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Uncertainty analysis of absorbed dose calculations from thermoluminescence dosimeters

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Thermoluminescence dosimeters (TLD) are widely used to verify absorbed doses delivered from radiation therapy beams. Specifically, they are used by the Radiological Physics Center for mailed dosimetry for verification of therapy machine output. The effects of the random experimental uncertainties of various factors on dose calculations from TLD signals are examined, including: fading, dose response nonlinearity, and energy response corrections; reproducibility of TL signal measurements and TLD reader calibration. Individual uncertainties are combined to estimate the total uncertainty due to random fluctuations. The Radiological Physics Center's (RPC) mail out TLD system, utilizing throwaway LiF powder to monitor high-energy photon and electron beam outputs, is analyzed in detail. The technique may also be applicable to other TLD systems. It is shown that statements of $\pm 2\%$ dose uncertainty and $\pm 5\%$ action criterion for TLD dosimetry are reasonable when related to uncertainties in the dose calculations, provided the standard deviation (s.d.) of TL readings is 1.5% or better.

I. INTRODUCTION

Thermoluminescence dosimeters (TLD) are used to verify absorbed dose calculations at specific sites in a radiation field, either directly on a patient or in a phantom. As with any measurement, there are associated random and systematic uncertainties with the determination of dose from the TLD. These uncertainties in the TLD reading process arise due to measurement imprecisions in the TLD signal as well as the various experimental determinations of correction factors of TL fading, nonlinearity, and energy response. A specific system using LiF TLD-100 powder is analyzed, but the method may be applicable to other phosphors and forms (e.g., chips) as well.

The Radiological Physics Center (RPC) operates a mailed thermoluminescence dosimetry system which is used to monitor the outputs of megavoltage photon (cobalt-60 to 45 MV) and electron beams from 6–25 MeV used in radiation therapy.¹ The RPC provides this service semiannually routinely to all National Cancer Institute radiotherapy clinical trial participants, which includes about 875 institutions with more than 2000 therapy machines in North America and Europe. The results of these checks are reported to each institution and include the calculation of the dose delivered to the institution's beam calibration reference point along with an estimate of the overall accuracy of the dose. Agreement of the RPC TLD measurements within 5% of the institution's stated output is considered to be acceptable. If the disagreement is greater than 5%, the discrepancy is resolved through phone calls, correspon-

dence, repeat TLD checks or a review visit by an RPC physicist.

The RPC's system consists of three disposable polyethylene capsules of lithium fluoride powder (Harshaw Chemical Company TLD-100 or equivalent) in acrylic blocks which approximate miniphantoms for photons and full phantoms for electron beams. The TLD/block system is used as a relative dosimeter, with the reference being absorbed dose measurements with Farmer-type ionization chambers in a water phantom. The RPC used the SCRAD² and ICRU-21³ calibration protocols until 15, April 1984 at which time the AAPM TG-21⁴ protocol was adopted.

II. METHODS

There are three sets of measurements which are necessary to calculate the absorbed dose from a set of TLD samples [discussed in Eq. (3) below]. The first is the measurement of TL signals which will vary from one sample to the next, depending on the energy and dose to which the sample was exposed. Next, the system calibration factor, which applies to all of the sample dose calculations, will change with each readout session due to changes in the electronics and optics of the reader, planchet reflectivity, heating characteristics, and so forth. Finally, if the TLD samples have all been taken from the same manufacturing run, they may be assumed to have consistent "batch characteristics," which include TL fading, dose-response nonlinearity and energy dependence.

This section describes the statistical and experimental

methods used to determine the uncertainty in each of the parameters in Eq. (4). The equation for the individual s.d. are given but the partial differentials are omitted in the interest of space.

A. Calculation of absorbed dose

The absorbed dose, D , to the reference medium at location of the TLD may be calculated from the thermoluminescence measured by the reader as:

$$D = TSK_L K_F K_E, \quad (1)$$

where T is the TL reading per unit mass for a single sample; S is a system calibration factor; K_L is the dose response linearity correction; K_F is the fading correction; and K_E is the energy correction. Each of these factors is an experimental value or an estimated value of an experimentally determined function and therefore all have associated random uncertainties. Other factors may be included to convert the TLD measured dose to another reference point but are not considered here because they do not contribute to the uncertainty of the dose measured by the TLD, relative to the ionization chamber determination.

