Uncertainties in Reference Dosimeters

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Disclosure

- Larry DeWerd has partial interest in Standard Imaging Inc.

Outline of Talk

- Formation of Uncertainties
- Uncertainty for External Beam Dosimetry with Reference Chambers
  - Primary standards
  - Transfer of standards to ADCL and uncertainties
  - Transfer to the clinic
- Uncertainties in Nonstandard Applications
- Conclusions

Uncertainty

- Uncertainty tables and determinations are important for the accuracy of your measurements
- Uncertainty gives an indication of where you would expect your measurements to fall whenever you measure
- Overall uncertainty is larger than precision of measurement

Accuracy and Precision

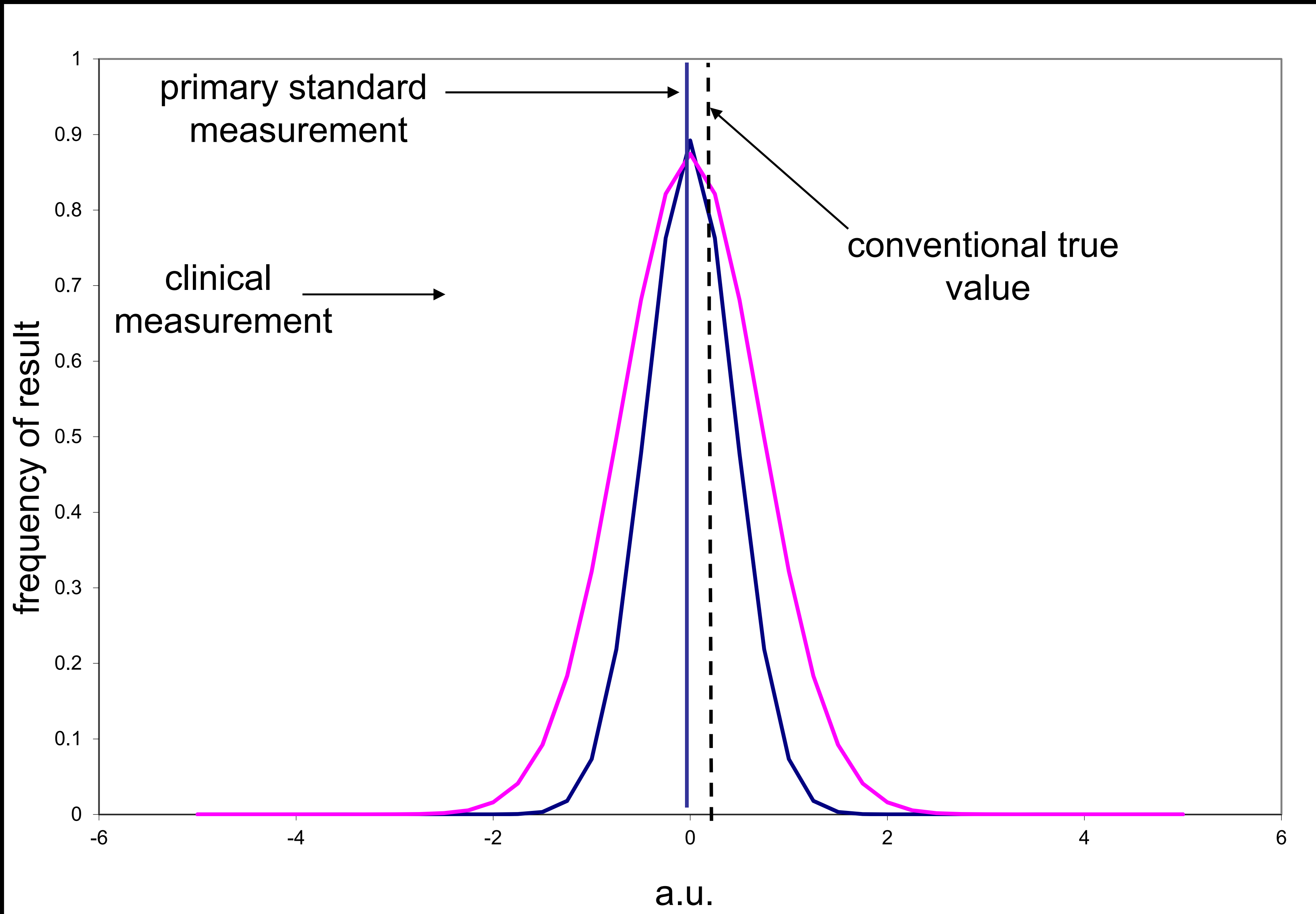
- Accuracy is how close the result is to the conventional true value or a measure of the "correctness" of the result
- Precision is a measure of how exact the result has been determined or a measure of the reproducibility of the result
- See back of summer school shirt
- An accurate and precise instrument is desired. However, a working - precise instrument is preferable since it can be calibrated

