RPC Experience with TLD for Output and Energy Monitoring of Radiation Therapy Beams

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Abstract

The Radiological Physics Center (RPC) has been utilizing TLD to verify photon-beam output, and electron-beam output and energy for many years. The RPC currently monitors over 1200 institutions, monitoring 4000 photon and 3500 electron beams per year. Control TLD, irradiated on one specific Co-60 machine, are used for a performance check of our TLD system. Analysis of these data over 5 years, reveals high precision (SD =0.9%) in beam output verification. Analysis of all TLD results, since 1990, for remotely monitored photon beams (27,900) and electron beams (23,000), shows a spread (SD) of 1.9% and 2.2% respectively in beam output. The increased spread arises from the variability in beam energies, makes/models of machines, and institutional performance. In view of these variabilities, the results are extremely encouraging. Institutional performance includes uncertainties in beam-output calibration, set-up errors, and beam drifts. The Spread (SD) of individual beams varies widely from beam to beam and Institution to institution. The spread of individual beams has been used to identify “good” beams (SD < 2%) which are to receive TLD less frequently than others.

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Introduction

Thermoluminescent Dosimetry is a well-established technique whose scientific basis and its use for irradiation dosimetry is well documented in the scientific literature. It is widely used for in-vivo and experimental dosimetry for complex geometries. The Section of Outreach Physics at MDACC has been using TLD as a remote-monitoring tool for more than 30 years.

TLDs are available in the form of rods, chips and powder. The characteristics are basically the same irrespective of the form or shape of the TLD material.

The technique for LiF TLD rods or chips has been detailed in other publications. Kirby et. al. (1986) have discussed the use of powder for a mailable TLD system for monitoring calibrations of photon beam energies for Cobalt 60 to 25M and electron energies from 6 to 20 MeV. An uncertainty analysis by Kirby et. al. (1992) for absorbed dose calculations, showed that a ±2% dose uncertainty and ±5% acceptance criteria for TLD dosimetry was possible.

This work presents analysis of TLD results from both, the RPC's internal quality assurance and from the users over past 8 years. The former shows a precision of 1% under irradiations with high-precision set up. This implies that the RPC can implement a tighter quality-assurance criterion for beam output.

The analysis of history of TLD results for individual beams of users has led to a promising tool to identify two types of potential problems. First, a systematic departure of the multiple TLD results from the expected value indicates a potential problem in beam-output calculation or electron depth dose data. Second, a significant variability of multiple TLD results indicates potentially poor quality-assurance window for beam. The action levels suggested by the data are presented.

Materials and Methods

- TLD Powder, about 20 mg per sample, disposed of after one use.
- TLD readers: Harshaw 3500 and Teledyne 7300; Dry Nitrogen Flushes
- TLD are massed with Metler Balances (accuracy of 0.1 mg)
- The signal (T) is therefore: TLD reading per unit mass (volt/mg)
- TLD irradiation system: Lucite "miniphantom" for photons, "full" phantom for electrons.*
- Photons, Dose at d_{max} only; Electrons, Dose at d_{max} and energy check
- Standards, irradiated on Cobalt 60, are used for system calibration of every session.
- Controls, irradiated on another Cobalt unit, are used to monitor stability of the reader throughout the session. Controls also provide a redundant calibration check.
- Each Batch of TLD (approximately 100,000 samples) is commissioned prior to use:
  - ✓ Reproducibility
  - ✓ Linearity
  - ✓ Fading
  - ✓ Energy/Phantom dependence
- Quality Assurance Procedures:
  - ✓ Response of Controls and Standards throughout the session. (Drift is flagged automatically)
  - ✓ Balance is monitored throughout the session. (standard mass before and after session)
  - ✓ Glow curve shape is monitored.
  - ✓ Control response is tracked over time.
  - ✓ Other tests include: dark current, standard light, record of faults.
  - ✓ Outliers are evaluated.

Concepts and Definitions

Standards: TLD are irradiated on a specific Cobalt 60 Irradiator, one set at a time, in the Cobalt “miniphantom”, in the center of a 10cm x 10cm field. One set of Standards is read at the start of a session and one at the end of the session (approximately 18 samples per session). The responses of the two sets are compared to determine reader drift.