The system calibration factor is defined as the inverse of the thermoluminescence response of the TLD system per unit dose (in the RPC system, 3.00 Gy from a cobalt-60 beam). Using a prime (') to denote factors relating to these "standard" TLD which are used to determine S , we have

$$S = D' / (T' K_{F'} K_{L'}). \quad (2)$$

Note that the energy dependence correction factor K_E is normalized to unity for $^{60}\text{Cobalt}$ and so is not included in this equation. Also note that T' is the mean value of TL response per unit mass of the capsules used to determine S , as opposed to T which is for a single TLD sample which may have been irradiated with different energy, dose and at a different time. Substitution of Eq. (2) into Eq. (1) and some rearrangement gives

$$D = TD' K_E 1/T' (K_F/K_{F'}) (K_L/K_{L'}) \quad (3)$$

B. Uncertainty calculation

The analysis of the uncertainty in dose calculations is based on the assumptions that the uncertainties in individual terms in Eq. (2) are independent, since they are independently determined, and that each term is a normally distributed variable. The sample variance of the calculation can then be determined by summing the individual sample variances.^{4,5} There is a potential limit to this method in that if this assumption is violated it can readily produce variables whose ratios are Cauchy distributed and have no mean or variance defined.⁶ Treating Eq. (3) as the combination of six independent variables allows an expression for the sample variance s_D to be derived for a dose calculation from a single sample, in terms of the individual variances and partial differentials of the dose. Letting $F = K_F/K_{F'}$ and $L = K_L/K_{L'}$, the fractional variance becomes

$$s_D^2 = \left(s_T \frac{\partial D}{\partial T} \right)^2 + \left(s_{D'} \frac{\partial D}{\partial D'} \right)^2 + \left(s_E \frac{\partial D}{\partial K_E} \right)^2 + \left(s_{T'} \frac{\partial D}{\partial T'} \right)^2 + \left(s_F \frac{\partial D}{\partial (F)} \right)^2 + \left(s_L \frac{\partial D}{\partial (L)} \right)^2. \quad (4)$$

For a single TLD reading, the standard deviation s_D represents the uncertainty of the dose calculation. The problem has then been reduced to the determination of each of the individual terms in Eq. (4). For multiple measurements, a mean value of the dose may be determined which should have less uncertainty in the value of D , the mean dose. The s.d. of the mean dose SE_D calculated from n (in the RPC system $n=3$) samples is

$$SE_{D'} = s_{D'} / \sqrt{n}, \quad (5)$$

and the confidence interval CI at the 100 (1-x)% level (e.g., $x=0.05$ corresponds to a 95% confidence interval) is related to the student's t value and the mean dose D by

$$CI = D \pm SE_{D'} t_{2,n-1,x}. \quad (6)$$

This is the recommended method for the expression of experimental uncertainties in terms of confidence intervals for given confidence limits and has been followed in this paper.⁷

C. Sample and standard readings

The uncertainty of individual TLD readings can be estimated from the variance of a large sample of TLDs irradiated to the same dose and readout in the same session. Since the system calibration changes with each session, this is usually expressed as the fractional variance. For multiple TLD samples, the upper limit of the confidence interval for the population variance σ^2 has been used to estimate s_T/T :

$$(s_T/T)^2 \approx \sigma^2 < (s_T/T)^2 (n-1) / X^2_{(1-0.05/2),n-1}. \quad (7)$$

The relative sample standard variation in the mean TLD readings from the standards, $S_{T'}/T'$, is the standard error of the mean of n TLD readings and is calculated from the population variance (estimated from a large sample of readings) and the number of samples used to determine T' :

$$S_{T'}/T' = S_T / (T \sqrt{n}), \quad (8)$$

where n is the number of samples: $X^2_{(1-0.05/2),n-1}$ is the chi-square statistic for the 95% confidence limit with $n-1$ degrees of freedom.⁶

