overline{TL})^2)^{\frac{1}{2}} \qquad (4)$$

Second, the harshaw suggests the Elementary Correction Coefficient (ECC) for each dosimeter which is calculated as [5]:

$$ECC_i = \frac{\overline{TL}}{TL_i} \qquad (5)$$

By considering the ECC, the U_a would be negligible, but the ECC should be applied in any dosimetry calculations.

b) Variability of detector readings due to

limited sensitivity and background;

An alternative name for this type A of uncertainty in TLD, is the uncertainty in "repeatability" of the measurements (or stability of response during repeats on its using) [6]. For the measurements, the cycle of expose-reading is repeated by n time and the uncertainty is calculated via equation (4). The number of n in this Type A uncertainty depends on both the number of dosimetry period per year and time of re-calibration (e. g. for a bimonthly dosimetry period and re-calibration of TLDs after 5 years, the minimum value for n is 6x5=30).

c) Variability of detector readings at zero dose;

Although the TL values at zero dose are very low, but the variability of detector readings at zero dose generally make a significant amounts in standard deviation of the readings by TLD readers due to the variations in Photomultiplier Tubes currents of TLD readers. That is, the average value of the zero doses is very low, but the standard deviation of readings is high. Since the reporting level is more important and its values are higher than zero doses (e.g. 1 mSv), so we can ignore the uncertainty of variability of detector readings at zero dose for TLDs in personal dosimetry.

Type B

a) Energy dependence;

Most of the personal dosimeters as well as the TLDs have energy dependency which causes one of the main source of uncertainty. The reasons we should consider the uncertainty is the sources with different energies (from x-ray energies in mammography to gamma ray energy of ^{60}Co in radiotherapy) and that scattered photons may reach to the dosimeter from scattering materials and body. For energy dependency, the TLDs have been exposed by five optional different photon energies, 78.9, 110.3 and 139.0 keV of x-ray as well as 663 keV of ^{137}Cs and 1250 keV of ^{60}Co in an identical dose.

b) Directional dependence;

Since the person who deal with the radiation is not necessarily exposed by a direct beam, and also the badge of a dosimeter may be sensitive to the beam direction, the uncertainty due to angular dependency of dosimeter is very important. For this case, five dosimeters have been exposed identically by their badge
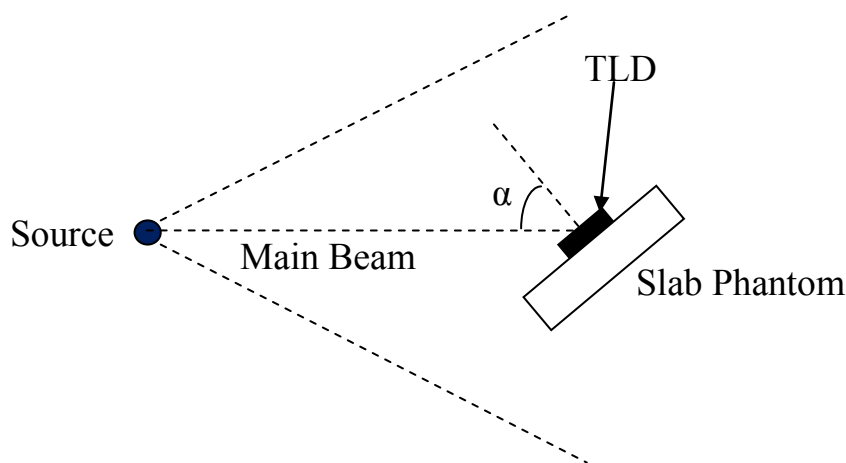

Figure 1: Schematic of exposure configuration for angular dependency, α= 0, 20, 40, 60 and 80°

on a slab phantom at five various angles, 0, 20, 40, 60, 80 degree (see figure 1).

c) Non-linearity of the response;