Controls: TLD are irradiated on a second Cobalt 60 irradiator, 60 samples at a time, in a rotating jig. 4 sets of control TLD are read spread throughout the reading session. Each control TLD is compared with the initial control and outliers are flagged by the computer so additional controls can be read if necessary. Controls monitor for reader drift, and serve as a redundant check of calibration.

System Sensitivity (S): Dose per unit TL signal corrected for fading and linearity, calculated from the average response of the standards. (See Kirby et.al.)

Dose to Samples (D):

$$D = S \bullet T \bullet K_E \bullet K_L \bullet K_F \qquad (1)$$

Where K_E, K_L, and K_F are corrections for Energy, Linearity and Fading (Kirby et.al.), respectively.

Measured/Predicted for controls: The control signals are averaged over the whole session and dose calculated from the above formula (measured). The dose is also determined from decay of the Cobalt output (predicted). [KE is 1.00 by definition for ^{60}Co].

Results and Comments

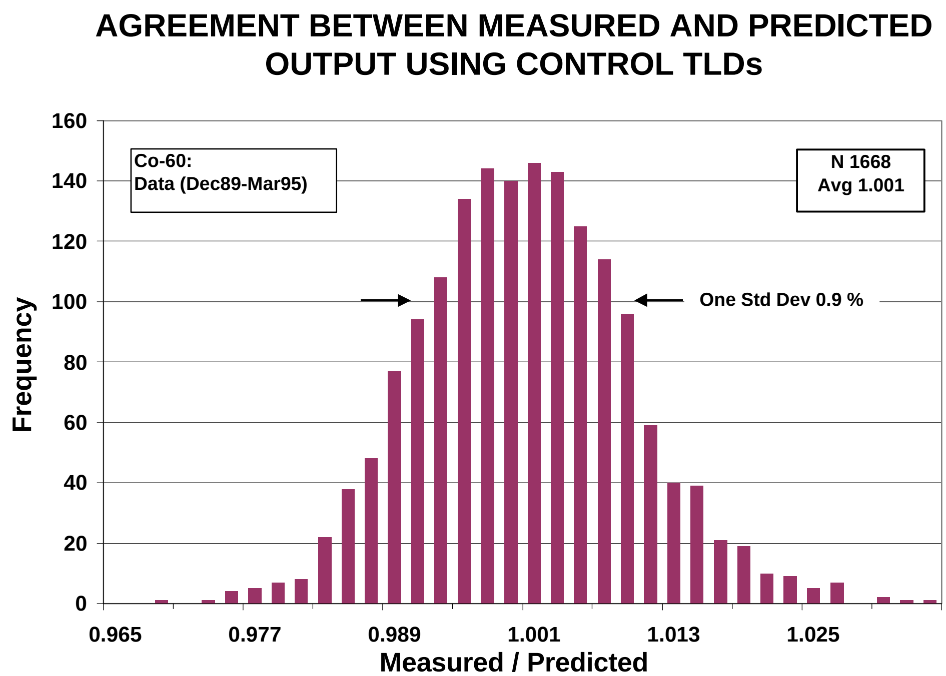


Figure 1: Histogram of measured to predicted dose using controls for nearly 1,700 TLD reading sessions over 5.5 years. This data is representative of the tightest TLD results achievable by our system. During this time period, each Cobalt 60 machine underwent a source change and an ion-chamber calibration.