D. Standard dose

The dose to the standards D' is calculated from measurements with an ionization chamber in water and delivered in fixed irradiation conditions. The uncertainties associated with the ion chamber measurements are estimated from probable setup errors. Although other uncertainties, such as different spectra in plastic or water, may contribute, their magnitude has been taken to be negligible or have been taken to be systematic errors rather than random.^{8,9} The distance and position of the TLD in the beam are fixed

by a rigid attachment to the blocking tray and are not considered to contribute any uncertainty to D' . Systematic calibration protocol errors are not considered. The achievable setup precision for an ion chamber in a water phantom is assumed to be ± 1 mm for both source to chamber distance (SCD) and depth d of the chamber in water. The inverse-square law and depth dose for the "standard" beam are used to predict the fractional variation (s.d.) in dose. The total uncertainty in the dose to the standards is the square root of the sum of the squares of the s.d., times the dose,

$$(s_{D'}/D')^2 = [1 - (\text{SCD} + 1 \text{ mm})^2 / (\text{SCD})^2]^2 + [1 - (\text{TMR}_{d+1 \text{ mm}} / \text{TMR}_d)]^2. \quad (9)$$

E. Energy correction

The energy correction factors K_E are determined by comparing the response of the TLD exposed in the appropriate phantom and radiation beam to the response of TLD exposed to the same absorbed dose in a ^{60}Co beam.^{8,10,11} The absorbed dose in all cases is determined from ionization chamber measurements in a water phantom. If fading corrections can be neglected, K_E is

$$K_E = (DT') / (D'T). \quad (10)$$

The only uncertainties in the determination of K_E are in the calibration of the beams (standards and other energy being tested) and in the uncertainties in the respective TLD readings. Again, assuming that the total variance of K_E is the sum of the individual variances and that $s_x = (\partial K_E / \partial x) dx$ (x being one of the variables), then the variance of the dose due to the determination of the energy correction factor is

$$s_E^2 = K_E [2(s_{D'}/D')^2 + (s_T/T)^2 / 2], \quad (11)$$

where Eqs. (7) and (9) may be used for their respective variances.

F. Nonlinearity correction ratio

The dose-response nonlinearity correction K_L is determined by a linear least-squares fit of the system calibration factor S as a function of dose, such that the correction factor is 1 at the normalization dose. Thus

$$K_L = a_L + (b_L D), \quad (12)$$

where a_L is the intercept of the linear least-squares fit, divided by the value at the normalization dose; b_L is the slope, divided by the normalization value; and D is the absorbed dose. If the dose is known (in the case of the standards), Eq. (12) is used. If not (in the case of the samples), an expanded equation must be used, introducing some slight error since the dose-response nonlinearity correction is itself a part of the expression for D ; but, for simplicity, that is ignored.

The nonlinearity correction ratio L is treated as one variable in Eq. (4). The rationale behind this assumption is that the overall dose uncertainty does not depend on the individual uncertainties, but rather on the uncertainty in

the determination of the slope b_L of the linear function connecting the two values and the separation of the two values on that line (as illustrated in Fig. 2). Even though the exact function may not be known, the uncertainty in this ratio depends only on the uncertainty in the slope of the linearity correction function and the dose difference between the standards and the samples. For instance, a difference in dose of 0.5 Gy will result in approximately the same uncertainty at 3 Gy as at 4 Gy, provided the correction factor is linear.

A quantity called the standard error of the regression coefficient (slope) s_b can be calculated from a linear regression.⁵ This quantity is the s.d. of the possible slopes determined by the linear regression. Using Eq. (12) and the same procedure as before for standards and samples, the variance of the quantity L , in terms of s_{b_L} , the standard error of the regression coefficient for the linearity correction is

$$s_L^2 = [s_{b_L} (D - D') a_L / (a_L + b_L D')]^2. \quad (13)$$

G. Fading correction ratio

Corrections for fading of the TL signal must be made if there is no pre-read anneal to eliminate the low temperature peaks and if the standards and samples were irradiated on different dates. Fading differences between the standards, controls, and samples may be minimized in practice by irradiating standards and controls once per week and reading them with samples irradiated at about the same time.