Example of Accurate Instrument

- If the correct number (God's number or the conventional true value) was 5.002 and the average given by the instrument was 5.002, it would be extremely accurate.

- However, if the reproducibility of the instrument was large (e.g., $\pm$ 90%) it would not be very precise and you could not know that you have taken enough measurements to produce an accurate result.

- This instrument would be classified as extremely unreliable.


primary standard
measurement
conventional true
value
clinical
measurement
frequency of result
a.u.
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-6
-4
-2
0
2
4
6

Uncertainties

- Today possible variation in readings are characterized by uncertainties
- The difference between the measured value (measurand) and the conventional true value is generally never zero
- There are uncertainties involved in the measurement that can be expressed

Expression of Uncertainties

- Type A and Type B uncertainties are used
- Type A uncertainty is estimated by the standard deviation of the mean value. These are measured results
- Any valid statistical method for treating data can be used for Type A uncertainties

Expression of Uncertainties:
Type B

- Type B uncertainty is not able to be estimated by repeated measurements (standard deviations)
- Type B is based upon scientific judgment but using that which applies to the measurement – also from Manufacturer's specifications
- Generally it is based on a confidence interval

Expression of Uncertainties:
Type B

- A limit (confidence interval) is generally used for Type A or B, designated by *k*

- For Gaussian distributions, if we are certain that the value lies between $\pm$ L then 99% lie here and the confidence limit is designated as k=3. Express L in %, call it $L_{\%}$ The uncertainty is then $u=L_{\%}/k$ and expressed in a %. For 95%, k=2 and for 67% k=1

Expression of Uncertainties:
Type B

- Also can assume some type of probability distribution, e.g. rectangular or triangular

- Rectangular: all values fall within these maximum limits, $\pm M_{\%}$ then $u=M_{\%}/\sqrt{3}$.

  Example: This is used when a manufacturer gives maximum limits for a parameter, such as the range of the calibration extends from 4.7 to 5.3.
  (u=3.5%)

- Triangular: all values fall with limits of $\pm L_{\%}$, but the values are more weighted toward the central value. All values do not have equal probability