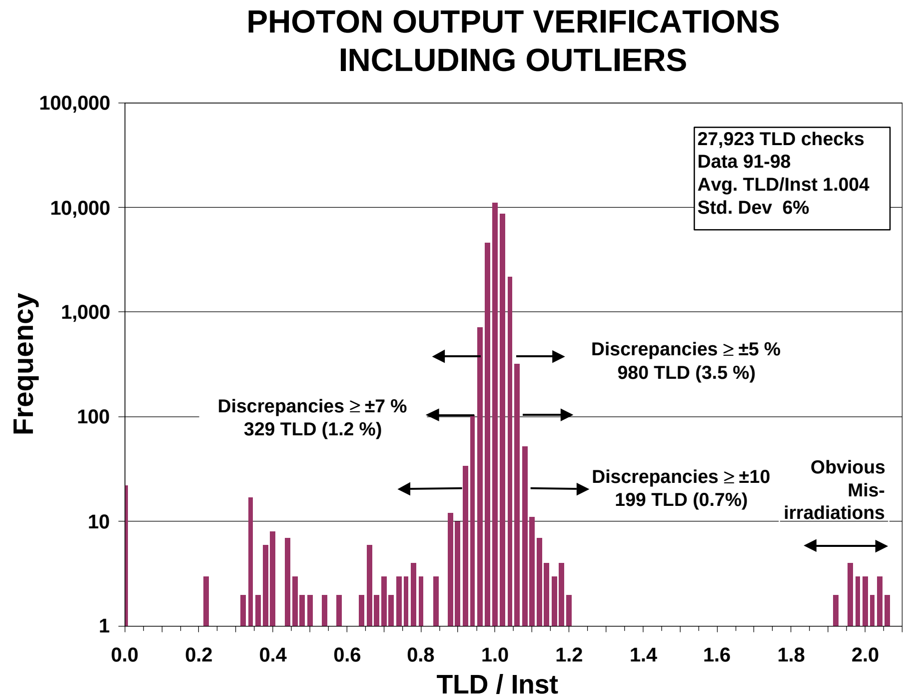


Figure 2: Frequency histogram of photon irradiation at participating institutions over an eight year period.

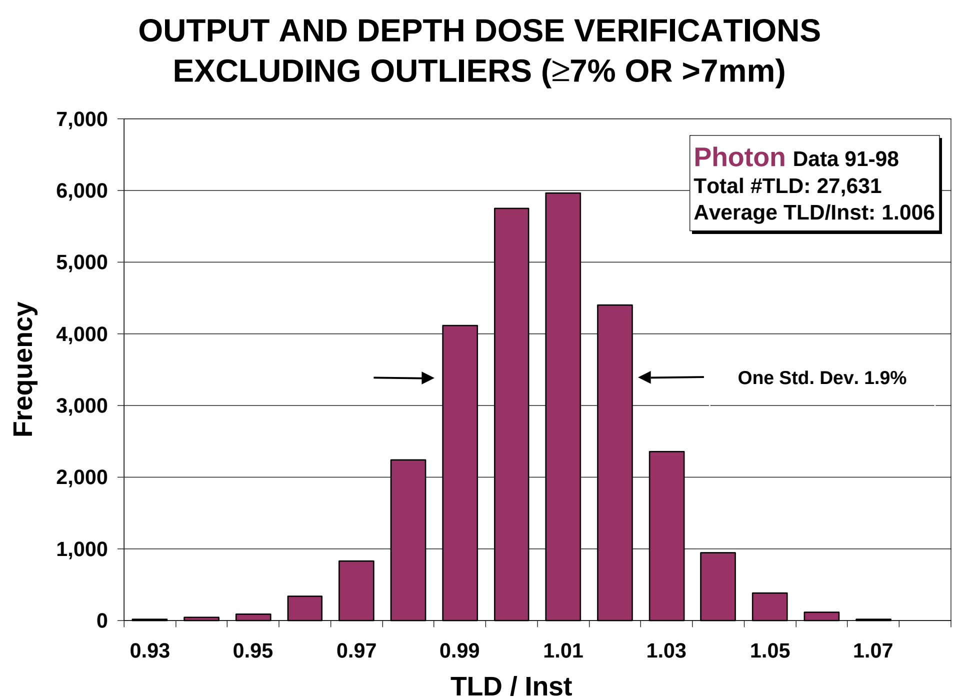


Figure 3: TLD/Inst. for photon irradiation's at participating institutions over an eight year period.