The resultant fading curve is the sum of several exponential functions which correspond to fading from each of the trap levels. This has been approximated by two linear functions, one from 10 days to the time when the fading curve becomes relatively constant, denoted as time t_c , and the other from that point and beyond. The assumption that no fading occurs after t_c becomes less correct with longer times after irradiation. Shorter term fading can also be determined but the simple linear relation does not describe the fading before 10 days well. Also, the variability of TLD readings becomes greater in that region. The data are renormalized to the $t=0$ intercept on the T axis, and K_F is

For time $t < t_c$:

$$K_F = a_F - (b_F t), \quad (14)$$

and for $t \geq t_c$:

$$K_F = a_F, \quad (15)$$

where a_F is the intercept and b_F is the slope of the linear least-squares fit of the fading data from 10 to t_c days. Here, b_F is negative since the TL signal fades, so K_F will always be greater than unity. Here, K_F is defined to be unity for TLD the same day as the irradiation and is a constant for times greater than t_c .

The uncertainty analysis is somewhat complicated by this two function model. For samples and standards which were all irradiated either before or after t_c , the uncertainty analysis is the same as that for the linearity correction

TABLE I. Typical data for the TLD powder irradiated to 3.00 Gray to muscle nominal dose at isocenter on three different energy photon beams. The dose given, D , is the dose at the location of the TLD. For definitions of the parameter symbols, refer to the text. The ^{60}Co standards (STDS) were irradiated for 2 min.

Parameter	Values for photon beam energy			
	STDS (^{60}Co)	^{60}Co	10 MV	24 MV
S [Gy/(V/mg)]	45.0	45.0	45.0	45.0
D (Gy)	2.091	3.06	3.12	3.24
T (V/mg)	0.0439	0.0662	0.0648	0.0658
K_E	1.00	1.00	1.04	1.07
K_F	1.036	1.029	1.029	1.029
K_L	1.023	0.998	0.999	0.995

ratio. Otherwise, there is no such simple relation. An approximation is therefore made that the uncertainty in the ratio is dependent only on the standard error of the regression coefficient of the function before t_c . This will apply if the slope of the function after t_c is indistinguishable from zero and the values of K_L and $K_{L'}$ are not too much different from unity. Following the same arguments as with the linearity correction ratio, the variance of the fading correction ratio in terms of s_{b_F} , the standard error of the regression coefficient for the fading correction ratio is

$$s_F^2 = [s_{b_F}(t-t')a_F / (1+t'b_F)^2]^2, \quad (16)$$

where t and t' are the times from irradiation to readout of the samples and standards, respectively, and b_F is the regression coefficient (slope) of the linear least-squares fit to the data prior to t_c .

III. RESULTS & DISCUSSION

The calculation of uncertainties described in the previous section were done for the RPC's available TLD system for a typical batch of TLD. Equipment used for the measurements consisted of a Radiation Detection Company Mark IV, Model 1100 TLD reader and a Cahn Instrument Company Model TA 4100 Balance. The powder used is throwaway TLD-100 (Harshaw Chemical Company, prepared and packaged by Radiation Detection Company, preirradiation annealed but not pre-read annealed). The TLD are requested to be irradiated such that the institution's reference point would receive a nominal dose of 3.00 Gray. The photon checks are done in acrylic phantoms which are d_{max} thickness and are placed on a platform, the surface of which is at the nominal isocenter for that machine. The TLD are therefore closer to the source or target than is the reference point and so the dose at the location of the TLD may be considerably larger than 3 Gray (i.e., the block thickness increases with photon energy). Appropriate corrections have been made in these calculations for dose delivered at the location of the TLD for the nominal dose listed and the given energy. For this analysis, it is necessary to utilize typical data for a readout session, given in Table I.