  Then the uncertainty is estimated by $u=L_{\%}/\sqrt{6}$

Example of Distributions

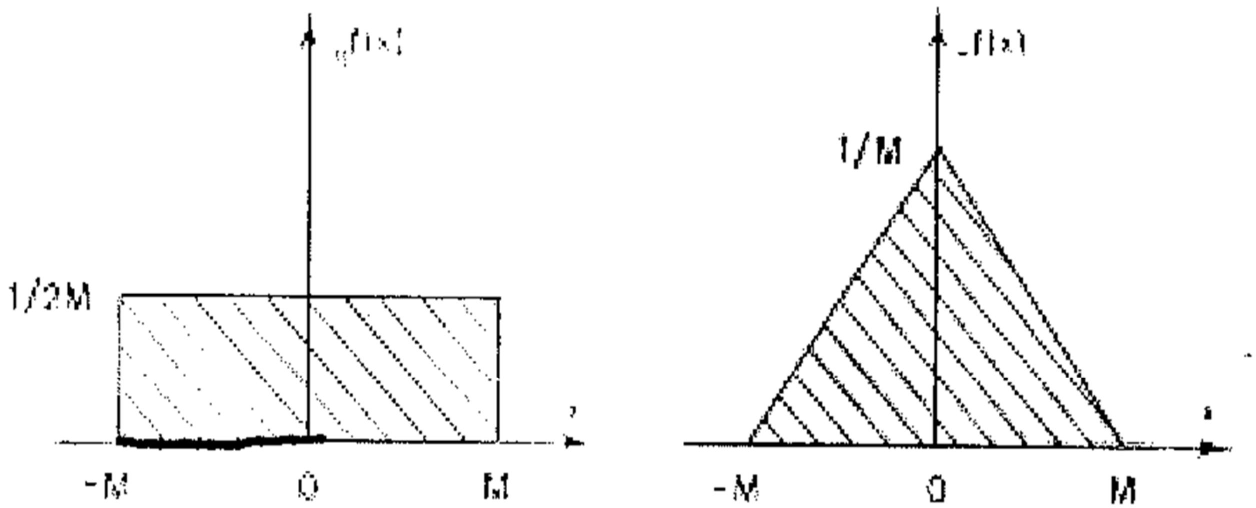


Fig...... The two simple probability density functions, rf(x) and tf(x), with a rectangular or triangular shape, may be useful models for unknown distributions.

Procedure Used to Determine Uncertainty of Results

- Procedure is outlined in NIST Technical Note 1297 (1994) and more detailed information in IAEA TECDOC 1585

- Each uncertainty component is propagated sequentially throughout the measurement pathway by quadrature summation: Square root of sum of squares for k=1

Combining Uncertainties

- Uncertainties in % are combined as: $u_c=(u_A^2 + u_B^2)^{1/2}$ This can be done in tabular form.
- Calculations are done at k=1 the result is expanded (the expanded uncertainty) and reported at k=2.

$$U=ku_c$$

- If a mathematical relationship is known the propagation of uncertainties can be done by partial differentiation of the equation

Example of Use of Probability Distribution

- Manufacturer claim: The chamber to chamber tolerance for the volume for a 0.6cc chamber is $\pm$3.3%
- Assuming a rectangular distribution, would expect at *k*=1: $u = 3.3/\sqrt{3} = 1.9\%$
- If assume a triangular distribution u=1.3%
- For a sample of over 501 chambers calibrated at the ADCL a standard deviation of $\pm$ 1.6% was observed

Use for Distributions

- Therefore the tolerances on the chambers show that the response is related to the volume of the chamber - Not surprising

- Note this is why each chamber is individually calibrated

- The precision on a calibration is about ±0.2%

Relative Uncertainty

- Finally, the contribution of the calibration or traceability to NIST is added in

- For example, if the NIST traceable calibration has an uncertainty of 1% at *k*=2, then u_{NIST}=0.5%. This is added "in quadrature" to your measurement *k*=1 value or:

$$u_{total} = \sqrt{u_{lab}^2 + u_{NIST}^2}$$

Traceability Path From NIST to the Clinic

- Reference dosimetry is directly traceable to a primary laboratory (NIST). Criteria for reference chamber coming from WG on TG51
- NIST determines standard
- NIST transfers standard to an ADCL
- Standard is then transferred to clinic's ionization chamber and electrometer

Hierarchy of Standards

International & National Standards	Primary Calibration
↓	
Secondary Standards ADCL	Secondary Calibration
↓	
Hospital or Clinical Standards	Tertiary Calibration
↓	
Operational Standards	

Components of Total Uncertainty

$\sigma_{\text{Total}} \Rightarrow$

- $\sigma_{\text{NIST-ADCL Chamber Transfer}}$
- $\sigma_{\text{NIST-ADCL Electrometer Calibration}}$
- $\sigma_{\text{ADCL-Clinic Chamber Calibration}}$
- $\sigma_{\text{ADCL-Clinic Electrometer Calibration}}$
- $\sigma_{\text{Clinic Chamber / Elect Measurement}}$