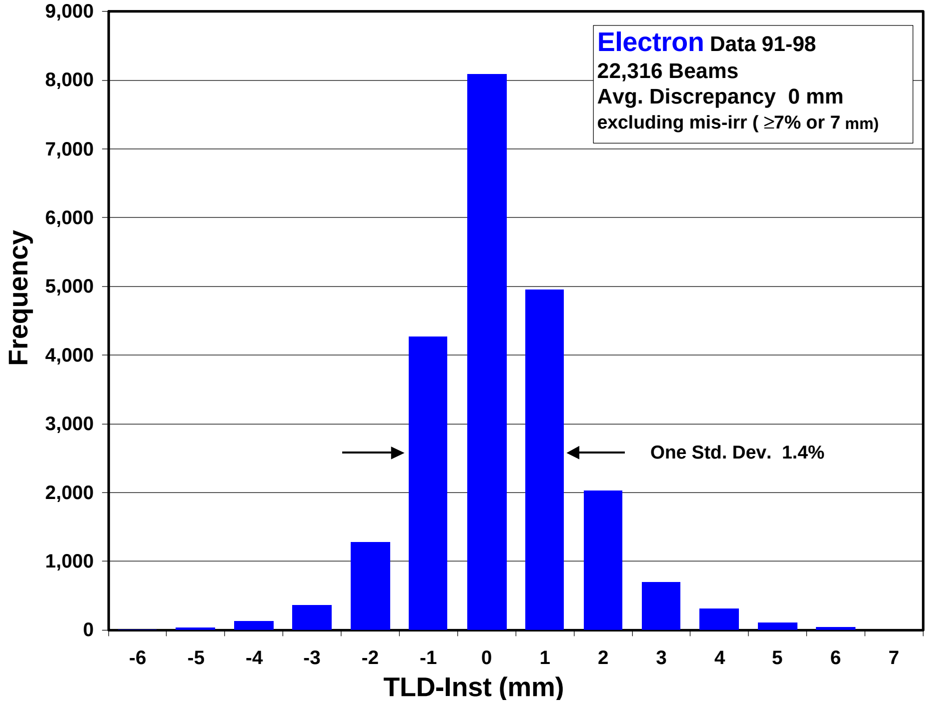


TABLE 1: MEAN AND STANDARD DEVIATION OF THE RPC'S MAILABLE TLD RESULTS.

	Mean	Standard Dev.
Co-60 Output check with Controls (1, 668 pts.)	1.001 (Meas/Expt)	0.9%
INST. X-ray output (27,631 pts.)	1.006 (TLD/Inst.)	1.9%
INST. e- output (22,653 pts.)	1.003 (TLD/Inst.)	2.2%
INST. e- depth (22,316 pts.)	0 mm (Meas-Inst.*)	1.4 mm

*The difference in the depth of a given % depth-dose line as measured by TLD vs. that stated by the institution.

Note that the mean value in all cases is near unity suggesting no major systematic discrepancies in the dosimetry parameters used by the RPC TLD program. The extremely tight SD (<2%), indicates a high level of consistency among the majority of participating institutions.

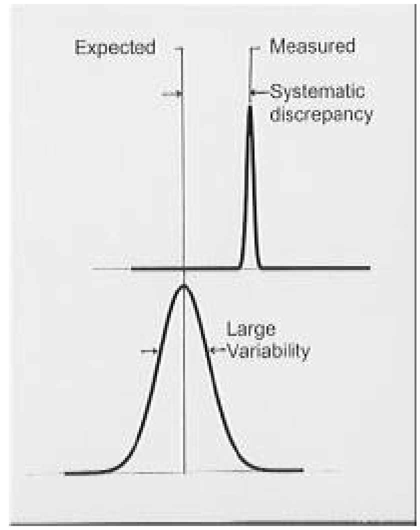
Notice that the standard deviation of the TLD measurements (~2%) is comparable to that of ion-chamber measurements (~1.5%).

Figure 4: Difference in depth dose measured by TLD vs. institution values for all electron beams, monitored over an eight year period

CONCEPT: TLD HISTORY FOR EACH BEAM

- Systematic Bias: Indicator of potential problem related to output calculation or, depth-dose data.

- Variability: Indicator of potentially poor quality-assurance or careless irradiation.