Experimental determinations of TLD reading reproducibility, linearity, and fading corrections are illustrated in

TLD READING REPRODUCIBILITY (Cobalt-60 controls)

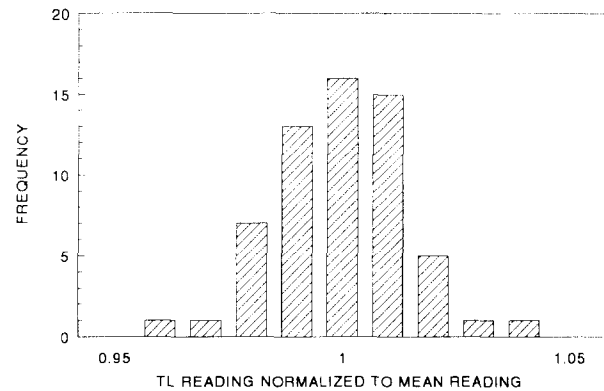


FIG. 1. Experimental determination of the sample s.d. of TLD readings. Four separate sessions of 15 readings each were combined by normalizing each set of measurements to the mean reading for that session. The s.d. of these data can be used to estimate the population variance, as explained in the text.

Figs. 1, 2, and 3. Data from different reading sessions were normalized to the mean readings of TLD controls which had been uniformly irradiated. Figure 1 shows a frequency histogram of the TL response of 60 TLD samples normalized to the mean TL response. The fractional s.d. of these data is 0.014. The estimate of the fractional population variance is given by Eq. (7) and must be multiplied by the appropriate mean T to get the population variance. The fractional standard error of T' is calculated from Eq. (8), where the number of TLD standards is six. The fractional variance in the standard TLD dose, calculated by Eq. (9) is approximated using $\text{SCD}=80.0$ cm, $d=5.0$ cm, and

DOSE-TL RESPONSE NONLINEARITY CORRECTION FACTOR

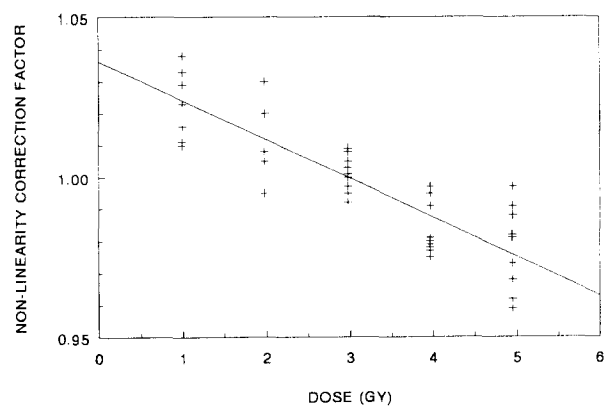


FIG. 2. Uncertainty in the ratio of dose-response nonlinearity corrections due to the experimental uncertainty in the slope of the linear least-squares fit. The solid line represents the mean slope (regression coefficient). The regression coefficient is interpreted to be a normally distributed variable with s.d. of the mean value equal to the standard error of the regression coefficient. The standard error in the ratio of the nonlinearity corrections of the sample and standard TLDs is then dependent on the uncertainty in the slope of the line and the difference in the standards and sample doses.

TL FADING CORRECTION FACTOR

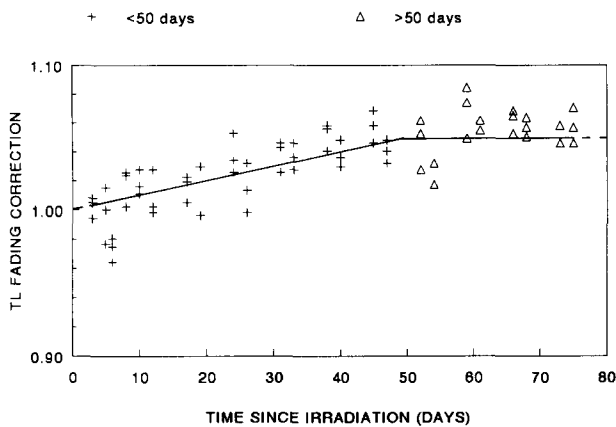


FIG. 3. Fading correction relation, K_L versus time elapsed between irradiation and readout. For irradiation times of samples and standards both less than or both greater than t_0 , there is the added complication that two linear least-squares fits are used for the same function. However, the uncertainty is still determined by the standard error of the regression coefficient in the function before t_0 , provided that the fading past that point can be shown to be negligible. The data shown here indicate TL fading of approximately 0.1% per day up to 50 days from irradiation and negligible fading after that. The correction factors shown here are the inverse of the TL versus time relation (fading curve).

published depth-dose data.¹² The dose-response nonlinearity data and the associated uncertainty in the slope of the regression are shown in Fig. 2. Fading data are likewise shown in Fig. 3. Table II summarizes each of these fractional variances.