The non-linearity of response for TLDs is due to both type of TLD and electronic characteristics of the TLD-reader system. For this uncertainty, the TLDs have been exposed in five different dose values (from reporting level to a five-yearly dose limit, i.e. 2 mSv to 100 mSv), since the TLD-100 dosimeter should have a linear response up to 1 Gy and may show supralinearity up to 10 Gy [7]. The half range of variations from the linear curve response has been considered as the uncertainty.

d) Fading, dependent on ambient temperature and humidity;

Fading in TLDs is due to the discharging of superficial traps in TL materials at ambient temperature. There are no criteria how we can calculate this uncertainty. In the case of high exposure in radiological incidents, a long time pre-heating procedure can be applied for the dosimeters, so that the uncertainty being negligible, but it cannot be applied in large scale measurements. In normal exposures particularly in short term periods, the uncertainty depends on the term of dosimetry. In this research, considering a bi-monthly term of dosimetry, it is suggested two groups of TLDs were identically exposed in a given dose value, and then one group red soon after the exposure and another group red after passing half of the term (i. e. 30 days). The difference has been considered as the uncertainty.

e) Effects due to exposure to light;

The TLD-100 is not sensitive to the light exposure when it is placed inside of its badge. So the related uncertainty is zero.

f) Effects due to exposure to types of ionizing radiation that are not intended to be measured by the dosimeter;

In medical exposures, the situations in which

the workers may deal with a mixed radiation type (neutrons, protons and gamma) are radiotherapy with HV machines, proton therapy [8] and BNCT [9]. Since the radiation background due to neutron and beta emitters are negligible (in comparison with reporting level), and also TLD-100 are not so sensitive to neutrons, we can ignore the uncertainty here.

g) Effects from mechanical shock;

The TLD-100 is not sensitive to the mechanical shocks and it can not cause any uncertainty

h) Calibration errors;

This uncertainty depends on the uncertainty of the used radiation field in SSDL.

i) Variation in local Natural Background.

The uncertainty due to variation in local background generally can be considered to be a zero in personal dosimetry by TLD, unless the background is considered as the reporting level. In the later case, TLDs should be annealed and placed in one area in one dosimetry period. The uncertainty can be measured by the standard deviation of the measurements. Since the zero doses as well as the background readings may be highly different in one group of TLD, so the uncertainty may significantly increases the total uncertainty.

Results and Discussions

Table 1 shows the results of the measured and calculated the uncertainties which have been done in this work. Evidently, the uncertainty value due to inhomogeneity of detector sensitivity which is 6.67% can be decreased using high precision TLDs, whereas there is no way to decrease the uncertainty due to repeatability (i.e. 1.55%).

The RS-G-1.3 (IAEA Safety Guide, 1992) states that, in practice, the uncertainties caused by the energy and angular dependence of the response of the dosimeter received more attention than any other source of error, because the effects from all other uncertainty components

Table 1: The measured uncertainty values in personal dosimetry by TLD.

Source of Uncertainty	Type of Uncertainty	Number of TLDs	Uncertainty Values	Confidence Level
Inhomogeneity of detector sensitivity	A	100	6.67%	68%
Variability of detector readings due to limited sensitivity and background	A	5	1.55%	68%
Variability of detector readings at zero dose	A	-	0	-
Energy dependence	B	15	2.06%	60%
Directional dependence	B	15	4.23%	60%
Non-linearity of the response	B	15	4.05%	60%
Fading, dependent on ambient temperature and humidity	B	6	6.44%	60%
Calibration errors	B	-	2.5%	60%
Variation in local Natural Background	B	-	0	-

are assumed to be much smaller. But the results in the tables show that the uncertainties due to non-linearity and fading are comparable to those cases in personal dosimetry by TLD.