SYSTEMATIC DISCREPANCIES FROM TLD HISTORY OF INDIVIDUAL BEAMS

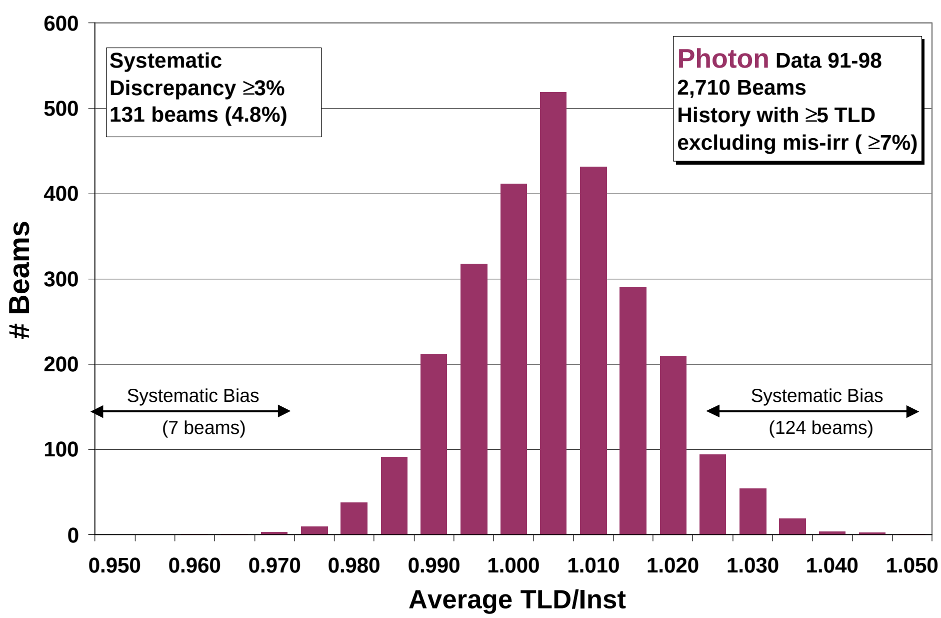


Figure 5: Frequency distribution of an average TLD/Inst. results of multiple checks (>=5) for each beam. Departure of the average results from each beam. Departure of the average results from 1.000 represents a potentially systematic discrepancy. Electron beams results show similar characteristics.

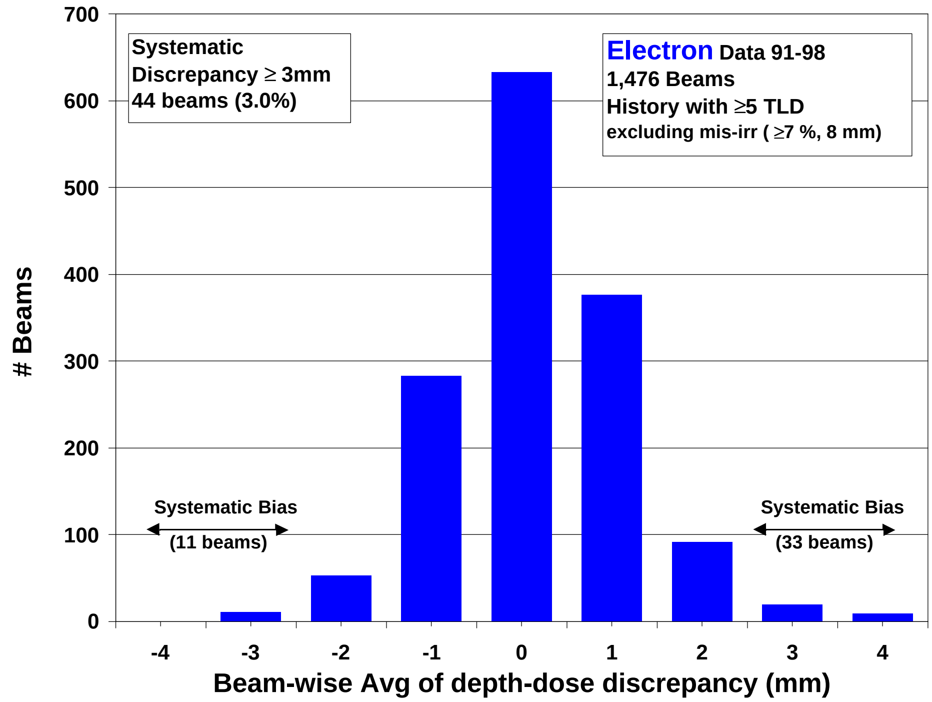


Figure 6: Frequency distribution of an average depth-dose discrepancy for multiple checks (>=5) for each beam. Departure of the average results from zero mm indicates a potentially systematic discrepancy.