These are sequentially propagated in quadrature
(the square root of the sum of the squares)

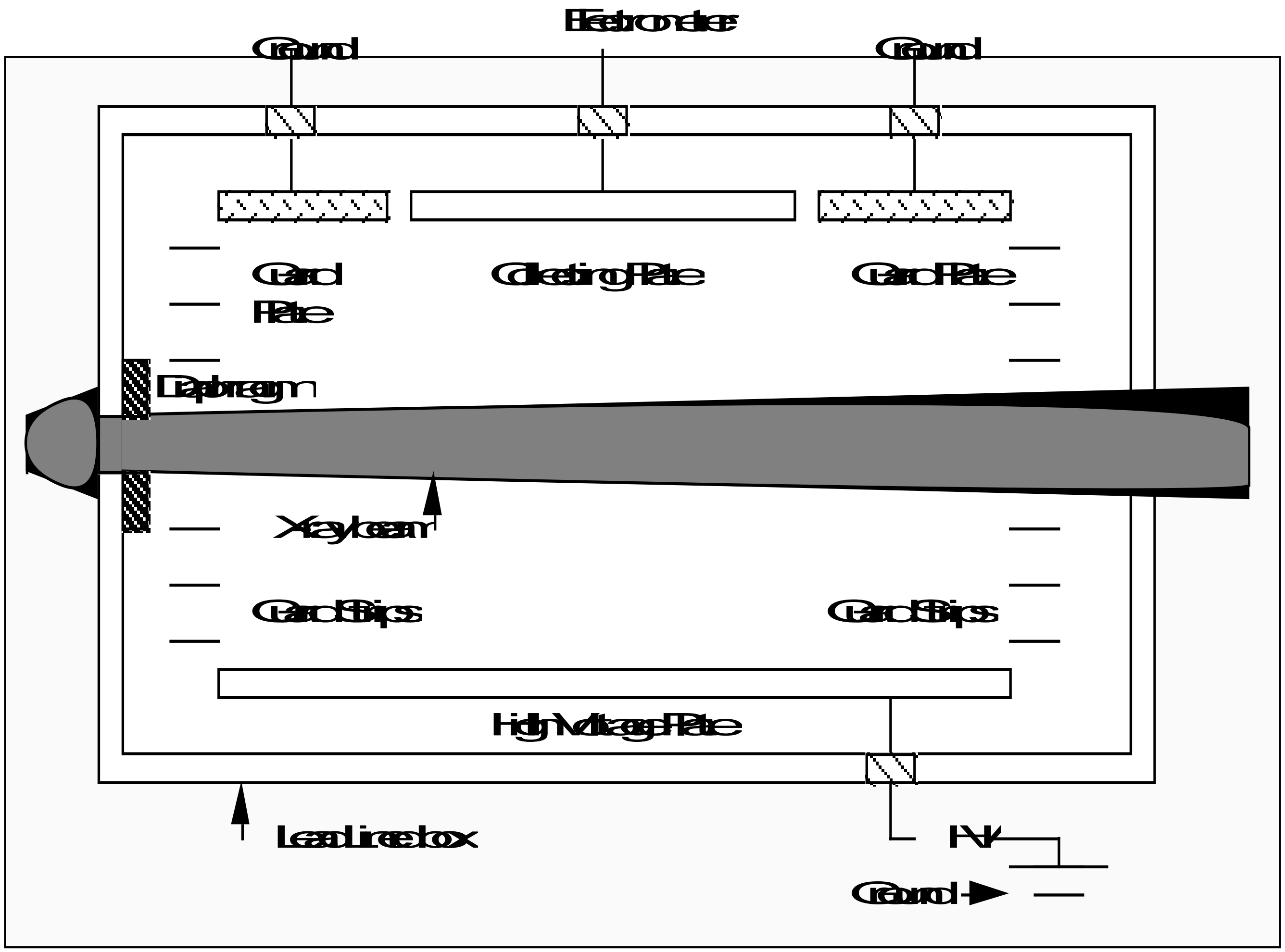
Areas of Uncertainty

- We will look at typical uncertainty tables for NIST to clinic through ADCL for
  - Air kerma (x-ray therapy)
  - Air kerma (cobalt)
  - Absorbed dose to water (cobalt)