Uncertainties acceptable in routine monitoring for external radiation should be somewhat less than the investigation level. The general guidance on uncertainty levels is based on the recommendations of the ICRP [10]. It is recognized that the acceptable relative uncertainty at higher levels of exposure should be more restrictive than at lower levels because of the potential impact of errors. Therefore, at the annual limits, the uncertainties should not exceed a factor of 1.5 at the 95% confidence level. Where they amount to less than 10 mSv an uncertainty of a factor of 2 at the 95% confidence level is acceptable. For doses of the order of the annual limits, the apparent annual dose to an individual HP(0.07) and HP(10) as indicated by a number of basic dosimeters, issued regularly during the year and worn on the surface of the body should not differ by more than: - 33% or + 50% (at the 95% confidence level) from the dose equivalents that would be indicated by an ideal dosimeter worn at the same point at the same times. This allowable

uncertainty of dose being measured can be met at 95% confidence level if

$$1.96 U_c \leq 0.5 \times (0.33 + 0.50) \qquad (6)$$

and accordingly from equation(1):

$$U_c = \sqrt{U_A^2 + U_B^2} \leq 0.21 \qquad (7)$$

Regarding the results in table1 and equations (1-3), the total uncertainty is calculated 17.5% with 95% confidence level. This value is less than the admissible value of 42% which is suggested by RS-G-1.3 [3].

Conclusion

The effective sources of uncertainties in personal dosimetry by TLD are included; inhomogeneity of detector sensitivity, variability of detector readings due to limited sensitivity and background, energy dependence, directional dependence, non-linearity of the response, fading, dependent on ambient temperature and humidity and calibration errors. Considering the reporting level used in personal dosimetry, the other sources of uncertainties, i. e. variability of detector readings at zero dose, and variation in local natural background will not cause in the total uncertainty in TL dosimetry. The sources of uncertainty such as effects due

to exposure to light, effects due to exposure to types of ionizing radiation that are not intended to be measured by the dosimeter and effects from mechanical shock and variation in local natural background are not applicable in personal dosimetry by TLDs. So the TLD-100 personal dosimeters as well as the Harshaw TLD-100 reader 6600 system show the total uncertainty value which is less than that of admissible value of 42% for personal dosimetry services.

Conflict of Interest

None

References

1. Wernli C, Barthe J, Dietze G. Individual Dosimetry. *Radioprotection*. 1996;**31**:17-35. doi:10.1051/radiopro/1996021.

2. Petrucci C. Assessment of the effective dose to personnel in interventional radiography: a review of methods. *Radioprotection*. 2008;**43**:35-52. doi:10.1051/radiopro:2007047.

3. International Atomic Energy Agency, International Labour Office. Assessment of occupational exposure due to external sources of radiation: Safety Guide. Michigan: International Atomic Energy Agency; 1999. p. 89.

4. Harshaw/Bicron Radiation Measurement Products. Harshaw TLD Model 6600 Plus Automated Reader User Manual. Ohio: Thermo Scientific; 1992. p. 1-5.

5. Bureau International des PoidsetMesures. GUM: Guide to the expression of Uncertainty in Measurement. Geneva: BIPM; 1995.

6. Pedersen K, Andersen TD, Rødal J, Olsen DR. Sensitivity and stability of LiFthermoluminescence dosimeters. *Med Dosim*. 1995;**20**:263-7. PubMed PMID: 8703321.

7. Troncalli AJ, Chapman J. TLD linearity vs. beam energy and modality. *Med Dosim*. 2002;**27**:295-6. PubMed PMID: 12521077.

8. Zullo JR, Kudchadker RJ, Zhu XR, Sahoo N, Gillin MT. LiF TLD-100 as a Dosimeter in High Energy Proton Beam Therapy--Can It Yield Accurate Results? *Med Dosim*. 2010;**35**:63-6. doi: 10.1016/j.meddos.2009.03.001. PubMed PMID: 19931017.

9. Barth RF, Coderre JA, Vicente GH, Blue TE. Boron neutron capture therapy of cancer: current status and future prospects. *Clin Cancer Res*. 2005;**11**:3987-4002. doi: 10.1158/1078-0432.ccr-05-0035. PubMed PMID: 15930333.

10. International Commission on Radiological Protection. General Principles for the Radiation Protection of Workers. Oxford, New York: Pergamon Press; 1977. p. 50-2.