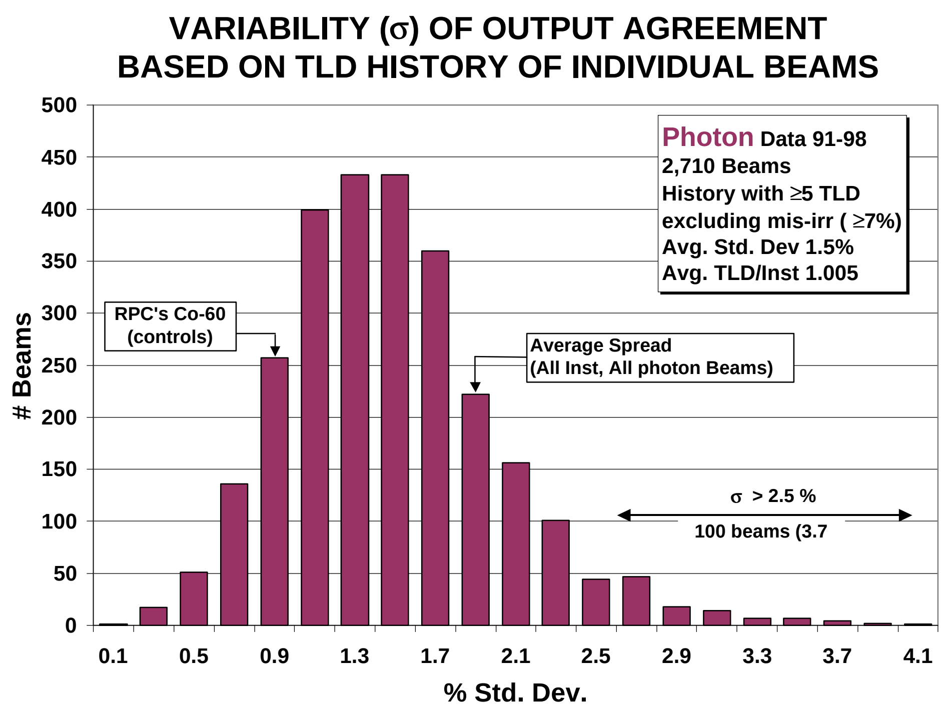


Figure 7: Frequency distribution of variability (as represented by σ) of multiple TLD/Inst. results for individual **photon** beams. Large variability indicates potentially poor quality-assurance window for beam output.