The data in Tables I and II, along with the appropriate equations for the variance and partial differential equations were used to calculate the total uncertainty in the dose calculation. Results are summarized in Table III. The s.d. of the individual TLD readings is estimated to be less than 1.5%, while the s.d. of a dose calculation from a single TLD reading is about 3%. The standard error of the mean dose calculation for the three samples which constitutes a single data point is then 1.3%, implying a confidence interval of $\pm 4\%$ at confidence limits of 90% and a confidence interval of $\pm 6\%$ at the 95% confidence limit. This

TABLE II. Example of contributions of each parameter to the total uncertainty in the dose calculation for the RPC's mailable TLD system. Uncertainties are expressed as fractional variance of the nominal dose. Calculations were done for three TLD samples receiving a nominal dose of 3.00 Gray for parameters measured for a typical batch of LiF powder. The fractional variances were calculated assuming the parameter being examined was the sole contributor to the uncertainty in the dose determination.

Parameter	Fractional variance
Sample readings (T)	0.017
Standards dose (D')	0.006
Energy correction (K_E)	0.011
Standards readings (T')	0.007
Fading correction ratio (F)	0.007
Linearity correction ratio (L)	<0.001

TABLE III. Estimates of the uncertainty in dose calculations for a powder TLD system. Here s.d. is the standard deviation, SE is the standard error of the mean, and CL denotes confidence limits. Three samples are read for each dose determination. The TLD check is acceptable if the dose agreement is within 5% of the stated dose, corresponding to a 93% confidence limit.

Measure of uncertainty	Value (%)
s.d. (1 sample)	2.3
SE (3 samples)	1.3
80% CL	2.5
90% CL	3.9
93% CL	5.0
95% CL	5.8

means that the dose calculated is expected to be within 4% of the dose measured by an ionization chamber 90% of the time and within 6% of that dose 95% of the time.

The fractional uncertainty in the dose was found to be independent of beam energy, dose to the samples (to at least 20% different dose than the nominal 3 Gray requested), and time between irradiation of the samples and standards. The energy independence is due to the assumption of equal uncertainties in ionization chamber calibrations of all beams, regardless of energy. Dose and time independence is due to the small uncertainties in the determination of the fading and dose-response functions which are near unity for the range of circumstances normally encountered and so contribute little uncertainty in the final dose calculation. Examination of Eq. (13) and (16) shows that the uncertainties in the fading and linearity correction ratios can be minimized by irradiating the standards and samples as closely as possible at the same time and to the same dose. As seen from these results, the largest contributors to the total uncertainty in the dose calculation are the uncertainties in the individual TLD readings and the energy correction factors. The small uncertainty in the TLD readings (less than 1.5% in the RPC experience) is essential for the good results reported here. For comparison, Oberhofer estimates TLD measurement precision for LiF powder to be from 2% to 3% (s.d.), although at lower doses.¹³

A check of these uncertainty calculations was done by comparing predicted and measured doses on a cobalt machine. The predicted doses were based on ionization chamber calibrations. The measured doses were the mean of 6 TLD dose measurements over 17 sessions. The results are shown in Fig. 4. The fractional s.d. of these data is 0.006. Equation 5 with $n=6$ and the fractional variance of 0.023 from Table III predicts a relative s.d. of the mean readings of 0.009.

Results from the RPC's mailout system can be compared with this model. For 10 400 photon beam checks, 4.2% were outside the $\pm 5\%$ criterion (TLD/institution) while, for 6 300 electron beam checks, 7.5% were outside the $\pm 5\%$ criterion. The above model would suggest that this distribution was strictly random, in agreement with the predicted $\pm 5\%$ at the 93% confidence level. However, RPC ion chamber measurements verify that there are, in

MEASURED VS. PREDICTED DOSE (AVERAGE OF 6 CONTROLS)