Uncertainty for Primary Lab (X-ray)

- The primary labs maintain standards with a high level of accuracy
- The standard for x-ray beams <300kVp is a free air chamber
- Ionization products do not interact with the walls of the chamber – thus, free air
- The NIST uncertainty at k=1 is 0.31%

Ritz FAC



Uncertainty for Primary Lab:
Air Kerma for Cobalt and Higher

- The standards for Cobalt air kerma are two spherical graphite-walled ionization chambers
- The NIST uncertainty at k=1 is 0.31%

Uncertainty for Primary Lab:
Absorbed Dose to Water for Cobalt

- The standard used is a water calorimeter (at NIST developed by Domen) – other calorimeters are used
- The incident ionizing radiation raises the temperature, which is measured
- NRCC also uses a water calorimeter for linac energies
- The NIST uncertainty at 5 cm deep at k=1 is 0.42%

Uncertainty for Secondary Labs

- The primary labs transfer the standards to ADCLs via reference chambers
- ADCL standards are maintained with great precision
- ADCL participates in NIST-sponsored biennial proficiency tests and must fall within 0.5% of the NIST value

ADCL Uncertainties

Quantity	NIST uncertainty *k*=1	ADCL ind uncertainty *k*=1	Combined uncertainty *k*=1 (*k*=2)
Air kerma (x-ray)	0.39%	0.22%	0.45% (0.90%)
Air kerma (cobalt)	0.68%	0.22%	0.72% (1.44%)
Absorbed dose (cobalt)	0.61%	0.21%	0.64% (1.28%)

ADCL Calibration Conditions

- The absorbed dose to water is for a 10x10 cm^2 field at 5 cm deep at 100 cm SAD in a phantom of minimum size 30x30x30 cm^3
- Applications beyond this setup increase the uncertainty

Transfer to the Clinic

- All ADCLs use the transfer technique to calibrate clinical chambers
- A standard output is determined with the ADCL reference chamber, then the clinic chamber is substituted for the ADCL reference and a comparison is made determining the calibration coefficient for the clinic chamber

Clinic Chamber Uncertainties at ADCL

- An example table is given in the chapter of the summer school book
- Environmental conditions are allowed to equilibrate and stabilize in the clinic chamber
- All other parameters are controlled to obtain the smallest uncertainty
- The following table is the uncertainty as the clinic chamber leaves the ADCL (ADCL adds another 0.22%)

Uncertainties for Clinic Chamber

Quantity	Combined Uncertainty (including NIST) *k*=1	Combined Uncertainty (including NIST) *k*=2
Air kerma (x-ray)	0.5%	1.0%
Air kerma (cobalt)	0.75%	1.5%
Absorbed dose (cobalt)	0.68%	1.4%

Uncertainty Considerations in Clinical QA

- X-rays
  - Position of the chamber wrt the x-ray tube can increase the uncertainty
  - Differences in HVL from calibration points may affect the calibration

- Linacs
  - Phantom depth, machine output stability
  - k_Q uncertainty must be added in – this has led to the argument to calibrate at linac energies (Andreo 2011 IAEA)
  - Energy differences from standard must be added in if calibrate with linac

Uncertainty in Nonstandard Conditions

- Small fields, SRS etc. require another correction factor in addition to k_Q. This adds another quantity to the uncertainty

- A conservative guess for now would be an additional 0.5 % to 1% to the uncertainty

Conclusion

- Uncertainty determinations aid in understanding to accurately quantify the dose to the patient

- A stable (reference) chamber and electrometer capable of making high precision measurements can be calibrated to deliver the lowest uncertainty compared to the conventional true value

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