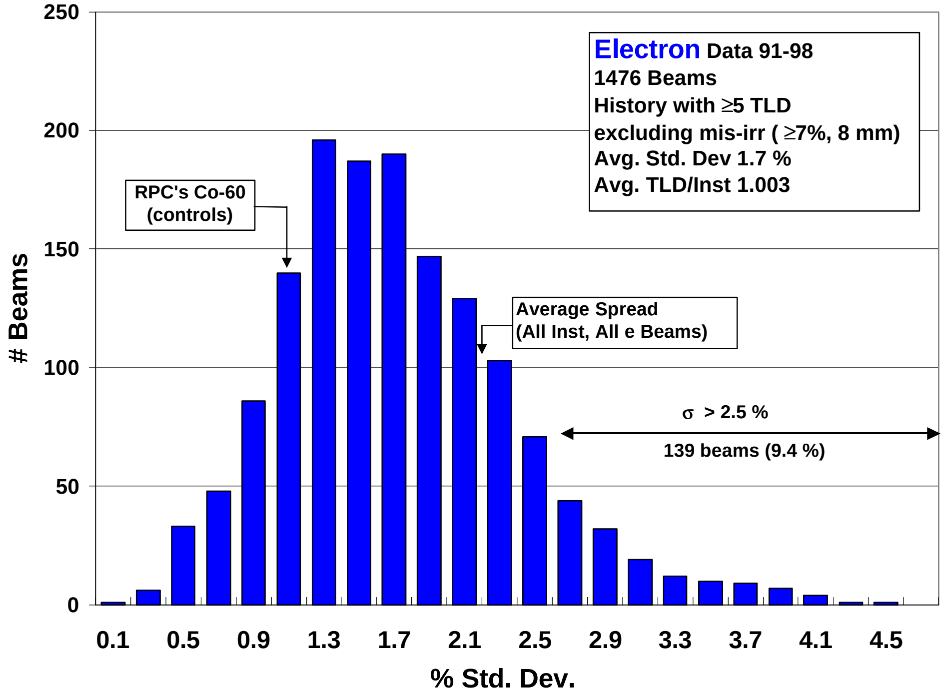


Figure 8: Frequency distribution of variability (as represented by σ) of multiple TLD/Inst. results for individual **electron** beams. Large variability indicates potentially poor quality-assurance window for beam output.

TABLE 2: RESULTS OF TLD-HISTORY ANALYSIS FOR INDIVIDUAL BEAMS

Potential Problems	Modality	Total Beams	Beams outside an arbitrary limit*	*Limit
Output discrepancy (systematic)	Photons Electrons	2,710 1,476	5% 9%	2.5% 2.5%
Depth-Dose discrepancy (systematic)	Electrons	1,476	3%	2.5 mm
Output variance in TLD/Inst. history	Photons Electrons	2,710 1.476	4% 9%	σ=2.5% σ=2.5%

Correlation of Variability in Output Checks

A) Control-TLD irradiation on Co-60:

- A little manipulation of Eqn 1 leads to (Kirby et. al.) a conservative estimate for σ_D.

$$\sigma_D^2 = \sigma_{Ts}^2 + \sigma_{Tc}^2 + \sigma_{KI}^2 + \sigma_{Kf}^2 \qquad (2)$$

- Where T_S and T_I correspond to average TLD signals for standards and controls, respectively.

- From commissioning data, we have determined that the standard deviation of a single TLD reading is 1.0%. Since T_S and T_C are average values for 6 and 10 TLD samples, respectively, the standard errors, σ_{T_S} and σ_{T_C}, are 0.41 and 0.32% respectively.
- Since the dose difference for standards and controls is always small (<12 cGy), the linearity contribution, σ_{Kl}, is negligible (0.01%).
- Since difference of elapsed time (irradiation to reading) for standards and controls is kept minimal (<2 days), the contribution, σ_{Kl}, is small (0.03%).
- Thus, the major contribution to σ_D comes from σ_{Ts} and σ_{Tc} alone.
- Eqn 2, thus leads to a conservative estimate of σ_D = 0.5%.
- Approximately 0.3% contribution appears to result from uncertainties in
  (i) set-up reproducibility (especially the field size) and
  (ii) Irradiation time of the two 60Co units used for irradiation of standards and controls.
- An additional uncertainty arises from the observed cyclic behavior of the measured-to-predicted ratio of the controls.
- All of the above is consistent with the measured overall variability (σ) of 0.9% in the output checks by control TLDs.

Conclusions

- Output checks by TLD have a remarkable precision for both photon and electron beams. (one standard deviation of 2% for all institutions versus 0.9% for irradiation with a high-precision set up)

  ⇒ This is suggestive of a possibility of tightening the RPC's present 5% criterion for beam output.

- Energy check by TLD for remote electron beams, shows one standard deviation of 1.4 mm.

  ⇒ This would allow the RPC to set a tighter criterion than the present 5 mm for depth-dose agreement.

- The data confirm the accuracy of the parameters (Eqn 1) in current use for dose determination by TLD. *The overall agreement for output check is less than 0.5%, irrespective of beam energy or modality (electron, photon).*

- Attention to beam-wise history of TLD results provides a new promising tool to identify two types of potential problems.

(i) Systematic discrepancies in dosimetry parameters for beam output calculation well below the 5% and 5 mm criteria. The results suggest 3% and 3 mm as action levels to pursue resolution of systematic discrepancies.

(ii) About 4% of the monitored beams show a variability (σ) exceeding 2.5% in beam output over time. This suggests poor QA regarding beam outputs and electron depth doses, or poor irradiation techniques by the user.

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