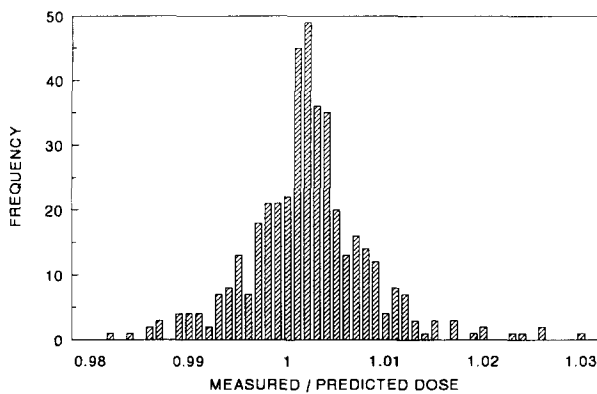


FIG. 4. Measured to predicted ratio of TLD irradiated to a known dose on a cobalt-60 machine. Six samples were read in 17 different sessions. The mean doses were calculated according to Eq. (1) and then compared to the dose predicted from ionization chamber calibrations. The relative s.d. of these data is 0.006, compared to 0.010 calculated according to the method described in the text, indicating that the analysis may be conservative.

addition, systematic discrepancies between the RPC and the institutions. RPC data on beam calibration agreement are often presented as a frequency histogram of the dose measured by the RPC divided by that stated by the institution. For ionization chamber measurements on approximately 1000 therapy units, the s.d. deviation of these data is 1.9% for photons and 2.2% for electron beams. The standard deviation of the same data for TLD measurements is 2.4% for photons and 3.2% for electrons.¹⁵ If we sum in quadrature, this implies a s.d. of 1.5% and 2.3% due the TLD uncertainty for photon and electron beams, respectively. This compares favorably with the standard error of our 3 TLD samples of 1.3% seen in Table III, especially for the photons.

Systematic errors have not been considered in this analysis. Systematic uncertainties in beam calibration with ionization chamber measurements in a water phantom may be 3% or higher.¹⁶ Another systematic uncertainty is the calculation of the dose to the TLD as dose in muscle for the RPC system, regardless of the medium used for reference by the institution. This was used because the NCI radiotherapy protocols specify doses in muscle.

Uncontrollable errors which were also not included are: (1) TLD setup and irradiation by the institution; (2) misinterpretations of the definition of dose reference points; (3) anomalous energy response to machine models; and (4) atypical machines.

IV. CONCLUSIONS

A system of uncertainty analysis for thermoluminescent dosimetry has been described. This analysis includes experimental uncertainties in TL signal, fading, energy dependence and dose-response nonlinearity measurements.

The results of the RPC and TRMP mailout TLD beam monitoring systems indicate that the analysis in this paper

may be conservative. In addition, the assumption that the factors in Eq. (3) are independent, random variables whose total variance can be determined by a sum of squares process is rather robust.

The major experimental uncertainties are shown to be the TL signal measurements with a s.d. of less than 1.5%. This analysis predicts that the dose calculated from the TLD system is within 5% of ionization chamber measurements 93% of the time. The model is independent of absorbed dose, beam energy and time between irradiation of samples, and standards over the ranges of the values encountered by the RPC.

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APPENDIX: DEFINITION OF VARIABLES

a_L	= intercept (at $D=0$) of the linear least-squares fit to K_L vs D
b_L	= slope of the linear least-squares fit to K_L vs D
CI	= confidence interval
D	= absorbed dose calculated from TLD readings (Gy)
F	= $K_F/K_{F'}$
K_E	= energy response correction factor
K_F	= TL fading correction factor
K_L	= dose-response nonlinearity correction factor
L	= K_L/K_L'
n	= number of TL readings for a given dose determination
S	= system calibration factor (Gy mg/rdg)
SCD	= source to chamber distance (mm)
s_D	= sample variance for D
s_E	= sample variance for E
s_T	= sample variance for T
SE	= standard error (standard deviation of the mean)
T	= TL reading per unit mass (rdg/mg)
TMR	= tissue-maximum ratio
$t_{2,n-1,x}$	= Student's t value (2 sided, n° of freedom, $1-x$ confidence)
σ	= population variance
$\chi_{(1-0.05/2)n-1}$	= chi-square statistic, 95% confidence, $n-1$ deg of freedom
'	= variable of "standards" TLD.
	Unprimed variables = samples

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